Spring 2023

Habitat associations and fine-scale movements of the Red-Spotted Toad (Anaxyrus punctatus) in Kansas and the efficacy of remote telemetry for monitoring small-scale movements

Elisabeth Russell
Fort Hays State University, ejrussell_29@yahoo.com

HABITAT ASSOCIATIONS AND FINE-SCALE MOVEMENTS OF THE RED-SPOTTED TOAD (*ANAXYRUS PUNCTATUS*) IN KANSAS AND THE EFFICACY OF REMOTE TELEMETRY FOR MONITORING SMALL-SCALE MOVEMENTS

being

A Thesis Presented to the Graduate Faculty
of Fort Hays State University in
Partial Fulfillment of the Requirements for
the Degree of Master of Science

by

Elisabeth Russell

B.S., Liberty University

Date 04/14/2023

Approved ______________________
Major Professor

Approved ______________________
Graduate Dean

This Thesis for

The Master of Science Degree

By Elisabeth Russell

Has Been Approved

Chair, Supervisory Committee

Supervisory Committee

Supervisory Committee

Supervisory Committee

Chair, Department of Biological Science

ABSTRACT

As climate change progresses, arid-adapted anurans might be particularly susceptible to population declines because of their reliance on ephemeral pools for successful reproduction. Because arid-adapted anurans are difficult to study due to short active seasons and cryptic lifestyles, little is known about their habitat preferences. One such arid-adapted species is the Red-Spotted Toad (*Anaxyrus punctatus*; RST), a Kansas Species in Need of Conservation. Since this designation in 1987, little research has been conducted to understand their conservation needs. During the summers of 2021 and 2022, RST surveys were conducted both near areas where the species has historically been observed in Clark, Comanche, and Barber counties, Kansas, as well as in areas just outside the border of their known range, including Kiowa County, Kansas. Automatic recording devices were deployed to detect signs of breeding activity. To understand finer-scale movement patterns, unmanned aerial sensing and developing telemetry techniques were combined to map RST movements. Excluding the RST observations at the telemetry site, 96 RST were observed across both summers. The majority of these observations were after sunset. Active toads were observed on gypsum outcrops. Calling RST were detected at five locations. The results of this study increase our understanding of the habitat associations of RST in Kansas and provide insights and recommendations for their conservation.

ACKNOWLEDGEMENTS

I first thank my advisor, Dr. Stark, for his support and enthusiasm of my earliest ideas and for his guidance throughout the development and execution of my project. I also thank Curtis Schmidt for adding his insights to my initial thoughts. He is missed. Thank you to Travis Taggart and to my graduate committee, Dr. Ambardar, Dr. Patrick, and Daren Riedle for their assistance in refining my ideas and my writing.

Thank you to Ethan Grennan, Colton Farra, and Cinthya Lechuga, my research assistants, for their dedication, energy, and hard work in the field. Thank you to those who were willing to step in when extra help was needed: Alec Zaborniak, Sandra Guzman, Allison Pardis, and April Green. I could not have done this without their help.

Thank you to Mackenzie Reh, Vinita Karki, Rob Penner, and The Nature Conservancy for assisting in the navigation of learning telemetry techniques and analysis.

I especially thank the myriad of landowners in Clark, Comanche, Barber, and Kiowa counties, Kansas, who allowed access to their lands. I particularly thank Roy Beeley, and Keith and Eva Yearout, Z Bar Ranch, and Turner Enterprises, Inc.

Thank you to the Kansas Department of Wildlife and Parks, the Kansas Academy of Science, and the Fort Hays State University Graduate School for funding my project.

There are so many others I must thank. Without their friendship and support I never would have excelled in graduate school. These include my fellow graduate students and the amazing community at Cornerstone Baptist Church. Thank you especially to the Green family for adopting me into their home. Thank you to my family, my parents and my siblings, for their unending support. Finally, thank you to the Maker of this world for the incredible ability to discover just a small sampling of the details of how it works.

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INTRODUCTION

Amphibians are the most imperiled class of vertebrates with at least 41% of species experiencing population declines. Habitat loss, fragmentation, and the effects of climate change are the most cited contributors to population declines (Alexander & Eischeid, 2001; Bartelt et al., 2004; Boeing et al., 2014; Hocking & Babbitt, 2014; Leeb et al., 2020). Other major threats include human-caused mortality, disease, UV-B radiation, pesticides, and pollutants (Ficetola et al., 2015; Hocking & Babbitt, 2014). The permeable skin characteristic of amphibians makes them particularly sensitive to environmental change. Accordingly, they are proposed frequently as "bioindicator species" – a proxy measure to assess the condition of a habitat or to track environmental changes over time (Boeing et al., 2014; Bradford et al., 2003; Saber et al., 2017).

As with the loss of any species, the loss of amphibians will cause declines in the ecosystem services they supply (Hocking & Babbitt, 2014). These services include functioning as a vital role in aquatic and terrestrial food webs, minimizing pest outbreaks, and reducing disease transmission, particularly from arthropods to humans. Among the other services they provide, many remain under- or unexplored. Researching this class of vertebrates will contribute to the understanding of the services they provide to human populations and will enhance the effectiveness of conservation practices.

Arid-adapted anurans might be particularly susceptible to population declines because they depend on ephemeral sources of water to reproduce, but the availability of these pools is predicted to decrease as climate change continues (Archer & Predick, 2008; Boeing et al., 2014). However, it is difficult to monitor arid-adapted anuran populations because individuals are typically cryptic and active only for short durations. Due to these challenges, the habitat preferences of these anurans are not well understood (Boeing et al., 2014; Kiesow & Griffis-Kyle, 2017). The Red-Spotted Toad (*Anaxyrus punctatus*; RST) is one such arid-adapted anuran.

RST have a distribution that extends eastward from southeastern California to western Oklahoma. The range continues south to Hidalgo, Mexico, and north into the southeastern quarter of Utah, parts of Colorado, and southwest Kansas. Kansas comprises both the northern and easternmost extent of their range (Jones et al., 2017). Within Kansas, the species is documented in four counties: Clark, Comanche, Barber, and Morton (Taggart, 2006). However, the specimen from Morton County was collected in 1927, and no toads have been documented in the area since. RST were likely extirpated from that county in the 1930s (Taggart, 2006). This species was listed as a Kansas Species in Need of Conservation in 1987.

The population of RST in the northern portion of Clark County is isolated from the contiguous population in western Barber and southeast Comanche counties (Taggart, 2006). The RST populations in Barber and Comanche counties are primarily in the Red Hills physiographic region and in the southernmost parts of the High Plains. Documentation of RST in Clark County is restricted to the area near Clark State Fishing Lake (Miller, 1983; Taggart, 2006).

There is a current need to understand amphibian terrestrial habitat in addition to their aquatic environment. For many amphibians, it is important for suitable aquatic habitat and terrestrial habitat to exist adjacent to each other because both these habitat types are necessary to support their biphasic lifestyle. For example, if suitable aquatic habitat exists in unsuitable terrestrial habitat, an amphibian is not likely to occupy that area (Annich et al., 2019; Pope et al,. 2000). However, the converse might not be true (Kiesow & Griffis-Kyle, 2017). Recent research has combined acoustic or visual encounter data with habitat data acquired via remote sensing to determine which factors are most meaningful in influencing habitat selection among toads

(Annich et al., 2019; Berlow et al., 2013; Boeing et al., 2014). Other researchers have used radio telemetry to obtain habitat preference data on a finer scale (Goates et al., 2007; Leeb et al., 2020).

Little research has been conducted on understanding the specific habitat requirements for RST, particularly in Kansas. Most of the information currently available is observational (Guarisco, 1981; Jones et al., 2017; Miller, 1983). No thorough investigation into habitat associations within the Red Hills physiographic region has been conducted. However, there has been some effort to understand RST breeding habitat selection in the Sonoran Desert in Arizona (Kiesow & Griffis-Kyle, 2017). Bradford et al. (2003) examined factors, such as elevation, terrain, and patch size, that might influence RST patch occupancy in the Mojave Desert, and Dayton and Fitzgerald (2006) constructed a habitat suitability model to predict where RST occurred throughout Big Bend National Park in Texas.

While RST finer-scale habitat associations are largely unknown, the coarse details have been delineated. RST typically inhabit rocky areas of arid and semiarid prairies, deserts, and canyons (Bradford et al., 2003; Miller, 1983). Bradford et al. (2003) reported these toads often occur in association with ephemeral pools. Throughout their range, they typically have a patchy distribution with each population consisting of a small number of individuals. Miller (1983) reported never finding more than twelve toads at any site in Kansas. RST might occur in higher abundances near areas where there is a higher density of potential breeding locations (Bradford et al., 2003; Griffis-Kyle et al., 2011).

Unlike most amphibians, RST are capable of living in extreme xeric environments, due in part to their ability to aestivate (Tevis, 1966). Additionally, they are able to use water stored in their bladders to delay dehydration and can tolerate losing up to 40% of the water stored in their bodies (McClanahan, 1994). Behaviorally, they reduce water loss staying hidden under rocks or within burrows during the day where it is cool and moist and emerge at night to forage and breed (Bradford et al., 2003; McClanahan, 1994; Weintraub, 1974).

In Kansas, RST have been collected from early April through early September (Taggart, 2006). Chorusing was reported from late May to late July and typically peaks within the first two weeks of June, but this is based on too few observations to provide much confidence (Taggart, 2020). In other portions of the range, RST breed as late as September and chorus as early as late February (Behler & King, 1979; Turner, 1959). RST are opportunistic breeders and typically mate after spring and summer rains (Bradford et al., 2003; Goldberg, 2016; Tevis, 1966; Turner, 1959). Both Turner (1959) and Tevis (1966) reported air temperature as a factor that initiated chorusing and mating, unlike in many other amphibians that respond to water temperature. Tevis (1966) reported these toads need an air temperature of at least 18° C to be active and that breeding activity does not commence until after air temperature reaches at least 24° C. Turner (1959) recorded breeding at a slightly cooler air temperature of 21° C.

RST require open water for successful reproduction. During the breeding season, males typically chorus along the edge of a stream or pool, without differentiating between high-quality and low-quality breeding sites. Rather, males appear to choose the most proximal location (Kiesow & Griffis-Kyle, 2017; Tevis, 1966; Turner, 1959). Females place their eggs in shallow, slow-moving water. Larvae hatch from eggs within approximately five days. The black-pigmented tadpoles take between four to eight weeks to metamorphose into adult form, and the size of the new adults can vary widely (Degenhardt et al., 1996; Tevis, 1966; Turner, 1959). Males mature within one to two years of metamorphosis and tend to trill along flowing water (Bradford et al., 2003; Tevis, 1966). Because of the specific conditions required for successful breeding, longevity might help this species persist (Tevis, 1966). In Arizona, the average age observed in an RST population was two years old and the maximum was six (Sullivan & Fernandez, 1999). Tevis (1966) reported finding some RST four years after they had been marked.

Dispersal distance is unknown; however, adults have been recorded to move between 0.4-0.8 km. The longer distance movements were along drainage channels (Tevis, 1966; Turner, 1959). Weintraub (1974) reported some RST were able to home after being displaced at least 900 m from where they were first observed. Bradford et al. (2003) suggests these toads are capable of traveling distances greater than 1 km based on their patchy occurrence and that frequent dispersal would be necessary to sustain these patches.

Adults appear to have home ranges (Tevis, 1966) and remain in the vicinity of their breeding pools (Bradford et al., 2003). However, Tevis (1966) did record some females wandering notable distances away from water. In other species of toads, males tend to stay nearer to breeding pools while females are more likely to use upland habitat (Goates et al., 2007).

Although RST were listed as a Kansas Species in Need of Conservation in 1987, there is currently no known population estimate of the species in Kansas. Habitat associations and what constitutes high quality habitat are poorly understood, particularly in the Red Hills physiographic region. Potential threats to this species in Kansas are agricultural runoff, gypsum mining, overgrazing, and encroaching red cedar (Taggart, 2006).

This study sought to fill some of these knowledge gaps. To identify areas of conservation priority, a habitat suitability model (HSM) was created. To determine the relative abundance of RST in southern Kansas, audio and visual surveys were performed throughout Clark, Comanche, Barber, and Kiowa counties. To elucidate finer-scale habitat preferences, 15 RST were tracked in June and July of 2022, using both manual and contemporary remote forms of radio-telemetry. Because female RST were expected to travel greater distances from water and to use upland habitat more frequently than males, sex was examined as a factor influencing movement and habitat use.

METHODS

Study Area

This study took place in Clark, Comanche, Barber, and Kiowa counties in south-central Kansas. The majority of the study occurred in the Red Hills physiographic region of Comanche and Barber counties. The area around Clark State Fishing Lake (CSFL) in Clark County and the southeast region of Kiowa County were also surveyed. The Blaine Formation, the exposed portions of which are gypsum, extends through Comanche and Barber counties. Kiowa Shale and Cheyenne Sandstone comprise the surface geologic formation around CSFL and southeast Kiowa County.

Agriculture, and to a lesser degree gypsum mining, are the primary sources of income in the study region. Most of the land is rangeland comprised of mixed-grass prairie. However, in some areas, the encroachment of Eastern Red Cedar (*Juniperus virginiana*) threatens the natural flora.

Habitat Suitability Model

To identify potential survey sites, a habitat suitability model (HSM) for the RST, modified from Dayton and Fitzgerald (2006), was produced in ArcGIS Pro (3.0.2). The raw data layers were downloaded from the Data Access & Support Center (DASC) Kansas Geoportal website. A slope layer was created using the National Elevation Dataset (NED) Elevation Raster with the slope tool in ArcGIS Pro. The USGS National Hydrography Dataset of Kansas Waterbodies was used as the lake and pond layer. Additionally, all the named waterways in the USGS National Hydrography Dataset of Kansas Flowlines were used in the waterway layer. For both water layers, Euclidean distance from water sources was determined.

The slope layer and the two Euclidean distance layers were reclassified based on rankings of habitat variables, e.g., steeper slopes and areas closer to water were given higher habitat suitability rankings (Table 1, Table 2, Table 3). These rankings were based on RST observations recorded in the literature and on the natural history of amphibians. Areas with steeper slopes had higher ranks because, in Kansas, RST occur in the Gypsum Hills, where the slope is steeper than in other regions of Kansas. Areas near water were ranked higher because RST require water to complete their lifecycle and are thought to have low vagility. The reclassified raster layers were multiplied, and the product was the score used to spatially represent the HSM.

To test HSM performance, georeferenced observations of RST in Kansas were downloaded from the Kansas Herpetofaunal Atlas and added to the HSM. A 500 m buffer was generated around each observation. This buffer distance was based on the RST movement data from Tevis (1966) and Turner (1959), indicating RST are capable of movements between 0.4-0.8 km. The mean and the majority pixel values of the HSM within each buffer region were used to confirm that RST observations did largely occur in higher ranked areas. Survey locations were selected based on the HSM values and proximity to historic records of RST. Sites with higher HSM values and sites closer to historic observations were given higher survey priorities.

Call Surveys

Call surveys were conducted during the summers of 2021 and 2022 to document potential RST breeding activity. During both summers, ten automatic recording devices (ARD) were placed across Barber and Comanche counties. Collection methods of audio recordings differed between the two summers due to equipment availability.

2021 Call Surveys

In the summer of 2021, call surveys were conducted using Olympus Digital Voice Recorders (DS-30/40/50 and Olympus DM-720) with an external microphone attachment. These ARD were set to record for ten minutes each of the first three hours after sunset (2100-2110 hours, 2200-2210 hours, and 2300-2310 hours). The Olympus DS-30/40/50's had their recording mode set to ST XQ and the microphone set to conference. The DM-720 recording mode was set to MP3, 320 kpbs, and the recording level was set at 'middle'.

ARD were placed in the field in a temporally staggered fashion throughout the month of June as resources became available. The first ARD was placed in the field on June 8, 2021. A second ARD was deployed on June 11. Two more ARD were deployed on June 14, and another five were deployed on June 15. The last recorder was set up on June 29, 2021. Locations were adjusted and ARD were removed as necessary due to technical failures or a lack of water.

ARD were placed in areas where there had either been a confirmed RST observation or where RST presence was likely but had not yet been confirmed. They were placed near standing water or near areas where ephemeral pools were considered likely to form.

Because these ARD were not designed for outdoor use, they were wedged into PVC pipe using insulating foam. The microphone was positioned downward, toward the open end of the pipe, and the foam was positioned so as not to cover the microphone. The PVC pipes were strapped to woody vegetation using zip-ties. ARD maintenance occurred periodically throughout the summer. All ARD were removed from the field by July 27, 2021.

Audio files were processed with Kaleidoscope Lite Analysis Software from Wildlife Acoustics. Each spectrogram was visually scanned for RST calls. Segments containing suspected anuran calls were manually evaluated to confirm species identification.

In addition to the ARD, in-person call surveys were conducted on five occasions. In-person call surveys were conducted after sunset with a parabolic microphone dish. After waiting for three minutes in silence at the call survey location, the microphone was turned on and the dish was used to scan the area for five minutes. At most of the sites, a recorded RST call was played from a speaker for one minute prior to conducting the survey. After the call was played, there was a three-minute waiting period before the parabolic microphone was used to scan the area for any calls.

Between two to four sites were visited each night. Additionally, while driving between call survey sites, roads where calling had been historically reported were driven along slowly with the windows rolled down in case any RST calls could be heard from the road. All call surveys, except for one, occurred one to two days after a rain event. Call surveys were not conducted during or immediately after rainfall due to poor road conditions. The call survey that was not conducted shortly after rain was performed following visual encounter surveys.

2022 Call Surveys

During the summer of 2022, ten Song Meter Micro ARD from Wildlife Acoustics were used to detect RST calling activity. The ARD were on default setting and recorded for five minutes every half hour from sunset to sunrise. All ARD were placed in the field between May 26 and June 3, 2022. They were zip-tied to fiberglass poles positioned near standing water where RST had previously been observed or where they were predicted as likely to occur. ARD batteries and SD cards were replaced periodically throughout the summer. The ARD were removed from the field between July 25 and July 27, 2022.

Audio files were processed with Kaleidoscope Pro 5.4.6 from Wildlife Acoustics using a simple cluster analysis. The program was trained to identify the calls of RST, Woodhouse Toads

(*A. woodhousii*), and Great Plains Toads (*A. cognatus*) using at least three different audio clips of each species calling. These audio clips were downloaded from YouTube. Audio files marked by Kaleidoscope Pro as containing anuran calls were checked manually.

Visual Encounter Surveys

To further determine RST spatial distribution, relative abundance, and habitat use, visual encounter surveys (VES) were conducted across Comanche and Barber counties, May through July of both 2021 and 2022. Clark and Kiowa counties were surveyed for RST presence in June and July 2022.

Because RST are nocturnal, surveys were usually conducted during and after sunset. However, five surveys were conducted during the day. At sites in Barber and Comanche, there were few movable objects in the landscape, so the exposed portions of the gypsum were the primary search habitat. In Clark and Kiowa counties, rocky hillsides and fields were searched because gypsum outcrops were absent, and more rock coverage could be manipulated.

At the start of each survey, temperature in degrees Celsius and relative humidity were recorded using a Kestrel 5000 Environmental Meter. During surveys in 2022, wind speed was recorded. Additionally, in 2022, GPS tracks were turned on to record the survey path. When a toad was located, the standard measurements of sex, snout-vent length (SVL), and mass as well as the GPS coordinates and time of capture were recorded. Behavioral activity was recorded as “active”, “sitting”, or “hiding”. Non-target herpetofauna species observed during a survey or along the road while driving between sites were documented, and the GPS coordinates were recorded.

Telemetry

In 2022, radio-telemetry was used to assess movement of RST within a 20-ha site in Comanche County. The telemetry site was chosen because a high number of RST were observed in and near the area in 2021. The site occurred within grazed rangeland and had a southwesterly facing gypsum bluff with a permanent creek running along the base (Figure 1).

Fifteen small (0.35 g) radio-transmitters or tags (PowerTags from Cellular Tracking Technologies (CTT)) were deployed: five tags had a beep rate of once every 10 seconds and were expected to have a battery lifespan of 16 days; five tags had a beep rate of once every 20 seconds and were expected to have a battery lifespan of 32 days; and five tags had a beep rate of once every 60 seconds and were expected to have a battery lifespan of 97 days.

Harnesses were fashioned from a single loop of Stretch Magic Cord. Cord diameters of 0.5 mm and 0.7 mm were both used, depending on what was on hand at the time. Superweld Light Activated Instant Glue was used to glue harnesses to the back of the tag. Light activation allowed for quick dry times and minimized handling time. The tags, combined with the harness, weighed approximately 0.41-g. As recommended by Richards et al. (1994), total weight of the tag and belt never exceeded 10% of body weight and, for the majority of RST, consisted of less than 5% of body weight.

Tags were deployed in a temporally staggered fashion starting on June 2, 2022. Telemetry was conducted during the evening, beginning around sunset and continuing, if possible, until all toads with active signals had been located. At the start of each session, temperature, relative humidity, and wind were recorded with a Kestrel 5000 Environmental Meter. When a toad was located, the time and GPS coordinates were noted. By July 1, all tags had been deployed. The study ended on July 19 when no transmitter signals were detected by the CTT Locator after thirty minutes.

In an attempt to gain further information regarding the movements of the RST, a series of 10 radio-receivers or nodes (CTT Node, Version 2.0 with GPS) were deployed within the telemetry site. Because toads typically were encountered on the exposed portion of the gypsum hills, nodes were placed in an uneven grid along the slopes and tops of the gypsum hills. Nodes were placed between 100 - 200 m apart, with one exception. In the middle of the grid, two nodes were placed within 50 m of each other due to a hill blocking line-of-sight signal transmission.

A CTT SensorStation (Version 2.0) antennae array was installed 870 m from the most distant node on May 28, 2022. It was sited on a ridge west of the node array so that all nodes were within line-of-sight of the antennae array and could transmit data to the station. Due to supply-chain issues, the SensorStation was not installed until June 30, 2022. On this date, it was noticed that three nodes had failed. Two of these nodes were replaced by operational nodes the same day. However, the third node was not replaced until July 6. The SensorStation and arrays were removed at the end of the season on July 27, 2022.

On June 3, a Kestrel 5000 Environmental Meter was installed at the SensorStation and was set to record weather data (temperature in degrees Celsius and relative humidity) every 6 hours at the telemetry site until the array was removed on July 27.

On July 26, the node array was calibrated to establish a relationship between receiver signal strength (RSS) and distance. The methods used were similar to that described by Paxton et al. (2021). Due to the hilly terrain, each pair of nodes, excluding the nodes placed within 50 m of each other, were calibrated with a tag (CTT LifeTags). The tags, which emitted a signal every 2 seconds, were held stationary for 5-minute intervals starting at a ground-distance of 20 m from a node. After 5 minutes, the tag was moved another 20 m away from the starting node and toward an adjacent node in the array. Tags were held at ground-level and were periodically rotated to alter antenna angle.

The three nodes on the south edge of the grid and the two outer nodes in the center grid row were also calibrated in directions extending away from the grid center. Rather than the tag being placed between two nodes, it was carried outside and perpendicular to the grid at distances of 20 m, 40 m, and 60 m. The two corner nodes were calibrated in both directions that extended away from the grid.

Telemetry Analysis

Remote telemetry data was analyzed in R using the functions written by CTT. An exponential decay model was built using the known locations from the calibration data:

$$avgRSS = -a * exp(-S * distance) + K$$

where avgRSS is the average receiver signal strength, a is the intercept, S is the decay factor, and K is the horizontal asymptote.

The first and last minute of each known location was discarded from the calibration data prior to analysis to account for relocating the tag within that time frame. The node-distance relationship was averaged for all nodes, and differences between individual nodes were not accounted for. The result was a single equation that estimated, when possible, the locations of the tagged toads.

When using the signal data from the tags on the RST, RSS values were averaged over 10-minute time frames to minimize the signal variation caused by signal bounce and antenna orientation. Locations were triangulated only when three or more nodes were detecting a given tag and when three or more RSS values were greater than -100.

Where possible, home ranges, using RST locations gathered by the handheld receiver, were determined by minimum convex polygons (MCP) and maximum linear Euclidean distances between the two most distant points a toad traversed while tagged were estimated in ArcPro.

A DJI Phantom 4 Pro was used to map the telemetry area. The flight was planned with the Pix4D iPad Application. On July 6 and 7, 2022, between 1000 hours and 1300 hours, a single grid (653 m x 758 m) automated flight captured imagery with a ground-sampling distance (GSD) of 0.95 cm/px. The camera angle was set to 90°. Front and side image overlap were 75% and 60%, respectively. An orthomosaic was produced by stitching the captured images in ERDAS IMAGINE 2022.

RESULTS

Habitat Suitability Model

Each pixel in the HSM raster represented an area of 31 m^2 and had a unitless value between 1 and 1,000. Higher values represented areas with steeper slopes and areas closer to permanent or semi-permanent sources of water (Figure 2). Within the 500 m buffer around each historic RST observation, 87.7% of these zones (57 out of 65) had mean HSM values greater than 500 (Figure 3), and 86.2% of all historic RST observations (56 of 65) occurred in areas where the majority (> 50%) of the HSM pixel values were 700 or greater (Figure 4). Only eight locations had mean HSM values of 500 or less, and five had majority HSM values of 300 or less. At VES sites in 2021 and 2022, there was no difference in the HSM mean or majority values for sites where RST were observed or where they were not (Figure 5).

Call Surveys

2021 Call Surveys

In 2021, a total of 197.27 hours of audio were recorded, and no RST calls were documented. At 5 of the 11 sites, Blanchard's Cricket Frogs (*Acris blanchardi*) were detected calling. At 3 of the 11 sites, American Bullfrogs (*Lithobates catesbeianus*) were detected calling. At all sites where *L. catesbeianus* was detected, there were also *A. blanchardi*. These species called nearly daily throughout the summer. At one location in Barber County, Western Narrow-mouthed Toads (*Gastrophryne olivacea*) were detected calling between June 26-30, 2021. This event occurred after several days of rainfall in the area.

In some cases, recordings contained a lot of background static that made it difficult to detect anuran calls. Additionally, over half of the recorders failed to consistently record when scheduled. Occasionally, even if they did record when scheduled, they did not record for the full ten minutes. Recorder failure increased as the summer progressed.

No RST calls were documented by in-person call surveys conducted on the nights of June 14, June 28, June 29, July 26, and July 27, 2021. June 14 was the only call survey conducted immediately following a VES. It was also the only call survey that did not occur one to two days after a rain event. The most proximal rain event occurring before the June 14 call survey took place on June 3, 2021, in Barber County. The June 14 surveys were also the only call surveys where a recorded RST call was not played from a loudspeaker prior to the survey start. At two survey locations on June 28 RST calls were not played from a loudspeaker prior to the survey due to technological problems.

2022 Call Surveys

In the summer of 2022, a total of 900.25 hours of audio were recorded. RST were detected by ARD at 2 sites. RST calling was recorded by the ARD between May 27-29 and June 5-9.

One of the ARD locations where RST were detected had also been used as an ARD location in 2021. At this site, the ARD was located near a stream flowing into a permanent, man-made pond. Short gypsum hills ran along either side of the stream and encircled the pond. A faint RST call was detected at this site by the ARD on June 6. Although a VES was conducted at this site in both 2021 and 2022, no RST were observed. Woodhouse's Toads (*Anaxyrus woodhousii*) calls also were detected by the ARD at this site on the same evening. Other species detected at this site were Plains Leopard Frogs (*Lithobates blairi*), *L. catesbeianus*, and *A. blanchardi*. However, *L. blairi* were not detected calling at this site until July. Additionally, no tadpoles were observed in the water at this site.

The second ARD site where RST were detected was located beside a semi-permanent, somewhat shallow, spring-fed pool lying at the bottom of a small canyon. A pile of dead cedar trees was next to the pool. RST chorusing was detected from May 27-29 and June 5-9. *A. woodhousii* were also detected calling during this time. Other species documented were *L. blairi*, Spotted Chorus Frogs (*Pseudacris clarkii*), and *G. olivacea*. All these species had overlapping calling dates with the RST and *A. woodhousii*. *L. blairi* called intermittently throughout the entire summer at this site while *P. clarkii* were only detected in late May. *G. olivacea* were heard calling from June 2-12. *L. blairi* tadpoles were observed at this site on June 20, but no tadpoles of other species were observed.

On three occasions, RST were heard calling during VES (Figure 6). Two of these calling events occurred on June 8. One of these events was at the telemetry site and consisted of a single toad calling intermittently along the permanent stream running between the gypsum hills at about 1845 hours when the air temperature was near 26.7°C. The same evening, 16 RST were encountered, and chorusing was reported during a night survey on Z Bar Ranch (Diedre Kramer KDWP, pers. com). The survey occurred along the tops of the gypsum hills and chorusing emanated from a shallow spring-fed stream flowing at the base of the hills.

Subsequently, on June 26, both locations were searched for evidence of RST tadpoles, but none were observed. Also, on June 26 at approximately 2100 hours a single RST called intermittently at Alexander Ranch when the air temperature was approximately 20.3° C. The call emanated from the area around a small pool within a permanent stream flowing alongside the gypsum hills. All documented RST calling activities in 2022 were associated with over 1.5 inches of cumulative rainfall during the 5 days prior to the event (Figure 7).

At 7 of the 10 ARD sites, *A. blanchardi* were detected. At 6 sites, *L. catebeianus* were detected. These species were recorded intermittently throughout the entire summer. Many of the sites where these two species were detected overlapped.

A. woodhousii, *P. clarkii*, and *G. olivacea* were each recorded at 4 sites. Only some of these sites overlapped between these three species. *G. olivacea* were detected in late May, periodically throughout June, and into the first week of July. *A. woodhousii* were detected in late May and early June. *P. clarkii* were detected in late May and periodically throughout June. *L. blairi* were detected at 7 sites and called intermittently throughout the summer. A single call of a Plains Spadefoot (*Spea bombifrons*) was detected at one location on May 27. Dates of anuran calls recorded at specific locations are listed in Appendix A.

Visual Encounter Surveys

A total of 39 VES were conducted across the 4 counties comprising the study region. Twenty-one VES were conducted in 2021, and 18 VES were conducted in 2022. Three VES were conducted in Clark County around the CSFL area, and three VES were conducted in Kiowa County. Twenty-three VES were conducted across Barber County. Two of the sites in Barber County were surveyed twice, once in 2021 and once in 2022. Ten surveys were conducted in Comanche County. One of the sites was surveyed twice, once in 2021 and again in 2022.

RST were encountered on 13 VES, and none were encountered in Clark or Kiowa counties. RST were encountered at 7 sites in Comanche County and at 5 sites in Barber County. At one of the double-surveyed sites in Barber County, RST were encountered on both occasions (Figure 8).

All VES, except for 5, started near sunset and continued until after dusk. Of the daytime VES, 3 of them occurred close to, but prior to, sunset. The other 2 took place beginning around

1330 hours. Mean VES length was 1.86 hours. The shortest VES was 0.67 hours, and the longest VES was 4.08 hours. Excluding the 5 daytime VES, searches extended for 1.64 hours after sunset on average. The minimum length of time searched after sunset was 0.67 hours and the maximum length of time searched after sunset was 4.08 hours. A total of 72.10 hours were spent surveying for RST in the field: 42.33 survey hours in 2021 and 29.77 in 2022.

Of the 5 daytime VES, only 1 RST was encountered. At a site in Comanche County on June 8, 2021, during midday, a female RST with a missing left rear foot was encountered underneath a rock near the top of a gypsum hill. On May 19, 2022, this same female RST was encountered at the same location, underneath the same rock. Another daytime VES occurred June 17, 2021, in Barber County, ending three minutes after sunset, approximately one hour after the survey began. A daytime VES in Kiowa County began near 1930 hours on June 5, 2022, but was cut short due to weather. This site was resurveyed after sunset on June 28, 2022. Two VES in Clark County (June 1 and June 7, 2022) were conducted during the daytime due to difficult site accessibility and a higher volume of rock that was available to manipulate.

A total of 167.36 hours of search effort was expended on surveys in 2021 and 2022: 78.26 hours in 2021, and 89.1 hours in 2022. Catch per unit effort on VES was 0.32 toads encountered/person-hour. On average, it took 1.67 hours of search effort to encounter the first RST at a given site. When no RST were encountered, an average of 3.94 hours of search effort was expended (Figure 9). RST were typically first encountered 1.06 hours after sunset (Figure 10). However, RST were encountered as soon as 41 minutes after sunset. The longest time to encounter an RST after sunset was 1 hour and 29 minutes.

A total of 96 RST were encountered between 2021 and 2022, contrasted with the 68 RST encounters reported from 1933 - 2020 in Kansas (Kansas Herpetofaunal Atlas; Figure 11).

Thirty-nine RST were encountered in 2021, and 17 RST were encountered in 2022. The Kansas Department and Wildlife and Parks (KDWP) encountered 40 RST during their surveys in Barber and Comanche counties in 2022. A list of the number of RST encountered during each survey is in Appendix B.

The perceived sex ratio of females to males was 1.17, including the toads from the KDWP surveys. Nine toads were classified as juveniles and were not sexed. The mean mass of RST encountered was 10.1 g and mean SVL was 46.2 mm, including the 9 juveniles.

Surface-active RST were typically encountered on the exposed gypsum near the crest of the gypsum cliffs. Often, the RST were near the edge of the cliffs, but some were encountered on larger gypsum flats, several meters away from the cliff edge. No RST were encountered in grassy areas. Other herpetofaunal species encountered in Clark, Comanche, Barber, and Kiowa counties are listed in Appendix C.

Telemetry

Manual Telemetry

On June 2, 2022, five radio-transmitters or tags were deployed on 5 RST. Three had a beep rate of once every 20 seconds and two had a beep rate of once every 60 seconds. All 5 tags were recovered over the next two evenings at the entrances of crevices in the gypsum because the harnesses had been fitted too loosely around the toads. One of these tags was redeployed on a male on June 3. The other four tags were redeployed June 4. Two were attached to males and the other two to females. Another four tags were deployed on June 15, using two females and two males. These tags all had beep rates of either 20 or 60 seconds. Two days later, one of the tags from a male was recovered near a gypsum crevice. This tag was redeployed the same evening on another male toad. On June 27, three female toads and two male toads were tagged with the 10 second beep rate transmitters. Then, on July 1, the final tag, which had a beep rate of 20 seconds, was deployed on a female toad.

The telemetry site was visited 21 times between June 2 and July 19. On July 19, no transmitter signals were detected by the handheld receiver. It was assumed that toads with expected active transmitters had burrowed too far underground for the receiver to detect the signals and that the remaining transmitter batteries had died.

Seventy-eight surface active RST were documented at the telemetry site, excluding survey efforts in 2021 (Figure 12). A total of 59.47 hours (178.45 hours of search effort) were expended at the telemetry site tagging and locating toads. Catch-per-unit effort at the telemetry site was 0.44 toads encountered/person-hour. Perceived sex ratio of females to males at the telemetry site was 1.53. Typically, more females were encountered active on the surface than males (Figure 13). Other herpetofaunal species encountered are listed in Appendix D.

RST were tracked between 4-39 days. RST fitted with a 60 second beep rate transmitter were tracked for a mean of 29 days. RST fitted with a 20 second beep rate transmitter were tracked for a mean of 15 days, and RST fitted with a 10 second beep rate transmitter were tracked for a mean of 13 days. Ten of the 15 RST were detected 6 or more times, but this value ranged from 0-15 (Table 4).

Of the 15 tagged RST, only one of them (TagID: 61782A55) was recorded active on the surface after being tagged. This female was observed active on two occasions. On June 7, she was seen hopping along the side of the gypsum cliff. This observation took place after rains had occurred several days that week, including the night previous. On June 27, she was observed emerging from a gypsum crevice. By this time, her transmitter battery had died, so she was weighed and measured to confirm her identity and released from the tag. This observation took place after approximately 0.5 inches of rain the night prior, and there had been some rain on several days earlier that same week.

Three other RST were visually observed hiding in burrows (TagIDs: 33074B2A, 7866332A, and 2D19331E). On June 4, a male (TagID: 33074B2A) was observed hiding in a gypsum crevice along the south side of the cliff. Another male (TagID: 7866332A) was observed inside a burrow with the transmitter antenna protruding from a gypsum crevice on the lower slope of the south cliff face. He was observed on all dates he was detected (June 29, July 1, and July 6). After July 6, the signal was lost. He either moved burrows after this date, burrowed deeper into the rock, or the transmitter failed, because he was not detected inside the burrow again.

On June 27 and June 29, a female RST (TagID: 2D19331E) was observed inside her burrow. She was inside of a gypsum crevice on the east side of the cliff, about halfway up the slope. No other toads were visually observed after tagging.

Of the 7 tagged males, one of them was never detected (TagID: 3355332A). Three of the male RST moved less than one meter from the entrance of the burrows where they were first located (TagIDs: 1E1E6634, 522A4C61, and 7866332A). Two of these males (TagIDs: 522A4C61 and 7866332A) were inside their burrows each time they were located. Male 1E1E6634 did make minor vertical movements along the west cliff face, in the upper, nearly vertical region of the wall. There were many crevices contained in this section of the cliff.

Three of the male RST (TagIDs: 4C07E52, 612A5234, and 33074B2A) did relocate burrows several times throughout the season. Male 4C07E52 was documented at 4 different burrow sites within a 10.1 m^2 area. The farthest straight-line distance between the points where he was located was 5.22 m. On June 8, this male and a tagged female (TagID: 34662A2A) were located inside the same burrow. On June 13, the male had relocated burrows. The entrance of the burrow was not evident, but the signal emitted from under the gypsum rock on the top of the cliff. This male moved burrows two more times (June 15 and June 17). On June 15, he was underground beneath a patch of grass, and on June 17, he remained underground and had moved underneath a smaller grass patch. He was not recorded moving locations after June 17. The transmitter lost signal on July 13.

Male 612A5234 was documented at 3 different burrow sites within a 50.29 m^2 area. He was first located in a burrow on June 29, about halfway down the south facing slope. By July 6, he had moved approximately 6 m south and was encountered in another gypsum burrow. Between July 6-8, he moved west 16.49 m straight-line distance, to another gypsum crevice. There was a small amount of rainfall, approximately 0.04 inches, on July 7. He was not recorded moving after this date, and the signal was lost on July 11.

Male 33074B2A was located at 4 different burrow sites. He was first encountered on June 3 underneath a gypsum rock beneath a cedar tree near the bottom of a south-facing slope. Here, he was retrieved, tagged, and returned to his initial location. On June 4, he was visually observed hiding in a crevice higher up on the south side of the cliff. Then, on June 8, he was located across the creek on the opposite gypsum ridge facing north, along the upper portion of the wall. This location was approximately 138.64 m straight-line distance from his previous burrow. He made this larger movement during a week of frequent rains. Between June 2-8, there was rain every evening, except for June 5. Total precipitation was approximately 1.89 inches. Between June 13-15, he moved downslope into a thick cedar grove where there was an exposed portion of gypsum rock containing many crevices. He remained there until the signal was lost on June 19 (Figure 14).

Eight female RST were tracked during the study. One of these females (TagID: 554C4B2A) was located only one time and was excluded from analysis. She was located underground at the top of the south cliff face under a small patch of vegetation. Another female (TagID: 34662A2A) was only located twice. The first time she was located (June 7) she was underground on the top of the cliff, and the second time, on June 8, she was sharing a burrow with male 4C07E52. This burrow was 24.47 m straight-line distance from the first location.

Two female RST (TagIDs: 192D6178 and 522D612D) did not relocate burrows. Female 192D6178 occupied a burrow along the west cliff face. Female 522D612D was first observed hopping along the top of the west cliff on July 1. On July 6, she was located in a burrow on the top of the gypsum cliff, 29.42 m straight-line distance from her initial location. No burrow entrance was visible. She was located there on two more occasions (July 8 and July 10) before the signal was lost.

Four female RST (TagIDs: 1E552D33, 332D4B33, 61782A55, and 2D19331E) did relocate burrows at various times throughout the season. Female 1E552D33 was located in 2 different burrows. She was first located on June 29 inside a crevice along the west cliff face but by July 1, she had moved toward the top of the cliff and remained underground, staying near the same region until the transmitter signal was lost after her last recorded location on July 11. Because her movements were vertical, no measurements were made.

Female 332D4B33 was located in 4 different burrows within a 396.39 m^2 area. She was first located on June 17 underground in a part of the gypsum where many crevices were present. On June 19, she was located underground, beneath a patch of vegetation, approximately 2.84 m from the first burrow. Between this date and June 25, she moved west 42.08 m and was located inside a clay crevice. It rained approximately 1.12 inches between June 22-23, with over an inch of total rainfall occurring on June 23. Between June 29 and July 1, she moved north 13.43 m and was located underground along the southwest of a hillside. Her exact location could not be determined, and the signal was lost after this date.

Female 61782A55 was tagged on June 4. She was detected in 7 burrows within a 91.16 m^2 area. She was first located June 6 in a gypsum crevice. Later, on June 7, she was observed active along the side of the gypsum cliff. On June 8, she was detected in a different gypsum crevice. By June 13, she had relocated to an area underground where no burrow openings were evident. By June 15, she relocated again, still underground, near a grass patch. June 17, she was located underground underneath a different patch of grass. By June 19, she had moved again, seemingly deeper underground within the gypsum cliff face. The signal was subsequently lost. However, on June 27, she was observed emerging from a burrow on the top of the gypsum. After her body measurements were taken to confirm her identity, her transmitter was removed. Although her transmitter had flipped onto her stomach, no abrasions from the transmitter or harness were observed on her body.

Female 2D19331E was located in 8 different burrows in a 40.43 m^2 area. She remained in the vicinity of the southeast portion of the cliff wall about halfway up the slope. This toad was tracked from June 15 - July 13. Initially (June 17), she occupied an area underground beneath a grassy thicket. June 19, she moved but remained underground. By June 25, she had moved beneath a bush, continuing to remain underground. June 27, she moved into a gypsum crevice and was visually observed. She was visually observed again on June 29 in the same crevice. By July 1, she had moved to an area underground where no burrow entrances were evident. She changed burrows on both July 10 and July 11. By July 13, she had relocated back to the grassy area near where she had first been located. The signal was lost after this date (Figure 15).

MCP home ranges were determined for 6 RST, 3 males and 3 females. Home ranges ranged between 10.10 m^2 and 2,957.01 m^2. The maximum Euclidean distance traveled by toads was determined for 8 RST, 3 males and 5 females, and ranged between 5.22 m and 156.77 m (Table 5, Figure 16).

Remote Telemetry

The exponential decay model used to estimate the unknown locations of the tagged RST with transmitter to node RSS values was

$$avgRSS \sim -53.08 * exp(-0.03164 * distance) + -102.60$$ (Figure 17)

Locations were estimated for 6 of the 15 RST (Figure 18, Figure 19). The location estimated error ranged from 13.16 - 309.52 m. Mean location estimated error was 57.21 m. 91.62% of the estimated locations had estimated errors falling between 25 - 75 m.

DISCUSSION

Habitat Suitability Model

Although the HSM only included coarse habitat details, it accurately described where historic RST observations occurred. Eighty-six percent of historic RST observations were in areas where greater than 50% of pixel values within a 500 m buffer around the location was 700 or greater compared to 43% of all historic RST observations occurring in areas where the mean of the pixel values inside the buffer was 700 or greater. Thus, majority pixel values within a 500 m buffer around an RST observation better described RST habitat than the mean pixel value within the buffer. Of the 5 historic RST observations where the majority HSM values were less than 300, one was located along the edge of a high value location, and the other four were located along waterways between high value areas. While the area in a 500 m radius around the observation had a majority HSM value less than 300, the coarse habitat requirements containing high HSM values were still within the estimated 1 km movement range of RST (Bradford et al., 2003). Although RST have not been observed moving as far as 1 km, other species of toads have been documented migrating up to 2.6 km, and some toads are capable of moving even greater distances (Muths, 2003; Sinsch, 1992; Thompson, 2019). Despite RST occasionally being encountered in areas considered as less suitable by the HSM (pixel values of < 500 majority in the 500 m buffer around the observation), all toads were still well-within travel distance of the coarse details of their terrestrial habitat as judged by the HSM.

In Barber and Comanche counties, Kansas, RST are largely associated with the Red Hills physiographic region in local areas with steeper slopes. Proximity to water was an accurate predictor of suitability because amphibians have low vagility compared to other groups of organisms and need access to water to complete their life cycles. However, there is likely more water in the landscape than was included in the HSM because ephemeral pools and some of the natural springs were not mapped, but these are important amphibian breeding habitats because they lack carnivorous species, such as fish and bullfrogs, that require permanent water.

Although the coarse scale HSM performed well in describing where RST had historically been encountered, RST were only encountered at 33% of VES locations, despite there being no difference in mean or majority pixel values of the 500 m buffers surrounding VES sites. Incorporating other habitat variables into the HSM might refine the model to better serve as a tool to identify areas of conservation priority for this species. For Barber and Comanche counties, the boundaries of the Blaine Formation might be important. For the entire RST range in Kansas, factors might include available rock cover and refining the water layer to include ephemeral pools and shallow springs. Soil type, although largely the same in the region surveyed, might also be an important factor and thus might play a role in their specific distribution (Baumberger et al., 2019; Dayton et al., 2004; Dayton and Fitzgerald, 2006; Riddle & Bateman, 2020). However, GIS layers containing this fine-scale information might not be available, so closely examining satellite images and ground-truthing locations are important next steps in identifying areas of conservation priority (Goates et al., 2007).

Call Surveys

No RST calling activity was documented in 2021. However, because there were only three 10-minute recordings each night and many occasions on which ARD failed to record, detection was limited. Additionally, background static in the audio files decreased my ability to detect and identify RST calls.

In 2022, the use of Song Meter Micro ARD improved audio quality and consistency in recordings and allowed for more frequent recording times. Six RST calling events were recorded, three of which were chorusing events. All calling events fell within the reported range of RST calling activity in Kansas (Taggart, 2020) and were associated with at least two consecutive days of rainfall prior to the event. This suggests that multi-day rain events accruing at least 1 inch of total rainfall are necessary to stimulate breeding activity. This observation seems to be consistent with the observations of Sullivan and Fernandez (1999). However, the first documented RST chorus occurred on the same evening that the ARD was deployed in the field (May 27), so it is possible RST were calling at this site earlier and prior to rain events.

On the two occasions when air temperature was measured at a site where an RST was heard calling during a VES, air temperature measurements agreed with Turner's (1959) observation that RST call at temperatures near 21°C. However, Turner (1959) was reporting mean daily temperature, rather than air temperature at the time of calling.

It appears RST prefer to breed in shallow ephemeral or semi-permanent streams and pools at the bottom of gypsum canyons. Both sites where chorusing events did occur took place in shallow, spring-fed waters in gullies surrounded by gypsum hills. Miller (1983) also reported several chorusing events, with breeding aggregations typically consisting of less than a dozen individuals and occurring in shallow pools or streams at the bottom of canyons. Knight et al. (1972) reported hearing several RST calling from within crevices along the gypsum walls.

In 2021 and 2022, no eggs or tadpoles were observed at locations where RST were heard calling, but it might be possible RST had already metamorphosed by the time the pools were examined for tadpole presence (Rausch, 2007). However, this is not too surprising because neither Miller (1983) nor Knight et al. (1972) observed RST eggs or tadpoles in Kansas, although Knight et al. (1972) did find RST in amplexus. In other parts of the RST range, Tevis (1966) reported finding eggs and tadpoles, but due to the rapid drying of a canyon stream, few individuals reached metamorphosis. Neither Turner (1959) nor Sullivan and Fernandez (1999) observed RST oviposition or tadpoles. However, Sullivan and Fernandez (1999) did report indirect evidence of successful RST reproduction, likely from a breeding location near their study site. Sullivan (1984) reported encountering chorusing males but observing few females near breeding aggregations.

In a histological examination of the ovaries of 19 female RST from a natural population located in Riverside County, California, some level of follicular atresia was observed in every specimen, indicating lower fecundity (Goldberg, 2016). Whether this observation can be extrapolated to other parts of the RST range needs further study, but lower fecundity combined with their opportunistic breeding behavior and small breeding aggregations (Miller, 1983; Sullivan, 1984; Sullivan & Fernandez, 1999) might explain some of the difficulty in documenting eggs and tadpoles.

On the three occasions when RST were chorusing, *A. woodhousii* called on the same evenings. The report of this specific mixed species chorus is not unique. These species were rarely encountered at the same locations during surveys in 2021 and 2022 perhaps because of apparent local preference of *A. woodhousii* for lowlands and RST for rocky canyons. However, Miller (1983) observed a male RST in amplexus with a female *A. woodhousii*, and natural hybrids between the two species have been reported (Malmos et al., 1995; McCoy et al., 1967). RST calls also overlapped with *L. blairi*, *P. clarkii*, and *G. olivacea*. Sullivan and Fernandez (1999) documented a mixed species chorus involving RST, the Colorado River Toad (*Incilius alvarius*), the Great Plains Toad (*A. cognatus*), and Couch's spadefoot toad (*Scaphiopus couchii*). Though, there is some indication RST might avoid calling with other species of spadefoot toads (Guarisco, 1981).

Based on the 9 juveniles encountered during the 2022 VES and the continued presence of the RST population in Kansas, there is clearly successful RST breeding in the area despite the paucity of observations. This lack of direct observation might be due to the remote nature of their chorusing locations and lack of access to private lands. The pattern of patchy rainfall in the Red Hills might also present a challenge when searching for RST breeding aggregations because one region might receive sufficient rainfall to stimulate breeding activity, but the surrounding regions might not. Additionally, RST chorusing might be difficult to detect due to mixed breeding aggregations where the calls of *A. woodhousii* mask the calls of RST. Finally, during drought years, RST might not engage in breeding activity.

In summary, there are few observations of RST male chorusing activity in Kansas, and no published reports investigating RST reproduction in Kansas. The few reported chorusing events in this study do agree with what has been previously described in the literature. However, there have been few studies investigating female response to male chorusing or examining breeding success in this species. Most of the observations surrounding RST breeding are discouraging. It is necessary to conduct studies examining RST breeding ecology more thoroughly, particularly because amphibians are undergoing a worldwide decline. With a changing climate creating potentially fewer breeding opportunities for this and other arid-adapted anurans, understanding current recruitment is important. Although successful breeding must be occurring in Kansas, it might be necessary to implement management strategies that would increase RST breeding success.

Visual Encounter Surveys

During VES, RST were observed in Barber and Comanche counties within the central core region of their distribution as delimited by the localities in Figure 8. No RST were encountered in Clark or Kiowa counties or along the margins of their historic range. However, most survey sites were searched only once, so factors such as weather and a low population density at the periphery of the distribution in Kansas might have reduced detection probabilities.

More VES need to be conducted along the margins of their historic distribution to determine RST presence, particularly at the north end of their known range and in Clark County. There was only one RST observed in Clark County in 2020 and two in 2005. Prior to that, the most recent observation, as reported on the Kansas Herpetofaunal Atlas, was from 1971. There have been only 6 reported RST encounters near CSFL, and those observations are dispersed throughout that landscape. Because the habitat around CSFL differs from that in Barber and Comanche counties, studies focusing on the RST population around CSFL would inform conservation efforts for this disjunct population.

In Barber and Comanche counties, the northernmost record of an RST was documented in 2005. This was in the northwest corner of Barber County. The most recent northernmost encounter was approximately 9 km south of that point and occurred in 2020. This might indicate a shrinking distribution or could be the artifact of a lack of search effort on the northern end of their distribution in recent years.

There have been more recent RST observations along the eastern and western edges of their known historic distribution in Kansas. There were four reported observations in 2020, the farthest east being just 2 km west from the most easterly known RST occurrence recorded in 1971. Two RST were observed in 2020 along the western edge of their known historic distribution in Kansas, so it is likely they are still present along the eastern and western boundaries. Surveys should be conducted south of the most easterly of the RST encounters because no RST have been recorded there and it seems likely that they might be present based on the HSM.

VES were more successful at least one hour after sunset, particularly if it was warm and humid. Bradford et al. (2003) also had more success during night surveys. Recent rain improved the probability of encounters. If population densities are lower along the margins of their range, multiple surveys at a site will be required to confirm presence.

During VES, toads were not encountered in the grass. They were most often observed sitting or hopping along the edges of the gypsum hills or along the gypsum cliff faces, so survey paths following the exposed gypsum, particularly along the edges of the gypsum hills, seemed to be most effective in determining if RST were present at a location.

Except for at the site where telemetry was conducted, no more than 8 RST were encountered at a site on a single night, so, as in other parts of their range, individual populations appear to be small (Bradford et al., 2003). However, the apparent strong preference RST has for gypsum outcroppings in Barber and Comanche counties, suggest their populations might be relatively well-connected in Kansas.

In Barber and Comanche counties, it appears RST are associated with the Blaine Formation. They also occur near CSFL in the Kiowa Shale and Cheyenne Sandstone geologic formations. Although these formations also extend into the southeast of Kiowa, it is unclear why they are not documented in that area. It is likely other factors are contributing to limit their range.

Telemetry

Manual Telemetry

In general, RST prefer the exposed portion of the gypsum, and they typically select crevices in the gypsum cliff face for their burrows. No RST were located in the confluent grass areas at the telemetry site. Instead, they were most frequently encountered either at the summit of the gypsum hill near the crest or along the cliff face. Occasionally, a toad was encountered further away from the edge of the gypsum cliff. These results agree with the study by Bradford et al. (2003) where RST were positively correlated to rocky terrain and negatively correlated with vegetation cover. Other species such as the Yosemite Toad (*A. canorus*) and the Arroyo Toad (*A. californicus*) also prefer more open habitats (Griffin & Case, 2001; Liang, 2013).

Within Kansas, RST might prefer these rocky areas and the gypsum cliff faces because refugia are available and common. Movement along the bare rock might require less energy and provide more foraging success than moving through the grass. Cane Toads (*Rhinella marina*) actively seek light, rugose surfaces that increase contrast and decrease an insect's ability to escape (González-Bernal et al., 2011). These two characteristics, light coloration and a rugose surface, describe the gypsum well, so foraging success might be better for RST in these areas.

The female RST moved more frequently than males. They also changed burrow locations more often than the males did. Length of time tracked was not correlated to the distance an individual moved. Sex specific differences in toad movement and habitat use have been documented in other toad species as well. Female toads typically have larger home ranges than males and tend to prefer more upland habitat than male toads, perhaps because they have higher energetic demands in order to produce eggs (Liang, 2013; Muths, 2003). Male toads use areas closer to breeding sites because breeding success increases if a male arrives at the site earlier than his competitors (Bartelt et al., 2004; Griffin & Case, 2001; but see Daversa et al., 2012). While differences in habitat use between male and female RST were not clear in this study, further observations might yield insight that, similar to other species of toads, female RST do use upland habitat more frequently than males while males prefer to seek burrows closer to breeding sites, especially during the active season.

The female RST home range varied from 41.86 m^2 to 396.39 m^2 and the maximum linear distance across those ranges varied from 18.22 m to 50.04 m. The male RST home range varied from 10.10 m^2 to 2,956.22 m^2 and the maximum linear distance across those ranges varied from 5.22 m to 156.77 m. These are likely underestimations of the true distances. In most cases, the home ranges might be larger than determined by MCP because estimates were based on two dimensions and did not account for the hills in the terrain. Additionally, the measurements assume the toads moved the shortest distance between two points and did not move outside the bounds of the lines that connected the burrows of an individual RST, but that is unlikely.

However, the 2,956.22 m^2 home range calculated for male 33074B2A is likely an overestimation. This home range spanned a creek between two gypsum ridges. In reality, male 33074B2A wandered the area around the creek for a maximum of 3 days in early June (June 5-7) while it was wet and rainy. It is possible he trilled along the creek during those nights. Sometime on June 7 or June 8, he climbed the opposite gypsum ridge and burrowed there. For the remainder of the summer, he used a small area along the gypsum cliff face.

Male 33074B2A was the only male whose movements were followed during the rainy period in early June. While no clear patterns were observed between movement and weather, more toads were observed on the surface after rains and when the ground was visibly moist. However, some toads were on the surface when it was dry and hot. It seems likely that largescale movements, such as the one made by male 33074B2A, would be more common during periods of rain and high humidity because desiccation is less likely (Bartelt et al., 2004; Baumberger et al., 2019). It would be interesting to follow RST males and females for longer periods of time to determine if there are sex-based differences in how the toads respond to weather events and if their movements change as the year progresses.

Four RST (TagIDs: 522A4C61, 192D6178, 7866332A, and 522D612D) were documented only in a single burrow. It is possible these toads did move away from their burrows only to return by the next time they were located. Some RST might be faithful to a particular burrow site (Weintraub, 1974), emerging during the night to forage or breed and then returning.

However, nine RST (TagIDs: 1E1E6634, 4C07E52, 33074B2A, 612A5234, 332D4B33, 34662A2A, 1E552D33, 61782A55, 2D19331E) used multiple burrows. The burrow an RST chooses and how long the burrow remains in use might depend on the microclimate (Liang 2013; Long & Prepas, 2012) as well as on that particular individual. However, microclimate was not assessed during this study. Weintraub (1974) observed that multiple RST will use the same burrow and, on June 8, male 4C07E52 and female 34662A2A were observed in a single burrow.

Remote Telemetry

Automated radio telemetry systems (ARTS) have many applications and recent research has focused on analytical approaches to improve the accuracy of predicted locations for both indoor and outdoor use (Ainul, 2022; Jondhale et al., 2021; Luo et al., 2022; Luomala & Hakala, 2022; Paxton et al., 2021). Using the R code provided by CTT, the nodes in this study were able to predict locations for 6 of the 15 tagged RST. Predicted locations were not able to be made for the remaining 8 RST because these RST were either not within line-of-sight of at least three nodes, or, if they were being detected by at least three nodes, the RSS value was greater than -100 for less than three nodes.

RSS- and distance-based filters, which have been shown to improve accuracy of RSS-based trilateration (Paxton et al., 2021), were not applied to the analysis because the node array was small (10 nodes), the nodes were placed in relatively close proximity (~100 m apart), and there was rapid signal attenuation at this site. The hills in the terrain limited detection range, so when a location was able to be predicted, generally no more than three nodes contributed to the prediction. Under these conditions, filters would hinder trilateration efforts.

The predicted locations were tightly clustered, but the estimated error ranged widely, from 13.16 m to 309.52 m. None of the estimated locations matched where the toads were located with the handheld receiver. However, most of the estimated errors fell within 25 m to 75 m. When the predicted locations were compared to the locations obtained from manual telemetry, the predicted locations were pulled toward the center of the node array. This phenomenon has been observed in other studies, but filters and regression-based corrections seem to minimize this effect (Baldan & van Loon, 2022; Paxton et al., 2021). Other researchers have calibrated each receiver independently to improve accuracy (Bircher et al., 2020). When RST were outside the node array completely, location error was highest because there is no directionality associated with RSS values. For example, RST 33074B2A was positioned approximately 130 m outside of the array (manual location) but the remotely predicted location was approximately 130 m inside the array.

In this study, nodes were placed on the top of the gypsum hills, based on observations from visual encounter surveys in 2021. However, the telemetry study in 2022 revealed RST prefer the edge or crest of the gypsum hills or cliff faces. Location error tends to increase when transmitters are located along the edge of the node array (Paxton, 2021), which was the case for each of the RST tagged, so a larger grid, with nodes placed at the bottom of the gypsum hills in addition to the top might have improved the results. If more than three nodes detected each toad, RSS- or distance-based filters might have proven useful in minimizing the estimated location error.

This is the first study examining the efficacy of using a small node array for monitoring fine-scale amphibian movement in visually obstructed “hilly” terrain. Due to the terrain and the small body size of RST, the primary challenge of the ARTS was rapid signal attenuation which precluded detection by three nodes simultaneously. Nodes, in this array, were spaced 100 m apart, and RSS values less than -100 could not be used in trilateration analysis. However, deterioration of the RSS signal to less than -100 occurred near 100 m. Larger transmitters are capable of producing stronger signals and would have reduced attenuation of the RSS signal. However, the small body size of RST limited transmitter size.

Use of the ARTS in a similar environment might be more suited for a larger, more vagile organism fitted with a larger transmitter. If a more vagile organism was the focal subject of the study, inferences regarding activity pattern might yield fruitful results (Kays et al., 2011), even if the predicted locations were not accurate. Additionally, future studies should focus on developing methods to optimize node placement and minimize blind spots for small arrays in these types of environments. While ARTS appear promising for future studies of this type, manual telemetry should continue to be used to verify locations. Use of the CTT tags and the handheld receiver allow for the simultaneous scanning of all deployed tags and streamline the tracking process. Such efficiencies relative to analog systems would allow an increase in both the number of individuals that could be tracked and the frequency of detections.

CONCLUSION

This study demonstrates that a coarse-scaled HSM incorporating only two habitat variables – areas of steep slopes that are proximally close to water – can serve as an effective starting point when prioritizing VES and ARD locations for an understudied species. However, although the HSM accurately described previous encounters, RST were only encountered at 33% of the VES sites, despite no difference in HSM mean or majority pixel values surrounding these locations. Because RST in Barber and Comanche counties were observed almost exclusively on gypsum uplands, adding the Blaine Formation as an additional layer in the HSM might help refine predictions for VES. In addition, examining satellite images and ground-truthing are important aspects of refining site selection and in prioritizing areas for conservation. This is because GIS layers are often too coarse in scale to accurately assess fine-scale habitat, such as ephemeral pools and canyon springs that might be important breeding grounds for RST.

No observations of successful RST breeding are reported in Kansas. However, inference for occurrences suggest that RST likely breed in spring-fed streams at the base of gypsum canyons. Studies examining RST reproduction success and the specific environmental cues that initiate RST breeding response, particularly in females, are important next steps in fully understanding the ecology of this species and in determining conservation approaches. Fine-scale breeding habitat characteristics should also be examined. Vegetation removal along gypsum slopes, particularly of *J. virginiana*, might aid in the creation of RST breeding grounds because removal of vegetation can free groundwater resources and allow the water to reach the surface (Bren, 1997). Artificial breeding sites might also be helpful for RST, especially because models of climate change predict reduced and more variable precipitation in the region (IPCC, 2021). Artificial breeding sites should be constructed in such a way as to prevent the buildup of harmful levels of ammonia or other toxic compounds that would hinder tadpole development and survival (Kiesow and Griffis-Kyle, 2017). Additionally, RST might not prefer to breed in permanent water (Bradford et al., 2003; Dayton & Fitzgerald, 2001), so these sites should be constructed to imitate the characteristics of ephemeral pools. However, water should persist at least 9 weeks to ensure RST tadpoles have time to metamorphose.

ARD were minimally effective in elucidating breeding habitat or in detecting RST presence throughout the landscape. Conducting VES is more effective in determining RST presence. VES are more successful when conducted after sunset during warm and humid conditions, particularly if the ground is visibly moist. In Barber and Comanche counties, RST encounters were higher along the exposed portions of the gypsum near the cliff-faces or along the cliff walls. To increase RST detection probability, VES routes should follow the gypsum outcroppings and should be planned to occur on warm nights one to three days after spring and summer rain events, if possible. VES might still be useful in determining presence when conducted under non-ideal conditions – hot and dry – but encounter rates will be lower and multiple VES at a single site might be necessary. VES appear to be the most successful way to monitor the persistence of RST populations in Kansas.

No RST were encountered in Clark or Kiowa counties. RST were not encountered along the margins of their historic distribution. Along the eastern and western boundaries of their historic range, RST were encountered in 2020, so they are likely still present along those margins. However, the northernmost observation of an RST was in 2005, northwest of Sun City in Barber County and approximately 625 meters north of the Medicine Lodge River. The most recent northernmost RST encounter (2020) was 10 km south of the 2005 encounter, directly south of Sun City. Two VES were conducted on the northernmost edge of the RST distribution at different sites, but no RST were encountered. This could indicate a shrinking distribution. However, it is possible RST continue to persist along the northernmost edge. Multiple VES surveys at a single site would help to elucidate this information (MacKenzie et al., 2002). VES focusing on the area south of the easternmost RST observations in Kansas should be conducted because it seems likely RST might be present there based on the values of the HSM, despite a lack of observations. Additionally, VES focusing on the disjunct population in Clark County are necessary to determine the full extent of the RST distribution around the CSFL area.

During the summer, RST use the edge of the gypsum and extensively use the crevices on the gypsum cliff face. They also appear to use a network of tunnels that extends through the gypsum rock. It appears they emerge from their crevices to forage on the gypsum and likely only travel through grass when necessary (e.g., to migrate to breeding pools or to disperse after metamorphosis). It seems probable that they continue to use the gypsum habitat throughout the winter, but a telemetry study extending into the winter months should provide this information.

The way in which certain activities, such as gypsum mining, would alter critical RST habitat (gypsum and the networks that extend underneath it), should be carefully considered. Prior to such a project, multiple VES should be conducted at the site to determine whether such anthropogenic activities would affect an RST population. A project's potential effects on RST population connectivity should also be considered, because RST populations are small and dispersal between populations is likely an important contributor to RST persistence.

Finally, ARTS cannot effectively monitor RST movement and activity in hilly terrain. RST are too small to carry a transmitter of sufficient signal strength in this terrain. The hilly terrain also prevented clear line-of-sight transmission and resulted in rapid signal attenuation. ARTS might be more effective in elucidating information on a larger, more vagile organism.

When the ARTS was able to estimate an RST's location, the points were tightly clustered, indicating preciseness. However, accuracy was too coarse to be useful in determining RST habitat associations. Additionally, because of loss of line-of-sight transmission, small-scale movements, and long periods of inactivity of RST, ARTS was not effective in estimating activity patterns. However, as ARTS technology, optimal placement, and analytical techniques advance, this system might produce beneficial results in tracking small organisms with low vagility. However, for the time being, ARTS systems used on larger and more vagile organisms might produce results more useful for conservation purposes.

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TABLES

Table 1. Reclassified values of the slope, measured in degrees, as used in the habitat suitability model.

Reclassified Value	Slope (degrees)
10	Steep (> 9°)
5	Moderate (6° - 9°)
1	Flat (< 6°)

Table 2. Reclassified values of distance in meters from a waterbody as used in the habitat suitability model.

Reclassified Value	Distance from Waterbody (m)
10	0 – 879.43
9	879.43 – 1758.86
8	1758.86 – 2638.29
7	2638.29 – 3517.72
6	3517.72 – 4397.15
5	4397.15 – 5276.58
4	5276.58 – 6156.01
3	6156.01 – 7035.44
2	7035.44 – 7914.87
1	7914.87 – 9146.46

Table 3. Reclassified values of distance in meters from a waterway as used in the habitat suitability model.

Reclassified Value	Distance from Waterway (m)
10	0 – 1010.99
9	1010.99 – 2021.98
8	2021.98 – 3032.96
7	3032.96 – 4043.95
6	4043.95 – 5054.94
5	5054.94 – 6065.93
4	6065.93 – 7076.92
3	7076.92 – 8087.90
2	8087.90 – 9098.89
1	9098.89 – 14690.72

Table 4. The number of times each RST was detected within the dates its transmitter remained active.

TagID	Beep Rate (seconds)	Start Date	End Date	Days Tracked	Sex	Weight (g)	SVL (mm)	Times Detected
192D6178	10	06-27	07-11	14	F	17	59	6
1E552D33	10	06-27	07-11	14	F	14.5	59	6
612A5234	10	06-27	07-11	17	M	8	46	6
554C4B2A	10	06-27	07-06	9	F	7.5	47	1
7866332A	10	06-27	07-08	11	M	10.2	50	3
522D612D	20	07-01	07-10	9	F	12.5	53	4
1E1E6634	20	06-17	07-08	19	M	8.8	45	6
33074B2A	20	06-03	06-19	19	M	11	52.5	7
34662A2A	20	06-04	06-08	4	F	16.5	58	2
61782A55	20	06-04	06-27	23	F	10	47.5	8
2D19331E	60	06-15	07-13	28	F	13	54	11
4C07E52	60	06-04	07-13	39	M	12	52.5	15
332D4B33	60	06-15	07-06	21	F	8	48	6
3355332A	60	06-04	06-06	31	M	12	50	0
522A4C61	60	06-15	07-10	25	M	9.2	49	8

Table 5. RST home ranges as determined by minimum convex polygons (MCP) and the maximum Euclidean distance each RST moved across its range.

TagID	Sex	Weight (g)	SVL (mm)	Home range (m^2)	Max Euclidean distance (m)
192D6178	F	17	59		
1E552D33	F	14.5	59		
612A5234	M	8	46	50.29	16.49
554C4B2A	F	7.5	47		
7866332A	M	10.2	50		
522D612D	F	12.5	53		29.42
1E1E6634	M	8.8	45		
33074B2A	M	11	52.5	2957.01	156.77
34662A2A	F	16.5	58		24.47
61782A55	F	10	47.5	91.16	23.11
2D19331E	F	13	54	41.86	18.22
4C07E52	M	12	52.5	10.10	5.22
332D4B33	F	8	48	396.39	50.04
3355332A	M	12	50		
522A4C61	M	9.2	49		

FIGURES

Figure 1. The telemetry site. The ‘X’s represent the node array. The telemetry site encompasses approximately 20 hectares.

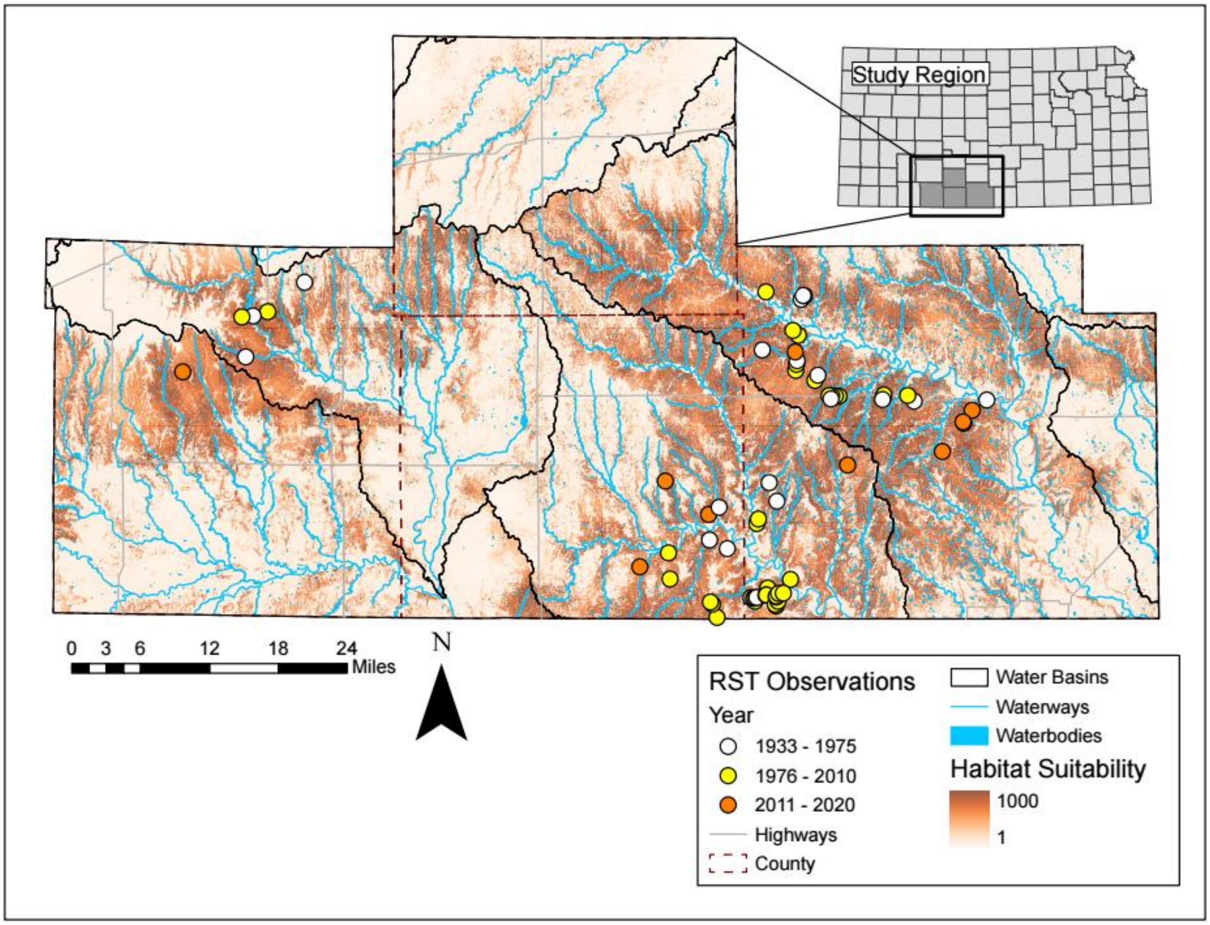


Figure 2. A habitat suitability model (HSM) of Clark, Comanche, Barber, and Kiowa counties, Kansas. Historic RST observations, spanning from 1933-2020, are from the Kansas Herpetofaunal Atlas. They are color coded by year. The majority of RST observations are from the years 1976-2010. Of these, most are from the 1980s when Larry Miller was doing work in this region. There are only ten observations between 2011-2020. The high value regions, colored dark orange, represent areas with steeper slopes that are closer to water. These areas were considered to have a higher likelihood of RST presence and were prioritized when selecting survey sites.

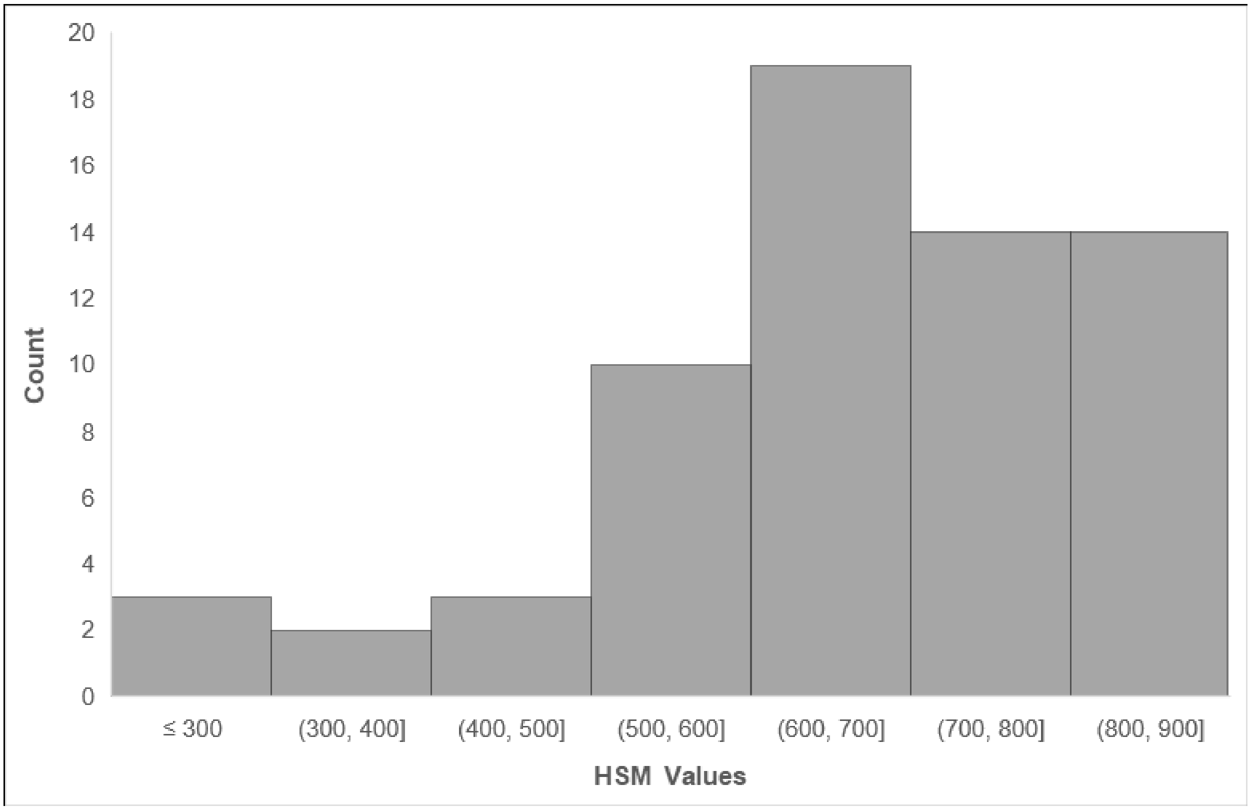


Figure 3. Histogram of the mean HSM pixel values within a 500 m buffer surrounding 65 RST observations from 1933-2020. Forty-three percent of mean values are above the HSM pixel value of 700 and twelve percent are less than 500.

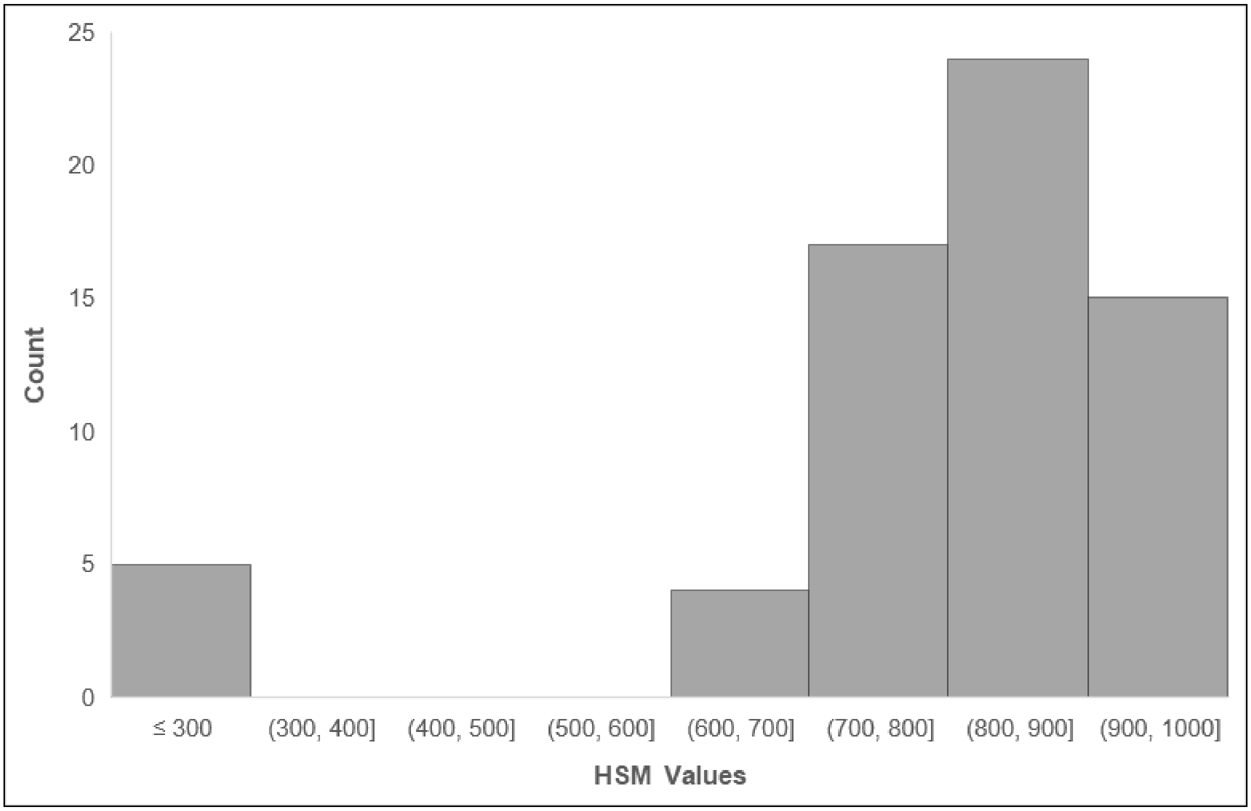


Figure 4. Histogram of the majority (> 50%) of HSM pixel values within a 500 m buffer surrounding 65 RST observations from 1933-2020. Eighty-six percent of majority pixel values are above 700, and seven percent are less than 500.

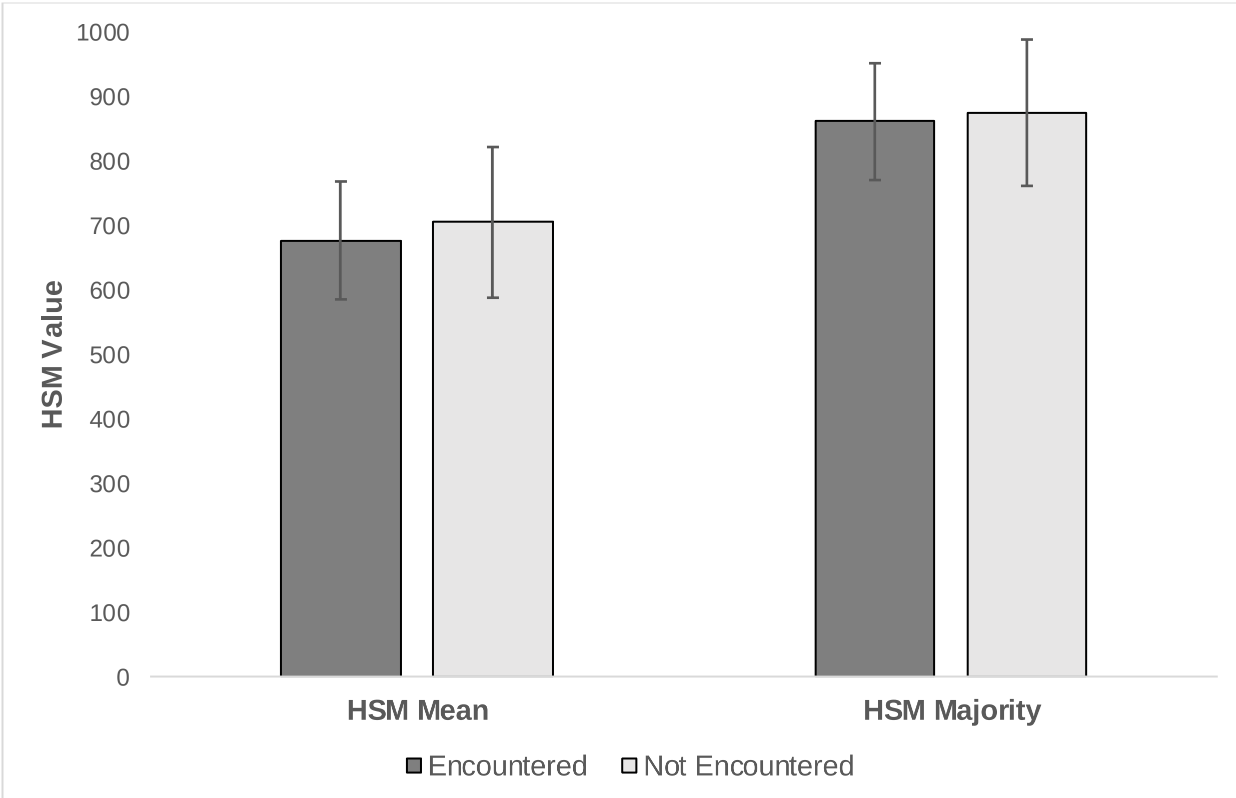


Figure 5. A comparison of the mean and majority HSM values of a 500 m buffer around visual encounter survey (VES) locations where RST were encountered and not encountered. Error bars represent one standard deviation.

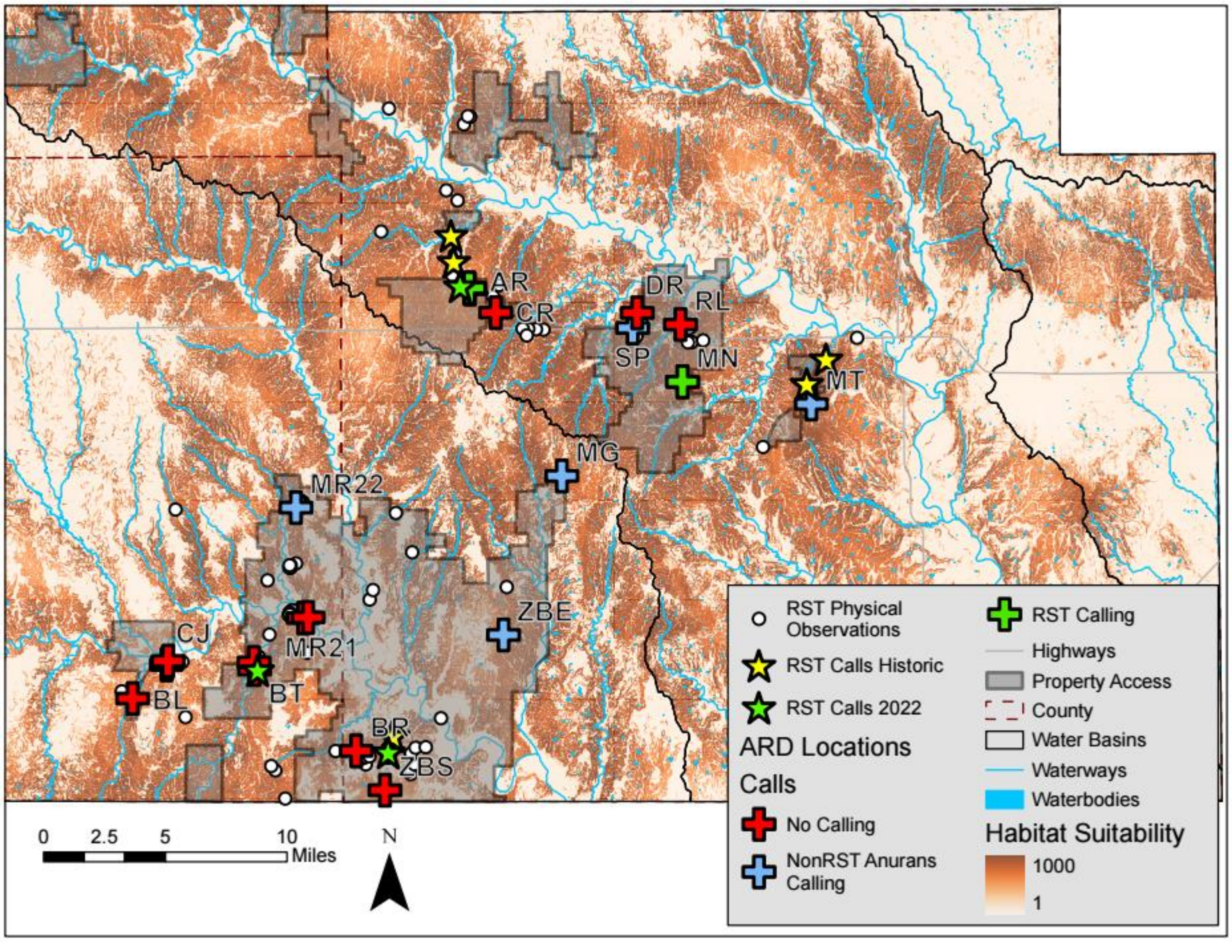


Figure 6. The locations of ARD in 2021 and 2022 in Barber and Comanche counties, Kansas. Historical RST calling records, as documented on the Kansas Herpetofaunal Atlas, are denoted by the yellow stars. Green stars indicate where RST were heard calling during 2022 visual encounter surveys. Red crosses indicate ARD localities where either no anurans were recorded or where only *Lithobates catesbeianus* and *Acris blanchardi* were recorded. Blue crosses indicate where any other non-RST anurans were recorded by the ARD. Green crosses indicate where ARD recorded RST. Because ARD locations between years were often in close proximity, some points are stacked. Consequently, ARD, except for MR21 and MR22, are labeled with only the letters of the location names and correspond to those locations listed in Appendix A.

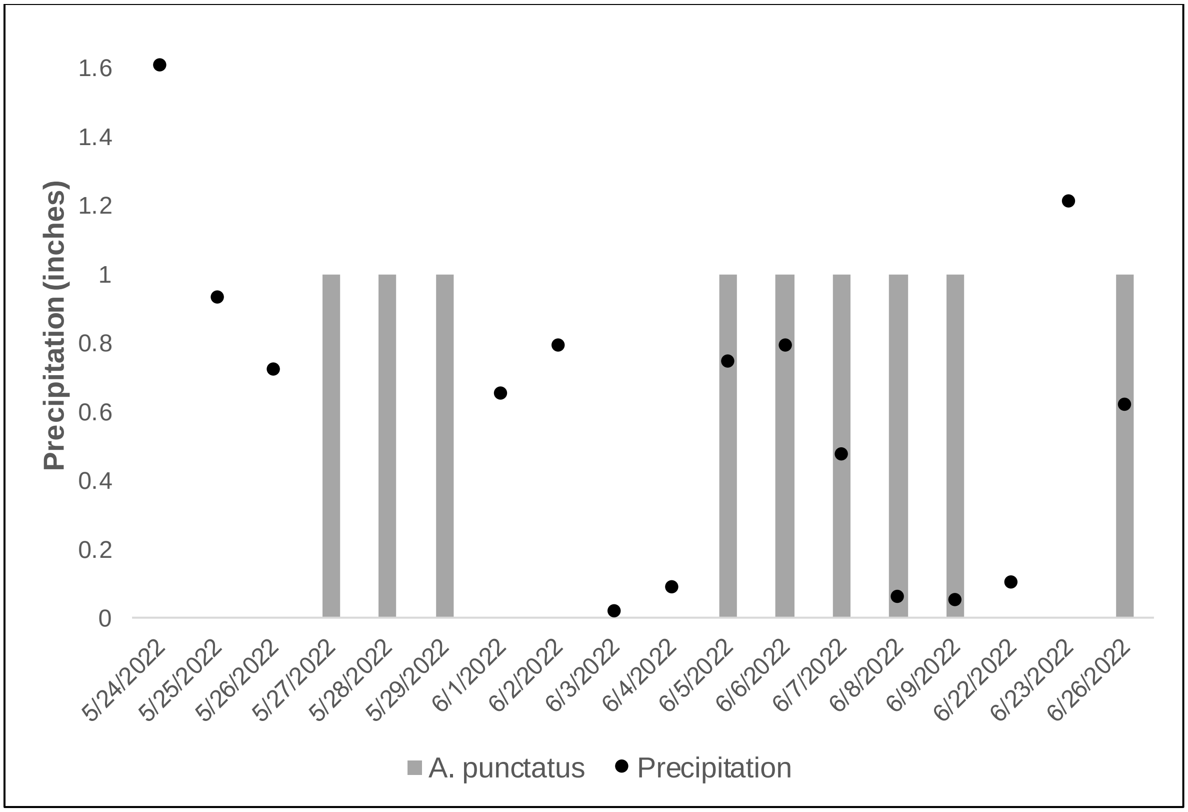


Figure 7. RST calling activity and occurrence of precipitation during the 2022 active season. Gray bars represent the nights when RST were calling. Black dots represent precipitation amounts. Precipitation data was collected from the Community Collaborative Rain, Hail & Snow Network. Recorded precipitation amounts within the county where the calling event occurred were averaged to account for variable rainfall over the study region. ARD were not deployed until May 27, so it is possible RST were calling prior to the first recorded instance depicted here.

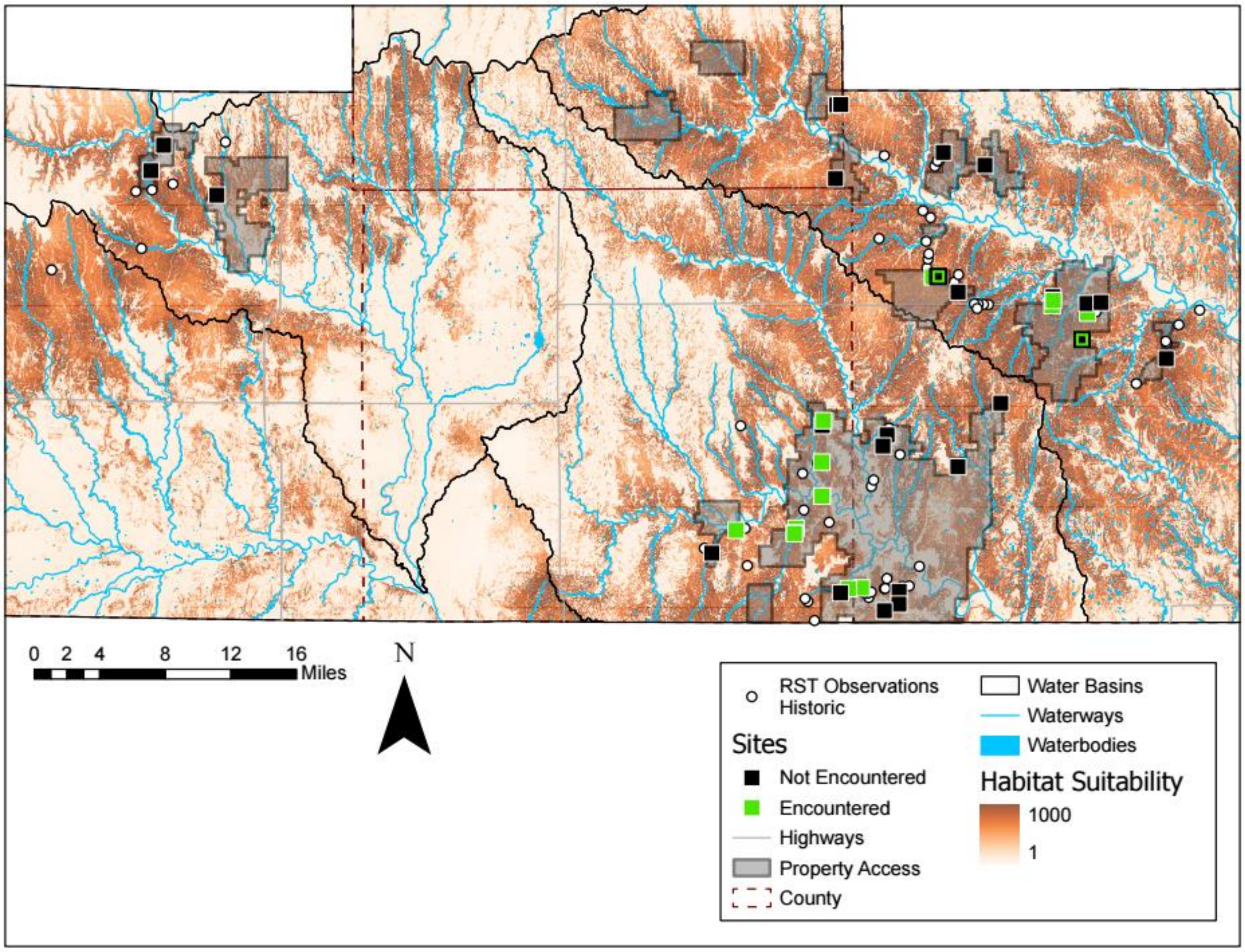


Figure 8. RST survey sites in Clark, Kiowa, Comanche, and Barber counties, Kansas in 2021 and 2022. A total of 39 surveys were completed in 2021 and 2022. Twenty-one surveys were conducted in 2021, and 18 were conducted in 2022. Only 3 of the sites were surveyed twice. RST were encountered during 13 surveys. Black squares denote areas that were surveyed where RST were not visually encountered. Green squares denote areas that were surveyed where RST were visually encountered. Green squares with black centers denote areas where RST were not visually encountered but are known to occur because they were documented calling on ARD placed in the area in 2022.

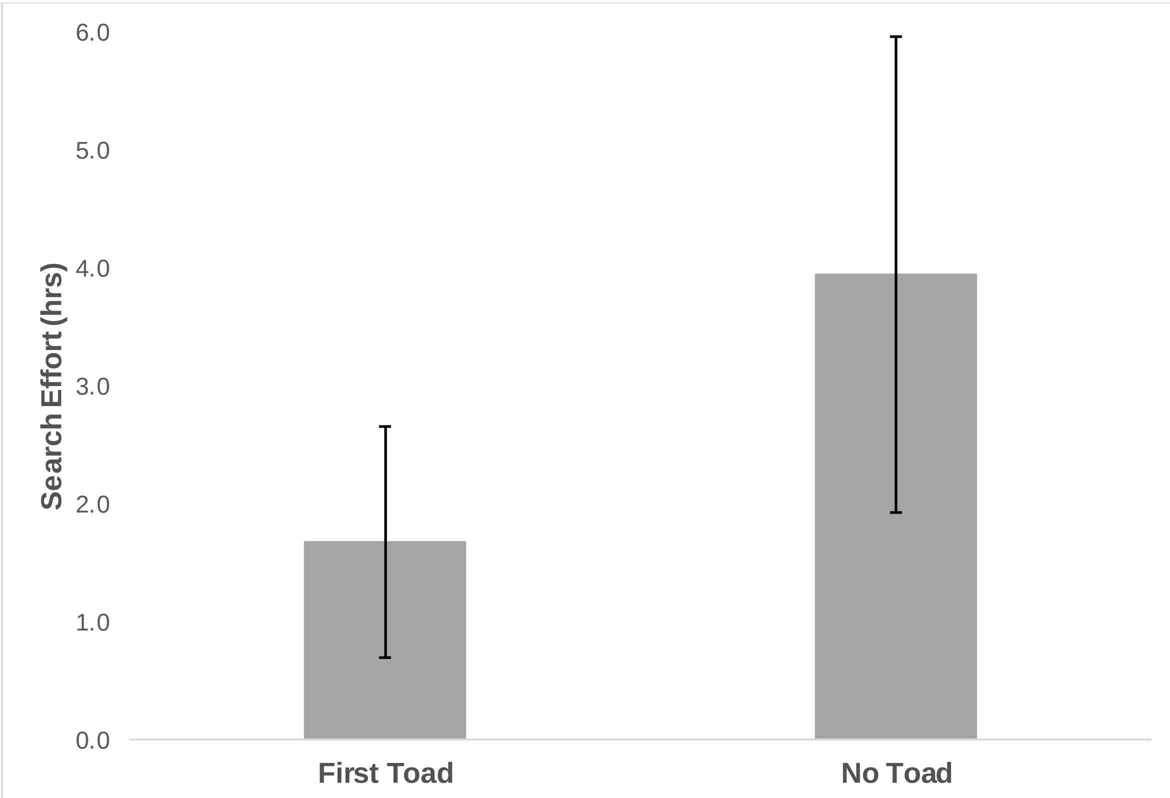


Figure 9. A comparison of mean search effort until the first RST was encountered during a survey to mean search effort when no RST were encountered during a survey. A mean of 1.67 hours of search effort was needed to confirm RST presence at a site. A mean of 3.94 hours of search effort was expended at sites where no RST were encountered. Error bars represent one standard deviation.

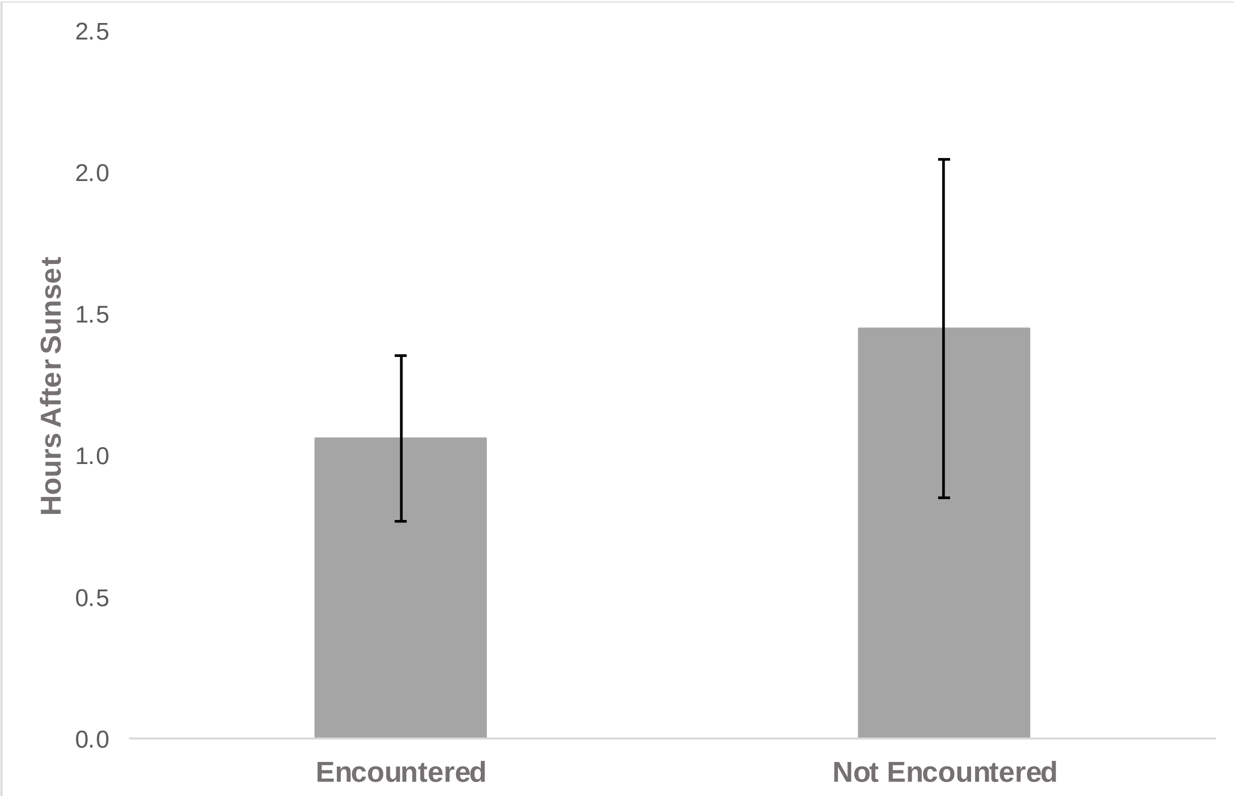


Figure 10. A comparison of the mean number of hours after sunset when the first RST was encountered during a nighttime survey to the mean number of hours spent searching after sunset when RST were not encountered on a nighttime survey. On average, RST were encountered 1.06 hours after sunset. When no RST were encountered, a survey extended a mean of 1.45 hours after sunset. The calculation of time searched after sunset at a location where RST were not encountered was determined to begin either at sunset or at the survey start time, whichever occurred later. Error bars represent one standard deviation.

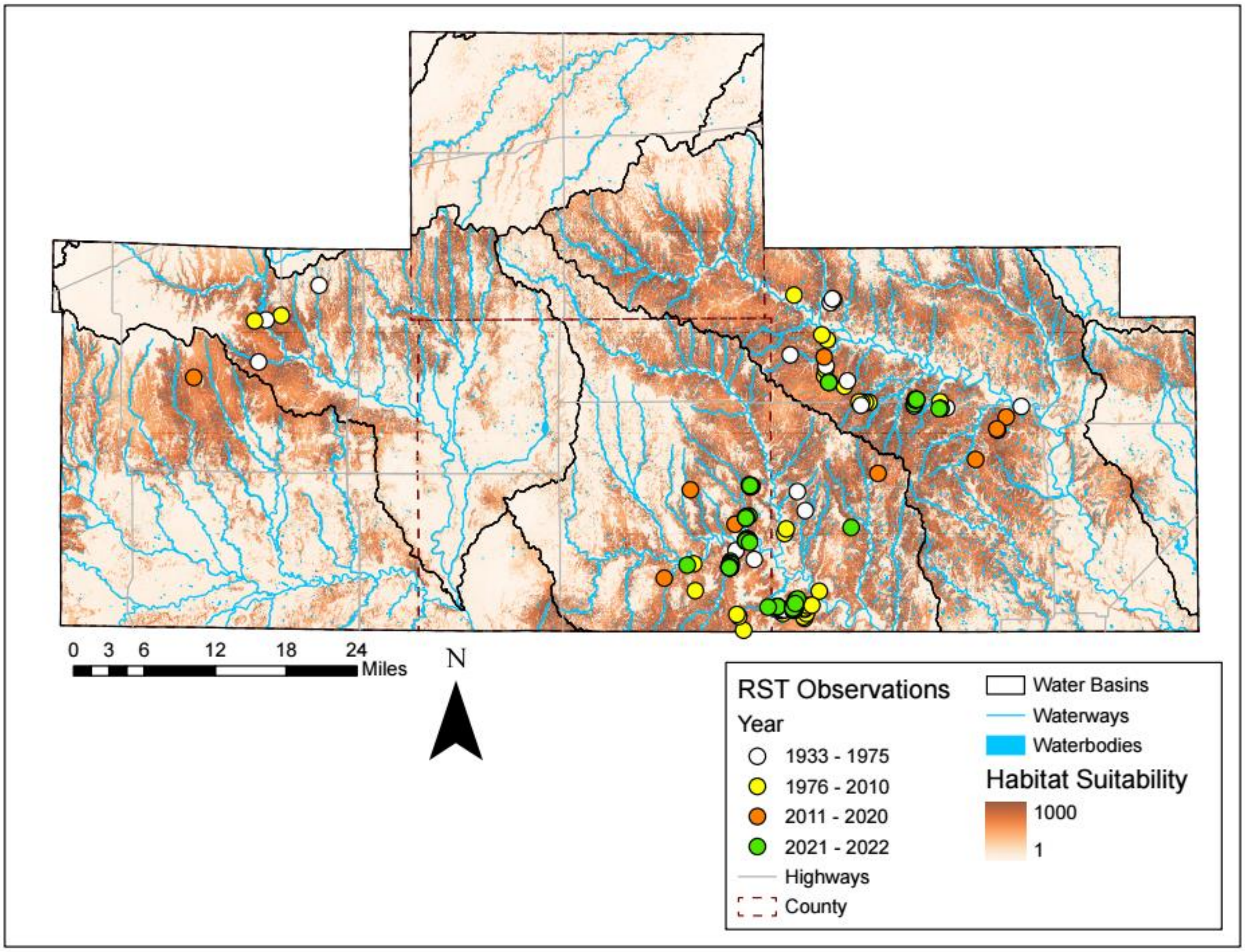


Figure 11. Historic and recent observations of RST across Clark, Comanche, and Barber counties. RST observed in 2021 and 2022 are denoted in green. The most recent RST observations include the 40 observations made by KDWP during surveys in Comanche and Barber counties in 2022.

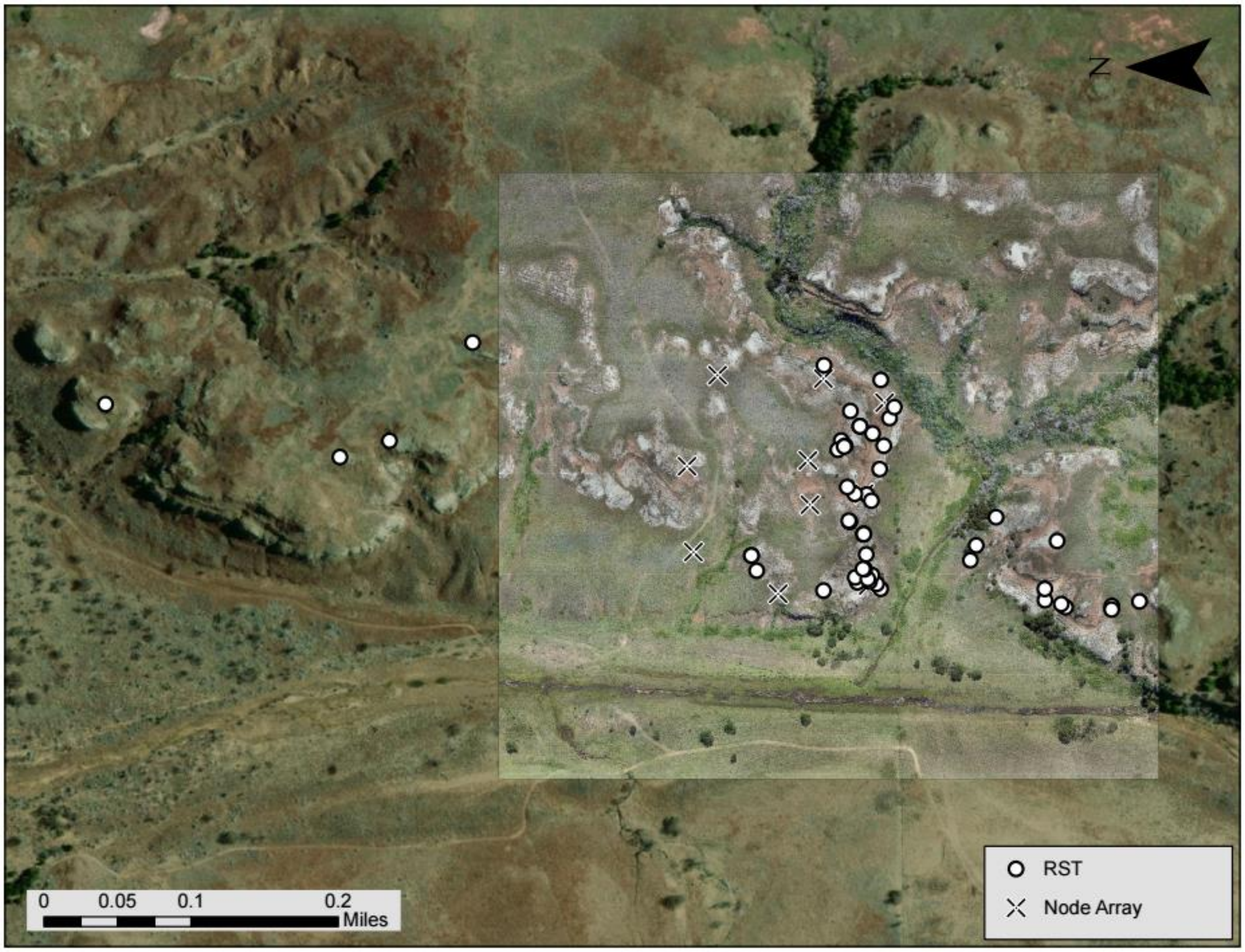


Figure 12. The locations of 54 surface-active RST encountered at the telemetry site during 2021 and 2022. The inset is an orthomosaic of the telemetry site. Note that RST were observed primarily on the exposed portions of the gypsum, near the edges of the cliffs, and along the cliff faces.

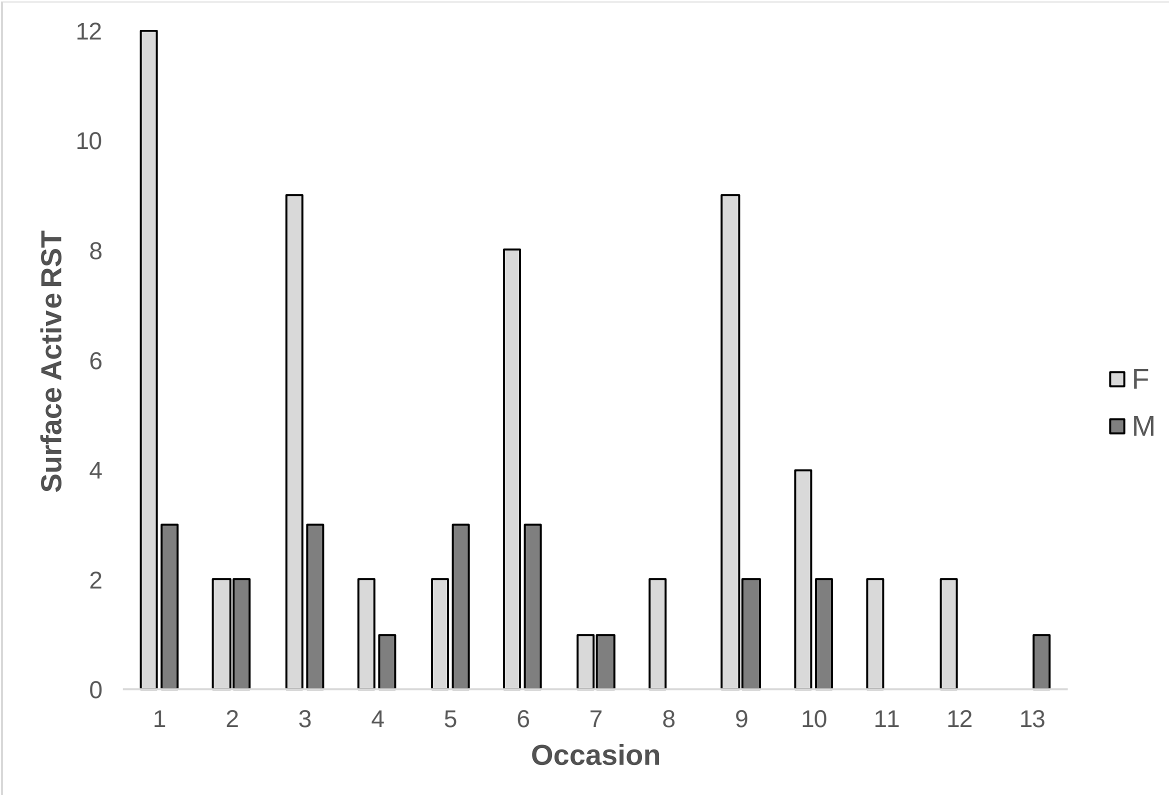


Figure 13. The number of surface-active female and male RST observed at the telemetry site per visit. The telemetry site was visited a total of 21 times throughout the summer of 2022 beginning June 2 and ending July 19. On 13 of the 21 visits, surface-active RST were encountered. Occasions when surface-active RST were not encountered are excluded.

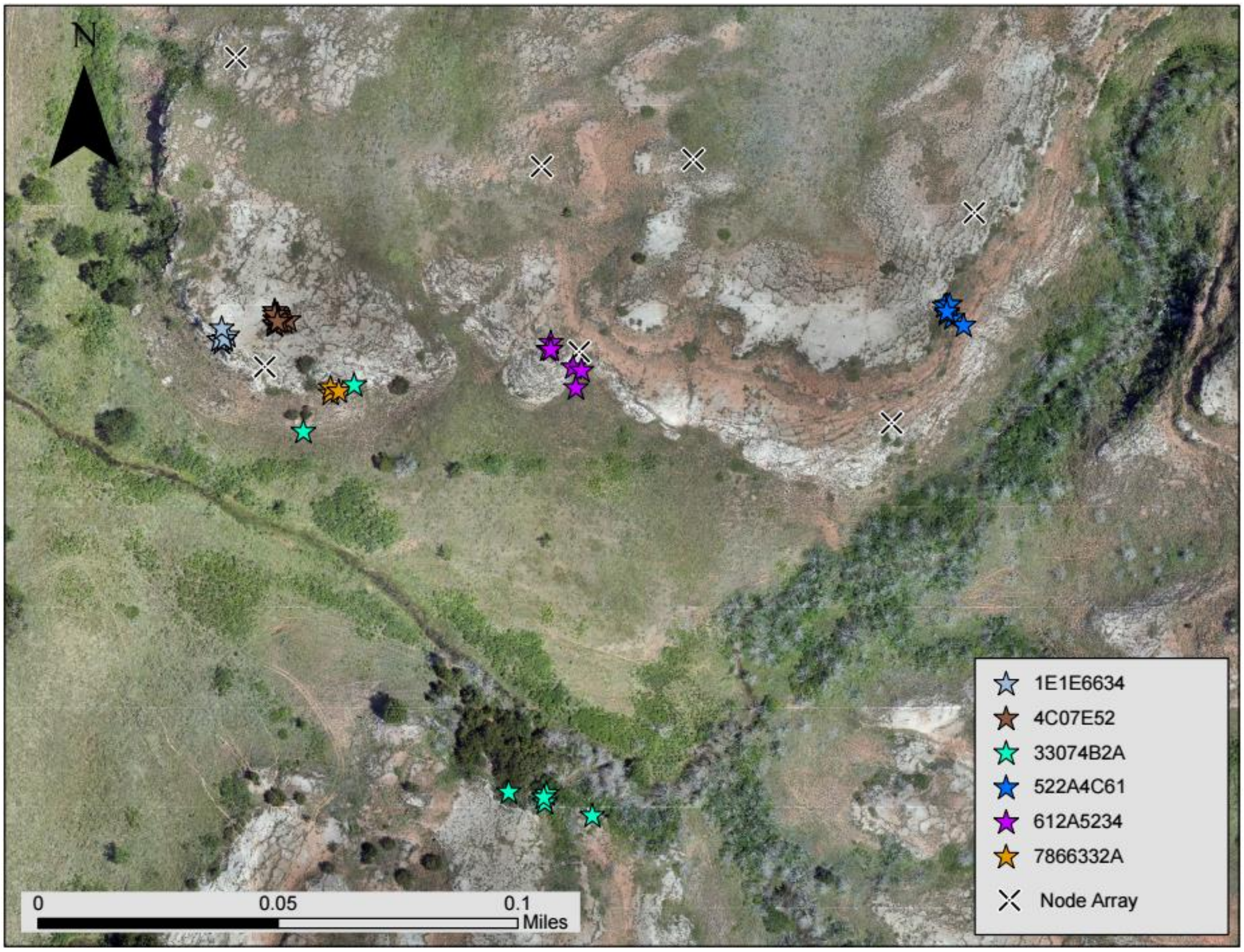


Figure 14. The movements of 6 male RST as recorded by a handheld receiver and a handheld GPS unit. Detection of specific individuals (alphanumeric number) are depicted by the colored stars. The background is an orthomosaic of the telemetry site collected with a DJI Phantom 4 Pro and stitched in ERDAS IMAGINE 2022.

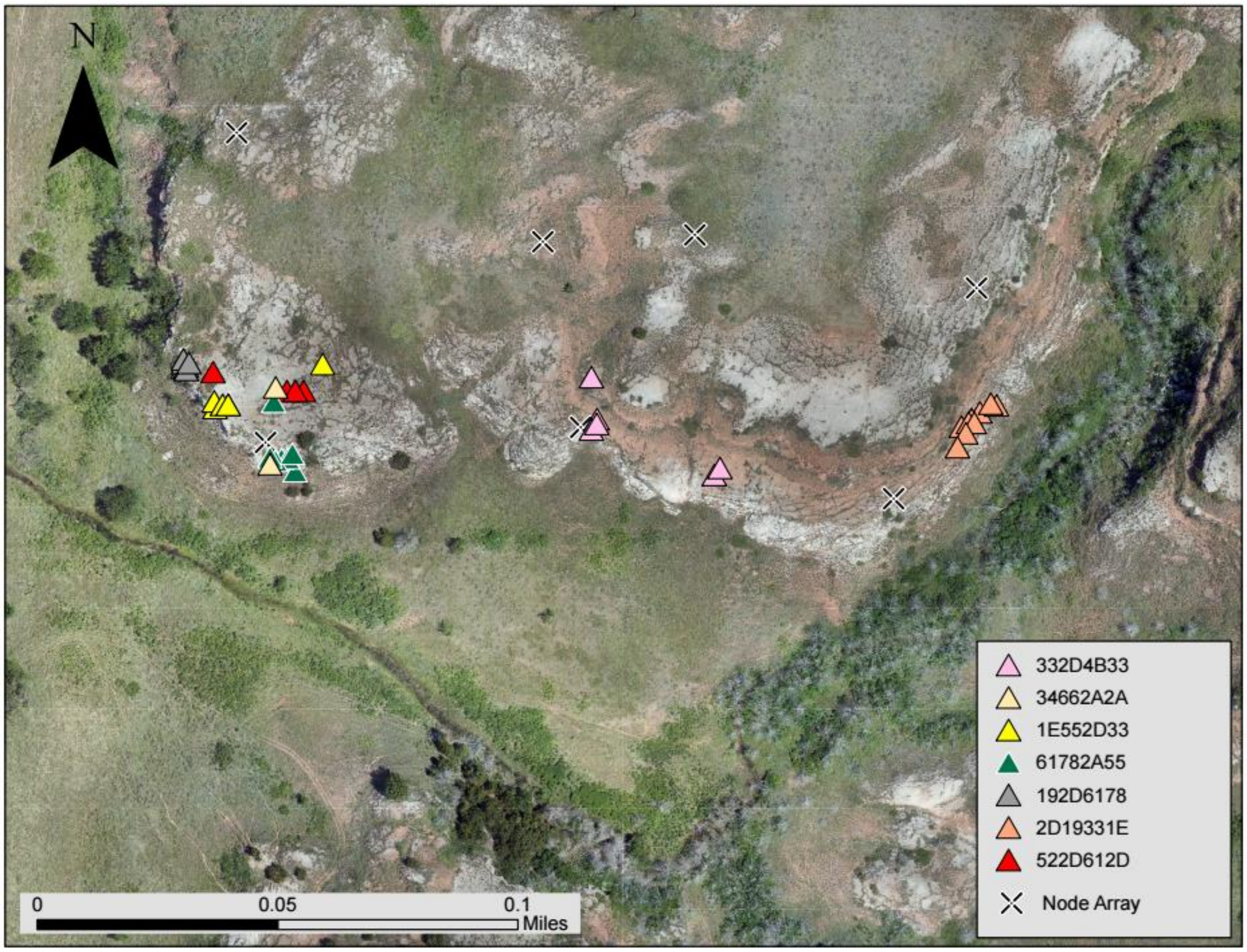


Figure 15. The movements of 7 female RST as recorded by a handheld receiver and a handheld GPS unit. Detection of specific individuals (alphanumeric number) are depicted by the colored triangles. The background is an orthomosaic of the telemetry site collected with a DJI Phantom 4 Pro and stitched in ERDAS IMAGINE 2022.

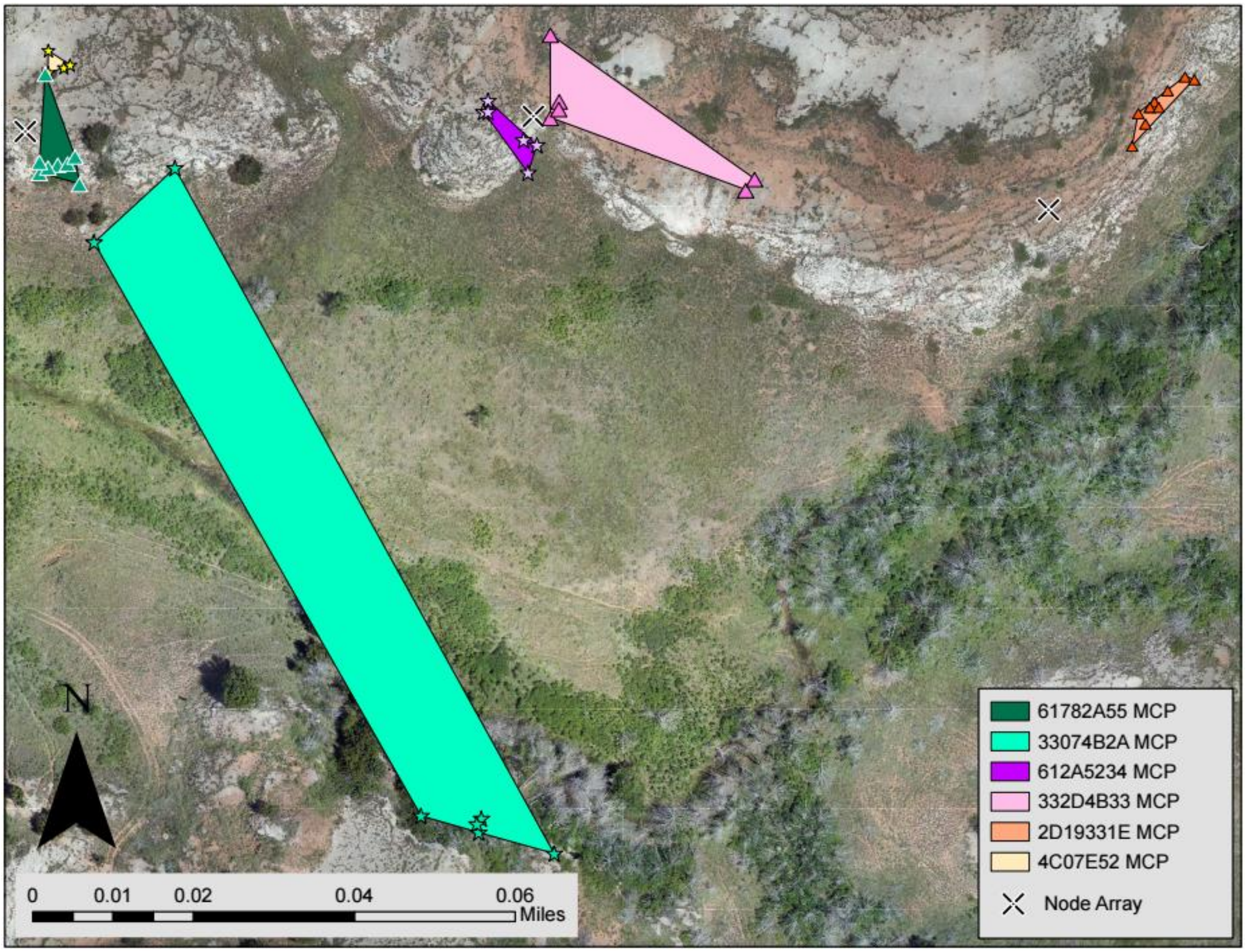


Figure 16. Minimum convex polygon (MCP) home ranges of 6 RST. Points inside the polygons represent physical locations where RST were detected with the handheld receiver. Stars represent male RST and triangles represent female RST. The background is an orthomosaic of the telemetry site collected with a DJI Phantom 4 Pro and stitched in ERDAS IMAGINE 2022.

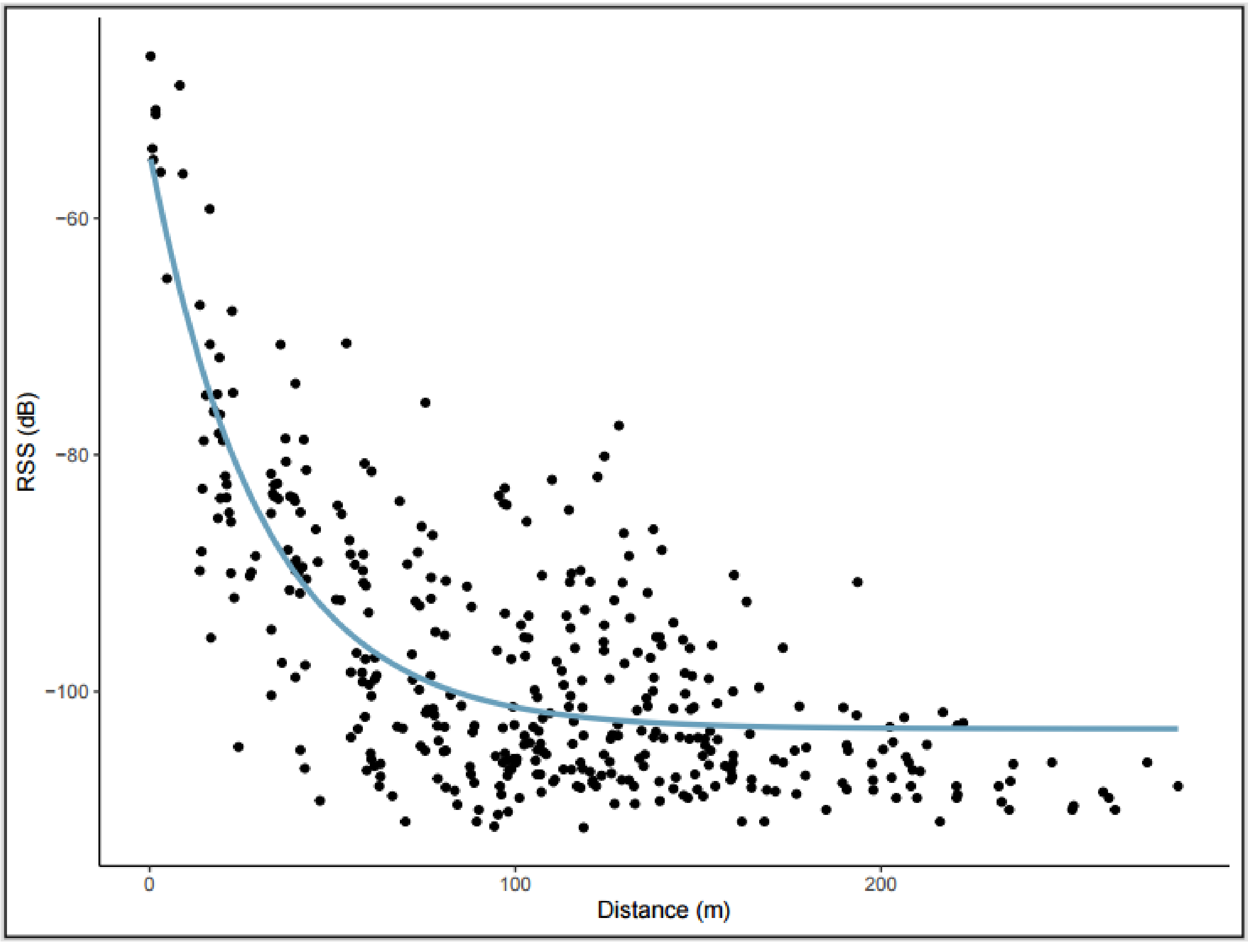


Figure 17. An exponential decay model indicating the relationship between receiver signal strength (RSS) and distance. The equation of the line is avgRSS = -53.08 * exp(-0.03164 * distance) + -102.60. RSS values less than -100 were not used to triangulate RST locations.

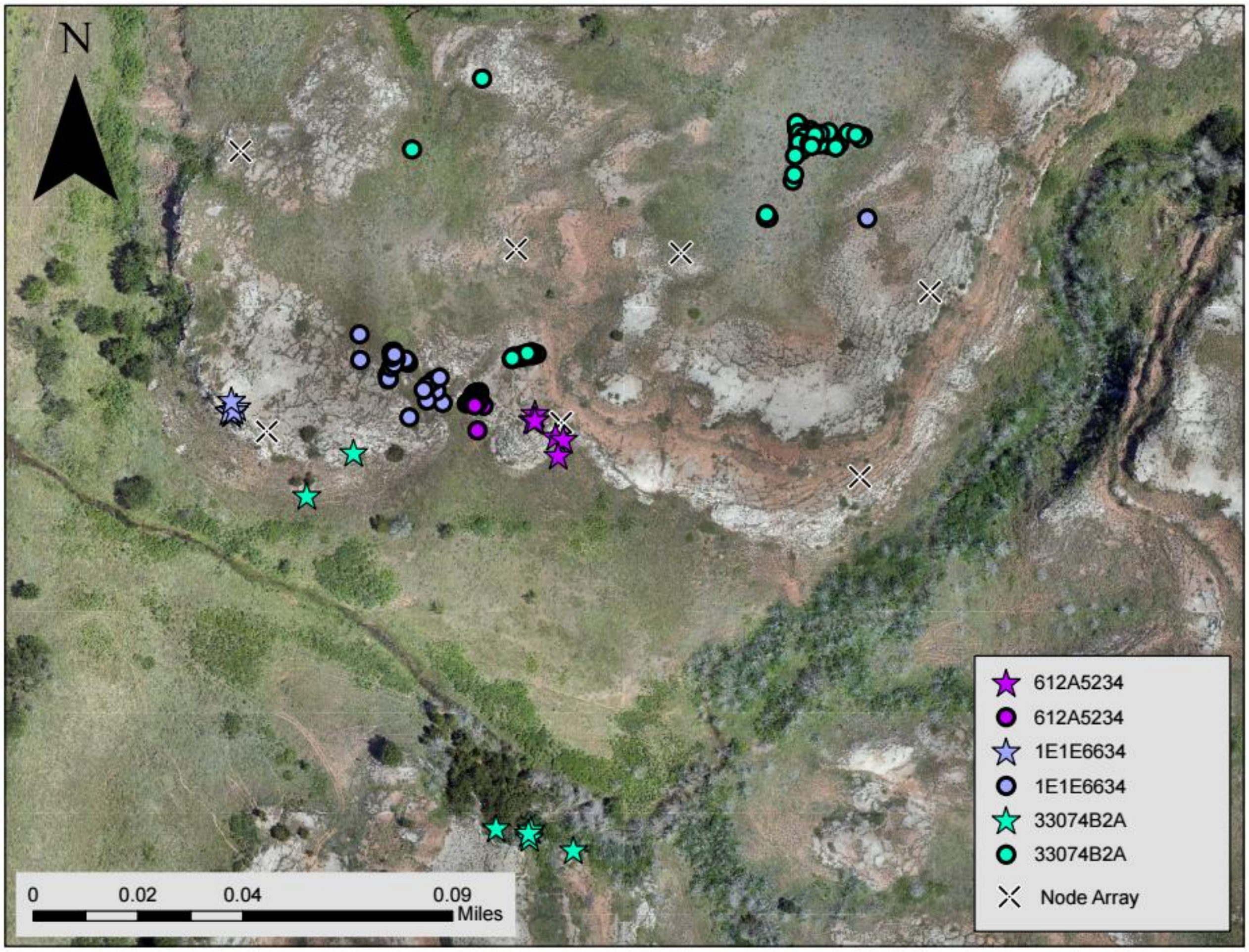


Figure 18. Detections of three RST (TagIDs: 612A5234, 1E1E6634, and 33074B2A) as estimated from a handheld receiver (stars) and from remotely received signals estimated by the exponential decay model (circles) (Figure 14). Note that 33074B2A was located outside the node array but the estimated location was always inside the node array. The background is an orthomosaic of the telemetry site collected with a DJI Phantom 4 Pro and stitched in ERDAS IMAGINE 2022.

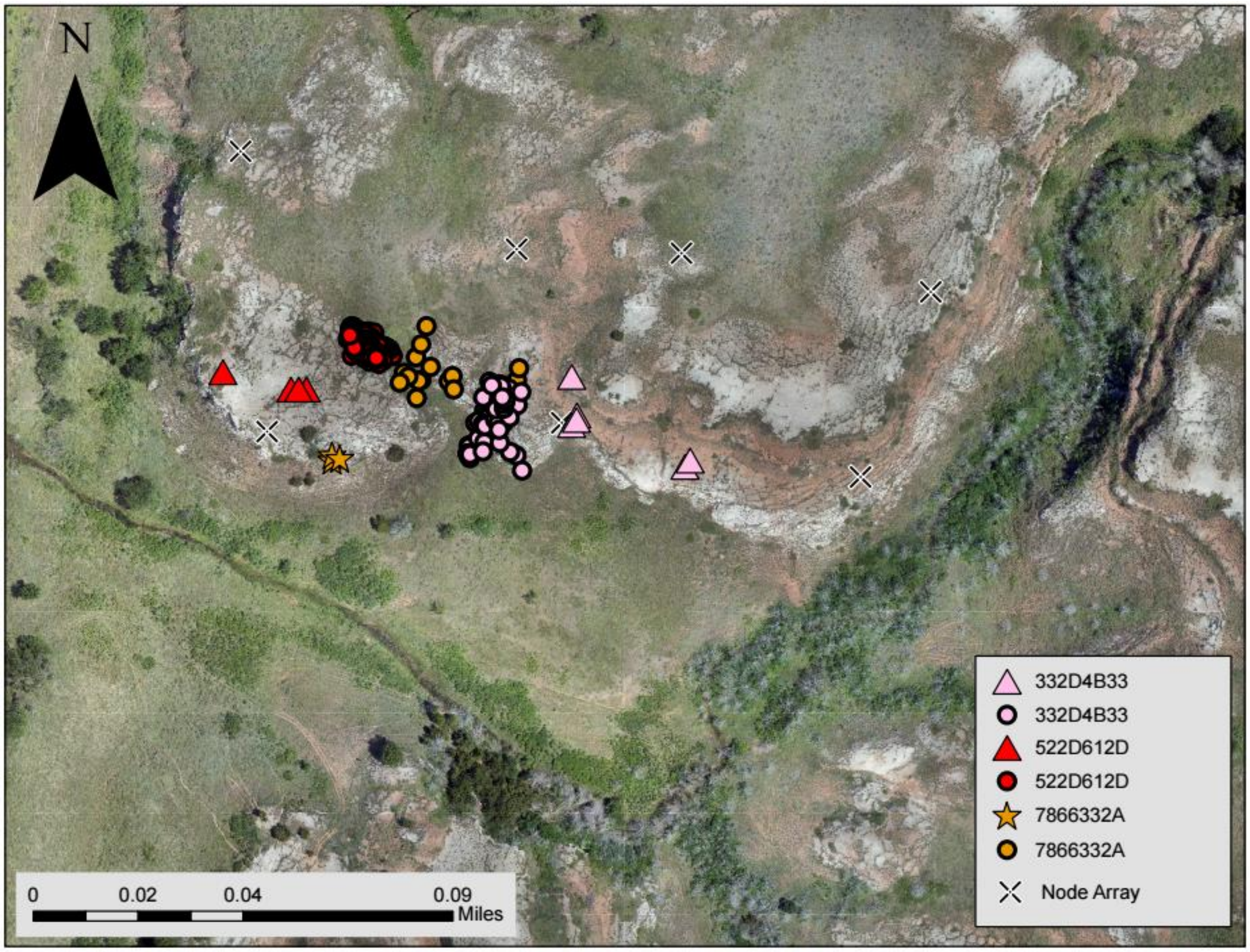


Figure 19. Detections of three RST (TagIDs: 332D4B33, 522D612D, and 7866332A) as estimated from a handheld receiver (stars and triangles) and from remotely received signals estimated by the exponential decay model (circles) (Figure 14). The background is an orthomosaic of the telemetry site collected with a DJI Phantom 4 Pro and stitched in ERDAS IMAGINE 2022.

APPENDICES

Appendix A: Calling dates of anuran species as recorded by automatic recording devices (ARD) in 2021 and 2022. Species are as follows: *Anaxyrus woodhousii* (WT), *Anaxyrus punctatus* (RST), *Lithobates blairi* (PLF), *Pseudacris clarkii* (SCF), *Gastrophyrne olivacea* (WN), *Spea bombifrons* (PS), *Lithobates catesbeianus* (AB), and *Acris blanchardi* (BCF). An asterisk without a date indicates the species was recorded calling intermittently throughout the entire period the ARD was at the location. The letters of each location correspond to the ARD labels in Figure 2. However, because MR21 and MR22 were not close in proximity, the Figure 2 labels do distinguish between these sites.

Location	Setup Date	Removed	WT	RST	PLF	SCF	WN	PS	AB	BCF
AR21	6/8/21	7/27/21					*6/26-27, 29-30			*
AR22	5/27/22	7/25/22	*6/6-7	*6/6	*7/9				*	*
BL21	6/15/21	6/29/21							*	*
BR21	6/14/21	7/27/21								
BT21	6/29/21	7/27/21							*	*
BT22	5/27/22	7/25/22							*	*
CJ21_1	6/15/21	7/27/21							*	*
CJ21_2	6/15/21	7/27/21								
CJ22	5/27/22	7/25/22								
CR21	6/11/21	7/27/21								
DR21	6/15/21	7/27/21								
MG22	5/26/22	7/25/22			*5/26-28, 30; 6/1-10	*5/26; 6/4-9, 15	*5/26; 6/5-11		*	*
MN22	5/27/22	7/27/22	*5/27; 6/6-8	*5/27-29; 6/5-9	*			*5/27		

Appendix A (*continued*): Calling dates of anuran species as recorded by automatic recording devices (ARD) in 2021 and 2022.

Location	Setup Date	Removed	WT	RST	PLF	SCF	WN	PS	AB	BCF
MR21a	6/14/21	6/24/21								
MR21b	6/24/21	7/27/21								*
MR22	6/2/22	7/25/22			*				*	*
MT22	6/3/22	7/27/22	*6/6		*6/5-11	*6/4-12	*6/5-8			*
RL21	6/15/21	6/23/21								
SP22	5/27/22	7/27/22	*6/6-7		*6/6	*5/28, 30	*6/6-12		*	*
ZBE22	6/2/22	7/25/22	*6/2, 6-9		*6/2-3, 6-10	*6/2-12, 26-28	*6/2-10, 15, 24, 26-28; 7/5-7			*
ZBS22	5/26/22	7/25/22							*	

Appendix B: The number of RST encountered on surveys conducted in 2021 and 2022. Relative humidity (RH) and temperature (Temp) as well as the number of observers conducting the survey and the search effort expended are also included.

Date	RH (%)	Temp (°C)	Number of RST Encountered	Start Time	Stop Time	Number of Observers	Search Effort (hrs)
6/9/2021	69.5	28.6	0	23:15	0:00	2	1.50
6/10/2021	68.2	29.2	0	21:00	23:30	2	2.00
6/14/2021	57.5	28	0	21:00	22:00	2	2.00
6/14/2021	61	25.2	0	23:00	23:45	2	1.50
6/15/2021	43.3	30.8	0	20:45	22:30	2	3.50
6/17/2021	34.5	34.4	0	20:07	21:00	2	1.77
6/17/2021	38.6	29.6	0	21:26	22:15	2	1.63
6/22/2021	38.8	29	0	19:32	22:10	2	5.27
6/23/2021	52.7	31	0	21:15	22:40	1	1.42
7/8/2021	53.5	29.3	0	20:30	23:30	2	6.00
7/12/2021	49.8	26.7	0	20:45	23:00	2	4.50
6/8/2021	56.5	30.6	1	13:20	16:30	2	6.33
6/8/2021	71	26.3	3	21:10	23:30	2	4.67
6/9/2021	69.5	28.6	1	21:00	22:30	2	3.00
6/10/2021	68.2	29.2	1	21:00	23:30	2	3.00
6/16/2021	49.1	29	4	20:50	23:50	2	6.00
6/21/2021	59.2	21.1	2	22:00	23:30	2	3.00
6/24/2021	41.6	34.5	1	20:30	22:45	2	4.50
6/30/2021	78	25.9	21	21:15	1:20	2	8.17
7/13/2021	52.5	28.3	2	21:00	23:15	2	4.50
7/14/2021	54.6	28	3	21:30	23:30	2	4.00

Appendix B (*continued*): The number of RST encountered on surveys conducted in 2021 and 2022.

Date	RH (%)	Temp (°C)	Number of RST Encountered	Start Time	Stop Time	Number of Observers	Search Effort (hrs)
5/19/2022	50.1	27.7	0	21:00	23:42	3	8.10
6/1/2022	60.8	18.2	0	18:47	21:20	3	7.65
6/5/2022	69.7	25	0	19:30	20:37	3	3.35
6/7/2022	53.4	31.3	0	13:30	15:00	3	4.50
6/9/2022	67.4	24.8	0	20:40	22:28	3	5.40
6/14/2022	50.1	29.8	0	21:00	23:15	3	6.75
6/16/2022	59.1	28.1	0	21:40	22:20	3	2.00
6/18/2022	45.1	29.4	0	21:18	22:55	3	4.85
6/19/2022	53	28.4	8	21:36	23:25	3	5.45
6/20/2022	47	28.4	0	21:30	23:23	3	5.45
6/26/2022	51.2	20.3	2	21:23	23:11	3	5.40
6/28/2022	58.5	25	0	21:15	23:28	3	6.65
6/30/2022	50.2	26.6	5	21:34	23:51	3	6.85
7/7/2022	54.3	30.2	0	21:14	22:31	3	3.85
7/9/2022	56.9	28.1	0	21:39	22:54	3	3.75
7/12/2022	44.8	27.4	0	21:31	22:30	3	2.95
7/14/2022	33.8	31	0	21:37	22:52	3	3.75
7/20/2022	46.4	29.3	0	21:29	22:17	3	2.40

Appendix C: Non-target herpetofaunal species observed on surveys, during telemetry, and along road routes during 2021 and 2022 in Clark, Comanche, Barber, and Kiowa counties, Kansas.

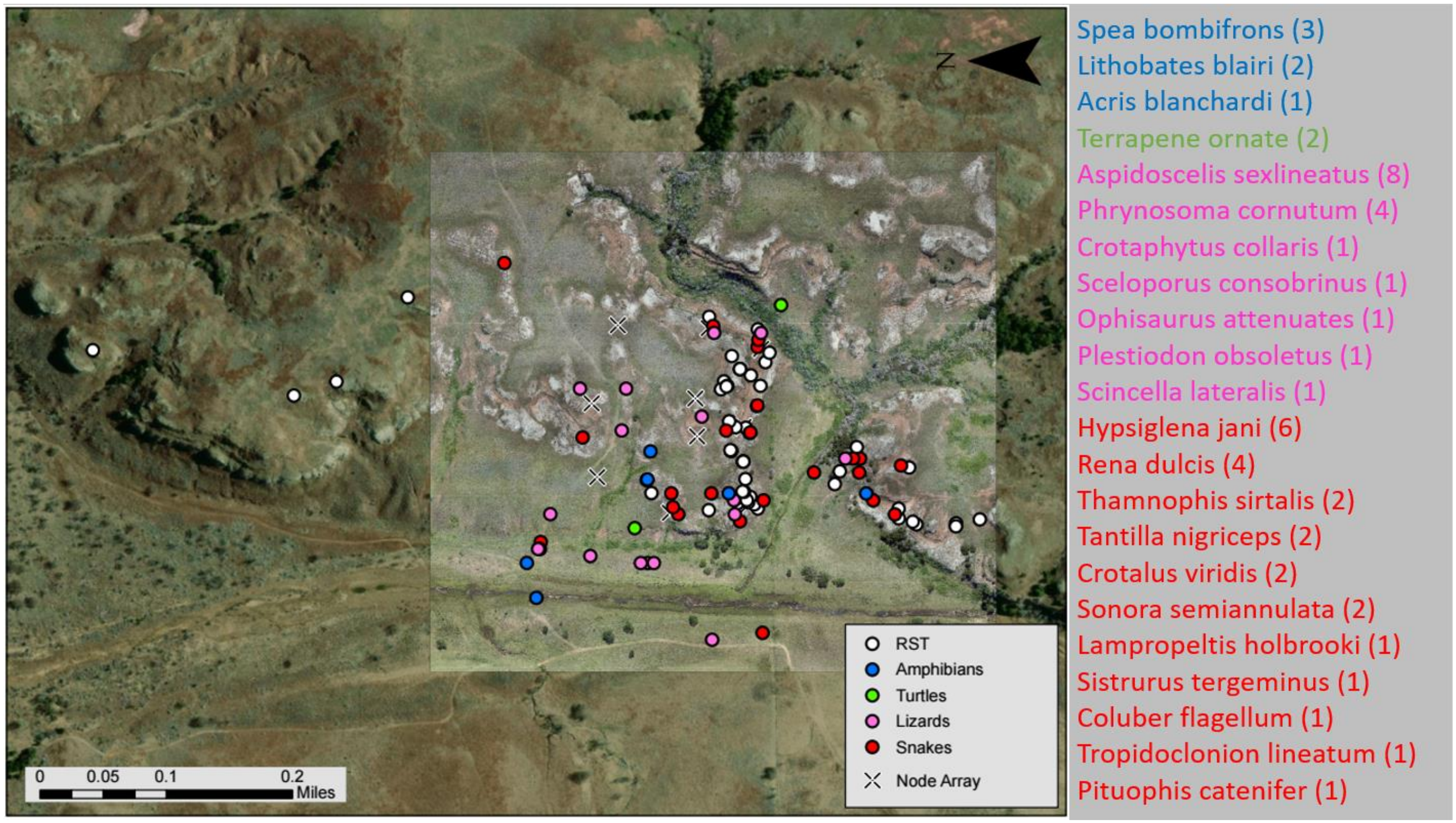
Common Name	Order	Scientific Name	Status	Quantity	Counties
Blanchard's Cricket Frog	Anura	*Acris blanchardi*		13	Barber, Comanche, Kiowa
Great Plains Toad	Anura	*Anaxyrus cognatus*		3	Barber
Woodhouse's Toad	Anura	*Anaxyrus woodhousii*		15	Barber, Comanche, Kiowa
Western Narrow-mouthed Toad	Anura	*Gastrophryne olivacea*		3	Barber
Plains Leopard Frog	Anura	*Lithobates blairi*		7	Barber, Comanche
American Bullfrog	Anura	*Lithobates catesbeianus*		3	Barber, Comanche
Spotted Chorus Frog	Anura	*Pseudacris clarkii*		2	Barber, Comanche
Plains Spadefoot	Anura	*Spea bombifrons*		6	Barber, Comanche
Spiny Softshell Turtle	Chelonia	*Apalone spinifera*		1	Comanche
Common Snapping Turtle	Chelonia	*Chelydra serpentina*		2	Clark, Kiowa
Yellow Mud Turtle	Chelonia	*Kinosteron flavescens*		3	Barber
Ornate Box Turtle	Chelonia	*Terrapene ornata*		29	Barber, Clark, Comanche, Kiowa
Pond Slider	Chelonia	*Trachemys scripta*		12	Barber, Comanche
Six-lined Racerunner	Squamata	*Aspidoscelis sexlineatus*		29	Barber, Clark, Comanche, Kiowa
North American Racer	Squamata	*Coluber constrictor*		2	Barber
Coachwhip	Squamata	*Coluber flagellum*		7	Barber, Comanche
Prairie Rattlesnake	Squamata	*Crotalus viridis*		5	Barber, Comanche
Eastern Collared Lizard	Squamata	*Crotaphytus collaris*		14	Barber, Comanche, Kiowa
Chihuahuan Nightsnake	Squamata	*Hypsiglena jani*	SINC*	9	Barber, Comanche
Speckled Kingsnake	Squamata	*Lampropeltis holbrooki*		2	Barber, Comanche
Plain-bellied Watersnake	Squamata	*Nerodia erythrogaster*		1	Comanche
Slender Glass Lizard	Squamata	*Ophisaurus attenuatus*		15	Barber, Comanche, Kiowa
Western Ratsnake	Squamata	*Pantherophis obsoletus*		1	Barber
Texas Horned Lizard	Squamata	*Phrynosoma cornutum*		38	Barber, Clark, Comanche, Kiowa
Gophersnake	Squamata	*Pituophis catenifer*		3	Barber, Comanche
Great Plains Skink	Squamata	*Plestiodon obsoletus*		3	Barber, Clark, Comanche

Appendix C (*continued*): Non-target herpetofuanal species observed on surveys, during telemetry, and along road routes during 2021 and 2022 in Clark, Comanche, Barber, and Kiowa counties, Kansas.

Common Name	Order	Scientific Name	Status	Quantity	Counties
Prairie Skink	Squamata	*Plestiodon septentrionalis*		1	Kiowa
Texas Threadsnake	Squamata	*Rena dulcis*	T**	4	Comanche
Prairie Lizard	Squamata	*Sceloporus consobrinus*		6	Clark, Comanche, Kiowa
Little Brown Skink	Squamata	*Scincella lateralis*		3	Comanche
Western Massasauga	Squamata	*Sistrurus tergeminus*		3	Barber, Comanche
Western Groundsnake	Squamata	*Sonora semiannulata*		9	Barber, Comanche
Dekay's Brownsnake	Squamata	*Storeria dekayi*		2	Barber, Comanche
Plains Black-headed Snake	Squamata	*Tantilla nigriceps*		3	Clark, Comanche
Common Gartersnake	Squamata	*Thamnophis sirtalis*		4	Barber, Comanche
Lined Snake	Squamata	*Tropidoclonion lineatum*		1	Comanche

*SINC = Kansas Species in Need of Conservation
**T = Kansas Threatened Species

Appendix D: Non-target herpetofaunal species encountered during the 21 visits to the telemetry site in 2022. Species are grouped by order. Within each order, species are listed from most frequently observed to least frequently observed. The number of observations of each species is placed in parenthesis beside the species name. The inset is an orthomosaic of the telemetry site.



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