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Research Article

Evaluating Detection and Occupancy Probabilities of Eastern Spotted Skunks

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ABSTRACT The eastern spotted skunk (*Spilogale putorius*) is a poorly understood mesocarnivore species that suffered a range-wide decline in the mid-1900s. Little is known about its current distribution or habitat needs, and in the southern Appalachians, where the Carolinas and Georgia converge, eastern spotted skunks were only recently discovered to persist. From January–April in 2016 and 2017, we used camera trap surveys to monitor eastern spotted skunks and used occupancy modeling to evaluate factors we hypothesized would influence the probability of spotted skunk detection and occurrence at the landscape scale. We detected spotted skunks at 55.6% of our sites and on 18.5% of sampling occasions. Our results suggest that detection probability was influenced by predation risk, camera setup, and the type of scent-based attractant used. Eastern spotted skunk occupancy probability had a negative relationship with elevation, such that the probability of occupancy on average increased 7% for every 100-m decrease in elevation. These results differ from previous findings from the northern Appalachian region, and suggest spotted skunks in the southern Appalachians may be more widely distributed than previously thought. To inform management, there remains a critical need for finer-scale investigations into resource selection and demographic trends.

KEY WORDS camera trap, cryptic, elevation, mesocarnivore, monitoring, *Spilogale putorius*.

The eastern spotted skunk (*Spilogale putorius*) is a species of conservation concern. Once an important furbearer, eastern spotted skunks previously ranged from southwestern Pennsylvania, south to Florida and west to the eastern foothills of the Rocky Mountains, USA (Kinlaw 1995). In the mid-1900s the species underwent a range-wide decline that was identified by wildlife biologists in 2005 (Gompper and Hackett 2005). The legacy of this population crash has not been thoroughly investigated, and although the eastern spotted skunk was upgraded to vulnerable by the International Union for the Conservation of Nature (IUCN; Gompper and Jachowski 2016), the current abundance, demographic trends, and distribution of the species remain largely unknown.

Understanding landscape-level habitat associations can provide important information about spotted skunk distribution and where to focus future studies or management efforts. Directed investigations of habitat associations of eastern spotted skunks are generally sparse, and strong predictors of occurrence have yet to be identified. One recently completed study from the central Appalachian Mountains in Virginia, USA, indicated that eastern spotted skunk occurrence is influenced by a combination of forest stand age and elevation (Thorne et al. 2017). Specifically, within occupied landscapes, eastern spotted skunks appear to prefer younger pine forests or mature deciduous forests, presumably because of the increased understory complexity these forest types offer at their respective stages of growth (Lesmeister et al. 2012, Thorne et al. 2017). Historically eastern spotted skunks were common on homestead farms throughout the Midwest (DeSanty 2001), and the Florida subspecies (*S. p. ambarvalis*) has recently been reported to be abundant in the dry prairie ecosystems of central Florida (Harris 2018). Thus, biologists still have a poor understanding of habitat associations and factors influencing the current distribution of eastern spotted skunks, particularly in the southern Appalachian portion of their range (Wilson et al. 2016).

An additional inhibitor to our understanding of eastern spotted skunks is a lack of knowledge regarding the specific methods that might be most effective for studying this species. Historically, the majority of reports of eastern spotted skunks were the product of incidental detections and furbearer trapping records (Gompper and Hackett 2005, Diggins et al. 2015, Jachowski et al. 2015). Camera trap technology has advanced greatly in the past decade and become a popular, cost-efficient, and effective way to monitor and investigate cryptic and highly mobile species over large areas (Burton et al. 2015), including recent studies of eastern spotted skunks. Reported detection and capture rates of eastern spotted skunks are typically low and rely on the use of baited monitoring stations to obtain even sparse records of detection (Hackett et al. 2007, Wilson

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et al. 2016, Thorne et al. 2017). It remains unclear if these low detection rates are the product of truly low species abundance, or simply the cryptic nature of this species. It is likely that a variety of temporal and site-specific factors influence the detectability of skunks. For example, Thorne et al. (2017) reported that moon illumination had a significant negative effect on detection rates of eastern spotted skunks, suggesting that spotted skunks would be less active because of increased susceptibility to predation on nights when moonlight was high. Additionally, eastern spotted skunk detection rates were reported to be greater during the colder winter months (Hackett et al. 2007), a trend that might be related to food availability or behavioral changes during the mating season (Hackett et al. 2007, Lesmeister et al. 2009). Conversely, more recent efforts to study eastern spotted skunks have reported successful trapping of the species throughout the summer in Alabama, USA (A. J. Edelman, University of West Georgia, personal communication), further illuminating the general uncertainty about what factors influence eastern spotted skunk detectability.

We performed a study of eastern spotted skunk detectability and occurrence in the southern Appalachians of North and South Carolina, USA, with 2 primary objectives. First, we sought to identify ways in which we might improve our ability to monitor this species by assessing which factors affect the detection probability of eastern spotted skunks. Second, we evaluated landscape-scale environmental factors that we hypothesized would influence eastern spotted skunk occupancy probability in this southern Appalachian region. Specifically, we hypothesized that detection probability would be influenced by factors associated predation risk (Lesmeister et al. 2012, Thorne et al. 2017), seasonal changes in food availability (Hackett et al. 2007), the use of different scent-based attractants (Schlexer 2008), and the monitoring station setup (Kays and Slauson 2008). We hypothesized that occupancy probability would be influenced by topographic features that relate to efficient movement (Fremier et al. 2015), the availability of warmer habitats during the winter to reduce thermoregulatory stress (Lesmeister et al. 2009), and predation risk (Lesmeister et al. 2012, Thorne et al. 2017).

STUDY AREA

We performed this study on an approximately 1,500-km^2 area at the tri-state convergence of North Carolina, South Carolina, and Georgia (Fig. 1). The surveyed area included parts of 3 National Forest ranger districts and 1 state management area: the Andrew Pickens Ranger District of Sumter National Forest and Jocassee Gorges State Management Area in northwestern South Carolina, and the Nantahala and Pisgah Ranger Districts of Nantahala and Pisgah National Forests in southwestern North Carolina. Each of these management districts or areas is primarily managed for recreation or timber production, with little to no human development within their boundaries. Topography in this portion of the Appalachian Mountains is rugged, ranging from 200 m to 1,600 m in elevation and is characterized by 4 primary forest compositions: cove hardwoods, mixed deciduous, northern hardwoods, and xeric oak (*Quercus* spp.)-pine (*Pinus* spp.) forests (Elliott et al. 1999, Turner et al. 2003). Forests are primarily dominated by deciduous trees; however, patches of evergreen coniferous trees are also present on the landscape.

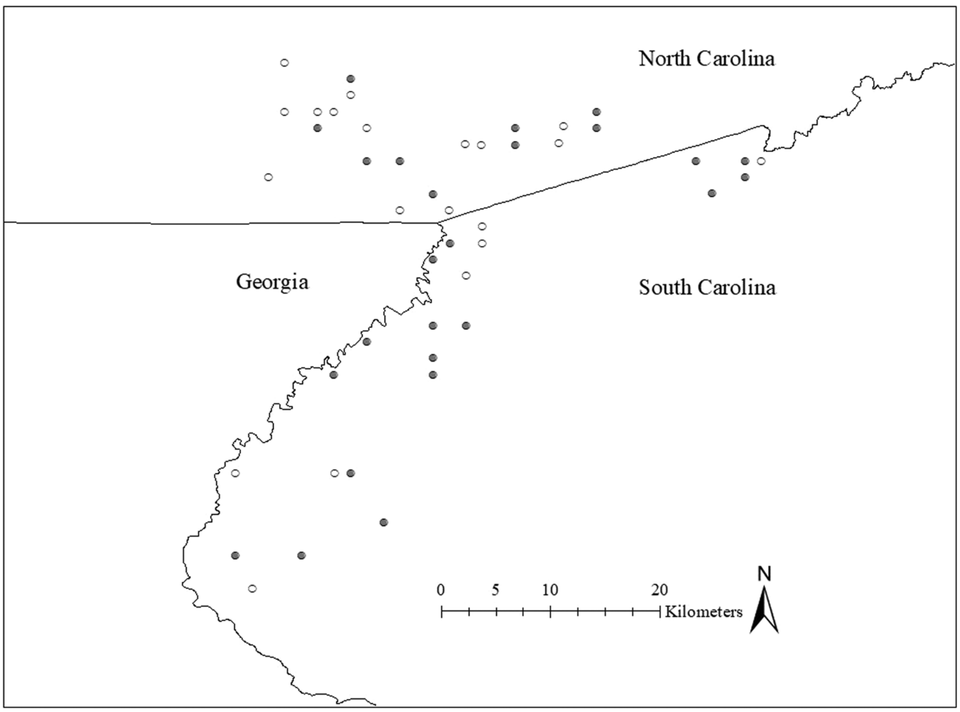

Figure 1. Study area for our evaluation of eastern spotted skunk occupancy in the southern Appalachian Mountains, USA, January–April 2016 and 2017. Filled points denote sites where eastern spotted skunks were detected and empty points indicate surveyed sites where spotted skunks were not detected.

Understory cover is dominated by dense stands of mountain laurel (*Kalmia latifolia*) and rhododendron (*Rhododendron maximum*), particularly in riparian areas and north-facing slopes (South Carolina Department of Natural Resources 2005, Warren 2008). A diverse suite of mammalian carnivores occupy this system and potentially compete with or predate spotted skunks, including striped skunks (*Mephitis mephitis*), racoons (*Procyon lotor*), grey foxes (*Urocyon cinereoargenteus*), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), Virginia opossums (*Didelphis virginiana*), and black bears (*Ursus americana*). This region typically undergoes 4 seasons, which coincide with eastern spotted skunk breeding during winter (Dec–Mar), and litter rearing during spring and summer seasons (Apr–Sep).

METHODS

Field Methods

We used baited camera trap surveys to monitor for eastern spotted skunk occurrence in the southern Appalachians around the North and South Carolina border. Between January and April 2016 we surveyed 18 sites continuously for 3 months, and between January and April 2017 we surveyed 27 sites continuously for 3 months. Recent detections of spotted skunks in the Appalachian Mountains have been primarily limited to higher elevation (>350 m) sites (Diggins et al. 2015, Wilson et al. 2016, Thorne et al. 2017), we therefore selected sites that were stratified by elevation to capture potential differences in topographic or vegetative conditions associated with elevation. We then created random points within our 5 elevational strata such that sampling points were ≥1.5 km from each other. We chose this distance because it represents an area slightly larger than the reported winter home range of male eastern spotted skunks (which are larger than female home ranges; Lesmeister et al. 2009) to meet the assumption of closure within a season of sampling (Wilson et al. 2016). We then used a generalized random tessellation stratified (GRTS) sampling approach (Gitzen et al. 2012) to identify coordinates for 20 potential sites within each elevational stratum of potential sampling points. We navigated to selected sites and identified a suitable site to set up our monitoring station within 50 m of the randomly selected coordinates. If conditions were unsafe or inaccessible by foot, we set sites within 250 m of the original coordinates in a direction that would not violate the 1.5-km minimum distance between sites. At each site, we deployed monitoring stations that consisted of a bait tree and a camera tree located 1.2–4 m apart. We used cameras (Bushnell Trophy Cams model 119736, Bushnell, Overland Park, KS, USA) set to operate continuously and capture 1 photo every 3 seconds when triggered. Like previous studies of eastern spotted skunk occurrence (Hackett et al. 2005, Lesmeister et al. 2012, Wilson et al. 2016, Thorne et al. 2017), we elected to use attractants at our monitoring stations because detection rates for this species are typically low (Hackett et al. 2007). We used a can of sardines in oil and 1 of 3 scent lure treatments at each bait tree: Caven's Gusto™ (Minnesota Trapline Products, Pennock, MN, USA) to represent the musky odor of other species, cherry oil to represent a sweet food source, or a control treatment with no additional lure. We rotated scent lure treatment every fourth week and randomly selected the starting lure for each site to avoid confounding the effects of season and scent lure treatment. We revisited monitoring stations every 2 weeks for 3 months, for 6 sampling occasions/site, each approximately 14 days in length ($\bar{x}$ = 12.6, median = 14, range = 1–31). During every revisit we replaced the bait and the camera memory card, either refreshed or changed the scent lure, and checked that the camera batteries were ≥50% full.

We used a combination of field and remote sensing methods to collect measurements for covariates we predicted to influence detection and occupancy probability at each site (Table 1). In the field, we estimated understory density by assessing the average percent visibility at camera height to 30 m in 4 cardinal directions from the camera. We evaluated coarse woody debris (CWD) abundance within a 30-m radius using an index of 1–10, with 1 representing no CWD >10 cm in diameter, and 10 indicating the area was mostly covered by fallen trees and large woody debris. We used the package suncalc (Agafonkin and Thieurmel 2018) in Program R version 3.4.2 (R Core Team 2017) to calculate moon illumination and the number of minutes the moon was above the horizon each night. We multiplied these values to obtain a single measure of moonlight for each sampling occasion of each site. We used geographic information system software (ArcGIS 10.4, Environmental Systems Research Institute, Redlands, CA, USA) and data from a 1/3 arc-second digital elevation model (DEM; U.S. Geological Survey 2014) and the National Land Cover Dataset (NLCD 2011; U.S. Geological Survey 2014) to identify the aspect, elevation, and forest canopy type for each sampling site. We calculated the average slope, elevation, proportion of area covered by evergreen forests, proportion of area with southwest facing slopes (157.5–292.5 degrees), and amount of impervious land cover (as a proxy for human development; Sutton et al. 2009) within a 750-m-radius circle around the site, which equates to an area slightly over 1.75 km^2, or the average winter home range of a male eastern spotted skunk (Lesmeister et al. 2009). Finally, we calculated the distance of each site to the nearest drainage channel and the length of drainage channels within our 750-m buffer (Montgomery and Foufoula-Georgiou 1993).

Analyses and Model Validation

Because we did not re-sample our sites across years, we used a single-season occupancy modeling framework (MacKenzie et al. 2006) to estimate detection and occupancy probability of eastern spotted skunks in southern Appalachian hardwood forests. By repeatedly sampling a site within a single season, occupancy modeling allows for evaluation of species occurrence while accounting for imperfect detection rates inherent in field monitoring studies (MacKenzie et al. 2006). For typically nocturnal spotted skunks, we first attempted to define survey periods based on nightly

Table 1. Descriptions of the 9 detection covariates and 6 site covariates included as potential factors influencing eastern spotted skunk detection and occupancy probabilities, respectively, southern Appalachian Mountains, USA, 2016 and 2017.

Variable	$\bar{x} \pm$ SE	Range	Description	Predicted direction of response
Scent lure treatment			Rotating scent lure added to each monitoring array every check	+
Bait height	68.19 ± 0.52	42–100	Height (cm) from the ground to the middle of the can of sardines	−
Camera height	79.10 ± 1.37	44–147	Height (cm) from the ground to the middle of the camera trap	−
Camera to bait distance	2.88 ± 0.04	1.27–4.10	Distance (cm) between the camera tree and the bait tree	+
Coarse woody debris	3.46 ± 0.05	0–8	Index of coarse woody debris within a 30-m radius of the site	+
Understory density	33.73 ± 1.40	0.5–91.25	Average of 4 estimates of percent visibility to 30 m from the camera tree	+
Distance to drainage channel	80.69 ± 3.90	0.20–252.74	Distance from site coordinates to nearest drainage channel (m)	−
Season	63.88 ± 1.43	18.5–118.25	Averaged ordinal date for all days included in that sample occasion	−
Moon illumination	267.59 ± 9.75	9.37–648.20	Average percent Moon illumination × Minutes the moon was above the horizon for all days in that sample occasion	−
Slope	18.69 ± 0.57	10.0–26.8	Average slope	+
Southwestern aspect	0.42 ± 0.013	0.22–0.64	Proportion of slopes facing approximately SW (from 157.5° to 292.5°)	+
Elevation	810.70 ± 42.06	340–1298	Average elevation (m)	+
Drainage length	695.6 ± 16.86	442–901	Total length of drainage channels (m)	+
Evergreen forests	0.12 ± 0.017	0–0.46	Proportion of land covered by evergreen forest	−
Impervious surfaces	0.16 ± 0.046	0–0.23	Proportion of land covered by impervious surfaces	−

intervals. Low nightly detection rates, however, led to model convergence issues. Therefore, we defined a sampling occasion as the full length of time between visits to a site (~2 weeks) when we downloaded camera photos and either refreshed or changed the lure treatment. We carried out our analyses in 2 stages. First, we evaluated support for our 4 hypotheses regarding factors predicted to influence spotted skunk detection probability while holding occupancy probability constant. Then, using the covariates retained in our top detection models, we evaluated support for our 3 hypotheses regarding factors we predicted to influence eastern spotted skunk occupancy probability. For both stages of analyses, we evaluated *a priori* hypotheses, and ranked models using Akaike's Information Criterion for small samples sizes (AIC_c) with a model retention threshold of 2 ΔAIC_c units (Burnham and Anderson 2002). We scaled all detection and site covariates to have a mean of zero and a standard deviation of one. Within each set of detection or site covariates, we checked for multicollinearity but found no variables with a correlation coefficient > 0.4 and therefore retained all variables. We used the Program R package unmarked (Fiske and Chandler 2011) to perform our analyses.

We evaluated support for 13 *a priori* models plus a null model and global model representing our 4 primary hypotheses related to factors we expected to influence detection probability (Table 2). To evaluate support for our hypothesis that detection probability was influenced by predation risk, we used average percent moon illumination as a proxy for predator avoidance because previous studies of spotted skunks (Thorne et al. 2017) and other nocturnal mammalian species have reported changes in behavior associated with moon illumination (Daly et al. 1992, Griffin et al. 2005, Prugh and Golden 2014). Specifically, we predicted less moonlight would increase our chances of eastern spotted skunk detection. Given the importance of cover in previous studies of spotted skunk habitat selection (Lesmeister et al. 2009, Sprayberry and Edelman 2018), we also predicted that increased CWD, increased understory cover, and proximity to a stream or drainage ravine would improve immediate structural cover and refugia from predators, thereby increasing detection probability. To evaluate support for our food availability hypothesis, we predicted that spotted skunks would spend more time actively foraging and be more willing to approach a bait station during the colder months earlier in the year when thermoregulatory demands were greatest and food resources were more limited. To evaluate support for our scent-lure hypothesis, we predicted that spotted skunk detections would be highest during sample occasions when sites were baited with the cherry scent lure followed by Gusto™ lure, whereas sites baited with the control treatment (sardines alone) would produce the fewest detections. Finally, to evaluate support for our hypothesis that camera setup could affect the probability of spotted skunk detection, we predicted that lower bait height, higher camera height, and greater distance between camera and bait tree would increase our chances of detecting eastern spotted skunks.

We evaluated support for 16 *a priori* models plus a null and global model containing 6 covariates and representing 3 primary hypothesized landscape-scale factors we thought would influence eastern spotted skunk occurrence (Table 3). To evaluate support for our movement facilitation hypothesis, we tested the prediction that areas with more drainage channels would improve occupancy probability because drainage channels can facilitate movement through

Table 2. Ranked *a priori* candidate models for evaluating eastern spotted skunk detection probability in the southern Appalachian Mountains, USA, 2016 and 2017. We held occupancy probability (ψ) constant at this stage of analysis.

Model	df	logLik[a]	AIC_c[b]	ΔAIC_c	w_i[c]
Lure+bait height+camera height+camera distance+ψ	7	−109.556	236.1	0.00	0.232
Bait height+camera height+camera distance+ψ	5	−112.569	236.7	0.54	0.178
Lure+ψ	4	−113.919	236.8	0.70	0.164
Bait height+camera height+camera distance+CWD[d]+distance to drainage+understory density+ψ	8	−108.832	237.7	1.52	0.108
Lure+bait height+camera height+camera distance+CWD+distance to drainage+understory density+ψ	10	−105.700	237.9	1.73	0.098
Lure+CWD+distance to drainage+understory density+ψ	7	−110.933	238.9	2.75	0.059
Null+ψ	2	−117.339	239.0	2.82	0.057
Moon phase+ψ	3	−116.962	240.5	4.37	0.026
CWD+distance to drainage+understory density+ψ	5	−114.531	240.6	4.46	0.025
Date+ψ	3	−117.325	241.2	5.10	0.018
Moon+date+lure+ψ	6	−113.538	241.3	5.15	0.018
Moon+date+ψ	4	−116.952	242.9	6.76	0.008
Detection global+ψ	12	−105.303	244.4	8.22	0.004
Moon+date+lure+CWD+distance to drainage+understory density+ψ	9	−110.665	244.5	8.33	0.004
Moon+date+CWD+distance to drainage+understory density+ψ	7	−114.238	245.5	9.36	0.002

[a] Log likelihood of the model.
[b] Akaike's Information Criterion corrected for small sample sizes.
[c] Model weight.
[d] Coarse woody debris.

mountainous areas (Campbell Grant et al. 2007). We evaluated support for our thermoregulatory stress hypothesis by testing the prediction that lower elevations, steeper slopes, and southwestern facing slopes would each potentially provide warmer temperatures and increase occupancy probability (Fekedulegn et al. 2003, 2004). To evaluate support for our predation risk hypothesis, we first predicted that eastern spotted skunks would be less likely to occupy areas with increased human development (represented by impermeable surfaces for this study) because eastern spotted skunks are known to be predated upon by domestic pets (Crabb 1948, Kinlaw 1995). We also evaluated the prediction that evergreen-dominated forests were associated with elevated risk of predation by owls and other native predators (Lesmeister et al. 2010), and less likely to be occupied. In addition to the 6 single-covariate models described above, we also evaluated more complex *a priori* models that included multiple covariates related to each hypothesis, and sub-global models that represented combinations of these hypotheses.

Table 3. Ranked *a priori* candidate models for evaluating eastern spotted skunk occupancy probability in the southern Appalachian Mountains, USA, 2016–2017. The following detection covariates were included in all models (denoted as *p*): bait height, camera height, distance to bait, coarse woody debris, distance to nearest drainage channel, understory cover, and scent lure treatment.

Model	df	logLik[a]	AIC_c[b]	ΔAIC_c	w_i[c]
p+elevation	11	−102.067	234.1	0.00	0.385
p+slope+elevation	12	−100.746	235.2	1.11	0.221
p+elevation+distance to drainage	12	−101.743	237.2	3.10	0.082
p+elevation+evergreen	12	−101.820	237.4	3.26	0.076
p+null	10	−105.700	237.9	3.74	0.059
p+slope	11	−104.003	238.0	3.87	0.056
p+slope+SW aspect +elevation	13	−100.536	238.8	4.68	0.037
p+distance to drainage	11	−104.649	239.3	5.16	0.029
p+impervious surface	11	−105.252	240.5	6.37	0.016
p+SW aspect	11	−105.627	241.3	7.12	0.011
p+evergreen	11	−105.693	241.4	7.25	0.010
p+slope+SW aspect	12	−103.929	241.6	7.47	0.009
p+slope+SW aspect +elevation+distance to drainage	14	−100.313	242.6	8.49	0.006
p+evergreen+impervious surface	12	−105.249	244.2	10.11	0.002
p+evergreen+impervious surface+distance to drainage	13	−104.492	246.7	12.59	0.001
p+slope+SW aspect +elevation+evergreen +impervious surface	15	−100.514	247.6	13.45	0.000
p+Global	16	−100.174	251.8	17.64	0.000

[a] Log likelihood of the model.
[b] Akaike's Information Criterion corrected for small sample size.
[c] Model weight.

We used k-fold cross validation to assess the predictive ability of our top ranked occupancy models (Boyce et al. 2002). This method allowed us to test the predictive ability of our top model using only the data we had already collected, by training our top model with only a subset of our data, and then evaluating how well the resulting model predicted the true state of the remaining portion of our data. We validated the detection component and occupancy component of our top occupancy model separately and used all covariates from our candidate models within 2 ΔAIC_c of our highest ranked occupancy model. We performed 20 iterations of k-fold validation using random divisions of our data into a 90:10 ratio to train and test our top model, respectively. We interpreted our validation results using receiver operating characteristics (ROC) and the area under the curve (AUC) value to evaluate how well our models were able to accurately predict if a skunk was detected or a site was occupied, based on the habitat variables contained in our top model (Metz 1978, Cumming 2000). We additionally performed a parametric bootstrap goodness-of-fit test of our most complex model, using 5,000 iterations to assess how well our models fit the collected data (MacKenzie and Bailey 2004).

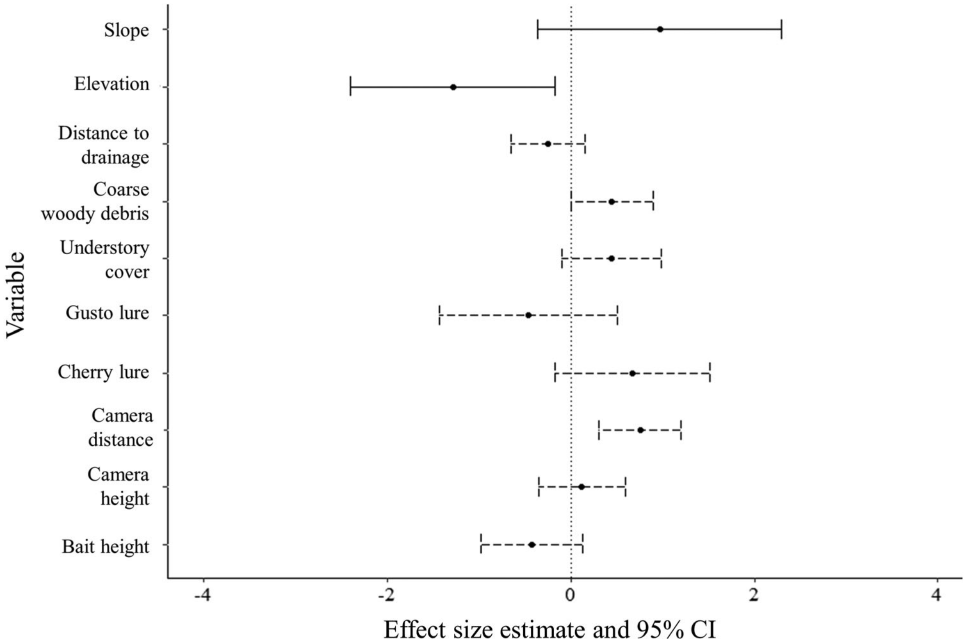

Figure 2. Standardized effect sizes and 95% confidence intervals for covariates from our top *a priori* models evaluating detection and occupancy probability for spotted skunks in the southern Appalachian Mountains, USA, 2016–2017. Solid lines indicate effect estimates and confidence intervals for our occupancy covariates, and dashed lines indicate estimates and confidence intervals for our detection covariates.

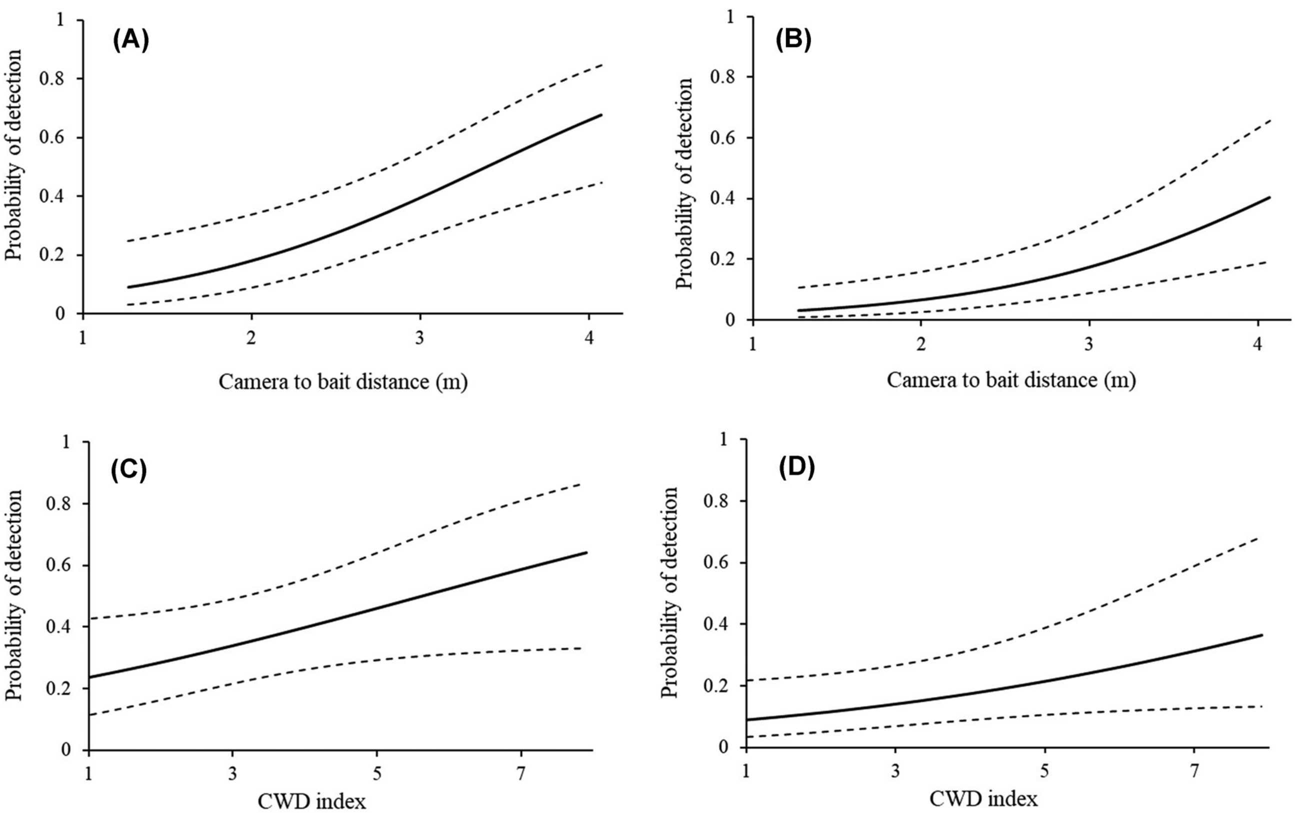

Figure 3. Predictive plots (with 95% CIs) illustrating the effects of our top detection covariates on probability of detection of eastern spotted skunks in the southern Appalachian Mountains, USA, 2016–2017, as a function of distance to camera based on lure type as being either cherry oil (A) or Caven's Gusto™ (B), and amount of coarse woody debris (CWD) based on lure type as being either cherry oil (C) or Caven's Gusto™ (D). Figures display predicted effects and 95% confidence intervals (dashed lines).

RESULTS

We detected eastern spotted skunks at 25 of the 45 sites surveyed (55.6% naïve occupancy) and had detections on 47 of our 254 sampling occasions (18.5% naïve detection). Of the intended 270 sampling occasions (6 occasions for each of the 45 sites), we missed 16 because of logistical constraints and camera malfunctions. On average, latency to first detection was 28.3 days (range = 1–71, SD = 23.1). Cameras were active for 4,689 trap-nights over the course of both years, with an average of 12.6 active trap-nights per sampling occasion (range = 0–31, SD = 4.6). Of sites occupied, we detected spotted skunks on 14.1% of active trap-nights (129 of 913 trap-nights); however, when including sites where we never detected spotted skunks, nightly detection was only 2.8% (129 of 4,689 trap-nights).

Five of our 13 *a priori* detection models fell within 2 ΔAIC_c of our top model in step 1, and these models supported our hypotheses that predator avoidance, olfactory attractants, and camera station setup affected detection probability. Our top models included 7 of our 9 detection covariates: scent lure, camera height, bait height, distance to bait, understory cover, CWD, and distance to nearest drainage channel (Table 2). In assessing parameter estimates (Fig. 2), distance to bait and CWD were our strongest predictors of detection probability with confidence intervals not overlapping 0. Our results indicated that conditional detection probability on average increased 8% (95% CI = 3–17%) for every 0.5-m increase in distance between camera and bait (Fig. 3A,B), and on average increased 5% (95% CI = 2–7%) for every 1-unit increase in CWD (Fig. 3C,D). Based on the 7 covariates contained in our 3 top detection models, our overall conditional point estimate of detection probability was 23.4% based on mean conditions, and average detection probability given the conditions of sample occasions in this study was 28.2%.

We observed support for 2 of our *a priori* occupancy models based on variables measured at the landscape scale in stage 2 of our analyses, both related to our hypothesis that thermoregulation would influence eastern spotted skunk occupancy probability. Elevation alone comprised our top model, whereas elevation and slope were both present in our second-ranked model (Table 3). Only elevation had a significant relationship with occupancy probability (Fig. 2), where the probability of occupancy on average increased 7% (95% CI = 0.5–10%) for every 100-m decrease in elevation (Fig. 4). Using model-averaged parameter estimates of slope and elevation, our overall point estimate of eastern spotted skunk occupancy probability given mean conditions was 82.1%. Based on conditions at the sites surveyed in our study area, we had an average of 70.4% estimated occupancy probability.

Results of our model cross-validation indicated that our covariates were generally poor at accurately predicting eastern spotted skunk detection or occupancy. Validation of our detection covariates returned an AUC value of 0.55, indicating poor predictive ability of our top detection model (Swets 1988, Morelli et al. 2017). The occupancy portion of validation performed slightly better with an AUC value of 0.65, indicating moderately low predictive ability of our top occupancy model. Our data showed slightly less variation than was expected, with the results of our goodness-of-fit test returning a $\hat{c} = 0.74$.

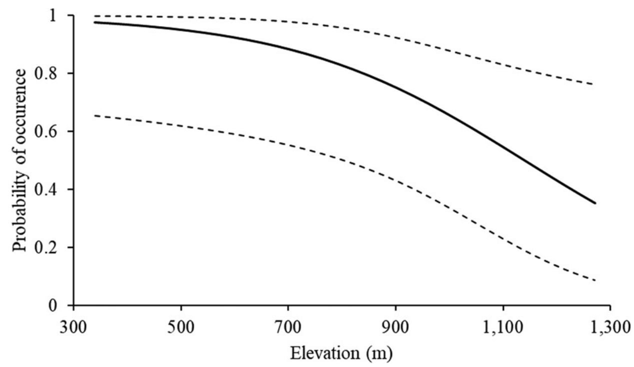

Figure 4. Predictive plot (with 95% CIs) illustrating the effect of elevation, our top site covariate, on the occupancy probability of eastern spotted skunks in our study area of the southern Appalachian Mountains, USA, 2016–2017.

DISCUSSION

Results from our study suggest that although eastern spotted skunks are difficult to detect, they are likely more widely distributed across our study area than previously thought. We detected eastern spotted skunks at over half of our sites but observed spotted skunks on <3% of our total trap-nights. Latency to initial detection ranged from 1 to 71 days, with first detection occurring on average nearly a month after deployment (28.3 days). This suggests that surveys for eastern spotted skunks that monitor sites for <1 month might produce underestimates of true occupancy rates. Indeed, recent sustained and dedicated efforts to identify persisting populations of eastern spotted skunks within the core of their historical range have been successful at detecting the species (Wilson et al. 2016, Thorne et al. 2017, Sprayberry and Edelman 2018). Given the current conservation attention being given to this species and uncertainty about its distribution in most states throughout its historical range (Eastern Spotted Skunk Cooperative Study Group 2018), our results emphasize the need for additional dedicated survey efforts to evaluate how widely distributed spotted skunks are throughout the remainder of their historical range.

Our results also indicate that the species might be extremely cryptic and highlight the need for an improved understanding of monitoring techniques that might increase eastern spotted skunk detection rates. Although we had uncertainty in the effects of our scent lure treatments, our results indicate that cherry lure might work as an attractant, whereas Gusto™ might act as a deterrent to eastern spotted skunks (Fig. 2). Spotted skunks typically did not spend prolonged periods at our baited camera stations, with 36% of detections consisting of only 1 photograph, and on average producing <3 photos/detection (range = 1–15, median = 2). Given that cameras recorded a photo every 3 seconds, these results suggest that on average, spotted skunks spent less than 9 seconds at our monitoring sites. This prompts the concern that our camera arrays could have missed detections when spotted skunks quickly passed through the camera's triggering frame. A greater distance between the camera and bait appeared to increase detection probability in our study, indicating that a larger frame of view may have positive effects on detection rates. However, increasing the distance between camera and bait too far can also result in decreased camera sensitivity for smaller species (Gompper et al. 2006). Future experimental studies using different sized animals or heated models at controlled distances could provide important information on how to identify ideal camera distances for spotted skunks and other mammalian species. Given that a consumable reward can increase the time spent at a monitoring site (Schlexer 2008), we suggest future studies consider using edible baits, such as deer (*Odocoileus* spp.) carcasses (Thorne et al. 2017) or raw chicken (Schlexer 2008) to increase the amount of time a spotted skunk will spend in front of the camera trap. Alternatively, close-proximity camera trapping approaches such as Hunt traps (McCleery et al. 2014) could be useful in increasing the likelihood that game cameras are triggered and collect high-quality images, provided spotted skunks would enter enclosed frames or buckets.

Elevation was the most important predictor of eastern spotted skunk occurrence in our study. However, unlike previous studies to the north of our study area in the same mountain range, we found a negative association with elevation (Diggins et al. 2015, Thorne et al. 2017). Diggins et al. (2015) sampled for and detected spotted skunks only at relatively high elevations (1,425–1,550 m). Thorne et al. (2017) sampled a range of elevations (349–1,469 m) similar to those in our study but found a strong positive effect of elevation on spotted skunk occupancy. However, the magnitude of this positive effect of elevation varied based on the age of the forest stand (a factor we were unable to evaluate). Thorne et al. (2017) hypothesized that this relationship was due to densities of understory cover associated with the different-aged forest stands. By contrast, low-elevation areas in our study might have been preferred because of their proximity to stream beds, where mountain laurel and rhododendron cover was high and increased herpetofauna and invertebrate forage might be available (Sprayberry and Edelman 2016, Thorne and Waggy 2017). Alternatively, low-elevation forest attributes in our study area might not be fully comparable with low-elevation sites in other portions of the Appalachian Mountain range (Simon et al. 2005). For example, cove hardwood forests are associated with low-elevation areas (Bolstad et al. 1998, Elliott et al. 1999, Warren 2008) and provide varied vegetative structure and high species diversity (Turner et al. 2003, South Carolina Department of Natural Resources 2015), potentially providing preferable habitat for eastern spotted skunks. It is also possible that within a heterogenous landscape such as the southern Appalachians, evaluating selection based on attributes averaged across >1.75 km^2 might have failed to capture the heterogeneity of conditions present in the landscape. Thus, we recommend additional, finer-scale studies to identify which biological factors associated with elevation have the most influence on eastern spotted skunk occupancy.

The large proportion of sites at which we detected spotted skunks combined with generally poor goodness of fit of our top ranked models suggests that additional, longer-term monitoring is needed across a wider range of habitat conditions. Given that we monitored the portion of South Carolina where spotted skunks were predicted to be most likely to occur (Wilson et al. 2016), we suggest that future studies additionally sample areas where occupancy might be less likely, such as unforested areas, private or heavily managed lands, and nearby non-mountainous regions. Such studies could help identify elevational thresholds and major habitat features that might constrain the distribution of eastern spotted skunks. Identification of these thresholds could allow for more accurate predictions of current distribution of this species across the eastern United States.

MANAGEMENT IMPLICATIONS

Managers interested in surveying for eastern spotted skunks should maintain survey periods >1 month in length to account for the long latency to detection that we encountered. Evidence that the species was more widely distributed than expected in our study area should be interpreted with caution because our study, like a majority of studies of eastern spotted skunks to date, occurred on public forested lands where spotted skunks were known to persist. Thus, assessing spotted skunk responses to agricultural and urban development in the remainder of their historical range will be critical for assessing the vulnerability of this species to regional extirpation. Specifically, we encourage managers to implement large scale, multi-year camera-trap monitoring of sites to refine predictive occupancy models and potentially assess colonization and extinction probability. Finally, although multiple studies now exist showing the efficacy of camera surveys for spotted skunk monitoring, information regarding survival and reproductive rates are urgently needed to determine the current demographic trend of the species in the southern Appalachians and throughout its range (Eastern Spotted Skunk Cooperative Study Group 2018).

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