Final Report

Life history and activity of the Peñasco least chipmunk (*Neotamias minimus atristriatus*)

Submitted to:
New Mexico Department of Game and Fish Share with Wildlife Program

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Introduction

The Peñasco least chipmunk (*Neotamias minimus atristriatus*) is endemic to the Sacramento Mountains of Lincoln and Otero counties, New Mexico (Bailey 1913, Conley 1970, Sullivan 1985, Sullivan and Petersen 1988). The state of New Mexico has listed this chipmunk as Endangered since 1983 and as a Species of Greatest Conservation Need. The New Mexico Department of Game and Fish (NMDGF) considers it threatened by habitat alteration, drought, wildfire, and potential competition (NMDGF 2016). In 2011, the United States Fish and Wildlife Service (USFWS) was petitioned to list this chipmunk under the Endangered Species Act and in 2012 the USFWS determined that listing the taxon was warranted but precluded and designated it as a Candidate with high magnitude threats (USFWS 2014). Historically, the Peñasco least chipmunk occurred in two distinct physiographic regions of the Sacramento Mountains: Sierra Blanca, Lincoln County, and the southern Sacramento Mountains, Otero County (Frey and Boykin 2007). However, the subspecies has not been verified in the southern Sacramento Mountains subrange since 1966, despite intensive sampling (Hope and Frey 2000, Frey and Boykin 2007, Wampler et al. 2008, Frey and Hays 2017). The Sierra Blanca population was verified in 1998, 2000, 2016, and 2018 (Ortiz 1999, Hope and Frey 2000, Frey and Hays 2017, Frey and McKibben 2018).

The Peñasco least chipmunk is a Pleistocene relic left on a "sky island" following the last glacial retreat (Patterson 1982). The least chipmunk is a high elevation, cold-adapted, montane species and so the Sacramento Mountains provide a mountaintop refugium in the hot and arid Southwest. A warming climate will force cold-adapted species to move up-slope, effectively shrinking the area of available habitat (Dirnbock et al. 2011). Species that undergo hibernation or winter torpor, such as the Peñasco least chipmunk, may be particularly vulnerable to changes in climate and weather patterns. In the face of anthropogenic climate change, it is critical to understand how the life history characteristics of the Peñasco least chipmunk (i.e., emergence, immergence, reproduction, activity) are influenced by, and dependent on, weather and climate. A better understanding of the interaction between climate and life history will help focus management and conservation strategies.

Our goal was to address important information gaps regarding the life history of the Peñasco least chipmunk that are crucial for making sound conservation and management decisions. We established an array of remote cameras and weather stations within the Lookout Mountain study area to monitor activity of the Peñasco least chipmunk population over the course of its active season during 2020. We collected weather data with iButtons for temperature and humidity and precipitation loggers for rain, and we linked life history traits to temperature, humidity, and rainfall, thereby providing key insights into how weather influences behavior and how climate change might alter the timing of life history events. Additionally, we used camera trap data to estimate abundance and density. Finally, the camera array represents an opportunity for the development of a long-term monitoring program for this core population of Peñasco least chipmunk at a relatively low cost.

Methods

Study area

We conducted the study in the Lookout Mountain-Ice Springs area of the Sierra Blanca subrange of the Sacramento Mountains in the Lincoln National Forest, New Mexico, USA (105°48'56.53"W, 33°23'48.41"N). The Sacramento Mountains are north-south trending mountains and Sierra Blanca (i.e., the White Mountains) is the northernmost subrange. Elevation of the study area ranged from 2900 m to

3530 m. Lookout Mountain is a prominent peak of the subrange, and Ski Apache, a developed ski area that receives heavy recreational use during winter and summer months, is located on the northeast face of Lookout Mountain.

Camera monitoring

We deployed 20 PC800 HyperFire camera traps (Reconyx, Holmen, WI, USA) in the Lookout Mountain-Ice Springs study area (Figure 1). We deployed the remote cameras within chipmunk home ranges identified during a radiotelemetry study in 2019 (McKibben and Frey 2020). We mounted cameras vertically approximately 45 cm above the ground using a PVC frame (McKibben and Frey 2021). We staked a PVC bait tube to the ground in front of each camera. We placed peanut butter inside the bait tube, which had holes to allow the scent to escape (Perkins-Taylor and Frey 2018). We rebaited cameras approximately once every month from 5 May through 5 November 2020. McKibben differentiated Peñasco least chipmunks from the sympatric and morphologically similar grey-footed chipmunks (*N. canipes*) using a key that we created and tested (McKibben and Frey 2021).

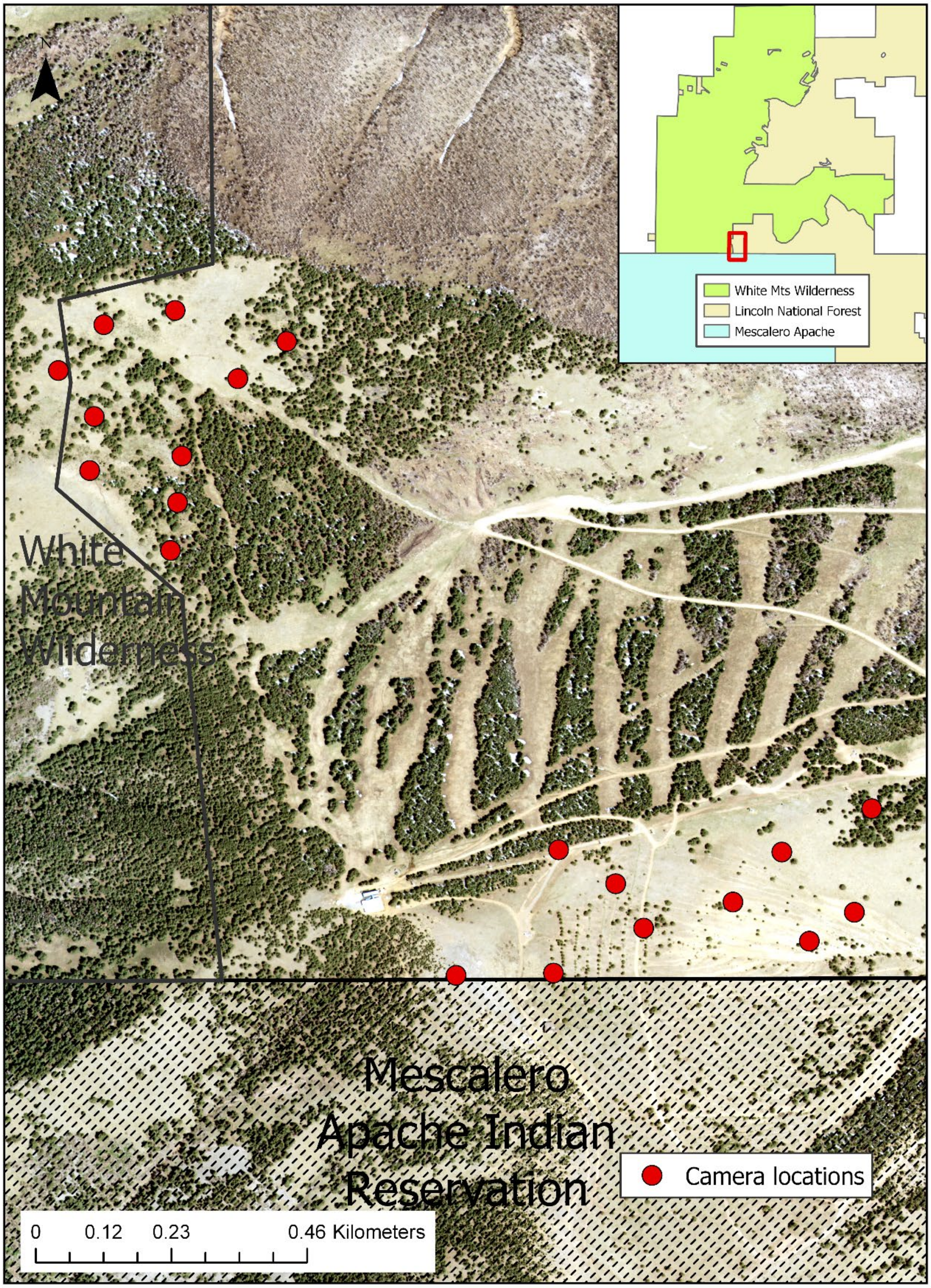

*Figure 1. Sites monitored for activity by the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2020.*

Climate and weather data collection

We deployed two Hobo Data Logging Rain Gauges (Onset, Cape Cod, Massachusetts, USA) within the study area to record precipitation. We deployed DS1923 Hygrochron iButtons (Thermodata, Whitewater, WI, USA) to record temperature and humidity at every camera trap site. We downloaded data and changed batteries approximately once every month from 5 May through 5 November 2020. We obtained climate data from the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information (NCEI) weather station at Sierra Blanca. The Sierra Blanca weather station is located at the base of Ski Apache (2900 m elevation), near the known Lookout Mountain population, and the data set runs from 2002 through present. We compared 17-year averages to the 2020 weather data.

Survival

During a separate field study conducted in 2019 in the Lookout Mountain-Ice Springs study area, we captured Peñasco least chipmunks and fit 23 chipmunks with uniquely numbered ear tags. We applied different colored nail polish to the ear tags to facilitate identification of individual chipmunks in photographs. We monitored the ear-tagged chipmunks via the remote cameras.

Abundance and density

Because we only obtained a small number of recaptures of ear-tagged, and thus uniquely identifiable, chipmunks on camera, we used two methods to estimate abundance and density. Spatially explicit capture-recapture (SECR) models use recapture data from uniquely identifiable individuals and relate the distribution of activity patterns to an observation model that estimates the probability of detecting an individual given the distance from its activity center (Borchers and Efford 2008). N-mixture models use repeat count data of unmarked individuals to relate abundance at detectors to the probability of detection (Royle and Nichols 2003). Because N-mixture models do not require individually-marked animals, they are easier to implement and can be estimated using only count data obtained from camera traps.

SECR model We used spatially explicit capture-recapture (SECR) models to estimate density of the Peñasco least chipmunk population in the Lookout Mountain-Ice Springs area. We used the “secr” package (version 3.0.1; Efford 2017) in program R to construct likelihood-based SECR models. We used a multi-session model to incorporate camera trap data from 2019 and 2020 (Figure 2). We treated each sampling session as independent. For the 2020 season, we used recapture data from 16 May to 4 June 2020, because the marks on the ear tags were most visible during the earliest capture month. For the 2019 season, we deployed 27 cameras in the same study area from 8 to 15 August (see McKibben and Frey 2020 for details of camera deployment). Because the sampling periods were relatively short (less than three weeks), we considered there to be both demographic and geographic closure in the population of interest during each session.

A SECR model estimates a state submodel (i.e., density) and an observation submodel. The state submodel describes the distribution of animal activity centers (D). In the original conceptualization of SECR models, the observation submodel relates the detection probability (g0) at a detector (e.g., camera trap) to the decline in detection probability as the distance between the detector and an animal’s activity center (sigma) increases. Instead of estimating g0 (the probability of detection for an individual at its activity center), we estimated lambda0 (the expected number of encounters per unit time for an individual). This was appropriate because camera traps are “count” detectors, allowing more than 1 detection of an individual per sampling occasion (Efford 2017). A detection function relates the expected number of detections to the distance from the home-range center for a given animal (Efford 2017). We assumed the shape of the detection function to be a hazard half normal function, which is appropriate when using a “count” detector, such as a camera trap (Efford 2017).

SECR models require an area of integration, commonly called a “habitat mask”, across which density is estimated (Efford 2017). The habitat mask should be a region in which all individuals with a non-zero chance of detection occur, and individuals that reside outside of the habitat mask should have a negligible detection probability (Borchers and Efford 2008). We defined our habitat mask by buffering camera traps by 666 m (a distance determined by the suggest.buffer function in the “secr” package), resulting in an area of integration that was 490 ha with average camera trap spacing of 93.1 m.

We hypothesized that detection would vary by time (t) and by a learned behavioral response (b). We tested three *a priori* models, including: a null model, a model in which detection varied with time, and a model in which detection varied as a learned behavioral response. We assessed relative model fit using Akaike’s Information Criterion for small sample size (AICc). We considered models with $\Delta AIC_c < 2$ as competitive models (Burnham and Anderson 2002).

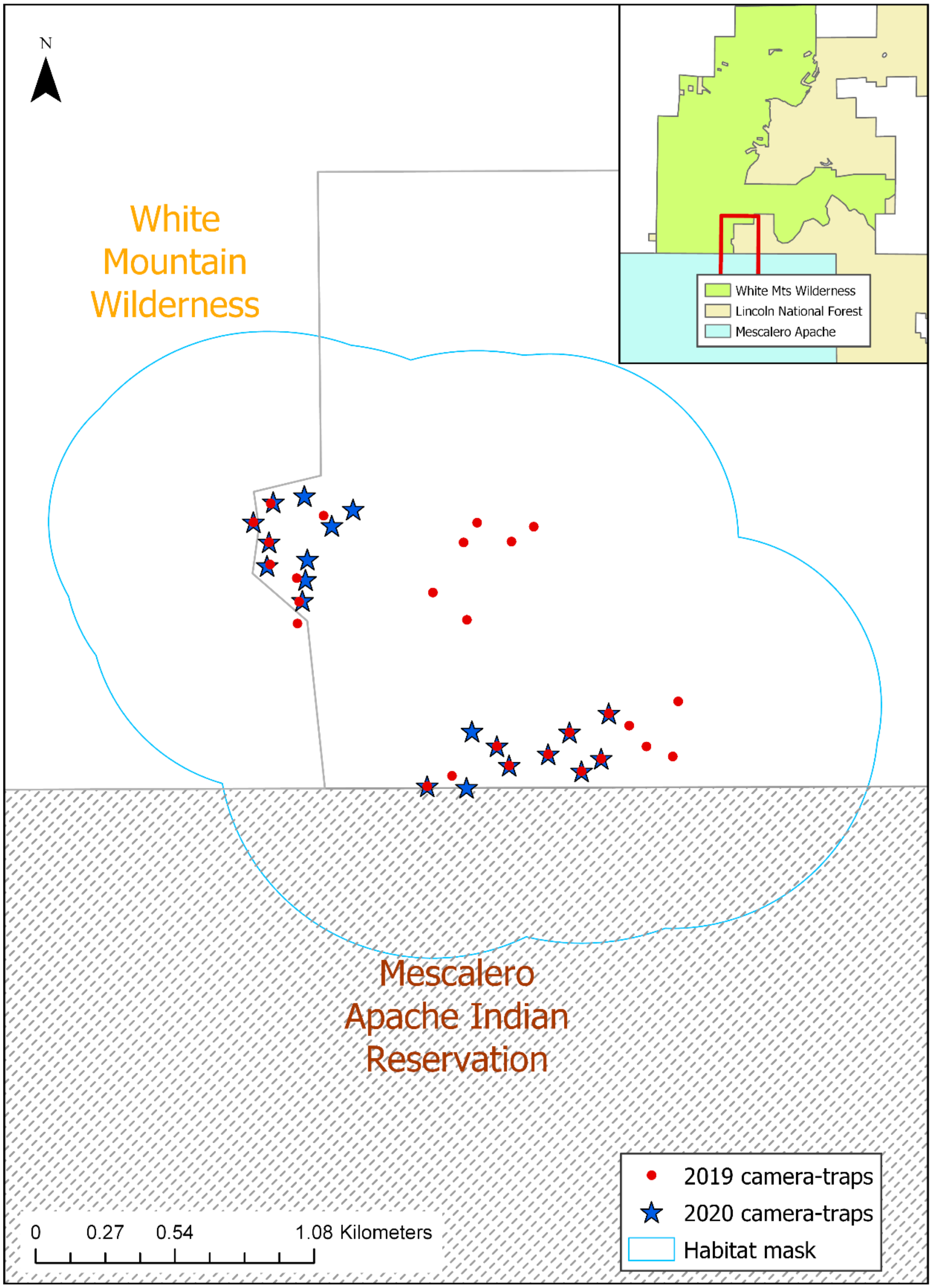

*Figure 2. Camera trap locations used in a spatially explicit capture-recapture model to estimate abundance of the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2019 and 2020.*

N-mixture model We used N-mixture models to estimate species abundance and density from count data, while accounting for imperfect detection (Royle and Nichols 2003). We used the count of individuals as the response variable in the N-mixture model. We set the latent abundance distribution as a Poisson random variable. We estimated abundance using camera trap data collected during 2019 and 2020. We fit separate models for each year because the sampling areas were different between the two years. During 2019, we conducted camera trap surveys in the Sierra Blanca subrange (see McKibben and Frey 2020 for details of data collection). We used 75 of these survey sites to estimate abundance (Figure 3). We chose these 75 sites because they were in the Lookout Mountain area above an elevation of 3248 m, which approximates the lowest elevation of a least chipmunk home range in the area, estimated based on camera trap data collected in 2019 (McKibben and Frey 2020).

We followed the same modeling process and tested the same hypotheses for each year. We hypothesized that detection would be influenced by bait age, maximum daily temperature, and daily precipitation. We hypothesized that abundance would be influenced by the proportion of montane tree cover, the proportion of subalpine tree cover, the proportion of herbaceous cover, an interaction between subalpine tree and herbaceous cover, and shrub cover. At each site, we calculated maximum daily temperature from the iButton sensor data and bait age. We obtained data on daily precipitation from the Sierra Blanca Trail weather station and created a categorical variable indicating if it had rained or not on each day (Menne et al. 2012). We did not use the data from the Onset rain gauge because these data were not collected during 2019.

We collected data on cover types throughout the study area from May – October 2019 to create a cover class map. We recorded the location of cover types using handheld GPS units during fieldwork. We obtained 4-band aerial imagery with 1-meter spatial resolution from 25 May 2016 from the National Agricultural Imagery Program (NAIP) United States Geological Survey (USGS) EROS Center (USDI 2016). We segmented the NAIP imagery before performing a classification (spectral detail=20; spatial detail=5; minimum segment size=20). We used the Support Vector Machine (SVM) classifier in the Image Analyst extension for ArcGIS Pro (ESRI 2017), which is a supervised classifier that uses a set of training samples to assign categories and has been shown to be highly accurate for land use/cover classifications (Tso and Mather 2009, Paneque-Galvez et al. 2013). We examined the field collected data and the NAIP imagery and manually selected a training dataset. The training data consisted of small polygons scattered across the image that represented the different land cover types of interest. Care was taken to distribute sufficient training samples within each land cover class to meet an appropriate minimum sample size as suggested by Tso and Mather (2009). We used the final cover map to estimate the proportion of montane tree, subalpine tree, herbaceous cover, and deciduous shrub cover within an 80 m radius of each camera trap site using the Focal Statistics tool in the Spatial Analyst extension for ArcGIS Pro (ESRI 2017). We calculated each variable within an 80 m radius of each camera trap site because we estimated that an 80 m radius circle approximated the home range of Peñasco least chipmunks in the Lookout Mountain-Ice Springs study area based on radio-telemetry data collected during 2019 (McKibben and Frey 2020).

We collected data on shrub cover at each site in the field on 3 equally spaced 20 m transects radiating from each camera site. Data collection occurred either simultaneously with or immediately after the camera was removed from a site. We recorded shrub cover at 1 m from the camera site and then every 2 m using a 20x50 Daubenmire plot and classing categories (0-5%, 5-25%, 25-50%, 50-75%, 75-95%, >95%; Daubenmire 1959). We read the Daubenmire frame from a 1 m height above the ground. We then calculated the mean % shrub cover at each camera site. We centered and scaled all variables by one standard deviation to improve model convergence and to facilitate interpretation of relative variable importance (Gelman and Hill 2007).

We first tested all possible combinations of the 3 detection covariates. We then tested 16 *a priori* models for abundance, testing combinations of the abundance covariates, while using the detection covariates from the best detection model. We assessed relative model fit using Akaike's Information Criterion for small sample size (AICc). We considered parameters to be uninformative if 85% confidence intervals overlapped zero, and we removed models with uninformative parameters from further consideration and recalculated model weights (Arnold 2010). We considered models with ΔAIC_c < 2 as competitive models (Burnham and Anderson 2002). When there was more than one competitive model, we model averaged to obtain a top predictive model. We fit the models using the unmarked and MuMIN packages in R (R Version 3.5.3).

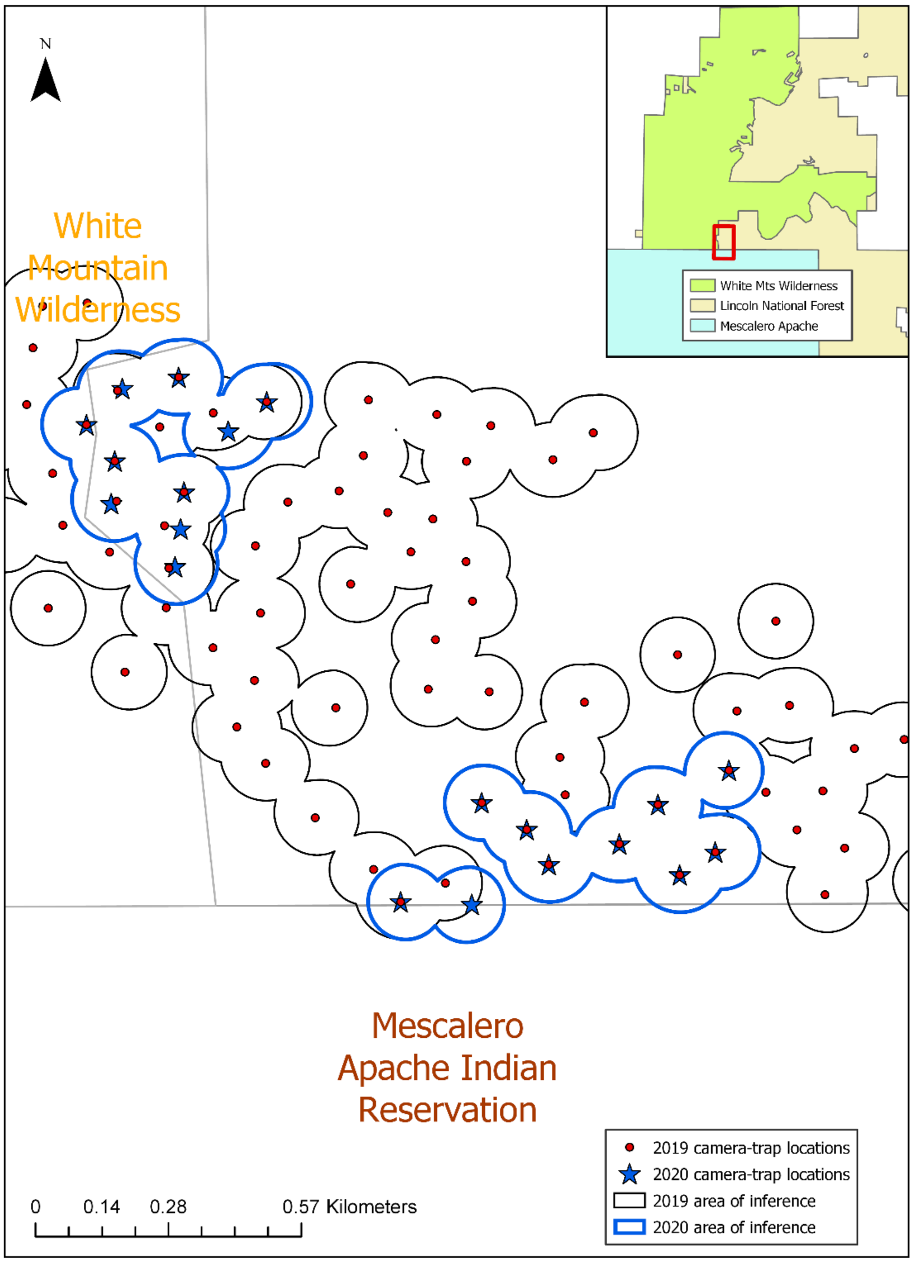

*Figure 3. Camera traps used in an N-mixture models to estimate abundance of the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, in 2019 and 2020. The area of inference is the area within an 80 m buffer of camera trap locations.*

Life history and reproductive data collection

We pooled reproductive data from three years of survey efforts in the Sierra Blanca subrange. During 2018, we conducted surveys using Sherman live-traps (model LFATDG; H. B. Sherman, Tallahassee, FL, USA) from 24 June through 17 September (Table 1), and we conducted surveys using remote camera traps at 40 sites from 21 June to 14 August. During 2019, we conducted surveys using Sherman live-traps from 29 May to 26 September (Table 1). During the same year, we deployed camera traps at 238 sites from 2 June to 7 October. In 2020, we deployed camera traps at 20 sites from 5 May through 5 November. We identified scrotal males, pregnant females, and juvenile chipmunks based on external characteristics. Scrotal males were chipmunks for which the testes were clearly visible, pregnant females were chipmunks with bellies that were visibly distended, and juveniles were small chipmunks with fluffier pelage. Due to small sample sizes, we pooled all the data across the three years and graphed the number of detections by day of the year.

*Table 1. Locations, dates, and effort for live-trapping surveys for the Peñasco least chipmunk (*Neotamias minimus atristriatus*), in the Sierra Blanca subrange of the Sacramento Mountains, New Mexico, USA, 2018-2019.*

Location Name	Survey dates	Trap days
Buck Mountain	25-28 July 2018	510
Ice Springs	23-27 June 2018	476
Lookout Peak	27-28 June 2018	102
Prospect	3-5 July 2018	255
Crest Trail	3-8 July 2018	340
White Horse Hill	9-12 August 2018	680
Lookout Mountain	23-24 August 2018	240
Ice Springs	25 August 2018	80
Buck Mountain	2-3 September 2018	240
Nogal Peak	14-17 September 2018	1440
Lookout Mountain	29 May - 1 June 2019	1000
Monjeau Peak	3-4 June 2019	500
Nogal Trailhead	14-19 June 2019	1920
Ice Springs	2-4 July 2019	720
Lookout Mountain	13 July 2019	300
Lookout Mountain	8-12 September 2019	1500
Ice Springs	23-26 September 2019	800

Influence of weather on activity

We evaluated the influence of weather on daily chipmunk activity using the camera trap data collected during 2020 and weather data collected via Hygrochron iButtons and Hobo Data Logging Rain Gauges. We hypothesized that daily chipmunk activity would decrease with daily temperature and would increase with daily humidity and daily inches of rainfall. We considered a count of daily detections as an index of daily activity (Schweiger 2021). We calculated the minimum, mean, and maximum daily temperature and the minimum, mean, and maximum daily relative humidity at each camera trap site, as well as the daily inches of precipitation. We used Poisson regression with a log-link to test how weather variables influenced daily chipmunk activity, as this method was used by Schweiger

(2021) to estimate the influence of weather on chipmunk activity in the Organ Mountains, New Mexico. We tested 16 *a priori* models, which consisted of combinations of the temperature and humidity variables. We did not include correlated variables in the same models (e.g., minimum temperature and mean temperature never appeared in the same model). We assessed relative model fit using Akaike's Information Criterion for small sample size (AICc). We considered parameters to be uninformative if 85% confidence intervals overlapped zero, and we removed models with uninformative parameters from further consideration (Arnold 2010). We considered models with $\Delta AIC_c < 2$ as competitive models (Burnham and Anderson 2002). For all competitive models, we assessed the variance inflation factor between predictor variables (VIF) and we considered variables with a VIF > 5 to be multicollinear (James et al. 2014). We did not model average across the competitive models because all of the models contained a combination of temperature and humidity variables and so model averaging would not have been appropriate.

Results and Discussion

Camera monitoring

Due to complications related to the COVID19 pandemic, we were unable to deploy cameras in April and thus may have missed the earliest dates of emergence from hibernation. A single remote camera, camera-stand, and iButton data logger were stolen from a survey site. We first deployed cameras on May 5, and we first detected a least chipmunk on 5 May. We detected least chipmunks at all of the 20 survey sites. We detected Peñasco least chipmunks at 19 of the survey sites, obtaining anywhere from 2 to 822 photographs at each camera site.

Survival

In 2020, we recaptured 4 known chipmunks on camera traps out of 23 chipmunks that had been fit with uniquely numbered ear tags during 2019 (Table 2). Because we only detected four known chipmunks out of the 23 that were originally marked, the sample size was insufficient to estimate overwinter survival rates. It is important to note that it is likely that more than 4 chipmunks survived, because we detected marked but unknown chipmunks via camera traps deployed in 2020 (i.e., an ear tag was visible, but we could not identify the individual because the colored paint was not visible or had chipped off).

Our system for marking individual chipmunks was partially successful, but a more permanent and visible marking technique (e.g., collars with colored beads) will be necessary to accurately estimate overwinter survival using camera traps. Because each ear tag has a unique identification number, which is usually not visible on camera trap photographs, survival rates might also be estimated using live-trap efforts in the future.

*Table 2. Unique field identification number, date marked with a numbered ear tag, and date first recaptured on remote camera during 2020 field season for four Peñasco least chipmunks (*Neotamias minimus atristriatus*) in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2020.*

Unique ID	Sex	Age/reproductive status when tagged	Date marked	Date first recaptured on camera	Number of recaptures on camera
1863	F	Juvenile	5/29/2019	5/25/2020	1
1869	M	Scrotal adult	5/30/2019	6/4/2020	6
1898	F	Adult	9/25/2019	5/16/2020	3
1900	M	Non-scrotal adult	9/24/2019	5/19/2020	1

Abundance and density

SECR model The null model was the only competitive model (Table 3). Using the null model, the estimated density was 0.03 chipmunks per hectare, with a 95% CI of 0.01-0.09 chipmunks per hectare (Table 4). Across the 490-hectare habitat mask, this model predicted a population of 14.7 chipmunks (95% CI = 4.9-44.1 chipmunks).

*Table 3. Spatially explicit capture-recapture models for estimating abundance of the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Sierra Blanca subrange of the Sacramento Mountains, New Mexico, USA, 2019-2020.*

Model name	K	AICc	delta AICc
Null	3	121.51	0.00
Behavioral response	4	196.97	75.46
Time	13	213.42	91.91

*Table 4. Back-transformed estimates (Estimate), standard errors (SE), and 95% confidence intervals (95% CI) for the top spatially explicit capture-recapture model to estimate abundance of the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2019-2020. D is mean chipmunks per hectare, lambda0 is the expected number of encounters per day for an individual, and sigma is a parameter relating the change in lambda0 to distance from an animal's activity center.*

Parameters	Estimate	SE	95% CI
D	0.03	0.02	0.01, 0.09
lambda0	0.09	0.04	0.04, 0.20
sigma	182.5	58.60	98.79, 337.21

N-mixture 2019 There was one competitive detection model for the 2019 data, which included the variables for precipitation and bait age (Table 5). There was one competitive model for abundance (Table 6). Abundance increased with an increase in shrub cover and decreased with an increase in subalpine tree cover (Table 7). Under the mean conditions across the sites where we surveyed, the model estimated 0.36 chipmunks per camera trap site. We used the top model to estimate the number of chipmunks per site, based on the conditions at each site. We estimated a total population of 46.4 chipmunks across the sites where we surveyed. Because the camera traps were spaced with a minimum of 80 m between survey sites, we considered each camera to represent a 2 ha area (80 m is approximately the radius of a 2 ha circle). Thus, our area of inference was a 150 ha area. Our top model estimates a density of 0.31 chipmunks per hectare.

*Table 5. Detection sub-models for the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Sierra Blanca subrange of the Sacramento Mountains, New Mexico, USA, 2019. Models with uninformative parameters were removed from the model set. Competitive models are indicated with bold typeface.*

Model number	Bait age	Precipitation (categorical)	Maximum daily temperature	K	AICc	ΔAICc	AICc weight
1	**X**	**X**		**4**	**248.53**	**0.00**	**0.65**
2	X			3	251.83	3.30	0.12
3		X		3	251.90	3.37	0.12
4			X	3	252.17	3.64	0.11

*Table 6. Abundance models for the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Sierra Blanca subrange of the Sacramento Mountains, New Mexico, USA, 2019. Models with uninformative parameters were removed from the model set. Competitive models are indicated with bold typeface.*

Model number	Montane tree	Subalpine tree	Herbaceous	Shrub	K	AICc	ΔAICc	AICc weight
1		**X**		**X**	**6**	**227.90**	**0.00**	**0.72**
2			X	X	6	232.08	4.18	0.09
3	X			X	6	232.66	4.76	0.07
4		X			5	232.93	5.02	0.06
5			X		5	233.17	5.26	0.05
6	X				5	237.04	9.13	0.01
7				X	5	246.54	18.63	0.00
8					4	248.53	20.63	0.00

*Table 7. Parameter estimates (β), standard errors (SE), and 85% confidence intervals (CI), for the top N-mixture models describing abundance and detection of the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Sierra Blanca subrange in the Sacramento Mountains, New Mexico, USA, 2019.*

	Variable name	β	SE	85% CI
Abundance	Intercept	-0.66	0.38	-1.41, 0.09
	Shrub cover	0.90	0.30	0.31, 1.49
	Subalpine tree cover	-1.09	0.27	-1.62, -0.55
Detection	Intercept	-2.31	0.52	-3.33, -1.29
	Bait age	-1.19	0.54	-2.25, -0.14
	Precipitation	0.78	0.36	0.07, 1.48

N-Mixture 2020 The top detection model for the 2020 data was the null model. The null model was also the only competitive abundance model for the 2020 data. Using the null model, we estimated the mean local abundance in the study area as 0.76 chipmunks per camera trap site. The average probability of detection was 0.07 at camera trap sites (Table 8). We estimated a population size of 15.2

chipmunks across the sites where we surveyed. Because the camera traps were spaced with a minimum of 80 m between survey sites, we considered each camera to represent a 2 ha area (80 m is approximately the radius of a 2 ha circle). Thus, our area of inference was 40 ha. The top model estimates a density of 0.38 chipmunks per hectare.

*Table 8. Back-transformed parameter estimates for an N-mixture abundance model for count data on the Peñasco least chipmunk (*Neotamias minimus atristriatus*) in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2020.*

Parameter	Estimate	SE	95% CI
Abundance	0.76	0.26	0.39, 1.48
Detection	0.07	0.02	0.04, 0.12

Abundance discussion During 2019, we affixed unique markings (ear tags and radio-telemetry collars) to 23 individual chipmunks. Therefore, we know that the SECR model underestimated the population size. In future studies, SECR models could be used to estimate abundance and density, if the system for marking individual chipmunks is improved. Because we detected marked but unknown chipmunks on camera in 2020 (i.e., an ear tag was visible, but we could not identify the individual because the colored paint was not visible or had chipped off), we suggest that a more brightly colored and permanent marking system would make it possible to more accurately estimate abundance/density from camera trap data. If chipmunks were marked shortly before the camera traps were deployed, the marks would still be visible and likely would result in a larger sample size of resighted animals.

The N-mixture model produced a more reasonable estimate of the population size. N-mixture models have an advantage over other methods for estimating abundance in that they require repeat count data without the necessity to mark individuals. However, Barker et al. (2017) show that N-mixture models are problematic and unreliable, in that they can produce vastly different inferences about total population size. Barker et al. (2017) suggest that N-mixture models are well-suited to estimating relative abundance; however, if reliable estimates of absolute abundance are necessary, researchers should spend effort acquiring recapture data.

Life history and reproduction

We pooled reproductive data from three years of survey effort. Our results indicate that reproductive males were scrotal by 8 May, which would be shortly after they emerge from hibernation. We detected scrotal males as late as 9 August suggesting that mating ceases by early August. We detected pregnant females from 29 May to 26 July. We detected juveniles from 29 May through 10 September (Figure 4).

We first detected a Peñasco least chipmunk on camera on 5 May 2020. Because the COVID19 pandemic prevented us from deploying cameras in early April, it is likely that chipmunks were active earlier than this date. The last date we detected a Peñasco least chipmunk was 5 October 2020. Because our 20 cameras monitored the area into early November, this date likely represents an approximation of final immergence for the population. On the date of the first detection the mean temperature was 47 degrees F and on the date of the last detection the mean temperature was 55 degrees F (Figure 5).

Life history discussion Our data on reproduction is consistent with findings on least chipmunks from other areas. Least chipmunks do not breed until their second year. They have one litter each year, although it may be possible for a female to have a second litter if she loses the first litter (Skryja 1974). Males are thought to emerge from hibernation first in order to gain access to females (Baker 1983). However, only females of sufficient body weight become reproductively active (Vaughn 1969). This means that some females are not able to breed until their third year, and these are likely to be those females that entered their first hibernation with low body weight. Least chipmunks have a gestation period of 28-30 days (Criddle 1943, Jackson 1961), and lactation requires 49 days (Skryja 1974). Thus, given the first noticeably pregnant female Peñasco least chipmunk was observed on 29 May, conception occurs around emergence. The young open their eyes at 30 days and are fully furred at 40 days when they start venturing out of the burrow. They become independent at 60 days when they are two-thirds grown subadults (Forbes 1966). Least chipmunks do not put on extensive fat reserves for hibernation but rather depend on stored food during hibernation. Thus, upon becoming independent, the young of the year must gather and store enough food to survive hibernation and gain enough body size to be able to reproduce the following year. Given these timing constraints, if a female emerged and conceived on 1 May, the young would be born on 31 May and they would become independent on 31 July. By 31 July, there is not enough time for the female to produce a second litter that would have enough time to build winter food stores, given that immergence into hibernation occurred 5 October. This reduced reproductive potential (one litter per year, females not able to breed until their second or third year) is a fundamental limitation on the ability of a Peñasco least chipmunk population to recover from disturbance.

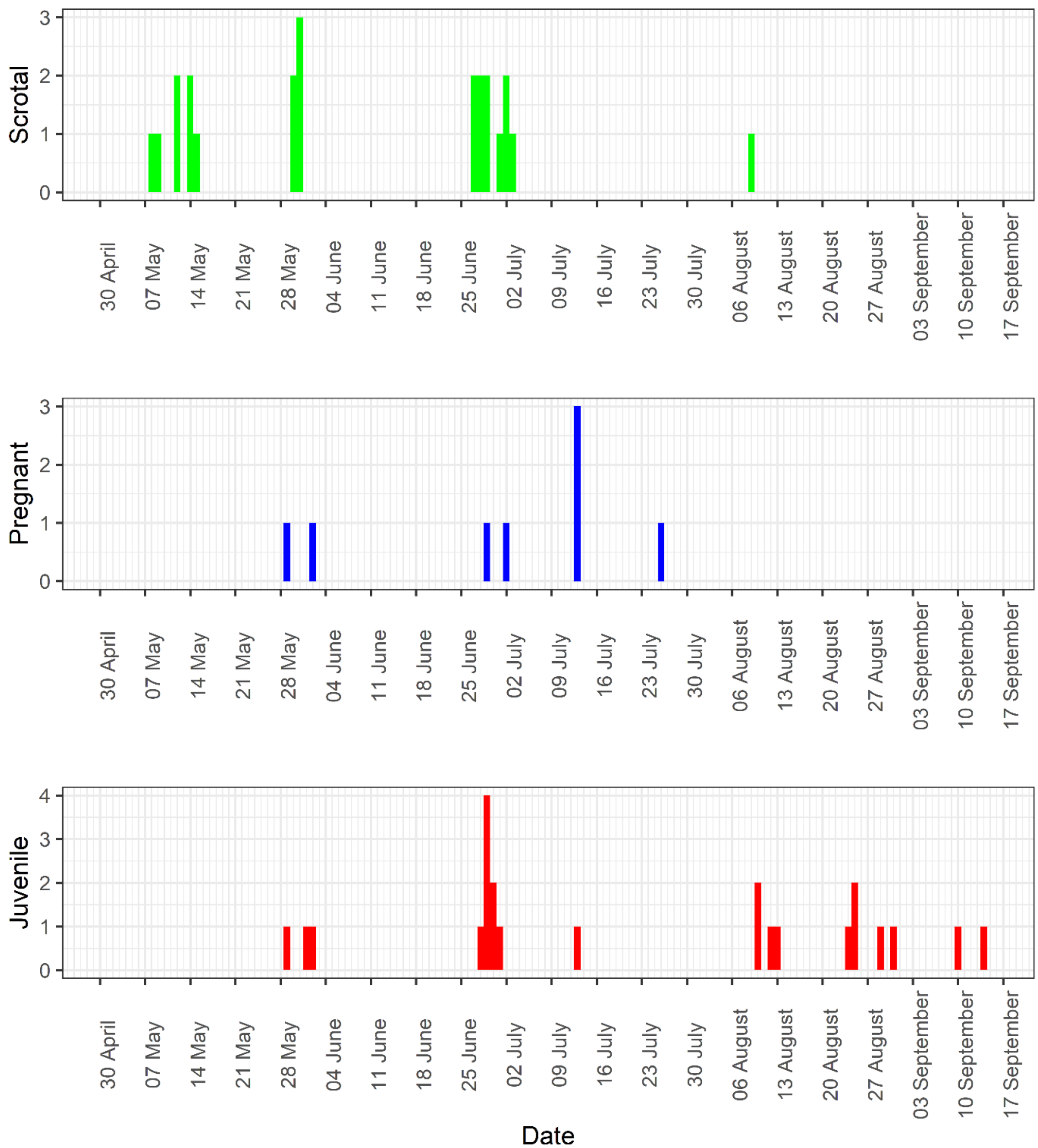

*Figure 4. Counts of scrotal, pregnant, and juvenile Peñasco least chipmunks (*Neotamias minimus atristriatus*) detected on camera traps and captured with Sherman live-traps in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2018-2020.*

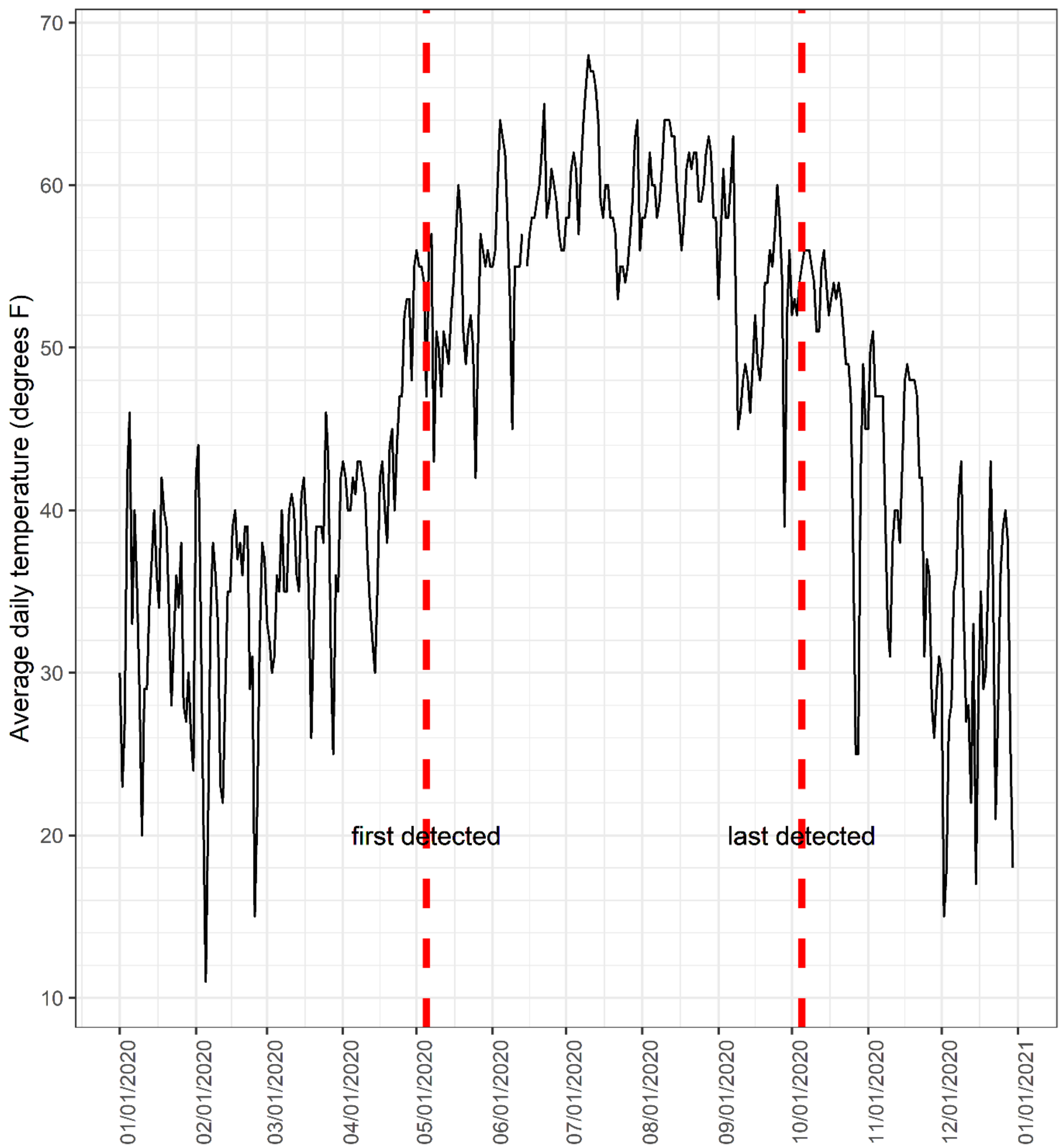

*Figure 5. Average daily temperatures (degrees F) in 2020 at the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information (NCEI) weather station at Sierra Blanca. Date of first and last detections of the Peñasco least chipmunk (*Neotamias minimus atristriatus*) as determined by camera traps in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2020.*

Influence of weather on activity

There were three competitive Poisson regression models with a $\Delta AIC_c < 2$. The variables in the competitive models were not highly correlated. The competitive models were similar to each other as each included minimum daily temperature and one of the variables for relative humidity. We considered the model with the lowest ΔAIC_c to be the top model (Table 9). The top model included mean daily relative humidity and minimum daily temperature. During the survey period, chipmunks were more active on days with higher mean relative humidity and lower minimum daily temperature (Table 10).

Time available when conditions are suitable to be active is an important resource for animals. Our results indicate that the Peñasco least chipmunk is limited by higher temperatures and lower humidity during the summer months. As the climate warms, temperatures will likely increase and there will be less precipitation (Kunkel 2013). These shifts could limit the available time for chipmunks to be active, which could ultimately influence fitness and species persistence.

*Table 9. Model selection results for models describing daily activity for the Peñasco least chipmunk (*Neotamias minimus atristriatus*) using data from camera traps in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2020. Competitive models are indicated with bold typeface.*

Model number	Mean daily temperature	Maximum daily temperature	Minimum daily temperature	Minimum daily RH	Maximum daily RH	Mean daily RH	Precip itation	K	AICc	delta AIC	AICc wt
15			**x**			**x**		**3**	**434.52**	**0.00**	**0.49**
14			**x**		**x**			**3**	**436.30**	**1.78**	**0.20**
13			**x**	**x**				**3**	**436.37**	**1.85**	**0.19**
9	x					x		3	438.68	4.16	0.06
8	x				x			3	439.95	5.43	0.03
7	x			x				3	440.60	6.09	0.02
3			x					2	446.46	11.95	0.00
17			x				x	3	446.79	12.27	0.00
1	x							2	449.16	14.64	0.00
18	x						x	3	449.60	15.08	0.00
12		x				x		3	463.60	29.08	0.00
11		x			x			3	463.75	29.23	0.00
10		x		x				3	465.02	30.50	0.00
2		x						2	465.66	31.14	0.00
19		x					x	3	467.60	33.08	0.00
20								1	501.41	66.89	0.00
16							x	2	502.27	67.75	0.00
4				x				2	502.65	68.13	0.00
6						x		2	503.32	68.80	0.00
5					x			2	503.34	68.82	0.00

*Table 10. Unstandardized parameter estimates (β), standard errors (SE), 85% confidence intervals (85%CI), and variance inflation factors (VIF) for the top model for daily activity of Peñasco least chipmunks (*Neotamias minimus atristriatus*) in the Lookout Mountain-Ice Springs study area in the Sacramento Mountains, New Mexico, USA, 2020.*

Variable name	β	SE	85% CI	VIF
Intercept	-7.35	1.42	-9.37, -5.27	
Mean daily relative humidity	0.16	0.04	0.10, 0.21	1.11
Minimum daily temperature	-0.18	0.03	-0.22, -0.14	1.11

Climate

In 2020, during the active period of the least chipmunk (May-September), the average monthly temperatures was slightly higher than the 17-year average (Figure 6) and the average precipitation was lower than the 17-year average (Figure 7). Given that the top activity model indicated a negative response to higher temperatures and lower humidity, activity of the chipmunk could have been depressed in 2020. This underlines concern regarding our currently warming climate if the chipmunk's activity is constrained to the point where it limits its ability to acquire resources.

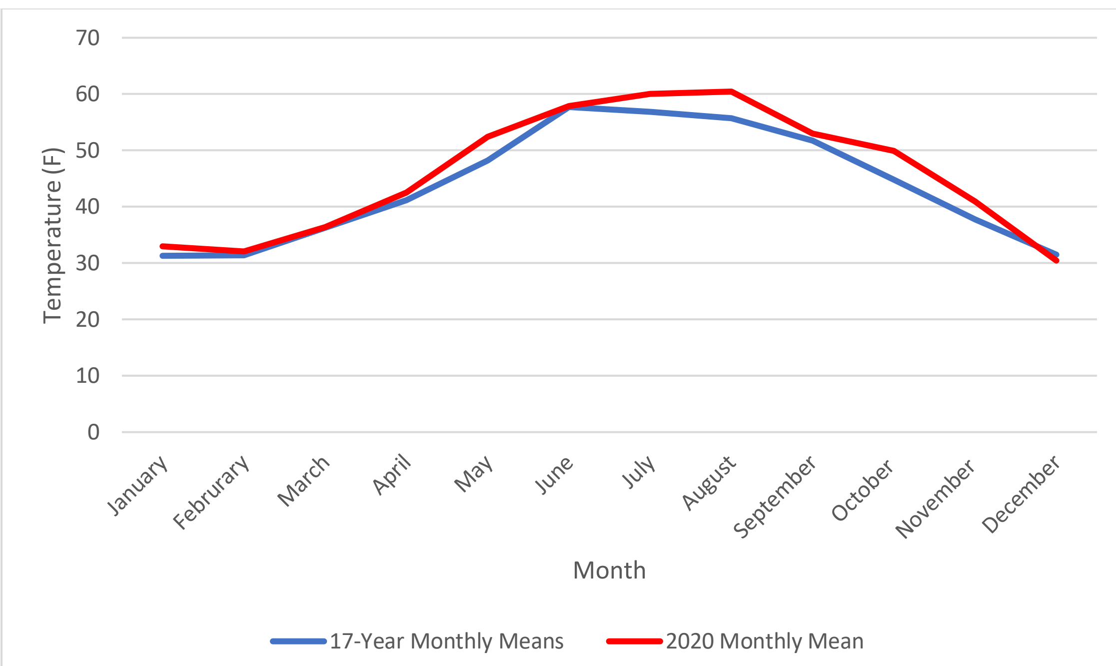

Figure 6. Mean monthly temperatures in degrees Fahrenheit at the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information (NCEI) weather station at Sierra Blanca. The 17-year monthly means were calculated for 2002-2019.

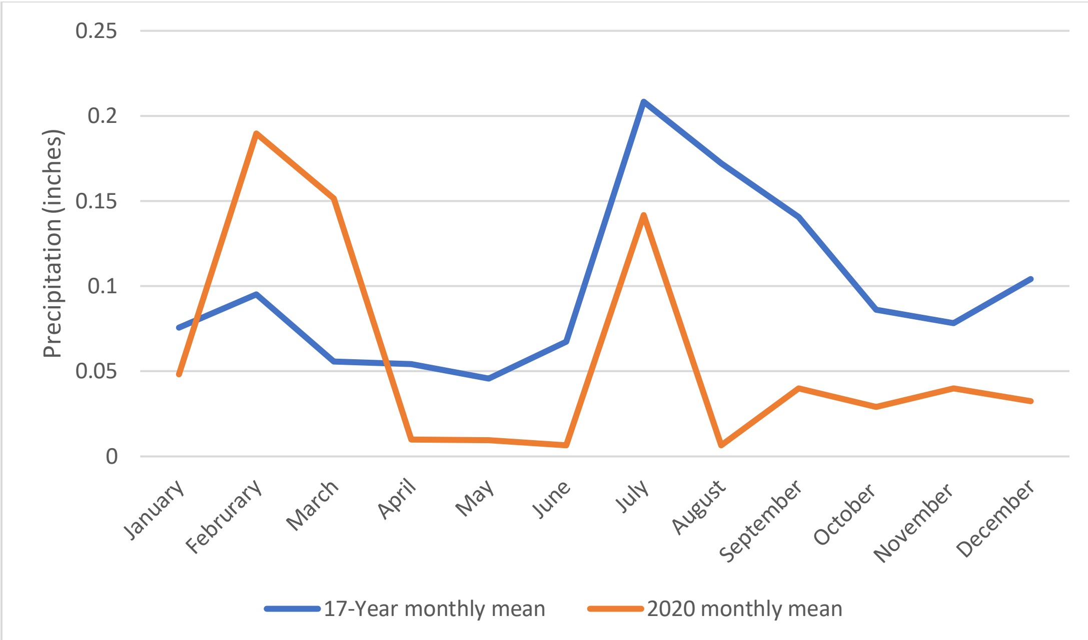

Figure 7. Mean monthly precipitation in inches of rainfall at the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information (NCEI) weather station at Sierra Blanca. The 17-year monthly means were calculated for 2002-2019.

Conclusions

Our results provide the first data on key life history characteristics for this subspecies of least chipmunk. We found that Peñasco least chipmunks survived overwinter, but more data are needed to achieve an accurate estimate of overwinter or two-year survival rates. We estimated that the population at Lookout Mountain-Ice Springs contains approximately 44 chipmunks, indicating that the population is extremely precarious and in need of protection and aggressive conservation measures. Our data on reproduction indicate that the subspecies likely has a low reproductive rate, which can make it difficult for the population to rebound after disturbance. Finally, our activity model indicates a strong influence of weather on the chipmunk's activity, with its activity constrained by higher temperatures and lower humidity. Changes to daily weather patterns can lower individual fitness and species persistence. While managers cannot change weather patterns, policies to mitigate the impacts of climate change could reduce threats to this least chipmunk subspecies.

Management recommendations

Future studies to investigate overwinter survival and to estimate abundance and density will need more permanent marking systems. We recommend investigating the use of uniquely marked collars rather than ear tags, because collars can be marked with beads, which do not fade over time. Future surveys to detect the Peñasco least chipmunk should consider the species' phenology and activity in relation to weather. Our abundance estimates indicate that the population at Lookout Mountain-Ice Springs is small and precarious. Protecting this population is of the utmost importance. Threats to the species' persistence include wildfires and disturbance from ski run construction and maintenance. Because the population is so small, mitigating threats to individual chipmunks is of the utmost importance. Finally, we demonstrated that our remote camera methods can generate much needed data on this population. We recommend that our methods be implemented for long-term monitoring of the population at Lookout Mountain-Ice Springs. As the largest known population of the subspecies, monitoring trends in population size, survival, and phenology will help better understand the influence of anthropogenic change on the subspecies' life history, can provide critical information on its persistence, and can serve as an important tool for adaptive management practices.

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