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The Effect of Snorkeling on Coral Reef Soundscapes

The Ecotourism Snorkeling Industry and Hawai‘i Reef Soundscapes: An Exploratory Study

Altitudinal Effects on Bioacoustics and Allometry in Coquí Frogs

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Letter from the Editors

Dear reader,

We are excited to present the sixth issue of the Cornell Undergraduate Research Journal (CURJ). CURJ is Cornell's peer-reviewed bi-annual publication of exemplary research work from undergraduates across many disciplines. We aim to allow all students to showcase their work to their peers and the general public, foster intellectual discussion and collaboration, and provide a wide range of academic perspectives.

We would like to thank our amazing staff for their commitment to the team. This past academic year, our team has been hard at work, building this publication from start to finish, which is no easy feat. Especially with the current political climate surrounding scientific research, CURJ is a stanchion that upholds the importance of disseminating scientific research to the general public. We are committed to highlighting the significant contributions made by the student researchers here at Cornell and ensuring their work reaches a broader audience. We proudly recognize and celebrate the dedication and achievements of our peers.

In addition to giving thanks to our staff members who have been working for months to develop the Spring 2025 issue, we would like to applaud each student who submitted their work for publication in this issue. This journal is only possible due to the diligent work of all the student researchers who have submitted their projects to CURJ — without the contribution of Cornell's undergraduate researchers, this publication would not have been possible. Furthermore, the dedication of the graduate reviewers and faculty advisors who bring the hard work of each Cornell student's unique manuscript to the forefront must be mentioned.

This semester, our issue is displaying the work of undergraduates from NTRES 3152/6152, a 2-week course where undergraduates conduct independent research projects revolving around conservation bioacoustics in Hawaiʻi. CURJ has always focused on ensuring the Cornell community can learn about research across all subjects, and we believe that the research performed by the students in this course is not only underrepresented in mainstream media but also highlights the importance and diversity of conservation research through various natural ecosystems.

We are delighted to share the sixth issue of the Cornell Undergraduate Research Journal with you and hope you enjoy reading the edition as much as we enjoyed producing it.

Sincerely,

irene hwang

Isaac Chang Irene Hwang

Introduction from the Instructors of Hawaiʻi Field Course

In recent years, the field of bioacoustics—the study of animal sound—has opened new frontiers for conservation. With the rise of passive acoustic monitoring (PAM), researchers now deploy autonomous sound recorders across vast landscapes and seascapes, capturing biodiversity data in ways that once seemed impossible. By eavesdropping on ecosystems, we can investigate elusive species, track shifting biodiversity, and detect emerging threats.

To advance the conservation of wildlife and habitats, the K. Lisa Yang Center for Conservation Bioacoustics at the Cornell Lab of Ornithology serves as a global leader in developing, applying, and sharing innovative conservation technologies. Central to our mission is building capacity in conservation bioacoustics, supporting practitioners around the world as well as the Cornell community. Our courses—Introduction to Conservation Bioacoustics and Field Methods in Conservation Bioacoustics—lay the foundation for students to conduct research that addresses real-world conservation challenges. Experiential learning is central to these courses, and there is no place in the U.S. where conservation urgency is more pressing than Hawaiʻi—precisely where the field course takes place.

The Island of Hawaiʻi is a place of contrasting extraordinary biodiversity and remarkable loss. Often called 'the extinction capital of the world', Hawaiʻi has lost many of its native species in recent decades. The island's soundscape reflects these changes: once dominated by the calls of endemic birds, it now includes the voices of introduced frogs, mammals, and insects. What remains is a layered and evolving mix of sounds, shaped by extinction, invasion, and climate. But Hawaiʻi is also home to a vibrant culture with deep ties to the natural world. For many Kānaka ʻŌiwi (Native Hawaiians), relationships with land and sea are guided by kilo—careful observation—and a sense of kuleana, or responsibility, to place. These ways of knowing are woven into our field course, shaping not only how we listen to ecosystems but how we connect with them.

This special issue highlights the work of three undergraduate teams who conducted original research in January 2025 as part of the Conservation Bioacoustics Field Course. Since 2023, the course has taken students to Hawaiʻi to design and carry out field-based projects that utilize acoustic monitoring to address ecological and conservation questions. The 2025 cohort focused on species and habitats that are difficult to study by sight alone. Using underwater and terrestrial microphones, they investigated native bats in a newly designated coastal reserve, the distribution of coquí frogs across the island, and fish behavior on a coral reef.

By showcasing the scientific output of student-led research projects in this CURJ edition, we hope to encourage Cornell students to pursue high-impact conservation research by leveraging in-house, globally renowned expertise in acoustic technologies.

This work would not have been possible without the support and generosity of many partners and collaborators. We offer our deepest thanks to Lisa Mason, Patrick Hart, Ruby Mandini, Adam Frankel, the Pua Ka ʻIlima crew, LOHE Lab at University of Hawaiʻi Hilo, the Hawaiʻi Marine Mammal Consortium, Cindi Punihaole, Kathleen Clark, the ReefTeach volunteers, Keone Emeliano, and others who contributed their knowledge, time, and access to field sites.

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The Ecotourism Snorkeling Industry and Hawai‘i Reef Soundscapes: An Exploratory Study

By Tiernan Tobin and Larissa Sugai
K. Lisa Yang Center for Conservation Bioacoustics

Abstract

Coral reefs have distinctive soundscapes consisting primarily of reef associated fish, with most sounds resulting from various behaviors of said species. Ecotourism, particularly through snorkeling in coral reefs, can affect behavior in fish, therefore potentially altering the soundscape. Four different reefs across the western coast of Hawai‘i were assessed both acoustically and visually through periodical deployment of a HydroMoth and a GoPro. Reefs were selected based on the amount of snorkelers present, ranging from none to high (over 16 visually identified). Recordings were analyzed in RavenPro and VLC Media Player to identify species, create a count of instances of biophony, and a count of instances of anthrophony. Results indicated that the sites with higher amounts of anthrophony instances correlated with a higher amount of snorkelers present, but there were no correlations between amount of biophony and presence of snorkelers. This research serves as an exploratory study and aims to lay the groundwork for future research with interest in the correlations between snorkeler presence and reef soundscape by describing potential patterns observed and identifying common reef associated fish sounds.

Keywords: Ecotourism, marine soundscape, reef associated fishes

Introduction

Hawaiian coral reefs are defined by high biodiversity, with 276 reef associated taxa identified across the Hawaiian Archipelago, and 17%-55% of those species being endemic (Friedlander et al., 2020). Therefore, the unique composition of ichthyphony creates a similarly unique ambient soundscape across Hawaiian coral reefs (Kaplan et al., 2017). Identification of ichthyphony in various fish species is a somewhat recent topic of study. In 2014, one study created a library of ichthyacoustics from coral reefs on the western coast of Hawai‘i Island, which resulted in the documentation of 85 sounds produced by 45 different species, or about 47% of all species observed throughout the course of the study (Tricas and Boyle, 2014). Identification of species that create sound is incredibly relevant and important in order to develop the soundscapes of coral reefs. Sounds are often correlated with different behaviors, including foraging, feeding, competition over resources such as nesting sites, space, or food, and reproductive activities, including courtship, nest defense, and spawning. (Tricas and Boyle, 2014). In addition to acoustics produced by reef dwelling fish, many coral reef soundscapes are also saturated with anthropogenic sounds, which are observed to have a negative effect on the general soundscape. One study reports that during COVID-19, when ship traffic was greatly reduced, the Hapuna Bay coral reef experienced a one decibel (dB) increase in the intensity of fish calls (Duane et al., 2021). The impact of noises also depended on the species and its developmental stage, mobility, and/or acoustic sensitivity, and may impact ability to communicate, reproduce, forage, and conduct other natural behaviors (Ferrier-Pagès et al., 2021). Most research identifying the negative effects of anthrophony on the reef soundscape are primarily focused on impacts of machine produced sound, such as from sailing vessels and vehicles. Thus far, the impact of human-produced sound, especially in relation to the ecotourism snorkeling industry, remains a subject of lesser interest compared to studies focusing on other forms of anthrophony.

Tourism, especially ecotourism, contributes the most to Hawai'i's GDP, accounting for 17.7% in 2022 (DBEDT Research Division, 2024). Snorkeling, a huge component of ecotourism, is a massive industry, with the recreational value in 2004 being $281 million, making up 78% of the net benefits of coral reefs for the economy (Cesar and Beukering, 2004). In 2001, 14,640 snorkeling trips occurred, with 91.5% of trips consisting of primarily non-locals, or tourists (Cesar and Beukering, 2004). Therefore, coral reefs often experience large amounts of snorkeling activity, with the majority of trips involving tourists, who often have less experience and knowledge about reefs and reef associated fish than residents. Reefs already experience severe degradation in part due to tourism, but little research has been done to determine if excessive sound production from tourists is also responsible for alterations in this habitat. The goal of this study is to explore whether or not snorkelers have an impact on coral reef soundscapes, specifically ichthyphony, in Hawai'i, and if the impact differs with the amount of snorkelers present at the reef. To accomplish this, acoustic and visual data was collected at four locations across the western coast of Hawai'i Island, with each location categorized based on the amount of snorkelers present at the site. It is hypothesized that the location with the highest number of snorkelers present will correlate with a soundscape with lowest amount of ichthyphony and highest anthrophony.

Materials and Methods

Study Sites

Four sites were used for the study, conducted at four different reefs across the western coast of Hawai'i Island, HI, USA. Sites were categorized into four categories based on the amount of snorkelers present at the location. To determine the number of snorkelers, a visual survey was conducted upon arrival at the site and included all snorkelers currently observable in the water. The categories include high presence ('H'), with 16 or more snorkelers observed, medium presence ('M'), with 6-15 snorkelers observed, low presence ('L'), with 1-5 snorkelers observed, and control ('C'), with no snorkelers observed. Due to the exploratory nature of the study, there was one site per category; therefore, sites will be referred to as their category for clarification. At each site, two plots were also recorded. A plot was defined as the point where recording equipment was deployed and the surrounding five meters circumference. Plots were selected at a distance of 20 meters (m) or more away from each other in order to gain a better understanding of the entire reef and avoid any possible replicates in the dataset.

The high presence site ('H') was located at Kahalu'u Beach Park, which is a publically accessible snorkeling site. Upon arrival, approximately 35 snorkelers were noted. Exact counts are unavailable due snorkelers diving and surfacing frequently. Recording occurred on January 13th, 2025, between 11:50 and 12:48 HST (Hawai'i Standard Time). Plot 1 (HP1) was located at 19.5796, -155.9673. Recording started at 11:50 and concluded at 12:07, with the equipment placed on a sandy substrate between two stony coral heads. Plot 2 (HP2) was located at 19.5791, -155.9666. Recording started at 12:33 and concluded at 12:48, with the equipment placed on a sandy substrate close to a stony coral head.

The medium presence ('M') and low presence ('L') sites were located at two different reefs at Kaloko-Honokōhau National Historical Park. 'M' had approximately 12 people visually identified upon arrival. Recording occurred on January 16, 2025, between 15:00 and 16:00. Only one plot was recorded due to time constraints. MP1 was located at 19.4017, -156.0133.

Recording started at 15:23 and concluded at 15:38. The recording equipment was located on a sandy substrate with only sparse, dead coral heads nearby. ‘L’ had approximately 3 people visually identified upon arrival. Recording occurred on January 16, 2025, between 13:00 to 14:30. LP1 was located at 19.4003, -156.0140. Recording began at 13:14 and concluded at 13:29, with the equipment placed on rocks near a steep ledge. Equipment was frequently moved due to strong waves. LP2 was located at 19.4003, -156.0139. Recording started at 13:53 and conducted at 14:08, with the equipment located on a sand with many rocks, but few coral heads. At this plot, recording was not conducted with the researcher in the water due to unsafe wave conditions.

The control site (‘C’) was recorded at Hawai‘i Ocean Science and Technology (HOST) Park. Though there were people standing nearby along the shore and in the water (around two meters into the water), there were no snorkelers upon arrival. Recording occurred on January 16, 2025, between 11:00 and 12:00 HST. CP1 was located at 19.4254, -156.0257. Recording occurred between 11:04 and 11:19, with the equipment deployed on a sandy bottom between many lava rocks and a few coral heads. CP2 was located at 19.4253, -156.0256. Recording occurred between 11:38 and 11:53, with the equipment deployed on a sandy bottom with some lava rocks nearby.

Data Collection Protocol

A HydroMoth, a modified version of an AudioMoth which is used for marine environments, was used for recording. The sampling frequency was set to 48 kHz, as sounds over this frequency were highly unlikely to occur within the reef, and a bit rate was set to the default setting. The device was set to record continually for about 15 minutes, then pause for one second, then repeat this cycle. This ensured the creation of unique audio files for ease during analysis. The HydroMoth was sealed in a waterproof container with a 1.5 m fishing line and bobber attached in order to locate the device after deployment. A small rock was strapped to the device in order to weigh it down so that it would rest on the reef floor. A GoPro camera was also utilized in order to gain footage of the species in range to allow for more effective identification. The camera was sealed in a waterproof container and was set to record continuously.

When the plot was reached, the researcher would deploy the HydroMoth on the reef floor for a period of five minutes. This time allowed

Figure 1: Location of plots within different sites, control plots (red, CP1 and CP2), low plots (yellow, LP1 and LP2), medium plot (green, MP1), and high plots (blue, HP1 and HP2), in Hawai‘i, HI, USA, created with Google Earth.

sea life to acclimate to the equipment in order to avoid damage to equipment or organisms. During this acclimation period, the depth was measured using a PVC pipe with 0.5, 1.0, and 1.5 m marked approximately to the best of the recorder's ability. Coordinates were taken using Google Maps. After the acclimation period concluded, the recording period began and lasted for approximately 10 minutes, with the start and end time of the HydroMoth noted. The GoPro camera was also deployed and held by the researcher who floated nearby and pointed at the HydroMoth and the surrounding area. At the end of the recording period, all equipment was removed from the water and notes were made and recorded with Epicollect5, including external temperature, observed snorkelers, and any notes and observations recorded with Epicollect5.

Files were offloaded from corresponding equipment and uploaded in the forms of WAV files and video, for the HydroMoth and GoPro, respectively. HydroMoth recordings were visualized in RavenPro 1.6 and the corresponding video was viewed using VLC Media Player. A contrast of 48, a brightness of 67, a FFT of 2048, and the color scheme of copper was utilized in RavenPro. Ten seconds were displayed horizontally and 2 kHz vertically. For each plot, a 60 second interval was randomly taken for further analysis. In each 60 second interval, the amount of anthrophony and biophony were recorded on RavenPro. Each entry in the selection table was annotated with sound type (anthropogenic or biological), source, and description. GoPro footage was analyzed similarly, with the 10 minute clip analyzed for number of species observed, number of individuals per species, and amount of snorkelers recorded. Individuals were counted every time it appeared on video, unless it was obvious that it was the same individual coming back in frame. Species identification was verified first through visual appearance, then secondly through the use of local field guides (Hoover).

Results

MP1 had the lowest amount of biophony instances recorded, with 16 instances, while LP2 had the highest amount recorded, with 99 instances (Table 1). 'M' had the lowest overall amount of biophony recorded, while 'L' had the highest overall amount recorded (Fig. 2). CP1 and LP1 had the most types of biophony (distinct sounds) recorded, with six types per site, while CP2, HP1, and HP2 had the least amount, with three types per site (Table 1). 'L' had the highest overall biophony type count, with an average of five between LP1 and LP2, while 'H' had the least amount, with an average of three between HP1 and HP2 (Table 1).

'H' had the highest amount of anthrophony, with an average of 3.5 instances across both plots, with HP1 having 7 total instances (Fig. 2). 'C' had the lowest amount of anthrophony, with an average of 0 instances across both plots (Fig. 2).

Based on GoPro video identification, four plots were able to have species visually identified: LP1, MP1, HP1, and HP2. Based on the available data, HP1 had the highest biodiversity based on taxonomic family, with approximately five families identified, while LP1 and MP1 had the lowest, with three families identified per plot (Table 2). MP1 had the most sightings, with 62 individuals identified, while LP1 had the least, with only 5 individuals identified (Table 2). Species belonging to *Diadematidae* and *Acanthuridae* were the most abundant across all plots, with *Diadematidae* being identified in all plots and *Acanthuridae* in three of the four plots (Table 2).

Discussion

Due to the exploratory nature of this study, few correlations can be drawn from the data; however a positive trend may exist between increased snorkeler presence and increased anthropogenic noise, though this trend should

Table 1: Numbers of biophony and anthrophony counts from a random 60 second sample from each recording based on snorkeler presence type and locations in Hawaiʻi, USA, recorded between January 13 and January 16, 2025.

Plot Info	CP1	CP2	LP1	LP2	MP1	HP1	HP2
Location	Kaloko	Kaloko	Historic Park	Historic Park	National Historic Park	Kaloko	Kahaluʻu Beach Park
HOST Park	National	National	Hono-kōhau	Kaloko	National	Historic Park	Kahaluʻu
Collection (m/d/y)	1/16/2025	1/16/2025	1/13/2025	1/13/2025	1/16/2025	1/16/2025	1/16/2025
Date of Data	1/16/2025	Date of Data	1/16/2025	Date of Data	1/16/2025	Date of Date	1/16/2025
Presence Type	Low (1-5)	Control (0)	Control (0)	Low (1-5)	Medium (6-15)	High (16+)	High (16+)
Depth (m)	0.50	0.50	1.60	0.75	1.50	1.20	0.75
Biophony Instance	55	41	52	99	16	43	21
Biophony Types	6	3	6	4	4	3	7
Anthrophony Instances	0	0	1	0	1	0	3

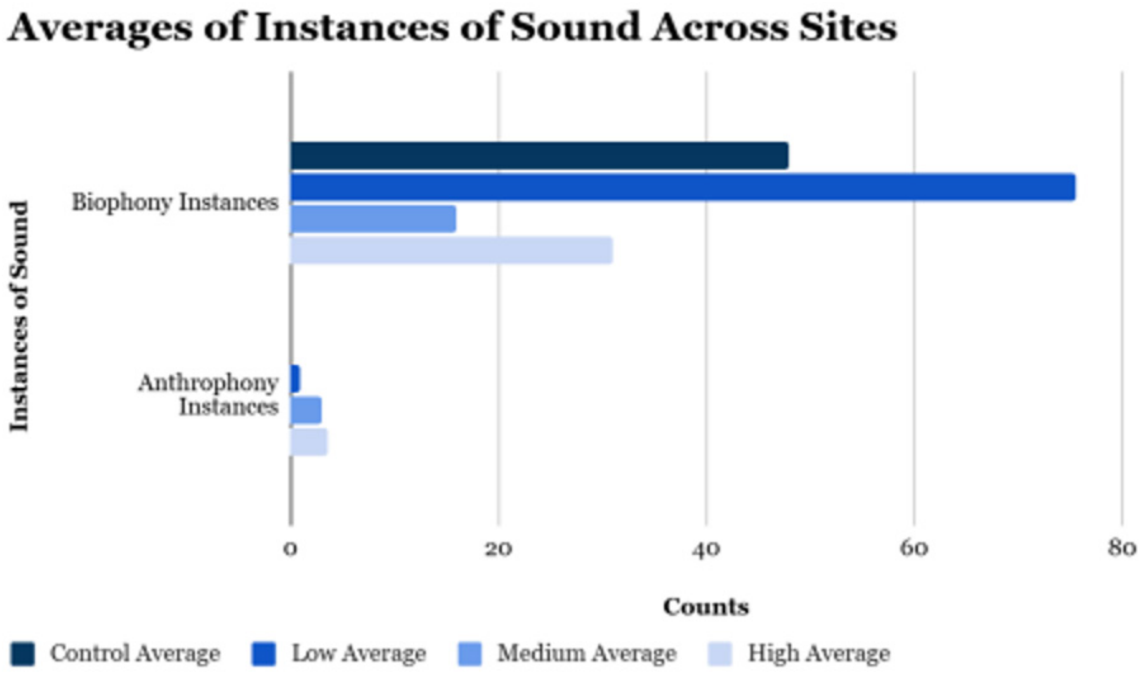

Figure 2: Averages of occurrences of sounds (anthropogenic or biological) across plots of all sites. Collected in Hawaiʻi, HI, USA, between January 13 and January 16, 2025.

Table 2: Abundance of various reef associated families from LP1, MP1, HP1 and HP2, identified using GoPro footage. Recorded between January 13, 2025, to January 16, 2025.

Genus	LP1	MP1	HP1	HP2	Species Included
Acanthuridae	2	0	2	3	*Z. flavescens,* *A. olivaceus,* *A. triostegus*
Zanclidae	2	0	0	2	*Z. cornutus*
Pomacentridae	1	3	1	5	*E. caeruleus*
Mullidae	0	5	8	0	*P. pleurostigma*
Tetraodontidae	0	1	0	0	*A. meleagris*
Labridae	0	0	2	0	
Chaetodontidae	0	0	4	0	*C. quadrivittatus*
Balistidae	0	0	6	1	Unknown
Total	5	62	36	17	

be researched in greater depth in the future. The site with the highest amount of anthropogenic noise recorded was HP1 and, when taking the average of the plots, 'H' has the highest amount of anthrophony recorded. Kahaluʻu Beach Park, the location of 'H', is a popular snorkeling spot that frequently has a high number of people both in the water and around the park. Most of the anthrophony identified from the HydroMoth recordings were the result of snorkelers, most commonly coming from snorkeling gear or people speaking. Additionally, Kahaluʻu Beach Park is located next to a major road and is used for other ecotourism activities, such as beachgoing and surfing, which may have added to the high amount of anthrophony. As mentioned, the small amount of data recorded means that future researchers should continue to research this trend to ensure credibility.

There are no apparent correlations between biophony and snorkeler presence, which could be attributed to a few reasons. One such is the difference in reef compositions between the sites. Though coral was present at all sites, the abundance of live coral changed dramatically across the sites, with 'H' having the most and 'M' having the least, though reef associated species were identified at each site. Abundance of coral is correlated with a higher amount of reef associated species and a higher amount of individual fish in the area, which was apparent at HP1 and HP2 (Bell and Galzin, 1984). This may have impacted the abundance of species at 'H'. Secondly, though sites had relevant species present, the composition of species differed across the sites, often dramatically. This could have altered the soundscape for each site. Therefore, it is important to identify which of these species are known to produce sound and, if they do, under what conditions they do so.

Sounds of Observed Families

Acanthuridae

There were three observed species belonging to this family: *Z. flavescens*, the yellow tang (lau'ipala), *A. olivaceus*, the orange-band surgeonfish (na'ena'e), and *A. triostegus*, the convict tang (manini). Some members of this family are known to produce sound, primarily during agonistic behaviors (Lobel et al., 2010). Specific frequencies and durations are largely unknown, but *A. bahianus* is known to produce sound between 150-4,700 Hz and for around 100 milliseconds (ms) (Lobel et al., 2010). This family was found at all plots except for MP1. Further study on sounds produced by *A. bahianus* would be of interest, especially due to the yellow tang's abundance in most coral reefs throughout the Hawaiian archipelago.

Zanclidae

There was one observed species belonging to the *Z. cornutus* family, the Moorish idol (kihikihi). This species is known to produce single pulsed sounds and longer trains that range from 176 to 520 Hz and last around 30 to 102 ms (Tricas and Boyle, 2014). They produce these sounds during aggressive acts and courtship behaviors (Tricas and Boyle, 2014). In addition, they also produce pulsed sounds ranging from 200 to 566 Hz during both courtship and agonistic behaviors, with the latter typically directed toward common conspecifics, a species often belonging to the family *Acanthuridae* (Tricas and Boyle, 2014). Moorish idols were observed at LP1 and HP1 and, in the case of HP1, would have been in the range of other species, most notably *Acanthuridae*. This may indicate that ichthyphony produced by Moorish idols may have only occurred in HP1 due to the presence of other species, but further research is required.

Diadematidae

E. calamaris, the double spined urchin (wana), was observed across all sites. In previous studies, sound has been detected coming from large aggregations of *D. setosum* which, although not a Hawaiian species, provides insight into the relevant species (Soars et al., 2016). Species from this family are known to produce wide frequency bands, ranging from 400 Hz to over 20,000 Hz (Soars et al., 2016). However, due to the often low frequency of the sound produced, it can be difficult to differentiate these from the sounds of snapping shrimps, which is the major producer of biophony in ocean soundscapes, particular in shallow areas, and are known to obscure sounds of other species (Au and Banks, 1998). Therefore, though *Diadematidae* are present throughout all measured plots, assessing soundscapes with use of *Diadematidae* would be difficult.

Mullidae

The only observed species belonging to *Mullidae* was *P. pleurostigma*, the sidespot goatfish (moano). Goatfish are known to produce sounds associated with reproductive behaviors, such as courtship, spawning, and nest defense, with males producing both single pulses and train sounds at low frequencies when observed chasing females in courtship (Tricas and Boyle, 2014). It is unknown if this species in particular produces sound. Reproductive behavior was not observed on the footage, which could contribute to the low amount of biological noise recorded in MP1 (Tricas and Boyle, 2014).

Tetraodontidae

A. meleagris, the golden puffer (kōkala) was the only observed species within this family and was identified at MP1. Though swim bladder vibrations occur as a secondary mechanism within this family, there is no known sound production to come from either this family or *A. meleagris* (Rice et al., 2022). This, coupled with the low presence across the sites indicates that this species would be of little use for understanding the soundscape composition of coral reefs.

Balistidae

Various species of triggerfish (humuhumu) were observed, though further identification could not be completed due to the quality of the video recording. Three different species of triggerfish are known to make sound while exhibiting agonistic behaviors during social interactions, with sounds ranging from short thump-like pulses, longer rasp-like pulses (both recorded from *M. niger*), single pusles, and pulse trains (recorded from both *S. bursa* and *Z. auromarginatus*) (Tricas and Boyle, 2014). These sounds can occur during behaviors such as territory defense, agonistic changes, and nest-guarding behaviors, exhibited by females only. Triggerfish sounds likely appeared on recordings.

Labridae

Labridae, particularly parrotfish, are well known for their sound production. Various genera of parrotfish are known to produce a distinctive biting sound when feeding and are often an important indicator of reef health as they feed on coral rock. Increased feeding activity was associated with decreased macroalgal cover, and therefore an increase in the density of new coral recruits (Tricas and Boyle, 2021, and Mumby et al., 2007). The species identified at HP1, *T. duperrey*, the saddle wrasse (Hīnālea Lauwili), is known to produce two types of pulse trains, with the Type I being indicative of spawning and courtship and Type II indicating just courtship (Boyle and Cox, 2010). Similarly to other species identified in the recordings, due to the low amount of wrasse spotted on video, it was unlikely that courtship and spawning behavior was captured auditorily, though this could be helpful in future studies.

Chaetodontidae

Chaetodontidae are well known for having sounds produced during social interactions, and are known to have two primary mechanisms of production: a tail slap that stimulates the lateral line and ear, and a head bobbing motion, producing a pulsing sound which stimulates the swim bladder and ear (Tricas and Boyle 2015). The two species identified in this family, *C. quadrimaculatus*, fourspot butterflyfish (lauhau), and *H. diphreutes*, schooling bannerfish (pāpā), are not specifically known to produce sound, but it is likely they do so based on other species in the family. This family would be a good indicator of coral reef soundscape due to their abundance in the reefs as well as if confirmation of sound production occurs in the future.

By understanding the contexts in which different ichthyological families and species produce sound and if they produce sound at all, future research on this subject can be more clearly conducted. By targeting reefs with similar ichthyological compositions, a better understanding of the changes in the soundscape could be identified.

This study remained limited due to many factors, including unsafe conditions preventing recording, limited sample size, limited time in collecting data, and last minute restructuring. One particular issue was that the GoPro would not remain stationary on the ocean floor and required the recorder to hold it during the entire recording period. Therefore, the observer contributed to the anthropogenic noise in each site where GoPro footage was recorded. However, despite the setbacks, this research may serve as an exploratory study on snorkeler presence and anthrophony interacting with coral reef soundscapes. With a more concrete dataset and a small redesign of the experimental procedure, correlations could be more clearly identified. When conducting potential follow up studies, research should be conducted so that site variation is temporal, not physical. By remaining at one site with a fluctuating amount of snorkelers in the reef from day to day, a better understanding of the changes of that specific soundscape could be identified. This would also allow the species composition in the reef to remain relatively consistent, despite changes tidally and seasonally. The author advises that, if further research were to be conducted, it should occur at Kahalu'u Beach Park, with monitoring occurring at three or more plots at the site at least twice per week. This could allow further clarification of potential correlations between snorkeler presence, anthrophony, and biophony in the coral reef soundscapes. If interest arises, all materials can be found here: https://cornell.box.com/s/3d5xsabr7a9t0n5ec7cs70jfuibrvb7m.

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Altitudinal Effects on Bioacoustics and Body Size Allometry on the Invasive Coquí Frogs in Hawaiʻi

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Abstract

The island of Hawaiʻi is a tropical and isolated island with unique endemic species. Over time, Hawaiʻi has become a breeding ground for invasive species, the common Coquí (*Eleutherodactylus coqui* Thomas, 1966) being one of them. These small ectotherms have intense vocalizations used for establishing territory and locating potential mates. On the island of Hawaiʻi, the Coquí has become persistent across many islands. There have been acoustic studies done on the frogs in their native habitat, Puerto Rico, yet little is known about the possible differences in calls between these two geographically distant groups. According to past studies, climate change in Puerto Rico could cause the Coquí frogs to expand their ranges into higher, cooler altitudes with larger body sizes and lower pitch ranges. This phenomenon has yet to be studied in Hawaiʻi. Through this study, I directionally recorded *Eleutherodactylus coqui* to obtain information on the peak frequency, body size, and altitude differences. All frogs were handled with proper permits from Cornell University.

Introduction

The common Coquí (*Eleutherodactylus coqui* Thomas, 1966) gets its name from the sound of vocalizations and is a native amphibian to Puerto Rico. The Coquí was introduced to Hawaiʻi in the late 1980's through imported nursery plants. Despite the frog's small body size, their unique and piercing calls can reach up to 70-80 decibels. Male Coquís produce variations of their vocalizations, "coqui": The "co" is used to establish territory and therefore deter the other males, whereas the high-pitched "qui" is used to attract females (Narins & Capranica, 1978). However, with their common call being "co-qui," they will also produce variations such as "co-co-co-qui" depending on the stage of calling (Narins & Capranica, 1978). These frogs can call at levels that make them the perfect candidate for acoustic monitoring. Understanding how, when, and where these frogs primarily vocalize and how they differ from the native calls could provide useful information for future behavior and preventative methods in Hawaiʻi.

Acoustic monitoring is a non-invasive method that can collect presence/absence information as well as gather principal characteristics of individual vocalizations. Coquí frogs are ectotherms that rely on the environment as a heat source for metabolic processes and sound production (Percino-Daniel et al., 2021). In Puerto Rico, populations of coquí frogs tend to show larger body size as altitude increases, indicating a positive linear relationship between altitude and body size (Narins & Meenderink, 2014). However, due to the inverse rule of bioacoustics, those with larger body size will create calls with lower frequencies (Narins & Meenderink, 2014). As global temperatures continue to increase due to climate change, it has been hypothesized that populations will shift their spatial distribution upwards, to higher altitudes, which would lead to larger bodied individuals occupying higher elevations (O'Neill & Beard, 2011). As a consequence, the allometric relationship between body size and frequency should also shift (Narins & Meenderink, 2014).

Overall, this study aims to explore the relationship between body size and bioacoustics of Coquí frogs along an altitudinal gradient in the island of Hawaiʻi. This study also confirms the possibility that previously established patterns of how altitude effects body size and vocalizations in native frogs may be similar in invasive frogs.

Goals/Questions/Hypothesis

The focus of this study is to explore the possibility of differences in vocalizations at different altitudes and how body size could play a role in this. I expect that higher altitudes would lead to increases in body sizes and a decrease in peak frequency. This is due to body sizes' direct inverse relationship with wavelengths. I would therefore expect a negative relationship between higher altitudes and frequency; at higher altitudes, there should be lower frequency calls and larger body sizes (Narins & Meenderink, 2014). Coquí frogs are quite cold tolerant, so it is possible that they will expand their regions to higher elevations even in areas that are not registered on iNaturalist (Narins & Meenderink, 2014). Temperature change in Hawaiʻi could result in a change in calls or amplitude.

The second foundation of this project focused on whether there are any differences between the native and invasive frogs. For this, I expect that there would be no difference between the native Coquís and the invasive Coquís, because species usually have fixed traits that do not vary much in location, especially if climates across their biomes are similar elevations (O'Neill & Beard, 2011).

Detailed Methodology

To locate the sampling areas, we used GBIF and iNaturalist to determine locations where people had heard or seen the Coquí frogs. I registered these onto a Google Map so that it was easily accessible. Given that Coquí frogs call from dawn until dusk we started sampling at 5:30 pm Hawaiʻi Standard Time (HST). We would drive to the area and detect if frogs were singing; if we could not hear the frogs, or if they were not easily accessible for us to collect data on (i.e., in private property), another location was chosen. Once we could find a location, we would record a GPS coordinate on GPSTracks and the altitude. We would begin by locating where the frogs were calling, and once we found the individual that we heard, we would turn the headlamp off due to the frog's sensitivity to light and then start recording. We would record for 2 minutes at a time, save the voice memo, and then attempt to collect the frog. Once the frog was captured, he was placed in a plastic bag, and given an individual ID based on site, collector, and date. We also collected very few females to get size estimates on them as well. We then would use a datalogger to take the temperature of the outside environment, and a digital caliper to obtain the frog's length from tip of nose to cloaca. This was then recorded on an Excel spreadsheet. We would spend 30 minutes in an active search, and then either drive to a new location or begin processing the individuals. Once the night excursion was completed, data was backed up, properly ejected, converted to correct formats, and renamed with a unique code. As an example, this is what the code looked like: "11_S1_Kay_1", where 11 was the date in January, S1 is site one of that night, Kay is the collector, and one is the first individual of the night caught. The data was subsequently uploaded to RavenPro to obtain information on peak frequency and change in (delta) time. RavenPro was also used to make annual annotations in an effort to obtain an average dominant frequency (Yang, 2024). The specific measurements that were captured were begin time (s), end time (s), low frequency (kHz), high frequency (kHz), peak frequency, delta time (s), and two annotation columns to describe the individual ID, and what call type it was using.

Additionally, two SwiftOne units (autonomous recording units developed at the K. Lisa Yang Center for Conservation Bioacoustics, Cornell Lab of Ornithology) were deployed to obtain data on diel variations throughout the night. The SwiftOne unit was configured with the default settings and then tied to a tree where Coquí frogs had been heard previously.

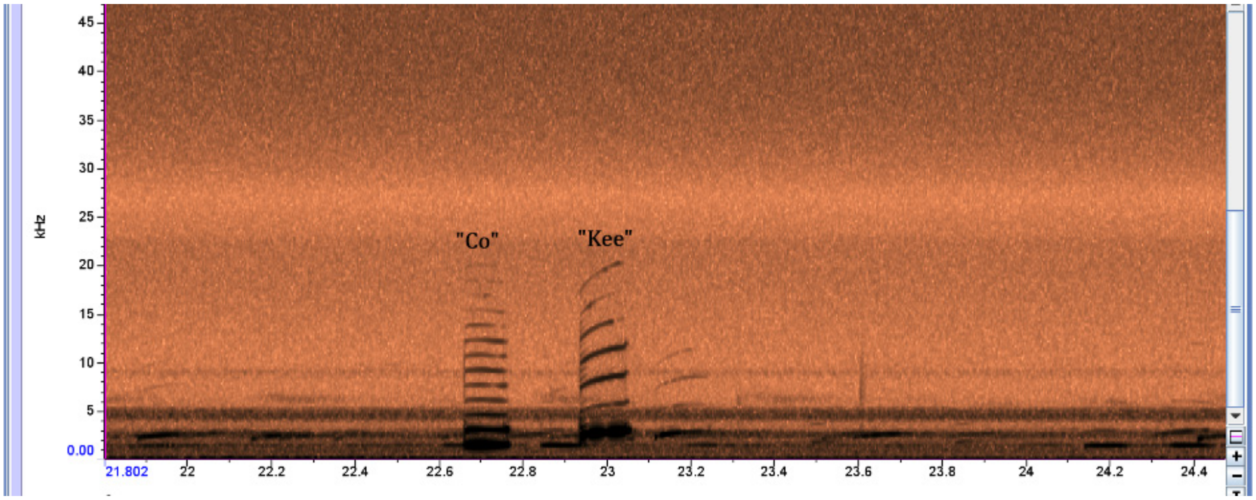


Figure 1: A spectrogram showing the different variations in the “co” and “qui” calls. The intensity of the sound is seen on the axis labeled "kHz", and the higher the frequency the higher the pitch of the call. The background in the red is the background noise and the black lines are the harmonics of the frog.

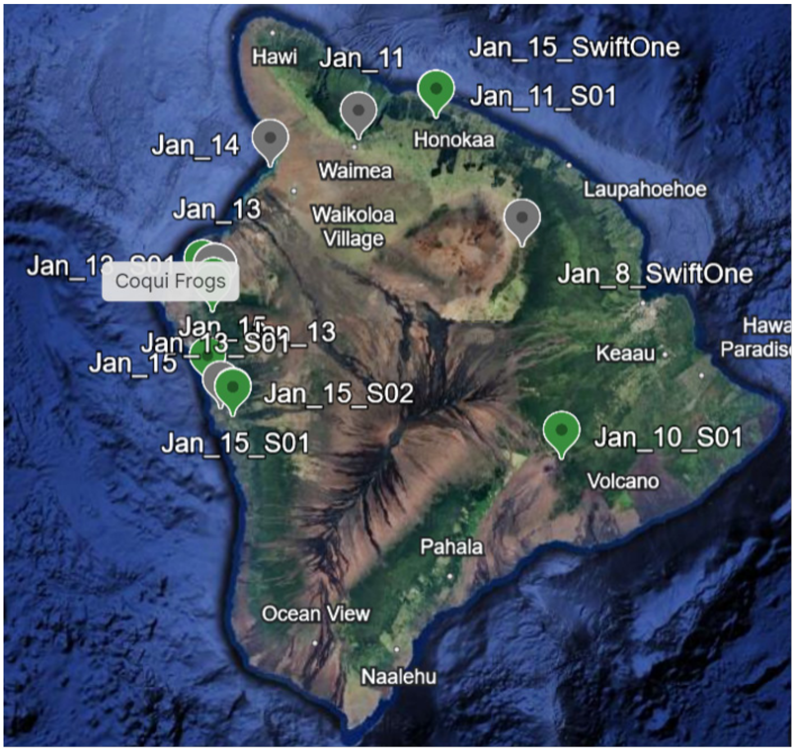
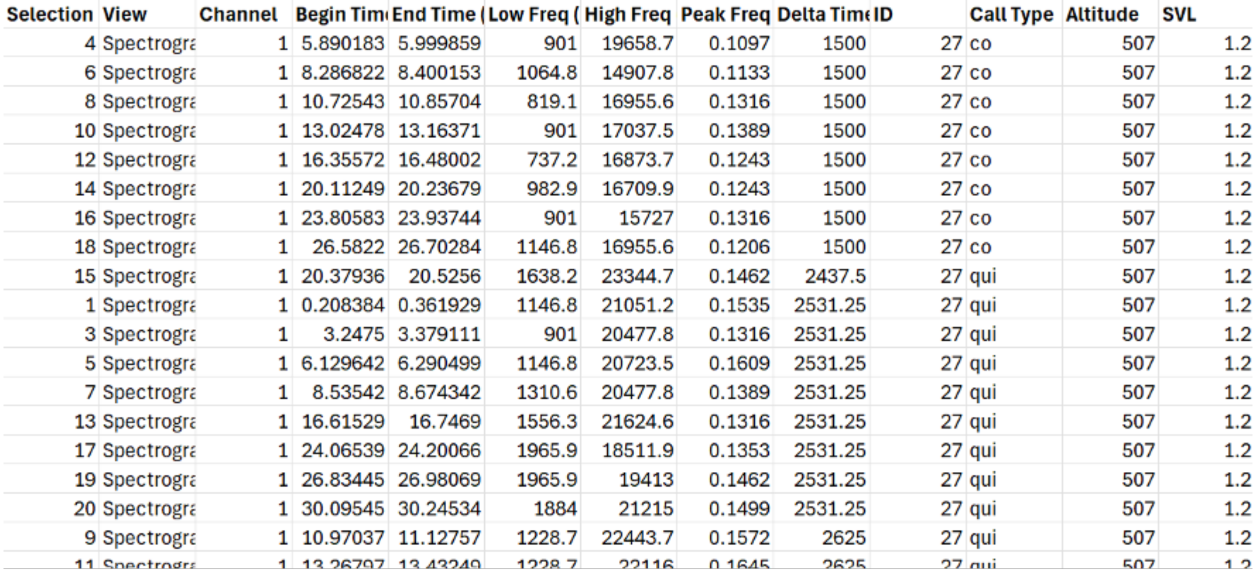


Figure 2: A map of the Island of Hawaiʻi, where data was collected between 01/10/2025 through 01/16/2025. The green markers indicate active coquí frog captures and recordings, whereas the grey markers are spots where there were either no or unattainable frogs.

The locations that were visited between the 10th-16th of January are located above. The entries labeled with month_date_site with a green marker are ones where I conducted an active search. Those that are just month_date and are green are ones where Coquí frogs were heard, but an active search was not conducted due to research limitations. Grey location markers are areas that I heard no Coquí frogs present. Additionally, seventeen of the twenty-two individuals caught have body measurements and directional recordings. The figure below shows the data collection sheet that explains how individuals were documented.



Selection	View	Channel	Begin Tim	End Time (	Low Freq (	High Freq	Peak Freq	Delta Time	ID	Call Type	Altitude	SVL
4	Spectrogra	1	5.890183	5.999859	901	19658.7	0.1097	1500	27	co	507	1.2
6	Spectrogra	1	8.286822	8.400153	1064.8	14907.8	0.1133	1500	27	co	507	1.2
8	Spectrogra	1	10.72543	10.85704	819.1	16955.6	0.1316	1500	27	co	507	1.2
10	Spectrogra	1	13.02478	13.16371	901	17037.5	0.1389	1500	27	co	507	1.2
12	Spectrogra	1	16.35572	16.48002	737.2	16873.7	0.1243	1500	27	co	507	1.2
14	Spectrogra	1	20.11249	20.23679	982.9	16709.9	0.1243	1500	27	co	507	1.2
16	Spectrogra	1	23.80583	23.93744	901	15727	0.1316	1500	27	co	507	1.2
18	Spectrogra	1	26.5822	26.70284	1146.8	16955.6	0.1206	1500	27	co	507	1.2
15	Spectrogra	1	20.37936	20.5256	1638.2	23344.7	0.1462	2437.5	27	qui	507	1.2
1	Spectrogra	1	0.208384	0.361929	1146.8	21051.2	0.1535	2531.25	27	qui	507	1.2
3	Spectrogra	1	3.2475	3.379111	901	20477.8	0.1316	2531.25	27	qui	507	1.2
5	Spectrogra	1	6.129642	6.290499	1146.8	20723.5	0.1609	2531.25	27	qui	507	1.2
7	Spectrogra	1	8.53542	8.674342	1310.6	20477.8	0.1389	2531.25	27	qui	507	1.2
13	Spectrogra	1	16.61529	16.7469	1556.3	21624.6	0.1316	2531.25	27	qui	507	1.2
17	Spectrogra	1	24.06539	24.20066	1965.9	18511.9	0.1353	2531.25	27	qui	507	1.2
19	Spectrogra	1	26.83445	26.98069	1965.9	19413	0.1462	2531.25	27	qui	507	1.2
20	Spectrogra	1	30.09545	30.24534	1884	21215	0.1499	2531.25	27	qui	507	1.2
9	Spectrogra	1	10.97037	11.12757	1228.7	22443.7	0.1572	2625	27	qui	507	1.2
11	Spectrogra	1	13.26797	13.43249	1228.7	22116	0.1645	2625	27	qui	507	1.2

Figure 3: Selection table containing annotations made in RavenPro from the frogs captured in Hawaiʻi. The selection table is a summary of the manual annotations including begin time (s), end time (s), low frequency (kHz), high frequency (kHz), peak frequency, delta time (s), and two annotation columns to describe the individual ID, and what call type it was using.

Preliminary Results

Due to time constraints, the results of this study may be slightly skewed as there are gaps in the data collection locations. Regardless, this study shows results of a negative relationship between peak frequency of the Coquí frog vocalizations and altitude. The negative relationship results correlating with the invasive Coquí are what were anticipated given the previous knowledge on the native Coquí frogs.

In order to understand intra-individual variability in peak frequency, I visually explored the distribution "co" and "qui" peak frequencies (Figure 4a-b). Overall, individuals showing small and high variability were not related to lower or high altitudes.

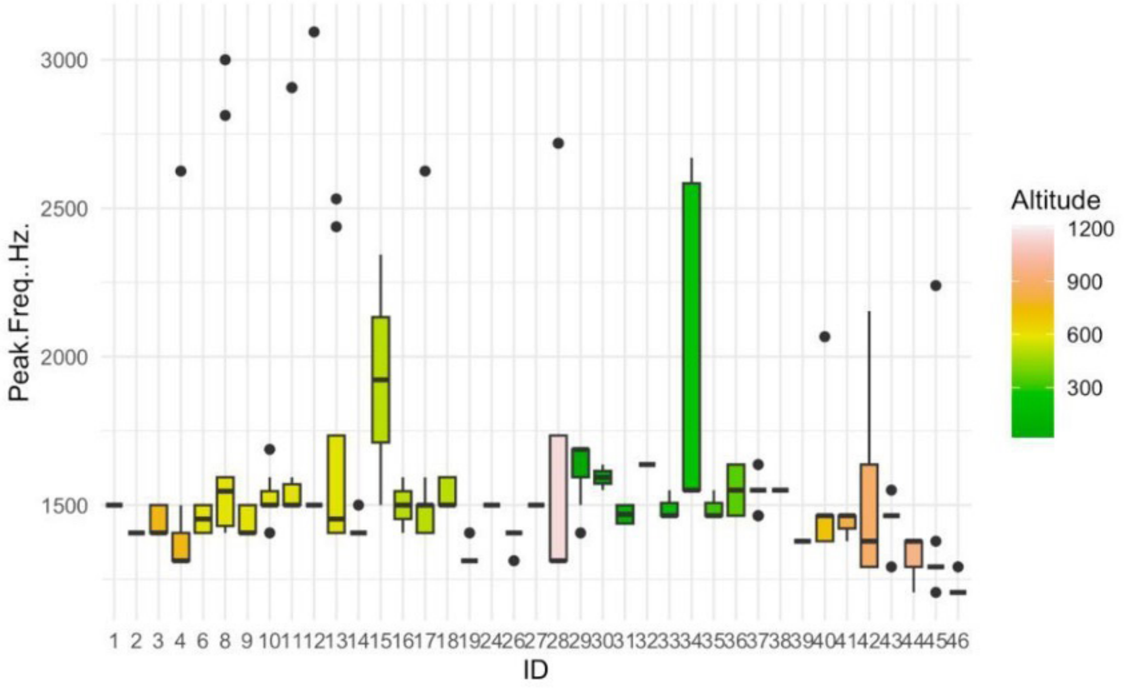


Figure 4-a: Box plot with peak frequency of "co" notes of Coquí frog individuals sampled in the island of Hawaiʻi. The color represents the altitude these individuals were sampled at.

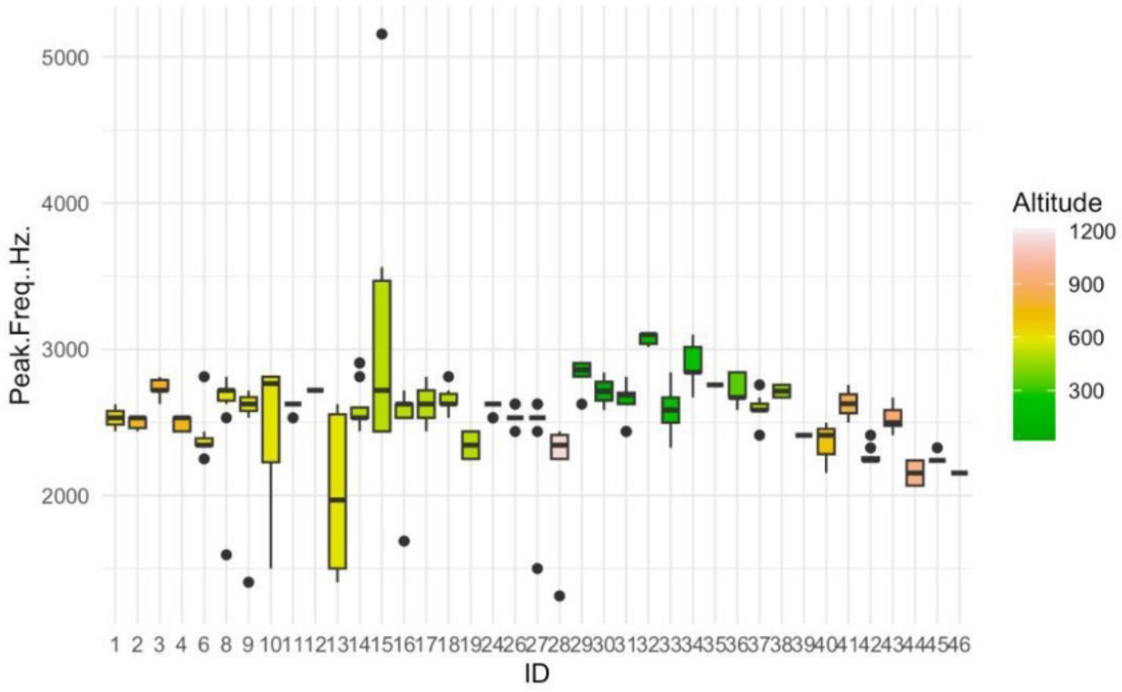


Figure 4-b: Box plots with peak frequency "qui" notes of Coquí frog individuals sampled in the island of Hawai'i. The colors represent the altitude these individuals were sampled.

Using the average peak frequency, I fitted linear models to visually explore the allometric relationship with body size. Following initial expectations, I found a negative relationship between the two variables (Figures 6a-b). The relationship seems to be especially stronger for the "qui" note (larger slope).

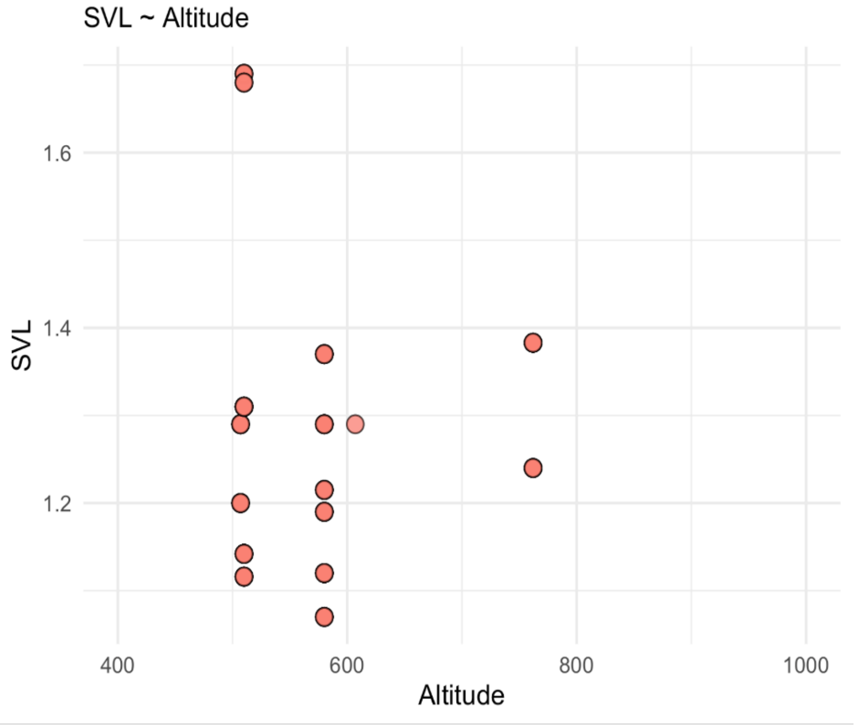


Figure 5: A dot plot showing the relationship between Altitude and Body Size.

For body size, it is apparent that there is a relationship that as altitude increases so does body size (Figure 5). However, these results are ambiguous because there is lack of samples from the higher altitudes of the study.

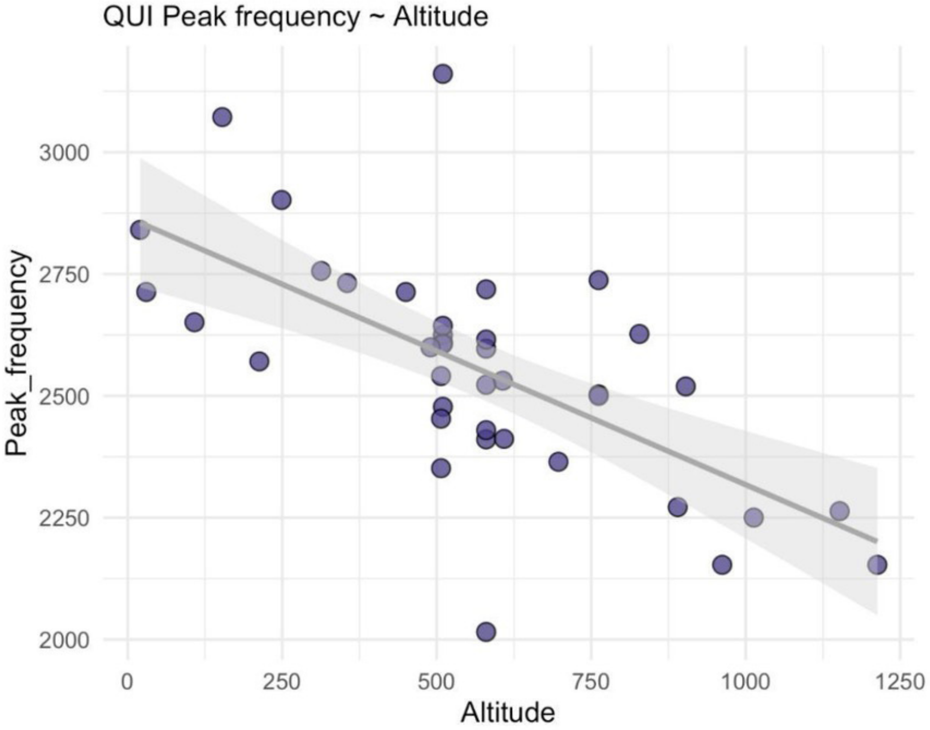


Figure 6-a: Dot plots with peak frequency of the "co" notes of Coquí frog individuals sampled in the island of Hawai'i. The other axis considers the altitudes of the captured frogs.

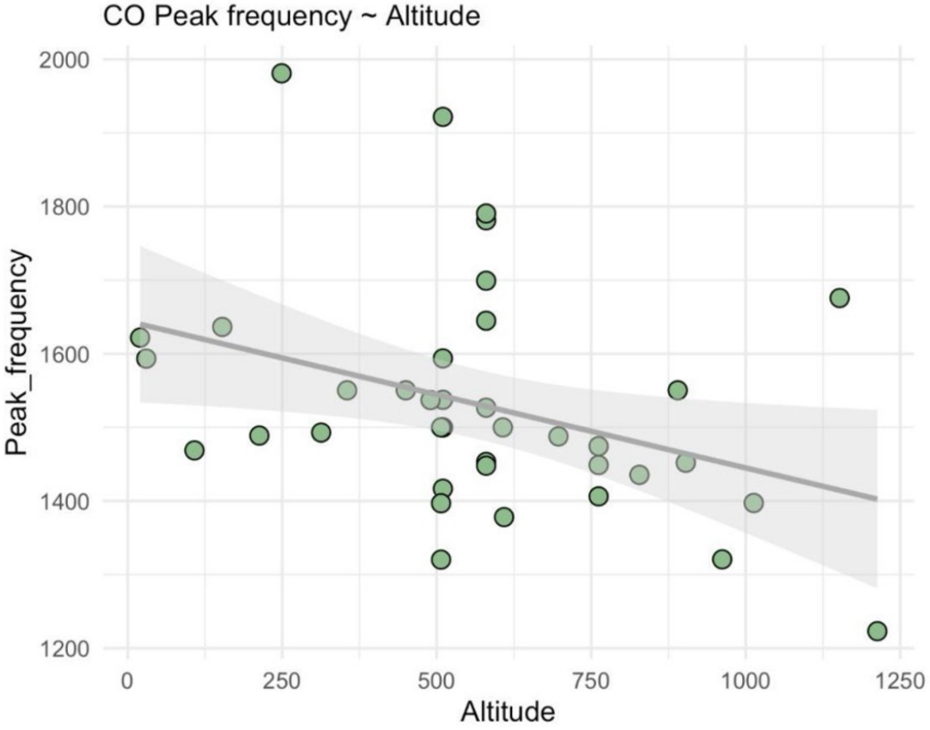


Figure 6-b: Dot plots with peak frequency the "qui" notes of Coquí frog individuals sampled in the island of Hawai'i. The other axis considers the altitudes of the captured frogs.

Using a 95% confidence interval and a .05 alpha, I tested the null hypothesis that there is no relationship between altitude and peak frequency vocalizations. These results indicate a clear negative relationship between the two variables. With a negative slope of -.3987, a P-value of 3.3E-185, and an adjusted R^2 of 0.027484, we reject the null hypothesis and conclude that there is a relationship between these two variables.

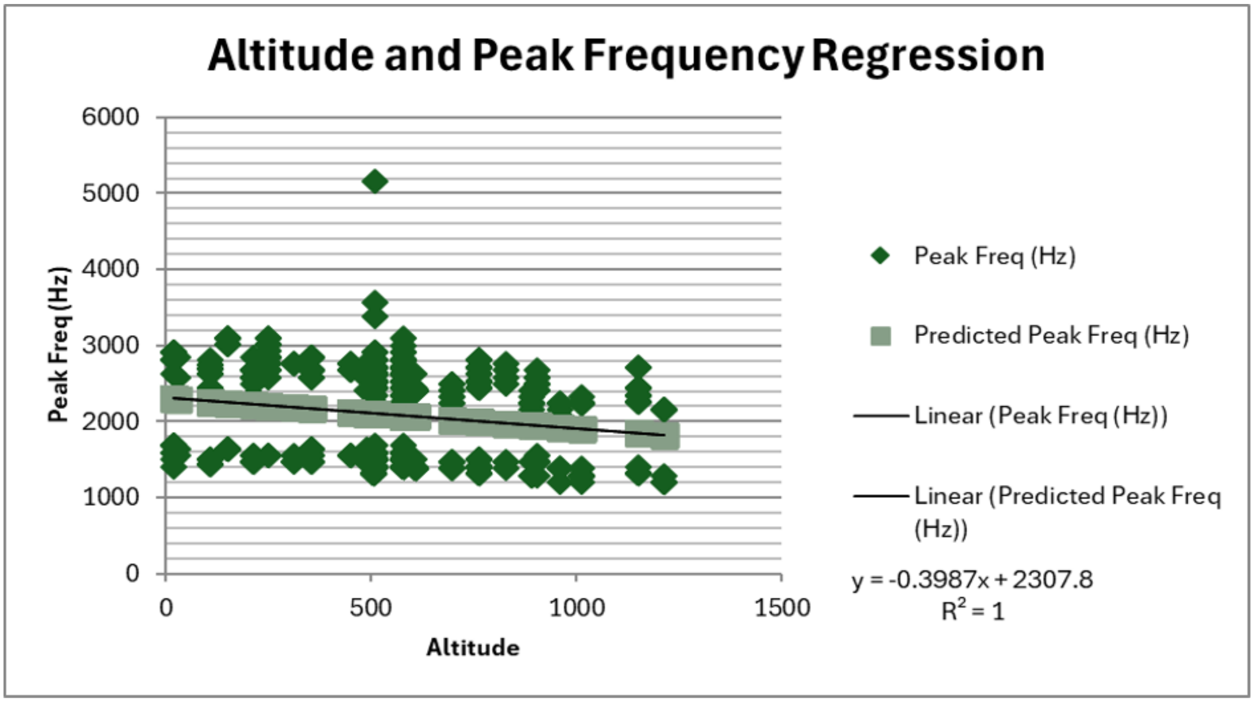


Figure 7: A linear regression plot between Peak Frequency (Hz) and Altitude (m).

Using a 95% confidence interval and a .05 alpha, I tested the null hypothesis that there is no relationship between SVL and altitude. These results indicate a slightly positive relationship between the two. With a slope of 3E-05, a P-value of 3.86E-62 and an adjusted R^2 value of -0.00298 we reject the null hypothesis and conclude that there is a relationship between SVL and altitude.

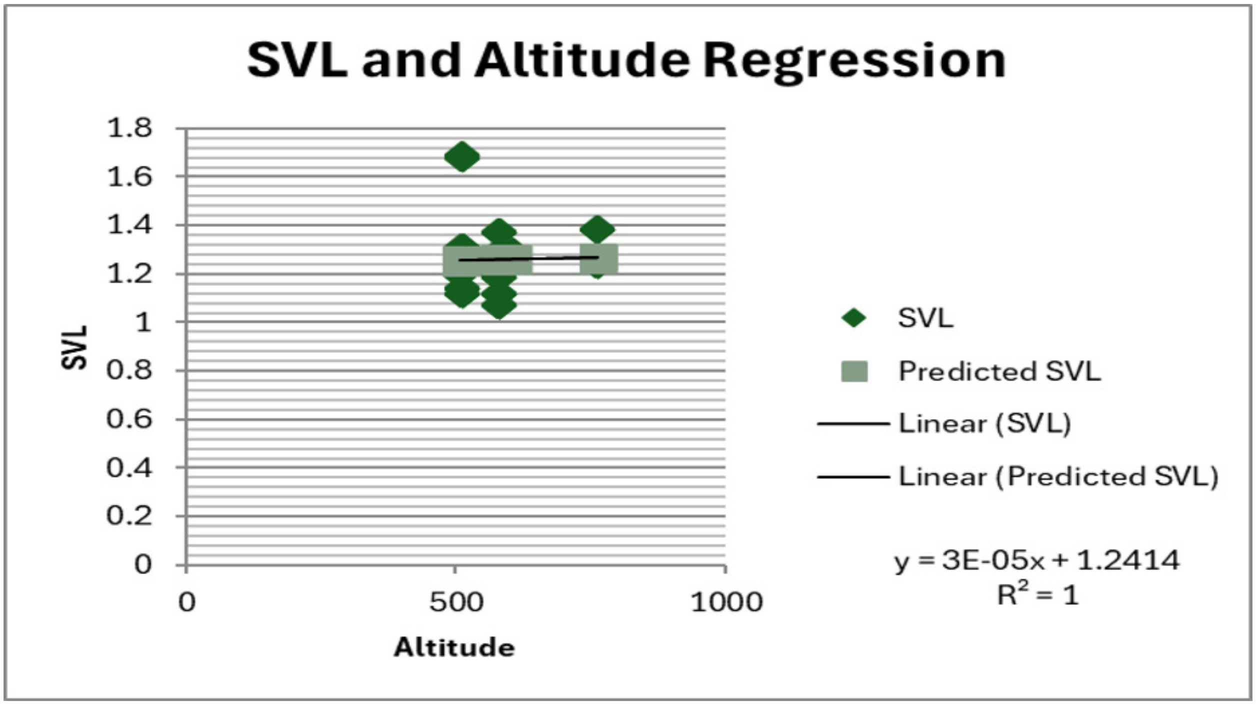


Figure 8: A linear regression model fit between SVL and Altitude.

Discussion

In their native habitats, Coquí frogs show lower call characteristics with increasing altitude because of larger individuals occupying higher altitudes. I found a similar relationship with invasive Coquí frogs on the island of Hawaiʻi. This finding establishes a new baseline from which the phenomena of upward shifting due to climate change can be compared and monitored over time. In Hawaiʻi, temperatures typically decrease by 3.5 degrees Fahrenheit per 1,000 ft of altitude increase and overall lower as altitude increases (Diaz et al., 2011). This temperature gradient is similar to that of Puerto Rico, where every 1,000 feet is associated with a decrease of 5.4 degrees Fahrenheit (Van-Beusekom et al., 2015). While the Hawaiʻi gradient may not be as drastic, it provides a similar baseline to compare locations.

Peak frequency altitude graphs matched initial expectations based on native populations: as altitude increased, the peak frequency, of both the "co" and the "qui" vocalizations decreased, a result consistent with past studies in Puerto Rico. When tested with a regression model (Figure 7), the slope indicated a negative relationship of -.3987, as well as the P-value of 3.3E-185 establishes that this is likely not due to chance. However, the adjusted R^2 of 0.027484 indicates that only a very small portion, about 2.75%, of the variation in the dependent variable around the mean. This indicates that while there is a relationship, it is a very weak relationship. This phenomenon is explained by the fact that for larger frogs, the amount of area that they have for a vocal size also increases, allowing for a larger vocal sac. These larger vocal sacs increase the amount of air that can be inhaled and vibrated to create larger sound waves. Frequency is described as the number of wave cycles that pass through a point in a second measured in Hertz. Larger waves are extended over time, resulting in lower frequencies. This relationship is clearly reproduced in the figures of this study. Due to being ectotherms as the weather becomes less favorable for rain conditions and overall becomes warmer which would lead to more of these low-frequency calls.

Additionally, the relationship between SVL and altitude was tested with a regression model. The slope indicated a positive relationship of 3E-05 as well as the P-value of 3.86E-62 shows that there is a relationship between these variables. However, with such a small adjusted R^2 value of -0.00298 this relationship is very weak. This is because of the time constraints leading to not having enough SVL data. The positive relationship is due to the cooler temperatures up in higher elevations. In ectotherms, colder temperatures allow for more body growth, enabling larger body sizes. Higher temperatures can inhibit the efficiency of cellular processes, leading to smaller cells, and consequently smaller body sizes (Angilletta et al., 2004).

Further analysis using this same dataset will give more insights into the spatial distributions of this invasive species. For instance, the large variations in individual calls shown in figure 4 could be due to analyzer bias, which is common in the field of bioacoustics when doing manual annotations. Although utilizing software-based models could be used in future studies to annotate recordings, many programs are designed for bird calls, not frog vocalizations. Bias is also created around the natural subjectivity of what constitutes a vocalization. This could also be due to some annotations coming from iNaturalist, a citizen science website for recordings. iNaturalist recordings also do not account for the distance between the frog and the physical recorder, leading to possible inaccuracies in the data.

Other environmental factors may be at play when it comes to the frequencies of vocalizations. For example, rain was an important bioindicator for when the frogs were vocalizing. On every night that we sampled it had either rained during the day or was raining while we were searching. This is not an uncommon occurrence for amphibians as "calling activity of frogs is influenced by local environmental factors such as relative humidity" (Hatano et al., 2002). This is because amphibians breathe through their skin which makes moist environments ideal to move around and find mates.

Overarchingly, some results were ambiguous, however the clear negative relationship between frequency and altitude (Figures 6a and 6b) are consistent with the expected results from the native frog research. This indicates that if this pattern holds true, with more studies we could determine that altitude does have a large effect on these vocalizations, and that overtime we may see these frogs shift into higher altitudes where they have a bigger body size, but a smaller peak frequency as expected in Puerto Rico.

Further Research

This study establishes a baseline which can be reassessed further as the global climate continues to warm. It also remains to be explored if climate will also impact the inverse relationship of the calls and change the calls of the frogs even at higher altitudes. It is possible that producing short and quick calls at higher frequencies may be less energy-intensive, so a future study should investigate if even at the higher elevations we are seeing distinct changes in the calls. Furthermore, a more in-depth process should redo manual review of the different variations in the "co" and "qui" to make sure each annotation is correctly identified. There could also be a study looking at the entire duration of one frog call to see if duration is also impacted by altitude gradients and anthropometrics.

Acknowledgements

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Acoustic Surveying for the Hawaiian Hoary Bat (*Lasiurus semotus*) in Māhukona Reserve, Hawaiʻi

By Grace Guo[1], Mei Rao[1], Keone Emeliano[2], Larissa Sugai[1]
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Abstract

We conducted passive acoustic monitoring for the Hawaiian hoary bat (*Lasiurus semotus*) in Māhukona Navigation and Ecological Complex, Hawaiʻi, a reserve recently purchased by the Hawaiʻi 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 ōpeʻapeʻa (*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 Hawaiʻi 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 Kapaʻa Nui, Kou, Kamano, Māhukona, Hihiu, and Kaoma ahupuaʻa. It was originally intended for resort development, but in 2023 it was purchased by the Hawaiʻi Land Trust for long-term preservation of historical and cultural sites. Most significantly, it is home to Koʻa 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 (Hawaiʻi 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 Hawaiʻi 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.

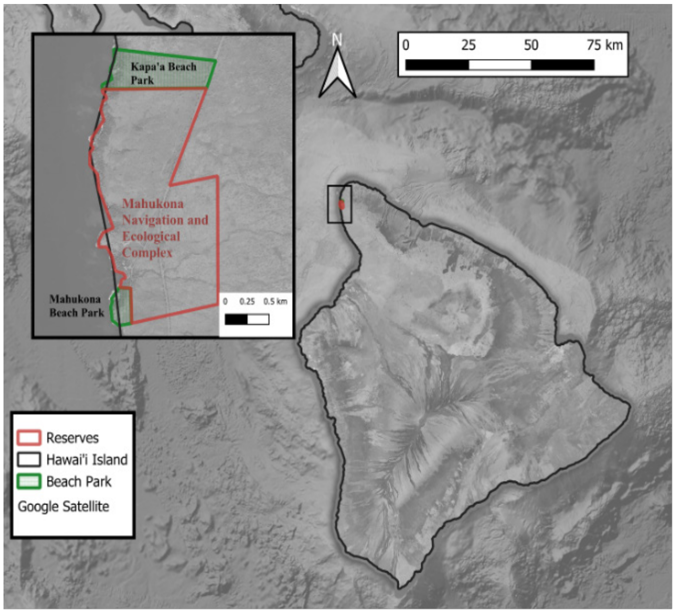


Figure 1: Map showing the study area on Hawaiʻi Island, focused on the Māhukona region along the island's northwestern coast. The main map depicts the full island with an inset box indicating the study location. The inset map zooms in to show the boundaries of the Māhukona Navigation and Ecological Complex (outlined in red) as well as nearby Kapaʻa 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 ʻuhaloa (*Waltheria indica*), along with sites designated for future native plant restoration across the reserve as shown in Figure 2 (Hawaiʻi 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, Hawaiʻi 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.

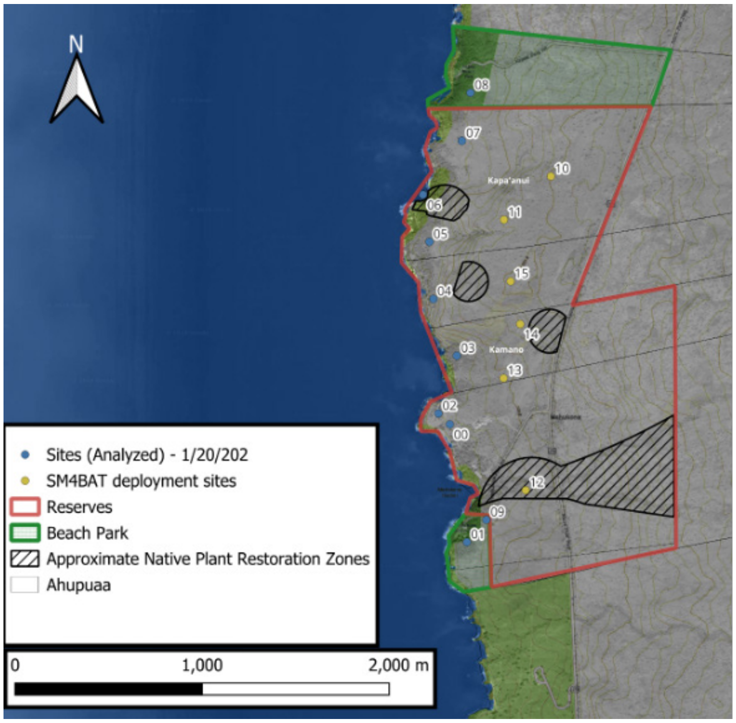


Figure 2: Map showing the spatial distribution of acoustic recorder deployment sites for monitoring Hawaiian Hoary Bat activity in the Māhukona Reserve region of Hawaiʻi Island. Ten monitoring sites (labeled 00–09) are positioned primarily along the coastline and within key land management zones. The 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).

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

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 Kapaʻa Beach Park, north of the Māhukona Reserve.

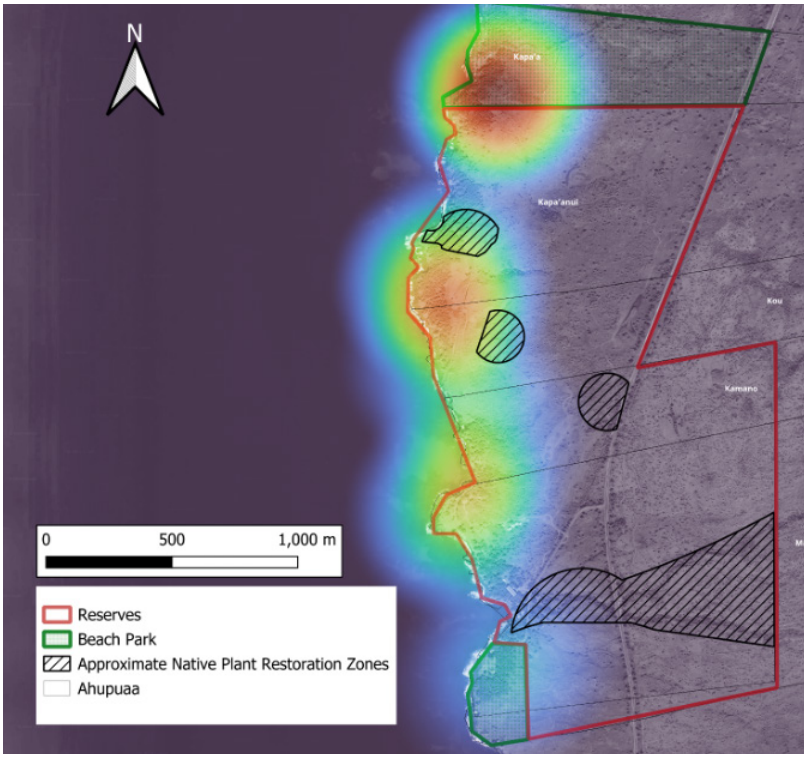
Discussion

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.



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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 Kapaʻa 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: Hawaiʻi 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 Hawaiʻi 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.

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Appendices

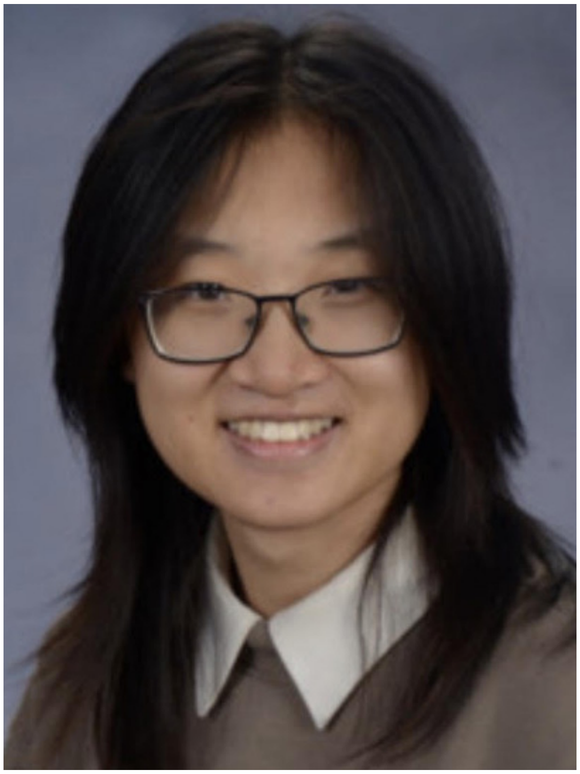
Table 1: MĀHUKONA SITE LOCATIONS – information on the deployment of the recorders in the Māhukona Navigation and Ecological Complex. For each site, we present the location in decimal latitude and longitude, the dates of deployment, the number of hours recorded, the altitude, and whether the site was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

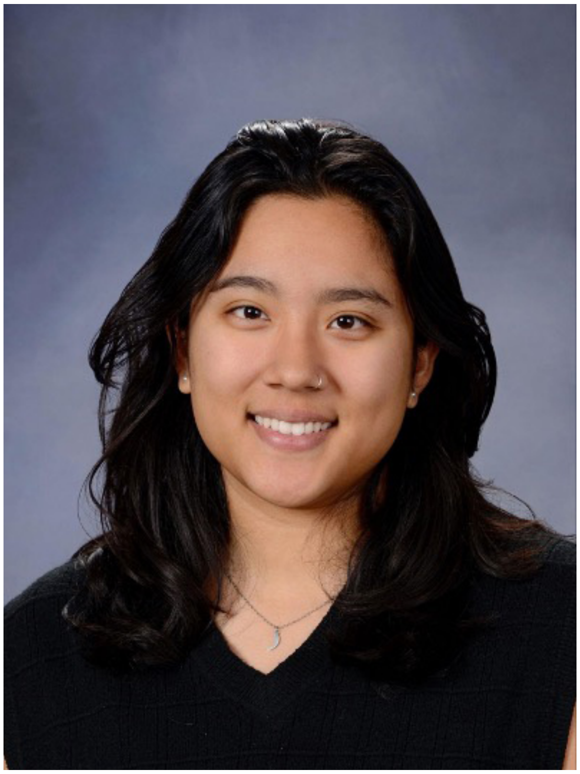
Table 2: BAT ACOUSTIC DETECTIONS BY SITE – A count of positive ōpeʻapeʻa detections for each of the sites included in this preliminary analysis, along with the total number of nights that the recorder was at the site. The average nightly detection count was calculated by dividing the positive ōpeʻapeʻa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

Authors' Biographies



Grace Guo is a senior from Atlanta, Georgia, studying Biological Sciences with a concentration in Ecology and Evolutionary Biology in the College of Agriculture and Life Sciences. They are pursuing a career in wildlife biology, and have worked on a variety of projects, including seabird fecal DNA/diet analysis as a lab technician at the Cornell Lab of Ornithology, nest searching and monitoring for black-throated blue warblers at Hubbard Brook Experimental Forest, and similar work for black guillemots at the Isles of Shoals in the Gulf of Maine. Grace is broadly interested in research in conservation biology, wildlife management, and spatial and foraging ecology. They are a test writer for the Cornell Science Olympiad program, writing and proctoring events focused on different scientific topics for grades 6-12 competitors. In their free time, Grace enjoys being out in nature and creating art of wildlife.



Mei Rao is a senior from Poughkeepsie, New York studying Ecology and Evolutionary Biology with a minor in Environment & Sustainability in the College of Agriculture and Life Sciences. She considers herself a conservation biologist, focusing on human-ecosystem interactions and local adaptation of various wildlife across anthropogenic gradients. They work as a lab technician for a variety of avian genomic research projects at the Fuller Evolutionary Biology Program in the Cornell Lab of Ornithology. Next fall, they will be starting the Ecology and Evolutionary Biology Interdisciplinary Doctoral Program at Texas A&M University in pursuit of a PhD. She is also the team manager for Varsity Men's Heavyweight Rowing and an Undergraduate TA for Environmental Conservation. In their spare time, Mei loves spending time outdoors and cooking for her friends.

Authors' Biographies

Tiernan Tobin is a senior studying Animal Science in the College of Agricultural and Life Sciences. She grew up in Syracuse, NY, where she developed a keen interest in the natural world. From her experience in the Lisa K. Yang Center for Conservation Bioacoustics, she has also gained an interest in bioacoustics. Her current research projects include identifying and visualizing elephant migrations from acoustic data with the Elephant Listening Project, developing a BirdNet model for identification of endangered Black and White Colobus monkeys in REDD+ protected land in collaboration with the University of Wisconsin-Madison, and determining if differing jaw sizes across different genera of parrotfish can allow for acoustic identification with Dr. Aaron Rice. Outside of academia, she enjoys aerial arts, acting, singing, hiking, and spending too much money on boba.

Kay (Akaysha) Williams is a junior from Washington studying Environment and Sustainability & Animal Science in the College of Agriculture and Life Sciences. She is interested in research concerning animal behavior, amphibians, and conservation biology implications. In her free time, Kay loves to read, crochet, and hike. She also raises future guide dogs through Guiding Eyes for the Blind.

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