Seasonal abundance, population structure, and diet of long-nosed bats in southwestern New Mexico in relation to contemporaneous food availability

June 2022 Final Report

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Background

The federally endangered Mexican long-nosed bat (*Leptonycteris nivalis*) and the federally delisted lesser long-nosed bat (*Leptonycteris yerbabuenae*) are both identified as Species of Greatest Conservation Need (SGCN) by the New Mexico Department of Game and Fish (NMDGF) in their State Wildlife Action Plan (NMDGF, 2016). Although the geographic distributions of the Mexican long-nosed bat and lesser long-nosed bat overlap across much of their ranges in Mexico, in the United States, the two species only co-occur in southwestern New Mexico, where they share common roosts and food sources in the summer and early fall (Bogan et al., 2017). The lesser long-nosed bat has been documented in the Animas, Peloncillo, Big Hatchet, and Little Hatchet mountains (Findley et al., 1975; Bogan et al., 2006; Fleming et al., 2013; Bogan et al., 2017), while the Mexican long-nosed bat has been documented in the Animas and Big Hatchet mountains (Bogan et al., 2006; Bogan et al., 2017). The majority of sightings of these species have been reported in July, August, and September, but can occur as early as June or as late as early October (Findley et al., 1975; Hoyt et al., 1994; Bogan et al., 2006; Fleming et al., 2013; Bogan et al., 2017).

Long-nosed bats in New Mexico are believed to feed almost exclusively on the nectar of agave flowers, which they in turn help pollinate. As agaves only flower once in their lifetime before they die, the density of flowering plants on the landscape can be highly variable from year to year. However, the greatest abundance of long-nosed bats in New Mexico often coincides with the blooming of ephemeral agave flowers in this region (Bogan et al., 2006). Between 2004 and 2005 in the Peloncillo Mountains, agave flowering began in late June, with 90% of the agaves flowering in mid-July and August and no flowering agaves remaining in late September (Bogan et al., 2006). In the northern Animas Mountains, the agaves' blooming period was approximately two weeks behind that of the Piloncillo's, though the blooming period still ended in late September (Bogan et al., 2006). Much less is known about the density and timing of flowering agave in the Big Hatchet and Little Hatchet mountains. Therefore, these migratory nectarivores, as well as their food sources, merit careful monitoring.

Long-nosed bats can travel up to 100 km round-trip between their roosts and nightly foraging grounds, exceeding the known travel distances of other nectar-feeding bats (Medellín et al., 2018). Additionally, flowers of both columnar cacti and paniculate agaves may only be available for short periods of time regionally (Bogan et al., 2017). Therefore, it is difficult to differentiate between the effects of habitat destruction and natural variation in flowering plant density on bat population density (Moreno-Valdez et al., 2000), necessitating a better spatial and temporal understanding of bat and plant populations across their range.

Our team has been working in the Bootheel region of New Mexico with support from the Bureau of Land Management (BLM) since 2015 and conducted extensive research at a roost in the

Big Hatchet mountains in summer/fall 2019 and 2020 prior to being awarded support from a New Mexico Share with Wildlife grant for work in 2021.

Objective

Our research aims to document the current status of migratory long-nosed bats (lesser and Mexican long-nosed bats) at the summer/fall roost site on Big Hatchet Mountain and elsewhere in southwestern New Mexico. We are monitoring long-nosed bat population sizes, arrival/departure times, and local food availability, as well as collecting basic population structure and dietary information about these SGCN.

Methods

To achieve our project's objective, we identified a few key tasks that are described in detail below.

1. Flowering agave timing and density effects on bat population ecology — To estimate local bat population sizes, we counted long-nosed bats emerging from and entering into the Big Hatchet Mountain roost using thermal camera imaging. Our team has been working to obtain estimates of weekly population sizes from the 2019-2021 field seasons. In the thermal camera videos, long-nosed bats can be discerned from sympatric insectivorous bats based on their size and by the prominent musculature in their forearms (Ammerman et al., 2009).

   To estimate bat food availability, we manually monitored flowering agave density and phenology (i.e., the timing of flowering) and recorded any observed threats (e.g., intensive cattle grazing, fire) to agave persistence at a set of randomly selected points on public land within a 50km radius of the roost. To monitor agave density, we used the stationary count method from the lesser long-nosed bat post-delisting plan (i.e., surveying non-flowering agave within a 50m radius and flowering agave within a 250m radius of a random point; if no agave were present, the team marked the nearest flowering agave, typically with a 750m radius). Agave phenology monitoring for the 2021 season took place from 5/13/2021 to 9/20/21. The team set up 6 transects for monitoring agaves (92 plants, Palmer's century plant [*Agave palmeri*]; 25 plants, Parry's agave [*A. parryi*]). To monitor the phenology transects, we followed the recommended forage phenology monitoring protocol supported by the USFWS (Posthumus & Weltzin, 2018). The team conducted observational surveys weekly to monitor phenophases (i.e., stalk emergence, budding, and flowering) of individual agaves. Flowering stages were monitored by counting the number of flowering umbels and total umbels present to determine the percent of open and fresh flowers per plant. Additionally, the team deployed trail cameras to monitor high elevation Parry's agave. Each camera was deployed on an individual Parry's agave plant on the hike up to the peak of Big Hatchet Mountain. We are using high-resolution satellite imagery to create an agave classifier to automatically monitor agave density more comprehensively across years and within flowering seasons. Ongoing manual data collection will be used to further calibrate and ground-truth the remote-sensing algorithm. We investigated how weekly bat population sizes relate to contemporaneous food availability using generalized linear models.

2. Seasonal and interannual patterns of bat activity — To study how long-nosed bat activity varies within seasons and between years, we captured long-nosed bats using mist nets placed just outside the Big Hatchet Mountain roost entrance no more than once per week. For captured long-nosed bats, we deployed passive integrated transponder (PIT) tags subcutaneously between the bats' shoulder blades. This roost is already equipped with a Biomark PIT tag antenna system, and these tags allow us to record when marked long-nosed bats leave and enter this roost without the need to recapture individuals. Collaborators in Arizona (e.g., Sandy Wolf, Debbie Buecher), Texas (e.g., Loren Ammerman), and Mexico (e.g., Winifred Frick, Ana Ibarra) use similar setups of PIT tag antenna systems at other long-nosed bat roosts, allowing us to document movements between key roost sites.
3. Individual dietary behaviors — Given the absence of columnar cacti in southwestern New Mexico, long-nosed bats are presumed to primarily or exclusively feed on agave nectar (Hoyt et al., 1994; Bogan et al., 2017). To determine if this assumption is true, we examined the diets of long-nosed bats using fecal samples collected from a plastic ground sheet positioned just inside the roost and collected in hand from captured individuals. Samples from the ground sheet were collected every 7–10 days throughout the field season, at which time the sheet was exchanged for a new one. A subset of samples was then sent to Pisces Molecular Lab in Boulder, Colorado for analysis.

Results & Discussion

We have summarized our preliminary results below based on the Methods tasks described above.

1. Flowering agave timing and density effects on bat population ecology — Preliminary results from the 2020 and 2021 seasons suggest a substantial decrease in population size compared to the 7,000 bats reported by Cryan & Valdez (2008). Current analysis of our thermal camera data performed by undergraduates shows that, in 2020, the long-nosed bat population peaked the week of July 31, 2020 at <300 individuals and, in 2021, the population peaked the week of August 16, 2021 at <800 individuals. However, due to variation between observers and days in the week (due to processing times, we are currently only analyzing one night a week), we are not very confident in these results and have started developing alternative methods to analyze our thermal camera imagery. We are currently working with the Keys lab out of North Carolina State University to apply methods used to count bat populations in Kasanka National Park, Zambia to our thermal camera imagery collected at the Big Hatchet Mountain roost. We intend to use these updated methods, paired with multiple observer validation, to decrease the amount of time necessary to analyze a nightly video and subsequently increase the number of videos we can analyze for each week. This will allow us to generate weekly averages for population counts, which will be an improvement on our current protocol where we only analyze one night a week. Analyzing only one night a week may cause inconsistencies in our data. Also, by analyzing multiple days in a row, we can compare AM return counts with PM emergence counts to determine if the majority of the bats are emerging from the main entrance or if they are utilizing an alternative exit.

In terms of bat food availability, agave nectar was available in 2020 from June 14 to September 26, 2020 and peaked during the week of July 12, 2020. Agave phenology was delayed in 2021, and we noted a smaller percentage of fresh flowers in June with the first fresh flowers of Palmer's century plant observed on June 15, 2021 and the last fresh flowers recorded September 20, 2021 (Figure 1).

2021 phenology transects—The locations of the 92 Palmer's century plants and 25 Parry's agave plants monitored along 6 phenology transects were:

a. Big Hatchets: the road and hike up to the Big Hatchet Mountain roost site (2 plants, Palmer's century plant).

b. Big Hatchets: the road to Thompson Canyon (26 plants, Palmer's century plant*;* 1 plant, Parry's agave).

c. Big Hatchets: the hike up to the weather station at the peak of Big Hatchet Mountain (24 plants, Parry's agave).

d. Little Hatchets: along the road from Playas to Granite Pass (16 plants, Palmer's century plant).

e. Animas: County Rd 45 (41 plants, Palmer's century plant).

f. Johnson's Gap: Border wall road near the Luna and Grant County line (8 plants, Palmer's century plant).

Parry's agave phenology— The team deployed 4 trail cameras on 6/7/2021 to monitor high elevation Parry's agave. Each camera was deployed on an individual agave plant on the hike up to the peak of Big Hatchet Mountain. Unfortunately, 3 of the cameras overheated and failed to collect sufficient phenology data. Sufficient data were collected from one camera, 21BH04, which captured flowers opening the evening of 6/18/2021 and captured long-nosed bats visiting the flowers that night. Long-nosed bat visits persisted throughout the life of the camera battery. The flowers appeared to cease producing nectar by 7/12/21, and the last captured long-nosed bat visit was on 7/14/21, the night the camera died.

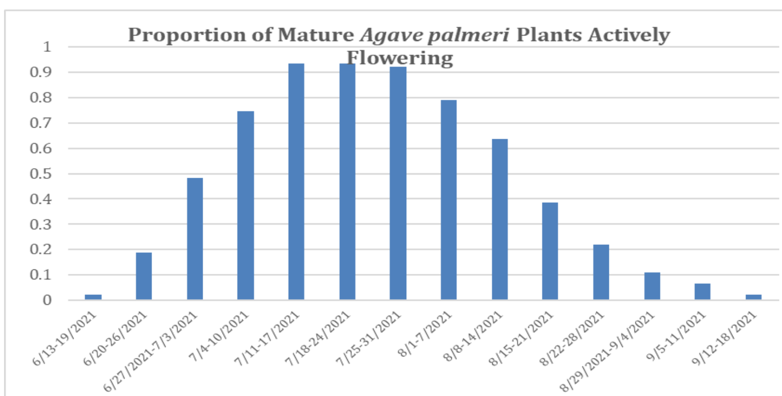

*Figure 1: Palmer's century plant (*Agave palmeri*) proportion of mature plants in 2021.*

2021 density of flowering plants—The team visited 59 of the 200 random points created in 2019, collecting a total of 385 agave plant locations. Combined with data collected during phenology surveys, the team collected a total of 502 individual agave plant locations to be used in the agave classifier.

2021 agave classifier—PhD student Mallory Davies built an agave classifier using a random forest model. Flowering agave presence and absence locations collected in the field (described above) were used to ground truth and train the classifier. Absence locations were generated using 500m buffers around completed agave density points, using Program R. To train the models, we used Normalized Difference Vegetation Index (NDVI) values that were calculated using Sentinel-2 multi spectral satellite imagery at a resolution of 10m and a previously constructed species distribution model (SDM) for agaves (Burke et al. 2019). Imagery was sourced from Copernicus Open Access Hub for a subset of the study region. Accuracy of the trained models were assessed using program R v4.1.0. Mallory determined that we can accurately identify patches of agave across the landscape using a random forest model paired with NDVI values from open source, 10 m resolution satellite imagery and the agave SDM (Figure 2). Further investigation is necessary to explore the possibility of distinguishing flowering agave from non-flowering agave. We plan to add additional variables, such as reflectance and pixel cover, to determine the number of flowering agave

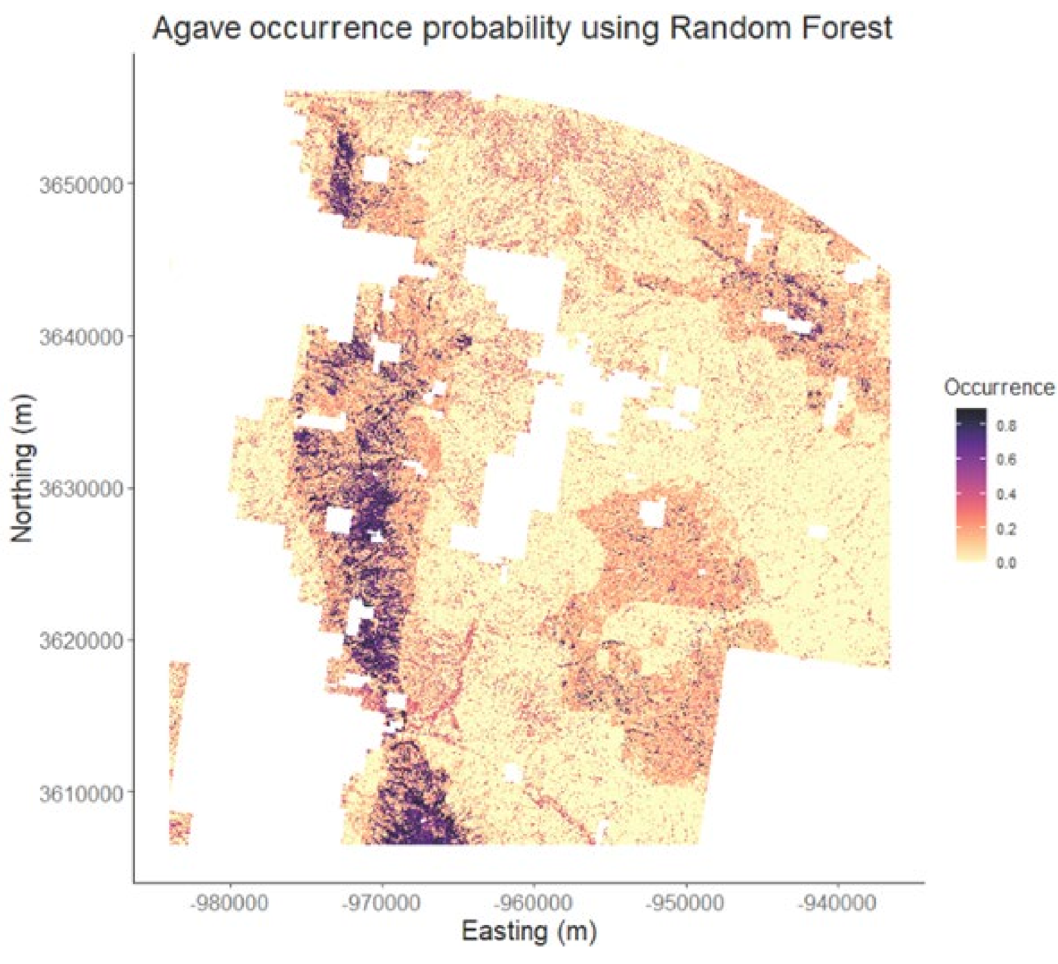

Figure 2: Random Forest model of agave occurrence probability for public lands in the northeast section of the Big Hatchet Mountain roost study area.

plants present per 10m pixel.

2. Seasonal and interannual patterns of bat activity — During the 2021 field season in the Big Hatchet Mountains, we detected 4 of 48 lesser long-nosed bats tagged by Theresa Laverty in 2019; 1 of the 4 went undetected in 2020. 17 of 75 lesser long-nosed bats tagged by Mallory Davies' field crew in 2021 were redetected that year. **Bolded DATES below** indicate detections that occurred the same night/morning the individual was initially tagged. 4 individuals that were tagged in 2019 and were redetected in 2020 but not in 2021 are included in the list. The list is ordered by the date the individual was originally tagged and dates from 2021 are listed first.

   1) From 2021: on 8/6/21, 8/8/21, 8/9/21, 8/10/21, 8/12/21, 8/13/21, 8/14/21, 8/15/21, 8/18/21, and 8/23/21; and from 2020: on 8/24/20, 8/25/20, 8/26/20, and 9/2/20, Tag # 982.000364842048 was detected. She was originally tagged as a juvenile female at 10:00 PM on 7/13/19.

   2) On 8/16/21, Tag # 982.000365079822 was detected. She was originally tagged as an adult female at 9:30 PM on 8/13/2019.

   3) On 7/24/21 and 8/17/20, Tag # 982.000364938633 was detected. She was originally tagged as a juvenile female at 9:43 PM on 8/13/19.

   4) On 8/7/20, Tag # 982.000364894153 was detected. She was originally tagged as an adult female at 12:30 AM on 8/14/19.

   5) On 8/3/20, Tag # 982.000364841968 was detected. She was originally tagged as an adult female at 1:16 AM on 8/14/19.

   6) On 8/20/20, Tag # 982.000364843939 was detected. She was originally tagged as an adult female at 10:04 PM on 9/6/19.

   7) On 8/19/20 and 8/24/20, Tag # 982.000364844508 was detected. She was originally tagged as an adult female at 5:56 AM on 9/7/19.

   8) From 2021: on 8/10/21, 8/11/21, 8/12/21, 8/13/21, 8/14/21, and 8/16/21; and from 2020: on 9/3/20, Tag #982.000365093084 was detected. She was originally tagged as an adult female at 6:19 AM on 9/7/19.

   9) On 7/29/21, Tag # 982.000364922048 was detected. He was originally tagged as a subadult male at 9:06 PM on 7/28/21.

   10) On 7/30/21 and 7/31/21, Tag # 982.000365083537 was detected. He was originally tagged as a juvenile male at 9:20 PM on 7/28/21.

   11) On **7/28/21,** Tag # 982.000364891044 was detected. He was originally tagged as a juvenile male at 9:39 PM on 7/28/21.

12) On **8/6/21**, Tag # 982.000365080522 was detected. She was originally tagged as an adult female at 5:38 AM on 8/6/21.

13) On **8/20/21**, 8/24/21, 8/26/21, and 8/27/21, Tag # 982.000365079811 was detected. He was originally tagged as a subadult male at 8:50 PM on 8/19/2021.

14) On **8/20/21,** Tag # 985.111000929223 was detected. He was originally tagged as a juvenile male at 9:06 PM on 8/19/21.

15) On 8/22/21, Tag # 982.000364836124 was detected. He was originally tagged as a juvenile male at 9:09 PM on 8/19/21.

16) On 8/25/21, Tag # 985.111000929224 was detected. He was originally tagged as a juvenile male at 9:28 PM on 8/19/21.

17) On **8/20/21**, Tag # 985.111000929227 was detected. She was originally tagged as an adult female at 9:14 PM on 8/19/21.

18) On **8/20/21**, 8/21/21/, and 8/26/21, Tag # 982.000364965961 was detected. He was originally tagged as a juvenile male at 9:35 PM on 8/19/21.

19) On 8/24/21, Tag # 985.111000929232 was detected. She was originally tagged as a juvenile female at 9:36 PM on 8/19/21.

20) On **8/20/21,** Tag # 985.111000929231 was detected. He was originally tagged as a juvenile male at 9:46 PM on 8/19/21.

21) On 8/23/21, Tag # 985.111000929229 was detected. She was originally tagged as an adult female at 10:04 PM on 8/19/21.

22) On **8/27/21** and 8/30/21, Tag # 985.111000929239 was detected. She was originally tagged as a juvenile female at 8:14 PM on 8/26/21.

23) On **8/26/21,** Tag # 985.111000929234 was detected. He was originally tagged as a juvenile male at 8:19 PM on 8/26/21.

24) On **8/27/21,** Tag # 989.001006772135 was detected. He was originally tagged as a juvenile male at 8:40 PM on 8/26/21.

25) **On 8/27/21**, Tag # 989.001006772166 was detected. He was originally tagged as a juvenile male at 8:44 PM on 8/26/2021.

Reproductive patch — Additionally, while PIT tagging, we made an unexpected observation during the 2021 field season. We captured two male lesser long-nosed bats with dorsal patches during mist netting in the Silver City area. Similarly, in 2019, at the Big Hatchet Mountain roost, we observed two males with a dorsal patch. Sexually active lesser long-nosed bat males often form an odoriferous dorsal patch during the mating season, created by a smearing behavior in which saliva, urogenital fluids, and anal secretions are spread over the interscapular dorsal region. Identifying regions where males present dorsal patches may not only assist in locating and protecting mating roosts but would also further our understanding of the population ecology of this migratory species.

3. Individual dietary behaviors — For the 2021 field season, the field team collected 319 fecal samples at the Big Hatchet Mountain roost site from the ground sheet and 6 fresh fecal samples from captured bats. Mallory and Kathryn sent 44 fecal samples (38 roost and all 6 from captured bats) to Pisces Molecular Lab in Boulder, CO to analyze samples to identify bat species, plant species, and insect species. The goals of these analyses are to further analyze long-nosed bat diet and test for the presence of the endangered Mexican long-nosed bat at the roost site. We are currently awaiting results. We intend to send samples from the 2022 field season for comparison. Remaining samples will be investigated under a compound microscope.

   From previous microscopic and molecular analysis of pooled bat fecal samples collected at the Big Hatchet Mountain roost in 2016 and 2017, our team confirmed that agave is essentially the only plant food source used by long-nosed bats and, surprisingly, about half of the pooled samples also contained insects (Sellers and Stoner, in prep.). Our lab results again confirmed that plants in the family *Asparagaceae*, presumably species of agave, are the only plant food resource in southwestern New Mexico but also found that 80% and 78% of our individual fecal samples in 2019 and 2020, respectively, contained arthropods (Laverty et al., in prep.). Long-nosed bats likely prefer nectar food sources but consume insects on nights when agave nectar is limited. BLM trail camera footage of long-nosed bats gleaning water from wildlife drip drinkers, and the presences of water lily aphids detected in guano via DNA barcoding analyses, suggests long-nosed bats are supplementing their diet with water sources, which is a unique observation for this species that was previously presumed to obtain enough water from the nectar they ingest. Results from the 2021 field season, as well as continued sampling, will allow us to determine how the long-nosed bat diet changes in relation to weather, local food availability, and bat population size.

   Molecular analysis of earlier pooled fecal samples confirmed the presence of Mexican long-nosed bats at the Big Hatchet Mountain roost in 2016. Without the genetic analysis of guano, this species otherwise would have gone undetected that year. The Mexican long-nosed bat has yet to be redetected using molecular techniques, but we switched from pooled to individual fecal sampling when our team restarted fieldwork in 2019. We may consider more pooled sampling efforts in the future (including samples from 2019, 2020, and 2021) to target redetection of the Mexican long-nosed bat. Additionally, in May 2022, in collaboration with the BLM and Bat Conservation International, Mallory Davies deployed a tarp deeper in the cave near the entrance of the main long-nosed bats' room to collect fecal samples throughout the period of bat occupancy in 2022. The tarp is scheduled to be collected at the end of October 2022; all fecal samples collected will be submitted for eDNA analysis to monitor for the presence of the Mexican long-nosed bat.

Products so far from SWW funding:

- Laverty, T.M., Davies, M.L., Wells, C.P., & Stoner, K.E. (in prep) Increased insectivory among the nectarivorous lesser long-nosed bats at the northern extent of its range. (Anticipated submission to: Animal Conservation).
- Laverty, T.M., Stoner, K.E., Wolf, S., Buecher, D.C., Davies, M.L., Medellín, R.A., & Frick, W.F. (in prep) Long distance movements of lesser long-nosed bats illustrate the value of PIT tagging networks. (Anticipated submission to: Journal of Mammalogy).
- Davies, M.L., Laverty, T.M., Caitlin, P.W., & Stoner, K.E. 2022. Plasticity of the lesser long-nosed bat diet at the northern extent of its range. *The Wildlife Society's 29th Annual Conference, in-person presentation to be presented in November 2022.*
- Davies, M.L., Laverty, T.M., Caitlin, P.W., & Stoner, K.E. 2022. Plasticity of the lesser long-nosed bat diet at the northern extent of its range. *50th Annual North American Bat Research & the 19th International Bat Research Conference, in-person presentation to be presented October 2022.*
- Davies, M.L., Laverty, T.M., & Stoner, K.E. 2022. Assessing long-nosed bat food availability by using remote sensing imagery to build an Agave classifier. *American Society of Mammologist, in-person and virtual poster, June 2022.*
- Laverty, T.M., & Stoner K.E. 2022. In search of bachelorettes: Observations of male *Leptonycteris yerbabuenae* with dorsal patches across its range. THERYA **13**.
- Peachy, G.J., Davies M.L., Walker B.R., & Stoner K.E. 2022. Impact of rainfall on insectivorous and nectivorous bats' emergence behavior and foraging timing. *Celebrate Undergraduate Research and Creativity conference, in-person and virtual poster, April 2022.*
- Davies, M.L., & Stoner, K.E. 2022. Long-nosed bat diet and movement in southwestern New Mexico. *Gila Natural History Symposium, virtual presentation, February 2022.*
- Davies, M.L., Laverty, T.M., & Stoner, K.E. 2021. Updates on *Leptonycteris* activity and nectar availability in southern New Mexico. *New Mexico Bat Working Group meeting, virtual presentation, December 2021.*
- Laverty, T.M., & Stoner, K.E. 2021. In search of bachelorettes: Observations of male *Leptonycteris yerbabuenae* with dorsal patches in southwestern United States. *Western Bat Working Group meeting, virtual presentation, April 2021.*

Note: We expect to develop and submit papers from most of the above presentations/posters.

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Impact of rainfall on insectivorous and nectivorous bats' emergence behavior and foraging timing

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Background and Significance

Bat populations in North America are currently in severe decline[1]. Effective monitoring strategies to obtain accurate population counts are necessary to conserve these populations. However, the effects of rainfall on bat activity are relatively unknown[2], leaving room for potential bias in population estimates under current monitoring protocols. Using thermal camera videos at a natural roost site in New Mexico, we assessed bat emergence times for nights with and without rainfall. We observed the timing of emergence and foraging activity (whether they exited and began foraging or returned to the cave) in both nectivorous and insectivorous bats to determine temporal and behavioral differences in response to rainfall throughout the season and between the two different foraging guilds. Understanding the effects rainfall has on bat emergence and foraging activity in arid environments can aid managers by identifying the most advantageous times to conduct population count surveys and aid future conservation efforts with insight on how climate change can affect different foraging bat populations[3].

Research Questions

1. **How does rainfall affect bats' emergence and foraging activity?**
2. **Do insectivorous and nectivorous bats react differently to rainfall ?**

Field Methods

Study Site and Research Design:

- Our study site was in a natural limestone cave within the Big Hatchet Mountains in Hidalgo County, New Mexico, United States.
- Axis Communications Q1942-E thermal camera was deployed just outside the main entrance of the cave and recorded nightly footage from May 2021– October 2021, data was downloaded weekly.
- A weather station installed at the base of the mountain recorded hourly rainfall (inches), data was downloaded weekly.
- We compared bat emergence on rainy (>0.015 in.) and non-rainy nights (=0.00 in).
  - lunar phase was controlled for nights with low moon.
- VirtualDub2 software was used to manually analyze nightly thermal footage.
  - Identification of individual bat foraging guilds (nectivorous/insectivorous)
  - Thermal video time of last frame bat was seen
  - Emergence bat behavior (to determine if they emerged and began to forage, or if they emerged and returned to the cave)
  - Other wildlife species and time frame recorded

Figure 1. Thermal camera video screenshot representing a nectarivorous bat (*Leptonycteris* spp.) emerging from the roost on the evening of 08/04/2021. This genus is identified by the warm yellow/orange body, pronounced forearm musculature, leaf-nose snout, and gap between its hind legs.

Preliminary Findings

- The **Expand Temporal Rain Effect Model** is our top performing model, holding 45% of the AICc Wt
- The top 3 models 99% of the weight of the AICc Wt

- **Bat emergence counts have a negative relationship with rain accumulation**
  - Model average of the rain effect parameter estimate is, -2.72
  - Rainfall negatively effects emergence timing and foraging behavior of both nectivorous and insectivorous bat foraging guilds.

- Also, **Expanded Temporal Rain Effect by Bat Foraging Guild Model** holds ~20% of the AICc Wt
  - The nectivorous bat foraging guild appears to be **affected more strongly by rainfall than insectivorous bats, but this pattern needs to be evaluated further**.

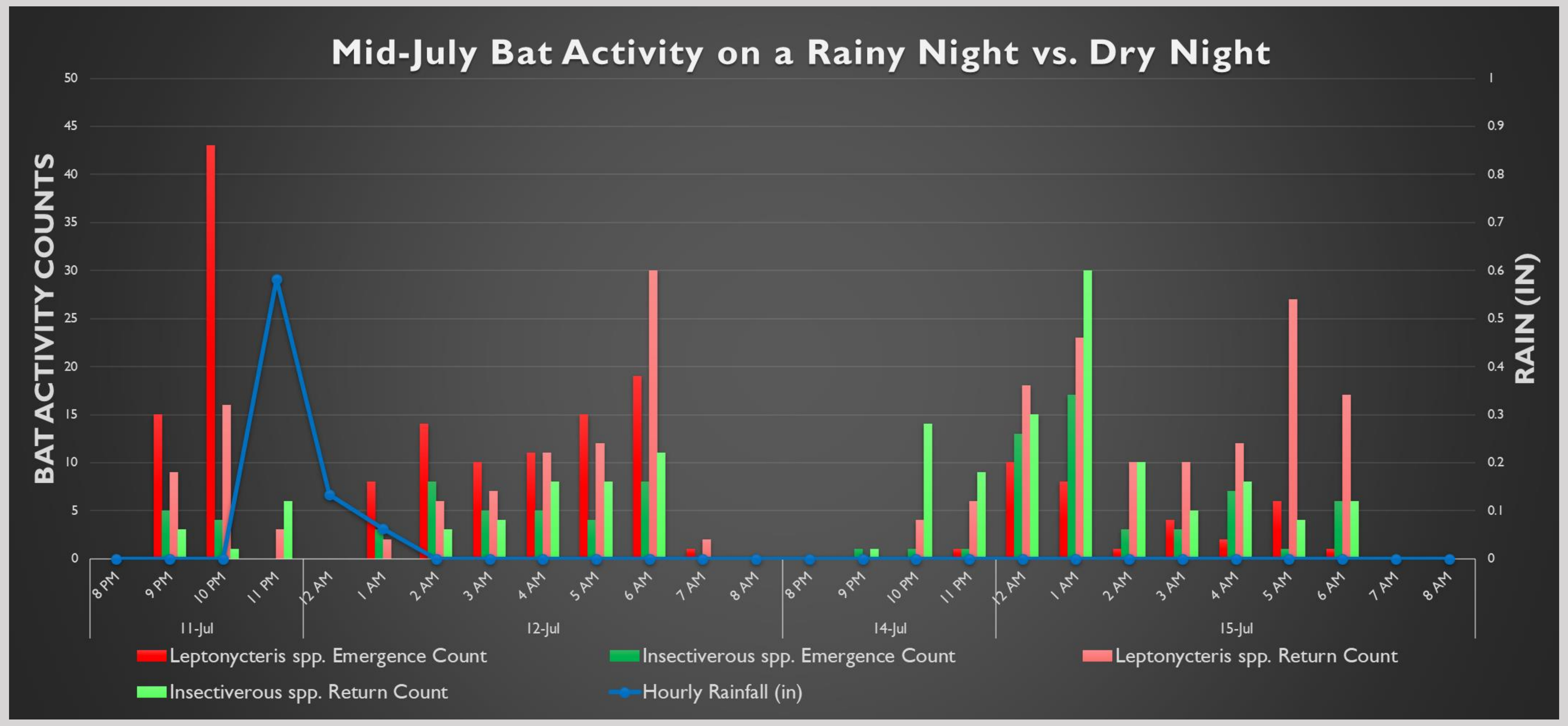

Figure 2. Bat activity over a subset of two nights, a rainy night (July 11th- 12th) and a dry night (July 14th- 15th), with distinct difference in activity patterns. The plot displays hourly rain (in.) and nectivorous (*Leptonycteris* spp.) and insectivorous bat hourly emergence and return counts. The rainy and non-rainy nights are paired to maintain a relatively constant bat population and lunar cycle. Rainfall was present from 10pm to 2pm of July 11th -12th showing less activity for both bat foraging guilds compared to the activity on the non-rainy night of July 14th-15th.

Discussion & Future Work

- Rainfall effects emergence of bats, since we have observed this while actively capturing bats in New Mexico.
- Rainfall appears to effect nectivorous bats more than insectivorous bats and we suggest this may be because insectivores forage closer to the roost, while the nectarivores must fly several km to reach foraging grounds with their flower resources.
- We plan on processing more thermal camera videos to evaluate a larger sample size of paired rainy to non-rainy nights to determine if the pattern observed here is consistent.
- We will continue to collect thermal camera nightly videos for 2022 and finish analyzing all videos from previous years,
- Other potential environmental factors that could be modeled that may affect bat activity include:
  - Weather; temperature, wind, atmospheric pressure
  - Migratory periods of the nectivorous bats (population changes on a weekly basis)

Data Analysis

Table 1. Results of AIC analysis, K is the number of parameters in the model. AICc is AIC for model c, and Delta_AICc is the difference between the AIC of the best fitting model and that of model c. AICcWt is the Akaike weight and Cum.Wt is the sum of Akaike weight. LL is the log-likelihood of the model c. Note- the bolded models (top 3) make up 99% of the model AICc weight .

Models	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
Expanded Temporal Rain Effect Model	**5**	**458.34**	**0.00**	**0.45**	**0.45**	**-223.93**
Expand Temporal Model	**4**	**458.82**	**0.48**	**0.35**	**0.80**	**-225.25**
Expand Temporal Rain Effect by Bat Foraging Guild Model	**6**	**460.01**	**1.67**	**0.19**	**0.99**	**-223.67**
Rain Effect Model	3	468.45	10.11	0.00	1.00	-231.13
Temporal Rain Effect Model	4	469.9	11.56	0.00	1.00	-230.79
Null Model	2	471.66	13.31	0.00	1.00	-233.78
Temporal Model	3	472.23	13.89	0.00	1.00	-233.02
Bat Foraging Guild Model	3	473.3	14.95	0.00	1.00	-233.55

We used generalized linear models and AIC model selection to determine if there was a significant difference in emergence time between nectivorous and insectivorous bat foraging guilds, and if there was a difference in foraging behavior.

Top 3 models

Expanded Temporal Rain Effect Model

- emergence counts vary hourly, weekly, and differ based on hourly rain (in.)

Expand Temporal Model Expanded

- emergence counts vary hourly and weekly

Expanded Temporal Rain Effect by Bat Foraging Guild Model

- emergence counts vary hourly, weekly, differ based on hourly rain (in.) and by bat foraging guild

Management Implications

1. Results of the effects of rainfall can aid managers by identifying the most advantageous times to conduct population count surveys.
2. Aid future conservation efforts with an insight into how climate change can affect different foraging guilds of bats in arid environments.
3. Support the monitoring efforts of the ESA listed *Leptonycteris nivalis* and the delisted *Leptonycteris yerbabuenae*
4. Support future research on what other environmental factors influence bat activity

Acknowledgements

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Assessing long-nosed bat food availability by using remote sensing imagery to build an *Agave* classifier

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Background

Long-nosed bats Populations of long-nosed bats (*Leptonycteris yerbabuenae* and *L. nivalis*) migrate 1,200 km north each spring from south-central Mexico to the southwestern U.S., following a hypothesized "nectar corridor" of flowering cacti and *Agave* spp. At roost sites, long-nosed bats travel up to 100 km round-trip to nightly foraging grounds, exceeding the known travel distances of other nectar-feeding bats (Horner et al., 1998; Medellin et al. 2018). Following the removal of the lesser long-nosed bat from the U.S. endangered species list in 2018, the U.S. Fish and Wildlife Service has advocated for post-delisting monitoring of bat populations at key roosts and estimates of local forage availability. However, the mosaic of landownership types surrounding roosts can render large portions of foraging areas inaccessible to researchers which impedes measurements of food availability.

Agave spp. In southwestern New Mexico (NM), *Agave* spp. are the primary food source of long-nosed bats. In this region of the Chihuahuan desert, the landscape is relatively open with sparse vegetation, allowing flowering agave to stand out. The dominant *Agave* species on the landscape is Palmer's century plant, *Agave palmeri*. This species only blooms once in its lifetime, can take 8-20 years to flower, and then fruits and dies. Agave density in this region ranges from patches of a singular plant to clusters of 10-25 individuals.

Objective

We aim to estimate the timing and relative amount of agave nectar that is available for the long-nosed bat population at the Big Hatchet Mountain roost in New Mexico by using remote sensing products paired with ground truthed data to overcome access barriers. In this preliminary work, we test the predictive power of two models, a random forest model and a generalized linear model, to create a classifier for flowering agave.

Field Methods

- Fieldwork was conducted in southwestern NM (Fig 1), from June to October 2020, coinciding with long-nosed bat occupancy.
- Agave plants were surveyed within a 50 km radius of the Big Hatchet Mountain roost, for a total of 7,853 km^2.
- To monitor agave density, we visited 87 of 200 random points generated in ArcGIS Pro using an agave species distribution model (SDM) (Burke et al., 2019).
- To monitor the seasonality of flowering, we identified 5 areas to conduct weekly phenology surveys, consisting of 125 plants.

Agave Classifier

- A random forest model and a generalized linear model (GLM), were used to determine the prediction power of flowering agave using remote sensed data.
- Flowering agave presence and absence locations collected in the field (described above) were used to ground truth and train the classifier.
- Absence locations were generated using 500m buffers around completed agave density points, using Program R.

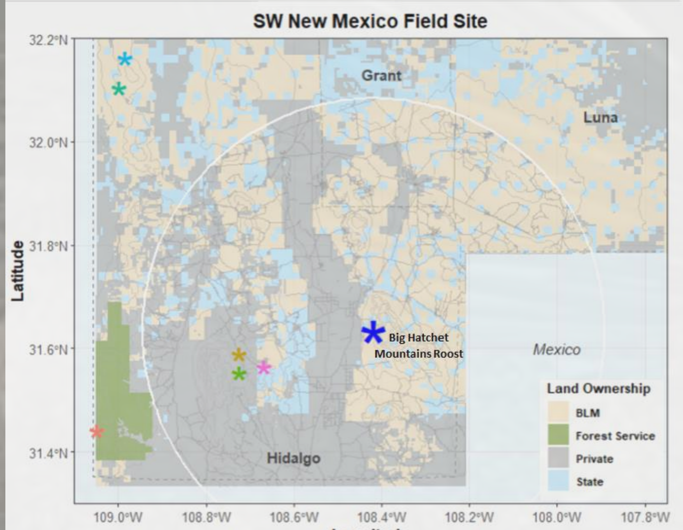

Figure 1: Map of the study area. White circle represents the 50 km radius around the Big Hatchet Mountain roost, the largest blue star. Other stars represent known roost sites and abandoned mines.

- To train the models we used Normalized Difference Vegetation Index (NDVI) values that were calculated using Sentinel-2 multi spectral satellite imagery at a resolution of 10m and the agave SDM (Burke et al. 2019).
- Imagery was sourced from Copernicus Open Access Hub for a subset of the study region.
- Accuracy of these models was assessed using program R v4.1.0.

Key Findings

- Using a random forest model, we can identify agave patches with freely sourced 10 m resolution remote sensing imagery.
- NDVI value is an important predictor for flowering agave occurrence.
- The development of vegetation classifiers using open-sourced remote sensing imagery can help managers overcome barriers to land access and is financially feasible.

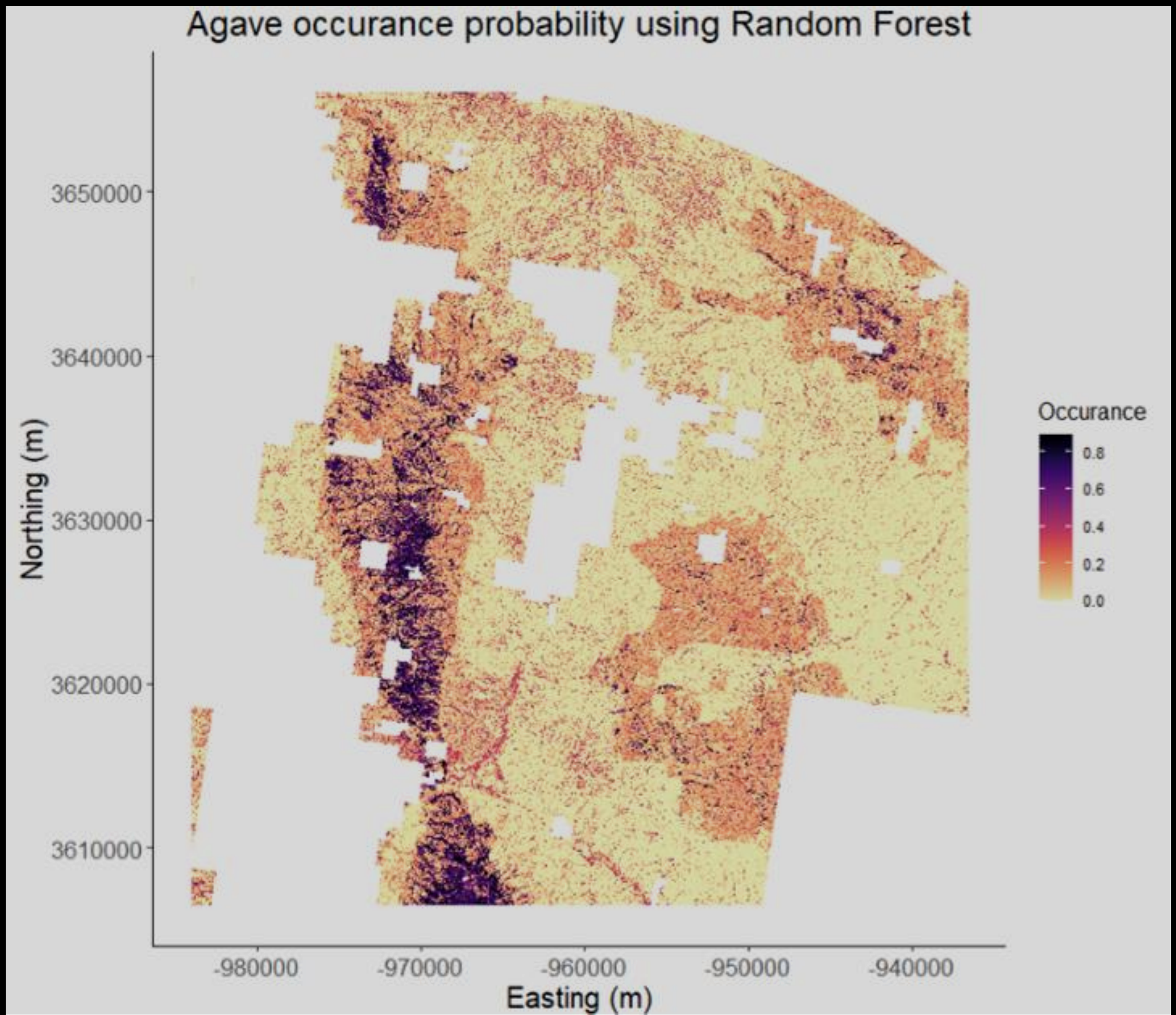

Figure 2: Random forest model, agave occurrence probability map, for public lands in the northeast section of the Big Hatchet Mountains roost study area.

Results

The random forest model performed better than the GLM using 2020 data on flower agave presence and absence locations, calculated NDVI values at 10-m resolution, and Burke et al.'s (2019) agave species distribution model.

- The random forest model had a greater area under the curve (1 vs 0.815), a higher correlation coefficient (0.816 vs 0.496), a greater True Skill Statistic [sensitivity + specificity -1] (1 vs 0.6), and a higher kappa value (1 vs 0.5) than the GLM. Overall, this shows a greater predictive strength and indicates high performance of the model.
- The variable importance plot (Fig 3) shows a high predictive power of NDVI values for identifying flowering agave across the landscape and shows a contribution from the agave class SDM layer as well.

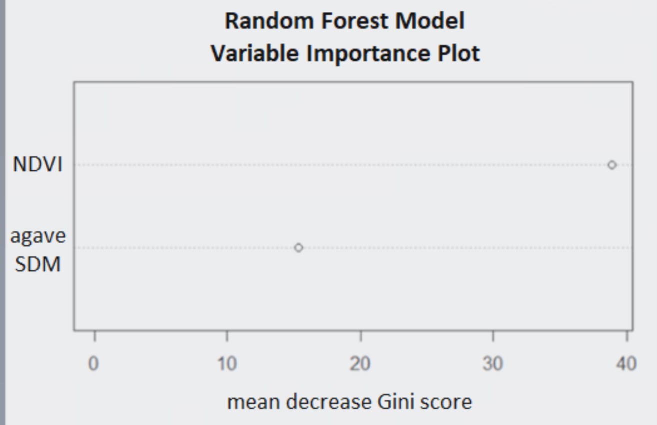

Figure 3: Variable importance plot showing the contribution of predictors to the random forest model.

Discussion

Using the preliminary 2020 flowering agave data with a 10-m pixel resolution the Random Forest model predicted agave occurrence for all known individuals set aside for validation at a minimum value of 0.25 probability of agave occurring with a mean of 0.48. The agave occurrence probability map (Fig 2) shows the areas of dark red and purple (occurrence from 0.3 and higher) make up dense patches within the study area separated by large patches of yellow and orange (occurrence from 0.2 and lower). Further analysis is necessary but preliminary findings show strong evidence the classifier can identify patches of agave across the landscape. Future work will focus on distinguishing flowering agave from non-flowering agave. Our findings will be useful for studying vegetation characteristics relevant, not only to long-nosed bat conservation, but also may be useful in developing vegetation classifiers for numerous species with other conservation applications.

Management Implications

Outputs form this research will allow both scientists and managers to better monitor flowering agave density and phenology across vast areas of open desert landscapes and help prioritize areas for ongoing agave restoration efforts. Collaborating with a network of scientists in the United States and in Mexico, we have learned of the timing of arrival and departures of long-nosed bats. Without a more systematic way to monitor food availability though, our insights are limited. If successful, this tool will ultimately allow us to test ecological theory in determining the drivers of movement and migration in both a near-threatened and an endangered species.

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Leptonycteris yerbabuenae photo by Kathy Adams Clark.

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