Influence of Meso-Mammal Predator Control on Predator Landscape-Level Spatial Occupancy in Northern Florida and Southern Georgia, USA

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ABSTRACT: Predator control to enhance avian reproductive success is a controversial issue in wildlife management, yet rarely is the effectiveness of this tool evaluated with respect to the impact it has on predator populations. Understanding predator demographic responses to intense predator reduction efforts has important applied implications, and provides data to answer to public scrutiny. Medium-sized, generalist mammals (i.e., meso-mammalian) are important nest predators of the declining gamebird, the northern bobwhite, and may limit bobwhite populations. To evaluate the effectiveness of intensive predator control on influencing meso-mammal populations, we monitored 4 primary meso-mammal nest predators of bobwhites. These species include raccoon, Virginia opossum, nine-banded armadillo, and bobcat. We used scent stations to monitor predators on 4 study sites (1,300-1,400 ha each) in northern Florida and southern Georgia during 2000-2006. Baseline data were collected in 2000 for all study sites. During 2001-2003, 2 sites received intensive meso-mammal predator reduction during the 7-month bobwhite breeding season, whereas the other two sites served as controls with no reduction occurring. After 3 years, the treatments were reversed. Using predator detection at scent stations, we modeled the probability that predators used 25-ha patches across the study sites via a community occupancy model. We examined the probability of patch use between years to determine the effectiveness of predator reduction and the resilience of predator populations to management. We removed a total of 5,161 meso-mammals from our study areas. Our results show meso-mammal predator control, as done on our study area, was sufficiently intensive enough to reduce predator use across target sites, but continued reduction would be needed to reduce predator patch use between years. Our findings demonstrate that a predator community can be reduced at the local scale; however, the predators remain on the greater landscape thereby minimizing potential for negative impacts on ecosystem integrity.

KEY WORDS: armadillo, bobcat, *Dasypus novemcinctus*, *Didelphis virginianus*, *Lynx rufus,* occupancy, opossum, predator control, *Procyon lotor*, raccoon

Proc. 24th Vertebr. Pest Conf. (R. M. Timm and K. A. Fagerstone, Eds.)
Published at Univ. of Calif., Davis. 2010. Pp. 273-277.

INTRODUCTION

One of the most controversial tools in wildlife management has been predator control to enhance avian reproduction (Messmer and Rohwer 1996). The predator control controversy surrounds two opposing demands from the public: One side of the argument is the public's demand for solutions to wildlife damage to game species populations or to agricultural and livestock production; the other side is the protection of wildlife from people because of their value to society and the ecosystem (Treves and Naughton-Treves 2005). Many predator control programs have been implemented in an effort to increase gamebird reproductive success and abundance, but with little understanding of the predator-prey complex and process. Typically, evaluations of the effectiveness of removal programs focus exclusively on the response of the targeted gamebird species. A wide range of outcomes have been reported regarding the effectiveness of predator control at increasing gamebird reproduction (Cote and Sutherland 1997, Newton 1998). Despite suggested experimental designs incorporating a measurement of predator populations, few predator control studies actually measure the effectiveness of reduction efforts at altering predator population dynamics (Leopold and Hurst 1994, Burger 2002).

Furthermore, perspectives of predator values have shifted from predators as competition for food resources to being viewed as important components of the ecosystem. With this shifting viewpoint comes the requirement of evaluating predator control programs to meet their intended objectives while maintaining biodiversity and ecosystem integrity. The objective of this study is to evaluate the population impact of predator control at reducing the 4 primary meso-mammal nest predators of northern bobwhite (*Colinus virginianus*) in southern Georgia and northern Florida, USA. These species include raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginianus*), nine-banded armadillo (*Dasypus novemcinctus*), and bobcat (*Lynx rufus*).

METHODS

Study Area

We studied meso-mammalian predator dynamics at 3 properties in southern Georgia and northern Florida during 2000-2006. Tall Timbers Research Station and Land Conservancy, Inc. (TT; Leon County, FL; 84º 13'

35" W, 30º 39' 39" N) and Pebble Hill Plantation (PH; Thomas and Grady County, GA; 84º 5' 48" W, 30º 46' 13" N) are located in the Red Hills physiographic region. Pinebloom Plantation (PB East and PB West; Baker County, GA; 31° 24' 42" N, 84° 22' 45" W) is located in the Upper Coastal Plain physiographic region. Pinebloom was divided into two 1,400-ha study sites with a cypress (*Taxodium distichum*) swamp buffer approximately 607 ha in size between the two sections. Detailed site description for the Red Hills sites can be found in Staller et al. (2005), and for Pinebloom in Sisson et al. (2000, 2009). Sites are dominated by loblolly pine (*Pinus taeda*) and shortleaf pine (*Pinus echinata*) with associated "old-field" ground cover vegetation and areas of longleaf pine (*Pinus palustris*) with associated wiregrass (*Aristida stricta*) ground cover. Hardwood drains, hammocks, and fallow fields are interspersed across the landscape. All sites use frequent fire, disking, roller-chopping, and mowing to maintain an open, low density pine forest structure.

Predator Reduction and Scent Station Monitoring

Predator reduction was conducted at the two pair of study areas, the Red Hills Region and the Albany Region. Each study region had a treatment and a control plot of approximately 1,300-1,400 hectares in size. One year of baseline data was collected in 2000. During 2001 - 2003, one plot in the Red Hills Region (PH) and one in Albany (PB East) received intensive predator removal using box traps and leg-hold traps during 1 March - 30 September of each year by USDA Wildlife Services personnel, whereas at the other sites predators were not removed. During 2004 - 2006, the treatments were reversed (i.e., TT and PB West trapped). The experiment followed a blocked, repeated measures cross-over design.

Meso-mammal predator use was examined using 30-40 scent stations at each site. Stations were located ≥500 m apart next to unimproved roads, fire breaks, and other potential travel lanes which resulted in 1 station per 25 ha. A station consisted of a 1-m circle cleared of all vegetation and covered in fine, sifted sand. A fatty-acid tablet acted as scent lure and was placed in the center of the circular station to attract predators. Scent stations were checked on 5 consecutive mornings during the first week of October, after predator trapping had ceased for the year. Each day, predators were identified by their tracks, then sand was raked and scent lures replaced as needed. Total number of different predators visiting scent stations divided by total scent station days provided a crude index of nest predator activity of the study areas.

Statistical Analysis

When scent stations are conducted over several consecutive days, occupancy modeling offers a convenient and appropriate analytical methodology to monitor predator population dynamics (Stanley and Royle 2005, MacKenzie 2006). During the sampling process, it is impossible to detect all predators present. Multiple observations on consecutive days provide information on the ability to estimate detection (i.e., the probability to detect predators, given they are present), reducing biases associated with the use of simple indices (MacKenzie 2006) typical of scent station data. To do so, we assumed each station provided a measure of occupancy of each 25-ha "patch" surrounding the station. A community occupancy model was constructed for the 4 primary meso-mammal predators of bobwhite nests based on the presence/absence of tracks at scent stations. Competing models were constructed in program MARK (White and Burnham 1999) using a robust occupancy design (MacKenzie et al. 2003) and evaluated using Akaike Information Theoretic (AIC) approach (Burnham and Anderson 2002). Pearson X^2 statistic divided by the degrees of freedom ($\hat{c}$) of a fully parameterized model (i.e. global) was examined to determine goodness of fit (MacKenzie and Bailey 2004). If lack of fit occurred, overdispersion would be observed as $\hat{c} > 1$ and could be adjusted within MARK.

We examined the role predictors, including trapping, had on the presence of each predator species (i.e., Ψ; patch occupancy), the probability of discontinued patch use (i.e., ε; local extinction in metapopulation vernacular), and the detection probability (p). The probability of recolonization (γ) was also examined as a derived parameter from the above parameters (MacKenzie et al. 2003, MacKenzie 2006). Detection was explored to determine if it varied by time within primary periods (t), by study site (site), by species (sp), or constant (.) and if it varied among primary periods. The predictors examined for local extinction (from a scent station patch) were study site, species, time, trapping (trap), constant, and additive relationships of these predictors. Since extinction describes a relationship between years, we modeled trap effect as dummy variables representing a year of no trapping to continued no trapping (N-N), no trapping to trapping (N-T), trapping to continued trapping (T-T), and trapping to discontinued trapping (T-N). Finally, we modeled occupancy each year by examining whether occupancy differed by site or region (Thomasville vs. Albany), species, trapping, or by additive combinations of these predictors. Model-averaged estimates were calculated for all parameters of interest.

Managers often use the raw scent station index to assess predator use and to help them decide if predators should be reduced. Therefore, we compared occupancy with raw scent station visitation rates to assess the reliability of the index as a management tool.

RESULTS

We removed a total of 5,161 meso-mammals during the study period across the 4 study sites, ranging from 243 - 737 predators per site in a single year (Table 1). Most of the meso-mammals removed were opossums (44.4%) and raccoons (29.0%). We ran 5,002 station-days (μ= 178 station-days per year per study site) and identified 814 unique tracks of the 4 mammalian species. Most of the meso-mammal tracks were identified as raccoons (53.4%).

We observed an adequate fit for our global model ($\hat{c}$= 0.998). The best approximating model from the 26 candidate models was where Ψ was influenced by the additive effects of trapping and region; ε was based upon trap effect only; and detection was different among years

Table 1. Number of meso-mammalian predators removed by species for each of 4 study areas (1300-1400 ha) in southern Georgia and northern Florida during 2001-2006.

Predator	Pinebloom West			Pinebloom East			Pebble Hill			Tall Timbers			Total
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	
Raccoon	193	236	104	175	140	169	90	47	57	104	87	95	**1497**
Opossum	60	179	276	406	164	174	106	186	140	246	153	203	**2293**
Armadillo	43	45	51	119	61	47	61	44	31	150	149	153	**954**
Bobcat	20	40	22	26	9	8	14	5	9	20	13	16	**202**
Coyote	9	14	6	4	7	14	13	13	4	12	12	12	**120**
Fox	4	8	7	1	2	3	6	0	1	0	6	5	**43**
Feral[a]	8	6	8	6	3	2	6	2	1	0	4	6	**52**
Total	**337**	**528**	**474**	**737**	**386**	**417**	**296**	**297**	**243**	**532**	**424**	**490**	**5161**

[a]Includes feral domestic dogs and cats.

Table 2. Summary of model selection results examining meso-mammal community occupancy (Ψ), local patch extinction (ε), and detection probability (*p*) with respect to trapping efforts during 2000-2006 in southern Georgia and northern Florida based upon Akaike's Information Criteria (AIC_c). Table includes number of parameters in model (K) and model weight (W_i). Predictor variables include predator trapping (trap), physiographic region (region), study site (site), species-specific, year (p_{1-7}), and constant (.). An additional 22 models were >10 ΔAIC_c and received no model weight.

Model	K	AIC_c	ΔAIC_c	W_i
Ψ(trap+region), ε(trap), p_{1-7}(species)	35	6193.0	0.0	0.75
Ψ(trap+site), ε(trap), p_{1-7}(species)	37	6196.1	3.0	0.17
Ψ(trap), ε(trap), p_{1-7}(species)	34	6197.8	4.7	0.07
Ψ(trap+region), ε(.),p_{1-7}(species)	32	6203.0	9.9	0.01

and species-specific (Table 2). This model had 75% of the model weight and was 4.5 times more likely than the next best-fitting model [Ψ(trap+site), ε(trap), p_1(sp), p_2(sp), p_3(sp), p_4(sp), p_5(sp), p_6(sp), p_7(sp)].

Occupancy of scent station patches was estimated as >0.49 on study areas when no predator control was occurring and <0.36 when trapping was conducted (Figure 1). The probability of discontinued use of an occupied patch was highest when trapping was preceded by no trapping and lowest in years when no trapping occurred in 2 consecutive years (Figure 2). The probability of recolonization of a scent station patch was highest following discontinued trapping efforts and lowest between years trapping (Figure 3). The probability an individual was present and detected was generally low (<10%) for bobcats, armadillos, and opossum (Figure 4). Detection ranged from 0.09 - 0.31 for raccoons across the 7 years of monitoring (Figure 4).

The raw scent station index was correlated with occupancy rates across all sites (r = 0.75). However, the correlation varied by sites (0.34 - 0.92). The correlation was strongest on areas where indices were dominated by raccoons (the species with highest detection probability).

DISCUSSION

A clear distinction in occupancy was observed between

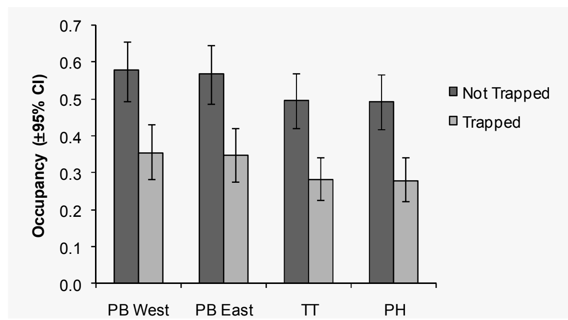

Figure 1. Model-averaged estimates (±95% CI) for the probability of use (i.e. patch occupancy) by raccoons, armadillos, opossum, and bobcats for 4 study sites in northern Florida and southern Georgia during 2000-2006.

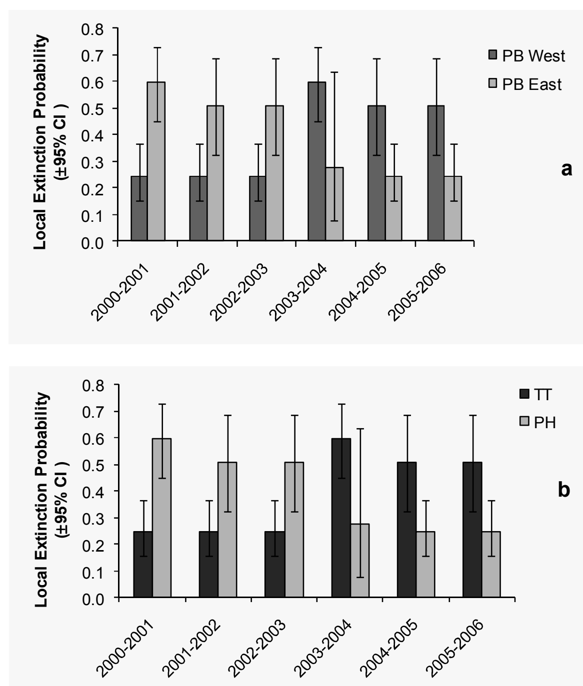

Figure 2. Probability of discontinued use (i.e. local extinction) by meso-mammals at a scent station patch in a) the Albany region and b) the Thomasville region. Meso-mammal predator reduction occurred for PB East and PH during 2001-2003 and for PB West and TT during 2004-2006.

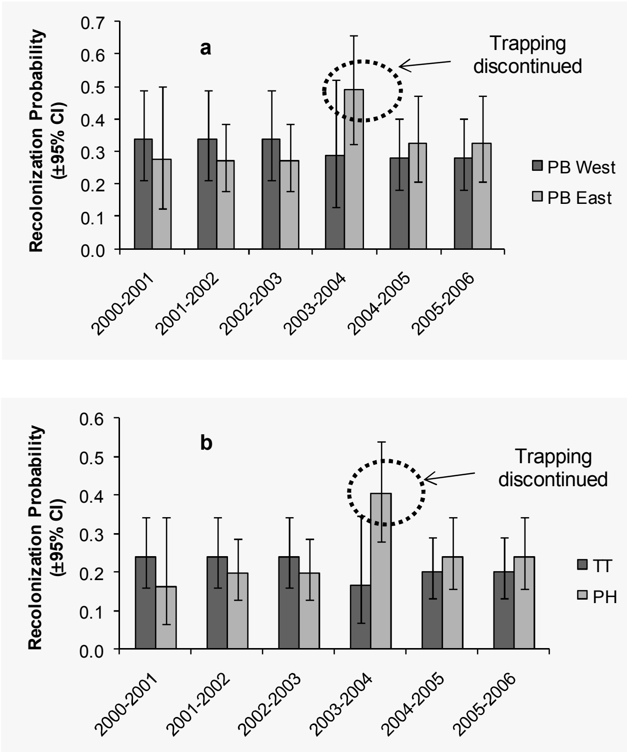

Figure 3. Probability of an unoccupied scent station patch becoming occupied (i.e., recolonization) for meso-mammals in a) the Albany region and b) the Thomasville region. Predator reduction occurred on PB East and PH during 2001-2003 and on PB West and TT during 2004-2006. The dotted circle highlights increased recolonization at the transition following discontinued trapping for PB East and PH. Note that trapping on PB West and TT stopped at the end of the study; therefore, we would predict that there would be no significant recolonization observed on those sites.

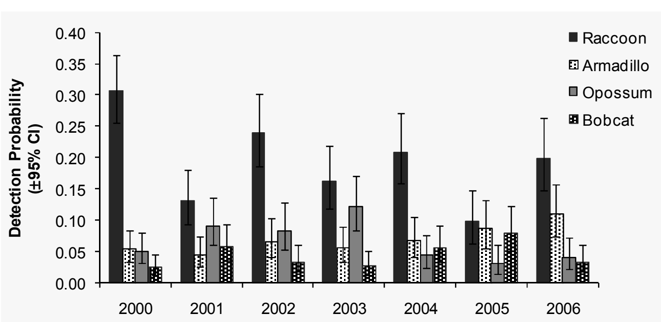

Figure 4. Detection probability of four mammalian predator species (raccoon, armadillo, opossum, and bobcat) during 7 years of monitoring using scent stations in northern Florida and southern Georgia.

trapped and not trapped years, demonstrating that our predator removal efforts were sufficient to reduce predator use across our study areas. The probability of predator presence at scent station patches was 2.5 times more likely on sites when they were not trapped than during years with predator control. In addition, we observed higher probabilities of discontinued use (local extinction) of patches by predators when predator control efforts were initiated. After the first year of trapping, the probability of additional local extinction declined, but was always higher than when there was no trapping, suggesting a slight multi-year additive effect. Although predation reduction efforts were sufficient to reduce predator use from the patch, reduction of these species on any of the study areas was only temporary. Previously, Treves and Naughton-Treves (2005) reviewed effectiveness of culling programs with various objectives for reducing mammalian populations, and observed only short-lived effectiveness with rapid recolonization. The predators in our study remained on the landscape and recolonized the study area by the following year after discontinued trapping efforts. Recolonization following trapping was likely due to increased immigration from surrounding properties. Additionally, it has been suggested that heavily exploited populations where mortality rates are high may exhibit compensatory reproduction when densities are below carrying capacity (Knowlton 1972, Knowlton et al. 1999).

The variability we observed in detection rates of predators among years suggests that raw scent station indices are not directly comparable over years. We show that occupancy modeling provides one means of dealing with changing detection over time and should be used when possible to improve reliability of raw indices. However, raw scent station indices were correlated with occupancy and provided similar trends in overall predator use on our study areas, indicating they provide useful, although less reliable, information for management purposes. Additionally, we observed low detection probabilities (<10%), or the ability to detect an individual given it is there, for 3 of the 4 predators of interest, raising concern about population inference using raw indices (O'Connell et al. 2006). Increasing the length of monitoring to more than 5 consecutive days can increase detection probabilities, but may be logistically challenging in the Southeast where fall rains frequently occur.

We assumed our sampling patches were independent from one another and that occupancy was closed during the 5-day sampling period. We realize these assumptions may have been violated given home ranges of some predators in our study are >25 ha, and the scent stations were place along roads which act as travel corridors. Future studies using occupancy should consider different sampling scales to account for variation in predator home range size.

Generally, it is thought that predator reduction efforts have little effect upon long-term densities of meso-mammals, but typically this is not examined (Treves and Naughton-Treves 2005, Berger 2006). Simultaneous study of predators, as well as species targeted for population enhancement or protection from predation, should be conducted. To date, only a handful of studies have conducted monitoring of both the predator(s) and prey to determine how predator abundance and activity relate to predation rates observed (Cain et al. 2003, 2006; Schmidt et al. 2006, Sperry et al. 2009) or the effectiveness of predator control programs on predator demographics (Sovada et al. 2000). From an experimental design perspective, we would also suggest that some of the highly variable outcomes in terms reported by Cote and Sutherland (1997) might actually be a result of researchers treating predator removal or no removal as a dichotomy when in fact it is likely a wide continuum. In some studies, removal may not even impact predator abundance and use of space even in the short term. We were able to assess the effectiveness of our predator control efforts using occupancy modeling.

Historically, predator removal focused on control of predator populations with the implication that elimination of predators from landscapes might be a positive objective (Treves and Naughton-Treves 2005). Predator control as part of predation management in support of a game species is a more representative description where the objective becomes one of minimizing interactions of meso-mammal predators with bobwhites (or other game species) during the breeding season. As predator control programs are likely to receive more scrutiny in the future, monitoring of the impacts and effectiveness of such programs will be required to justify their use as a management tool for enhancing game or imperiled species or to reduce human-wildlife conflicts. Our study demonstrates that the use of such reduction efforts achieves management objectives of reducing predators during nesting season locally, but maintains biodiversity by not eradicating targeted predators from the greater landscape.

ACKNOWLEDGMENTS

We thank Shane D. Wellendorf, numerous graduate students and technicians, USDA Wildlife Services, Tall Timbers Research Station and Land Conservancy, Inc., and the Albany Quail Project for field work assistance. Funding was provided by a Direct Congressional Appropriation, University of Georgia Warnell School of Forestry and Natural Resources, University of Georgia Graduate School, the McIntire-Stennis Projects GEO 100 and 136, Tall Timbers Research Station and Land Conservancy, Northeast Georgia Chapter of Quail Unlimited, Shikar Safari Club International Foundation Scholarship, and the American Association of University Women.

LITERATURE CITED

BERGER, K. M. 2006. Carnivore-livestock conflicts: Effects of subsidized predator control and economic correlates on the sheep industry. Conserv. Biol. 20:751-761.

BURGER, L. W., JR. 2002. Quail management: Issues, concerns, and solutions for public and private lands – A Southeastern perspective. Proc. Nat. Quail Symp. 5:20-34.

BURNHAM, K. P., and D. R. ANDERSON. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd Ed. Springer, New York, NY.

CAIN, J. W., III, M. L. MORRISON, and H. L. BOMBAY. 2003. Predator activity and nest success of willow flycatchers and yellow warblers. J. Wildl. Manage. 67:600-610.

CAIN, J. W., III, K. S. SMALLWOOD, M. L. MORRISON, and H. L. LOFFLAND. 2006. Influence of mammal activity on nesting success of passerines. J. Wildl. Manage. 70:522-531.

COTE, I. M., and W. J. SUTHERLAND. 1997. The effectiveness of removing predators to protect bird populations. Conserv. Biol. 11:395-405.

KNOWLTON, F. F. 1972. Preliminary interpretations of coyote population mechanics with some management implications. J. Wildl. Manage. 36:369-382.

KNOWLTON, F. F., E. M. GESE, and M. M. JAEGER. 1999. Coyote depredation control: An interface between biology and management. J. Range Manage. 52:398-412.

LEOPOLD, B. D., and G. A. HURST. 1994. Experimental designs for assessing impacts of predators on gamebird populations. Trans. No. Am. Wildl. Nat. Res. Conf. 59:477-487.

MACKENZIE, D. I. 2006. Occupancy estimation and modeling: Inferring patterns and dynamics of species. Elsevier, Amsterdam.

MACKENZIE, D. I., and L. L. BAILEY. 2004. Assessing the fit of site-occupancy models. J. Agric. Biol. Environ. Statistics 9:300-318.

MACKENZIE, D. I., J. D. NICHOLS, J. E. HINES, M. G. KNUTSON, and A. D. FRANKLIN. 2003. Estimating site occupancy, colonization and local extinction when a species is detected imperfectly. Ecology 84:2200-2207.

MESSMER, T. A., and F. C. ROHWER. 1996. Issues and problems in predation management to enhance avian recruitment. Trans. No. Am. Wildl. Nat. Res. Conf. 61:25-30.

NEWTON, I. 1998. Population Limitation in Birds. Academic Press, San Diego, CA. 597 pp.

O'CONNELL, A. F., JR., N. W. TALANCY, L. L. BAILEY, J. R. SAUER, R. COOK, and A. T. GILBERT. 2006. Estimating site occupancy and detection probability parameters for meso- and large mammals in a coastal ecosystem. J. Wildl. Manage. 70:1625-1633.

SCHMIDT, K. A., R. S. OSTFELD, and K. N. SMYTH. 2006. Spatial heterogeneity in predator activity, nest survivorship, and nest-site selection in two forest thrushes. Oecologia 148:22-29.

SOVADA, M. A., M. C. ZICUS, R. J. GREENWOOD, D. P. RAVE, W. E. NEWTON, R. O. WOODWARD, and J. A. BEISER. 2000. Relationships of habitat patch size to predator community and survival of duck nests. J. Wildl. Manage. 64:820-831.

SPERRY, J. H., D. A. CIMPRICH, R. G. PEAK, and P. J. WEATHERHEAD. 2009. Is nest predation on two endangered bird species higher in habitats preferred by snakes? Ecoscience 16:111-118.

STANLEY, T. R., and J. A. ROYLE. 2005. Estimating site occupancy and abundance using indirect detection indices. J. Wildl. Manage. 69:874-883.

TREVES, A., and L. NAUGHTON-TREVES. 2005. Evaluating lethal control in the management of human-wildlife conflict. Pp. 86-106 *in*: R. Woodroffe, S. Thirgood, and A. Rabinowitz (Eds.), People and Wildlife: Conflict or Coexistence? Cambridge Univ. Press, Cambridge, UK.

WHITE, G. C., and K. P. BURNHAM. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46:120-139.