

# Acoustic Surveying for the Hawaiian Hoary Bat (*Lasiurus semotus*) in Māhukona Reserve, Hawai‘i

By Grace Guo<sup>1</sup>, Mei Rao<sup>1</sup>, Keone Emeliano<sup>2</sup>, Larissa Sugai<sup>1</sup>

<sup>1</sup>K. Lisa Yang Center for Conservation Bioacoustics, <sup>2</sup>Hawai‘i Land Trust

## Abstract

We conducted passive acoustic monitoring for the Hawaiian hoary bat (*Lasiurus semotus*) in Māhukona Navigation and Ecological Complex, Hawai‘i, a reserve recently purchased by the Hawai‘i Land Trust in 2023. We aim to establish a baseline for bat acoustic activity in the area during the beginning of the reserve’s restoration. We collected nightly recordings in a grid layout throughout the reserve from January 3–18, 2025, cycling recorders between the sites. Preliminary analysis conducted in a BirdNET model trained on mainland U.S. bats revealed higher density of bat acoustic activity in certain areas of the reserve, but work remains to be done before any conclusions can be drawn regarding overall habitat usage.

## Introduction

The Hawaiian hoary bat, also known as ʻōpēʻāpēʻā (*Lasiurus semotus*) is a federally endangered species and the only terrestrial mammal native to the Hawaiian Islands. It is an insectivorous species that roosts in vegetation and lives in various habitats (Jacobs, 1994). The distribution of this species on the island of Hawai‘i is not well-understood, with previous acoustics studies suggesting seasonal migration from low-elevation to high-elevation regions during the non-breeding season (Menard, 2001) and lower winter occupancy of low coastal regions (Gorresen et al., 2013). However, radio-tracking research has revealed individual *L. semotus* movements between vast elevational zones within just a night (Bonaccorso et al., 2015). These somewhat conflicting reports obscure the understanding of habitat usage for the species. Due to the limited research into the spatial ecology of *L. semotus* across the island, particularly in patterns of activity across seasons, there is a need to further investigate the use of lower-elevation habitats in the non-breeding season.

The Māhukona Reserve (“Māhukona Navigation & Ecological Complex”) is a historical and ecological preserve covering 642 acres of land

and 4 miles of coastline on the Kohala coast within the land divisions Kapa‘a Nui, Kou, Kamano, Māhukona, Hihiiu, and Kaoma ahupua‘a. It was originally intended for resort development, but in 2023 it was purchased by the Hawai‘i Land Trust for long-term preservation of historical and cultural sites. Most significantly, it is home to Ko‘a Holomoana, a navigational heiau which remains a pilgrimage site for nautical voyagers. There have been an additional 175 ancient Hawaiian cultural sites which have been identified within the property (Hawai‘i Land Trust).

In addition to the maintenance of significant archaeological sites, the reserve aims to protect habitat through native plant restoration. There are several areas within the Māhukona Reserve that are designated for coastal sandalwood, wiliwili, and other native coastal plant restoration. There is also anecdotal evidence of *L. semotus* being present in Māhukona Reserve, although it is unclear during what season and with what frequency or regularity the bats occupy the region.

Understanding range and habitat use in different regions of the island of Hawai‘i is important to informing conservation efforts and land management for protecting this

threatened species. One effective way to increase our understanding of this animal's activity and spatial use of the island is through bioacoustic monitoring. For nocturnal species, such as bats, acoustic surveyal methods are especially useful because they reduce the difficulty associated with visual point counts. Here, we use passive acoustic monitoring at ultrasonic frequencies to detect and map *L. semotus* acoustic activity in a newly established reserve.

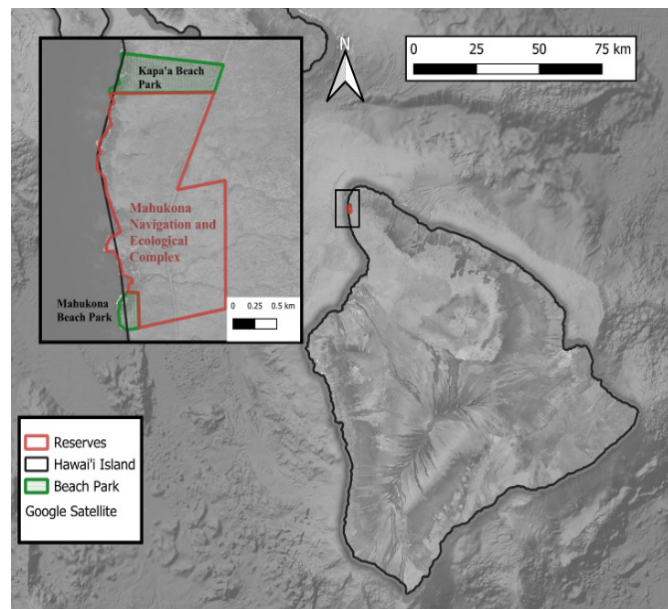
## Objectives

We aim to establish a bat activity baseline for the Māhukona Navigational and Ecological Complex. We hope that this baseline will prove

useful for future analysis regarding the potential efficacy of the restoration on *L. semotus* population recovery.

## Predictions

1. We predict that there will be present *L. semotus* acoustic activity at sites across the Māhukona Reserve, based on anecdotal individual sightings.
2. We predict that habitat type will affect the abundance of bat detections, particularly that there will be an increase in bat detections in open areas as opposed to dense tree canopy areas due to a lack of obstacles for nocturnal aerial foraging activity.



**Figure 1:** Map showing the study area on Hawai'i Island, focused on the Māhukona region along the island's northwestern coast. The main map depicts the full island with an inset box indicating the study location. The inset map zooms in to show the boundaries of the Māhukona Navigation and Ecological Complex (outlined in red) as well as nearby Kapa'a and Māhukona Beach Parks (outlined in green). This map situates the study area within the broader geographic context and highlights the overlap between ecological reserve lands and coastal public access zones.

## Methodology

### Study Area

The Māhukona Reserve habitat consists of mostly rangeland with rocky and soily terrain, sparse tree cover across most of the area and denser stands along the coast. It covers an elevational range of 0–100 meters above sea level. The reserve is on the leeward and western side of

the island, and it covers a 4-mile stretch of rocky coast, with a number of bluffs overlooking the ocean. The vegetation consists predominantly of non-native trees and grasses, including kiawe (*Prosopis pallida*) and buffelgrass (*Cenchrus ciliaris*) (National Cooperative Soil Survey, 2012). There are some native plants present, including 'uhaloa (*Waltheria indica*), along with sites designated for future native plant restoration across the reserve as shown in Figure 2 (Hawai'i Land Trust).

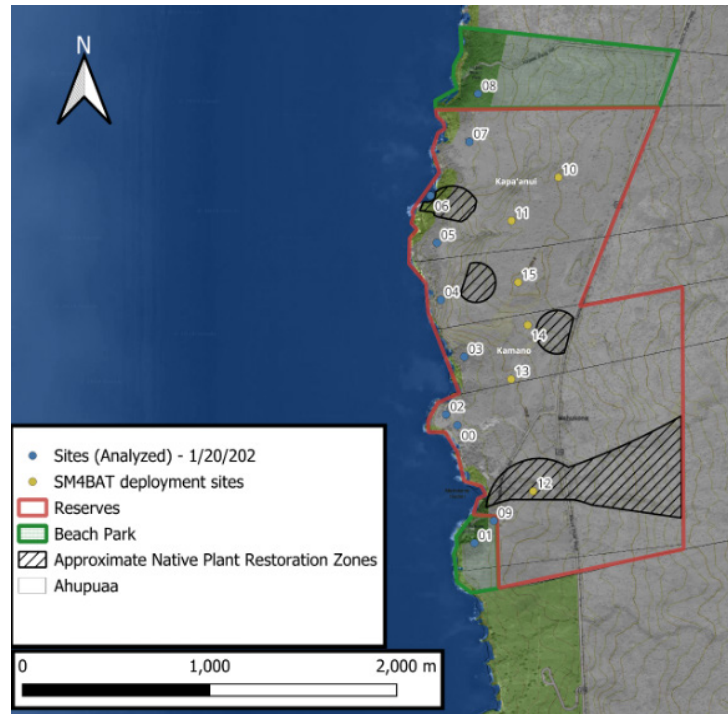
## Acoustic Data Collection

We used Song Meter SM4BAT FS Ultrasonic Recorders and SMM-U2 Ultrasonic Microphones (Wildlife Acoustics, Inc.) to conduct surveying of acoustic activity of *L. semotus* in the Māhukona Reserve in Kohala, Hawai'i at various sites (Appendix Table 1), from January 3 to January 17, 2025. We rotated two recorders daily among different locations within the reserve, enabling broad spatial sampling despite logistical constraints. Our spatial sampling was therefore composed of the following components: “micro” spatial scale (< 1 kilometer between sites), “high” total number of recorders (> 10 sites), “single recorder” distribution per site, and “rotating between-site” and “static within-site” recorder displacement following established protocol (Sugai et al., 2020). Sites were chosen to provide a broad coverage across the reserve with variable habitat and elevation. Some limitations to site selection included inaccessible terrain and archaeological

sites in the reserve. We deployed a grid layout of 16 sites throughout the reserve to establish a bat detection baseline for the area (Figure 2, Appendix Table 1). Location metadata were collected using the GPS Tracks mobile application (DM Software Solutions, 2012).

## Recorder Deployment

Recorders were secured to trees using zip ties and buckle straps. We attached the microphones between 1–2.5 meters above the ground, with the microphone facing upward. Recorders were programmed to record over a full spectrum continuously overnight, from 6pm to 7am (18:00-07:00) UTC-10:00, at a 256 Hz sampling rate, a bit depth of 16 bits, a 12 dB gain level, and no 16K highpass filter. After each recording, the recorders were re-deployed at a new location for the following night, with the exception of two deployments. “Recorder Deployment 00” and “Recorder Deployment 03” remained stationary for 9 and 3 nights, respectively, due to limited site access.



**Figure 2:** Map showing the spatial distribution of acoustic recorder deployment sites for monitoring Hawaiian Hoary Bat activity in the Māhukona Reserve region of Hawai'i Island. Ten monitoring sites (labeled 00–09) are positioned primarily along the coastline and within key land management zones. The map highlights areas of ecological importance, such as native plant restoration zones and protected reserve lands, to contextualize site placement. Sites analyzed as of January 2022 and those using SM4BAT detectors are indicated to distinguish between completed and active data collection efforts. This spatial layout supports investigations into how bat activity overlaps with habitat restoration and land use types.

# Acoustic Data Analysis

Due to time constraints, only recordings from sites 00–09 were included to identify bats for this preliminary analysis. Detections were identified using BatNET, a birdNET model trained for classifying multiple eastern North American bat species with 6x-slowed audio input (Kimmel, 2025 [Unpublished manuscript]). We set the confidence interval to 0.1 to maximize the number of potential detections made by BatNET.

We then manually evaluated the detections made by the first generation of the BatNET model through a combination of visual comparison of the spectrograms to known *L. semotus* calls (Gorresen et al., 2017) and aural comparison of the detections at normal speed in Raven Pro software to eliminate non-bat acoustic detections. For positive *L. semotus* classifications, we only included extremely confident search-phase clicks and feeding buzz detections (Gorresen et al., 2017), and excluded social calls in this analysis.

## Heat Map Generation

To reduce temporal bias for the recorders deployed at sites longer than others, we calculated the average number of nightly bat detections (Appendix Table 2).

$$\text{Avg. number of nightly detections} = \frac{\text{Total Site Detections}}{\text{Total \# of Hours Deployed at Site}}$$

Site locations were plotted on a map using QGIS and then transformed with heat map symbology weighted by the average nightly count. We increased the radius of each point's heat map to 150 meters at scale to introduce overlap. (QGIS Version 3.34.11)

## Preliminary Results

We manually reviewed approximately 5,000 out of 9,000 detections made by the BatNET model for sites 00–09. Approximately 0.8% of

the model's detections were recorded as true *L. semotus* positives.

*L. semotus* acoustic activity was detected at all sites included in this analysis, except for site 06 (Appendix Table 2). The heat map of the area, using average nightly detections, revealed higher density of bat acoustic activity in certain areas. The highest average detection value was found at Site 08 (Appendix Table 2), which was within the boundaries of Kapa'a Beach Park, north of the Māhukona Reserve.

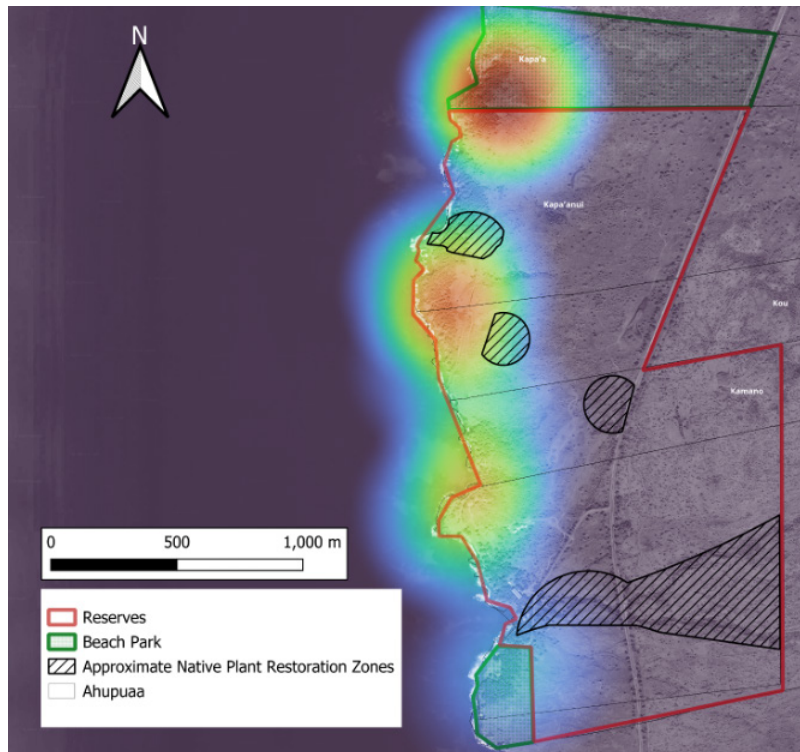
## Discussion

As predicted, there is *L. semotus* acoustic activity present in the Māhukona Navigational and Ecological Complex. We cannot yet determine whether habitat type has any effect on the acoustic activity density with the current limited dataset.

The manual detection evaluation process posed difficulties, mainly due to the high number of false positive detections made by BatNET in this first iteration. The low confidence interval, though it ensured the inclusion of most detections, increased the number of false positives made by the model and muddled analysis for any potential yet unconfirmed bat calls.

Furthermore, calls that were strongly suspected to be social calls were not included as positive detections in this specific analysis, resulting in a much lower detection rate than the likely true detection rate.

For the purposes of this preliminary analysis, we did not pursue reiterative BatNET model training, wherein manual review of detections will be categorized into the training dataset. However, future analyses, which will include more confident call identifications based on ongoing discussions with collaborators, will undergo this process, ideally improving overall model performance.



**Figure 1:** Map showing the study area on Hawai'i Island, focused on the Māhukona region along the island's northwestern coast. The main map depicts the full island with a red inset box indicating the study location. The inset map zooms in to show the boundaries of the Māhukona Navigation and Ecological Complex (outlined in red) as well as nearby Kapa'a and Māhukona Beach Parks (outlined in green). This map situates the study area within the broader geographic context and highlights the overlap between ecological reserve lands and coastal public access zones.

Nevertheless, the results from this analysis suggest patterns of occupancy along the coast of the region. The most detections were found in the wooded area of Kapa'a Beach Park. The reasons for the abundance of activity in this area are unclear, especially because the Māhukona Beach Park on the other end of the reserve did not see similar acoustic activity. Anecdotally, both these regions have similar anthropogenic footprints, particularly around sunset when residents of the area congregate for the view and the bats begin foraging.

## Conclusion

At this preliminary results stage, there is not enough information to make definitive conclusions about the habitat usage within Māhukona Navigation and Ecological Complex. We are proceeding with analysis for the non-coastal sites within the reserve which will bolster this dataset. Knowledge gaps in Hawaiian hoary bat vocalizations proved to be

significant barriers to our model's success. We would like to see an expansion of knowledge, particularly surrounding the library of known vocalizations, as we pursue further analyses. Once a satisfactory model has been made, we aim to correlate any potential environmental factors to the density of bat acoustic activity. We will also pursue other available automated detection models and compare their results against manual annotations.

Understanding how bat acoustic activity changes across the habitat holds significant conservation value and can inform habitat management throughout the restoration process for the Māhukona Navigation and Ecological Complex. As the Cornell undergraduate course NTRES 3152: Field Methods in Conservation Bioacoustics: Hawai'i Experience continues, we hope this project will continue to provide valuable experience for students interested in bat bioacoustics and that this baseline data can be used to support future temporal analyses of temporal *L. semotus* acoustic activity.

## Author Contributions

M.R., G.G., and L.S. put together efforts to deploy PAM recorders in the Māhukona Navigation and Ecological Complex. K.E. provided access to Māhukona Navigation and Ecological Complex and advised research activity on cultural and archeological sites. L.S. ran the BatNET model. M.R., G.G., and L.S. performed manual review of automated detection results. M.R. and G.G. wrote the manuscript. M.R. created the maps and figures.

## Acknowledgements

We would like to thank Dr. Larissa Sugai and the other instructors of the Conservation Bioacoustics Field Applications course for their time and dedication. We are extremely grateful to Keone Emeliano and the Hawai'i Land Trust team for their support in providing access to studys sites within the Māhukona Reserve. We would also like to thank Kris Hendrickson both for his previous *L. semotus* work in the Kohala region, which inspired this work, and for his expertise in bat identification software. We would like to thank Dr. Adam Frankel for the use of his SM4BAT recorder throughout our study period. Last but not least, we would like to thank our fellow classmates for their support during this course and the research process.

## References

Bonaccorso, F. J., Todd, C. M., Miles, A. C., & Gorresen, M. P. (2015). Foraging range movements of the endangered Hawaiian hoary bat, *Lasiurus Cinereus Semotus* (Chiroptera: Vespertilionidae). *Journal of Mammalogy*, 96(1), 64–71. <https://doi.org/10.1093/jmammal/gyu003>

DM Software Solutions. (2012). GPS Tracks (Version 2.0.8) [Mobile application]. App Store.

Gorresen, M. P., Bonaccorso, F. J., Pinzari, C. A., Todd, C. M., Montoya-Aiona, K., & Brinck, K. W. (2013). A five-year study of Hawaiian hoary bat

(*Lasiurus cinereus semotus*) occupancy on the island of Hawai'i. TR HCSU-041.

Gorresen, M.P., Cryan, P.M., Montoya-Aiona, K., Bonaccorso, F.J. Do you hear what I see? Vocalization relative to visual detection rates of Hawaiian hoary bats (*Lasiurus cinereus semotus*). *Ecol Evol.* 2017; 7: 6669–6679. <https://doi.org/10.1002/ece3.3196>

Jacobs, D.S. (1994). Distribution and abundance of the endangered Hawaiian hoary bat, *Lasiurus cinereus semotus*, on the island of Hawai'i. *Pac Sci* 48(2): 193-200.

Kimmel, B. (2025). "BatNET: a supervised machine learning approach to eastern North American bat acoustic activity detection." [Unpublished manuscript]. Virginia Master Naturalists Chapter.

Māhukona Navigation & Ecological Complex. Hawai'i Land Trust. (n.d.). <https://www.hilt.org/mahukona>

Menard, T. (2001). Activity patterns of the Hawaiian hoary bat (*Lasiurus cinereus semotus*) in relation to reproductive time periods [Master's thesis, University of Hawai'i]. [https://www.researchgate.net/publication/35229497\\_Activity\\_patterns\\_of\\_the\\_Hawaiian\\_hoary\\_bat\\_Lasiurus\\_cinereus\\_semotus\\_in\\_relation\\_to\\_reproductive\\_time\\_periods\\_electronic\\_resource](https://www.researchgate.net/publication/35229497_Activity_patterns_of_the_Hawaiian_hoary_bat_Lasiurus_cinereus_semotus_in_relation_to_reproductive_time_periods_electronic_resource)

National Cooperative Soil Survey (USA). (2012). Māhukona series. Official Series Description - MAHUKONA Series. [https://soilseries.sc.egov.usda.gov/OSD\\_Docs/M/MAHUKONA.html](https://soilseries.sc.egov.usda.gov/OSD_Docs/M/MAHUKONA.html)

Sugai, L.S.M., Desjonquères, C., Silva, T.S.F. and Llusia, D. (2020), A roadmap for survey designs in terrestrial acoustic monitoring. *Remote Sens Ecol Conserv*, 6: 220-235. <https://doi.org/10.1002/rse2.131>

Wildlife Acoustics, Inc. (2024). Song Meter SM4BAT FS Ultrasonic Recorder. [Apparatus and software]. <https://www.wildlifeacoustics.com/products/song-meter-sm4bat>

# Appendices

**Table 1: MĀHUKONA SITE LOCATIONS** – information on the deployment of the recorders in the Māhukona Navigation and Ecological Complex. For each site, we present the location in decimal latitude and longitude, the dates of deployment, the number of hours recorded, the altitude, and whether the site was included in this preliminary analysis.

SITE	ANALYZED FOR PRELIM. RESULTS?	DEC. LAT.	DEC. LONG.	DATES DEPLOYED (2025)	HOURS	ALTITUDE (m)
00	Y	20.18718	-155.9019	Jan. 3-12	126	37.0113714
01	Y	20.1816397	-155.9010229	Jan. 4-5	14	6.9000000
02	Y	20.18769	-155.90248	Jan. 5-7	28	43.2660053
03	Y	20.19041	-155.90154	Jan. 7-12	70	41.9698034
04	Y	20.19308	-155.90274	Jan. 12-13	14	29.2549029
05	Y	20.19577	-155.90294	Jan. 12-13	14	37.5586559
06	Y	20.19798	-155.90327	Jan. 13-14	14	53.3158684
07	Y	20.20052	-155.90128	Jan. 13-14	14	9.73566818
08	Y	20.20278	-155.90084	Jan. 14-15	14	19.43584442
09	Y	20.18269	-155.90003	Jan. 14-15	14	15.98609543
10	N	20.19885	-155.89673	Jan. 15-16	14	65.23017502
11	N	20.19681	-155.89913	Jan. 15-16	14	57.52485252
12	N	20.18408	-155.89802	Jan. 16-17	14	22.46815085
13	N	20.18935	-155.89915	Jan. 16-17	14	29.56678391
14	N	20.1919	-155.8983	Jan. 17-18	14	56.04310202
15	N	20.19391	-155.89879	Jan. 17-18	14	60.75648092

**Table 2: BAT ACOUSTIC DETECTIONS BY SITE** – A count of positive ope'ape'a detections for each of the sites included in this preliminary analysis, along with the total number of nights that the recorder was at the site. The average nightly detection count was calculated by dividing the positive ope'ape'a detection count by the number of nights recorded. This final metric was used to generate the heatmap of ope'ape'a acoustic activity (Figure 3).

SITE	DETECTION COUNT	# OF NIGHTS RECORDED	AVG. NIGHTLY DETECTION COUNT
00	7	9	~0.78
01	1	1	1
02	6	2	3
03	10	5	2
04	2	1	2
05	5	1	5
06	0	1	0
07	1	1	1
08	7	1	7
09	1	1	1