CONSERVATION STATUS OF THE PLAINS SPOTTED SKUNK IN TEXAS

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ABSTRACT

Research of rare or understudied species often benefits from the use of multiple methods and survey techniques. The potentially endangered plains spotted skunk (*Spilogale putorius interrupta*) is an uncommon mephitid historically distributed throughout much of Texas. To assess the status of the skunk, I collected presence data using both field surveys and crowd source methods. Field surveys were conducted throughout the state using live traps, trail cameras, and track plates. Additional presence data were also compiled from academic, wildlife, and citizen scientists' groups. Skunk presence data were used to create a species distribution model. The model predicts that the skunk is still widely distributed in Texas. The results of the project indicate that the skunk has low localized abundance, but there are at least 2 areas with high local abundance: native prairies northwest of Houston and mixed oak/juniper forests in the Cross Timbers ecoregion.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Spilogale putorius (eastern spotted skunk) is a rare, diminutive carnivore distributed in the southeastern and Great Plains regions of the United States. The plains subspecies (*S. putorius interrupta*) is found throughout the Great Plains region from Tamaulipas, Mexico, north to southern Canada (Kinlaw 1995). In Texas, this subspecies was historically distributed in the eastern half of the state, westward onto the Edwards Plateau, southward to the South Texas Plains, and northward through the Panhandle region (Dowler et al. 2008; Schmidly and Bradley 2016). While once common throughout its range, the skunk has experienced a significant population decline since the 1940s (Gompper and Hackett 2005). The status of the skunk is currently unknown in Texas. Historical trapping records in the state did not distinguish between the eastern spotted skunk and *Spilogale gracilis* (western spotted skunk), thereby making it difficult to ascertain historical population levels and trends in population for the plains subspecies. Texas Parks and Wildlife Department classifies *S. putorius interrupta* as a species of greatest conservation need (TPWD 2017) and the United States Fish and Wildlife Service is currently considering it for threatened or endangered status under the Endangered Species Act (USFWS 2012). While the evidence for these designations is mostly anecdotal, Gompper and Hackett (2005) used historical trapping records from multiple Midwestern states to confirm the sharp population declines since the 1940s.

Researching rare or secretive species often requires the use of multiple survey methods to increase the probability of detecting the target species and decrease the latency to detection (LTD) for the target species (Gompper et al. 2006; Hackett et al. 2007). Latency to detection is defined as the time (in days) between survey initiation and the initial

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Journal of Mammalogy

detection of the target species at a site (Hackett et al. 2007). Also by using multiple methods, researchers can utilize non-invasive methods (methods that do not require animals to be directly observed or handled) in place of traditional methods (Long and Zielinksi 2008). Hackett et al. (2007) reported that live trapping methods for eastern spotted skunks were sometimes more successful than less invasive methods; however, both camera traps and track plates were effective at detecting spotted skunks. Camera trap methodology consists of deploying trail cameras to capture images of the target species. Track plate methods include using a tracking medium, such as soot or carbon toner, and a track deposit area with a bait or lure to capture footprints of target species. Track plates can be modified to include hair snares to gather samples for genetic analyses (Zielinski et al. 2006). The combined use of these 3 methods can increase the detection rate of the target species above that observed when using only a single method.

Species distribution modeling (SDM) is widely used to extrapolate from point observations, over space and through time, the predicted occurrence of species for locations where survey data are lacking (Franklin 2009). SDMs relate species distribution data (both presence and abundance at known locations) with information on the environmental and/or spatial characteristics of those locations, thus allowing researchers to predict a species distribution across a landscape (Elith and Leathwick 2009). Increasingly the predictive capabilities of SDMs are used to direct field surveys to locate new populations of rare or secretive species (Wilson et al. 2016).

Maximum entropy (Maxent), a type of species distribution modeling, is a general-purpose machine learning method that utilizes presence only data (Phillips et al. 2006; Franklin 2009). Maxent is robust with small sample sizes and can utilize a suite of environmental variables including climate, soil type, land cover, and topography. This is a useful form of modeling because it is a density estimation method, as opposed to a regression model, that works well with rare or uncommon species (Phillips and Dudik 2008).

Crabb (1948) found *S. putorius interrupta* to be closely associated with Iowa farms, with many dens located in or under barns and other outbuildings. Choate et al. (1974) reported on the habitat surrounding the location of 6 salvaged skunks in Kansas. The skunks were found in areas of mixed tall grass prairie, with overgrazed pastures, overgrazed riparian zones, and agricultural fields present. Most of the salvaged skunks were either at or in the direct vicinity of a farm, feed lot, or farm outbuilding. Reed and Kennedy (2000) exclusively found *S. putorius putorius* (Appalachian subspecies) in rhododendron (*Rhododendron* spp.) thickets along streams in the Appalachian Mountains of Tennessee. In Arkansas, spotted skunks were found to inhabit both pine and hardwood forests, but selected for early successional forests with dense understories (Lesmeister et al. 2009). In Texas, plains spotted skunks are known to occur in wooded areas and prairies (Schmidly and Bradley 2016); however, this information is largely anecdotal because the habitat associations of eastern spotted skunks have never been studied in Texas. Based upon these previous findings, I anticipated the need to survey multiple habitat types to locate the skunk.

In this study, I used multiple methods to collect *S. putorius interrupta* presence data throughout Texas. Field survey results were used to compare the efficacy of 3 sampling techniques (trail cameras, track plates, and live traps) at detecting the study species. Presence data collected from these methods, data from historical museum records, crowd-source data, and exiting environmental data were used to create a current species distribution model.

MATERIALS AND METHODS

Study Site

As a preliminary assessment of the distribution of *S. putorius interrupta* in Texas, a species distribution model utilizing known museum records with georeferenceable locations from the 1890's through 2011 was created (Wolaver et al. 2015 A). Remaining core habitat for the skunk was also mapped (Wolaver et al. 2015 B). In conjunction with the species distribution model and the map of remnant habitat, a list of county economic impact (Comptroller 2015) was utilized to attempt to balance survey locations between counties having higher and lower economic importance. Ten counties were chosen for survey: Burleson, Calhoun, Coryell, Harris, Kleberg, Navarro, Tarrant, Waller, Wichita, and Wise (Figure1).

Museum Records

All known *S. putorius interrupta* records from natural history collections (Timeframe: 1892 - 2011) were amassed prior to the start of the project (Wolaver et al. 2015 A). Throughout the project, natural history collections in Texas were monitored for the accession of new skunks. All records used in analysis underwent a quality check which included removing those outside of the selected time frame, removing duplicate entries, georeferencing spatial data, and removing entries that lacked sufficient spatial or temporal data.

Field Surveys

To increase the probability of detection and decrease the latency to detection period for *S. putorius interrupta* surveys, I utilized multiple methods (camera trapping, live trapping, and track plates) based upon their demonstrated history of detecting spotted

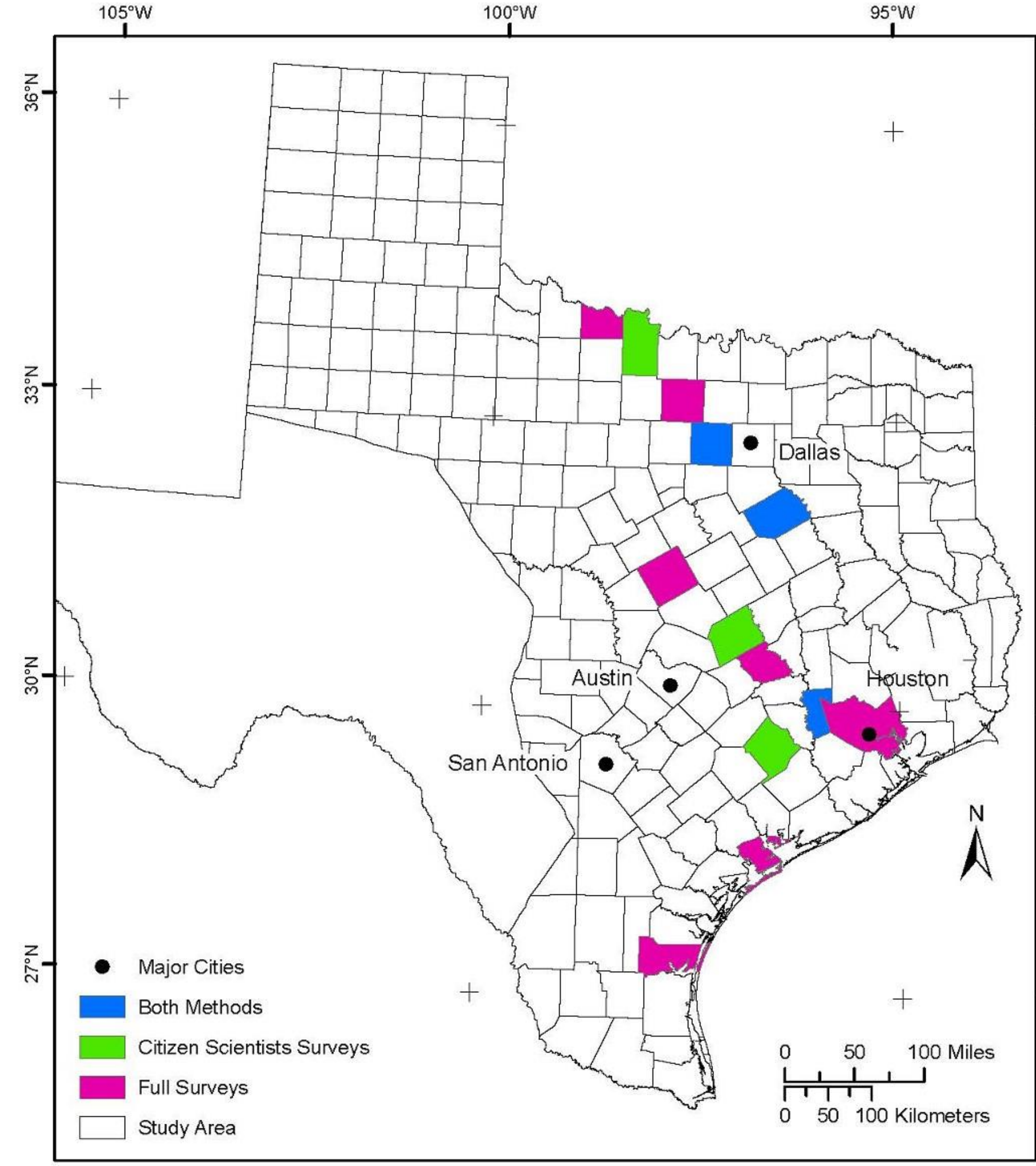

FIGURE 1. Counties surveyed for plains spotted skunks (*Spilogale putorius interrupta*) in Texas from 2015 through 2017.

skunks or their non-invasiveness (Gompper et al. 2006; Zielinksi et al. 2006; Hackett et al. 2007). I deployed detection devices either as grids or transects depending on temporal or spatial constraints at a given study site. Grids were set up by first partitioning the study area into 3 habitat types (open/grassland, shrub/scrub/savannah, and closed forest) based upon aerial imagery. Equal sized polygons were created across the study area; then a random number of polygons were chosen for sampling. The number of polygons per habitat type was proportional to the percentage of habitat type per study area. Finally, a 3 x 4 grid of survey stations was placed with random orientation in each of the chosen polygons. For transect arrangement, all roads (gravel and unimproved) trails, and hiking trails were digitized. Points were randomly placed along these transects. Finally, 6 survey points were randomly selected and the successive 19 survey points were chosen for survey. For grids, devices were deployed within a 5 m radius of the survey point. For transects, the survey point was moved 25 m perpendicular to the road or trail and devices deployed within the same 5 m radius. Individual survey stations were defined as the survey point, the 5 m buffer, and the deployed detection device.

The maximum number of devices deployed per site was 120 arrayed as 40 traps, 40 cameras, and 40 track plates. One device was deployed per station and stations were established 100 m from one another, in such a manner that 2 devices of the same type were never at adjacent stations. Surveys were conducted over a 10-day period with devices being operational for 7 of the 10 days. All devices were checked daily during the operational period. All methods followed guidelines for use of mammals in research (Sikes et al. 2011) and were approved by the Angelo State University Institution Animal Care and Use Committee (IACUC protocol 15-15).

Collapsible Tomahawk live traps (15 x 15 x 48 cm; Tomahawk Live Trap LLC, Hazelhurst, WI) were placed in the densest available habitat, within a 5 m radius of the survey point, and positioned so that the entrance was oriented away from the thick cover. Burlap (61 x 71 cm) was placed over each trap. Traps were baited with a piece of chub mackerel (Chicken of the Sea International, Mt. Olive, NJ) placed in a shallow aluminum pan. Traps were checked as early as possible each morning and rebaited with fresh bait every other morning.

I utilized 2 track plate designs during they survey, 1 using a modified hair snare to collect hair samples (modified from Zielinski et al. 2006) and a control without a hair snare. Track plate devices were composed of an aluminum insert inside a corrugated plastic enclosure (CoroplastTM; Coroplast Inc; Dallas, TX). The enclosure dimensions were 15 x 15 x 75 cm and it was open on one end. The track plate insert was a 70 x 15 cm aluminum plate (modified from Zielinksi et al. 2006; Hackett et al. 2007). The front half of the insert (35 x 15 cm) was covered with a tracking medium (recovered printer toner) and the back portion was covered with a 35 x 15 cm strip of contact paper, adhesive side up, and held in place by duct tape. Bait (chub mackerel) was placed in the back of the enclosure to lure the animal over the tracking medium and leave its footprints on the contact paper.

Half of the track plates (*n* = 20) were designed with a hair snare inserted into the track plate enclosure. The hair snare was affixed halfway (35 cm) between the open and the closed end. The hair snare was a 15 x 2.5 cm strip cut from a commercially available glue board (Tomcat Glue Boards, Motomco, Madison, WI) stapled to the bottom side of a 30 cm long wooden stake. The hair snare was inserted through the sides of the enclosure, approximately 6 cm from the bottom and perpendicular to the long axis of the enclosure, with the glue strip positioned on the underside (Zielinski et al. 2006). It was designed to pivot upward on one end an additional 2 cm to allow for the passage of animals that vary in size (Zielinski et al. 2006). A second stake (without a glue strip) was placed horizontally above the hair snare to hinder individuals from climbing over rather than under the hair snare.

A positive detection was considered any footprint deposited on the contact paper. A negative detection was any footprint deposited solely in the carbon toner. Positive and negative detections of all species were recorded and the species identified using Elbroch (2003). Digital images of *S. putorius interrupta* tracks were taken and the contact paper saved as a permanent record. Tracks of other species were not saved, except for those that needed additional consultation for identification of the species. Track plates were checked daily. After a visitation rendered the track plate non-operational, the tracking medium and contact paper were replaced. Track plates were rebaited every other morning.

Bushnell Trophy Cameras (Bushnell Outdoor Products; Overland Park, KS) were set approximately 0.5 m above the ground and 5 to 6 m from the baited area. The cameras were attached to either a tree or to a t-post depending upon the availability of trees at the survey site. Cameras were angled slightly downward to maximize detection of the skunks and bait was deployed at a slightly lower height from the camera. Bait at successive stations alternated between canned sardines (Beach Cliff Sardines; Bumble Bee Seafood; San Diego, CA) or commercial fish oil (WCS, 2016). All standing vegetation between the camera and the bait was removed to reduce false triggers. The cameras were set with the following settings: 3 picture burst, no delay between trigger events, factory defined "normal" trigger sensitivity, and 5 megapixel images. During the second year of the study, half of the LED flash unit on cameras was covered with duct tape to decrease intensity of the flash and improve image quality.

I analyzed the ability of the 3 survey devices (track plates, live traps, and trail cameras) to detect *S. putorius interrupta* using 3 separate techniques. First, the ability of each device to remain operational was analyzed. An operational device was defined as a device that is still capable of detecting the target species during morning checks. For example, a trap with a nontarget species in it, a track-plate with multiple positive tracks, and a camera with a full SD card were all considered nonoperational. The operational percentage for each deployed device was tabulated:

$$\text{Operational \%} = (\text{\# of nights}^{\text{operational}} / \text{\# of nights}^{\text{deployed}}) * 100$$

A permutational ANOVA test was utilized to analyze the ability of the 3 device types to remain operational. Post-hoc analysis was performed using a pairwise permutational t-Test.

Next, a permutational ANOVA test was utilized to analyze the ability of the 3 devices to detect skunks. For this analysis, only data from counties with a skunk detection was used. The detection rate per device was defined as:

$$\text{Detection \%} = (\text{\# of nights}^{\text{with a skunk detection}} / \text{\# of nights}^{\text{deployed}}) * 100$$

Finally, the LTD period for each device was calculated and compared. LTD was defined as the time in days until initial detection of a skunk per survey location per device (Hackett et al. 2007). The LTD for the first detection per device per site was tabulated. Then a permutational ANOVA test was used to analyze the LTD period of the 3 devices.

Spotted Skunk Captures

Captured *S. putorius interrupta* were chemically anesthetized using an intramuscular injection of ketamine hydrochloride at a dosage of 0.1cc per kg (Edwards et al 1998). A uniquely numbered metal tag (National Band and Tag Co., Newport, KY) was applied to the ear for identification. Samples (ear clip, hair, feces, ectoparasites, and blood) and morphological data (total length, tail length, hind foot length, ear length, weight, and sex) were collected from each individual. Afterwards, I placed the skunk back into a trap covered by a blanket for a brief recovery period (approximately 30 minutes). After full recovery from the effects of anesthesia, the animal was released at the trap site.

Crowd-source Data

In addition to museum records and field data collected on *S. putorius interrupta*, I used crowd-source methods to accumulate more observations. Crowd-source methods were broadly defined as engaging professional organizations and the public to locate previous and future observations of spotted skunks in Texas. Initially, email blasts were sent to the Texas Wildlife Rehab Coalition and to the Texas Society of Mammalogists. A wanted poster (Figure 2) was later created and sent, via email blast, to the listserv of the Texas Master Naturalist Program and the Texas Chapter of the Wildlife Society. The wanted poster was also shared on the Facebook pages of the Texas Society of Mammalogists, Texas Master Naturalist Program, the Texas Chapter of the Wildlife Society, Katy Prairie Conservancy, the Texas Trappers and Fur Harvesters, Texas Nature Trackers, and the Fort Worth Nature Center and Refuge. The poster was further shared more than 300 times by members of these organizations.

FIGURE 2. Wanted poster created to crowd source observations of both eastern (*Spilogale putorius*) and western (*Spilogale gracilis*) spotted skunks in Texas.

Additionally, a project (Spotted Skunks of Texas) was created on the citizen scientist platform iNaturalist (SST, 2016). This project along with the Mammals of Texas and Eastern Spotted Skunk projects was monitored weekly for reported observations of *S. putorius interrupta* in Texas. An article featuring Robert C. Dowler's previous skunk research and current research on *S. putorius interrupta* was published in Texas Parks and Wildlife Magazine (Roe 2016) and a dedicated project email address was included with a request for further information on spotted skunk observations.

Upon receipt of an observation, I first verified the identity of the species. The credibility of the observation and the temporal and spatial data associated with it were verified before the observation was added to the spotted skunk database. If accurate temporal data were not provided, the observation was associated to a month, the season, or year. Observations were verified temporally if they could at least be confirmed to the season level. If spatial data associated with the observation were lacking or not provided, the location was georeferenced with the assistance of the observer.

Citizen Scientist Trail Camera Surveys

In addition to the primary field survey and crowd-sourced search for observations, I also utilized citizen scientists to collect supplemental presence data. Participants included multiple Texas Master Naturalist Program chapters, individual members of 4-H, the Texas Christian University chapter of The Wildlife Society in coordination with the Fort Worth Nature Center and Refuge staff, and spotted skunk research collaborators.

Survey sites were at locations of credible *S. putorius interrupta* observations or areas where the preliminary species distribution model showed a high probability of occurrence. Once a site was selected for survey, a group of 3 survey points were chosen using methodology consistent with the regular field surveys. I then traveled to the site and assisted the citizen scientists with deploying the cameras using the methodology consistent with the full field surveys. The citizen scientists monitored the cameras for the following 3 weeks, checking and rebaiting the cameras every 7th day.

After assembling the database of observations, it was important to filter observations to a current time frame. Although the decline of *S. putorius interrupta* was first observed in 1940 (Gompper and Hackett 2005), I chose to quantify a more current time frame, by sorting the dataset into quartiles. The 75th, or most recent, quartile included skunks observed in the years 2012 to present. The National Land Cover Database-NLCD (Homer et al. 2015) had previously been selected for use. The NLCD published in 2011 was most closely aligned with the time period from the 75th quartile of the skunk observation database. All skunk records within a 10-year buffer of 2011 (2001 – 2017) were then selected for inclusion into the current dataset.

Species Distribution Model

A species distribution model was created to predict the current relative probability of occurrence of *S. putorius interrupta* within Texas (Maxent version 3.4.0; Phillips et al. 2017). Environmental variable layers, such as topographical (slope and aspect), land cover, and climate were altered using ArcMap 10.2 (ESRI 2014). The model utilized 18 climate variables (Table 1) averaged between the years of 1970 to 2000 (Fick and Hijmans, 2017).

TABLE 1. Variable, source, and covariates used in species distribution model for plains spotted skunk (*Spilogale putorius interrupta*).

Variable	Description	Source
Aspect	Derived variable showing the rate of downhill change from a raster cell to neighbor cells	USGS (2014)
Climate	18 Bioclimate predictors representing monthly temperature and rainfall variables	Fick and Hijmans (2017)
Land-use	National Land-cover database (2011). Derived variables: Cultivated, Developed (high, all, low), Forest, Grass, Shrub, Pasture, and Water	Dewitz et al. (2011)
Slope	Derived variable showing the rate of maximum change in z-value from each cell of a raster surface	USGS (2014)

Current land-use data were downloaded from the 2011 NLCD (Homer et al. 2015). The raster was first cut to the study area (Texas). Next, the NLCD raster was resampled to a 1 km resolution with land use being assessed as the majority category in a 4 km circular radius around each individual cell. The resample was performed to smooth the transition between habitats. Finally, the land-use categories were truncated from 15 to 10 general categories with all similar habitats combined (Table 2).

With the assumption that spatial data for *S. putorius interrupta* were biased towards areas with high crowd-source participation (population centers within the state) or areas with ongoing research, I filtered the records to remove bias and redundant records. The potential bias was most evident at 2 locations, Katy Prairie and Fort Hood; records at these locations accounted for 65% of all observations. First, all records at these locations were plotted in Arc GIS. Next, a 1 km buffer was placed around each record. This resulted in clusters of 1 km buffered overlapping records. The records within each individual cluster were randomly reduced to a single observation. This led to a series of spatially isolated records at each location. Finally, these isolated records were randomly reduced such that the number of observations at each location cumulatively approximated 33% of the final observation total (n = 8 per location).

Model validation was performed using a 2-fold cross validation (Fielding and Bell 1997; Franklin 2009). In this method, the presence data is divided into 2 groups, a train group which calibrates the model and a test group which validates the model. The model fit was evaluated using area under curve (AUC) of the receiver operating characteristic (ROC) (Delong et al. 1988; Phillips et al. 2017). When evaluating AUC, a value near 1 is representative of a good model fit (Fielding and Bell 1997).

TABLE 2. Truncated land-use variables used in model the species distribution of the plains spotted skunk (*Spilogale putorius interrupta*) in Texas. All land-use variables originated from the 2011 NLCD.

Land-use	NLCD variables	Description
Cultivated	Cultivated Crops	Area used for annual production of crops and all land actively tilled
Developed_all	Developed, Open Space	Impervious surface < 20% of total cover
	Low Intensity	Impervious surface 20% - 49% of total cover
	Medium Intensity	Impervious surface 50% - 79% of total cover
	High Intensity	Impervious surface 80% -100% of total cover
Developed_high	Developed, Medium	Impervious surface 50% - 79% of total cover
	High Intensity	Impervious surface 80% -100% of total cover
Developed_low	Developed, Open Space	Impervious surface < 20% of total cover
	Low Intensity	Impervious surface 20% - 49% of total cover
Forest	Deciduous Forest	Trees > 5 meters. >75% of trees shed foliage annually
	Evergreen Forest	Trees > 5 meters. >75% of trees maintain foliage all year
	Mixed Forest	Trees > 5 meters. Neither deciduous nor evergreen >75%
Grass	Grassland/Herbaceous	Graminoid or herbaceous vegetation >80%.
Pasture	Pasture/Hay	Areas of grasses, legumes, or a mixture planted for grazing or hay
Shrub	Shrub/Scrub	Shrubs or young trees < 5 meters tall and >20% of the canopy
Water	Open Water	Open water with < 25% cover of vegetation or soil
	Woody Wetlands	Forest or shrubland >20% of cover; substrate periodically floods
	Emergent Herbaceous	Perennial herbaceous vegetation

RESULTS

One hundred fourteen fully verified *S. putorius interrupta* records for Texas were amassed. All 4 techniques (museum records, field surveys, crowd sourcing, and citizen scientist surveys) were successful in documenting occurrences. Thirteen records were from museum specimens, 80 were from crowd-sourced observations, 12 were recorded during full field surveys, and 4 were recorded during citizen scientist camera surveys. Of the 114 observations, 89 were deemed unique individuals and 79 were available for use in the SDM (Figure 3; Appendix 2).

Of the 114 records, 5 were only verified to the county level. I was able to quantify the current occurrence of *S. putorius interrupta* in these counties, but the spatial data were not accurate enough to be utilized in the SDM. The Angelo State Natural History Collections (ASNHC) received 4 spotted skunks from the Texas Department of Health and Human Services (TDHHS) that had been submitted for rabies testing. All 4 were rabies negative, but because of internal policies, TDHHS could only release the county and year of submission for these specimens. These skunks were submitted in 2011 ($n = 2$) and 2017 ($n = 2$). The College Station Police Department reported an incident involving a single *S. putorius interrupta* from 15 October 2015. The species and temporal data were verified; however, the skunk arrived at the capture location in the engine compartment of a vehicle and the location of origin was unknown. For this reason, the spatial data associated was unverified and not included in the SDM. The counties of origin for these 5 skunks were Brazos, Caldwell, Gonzalez, Jack, and Robertson. These 4 specimens and 1 observation were the only known records of occurrence for these counties within the current time frame.

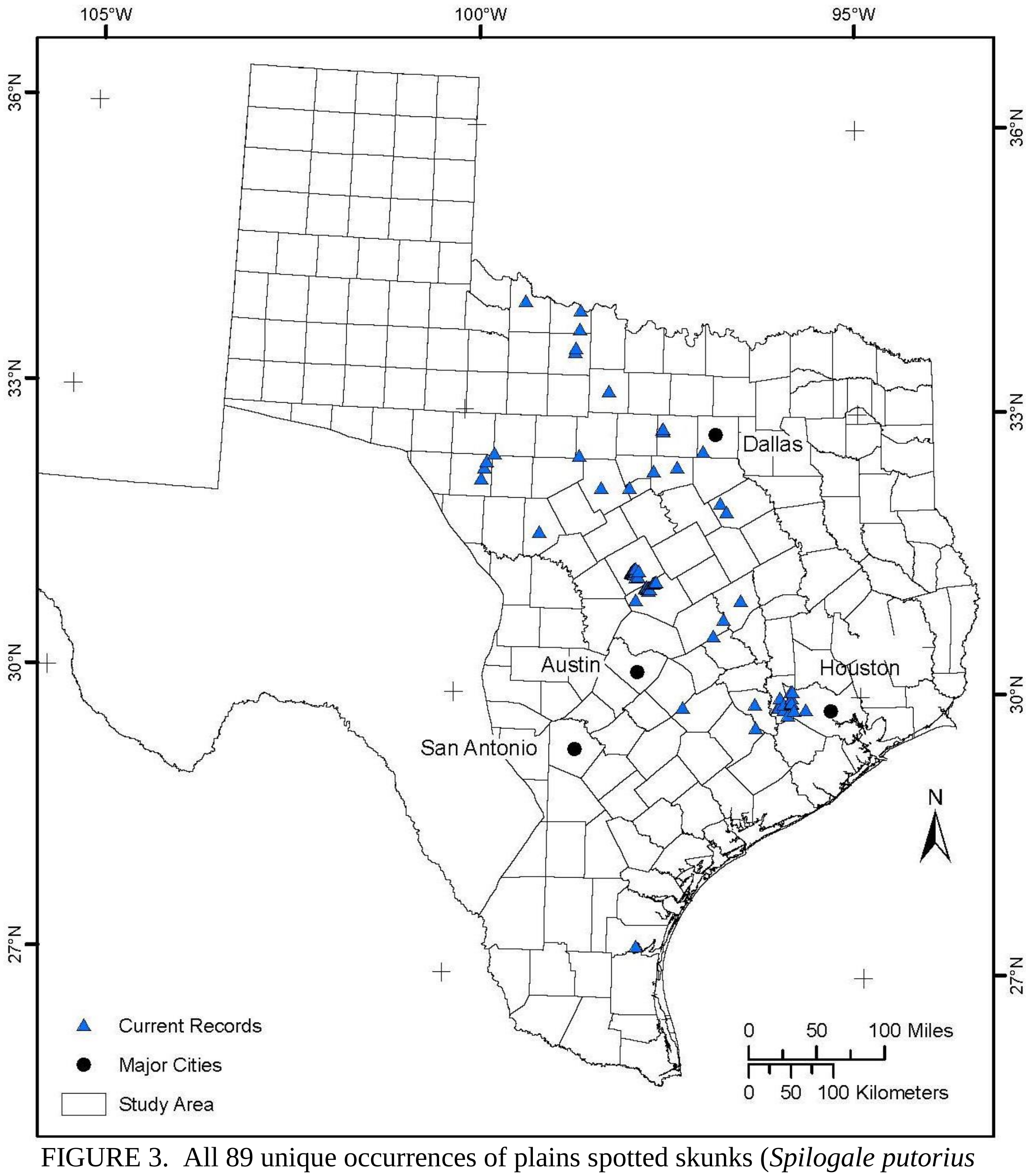

FIGURE 3. All 89 unique occurrences of plains spotted skunks (*Spilogale putorius interrupta*) recorded in Texas from 2001 to 2017.

Museum Surveys

Thirteen *S. putorius interrupta* specimens were identified from museum collections. Of these, 10 were in collections prior to the start of the project and 3 were accessioned since the project began. All specimens were verified and locations georeferenced, if required. These specimens came from 8 counties of which multiple skunks were from Harris (n = 3), Taylor (n = 2), and Waller counties (n = 2).

Field Surveys

Field surveys were initiated in September 2015 and concluded in January 2017. Sites in 10 counties were surveyed and *S. putorius interrupta* was detected in 4 of these counties. Survey devices were deployed 1179 times for a total of 8065 survey nights (Appendix 3). A minimum of 9 skunks were detected 12 times (detection rate = 0.15%) by all 3 survey devices (cameras, traps, and track plates). Skunks were detected 6 times by traps (detection rate = 0.22%), 4 times by cameras (detection rate = 0.15%), and twice with track plates (detection rate = 0.07%). Skunks were detected in Coryell, Harris, Waller, and Wise counties with detection rates of 0.36%, 0.73%, 0.27%, and 0.12% respectively. In Coryell County, a minimum of 2 skunks were detected 3 times at Fort Hood Military Installation. In Harris County, a minimum of 4 skunks were detected 6 times at the Katy Prairie Conservancy's Warren Ranch property. In Waller County, 2 skunks were detected at a private landowner's ranch. In Wise County, 1 skunk was detected at the Sid Richardson Scout Ranch.

Device Efficacy

To assess device efficacy, the ability of each device to remain operational was analyzed. A permutational ANOVA with 10,000 iterations indicated that there was a difference in the observed ability of each device to remain operational (Permutational ANVOA: $p < 0.00001$). A post-hoc analysis utilizing a pair wise permutational t-Test with 10,000 iterations and a Bonferroni adjustment indicated that trail cameras remained operational more reliably than both track plates and live traps (Permutational t-Test: $p<0.00001$) and track plates remained operational more reliably than live traps (Permutational t-Test: $p<0.00001$). This analysis was performed for all 10 counties, a subset of the data from the 4 counties where skunks were detected, and a subset of the data from the 6 counties where skunks were not detected. The results of the analysis was the same for all 3 groupings.

To assess each devices ability to detect *S. putorius interrupta*, a permutational ANOVA with 10,000 iterations was performed. Analysis indicated that there was no difference in the device's ability to detect skunks (Permutational t-Test: $p=0.415$).

Latency to detection period was also analyzed using a permutational ANOVA with 10,000 performed iterations. For analysis, 7 detections were utilized. Live traps had 3 detections utilized (2 day average LTD), trail cameras had 2 detections utilized (1.5 day average LTD), and track-plates also had 2 detections utilized (5.5 day average LTD). Analysis indicated that there was no difference in the observed LTD period of the 3 devices (Permutational ANOVA: $p=0.214$).

Crowd-source Data

Eighty-nine total observations were amassed of which at least 56 were deemed unique and utilized for analysis. These observations came from 19 counties including 4 (Austin, Eastland, Shackelford, and Wilbarger) without prior county records (Schmidly and Bradley 2016). Of these, the Austin County observation was a citizen-scientist report verified without pictorial evidence, the Eastland County observation was a citizen scientist report of 4 skunks captured and released with pictorial evidence, the Shackelford County observation was an Abilene Christian University wildlife survey with trail camera photo documentation, and the Wilbarger County observation was a road-killed individual with photo and tissue voucher. The time frame for all crowd-sourced observations was from 2003 to 2017; however, 88 of the 89 observations were from 2009 to present with only 1 occurring prior (2003).

Citizen Scientist Trail Camera Surveys

Field surveys by citizen scientists were initiated in September of 2016 and concluded in April of 2017. Nine locations in 6 counties were surveyed (Appendix 3). Trail cameras were deployed 54 times for a total of 1206 survey nights. Spotted skunks were detected in 2 counties, Tarrant and Waller. A minimum of 2 skunks were detected 4 times (detection rate = 0.33%).

S. putorius interrupta was detected at a private location in Waller County twice. This location had previously been surveyed during fall 2015 when 2 skunks were detected in traps rather than by trail cameras. The landowner/collaborator also reported a visual observation on this property in early December 2016. Because of the spatial and temporal relatedness of the observations by the citizen scientist and the landowner, I considered all 3 observations to be of the same individual.

There were 2 detections of *S. putorius interrupta* at the Fort Worth Nature Center and Refuge (FWNCR) in Tarrant County. Skunks were detected twice during a 24-hour period at the same camera, although during different nights. The spotting pattern of the skunk indicated that this was multiple observations of the same individual. Although the FWNCR had verified observations in 2015 and 2016, skunks were not detected during a fall 2015 survey.

Species Distribution Model

Of the 89 unique *S. putorius interrupta* observations available, only 79 were spatially distinct enough for use in the SDM. After records at 2 locations (Fort Hood and Katy Prairie) were filtered to account for redundancy, 45 unique observations were available for use in the model. The model showing probability of occurrence in Texas, predicted that *S. putorius interrupta* is presently found only in the central part of the state, west of the Piney Woods ecoregion and east of the Llano Estacado and Edwards Plateau (Figure. 4). The model predicted high probability of occurrence in the Central Great Plains, Cross Timbers, Texas Blackland Prairies, East Central Texas Plains, Western Gulf Coast Plains, and the far eastern portion of the Edwards Plateau ecoregions (Griffith et al. 2004). Within these large ecoregions, mean probability of occurrence is relatively low, with the Cross Timbers having the highest probability at 40%. When examined at the county level, however, 25 counties have a mean probability of occurrence above 50% (Table 3).

Shrub and forest land cover types are important to the occurrence of *S. putorius interrupta* according to the jack knife test of importance (Figure. 5). The land cover shrub was defined as areas dominated by shrubs, less than 5 m tall, with the shrub canopy comprising more than 20% of the total vegetation (this land cover is often associated with early succession trees). The forest land cover was a truncated land cover that included herbaceous, evergreen, and mixed forests with trees taller than 5 m. The jackknife test also indicated that annual precipitation (Bioclim 12), precipitation seasonality (Bioclim 15), and precipitation of wettest quarter (Bioclim 16) bioclimatic variables were the most important variables for predicting distribution. The receiver operator characteristics (ROC) area under curve (AUC) for the two models was 0.934 and 0.861 respectively (Figure. 6).

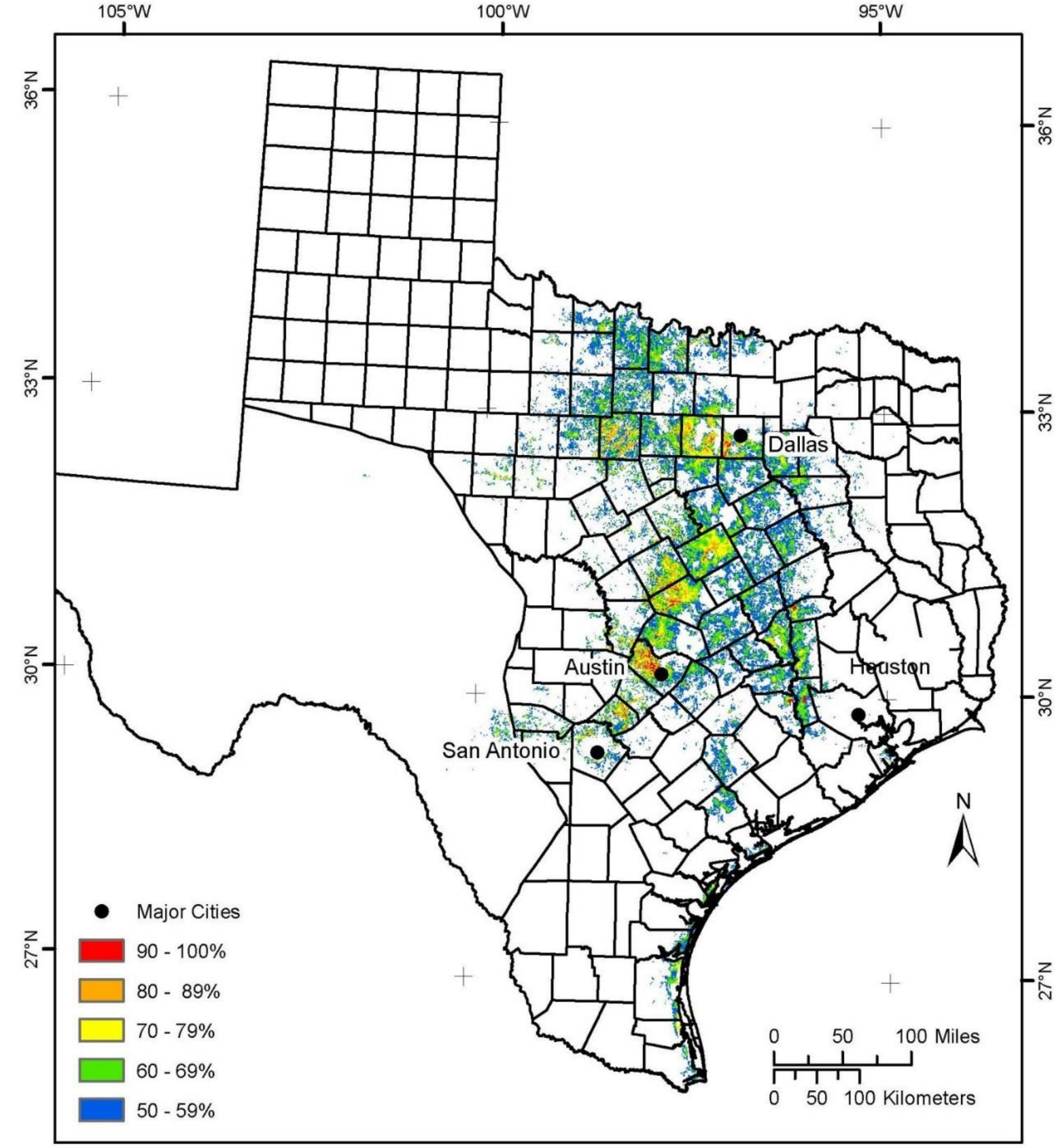

FIGURE 4. The current modeled distribution of plains spotted skunks (*Spilogale putorius interrupta*) in Texas using presence data from 2001 to 2017. This map shows >50% probability of presence.

TABLE 3. Texas counties within the current range of plains spotted skunk, *Spilogale putorius interrupta* with a mean probability of occurrence > 50%. Table also notes whether a skunk was recorded for the county during the 2015 - 2017 survey period.

County	Area (Km^2)	P_{mean}	Record
McLennan	2750	63	
Palo Pinto	2550	62	Yes
Bell	2814	59	Yes
Tarrant	2327	58	Yes
Travis	2656	57	
Brazos	1529	57	
Comal	1489	56	
Coryell	2736	56	Yes
Kaufman	2091	56	
Parker	2350	55	
Montague	2424	54	
Jack	2383	54	Yes
Waller	1343	52	Yes
Clay	2866	52	
Johnson	1901	52	Yes
Robertson	2242	51	Yes
Ellis	2464	51	
Washington	1609	51	
Freestone	2314	51	
Milam	2648	51	Yes
Hill	2552	50	
Grimes	2080	50	
Navarro	2817	50	Yes
Young	2409	50	

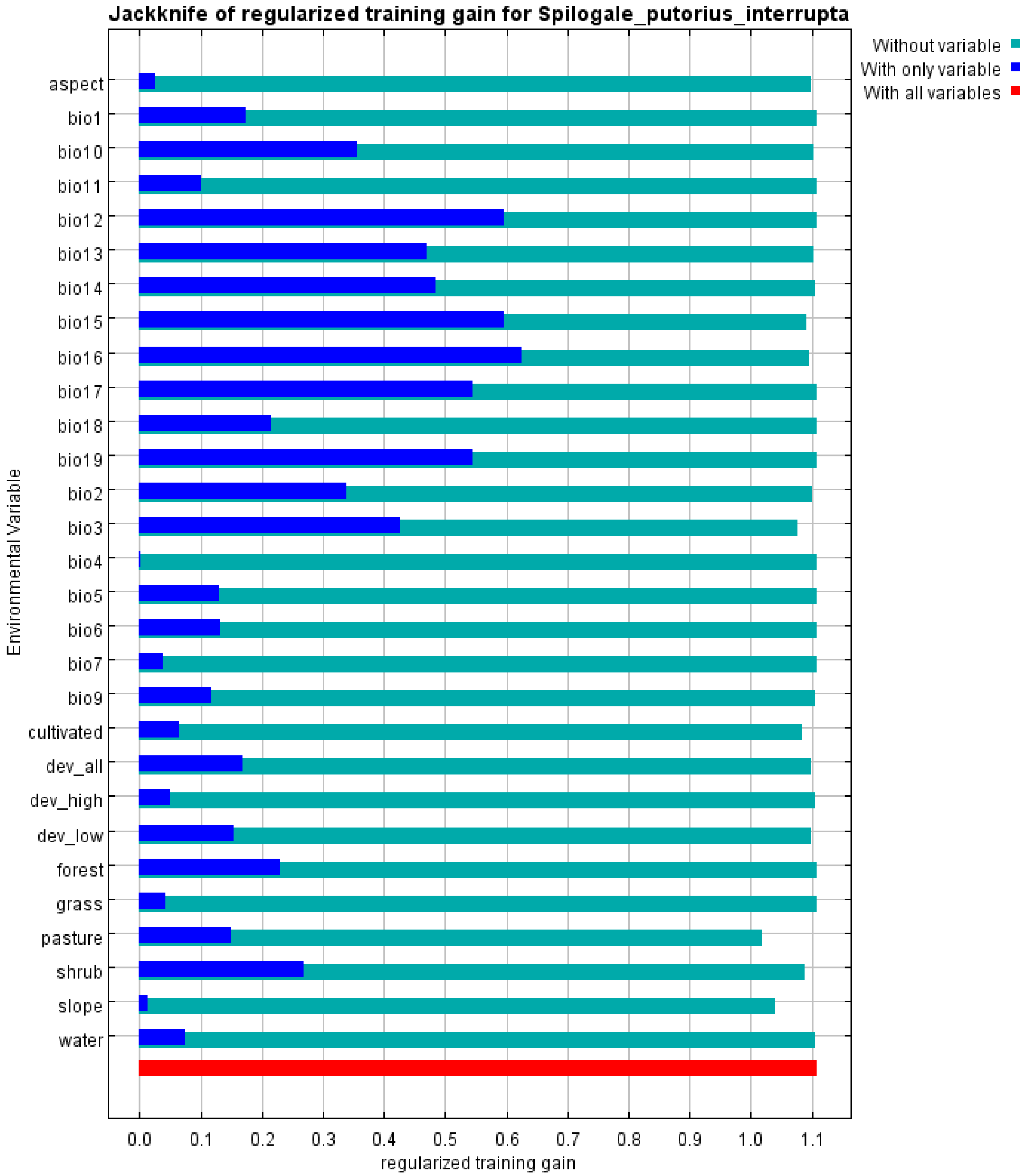

FIGURE 5. Jackknife test of input variable importance for species distribution of plains spotted skunk (*Spilogale putorius interrupta*). Bio 16 has the highest gain when used in isolation and therefore appears to have the most useful information.

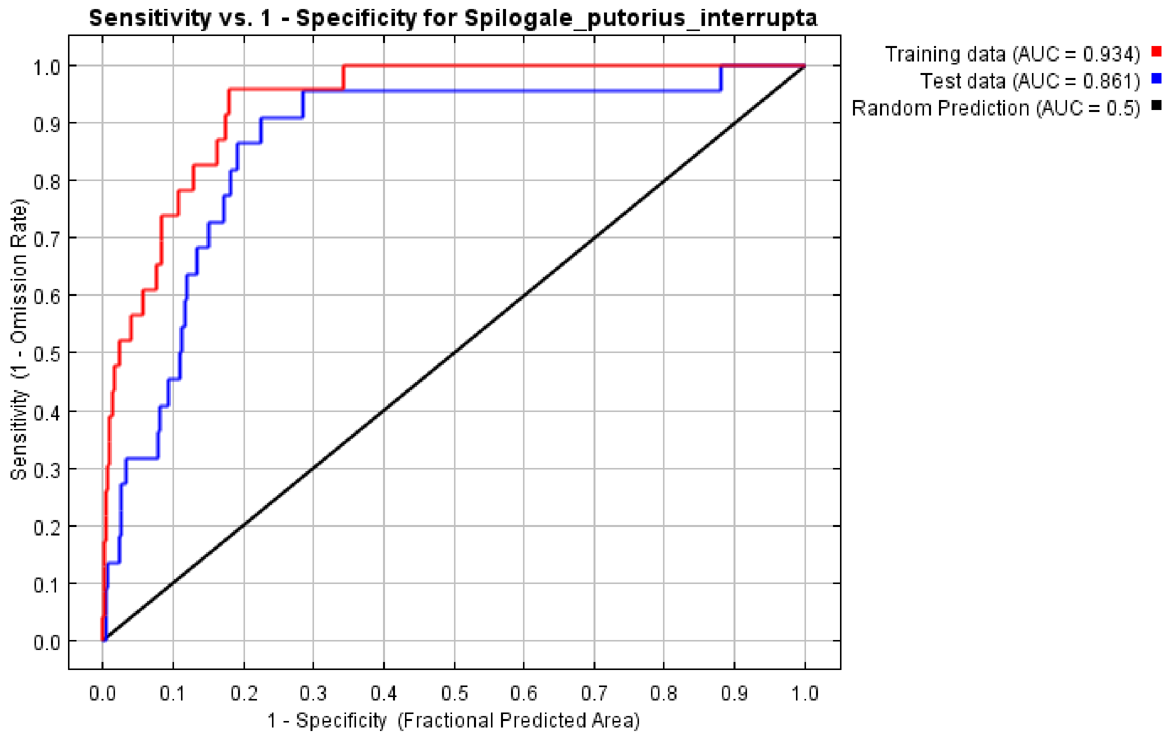

FIGURE 6. The area under the curve (AUC) for the receiver operating characteristic (ROC) curve. An AUC score near 1 is considered excellent. The AUC for training data (0.934) is considered excellent while the AUC on test data (0.8661) is considered above average.

DISCUSSION

Field efforts to locate *S. putorius interrupta* were intensive, time consuming, and of limited success; however, the overall detection rate (0.15%) was comparable to the detection rates recently observed in Missouri, 0.37% (Hackett et al. 2006) and Tennessee, 0.07% (Reed and Kennedy 2000). At the county level, the detection rates in Coryell (0.36%) and Waller (0.26%), compared favorably with those in Missouri and the rate in Harris County (0.73%) was comparable with that seen in Arkansas, 0.81% (Hackett et al. 2006). This study confirmed that live traps, track plates, and trail cameras will detect *S. putorius interrupta* if the species is present.

The full field surveys were designed to evaluate the relative success of the 3 methods of detection. Unfortunately, the low overall success rate (12 detections for 8065 survey night, 0.15% detection rate) provided too few data to assess relative efficacy of these methods. Although device efficacy was analyzed, using 3 different techniques, the sample size for detection success (n = 12) and LTD (n = 7) were likely too low to detect whether differences were present. As such, these results and analysis should be accepted with caution.

All methods detected *S. putorius interrupta;* however, it became clear that fewer spotted skunks utilized the track plate enclosures. This contrasts with previous data for eastern spotted skunks that showed enclosed track plates had greater efficiency, lower LTD, and higher probability of detection than cameras (Hackett et al. 2007). Only a single spotted skunk registered positive tracks or completely entered the track-plate enclosures. The reduction in size of the track plate enclosures, relative to those used in previous studies (Zielinski et al. 2006; Hackett et al. 2007) likely inhibited the entry of spotted skunks. The rationale for reducing the size to match live trap dimensions was to prevent larger mesocarnivores, such as *Procyon lotor* (raccoon) and *Didelphis virginiana* (Virginia opossum), from entering the enclosures. This was not the case as both non-target species often entered or destroyed the enclosures in an effort to reach the bait. The color of the enclosures (white) may also have played a role, as those deployed in previous studies (Hackett et al. 2007) were a uniform dark color. The insertion of the hair snare device, also could have prohibited skunks from entering as the devices used in Arkansas (Hackett et al. 2007) were not fitted with hair snares. In California, Zielinksi et al (2006) utilized hair snares in larger sized track-plate enclosure that allowed the incidental detection of *S. gracilis* while surveying for *Pekania pennanti* (fishers) and *Martes americana* (marten).

Live traps were least efficient at remaining operational throughout the survey; however, they detected as many skunks (6) as the other 2 devices combined. In Arkansas, detection success of live traps was not compared to the detection success of trail cameras or track-plates; however, it was reported that live traps were more successful than the other 2 devices (Hackett et al. 2007). Live traps do provide the potential for collection of tissue, ectoparasites, and other biological sampling not possible with cameras or track-plates; however, this trade off may require researchers to remain in the field for long periods of time.

In future studies aimed only at determining the presence or absence of *S. putorius interrupta*, I recommend the use of trail cameras over both track plates and live traps. While both trail cameras and track-plate methods are non-invasive, the cameras were more efficient at remaining operational, as efficient at detecting spotted skunks, required less time to deploy and check, and are not required to be checked daily to detect skunks. Trail cameras also had the lowest LTD period (1.5 days); however, these devices detected skunks less frequently than live traps, albeit not significantly so. If track plates are utilized, the enclosures should be enlarged to the size previously reported and dark in color. In future studies, I recommend against the use of live traps, unless live capture is needed for additional research goals.

With the lack of detections via full field survey, crowd sourcing provided a low cost alternative to locate additional records of occurrence. These methods were extremely beneficial and provided 89 additional *S. putorius interrupta* records. The distribution of the wanted poster, both by email blast and social media, provided the most verified records. Wanted posters also provided the most records of spotted skunks in the past in Minnesota, albeit distribution of the posters was accomplished by alternate means (Wires and Baker, 1994). Although these crowd-sourced methods were successful, all options for locating records were not exhausted. Notably, farmers, who were regarded as experts because of a Minnesota survey (Wires and Baker, 1994), were not directly contacted. A concurrent *S. putorius* crowd source project in Alabama has yielded verified reports by targeting agency-employed biologists and law enforcement officers as well as fur trappers, among other groups (Nick Sharp, [Alabama Wildlife and Freshwater Fisheries Division, Tanner, Alabama], personal communication, [September 2017]). These groups were not specifically targeted in Texas, although there was some overlap within these groups by targeting of other groups (i.e. individual trappers or ranchers reporting observations after seeing the TPWD article or being forwarded an email). In the future, crowd-sourced records should continue to be solicited, with methods that include of farmers, ranchers, fur trappers, and TPWD personnel.

Dowler et al. (2008) used museum records to plot the range of *S. putorius interrupta* in Texas. Data from this study indicates that the distribution of the plains spotted skunk has been reduced to the central portion of the state. This conclusion was based not only on the SDM but also on the fact that all but 1 of the 114 total verified observations are from the central region of the state. This area includes the cities of Dallas/Fort Worth, Houston, Waco, and Temple/Killeen. The lack of current records near San Antonio and Austin suggests that populations of the skunk in these regions are either very uncommon or have been extirpated. An additional possibility is that *S. gracilis* is expanding its range eastward at the expense of *S. putorius interrupta*, although there is currently no evidence of this. Even within this remnant core range, the spotted skunk appears to be uncommon relative to other mesocarnivores. It is encouraging, however, that there are at least 2 areas of high local abundance, Fort Hood Military Installation and Katy Prairie.

In ecological modeling, care must be taken to work only within a species known range and with environmental variables germane to the species (Franklin 2009). Because of the unknown distribution and interaction with *S. gracilis*, I ran the model on the entire state to potentially identify areas in and beyond the overlap zone where *S. putorius interrupta* may occur. This could have potentially led to errors of commission (false positives) and the model does in fact show some predicted probability of occurrence on the edge of the Edwards Plateau, west of San Antonio in an area where *S. putorius interrupta* has never been recorded. The eastern and southern edge of the plateau were represented in the SDM as a band with high probability of occurrence from north and west of Austin to west of San Antonio. This band included the farthest expected extent of the plains spotted skunk's range in Texas, the overlap zone with *S. gracilis*, and some areas where *S. putorius interrupta* has never been reported. While a few historical records from this area exist, *S. putorius interrupta* was not recorded from this area during the project; however, multiple reports of *S. gracilis* were received. In the future, surveys capable of differentiating between the 2 species should be implemented in this area to help define the western extent of the range of *S. putorius interrupta* and whether the 2 species are truly sympatric in this area.

There are 2 other potential areas of commission deemed worthy of discussion—the Dallas/Fort Worth (DFW) metro area and a coastal band in the Western Gulf Coast Plains ecoregion. There were 4 records of *S. putorius interrupta* from the DFW area (3 at FWNCR and one road-killed individual near Cedar Hill State Park) included in the model. These 4 records were split evenly between the test dataset and the training dataset. The model shows low probability of occurrence for each city proper, but high probability for the more rural areas of Tarrant and Dallas county. While results confirm the skunk is still present in both counties, it is most likely extremely uncommon and possibly isolated to pockets of suitable habitat such as at the refuge and state park. Although additional surveys for the skunk in this area should be initiated, issues encountered during the full survey at the refuge (massive non-target species interference) are likely still present and survey methodology should reflect this.

The second area of potential commission is a narrow band in the western Gulf Coast Plains, from Matagorda Bay south to Brownsville. This area was surveyed twice; once in Calhoun County, on the southern shore of Matagorda Bay, and once in Kleberg County, slightly west of the predicted area of probable occurrence. No *S. putorius interrupta* were detected via survey; however, 1 crowd sourced observation was verified in Kleberg County. Eastern spotted skunks have been reported to utilize coastal wetlands, dunes, and adjacent thickets in Florida (Kinlaw et al. 1995). While it is possible that the skunk is still present in this band, it is also possible that this region is a false positive. I recommend further examination of the area to verify the presence or absence of *S. putorius interrupta*. If the skunk is present in this area, it is likely geographically isolated from other populations in Texas.

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APPENDIX 1. Angelo State University Institutional Animal Care and Use Committee (IACUC) approval letter (IACUC # 15-15).

ANGELO STATE UNIVERSITY
College of Graduate Studies & Research
Institutional Animal Care & Use Committee

30 November 2017

Dr. Robert C. Dowler/J. Clint Perkins
Department of Biology
Angelo State University
San Angelo, TX 76909

Dear Dr. Dowler and Mr. Perkins:

This letter is to confirm that your proposed project titled, "Field survey of eastern spotted skunk" was reviewed by Angelo State University's Institutional Animal Care and Use Committee (IACUC) in accordance with the regulations set forth in the Animal Welfare Act and P.L. 99-158.

This protocol was approved for three years, effective 21 November 2015 and it expires three years from this date; however, an annual review and progress report form (www.angelo.edu/content/files/22583-iacuc-annual-review-progressreport) for this project is due on 15 August of each year. If the study will continue beyond three years, you must submit a request for continuation before the current protocol expires.

The protocol number for your approved project is 15-15. Please include this number in the subject line of all future communications with the IACUC regarding the protocol.

Sincerely,

Steven T. Brewer, Ph.D.
Co-Chair, Institutional Animal Care and Use Committee

Dr. Robert Dowler, IRB Chair | ASU Station #11025 | San Angelo, Texas 76909
Phone: (325) 486-6639

Member, Texas Tech University System | Equal Opportunity Employer

APPENDIX 2. All unique records of plains spotted skunk, *Spilogale putorius interrupta*. Includes record type, year, county, general location, and coordinates. Coordinates for private landowners have been masked with X.

Record Type	Year	County	Location (General)	Latitude	Longitude
Crowd Sourced	2003	Wichita	Wichita Falls	X	X
Museum	2004	Brown	Brownwood	31.725902	-99.007089
Museum	2004	Harris	Hockley	29.999086	-95.844170
Museum	2005	Milam	Gause	30.8300617	-96.689062
Museum	2005	Waller	Brookshire	29.893333	-96.013056
Museum	2006	Archer	Archer City	33.641737	-98.619574
Museum	2007	Taylor	Tuscola	32.271839	-99.756913
Museum	2008	Waller	Pattison	29.810950	-95.889897
Museum	2008	Harris	Hockley	30.065600	-95.855000
Crowd Sourced	2009	Navarro	Blooming Grove	X	X
Museum	2009	Harris	Hockley	30.060536	-95.841513
Crowd Sourced	2010	Waller	Waller	X	X
Crowd Sourced	2010	Harris	Katy	29.8608111	95.8152444
Crowd Sourced	2011	Coryell	Fort Hood	31.318902	-97.842629
Crowd Sourced	2011	Coryell	Fort Hood	31.307261	-97.838232
Crowd Sourced	2011	Coryell	Fort Hood	31.332948	-97.834532
Crowd Sourced	2011	Coryell	Fort Hood	31.336914	-97.834084
Crowd Sourced	2011	Coryell	Fort Hood	31.316997	-97.827540
Crowd Sourced	2011	Coryell	Fort Hood	31.319352	-97.822635
Crowd Sourced	2011	Coryell	Fort Hood	31.312193	-97.821169
Crowd Sourced	2011	Coryell	Fort Hood	31.313298	-97.814787
Crowd Sourced	2011	Coryell	Fort Hood	31.352818	-97.810370
Crowd Sourced	2011	Coryell	Fort Hood	31.306443	-97.806183
Crowd Sourced	2011	Coryell	Fort Hood	31.359323	-97.790134

APPENDIX 2 – Continued

Record Type	Year	County	Location (General)	Latitude	Longitude
Crowd Sourced	2011	Bell	Fort Hood	31.202289	-97.566267
Crowd Sourced	2011	Bell	Fort Hood	31.211714	-97.545950
Crowd Sourced	2011	Bell	Fort Hood	31.223882	-97.534709
Crowd Sourced	2011	Bell	Fort Hood	31.222131	-97.526685
Crowd Sourced	2011	Harris	Katy Prairie Conservancy	29.948138	-95.843990
Crowd Sourced	2012	Bell	Fort Hood	31.029671	-97.777024
Crowd Sourced	2012	Bell	Fort Hood	31.151518	-97.665919
Crowd Sourced	2012	Bell	Fort Hood	31.176290	-97.645544
Crowd Sourced	2012	Bell	Fort Hood	31.145712	-97.640479
Crowd Sourced	2012	Bell	Fort Hood	31.164090	-97.631205
Crowd Sourced	2012	Bell	Fort Hood	31.158110	-97.630462
Crowd Sourced	2012	Bell	Fort Hood	31.128471	-97.628518
Crowd Sourced	2012	Bell	Fort Hood	31.144763	-97.607045
Crowd Sourced	2013	Kleberg	Roadway	27.333081	-97.700233
Crowd Sourced	2013	Johnson	Alvarado	32.435750	-97.289389
Crowd Sourced	2013	Fayette	Cistern	X	X
Crowd Sourced	2013	Colorado	Attwater PC NWR	29.680000	-96.290000
Crowd Sourced	2014	Coryell	Fort Hood	31.301126	-97.809665
Crowd Sourced	2014	Coryell	Fort Hood	31.326268	-97.791167
Crowd Sourced	2014	Coryell	Fort Hood	31.266467	-97.785985

APPENDIX 2 - Continued

Record Type	Year	County	Location (General)	Latitude	Longitude
Crowd Sourced	2014	Coryell	Fort Hood	31.340457	-97.754994
Crowd Sourced	2014	Johnson	Godley	X	X
Crowd Sourced	2015	Palo Pinto	Palo Pinto Mountains SP	32.54356	-98.534300
Crowd Sourced	2015	Erath	Stephenville	32.205806	-98.240125
Crowd Sourced	2015	Tarrant	Fort Worth Nature Center	32.844880	-97.471690
Crowd Sourced	2015	Dallas	Cedar Hill	32.611039	-96.959206
Crowd Sourced	2015	Navarro	Silver City	31.973947	-96.657453
Crowd Sourced	2015	Austin	Bellville	29.926079	-96.301872
Survey	2015	Waller	Pattison	X	X
Survey	2015	Waller	Pattison	X	X
Crowd Sourced	2015	Austin	Bellville	29.926079	-96.301872
Museum	2016	Taylor	Abilene	32.459830	-99.700290
Crowd Sourced	2016	Shackelford	Abilene	32.544929	-99.600675
Crowd Sourced	2016	Wilbarger	Vernon	34.159310	-99.272550
Survey	2016	Wise	Sid Richardson Scout Ranch	32.216031	-97.888789
Survey	2016	Coryell	Fort Hood	31.317725	-97.826272
Survey	2016	Coryell	Fort Hood	31.296775	-97.806683
Survey	2016	Coryell	Fort Hood	31.296417	-97.805600
Crowd Sourced	2016	Coryell	Fort Hood	31.279227	-97.760779
Crowd Sourced	2016	Tarrant	Fort Worth Nature Center	32.839149	-97.481016
Crowd Sourced	2016	Milam	Milano	X	X
CS Camera Survey	2016	Waller	Pattison	X	X

APPENDIX 2 - Continued

Record Type	Year	County	Location (General)	Latitude	Longitude
Crowd Sourced	2016	Waller	Pattison	X	X
Survey	2016	Harris	Katy Prairie Conservancy	29.95334	-95.855900
Survey	2016	Harris	Katy Prairie Conservancy	29.94134	-95.847260
Survey	2016	Harris	Katy Prairie Conservancy	29.94134	-95.847260
Survey	2016	Harris	Katy Prairie Conservancy	29.947272	-95.843897
Museum	2017	Taylor	Abilene	32.391535	-99.723615
Crowd Sourced	2017	Archer	Archer City	33.681900	-98.609806
Museum	2017	Wichita	Burkburnett	34.078588	-98.557528
CS Camera Survey	2017	Tarrant	Fort Worth Nature Center	32.826400	-97.473106
Crowd Sourced	2017	Waller	Waller	29.993817	-95.993072
Crowd Sourced	2017	Waller	Pattison	29.873697	-95.944894
Crowd Sourced	2017	Waller	Pattison	29.811050	-95.889970
Crowd Sourced	2017	Harris	Houston	29.873030	-95.670761

APPENDIX 3. The location of all surveys for plains spotted skunks (*Spilogale putorius interrupta*) in Texas from 2015 to 2017. Listed are county, sites type of survey, survey dates, number of devices deployed, and survey nights.

County	Location	Survey Type	Survey Dates	Devices Deployed	Survey Nights
Waller	Private Property	Full	02 -11 Oct 2015	108	748
Tarrant	Fort Worth N.C.	Full	21 - 29 Nov 2015	120	741
Burleson	Lake Somerville S.P.	Full	07 - 15 Jan 2016	111	768
Wise	Sid Richardson S.R.	Full	26 Feb - 05 Mar 2016	120	839
Kleberg	King Ranch	Full	13 -21 Mar 2016	120	840
Clay	Lake Arrowhead S.P.	CSTCS	07 - 28 Sep 2016	6	126
Wichita	Private Property	Full	01 - 09 Oct 2016	121	825
Wichita	Private Property	Full	01 - 09 Oct 2016	121	825
Waller	Private Property	CSTCS	08 - 29 Nov 2016	3	63
Waller	Private Property	CSTCS	08 - 29 Nov 2016	3	63
Navarro	Private Property	Full	19 - 27 Nov 2016	111	804
Coryell	Fort Hood	Full	14 - 22 Dec 2016	120	838
Calhoun	Powderhorn Ranch	Full	05 - 13 Jan 2017	120	837
Tarrant	Fort Worth N.C.	CSTCS	13 Feb - 15 Mar 2017	24	504
Milam	Private Property	CSTCS	17 Mar - 18 Apr 2017	3	49
Milam	Private Property	CSTCS	16 Mar - 08 Apr 2017	3	56
Milam	Private Property	CSTCS	17 Mar - 18 Apr 2017	3	63
Colorado	Private Property	CSTCS	18 Mar - 09 Apr 2017	3	63
Navarro	Private Property	CSTCS	19 Mar - 09 Apr 2017	6	126

BIOGRAPHY

James Clinton Perkins III was born in Alexandria, Louisiana in 1983. He graduated from Rapides High School in Lecompte, Louisiana in 2002 and started casually attending Louisiana State University at Alexandria. Clint graduated in 2011, gaining research experience while conducting mesocarnivore habitat usage and small mammal diversity and abundance assessments.

After graduation, Clint worked a variety of wildlife technician jobs throughout the United States. He worked for the U.S. Fish and Wildlife Service in North Dakota, the Missouri Department of Conservation in Missouri, Utah State University in Utah, and Colorado State University in Louisiana. In 2013, Clint returned to Louisiana to work as the state Oil Spill Response Biologist for the Louisiana Department of Wildlife and Fisheries.

Clint was recruited to Angelo State University in the summer of 2015 to work on the plains spotted skunk project. While at Angelo State, he spent most of his time, either in office or in the field, working on this project. He was rewarded for this dedication by being able to travel and present at various professional meetings. While at ASU, Clint was able to present 8 first author presentations at meetings throughout the United States. When not working with skunks, he enjoyed collecting and preparing mammal specimens for the Angelo State Natural History Collections.

Clint does not have a permanent physical address; however, he can be reached at a permanent email address: jcplsua@gmail.com.