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HABITAT ASSOCIATIONS AND SPECIES DISTRIBUTION MODELING OF THE PLAINS SPOTTED SKUNK (SPILOGALE INTERRUPTA) IN KANSAS

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HABITAT ASSOCIATIONS AND SPECIES DISTRIBUTION MODELING OF THE PLAINS SPOTTED SKUNK (*SPILOGALE INTERRUPTA*) IN KANSAS

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While I can't recall the source of this, I was once taught that to facilitate personal growth, you need three cohorts of people. For walking ahead of me to provide guidance and support, I thank my tireless professor Dr. Christine Brodsky. For walking with me, commiserating at times and bearing the burdens of this project, I would like to thank my colleague, the skunk lady, Jenell de la Peña. Lastly for walking behind, providing the chance and grace to be a leader and mentor, I would like to thank Khloey Stringer. I would also thank my mentor and friend Clint Perkins for his guidance and continuing to mentor me beyond my initial tenure as his technician.

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HABITAT ASSOCIATIONS AND SPECIES DISTRIBUTION MODELING OF THE PLAINS SPOTTED SKUNK (*SPILOGALE INTERRUPTA*) IN KANSAS

An Abstract of the Thesis by
Daniel Benson

While once abundant across the central United States, the plains spotted skunk (*Spilogale interrupta* formerly *Spilogale putorious*) has experienced range wide population declines. In Kansas, the plains spotted skunk has suffered a particularly dramatic decline and is currently listed as a state-threatened species. Due to the deficit of knowledge on this species, we have paired a long-term, large-scale camera trap survey with the a regional, temporally discrete Species Distribution Model (SDM) to determine the ecology and presence of the plains spotted skunk in Kansas. We deployed camera traps for 40,393 trap nights across 29 counties between 2016 and 2023, resulting in spotted skunk detections at 6 unique camera sites. The last spotted skunk detection occurred in the state of Kansas in 2020, indicating a declining trend since 2005. Spotted skunks were found in locations with woody cover, and in landscapes with more grasslands and less row crop agriculture. To build a landscape-scale SDM, we used the R-based Maxnet algorithm. We trained the algorithm with spotted skunk presence locations between 1982 (i.e., year of state listing) to the most recent detection in 2020. The predictive map derived from our Maxnet model indicated only 7% of the state exhibited a greater than 50% chance of the plains spotted skunk occurrence. We found that spotted skunk presence was positively associated with landscape diversity and negatively associated with intensive agricultural practices. Overall, our findings suggest

that, if not already, the plains spotted skunk may soon be extirpated from much of the state of Kansas.

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CHAPTER I

MINIMAL DETECTIONS HINDER CONSERVATION EFFORTS FOR THE PLAINS SPOTTED SKUNK (*SPILOGALE INTERRUPTA*) IN KANSAS

ABSTRACT

While once abundant across central North America, the plains spotted skunk (*Spilogale interrupta*) has experienced range-wide population declines, resulting in their listing as a Species of Greatest Conservation Need in several Midwestern and Great Plains states. Our research objectives were to document plains spotted skunks in Kansas and describe their habitats to inform state conservation efforts. We conducted a large-scale baited camera trap survey at over 1,367 locations between 2016 and 2023, with targeted efforts focusing on state agency-designated spotted skunk critical habitat and historical detection locations in 29 counties. Even as one of the largest plains spotted skunk studies to date in terms of spatial and temporal scope, we only detected the species at six locations in 2017, 2019, and 2020, all in one county along the Arkansas River floodplain. We only detected spotted skunks at locations with woody cover, and in landscapes with more grasslands and less row crop agriculture. Recent intensive efforts to resample locations with detections yielded no spotted skunks in 2021–2023. The lack of recent plains spotted skunk detections suggests conservation actions may be warranted to prevent extirpation

from the central Great Plains. Our research could offer valuable insights regarding the decline of regionally rare small mammalian carnivores, potentially aiding in efforts to address and mitigate the decline of these sentinel species.

INTRODUCTION

The plains spotted skunk (*Spilogale interrupta*; hereafter, "spotted skunk") was once abundant across the Great Plains. Its range spanned from the Mississippi River west to the continental divide, as far north as North Dakota, and south into Mexico (McDonough et al. 2022). Historically, the spotted skunk was an economically important furbearer across its range, with state harvest records exceeding 100,000 annually during the 1930s–1940s. However, by the 1950s, trapper harvests exhibited range-wide population declines (Gompper and Hackett 2005).

Currently, plains spotted skunks persist in non-uniformly distributed isolated populations throughout the Great Plains (Perry et al. 2021). Contemporary studies attempting to document spotted skunks have resulted in low detection rates (number of unique detections / trap night) with an average of 0.35% currently reported from the southern Great Plains and Interior Highlands (Branham and Jackson 2021; Hackett et al. 2007; Higdon and Gompper 2020; Perkins et al. 2022). Limited information is available concerning spotted skunk distribution in the central Great Plains due to the lack of recent detections, resulting in an unclear understanding of the species' ecology and geographic distribution (Jachowski and Edelman 2021; Perry et al. 2021). This need for data is particularly necessary for Kansas, a state with contemporary detections, situated in the center of the spotted skunks' historic range. The spotted skunk is currently listed as state-threatened under the Kansas Nongame and Endangered Species Conservation Act of 1975 (Choate et al. 1973; Perry et al. 2021).

We surveyed the purported distribution of spotted skunks in Kansas by conducting a spatially extensive camera trap survey to describe the current population status and associated habitats in the central Great Plains. Our survey spanned multiple years and several survey efforts throughout Kansas, targeting state agency-designated critical habitats and locations of prior detections (Nilz 2008). Herein, we synthesized the results of multiple sampling efforts to derive a long-term understanding of detection trends and habitat associations.

METHODS

We conducted three distinct camera trapping surveys in 29 Kansas counties from 2016–2023 targeting the spotted skunk. Our surveys were guided by state agency-designated spotted skunk critical habitat and areas distinguished by contemporary spotted skunk detections to ensure a broad spatial survey (Fig. 1.1; Perry et al. 2021). We deployed camera traps positioned 2–4 m opposite the bait (sardines in oil replaced 14 days) affixed 0.5 m above the ground by available structures (Hackett et al. 2007). We deployed all camera traps for an average duration of four weeks and excluded those with < 14 trap nights from our analysis (Dukes et al. 2022). Although we aimed for methodological consistency, our primary focus was maximizing independent spotted skunk detections. Thus, our methods were modified over time and numerous sampling regions were targeted in different years to maximize effort constrained by temporal and funding limitations.

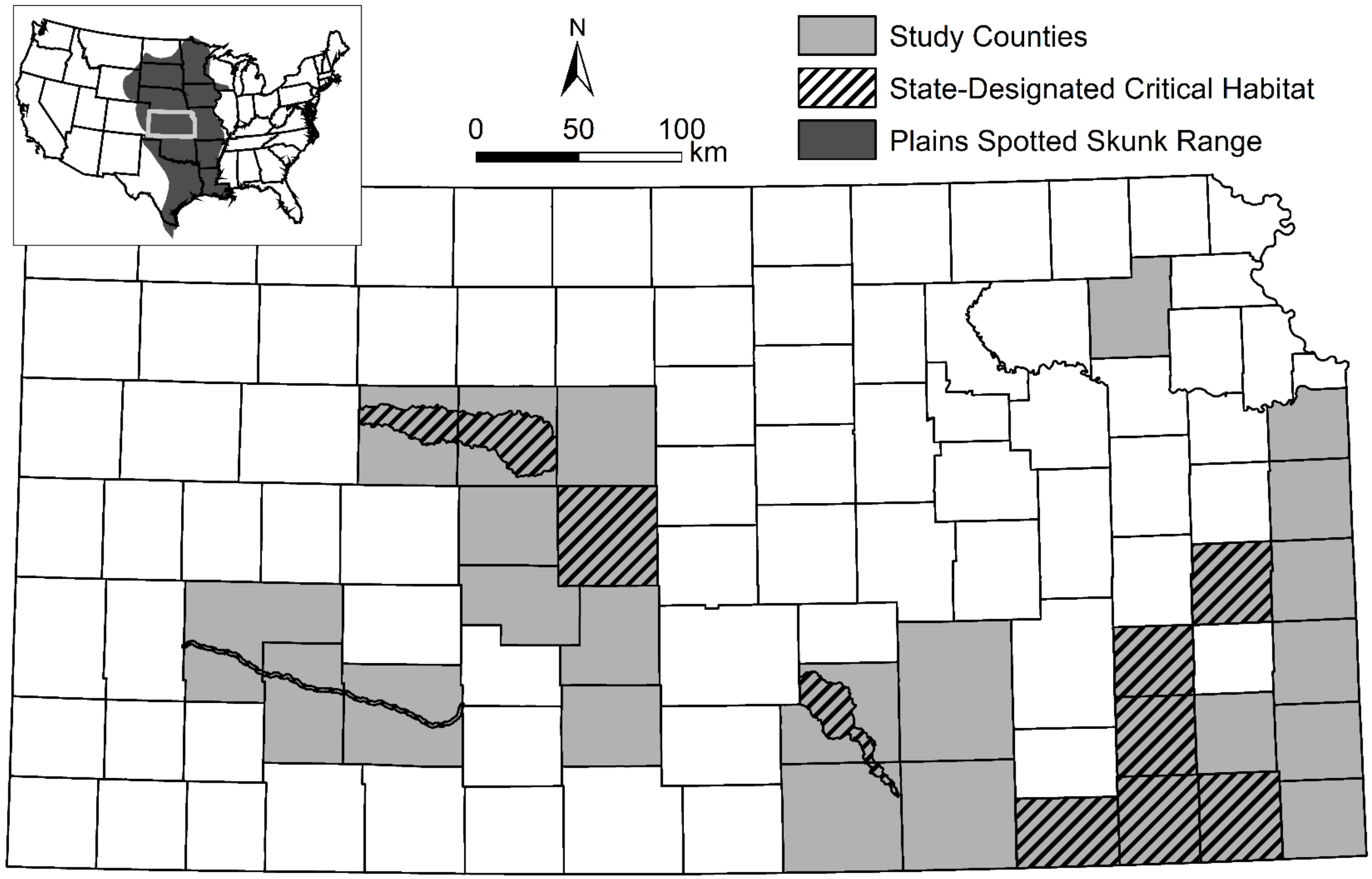

Figure 1.1. Kansas sits in the center of the plains spotted skunk range in the Great Plains (McDonough et al. 2022). Our study area included 29 counties across the state. We deployed cameras throughout these counties, prioritizing state agency-designated plains spotted skunk critical habitats as designated by the Kansas Department of Wildlife and Parks.

To derive a long-term understanding of spotted skunk detection trends, we synthesized our results with those of previous detection efforts in Kansas (Nilz 2008). We compared survey efforts using both annual detection rate averages and cumulative detection rates over an 11-year sampling period (i.e., 2005–2007, 2016–2023).

Initial Survey (2016–2021)

In an initial survey Kansas, we deployed 719 camera traps across 27 counties form 2016–2021 (20,801 trap nights). We affixed cameras (Browning Strike Force HD) to a tree or fence post and programed cameras to take a three-photograph burst per camera trigger event, with a one-minute delay setting. Additionally, we explored the use of a variety of scent lures (2016–2018: no scent lure; 2019: Caven's Gusto; 2020: cherry oil; 2021: Apple Road Lures predator bait) over the duration of our initial survey in hopes of increasing spotted skunk detections. We manually reviewed each camera trap image to identify the presence of spotted skunks.

Southeast Kansas Survey (2020)

Southeast Kansas (i.e., Crawford and Cherokee counties) was not sampled in the initial survey as the region lacks spotted skunk critical habitat; however, spotted skunks were detected in the region as recently as 2007 (Nilz 2008). Thus, we deployed 40 camera traps over 1,111 trap nights across public land units. We deployed camera traps in late winter (January–March 2020) and fall (August–October 2020), avoiding other seasons due to lower detection rates experienced in other studies (Hackett et al. 2007). All cameras (Bushnell Trophy Cam HD) were set to a three-photograph burst per camera trigger event with a five-second delay between motion triggers, and baited with one can of sardines in soybean oil. We uploaded all images to the eMammal (emammal.si.edu) repository. The eMammal program initially identified the species in each image and we subsequently manually reviewed each image to confirm the species' identification.

Intensive Survey (2022–2023)

Following the previous surveys, we recognized the need for a systematic approach and surveyed 19 counties, 16 from previous efforts and 3 additional counties. We established a 3 x 3 km grid over our study area and systematically selected 55 nodes per county (Higdon and Gompper 2020). Camera sites were then randomly selected by National Land Cover Database (NLCD) cover type, excluding nodes on agriculture and developed cover (Dewitz and USGS 2021). We sampled accessible sites on public and private land, with the majority on public land for ease of access. Using these predetermined locations, we deployed 608 camera traps over 18,477 trap nights. Cameras were deployed near year-round (February–March 2022, May–July 2022, and November 2022–July 2023); however, ≥ 61% of our sampling occurred during periods of reported high capture success (November–March; Dukes et al., 2022). We set cameras (Browning Recon Force Elite) to take a three-image burst per motion trigger event with a one-second delay between triggers. We affixed cameras and bait to trees or fence posts accompanied by a plywood scent block (5 x 7 cm) soaked in sardine oil (Hayes et al. 2021; Perkins et al. 2022). All camera trapping efforts during 2022–2023 occurred under the approval of the Fort Hays State University Institutional Animal Care and Use Committee (FHSU IACUC #22_0003). After downloading the SD cards from the trail cameras, two people manually reviewed all photographs for spotted skunks. We then used an artificial intelligence program (RECONN.ai, Michigan Aerospace Corporation, 2023) to flag images for any mammal activity and annotate all images. All RECONN.AI identifications were manually verified by at least one researcher. RECONN.AI stored information on the date, time, and species identification in each photograph.

Habitat Analyses

We documented vegetative cover descriptions such as canopy, sub-canopy, and ground cover classes by recording dominant species, secondary species, or other features (e.g., litter) at presence and absence sites during the initial survey. We recorded casual measurements of the presence and relative density of other features such as canopy coverage, surface rock, and woody debris. All features were classified into groups (e.g., 0 % not found in the immediate area, 25% composition in the immediate area, 50%, 75%). To compare presence and absence sites, we randomly selected absence sites from the initial survey that were ≥ 1.5 km away from detection sites (Lesmeister et al. 2009). We only selected sites for comparison from the initial survey due to data availability. We then compared sites using their categorical descriptions.

We derived cover types from NLCD (2019) to characterize landscape composition, simplifying land cover into six categories including developed, rock/sand, forest, shrublands, grasslands, and agriculture (Dewitz and USGS 2021). Developed, grassland, and forest categories represented their combined NLCD subcategories. We measured percent cover in a 1.5 km radius for detection and absence sites to compare land cover associations (Hesselbarth et al. 2019; R Core Team 2023). We compared land cover of detection and absence sites, with a sample size proportional to detection sites. The absence sites were randomly selected from all survey efforts located ≥ 1.5 km away from detection sites. We analyzed the differences in land cover between detection and absence locations by comparing their means and 95% confidence intervals. We considered differences in land cover significant if the confidence intervals did not overlap.

RESULTS

We deployed cameras over eight years and 40,393 trap nights (Table 1.1). Individual camera traps were active for an average of 30 trap nights (SD = 8.97; Fig. 1.2). Our efforts resulted in 15 spotted skunk detections at six unique locations (project cumulative detection rate of 0.04%), all in Gray County in 2017, 2019, and 2020 (Table 1.1, Fig. 1.2). The Southeast Kansas and Intensive Surveys (i.e., 2020–2023) resulted in no spotted skunk detections.

The six detections occurred in an 8.4 km area of Gray County in the Arkansas River floodplain (Fig. 1.2), with an average latency to detection of 7.5 days (Table 1.2). Spotted skunks were only found at sites that had dense canopy cover, consisting of Eastern Cottonwood (*Populus deltoides*), Osage-orange (*Maculura pomifera*), Siberian Elm (*Ulmus pumila*), and Hackberry (*Celtis occidentalis*) (Fig. 1.3). At three of these locations (i.e., detection locations 2017A, B, and C; Table 1.2), the dominant understory species was the invasive, nonnative Kochia (*Bassia scoparia*). No other understory plant species was shared across all six detection sites. However, a number of detection sites included a substantial amount of surface rock, consisting of scattered or piles of concrete (Figs. 1.3 and 1.4). The dominant landscape cover within 1.5 km of all detection sites was grassland (52%) followed by row crop agriculture (37%). We found skunks in landscapes with significantly less agriculture and more grassland cover (Fig. 1.5).

Synthesizing plains spotted skunk detection results from the past 11 study years (2005–2007, 2016–2023) in Kansas resulted in a total of 18 detections at seven unique locations in two counties (Fig. 6; Nilz 2008). All efforts have resulted in low yearly detection rates (mean = 0.05%, range = 0.0 – 0.2%). The most recent spotted skunk study beyond our efforts (Nilz 2008) recorded a higher detection rate of 0.09%, compared to our detection rate of 0.04%. Thus, we observed lower cumulative detection rates in our survey than Nilz's (2008) survey.

Table 1.1. Camera deployments and detection rates for each survey effort across Kansas.

Survey	Sampling Years	Duration (Years)	Counties Surveyed	Camera Sites	Trap Nights	Detection Rate
Initial Survey	2016–2021	6	26	719	20,801	0.07%
Southeast Kansas Survey	2020	1	2	40	1,111	0%
Intensive Survey	2022–2023	2	18	608	18,477	0%
Total	2016–2023	8	29	1,367	40,389	0.04%

Table 1.2. Descriptions of habitat features where spotted skunks were detected, all of which occurred in Gray County from 2017–2020. We recorded local habitat features, such as canopy and ground cover dominant species. Detections are the number of nights a spotted skunk was captured on the game camera, with latency to detection in days. While the use of scent lures differed across years, all cameras were paired with a sardine food lure.

Location	**Date**	**Scent Lure**	**Detections**	**Latency**	**Canopy Dominant**	**Ground Dominant**
2017A	February 2017	None	4	10	*Celtis occidentalis*	*Bassia scoparia* & Litter
2017B	February 2017	None	1	1	*Maculura pomifera* & *Ulmus pumila*	*Bassia scoparia* & Litter
2017C	March 2017	None	1	10	*Ulmus pumila*	*Bassia scoparia* & *Conyza canadensis*
2019A	March 2019	Caven's Gusto	1	6	*Maculura pomifera* & *Populus deltoides*	*Phragmites* & Litter
2020A	February 2020	Cherry Oil	3	16	*Populus deltoides*	None
2020B	February 2020	Cherry Oil	5	2	*Populus deltoides*	Native Warm Season Grasses

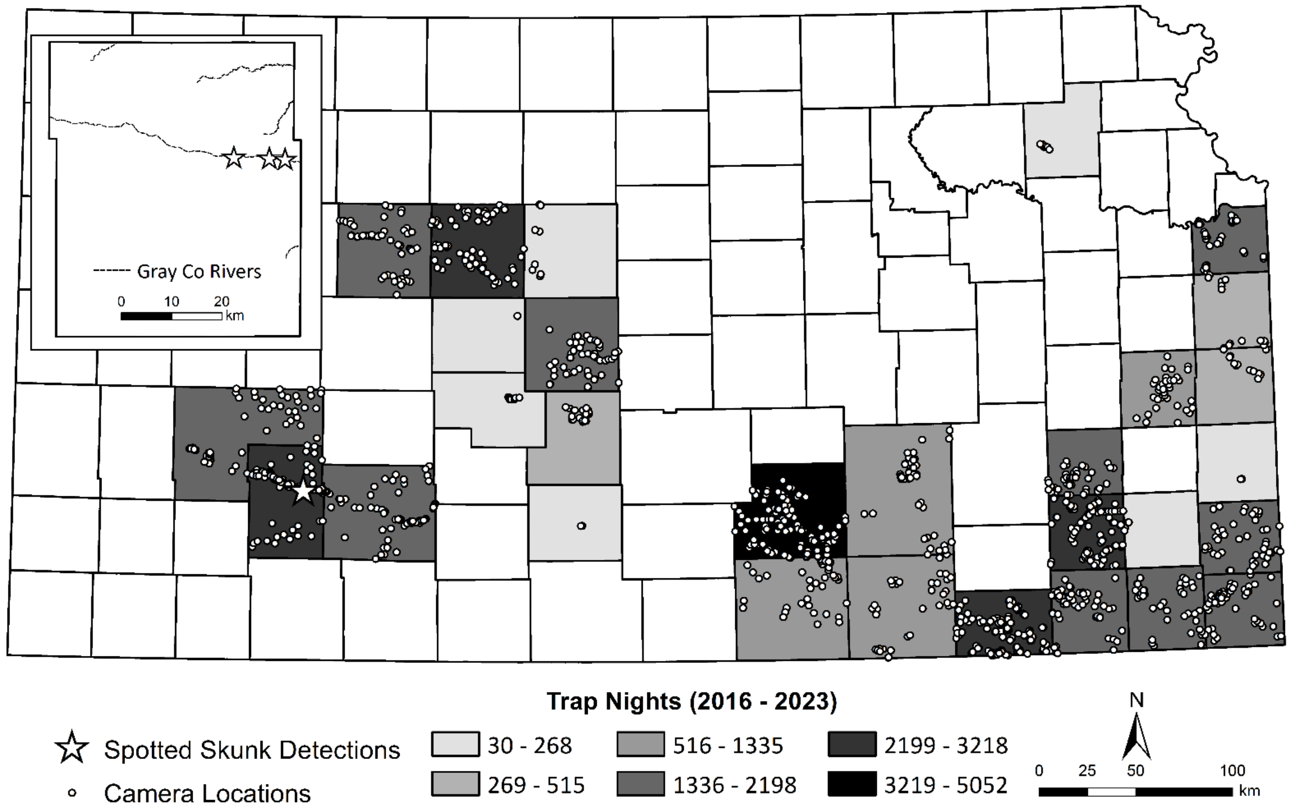

Figure 1.2. Spotted skunk survey effort represented as the number of trap nights per county. Spotted skunks were detected at six locations across three years (2017, 2019–2020) in Gray County. All detections were 1.5 km from one another along the Arkansas River. Due to their close proximity, only three stars represent the detection locations in Gray County.

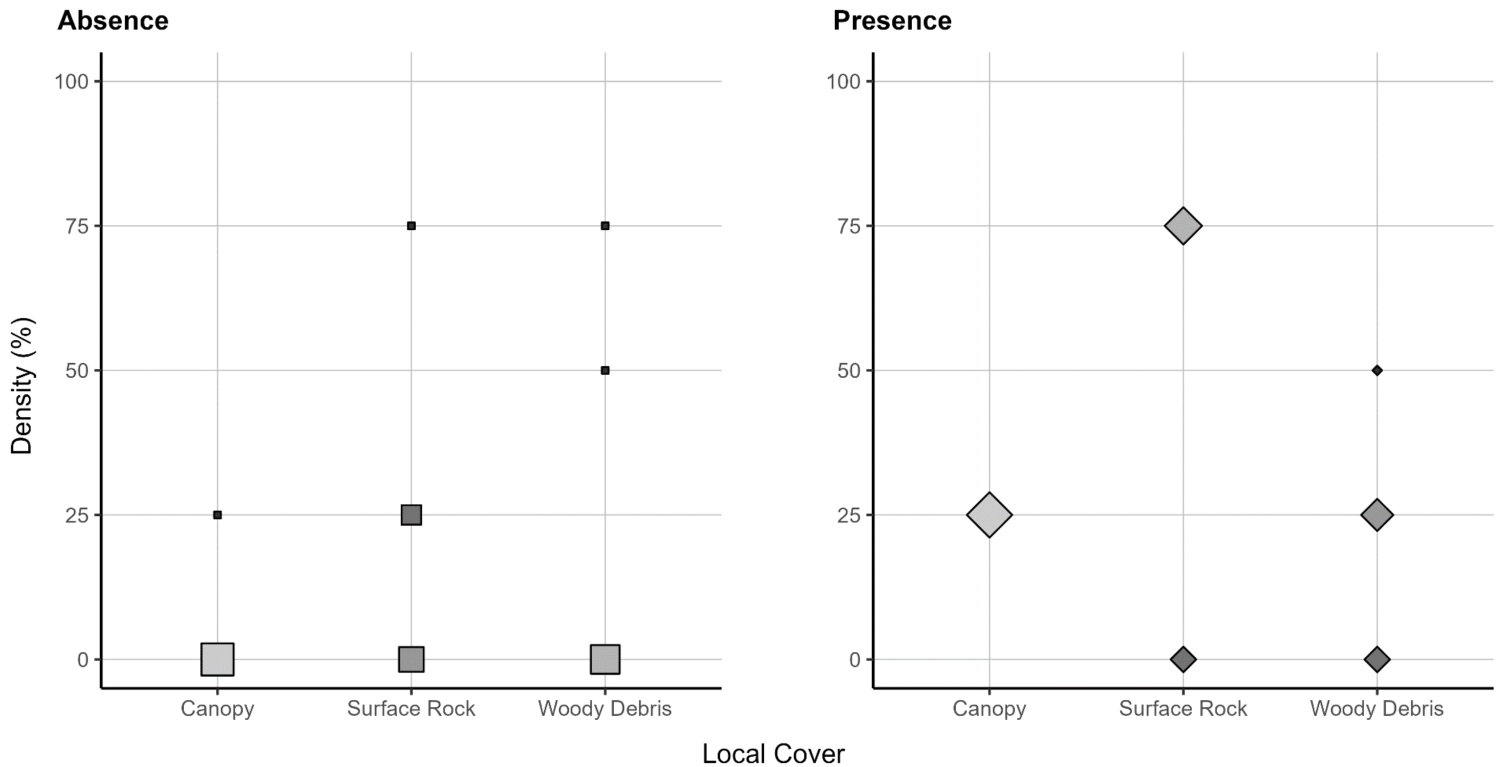

Figure 1.3. Comparison between absence (square) and presence (diamond) site local cover from Gray County in the initial survey effort (2016–2021). Local cover was separated into three categories (i.e., canopy, surface rock, woody debris) and compared by categorized composition (e.g., 25%, 50%, etc.). Size and color are indicative of repeat values (≤ 6); whereby, lighter larger symbols represent more samples and smaller darker symbols represent fewer samples. Spotted skunks were only detected at sites with forested canopy present.

Figure 1.4. Photograph of the 2017B plains spotted skunk detection. As seen in the photograph, concrete debris with protruding rebar was present at this location, which may have served as a suitable diurnal resting location for plains spotted skunks in this region.

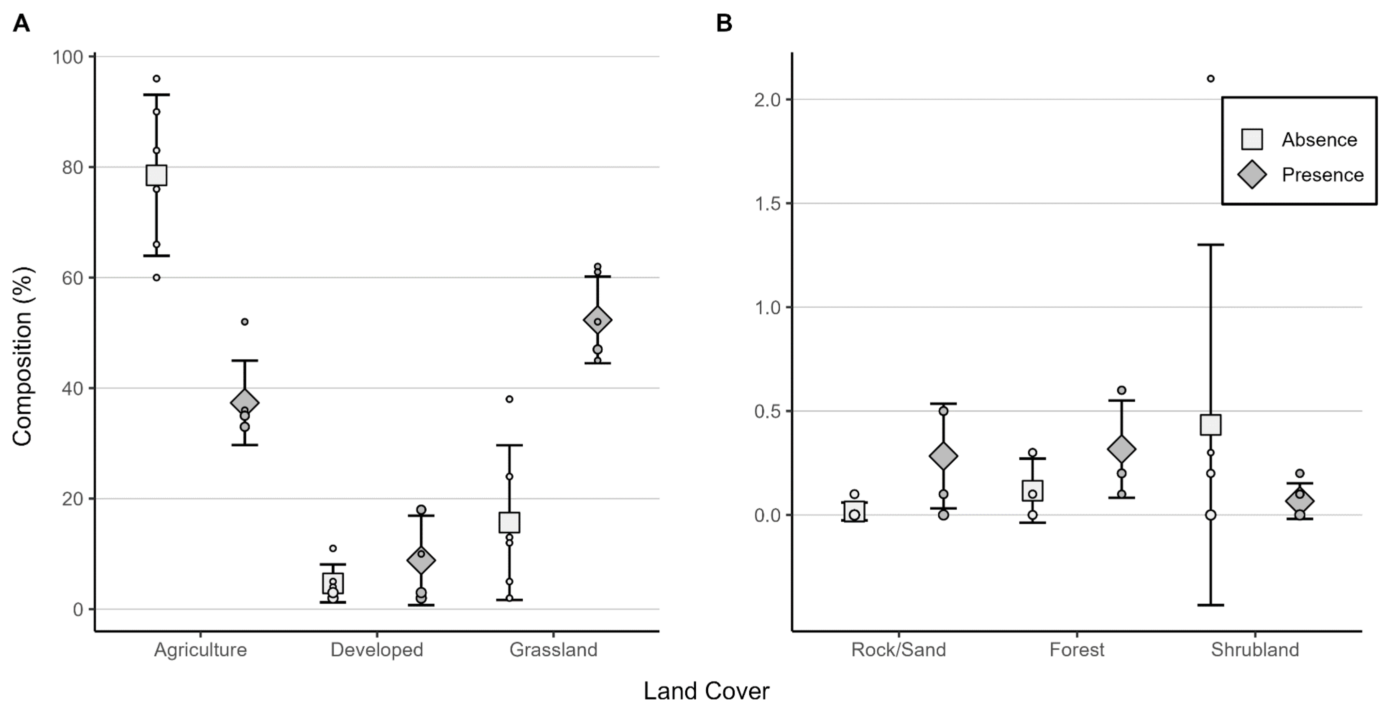

Figure 1.5. Land cover features at plains spotted skunk presence locations and randomized absence locations for mean cover values (± 95% confidence intervals) for land cover categories (A) > 2% composition and (B) < 2% composition of the landscape. Individual measurements are represented as circles, with circle size indicating repeat values (≤ 6). Spotted skunks were present in locations with less agriculture and more grassland cover, while the remaining land cover classes had overlapping confidence intervals for presence and absence locations.

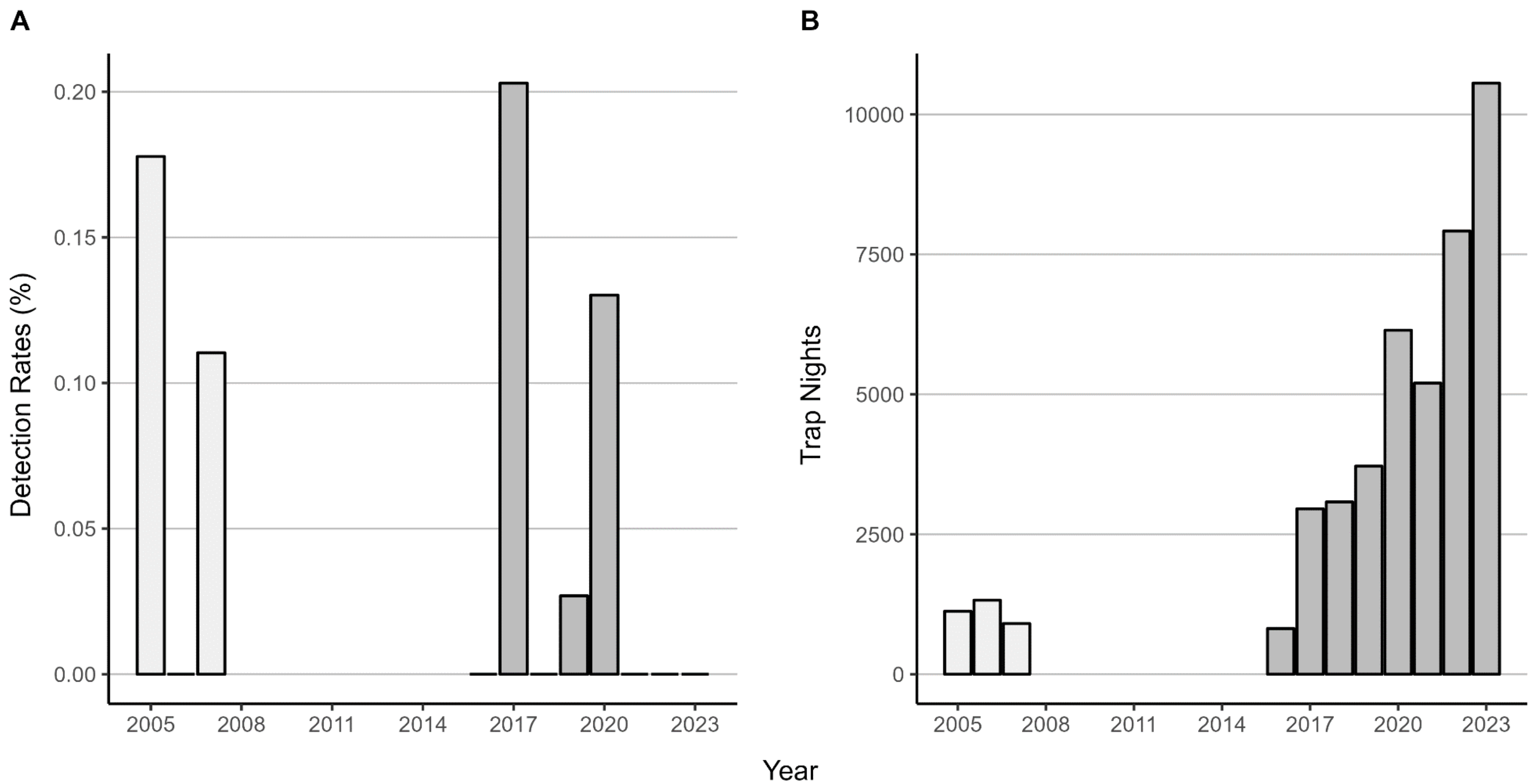

Figure 1.6. (A) Inconsistent, yet decreased detection rates compared to (B) increasing survey effort in Kansas by study years. Survey effort and detection rates were derived from our study (2016–2023) and those by Nilz (2005–2007; Nilz 2008).

DISCUSSION

Our study is one of the most temporally and spatially extensive camera surveys for plains spotted skunks to date, especially in the central Great Plains (Hackett et al. 2007; Higdon and Gompper 2020; Perkins et al. 2022); yet our low detection rate of this once abundant species is concerning (Gompper and Hackett 2005). Our efforts only yielded six novel spotted skunk detections, none of which occurred during our most recent and intensive camera trapping efforts (2022–2023).

Contemporarily, plains spotted skunks have been investigated to varying degrees of success, exhibiting an average detection rate of 0.35% in the southern portions of its range (Branham and Jackson 2021; Hackett et al. 2007; Higdon and Gompper 2020; Perkins et al. 2022). Our efforts yielded a lower-than-average detection rate of 0.04%, which has declined from 0.09% reported previously in Kansas (Nilz, 2008). These results suggest Kansas spotted skunks are less abundant than those of surrounding populations (Branham and Jackson, 2021; Hackett et al. 2007; Higdon and Gompper 2020; Perkins et al. 2022). While different sampling designs (i.e., camera vs. live trapping) may yield differing detection rates, previous studies have shown the utility of comparing spotted skunk populations based on their detection rates (Bolas et al. 2020; Perkins et al. 2022).

All of our detections occurred in riparian areas along the Arkansas River in woody cover and limited agriculture present in the landscape. These habitat features were structurally similar to detections in South Dakota that occurred in the available woody cover present in shelterbelts (Fino et al. 2019). Likewise, our detections occurred in the only woody cover available. We found plains spotted skunk detections were negatively associated with agricultural influence; instead, detections occurred primarily in landscapes dominated by grasslands, which aligns with findings in the Great Plains (Perkins et al. 2021; Perkins et al. 2022). This is further evidence for the hypothesis that plains spotted skunks are not tolerant of row crop agriculture, a dominant land use in the central Great Plains (Choate et al. 1973; Gompper and Hackett 2005). Local cover at detection sites primarily consisted of exposed surface rock, similar to findings previously described in the literature (Crabb 1948; Higdon and Gompper 2020; Lesmeister et al. 2008). Our data suggests the availability of rocky debris and small patches of dense vegetation in the local environment could be an important diurnal resting location feature for this species in open grassland habitats (Crabb 1948).

In contrast to our findings, other studies have associated plains spotted skunks with heavily forested regions, including detections in southeastern Kansas (Higdon and Gompper 2020; Lesmeister et al. 2009; Nilz 2008). The detections reported by Nilz (2008) only occurred at sites characterized by oak-hickory stands with thick understory cover in a reclaimed surface mined landscape (Bailey and Hooey 2017), which is structurally similar to detection locations in the forested Interior Highlands and Cross Timbers (Higdon and Gompper 2020; Perkins et al. 2022). Thus, habitats for the spotted skunk span from grassland to forested ecosystems throughout their current distribution. While our findings are informative for understanding the types of cover used by spotted skunks in the Great Plains, a larger sample size would be required to produce any significant conclusions about spotted skunk cover use.

Our results indicate that two former independent populations of spotted skunks were identified in Kansas. One population occurred in Cherokee County (detected in 2005–2007; Nilz 2008) with a second in Gray County (detected in 2017–2020). Given the expected average lifespan of a spotted skunk (3.5 years; Pacifici et al. 2013), individuals from recent detections (i.e., 2020) are likely deceased as of 2023. This is concerning, as the Gray County population could be extirpated or persist at a population size too small to detect. Similarly, this is a concern for areas with confirmed detections, for which individuals have not been detected since their respective reports. Thus, we recommend continued surveys of known populations surrounding Kansas, such as populations in the Interior Highlands (Branham and Jackson 2021; Higdon and Gompper 2020). Such efforts would allow for implementation of conservation efforts to prevent population trajectories like what has been observed in Kansas.

The results of our study emphasize the importance of continued conservation actions for the plains spotted skunk, despite recent federal decisions not to list the species under the Endangered Species Act of 1973 (USFWS 2023). Our data leads us to assume that the population of spotted skunks in Kansas is miniscule and likely extirpated from much of its former range (Davis et al. 2005; Taggart 2007). Notably, additional large-scale surveys focusing on detecting other mesocarnivore species have failed to detect the spotted skunk in Kansas (Werdel et al. 2022). There is little expectation of repatriation from populations in the surrounding regions, such as the Interior Highlands where the species is considered rare (Branham and Jackson 2021; Higdon and Gompper 2020). The western High Plains and central Great Plains appear to be no better off, as the last confirmed detection of a spotted skunk in Nebraska occurred in 2017, Colorado has no contemporary detections, and the only recent detections in Oklahoma have been in the Interior Highlands (de la Peña 2023; Jachowski and Edelman 2021; Perry et al. 2021). Concerns about genetic bottlenecks, population connectivity, and minimum viable populations should be considered, as we hypothesize that only low-density satellite populations remain (Perry et al. 2021; Wisely et al. 2003, 2008).

CHAPTER II

SPECIES DISTRIBUTION MODELING OF THE PLAINS SPOTTED SKUNK (*SPILOGALE INTERRUPTA*) FOR A HISTORICAL GREAT PLAINS POPULATION

ABSTRACT

While once abundant across Kansas, plains spotted skunk (*Spilogale interrupta*) populations have steeply declined in the central Great Plains. The paucity of contemporary data and the spotted skunk's cryptic nature has made studying this species difficult. Our objective was to build an ecologically relevant spotted skunk Species Distribution Model (SDM) with the MaxEnt algorithm for the state of Kansas, using historical detection data and associated land cover variables. The predictive map derived from our MaxEnt model indicated only 7% of the state as suitable cover for the spotted skunk. We found that spotted skunk presence was positively associated with landscape diversity. Additionally, our results further support the hypothesis that spotted skunks are negatively associated with intensive agricultural practices.

Introduction

An understanding of habitat associations and current distributions is critical to wildlife conservation; consequently, a paucity of ecological knowledge is a particular problem for the conservation of rare species, often requiring a mixture of methods and significant amounts of effort to study these species (Perkins et al. 2022). Such is the case with the plains spotted skunk (*Spilogale interrupta*; hereafter, “spotted skunk”), where there is a deficit of contemporary documentation of the species and its associated habitats, particularly in the central Great Plains (de la Peña 2023).

Plains spotted skunks were once a common, economically valuable furbearer in Kansas. The history of the plains spotted skunk in Kansas is disputed, but the species was noted as common in the state as early as 1840 (Carter 1939; Choate 1987; Van Gelder 1959). In the early 1930s, between 93,216 to 117,309 pelts were purchased annually in Kansas (Choate et al. 1973; Cockrum 1952). Pelt sales had fallen to less than 1,000 by 1950, and the season was permanently closed by the Kansas Department of Wildlife and Parks (KDWP) in 1977. In the 1970s, the species had become uncommon across much of the state, prompting the spotted skunk to be listed as a state-threatened species in 1982 under the Kansas Nongame and Endangered Species Conservation Act of 1975 (Choate et al. 1973). Detections of spotted skunks in the state have continued to decline to the present day, with few confirmed sightings statewide from 1982 to present, and with portions of the state havening gone decades without detections (Chapter 1; Choate et al. 1973; Perry et al. 2021).

While there are current distribution maps for the spotted skunk, they poorly represent the species true distribution due to their coarse resolution, potentially including large unoccupied areas in the species' current range (Brown and Lomolino 1998; Rapaport 1982). Misleading distributions can lead to inadequate sampling efforts in areas of uncertainty or avoiding areas of potential occurrence, wasted time, and resources (MacKenzie et al. 2003). To address this, recent research has shown the utility of supplementing and guiding research efforts with Species Distribution Models (SDM) algorithms (LaRose et al. 2022; Perkins et al. 2022; Wilson et al. 2016). The machine-learning algorithm maximum-entropy (MaxEnt) has been used to predict the presence of a species and refine the study area for targeted sampling (Perkins et al. 2022; Phillips et al. 2006; Phillips and Dudík 2008; Wilson et al. 2016).

We identified the potential distribution of the remaining populations of plains spotted skunk in Kansas. Our objective was to build a distribution map to guide future survey efforts for spotted skunks and identify potential habitat associations of spotted skunks in the central Great Plains. Due to published reports of spotted skunk habitat associations across its range, we chose to test five habitat features. We predicted that land cover diversity (Cheeseman et al. 2021), proportion of forest (Hackett et al. 2007; Lesmeister et al. 2009), and proportion of sand and rock (Chapter 1; Lesmeister et al. 2008) at the landscape level would be positively correlated with spotted skunk presence. We also predicted that agricultural cover (Chapter 1; Cheeseman et al. 2021; Choate et al. 1973; LaRose et al. 2022) and distance to water (Chapter 1; Choate et al. 1973; LaRose et al. 2022) would be negatively correlated with the distribution of the plains spotted skunk (Table 2.1).

Table 2.1. Tested land cover variables with associated hypotheses relative to the impact each feature would have on spotted skunk presence. Corresponding literature sources are provided that support the proposed hypotheses. All landscape variables were extracted from the National Land Cover Database (2004), while Euclidian Distance to Water was calculated from the National Hydrology Database (2004).

Variable	Hypothesis	Justification
Land Cover Diversity	Positive	Cheeseman et al. 2021
Proportion of Forest	Positive	Hackett et al. 2007; Lesmeister et al. 2009
Proportion Sandy / Rocky Cover	Positive	Chapter 1; Lesmeister et al. 2008
Proportion of Agricultural	Negative	Cheeseman et al. 2021; Choate et al. 1973; LaRose et al. 2022
Euclidian Distance to Water	Negative	Chapter 1; Choate et al. 1973; LaRose et al. 2022

STUDY AREA

The spotted skunk was once distributed across Kansas (Choate et al. 1973); thus, we included the entire state in our study area to derive an understanding of spotted skunk cover associations across a habitat gradient. Habitats in the state were historically comprised of a transition from oak (*Quercus* spp.)–hickory (*Carya* spp.) forests in eastern Kansas to tallgrass prairies, mixed grass, and finally shortgrass prairies in the western High Plains (Aber and Aber 2009). Currently, the state is dominated by row crop agriculture, especially in the western portions of the state, with interspersed remnant prairie cover (Aber and Aber 2009). While portions of eastern and southern Kansas were historically forested, most forested regions throughout the majority of the state were riparian forests along major waterways (e.g., Arkansas River) and forest patches in the eastern portion of the state (Peterson et al. 2004).

METHODS

We chose to build our models from verified detections collected from (1) spotted skunk research efforts (n = 9; Chapter 1, Nilz, 2008), (2) Museum specimens (n = 8; Schmidt et al. 2021), and (3) agency-verified reports of incidental captures by fur trappers and private landowners, including road kill specimens, across Kansas from 1982 (n = 56) to present (Fig. 2.1). Due to the rarity of the species in the state, we chose to extract data from these multiple data sources to allow for the maximum number of detections with minimal land cover change like similar studies (Fig. 2.1; Cheeseman et al. 2021; LaRose et al. 2022; Perkins et al. 2022; Serniak et al. 2023). We chose to extract data starting 1982, the year when the species was listed as threatened within the state of Kansas (1982). Following the methods of recent publications using MaxEnt, we defined verified reports as detections with associated museum vouchers or photographic evidence with locality and temporal data (LaRose et al. 2022; Perkins et al. 2022).

We derived our land cover variables from the National Land Cover Database (NLCD 2004). We chose to extract land cover data from the 2004 dataset due to its central placement between our earliest points (1982) and our latest points (2020). We calculated all variables at the 30 × 30 m resolution from the original NLCD raster. Additional variables were derived from surface water vector data from the National Hydrology Database (NHD, 2004). We simplified the land cover categories from 15 cover variables in the original NLCD (2004) to six (i.e., developed, rock / sand, forest, shrublands, grasslands, and agriculture). The forest and grassland categories represented their combined NLCD subcategories. We excluded developed land cover categories from our model because of sampling bias in our data set (i.e., skewed to development due to public sightings and roadkill specimens). We used values from the NHD (2004) surface water raster and subsequently calculated a Euclidian distance raster in QGIS (QGIS, 2023). All other environmental variables were calculated in a 1.5 km focal window based on the average reported spotted skunk home range (Lesmeister et al. 2009, Werdel et al. 2023).

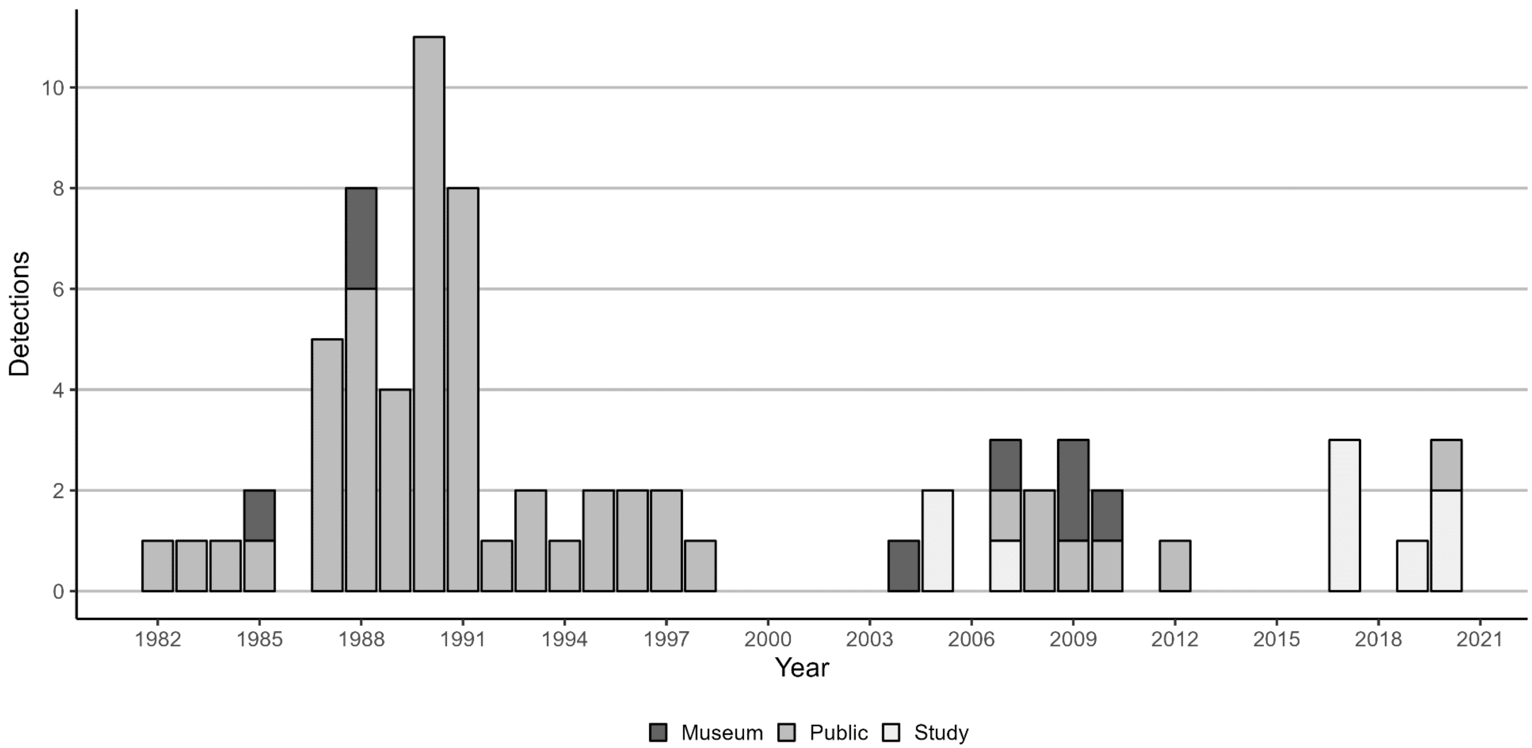

Figure 2.1. Number of confirmed plains spotted skunk detections by year in Kansas. Detections were composed of data collected from (1) spotted skunk research efforts (n = 9; Chapter 1; Nilz 2008), (2) Museum specimens (n = 8; Schmidt et al. 2021), and (3) agency-verified reports (n = 56) of incidental captures by fur trappers and private landowners, including road kill specimens, across Kansas. All points were selected from 1982 (the species listing under the Kansas Nongame and Endangered Species Conservation Act of 1975) to present.

Using our classified NLCD raster, we calculated land cover diversity using Shannon's diversity index in a 1.5 km focal window (Cheeseman et al. 2021; Lesmeister et al. 2009). This was calculated using the simplified NLCD described above. Prior to model development, we ran a correlation test on all our landscape variables and removed significantly correlated variables from our analysis (r > 0.5); however, none of our variables were found to be correlated (Aubry et al. 2017). All geoprocessing and analysis were conducted using readily available freeware using the terra package in R and QGIS (Hijmans 2023).

We used the maximum entropy (MaxEnt; Phillips et al. 2006) algorithm to build a SDM for the plains spotted skunk in Kansas. MaxEnt assesses correlations between broad-scale environmental predictors (e.g., precipitation, temperature, elevation) with presence points and pseudoabsence locations, allowing us to identify a refined predicted distribution for the plains spotted skunk. We use the SDMtune package (Vignali et al. 2020) to build our SDM using the R-based Maxnet algorithm (Phillips 2021). Our model was built with the previously identified true presence points from across Kansas with the goals of evaluating environmental variables as predictors of distribution and identifying regions with a higher predicted presence of plains spotted skunk.

To address potential spatial autocorrelation in our model, we chose to thin our data temporally and spatially to allow for the greatest number of independent observations. We split our data into groups by three-year generation based on the expected average spotted skunk's lifespan (Pacifici et al. 2013). Then, we thinned our data by 1.5 km using the spThin package to retain the most parsimonious number of data locations (Aiello-Lammens 2015; Cheeseman et al. 2021; Kiedrzyński et al. 2017). We trained our model using 10,000 pseudo-absence points, randomly selected from the study area, and added all points as background points for model training (Elith et al. 2011; Phillips et al. 2009; Phillips and Dudík 2008).

We used a single step approach to build our model, whereby we selected variables and built our model *a priori* to compare hypotheses at the landscape scale (Table 2.1). We selected automatic features (linear, quadratic, product, and hinge, regularization multiplier of 1), logistic output format, and used leave-one-out cross validation method to test our model (Vignali et al. 2020; Wong 2015). To test model accuracy, we used two metrics: the threshold-independent area under the receiver-operator curve (AUC) and the threshold-dependent true skill statistic (TSS), the difference between omission and commission errors). The TSS and AUC enabled us to determine if our model was able to predict plains spotted skunk presence better than random (AUC ≥ 0.5, TSS ≥ 1, Anderson and Gonzalez 2011; Guevara et al. 2018; Velasco and González-Salazar 2019). We conducted both permutation importance and a jackknife test for variable importance (Phillips et al. 2006). After developing the final model, we calculated the total area estimated to have a greater than random chance of species occurrence (> 0.5) divided by the total area of Kansas using the landscapemetrics package in program R (Hesselbarth et al. 2019; R Core Team 2023).

RESULTS

After spatial thinning, our data set was constructed with 61 independent true presence points across our study area. Our model had a test AUC of 0.76 and a test TSS of 0.76, indicating that our model correctly predicted spotted skunk presence 76% of the time. In this model, all five environmental variables all performed better than random at predicting spotted skunk presence in the univariate jackknife test (AUC ≥ 0.6; Fig. 2.2).

Shannon's diversity of land cover types was ranked as the top variable, with plains spotted skunks positively associated with landscape diversity (Fig. 2.3). The second most important variable in predicting spotted skunk presence was the proportion of agriculture, which exhibited a negative relationship with the likelihood of spotted skunk presence. All other land cover variables exhibited an individual permutation importance of less than 10% (Table 2.2).

Our predictive heat map derived from our MaxEnt model predicted only 7% of the entire state as having a 50% likelihood of occurrence. The bulk of suitable cover persists in the patches in the eastern portion of the state or near water sources (e.g., Arkansas River floodplain) in southwestern Kansas (Fig. 2.4).

Table 2.2. Variable importance calculated using permutation importance with standard deviation. Land cover diversity represented by Shannon's diversity was the most important variable with a 58.6% contribution to the model results. The next most important variable was the proportion of agriculture, and all other variables contributed less than 10% individually. Variables were calculated in a 1.5 km focal window excluding Euclidian distance to water.

Variable	Permutation Importance	Standard Deviation
Shannon's Diversity	58.6%	1.2
Proportion of Agriculture	20.4%	0.8
Proportion of Forest	8.6%	0.5
Euclidian Distance to Water	8.5%	1.0
Proportion of Sand / Rock Cover	4.0%	0.4

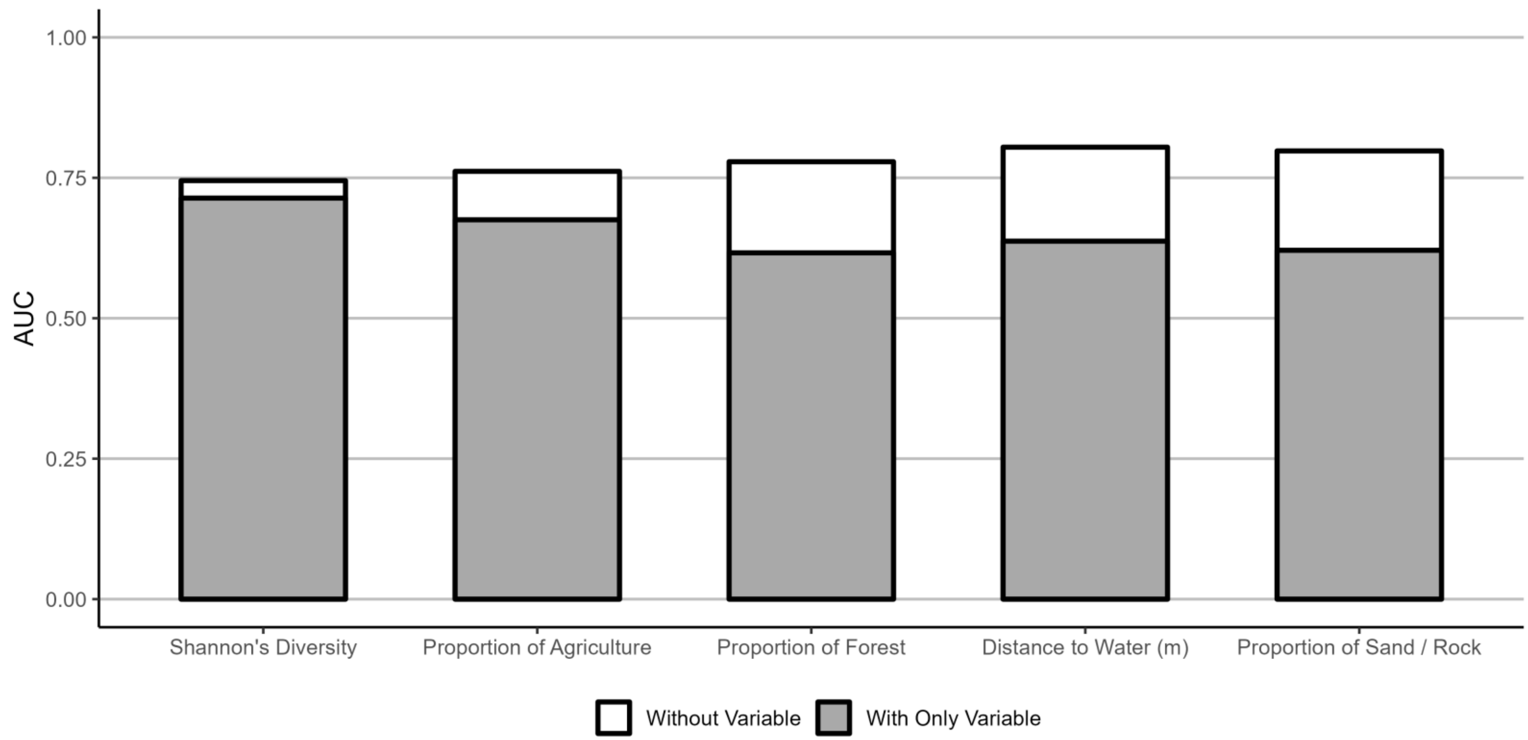

Figure 2.2. Results from the jackknife test of variable importance. High AUC (i.e., area under the receiver operating characteristic curve) in a univariate model indicated the variable was more important to the model, while high AUC in a model without the variable indicated lower importance. We found all land cover variables exhibited a greater than random effect on spotted skunk presence in univariate models. Land cover diversity, as represented by Shannon's Diversity Index, was the most informative variable.

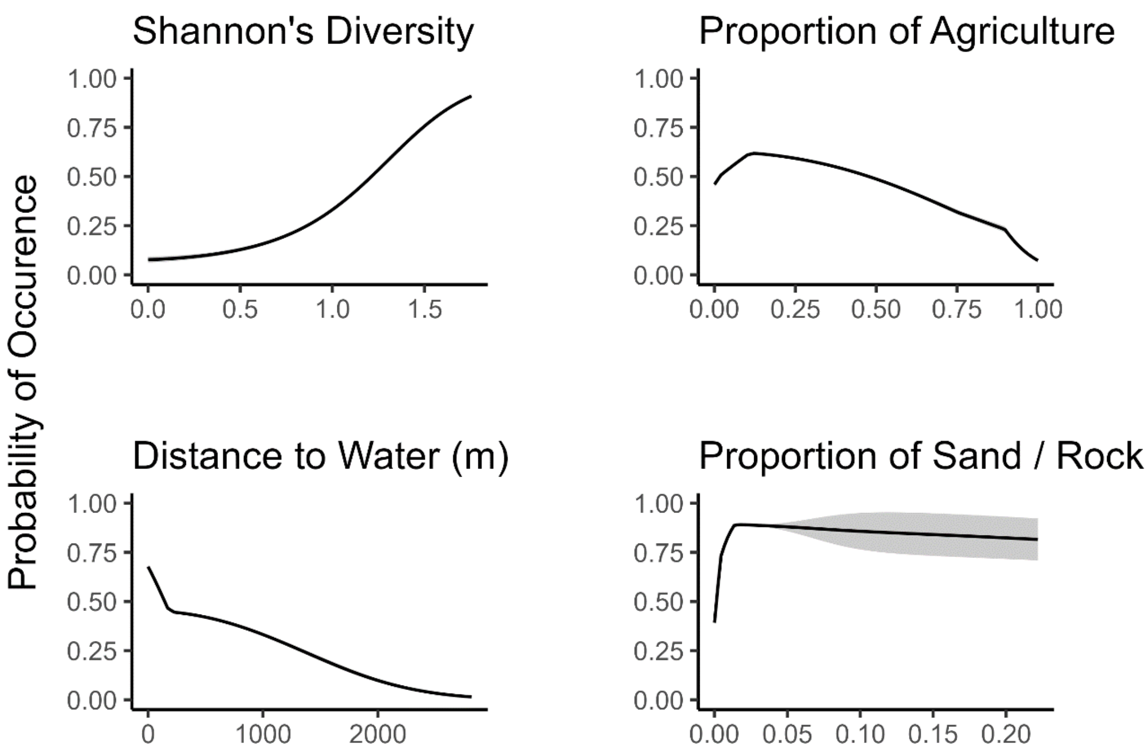

Figure 2.3. Response curves for each land cover variable with 95% confidence intervals for the plains spotted skunk in Kansas. Variables were calculated in a 1.5 km focal window, excluding Euclidian distance to water.

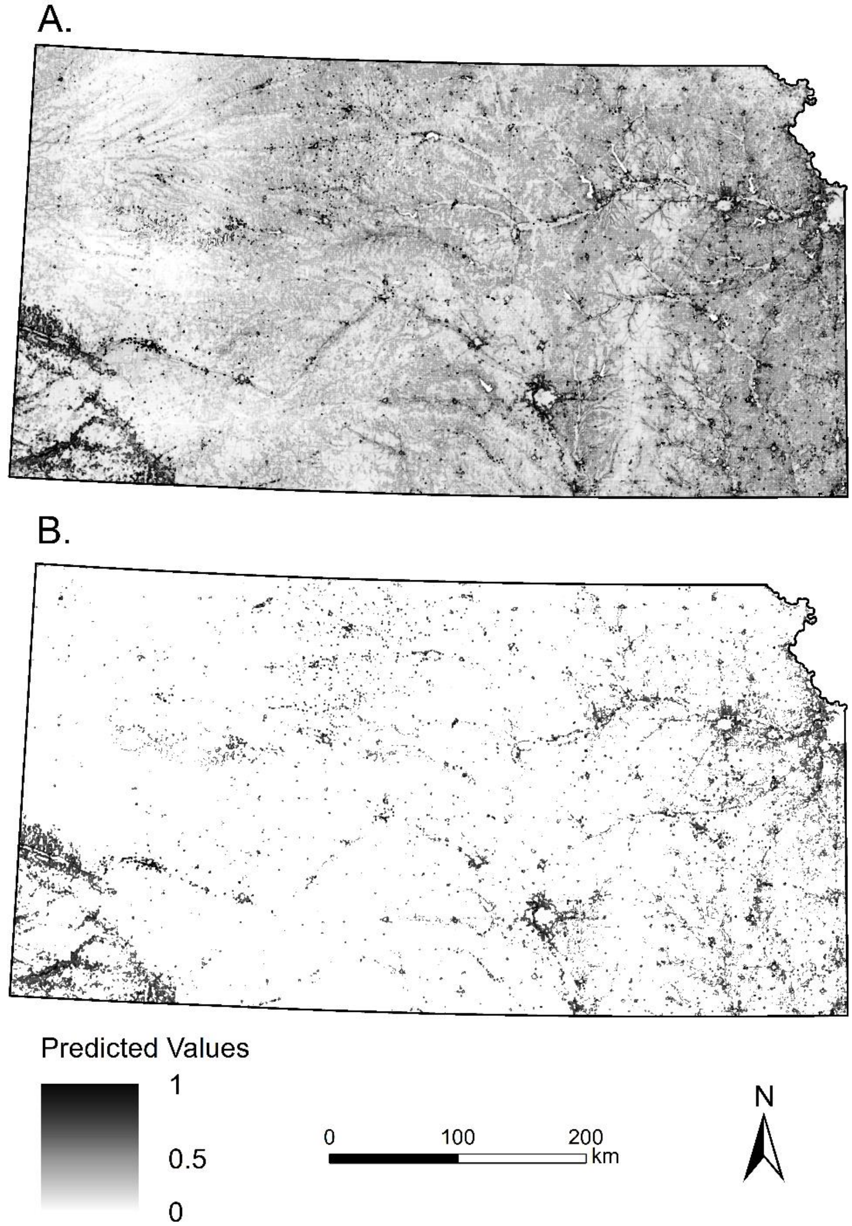

Figure 2.4. Species distribution map produced from a Maxnet model with (A) a range of probabilities of occurrence ranging from 0–1, and (B) probabilities of occurrence ranging from 0.5–1. We found 7% of Kansas had a greater than 50% likelihood of occurrence (≥ 0.5). Our model was built with 62 presence locations and 10,000 pseudo absence locations.

DISCUSSION

We determined that over the past 40 years, only 7% of Kansas had a greater than 50% likelihood of occurrence of the plains spotted skunk. Between 1900 and 1950, spotted skunks were reported as common statewide; however, our findings suggest that Kansas has suffered significant losses in suitable spotted skunk cover (Choate et al. 1973). Our model and subsequent predictive map provide a glimpse of what the spotted skunk distribution likely was in Kansas between 1982–2020 and the corresponding important landscape features to this species. While our model was a generalization of the plains spotted skunk population, our model provides useful insight for where to direct future survey efforts and provides indication factors that significantly impact the likelihood of spotted skunk presence.

Land cover diversity was the most important variable in our model; however, it is unclear what benefit landscape diversity provides due to the complex suite of interactions which could be occurring. These interactions could include benefits from increased floral and faunal richness (Curveira-Santos et al. 2017; Fahrig et al. 2011), decreased influence from any one cover type, particularly agriculture (Chapter 1; Aune et al. 2018; Fahrig et al. 2011), or increased edge (Lesmeister et al. 2009). In the central Great Plains, plains spotted skunk use of edge, such as riparian areas and windbreaks, has been documented and could prove to be important to plains spotted skunk region wide and warrants future research (Chapter 1; Fino et al. 2019; Wires and Baker 1994).

Row crop and mechanized agricultural practices have been hypothesized as one of the causes for the spotted skunk’s decline, particularly in Kansas (Choate et al. 1973; Gompper and Hackett 2005). Our findings support this hypothesis and suggest that spotted skunks may exhibit a tolerance for less intensive agricultural practices, but respond negatively as proportion of agriculture uses on the landscape increases as posited by previous studies (LaRose et al. 2022). We hypothesized that agricultural impacts have contributed in part to the loss of diverse edge habitats provisioned by small farms, a phenomenon that has been documented in grasslands (Aune et al. 2018; Samson and Knopf 1994). Such diverse edge along agricultural patches has been hypothesized to provide ground cover necessary for spotted skunk diurnal resting locations (Choate et al. 1973; Crabb 1948; Gompper and Hackett 2005; Lesmeister et al. 2009).

While most studies have shown forest cover to be an important landscape feature, our model found proportion of forest to be not as strongly associated with spotted skunk presence as other studies (e.g., LaRose et al., 2022). While this response is unexpected, spotted skunk may respond differently to forest cover in environments less dominated by forests, such as the central Great Plains. Additionally, we found that spotted skunk presence was significantly influenced by the presence of sand / rock cover, similar to contemporary literature (Chapter 1). Contrary to other research in the region, we found a negative relationship between spotted skunk presence and distance to water (LaRose et al. 2022). We hypothesize that all of these variables (i.e. forest, water, rock cover) likely co-occur within Kansas' floodplain areas, serving as an important refuge for the spotted skunk.

A significant amount of suitable plains spotted skunks cover has been lost in Kansas from their historic distributions, as indicated by our distribution map. Kansas has been suggested as a potential stronghold for the species in the central Great Plains (USFWS 2023), yet our model shows only 7% of Kansas has a greater than random chance for spotted skunk presence. The reduced distribution in Kansas from its historic statewide distribution does not bode well for other states in the central Great Plains that have gone longer without detecting a spotted skunk, especially Iowa or Colorado where the species is likely extirpated (Perry et al., 2021). As managers assess spotted skunk populations, efforts are hindered by the lack of contemporary data on the species distribution and habitat associations of the species in the central Great Plains. This gap can be partially bridged by using modern SDMs to guide future conservation and provide insight to potential new locations to search both in and outside of Kansas.

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