Predicted Spatial Distribution of the Eastern Spotted Skunk (*Spilogale putorius*) in Virginia Using Detection and Non-detection Records

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Abstract - The geographic distribution of a species is a fundamental component in understanding its ecology and is necessary for forming effective conservation plans. For rare and elusive species of conservation concern, accurate maps of predicted occurrence are particularly problematic and often highly subjective. *Spilogale putorius* (Eastern Spotted Skunk) populations have experienced large declines since the 1940s. Their elusive behavior and perceived rarity result in low detection probability when using conventional methods for sampling small mammals. Low detection probability often causes uncertainty as to where Eastern Spotted Skunks could be a management concern. We modeled the distribution of predicted occurrence of Eastern Spotted Skunks using verifiable occurrence and non-detection records obtained throughout Virginia from 2010 to 2020. Occurrence data consisted of trapping records reported to the Virginia Department of Wildlife Resources, incidental photo-verified reports of sightings and road-killed animals, and remote-camera detections. Non-detections were presumed at baited remote-camera locations following intense survey efforts. We fit predicted occurrence models using generalized linear modeling in an information-theoretic framework using the package 'stats' in Program R. Our results incidated a greater probability of presence from the Blue Ridge westward, increasing with slope steepness along northeastern- to southeastern-facing slopes and decreasing with slope steepness along southeastern- to southwestern-facing slopes. Emergent rock outcrops prominent along northeastern slopes offer ample protective rocky cover, whereas mixed *Quercus* spp. (oak), *Kalmia latifolia* (Mountain Laurel), and *Rhododendron maximum* (Rosebay Rhododendron) forest communities along southern-facing slopes provide suitable areas of cover, both of which are critical for spotted skunk survival and reproductive success. Our analysis provides insight into the relationships between landscape features and Eastern Spotted Skunk distributions across Virginia. Understanding these relationships is critical for the effective management and conservation of this vulnerable species.

Introduction

The geographic distribution of a species is a fundamental component in understanding its ecology and provides the foundational data needed for effective conservation and management plans. Conventional species range maps are often depicted as irregular polygons of coarse resolution with boundaries drawn around known species occurrences (Brown and Lomolino 1998). The interior of these coarse polygons often is misleading as unoccupied areas may be labeled as occupied or vice versa (Brown and Lomolino 1998, Rapaport 1982). Further confusion

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of range extent can arise when detection probability of a species is low, leading to assumptions of false absence. Rarity, low population density, and territoriality can increase detection difficulty and may lead to failed detection with inadequate sampling effort in areas of uncertain occurrence (MacKenzie et al. 2003). Patchy population distribution due to discontinuity of suitable habitat or limited dispersal ability may further decrease detection probability within a known range (Hubbell 2001, Lawton and Woodroffe 1991). For these reasons, accurate maps of predicted species occurrence, especially those that are rare, are particularly difficult to produce, and such range maps likely overestimate, or underestimate, the true distribution of the species.

Spilogale putorius (L.) (Eastern Spotted Skunk, hereafter "Spotted Skunk") is a once common species that was historically widespread throughout the eastern United States but has declined precipitously in number and distribution since the 1940s based on trapping reports and observations of furbearer biologists and is now considerd rare (Gompper and Hackett 2005). In the central and southern Appalachian Mountains, this species' elusive behavior and perceived rarity result in low detection probability when using conventional methods of sampling small mammals such as live-trapping (Eng and Jachowski 2019a, Lombardi et al. 2017, Thorne et al. 2017), thereby creating uncertainty about the species' status. In Virginia, the Spotted Skunk is listed as a Tier IV species (moderate conservation need) with not yet identified management, research, and conservation needs in Virginia's Wildlife Action Plan (Virginia Department of Game and Inland Fisheries 2015). The most recently available range map for Spotted Skunk depicts a continuous distribution encompassing the Appalachian Plateau, Valley and Ridge, and Blue Ridge physiographic subprovinces (Fig. 1; Patterson et al. 2005). However, recent research suggests Spotted Skunk habitat is distributed in small, spatially disjunct patches throughout this range, and populations may be genetically isolated due to limited dispersal (Thorne 2020, Thorne et al. 2017). Therefore, a finer-resolution species distribution map is needed to effectively monitor and manage this species in Virginia. Our objectives were to model the current distribution of predicted occurrence of Spotted Skunk throughout Virginia to determine areas for targeted monitoring and conservation efforts.

Methods

Field-site description

Our study was conducted throughout the Commonwealth of Virginia. The area comprises the Appalachian Plateau, Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain physiographic subprovinces from west to east, respectively. The Appalachian Plateau, in the southwestern region of Virginia, is characterized by sandstone plateaus cut with deep valleys. The Valley and Ridge and Blue Ridge subprovinces consist of parallel ridges and valleys that run southwest to northeast along western Virginia. These areas encompass the highest elevations and most rugged terrain in the state as well as low-elevation areas of the Shenandoah, Roanoke, and New River valleys. The Appalachian Plateau, Blue Ridge, and Valley and Ridge subprovinces are characterized by a cool-temperate climate. Annual rainfall is ~110 cm (Ford et al. 2015) and temperatures vary from -10.6 °C to 27.5 °C (National Oceanic Atmospheric Administration, public data 2019; www.noaa.gov). Elevations throughout vary from as low as 100 m in valley bottoms to >1500 m along the highest ridgelines (Ford et al. 2005). Separate from the Appalachian sections, the Piedmont begins at the low foothills east of the Blue Ridge Mountains and extends eastward into a broad, flat basin where it meets the Coastal Plain. Approximate annual temperature and precipitation vary from 4 °C to 22 °C and 110 cm to 115 cm, respectively (Lotspeich 2009). Elevation decreases from 250 m at the Blue Ridge–Piedmont transition to 20 m at the Fall Line where the Piedmont transitions to the Coastal Plain which meets the Chesapeake Bay or the Atlantic Ocean at sea level.

Forest composition varies across physiographic regions. The Appalachian, Valley and Ridge, and Blue Ridge regions contain mixed hardwood–pine forests dominated by *Quercus* spp. (oak) and oak–*Pinus* spp. (pine) forest types, to northern hardwood types and *Picea rubens* Sarg. (Red Spruce)–*Abies fraseri* (Pursh) Poir. (Fraser Fir) in the highest elevations (Braun 1950). The Piedmont region is characterized by oak–*Carya* spp. (hickory) forest, *Pinus virginiana* Mill. (Virginia Pine)–*Juniperus viginiana* L. (Eastern Red Cedar) successional forest, Piedmont bottomland forest types, and planted plantations, primarily of *Pinus taeda* L.

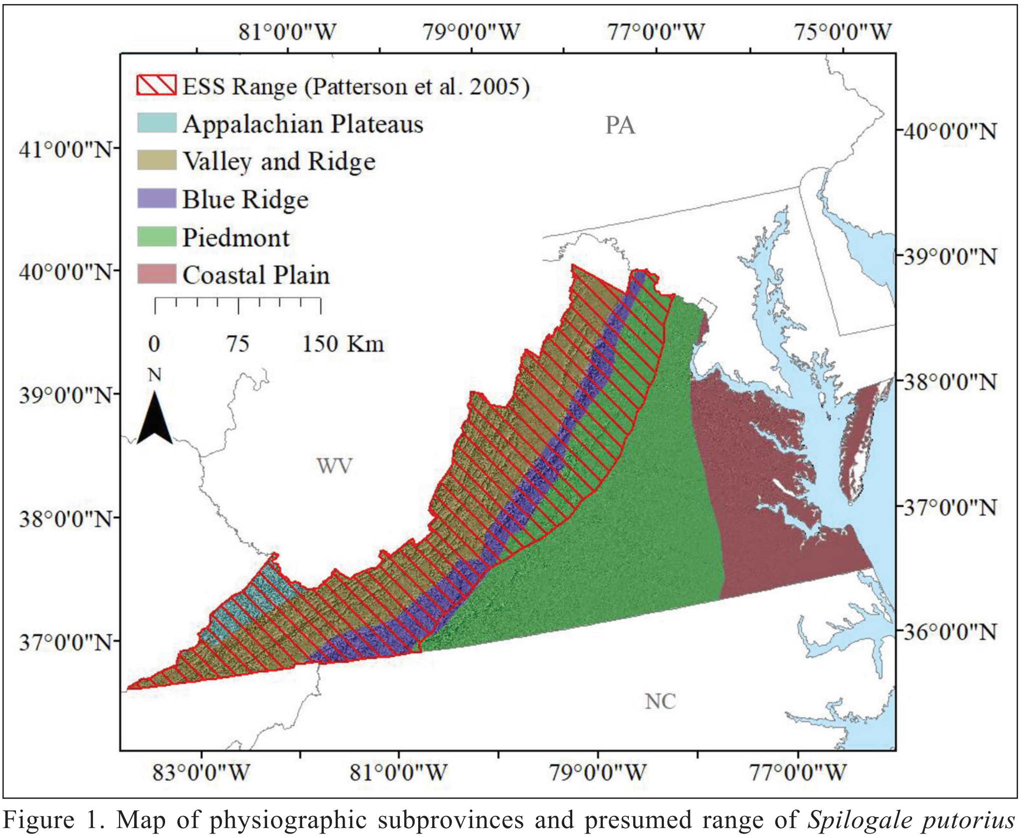

Figure 1. Map of physiographic subprovinces and presumed range of *Spilogale putorius* (Eastern Spotted Skunk [ESS]) (Patterson et al. 2005) in Virginia.

(Loblolly Pine) (Braun 1950, Fleming and Weber 2003, Rossell et al. 2005). Dominant forest types in the Coastal Plain region include southern mixed hardwoods, bottomland hardwoods, and pine types, including the northernmost *P. palustris* Mill. (Longleaf Pine) in the United States (Braun 1950, DeWitt and Ware 1979).

Due to the rarity of recent Spotted Skunk detections in Virginia, we combined various types of location data reported to the Virginia Department of Wildlife Resources from 2010–2020 including (1) photographs of Spotted Skunks acquired using remote-triggered cameras (baited or unbaited), (2) visual observations by wildlife professionals and researchers, (3) roadkill specimens opportunistically collected for demographic and genetic research, and (4) agency verified reports of incidental captures by fur trappers and private landowners. We obtained GPS locations for all reported occurrences. To supplement the dataset, we conducted a citizen science survey with the Virginia Master Naturalist program across an array of cooperating public and private lands throughout Virginia during February–April of 2016–2020. Location and sample number varied by year with ~50% of locations sampled for >1 year. Locations included 2 sites within the Appalachian Plateau, 11 within the Valley and Ridge, 17 within the Blue Ridge, 8 within the Piedmont, and 6 within the Coastal Plain. The number of yearly samples was 13 in 2016, 45 in 2017, 27 in 2018, 22 in 2019, 13 in 2020 for a total of 120 sites. We chose camera sites opportunistically as many sites were located on private land owned by project volunteers or on public land which the Virginia Master Naturalists had permission to access. Within study sites, we identified forested areas, and then camera locations were chosen at the discretion of the volunteers within the forested areas to increase probability of Spotted Skunk detection (Thorne 2020, Thorne et al. 2017). We trained volunteers on survey protocol either in person or through an online webinar and provided them with written survey protocols including methods of camera station deployment, bait use, and collection of site-level habitat data (i.e., percent canopy cover, percent understory cover, number of rocks greater than 10 cm diameter, and number of pieces of downed woody debris greater than 10 cm in diameter on average along the length of the piece). Camera stations consisted of 1 remotely triggered camera mounted to a tree ~0.5–1.0 m above ground and angled downward to ensure bait was visible within the camera frame. Bait was staked down with rebar or fastened to a tree with 12–14 gauge wire ~2–3 m in front of the camera following the methods of Thorne et al. (2017). If multiple cameras were deployed within a study site, we spaced cameras at a minimum of 1.75 km to ensure independence of detection events (Thorne et al. 2017). Camera brands we used in the citizen science survery included Browning models BTC-HDE and 940-HD (Browning Arms Co., Morgan, UT), Bushnel Trophy Cam models 119436, 119739, and 119776 (Bushnell Co., Overland Park, KS), Moultrie model D-35 (Moultrie, Birmingham, AL), Primos model 64054 (Primos Inc, Flora, MS), and Stealth Cam model STC-P12 (GSM Outdoors, Irving TX). Bait type included road-killed deer, raw chicken, canned catfood, or canned sardines.

For all detection and non-detection locations, we extracted landscape-scale habitat attributes using remotely sensed geographic information systems layers in

ArcMap 10.7.1 software (ESRI, Redlands, CA). We created a 1-km radius buffer around each location based on the approximate average Spotted Skunk home-range size in Virginia (Thorne 2020). Using a 30-m 3D Digital Elevation Model (US Geological Survey 2017), we calculated mean elevation within each 1-km buffer. Additionally, we derived mean slope gradient (percent) and mean aspect (degrees) using surface analysis tools in ArcMap and calculated topographic exposure index (TEI; Evans et al. 2014) within each buffer. We calculated majority tree canopy height category (LANDFIRE 2016a) and majority vegetation type (LANDFIRE 2016b) within buffers.

Statistical analysis

We compared continuous landscape-scale variables between sites where Spotted Skunks were detected and not detected using a non-parametric Mann–Whitney U test. We used a chi-square test to assess differences between canopy height category and forest type among sites. To assess Spotted Skunk distribution in Virginia, we used generalized linear models to compare landscape-scale habitat attributes at locations where Spotted Skunks were and were not detected. We compared Akaike's information criterion for small sample size (AIC_c) and Akaike's model weights (w_i) to select the best-supported model from a set of 29 a priori single variable, additive, and interactive models (Burnham and Anderson 2002). Before analysis, we examined all variables for multicollinearity using Spearman's rank correlation. No variables exceeded a correlation of $|r| > 0.7$, and so we retained all variables for model selection. We conducted all analyses listed above using the 'stats' package in Program R (Version 4.0.3; R Core Team 2016). We assessed model fit of the best-supported model using a Hosmer–Lemeshow test in package 'ResourceSelection' for Program R and considered model fit to be acceptable when $P > 0.05$. (Subhash et al. 2019). Finally, we used the best-supported model to estimate probability of occurrence based on landscape-scale habitat attributes to create a map of the current distribution using the Raster Calculator tool in the Spatial Analyst extension in ArcMap (ESRI, Redlands, CA).

Results

From January 2010 through April 2020, 54 verified occurrences of Spotted Skunks were reported to the Virginia Department of Wildlife Resources. Of these, 25 were verified with photographs, 8 were incidental captures of live animals, 3 were collected roadkill specimens, and 18 were visual observations reported by credible experts. Of the 54 occurrences, 38 were located in the Valley and Ridge, 12 in the Blue Ridge, and 4 in the Piedmont. No occurrences were reported in the Appalachian Plateau or Coastal Plain. No Spotted Skunks were detected at the 44 baited remote-triggered camera sites (120 samples) deployed by private citizens from 2016 to 2020. Though no continuous variables differed significantly among sites, a more restricted range of values was observed at occurrence sites than non-detection sites for all continuous variables except TEI (Table 1). All Spotted Skunk occurrences were located in areas with a tree canopy height of 10–25 m except

Table 1. Mean, standard error (SE), coefficient of variation (CV), and Mann–Whitney U test *P*-value (*P*) for continuous landscape-scale habitat variables for *Spilogale putorius* (Eastern Spotted Skunk) occurrence and non-detection sites throughout Virginia, from January 2010 to April 2020 (n =174)

	Occurrence sites (n = 54)				Non-detection sites (n =120)				
Variable	Mean	SE	Min–max	CV	Mean	SE	Min–max	CV	*P*
Slope (%)	14.52	0.60	2.78–22.44	0.31	12.93	0.47	0.23–21.64	0.41	0.11
Aspect (degrees)	178.77	5.03	118.04–249.14	21.00	184.29	3.26	68.67–284.91	0.19	0.33
Elevation (m)	806.69	38.75	156.02–1476.67	0.35	768.31	30.73	0.14–1532.92	0.44	0.86
Topographic exposure index[A]	18.55	7.73	-90.35–167.93	3.06	13.35	4.82	-82.35–142.43	3.95	0.47

[A]Negative values represent sheltered landforms and positive values represent exposed landforms.

1 occurrence in a non-forested area. Ninety percent of non-detection sites were classified with a tree canopy height of 10–25 m, 7.5% were located in non-forested areas, and 2.5% in areas with tree canopy height > 25 m. Proportion of forest type did not differ between occurrence and non-detection sites. Eighty percent of occurrence sites were located in hardwood forests, 13% in coniferous or mixed coniferous–hardwood forests, and 7% in non-forested areas. Non-detection sites were classified as 70.9% hardwood forest, 15.8% coniferous or mixed coniferous–hardwood forest, and 13.3% non-forested areas.

The best-supported of the 29 models assessed contained an interaction between slope gradient and aspect direction (Table 2). Probability of presence increased with slope steepness along northeastern- to southeastern-facing slopes, began to decrease along southeastern to southwestern slopes, and decreased drastically along southwestern to northwestern slopes (Fig. 2). This model showed an acceptable goodness-of-fit ($\chi^2 = 9.02$, df = 8, $P = 0.34$), and we used it to create a map of Spotted Skunk distribution throughout Virginia (Fig. 3). Areas of predicted occurrence

Table 2. Rankings of generalized linear models explaining the effect of landscape-scale habitat variables on predicted occurrence of *Spilogale putorius* (Eastern Spotted Skunk) in Virginia (n =174) based on Akaike's information criterion for small sample sizes (AIC_c).

Model	K	AIC_c	ΔAIC_c	Wi
Slope gradient * aspect	4	210.00	0.00	0.61
Elevation * topographic exposure	4	213.52	3.52	0.11
Slope gradient * elevation	4	213.84	3.84	0.09
Slope gradient	2	215.84	5.84	0.03
Aspect * elevation	4	216.25	6.24	0.03
Slope gradient+ aspect	3	216.64	6.64	0.02
Slope gradient * topographic exposure	4	217.47	7.47	0.01
Slope gradient + elevation	3	217.52	7.52	0.01
Null	1	217.57	7.56	0.01
Slope gradient + topographic exposure	3	217.91	7.91	0.01
Aspect	2	218.73	8.73	0.01
Canopy height	3	218.93	8.92	0.01
Elevation	2	219.07	9.07	0.01
Slope gradient + canopy height	4	219.09	9.08	0.01
Topographic exposure	2	219.27	9.26	0.01
Aspect + canopy height	4	219.63	9.62	0.00
Aspect + elevation	3	219.81	9.80	0.00
Aspect * elevation	4	220.26	10.26	0.00
Aspect + topographic exposure	3	220.35	10.35	0.00
Topographic exposure + canopy height	4	220.81	10.81	0.00
Elevation + topographic exposure	3	220.96	10.95	0.00
Elevation + canopy height	4	221.02	11.02	0.00
Global	9	224.52	14.51	0.00
Elevation + forest type	22	240.16	30.16	0.00
Forest type	21	241.27	31.27	0.00
Slope gradient + forest type	22	243.18	33.17	0.00
Aspect + forest type	22	243.65	33.65	0.00
Topographic exposure + forest type	22	243.80	33.80	0.00
Canopy height + forest type	23	245.85	35.84	0.00

≥ 0.5 occur along disjunct linear patches associated with ridgelines in the Appalachian Mountains throughout the 3 western subprovinces. Conversely, valleys between ridgelines and flatlands east of the Blue Ridge Mountains into the upper

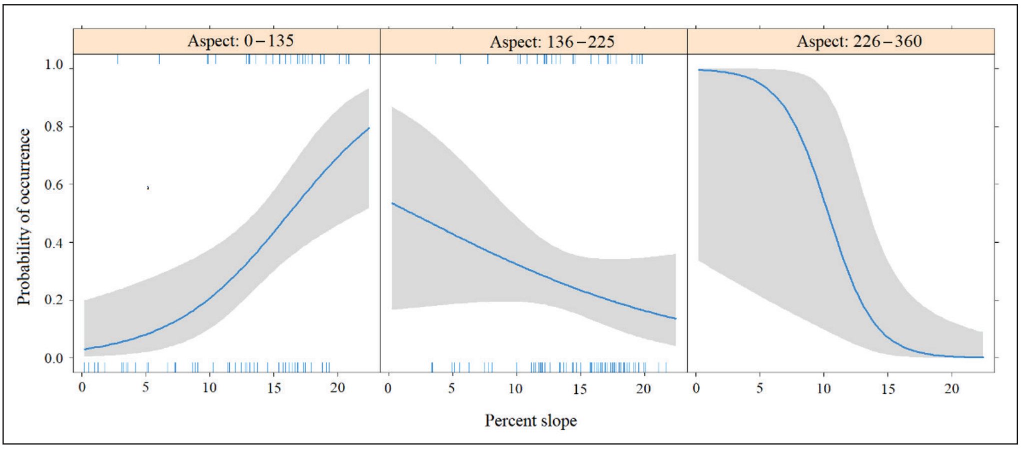

Figure 2. Predicted probability of *Spilogale putorius* (Eastern Spotted Skunk) occurrence relative to the interaction between slope gradient and degree aspect in Virginia.

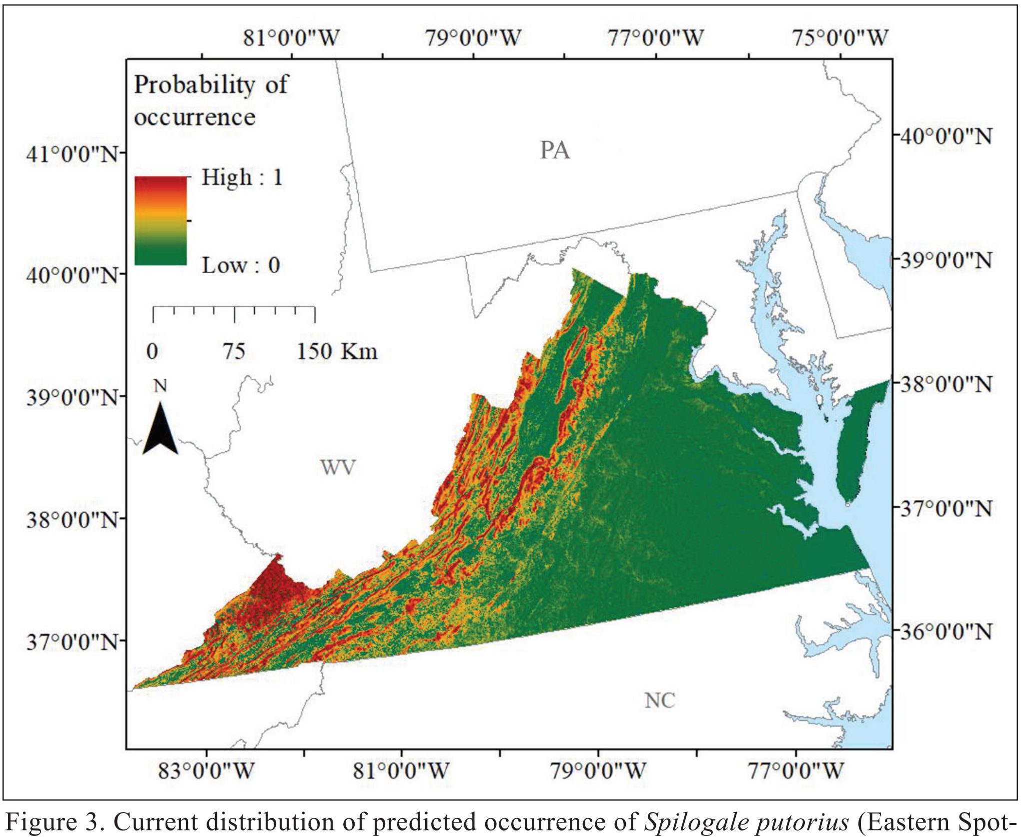

Figure 3. Current distribution of predicted occurrence of *Spilogale putorius* (Eastern Spotted Skunk) throughout Virginia, USA based on the interaction of slope gradient and aspect.

Piedmont and farther east into the Coastal Plain generally had low probability (<0.5) of Spotted Skunk occurrence.

Discussion

We found that Spotted Skunks did not occur in any forest type disproportionate to its availability. This observed lack of difference is likely an artifact of the scale at which data were collected rather than actual lack of Spotted Skunk habitat selection (Morris 1984, 1987; Wiser et al. 1996). Forested areas in Virginia are dominated by hardwood or mixed hardwood–coniferous forests, and selection for a specific forest type may occur at a scale too fine for our analysis to capture. For example, while this effort aimed to capture first-order selection (geographic range), Thorne (2020) found Spotted Skunks selected hardwood forests over most coniferous forests disproportionate to their availability (but see Diggins et al. 2016) when assessed at the second-order (location of home range) and third-order (locations within home range) scales (Johnson 1980). However, all occurrence locations, except 1, were located in forested areas where canopy height was 10–25 m, suggesting limited empirical evidence of selection. Though forest bole and canopy height vary by species, edaphic site conditions, and past and current management, Appalachian hardwood species commonly reach this height category between 20 to 40 years of age (Harrison et al. 1986, McClure et al. 2000), the preferred stand age of Spotted Skunks in Virginia (Thorne et al. 2017).

Our best-supported model revealed an interactive relationship between slope and aspect, suggesting topographic variation is an important factor determining Spotted Skunk distribution in Virginia. The effect of topographic variation on species composition, site productivity, and vegetation structure has been well-studied across forested landscapes in North America (Braun 1950, Odom and McNab 2000, Whittaker 1956). Moreover, topographic characteristics such as slope and aspect are important factors in the amount of drainage and solar radiation a site receives, ultimately impacting local microclimates and vegetation communities (McNab 1991, McNab and Thomas 2001, Simon 2013). In the Valley and Ridge and Blue Ridge subprovinces, southwest slopes are characterized by warmer, drier conditions and are dominated by mixed oak–pine associations, whereas northeastern slopes are dominated by mesic associations, i.e., *Liriodendron tulipifera* L. (Yellow Poplar) and *Acer rubrum* L. (Red Maple) (Fekedulegn et al. 2003, Wiser et al. 1996). Spotted Skunks in the Appalachian region frequently den in tree cavities, with a strong preference for oaks over other hardwood or coniferous species (Thorne 2020). Further, tree-cavity dens are used more than underground burrows or rock crevices in areas with sparse rocky or understory cover (Thorne 2020). In southern and central Appalachian forests, forested areas often are dominated by understory of *Kalmia latifolia* L. (Mountain Laurel) and *Rhododendron maximum* L. (Rosebay Rhododendron) which provide Spotted Skunks ample den sites and escape cover from avian predators (Wiser et al. 1996). However, along steeper slopes, emergent rock areas are more sparsely forested, and dominant vegetation can be limited to herbaceous, brushy, or fern species (Wiser et al. 1996). In the absence of dense forest structure, Spotted Skunks frequently use rock outcrops as protective den sites, particularly when rearing offspring (Thorne 2020). Variation in forest composition and geology coupled with flexibility in habitat and den use by Spotted Skunks in the Appalachian regions likely explain our dichotomous results of a higher probability of occurrence along more-steep northeastern to southeastern slopes and less-steep southeastern to northwestern slopes.

Though most of Virginia is dominated by forest that may provide suitable cover for Spotted Skunks, the amount of arable and developed land in the low valleys of the Valley and Ridge and Blue Ridge and the flatlands of the Piedmont and Coastal Plains reached a historic high during the late 19th century (Hendrick and Copenheaver 2009, Wilson 2005). Conversion of forests to agriculture was less common at high elevations due to low soil fertility, steep slopes, and a shorter growing season (Hendrick and Copenheaver 2009). Therefore, these areas may have provided the historic refugia for Spotted Skunks in Virginia, and the resulting habitat fragmentation likely contributed to a patchy current distribution. Nonetheless, we urge caution in the application of our model in that some areas of predicted high probability such as the Appalachian Plateau were relatively undersampled and with few or no documented occurences.

Based on the results of our mapping, as well as findings of recent habitat-selection studies in the central and southern Appalachians (Eng and Jachowski 2019b, Sprayberry and Edleman 2018, Thorne 2020, Thorne et. al. 2017), it is apparent that Spotted Skunk conservation in Virginia will require consideration of both landform characteristics at the lanscape scale and microhabitat characteristics within suitable geographical locations. Understanding the patchy distribution of this species will allow managers to identify key areas of conservation needs. Detailed survey of key areas will elucidate the complex interactions between microhabitat and landscape-scale requirements to better inform management decisions such as the need to increase habitat-patch connectivity.

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