Assessing ‘Ōpe‘ape‘a Habitat Use and Occupancy in the Helemano Wilderness Area, Central O‘ahu

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Abstract

‘Ōpe‘ape‘a, the Hawaiian hoary bat *(Lasiurus semotus)*, is the only extant, native, terrestrial land mammal in Hawai‘i. It has been listed as endangered under the Federal Endangered Species Act and Hawai‘i Endangered Species Laws since 1970. Despite this level of protection, there are large gaps in scientific understanding of this species’ general ecology. This is especially true on the Island of O‘ahu, where the bat’s population is thought to be the smallest of the main Hawaiian Islands. To better inform land management decisions, I examined how ‘ōpe‘ape‘a utilizes habitat in a diverse, 650 ha portion of Helemano Wilderness Area (HWA) that was purchased to protect and preserve vital bat habitat in central O‘ahu. I deployed ultrasonic acoustic detectors for one to two-week sampling periods at 80 sites across four habitat types (grazed grassland, ungrazed grassland, grazed evergreen forest, and ungrazed evergreen forest) from December 2019 to March 2020. Results from the 672 detector nights and 8,064 detector hours indicate that while bat detections were low (39 detections), bats are present in all habitat types, with the highest detection rate in grazed grassland (15 detections). The overall naïve occupancy rate across habitats was 35%. The best single species, single season occupancy model that considered habitat type, total nightly rainfall (mm) and month showed no statistically significant difference for occupancy between the four different habitats (P Value >0.05). However, detection probability was statistically different by month with the fewest detections occurring in December ($P<0.05$). In addition, while not statistically significant ($P>0.05$), total nightly rainfall (mm) had a negative association with detection rate as an increase in rainfall was correlated with a decrease in bat detections. Results from this study will provide a habitat use baseline for HWA, which will inform land use management decisions by the State of Hawaiʻi. In addition, this study increases understanding of the basic ecology of an understudied endangered species, which will be useful for land managers statewide.

Introduction

The Hawaiian hoary bat, *Lasiurus semotus,* locally known as ʻōpeʻapeʻa, is Hawaii’s only endemic terrestrial land mammal. While not easily detected due to its solitary, cryptic and over dispersed nature, it can be found on all the main Hawaiian islands, with the largest population on Hawaiʻi. island and the smallest on Oʻahu. It has been listed as endangered under the Federal Endangered Species Act (ESA) and Hawaiʻi Endangered Species Laws since 1970 (USFWS 1998).

In 2015 the State of Hawaiʻi passed House Bill 623 which requires Hawaii's electricity to come from 100 % renewable sources by 2045 (HB623 HD1). To achieve this goal, Hawaiʻi must increase its reliance on solar, wind, and other renewable energy sources to reduce its dependence on fossil fuels and, in turn, to reduce Hawaii’s greenhouse gas emissions. Wind energy, in particular, holds promise in Hawaiʻi for expanded renewable energy but has been shown to pose a threat to some native species. Specifically, there is concern with the number of Hawaiian hoary bats that are killed by wind turbines (State of Hawaii, DOFAW, 2015).

While there has been an increase in research focused on understanding the Hawaiian hoary bat's general ecology, there are still many unknowns that force researchers to rely on the life history of the North American hoary bat *(Lasiurus cinereus)* to guide management practices. The North American Hoary bat, like the Hawaiian hoary bat, is a solitary, foliage roosting bat. It has a seasonal migration, where many individuals fall victim to wind turbines. Between 2000 and 2011, approximately 650,000 to 1,300,000 bats were killed at wind farms across the United States and Canada (Arnett and Baerwald, 2013). Three species of bats, including the North American Hoary bat, accounted for 78 % of overall fatalities (Arnett and Baerwald 2013). Hawaiian hoary bats located on Hawaiʻi island have been observed migrating from Hawaii's eastern lowland rainforest to the interior highlands (Menard 2001). They have also been observed foraging at elevations as high as 3,600 meters above sea level during the winter and spring months (Bonaccorso et al. 2016). While these elevational movements have been predominantly observed on the larger and higher elevation islands of Hawaiʻi and Maui, there does seem to be a range restriction in the smaller North Koʻolau and Waianae Mountains on Oahʻu during the pre-pregnancy season (mid-December through March) and the pregnancy season (April to mid-June) (WEST Inc. 2020, Menard 2001). However, these range restrictions could also be due to the bat becoming more vocally cryptic during these reproductive periods, which prevents their detection by the predominant bat detection methods such as acoustic monitoring.

According to the 2020 Draft Hawaiian Hoary Bat Guidance Document, the majority of observed bat fatalities across all wind facilities in Hawaiʻi occur in August and September, which corresponds to pup fledgling season. Importantly, three of Hawaii's eight operational wind facilities have exceeded their permitted incidental take limits for Hawaiian hoary bats, which triggered mandated mitigation measures and revision of their Habitat Conservation Plans (HCP) for this species.

The Endangered Species Act of 1973 (ESA) defines "take" as: "*to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect endangered or threatened species of aquatic life or wildlife*" (16 U.S.C. 1532(19)). When a HCP exists, the appropriate governing body can issue an incidental take license (ITL) which absolves the applicant of the liability of killing species under the ESA when performing an otherwise lawful act (State of Hawaiʻi, DOFAW, 2015). To do so, the applicant must voluntarily agree to mitigate in some way, such as by enhancing the habitat of the listed species.

Due to the increase in take levels across the Hawaiian Islands, wind farm applicants are currently amending their Habitat Conservation Plans to implement new mitigations to offset bat deaths associated with wind facilities. One example of this can be found with the Oʻahu-based Kawailoa Wind Power LLC, which triggered tier four of their HCP in 2018. Tier four required them to provide capital to the State's planned purchase of Helemano Wilderness Area (HWA), 1,166 ha of diverse native and nonnative forest and fallow agriculture land in central Oʻahu that was previously owned by Dole Food Company Inc. Mitigation for this tier permits Kawailoa to increase their allowed incidental take from 60 bats to 115 bats over the life of the facility's 20 year permit term (Kawailoa HCP 2019). The State purchased this parcel of land to protect central Oʻahu's aquifers and watersheds, improve and protect valuable habitat for endangered native species, primarily the Hawaiian hoary bat as required by Kawailoa's HCP, and provide outdoor recreational opportunities for the public (DLNR 2018).

The 1,166 ha of HWA consists of a variety of different habitat types. Some of which DOFAW plans to alter and restore for public use. Before they can alter the property it is vital that they get an understanding of bat habitat preference, since the purchase of this piece of land satisfies Kawailoa's biological mitigation goal of "*maintain[ing] or increase[ing] the long-term availability of bat roosting and foraging habitat [and to] protect and preserve, in perpetuity, bat roosting and/or foraging habitat that would otherwise be threatened with degradation or development*" (p 18, 2019). The Division of Forest and Wildlife (DOFAW) as the land manager must incorporate "*research... into the overall management plan for the area that will focus on identifying optimal habitat or limiting factors for the Hawaiian hoary bat*" (p. 46, 2019), to increase the overall bat population. To do so DOFAW needs to determine a baseline habitat use for the bat which will, in turn, help guide future management decisions related to land use.

To determine if the Hawaiian hoary bats are using this mitigation area and, if so, what habitats they primarily utilize, I examined habitat use and occupancy of the bats across four distinct habitats (grazed grassland, ungrazed grassland, grazed evergreen forest and ungrazed evergreen forest). I tested a null hypothesis that assumed overall bat activity would not differ between habitat type vs. an alternative hypothesis that bat detections would be highest in grazed grassland and lowest in ungrazed evergreen forest. This alternative hypothesis is based on the assumption that there would be an increase in prey insects associated with domestic cattle (Downs and Sanderson 2010, Gorresen et al. 2015, Ancillotto et al. 2018), and open airspace which allows the bats to hunt without maneuvering around obstacles (Gorresen et al. 2017). To test these hypotheses, I deployed eight acoustic detectors, ten times for 1-2 weeks, across the four habitat types (*n*=80) from December 5, 2019 to March 23, 2020.

Methods

1.) Study Area

The focal region of this study consists of approximately 650 ha that span an elevation of 300 to 500 m a.s.l (Figure 1). Mean annual rainfall at low sites (300 m a.s.l.) was 1493 mm/year and at high sites (500 m a.s.l) was 2673 mm/year (Giambelluca et al. 2013). The mean annual nightly temperature ranges from December to March was 18-21°C at low sites and 17-20°C at high sites (Giambelluca et al. 2014). This focal area was chosen from the larger parcel because it is the only region within HWA that had pre-existing roads, and it is also the area that DOFAW is interested in altering for public recreational use.

The study area has four distinct habitats of interest; grazed grassland (38 ha), ungrazed grassland (62 ha), grazed evergreen forest (56 ha) and ungrazed evergreen forests (107 ha) (Figure 1). These habitats were determined based on preexisting land cover maps that were updated following multiple site visits. The grazed grassland was located in an area of active ranchland on the north-western portion of HWA. This habitat contained approximately 40 head of free-roaming cattle and two donkeys which kept the non-native Guinea grass *(Megathyrsus maximus)* under control. The cattle also had access to portions (56 ha) of the ranchland that had mature Christmas berry *(Schinus terebinthifolius)*, albizia *(Falcataria moluccana)*, and fiddlewood *(Citharexylum caudatum*). The forested ranchland was considered to be grazed evergreen forest habitat. The ungrazed grassland habitat was made up of fallow agricultural land and was predominantly covered in dense fields of Guinea grass with the occasional African tulip tree *(Spathodea sampanulata)*, albizia, eucalyptus, Christmas berry, fiddlewood, and Octopus trees *(Schefflera actinophylla)*. Lastly, the ungrazed evergreen forest was located along the eastern portions of HWA and primarily consisted of albzia, paperbark *(Melaleuca quinquenervia)* and native ‘ōhi‘a *(Metrosideros polymorpha)* and koa *(Acacia koa)* forests with an understory of uluhe fern *(Dicranopteris linearis)*. There were also a number of steep gulches breaking up this habitat.

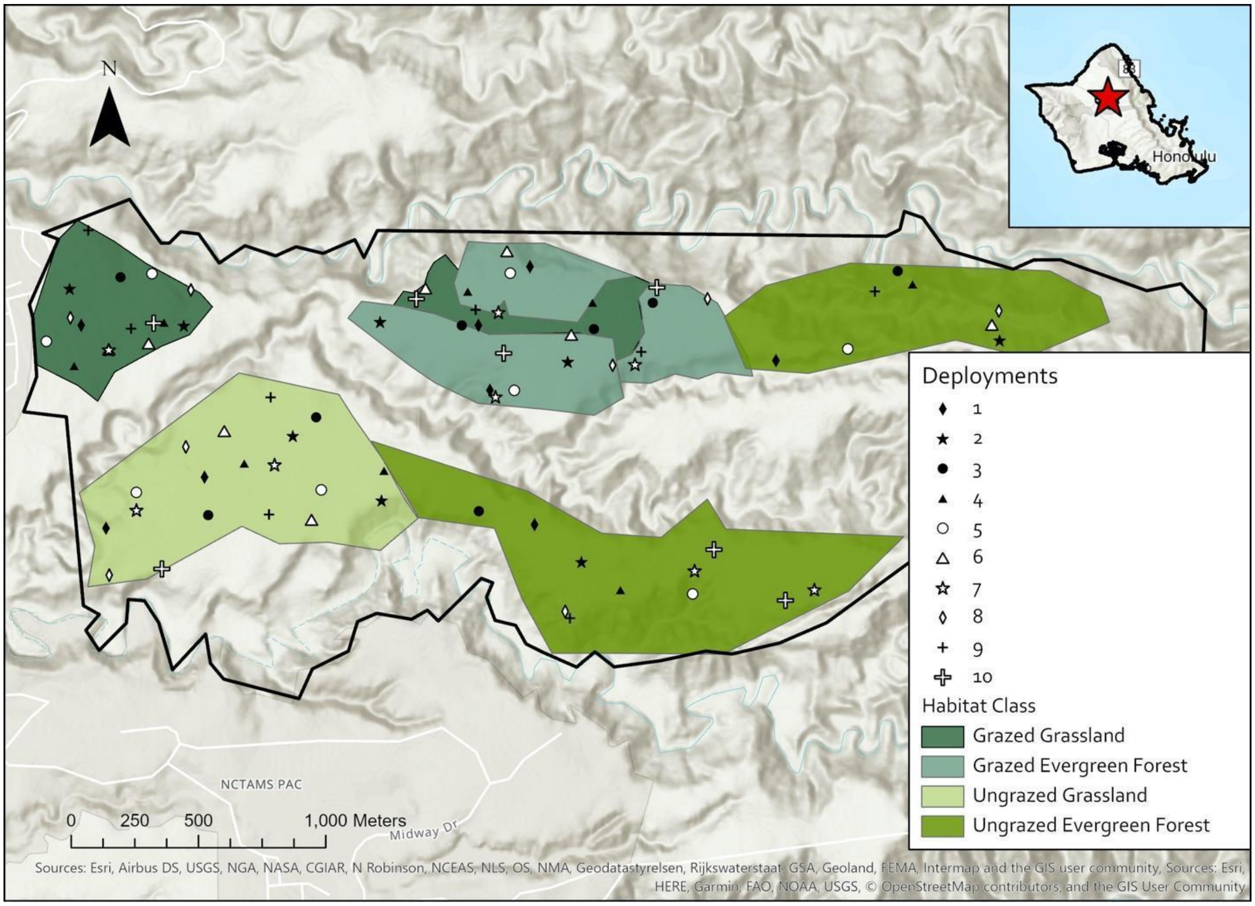

Figure 1. Map of the sampled area within Helemano Wilderness Area. Each habitat was sampled 20 times over ten deployments.

2.) Sampling Design

I generated 20 random sites per habitat, for a total of 80 sites (*n*=80), with an equiprobable generalized random-tessellation stratified sampling design (GRTS) using R package *spsurvey* version 4.1.0 (Kincaid et al. 2019; Stevens and Olsen 2003, 2004). After site generation, a sampling schedule was created following the requirement that each concurrent sampling period have all detectors 400 m away from each other. This requirement reduced the likelihood of sampling the same bat at more than one detector at a time, thus reducing the likelihood of double sampling any given bat and increasing independence between sites.

3.) Field Data Collection

Starting on December 5, 2019 and continuing till March 23, 2020, two Song Meter 4 full spectrum (SM4Bat-FS) bat detectors fitted with SMM-U1 ultrasonic microphones (Wildlife Acoustics Inc., Concord, MA) were deployed in each site. The detectors were attached to a 3 m metal pole with the microphone mounted at the top of the pole (Figure 2). This pole was then placed at least 1 m away from any vegetation in order to reduce excessive noise. Once deployed, detectors were left at each site for one to two weeks.

Detectors were programmed to activate nightly, starting one hour before sunset and stopping one hour after sunrise. The SM4 settings were configured to match that of ongoing USGS Hawaiʻi bat work with the following settings: digital gain of 12 decibels (dB); high pass filter of 16 kilohertz (kHz); sampling rate of 192 kHz; minimum duration of 1.5 milliseconds (ms); maximum signal duration off, minimum trigger frequency 16 kHz; trigger level of 12 dB; and a trigger window of 3 seconds. All acoustic events were recorded on a Secure Digital (SD) memory card without digital compression as a wav sound file. At the end of each deployment, the detectors were collected, and SD cards and batteries were changed. Detectors were then redeployed at the next set of random sites.

SD cards were downloaded to an external drive and processed using Kaleidoscope 5.1.9 (Wildlife Acoustics Inc., Concord, MA). All files were manually evaluated for bat echolocation calls. Nights with detection, regardless of how many, were labeled as 1 (positive detection) and nights without detection were labeled as 0 (no detection).

Figure 2. An example of the acoustic set-up used at an ungrazed grassland habitat site in Helemano Wilderness Area, Central Oʻahu. The pole was 3 m tall with the microphone placed on top. All vegetation was pushed away to reduce excess noise.

4.) Occupancy Modeling

Due to the fact that most bats are cryptic and hard to study, there is a high chance of imperfect detection where sites appear unoccupied when, in reality, they are occupied. This is especially prevalent when dealing with acoustic monitoring where there can be a number of missing bat passes due to the microphone not being within a detectable range or angle (Adams et al. 2012), the use of stealth calls that are too soft to be picked up, or when the bat is flying by but not echolocating (Corcoran & Weller 2018, Gorresen et al. 2017). In order to minimize the impact of these issues, occupancy models, which are informed by repeated observations at each site to acquire unbiased estimates of detection and occupancy in an area, are preferred (MacKenzie et al. 2002, Bailey & Adams, 2005). Once all data was examined and nightly site detections were labeled 0 (no detection) vs. 1 (detection), the data were run in a multiple single season, single species occupancy models with varying covariates using the R package *Unmarked* (Fiske & Chandler, 2011). This provided estimates of occupancy (psi,ψ) and detection (p) rates across the four habitats. The site-level covariates used were month (December- March) and total rain per night (mm) (Weather Underground) and the observation-level covariate was habitat type. The best model was selected based on the lowest Akaike Information Criterion (AIC_c) value as a low AIC_c signifies the "most parsimonious model, balancing model fit and parameter precision" (Bailey & Adams 2005).

Results

Over the course of 672 detector nights and 8,064 detector hours there were 39 positive bat detections at 28 of the 80 acoustic detectors. This provides a naïve occupancy of 0.35. Assuming perfect detection, this naïve occupancy rate indicates that Hawaiian hoary bats occur at 35% of the sites across HWA. Detector results also showed more bat calls in grazed grassland (15), followed by ungrazed evergreen forest (11), ungrazed grassland (9) and finally grazed evergreen forest (4) (Table 1).

Table 1. Hawaiian hoary bat detection rate by habitat type in Helemano Wilderness Area, O'ahu between the months of December 2019 and March 2020. Nights without detections were

determined by lack of any bat calls, while nights with detections had at least one call throughout the night.

Habitat	Nights without a detection	Nights with a detection
Grazed grassland	146	15
Ungrazed grassland	163	9
Grazed evergreen forest	163	4
Ungrazed evergreen forest	161	11

The probability of a site being occupied, $\hat{\psi}$, was estimated to be 0.69 (SE = 0.165) by the null model ($\hat{\psi}$ (.) *p*(.)).

The best model, as indicated by the lowest $AIC_{c,}$ was model 10 (Table 2). This model used detection level covariates of total nightly rainfall (mm) and month and observation level, covariate of habitat type, ψ (Hab) *p*(Month + Rain). The results from this model indicate that there is no statistically significant difference in occupancy between land use types (Table 3, P>0.05). There is, however, a statistically significant difference in detectability of the bats by month (P = 0.0327). and a weak negative association between detectability of the bats and total nightly rainfall (mm) (P = 0.116) (Table 3, Figure 3). This means bats were less likely to be detected in December than in January through March, and while not statistically significant, there was a decrease in bat detections when total nightly rainfall increased (Figure 3).

Table 2. Top models of Hawaiian hoary bat occupancy (ψ) and detection probability (p) at Helemano Wilderness Area, O‘ahu during sampling period of 5 Dec 2019 – 23 Mar 2020.

Model	n Pars	AIC_c	ΔAICc	Cum Wt.	ω_i

10 : ψ (Hab) *p*(Month + Rain)	7	289.67	0.00	0.5591	0.56
9: ψ (Habitat) *p*(Month)	6	291.51	1.84	0.2233	0.78
7: ψ (.) *p*(Month+Rain)	4	294.13	4.46	0.0600	0.84
6: ψ(.) *p*(Habitat+Month+Rain)	7	294.40	4.73	0.0525	0.89
5: ψ (.) *p*(Habitat+Month)	6	295.63	5.96	0.0284	0.92
11: ψ (Habitat) *p*(.)	5	295.84	6.17	0.0256	0.95
3: ψ (.) *p*(Month)	3	295.96	6.29	0.0241	0.97
4: ψ (.) *p*(Rain)	3	297.65	7.98	0.0104	0.98
8: ψ (.) *p*(Habitat+Rain)	6	297.98	8.31	0.0088	0.99
2: ψ (.) *p*(Habitat)	5	299.50	9.82	0.041	1.00
1: ψ (.) *p*(.)	2	299.67	10.00	0.0038	1.00

n Par = number of estimable parameters, AIC_c= Akaike's Information Criteria for small sample size, ΔAIC_c= the difference between the best model (lowest AIC_c) and subsequent model, ω_i = Akaike weights of individual model, Cum wt. = cumulative Akaike weights of the ranked models.

Table 3. Occupancy Model 10's results presented in the logit scale. Model 10 used site level covariates of Habitat and detection level of total nightly rainfall (mm) and month. It indicates that month and total nightly rainfall (mm) influenced the detection probability (P(>|z|)).

Occupancy Probability (ψ)	**Estimate**	**SE**	**z**	**P(>|z|)**
Grazed grassland	11.384	158.617	0.0718	0.943

Ungrazed grassland	0.759	0.973	0.7798	0.435
Ungrazed evergreen forest	0.154	0.747	0.2056	0.837
Grazed evergreen forest	-0.994	0.739	-1.346	0.178

Detection Probability (p)	**Estimate**	**SE**	**z**	**P(>|z|)**
(Intercept)	-1.580	0.2999	-5.27	1.38 e-07
Month	-0.152	0.0713	-2.14	3.27 e-02
Total nightly rain (mm)	-0.136	0.0867	-1.57	1.16 e-01

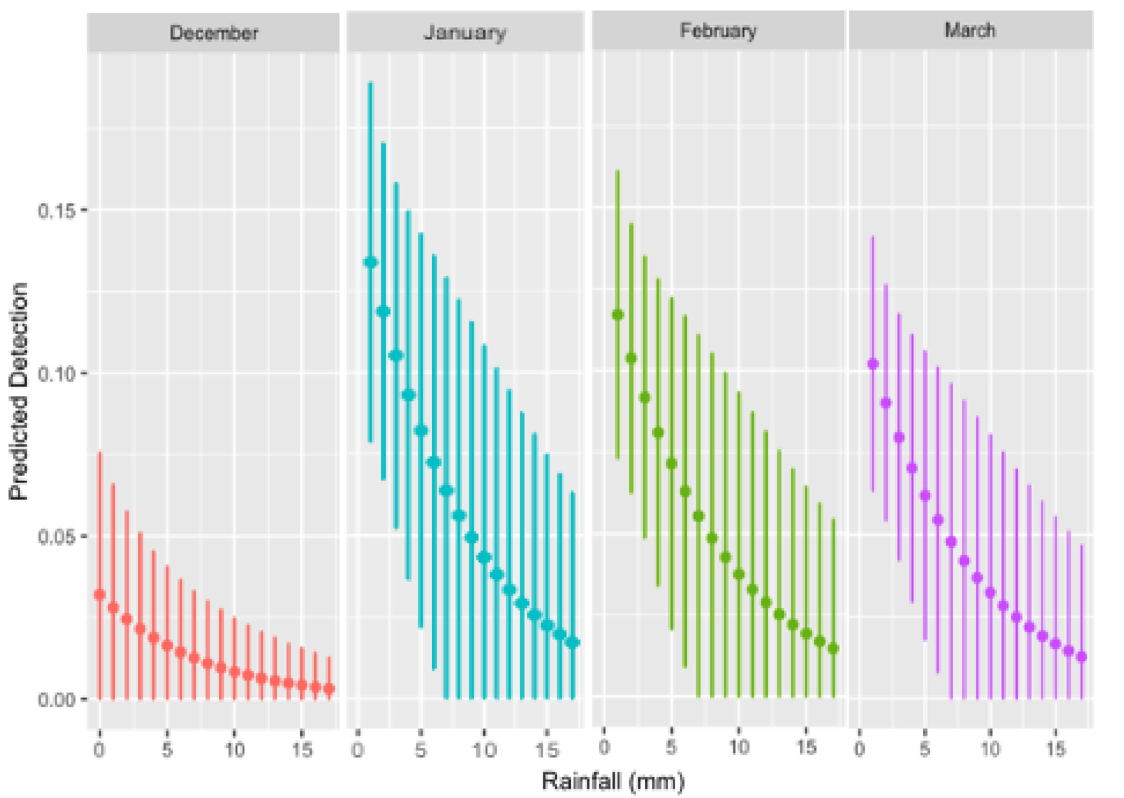

Figure 3. The best model's detection probability of *Lasiurus semotus* in Helemano Wilderness Area, O'ahu for the months of December to March based on total nightly rainfall (mm) and month. The model indicates that an increase in total nightly rainfall decreases the likelihood of detecting bats. Month also plays a role in detection as detections were much lower in December than they were in January.

Discussion

The results of the acoustic sampling coupled with the occupancy model indicate that the bats appear broadly distributed across HWA and are not concentrated into a given habitat type. My hypothesis that bat detections are higher in grazed grassland was supported by the raw acoustic results but the hypothesis that detections should be lowest in ungrazed evergreen forest was not supported. In fact, ungrazed evergreen forest had the second highest detections. This could have been influenced by the presence of steep gulches in this habitat type. H. T. Harvey & Associates' 2019 Maui study found that the habitat type "gulch" had the highest call/minute by habitat ratio (Johnston et al. 2019). They believed that this was due to a reduction in wind speed allowing insects to gather (Johnston et al. 2019).

A number of my sites associated with ungrazed evergreen forest fell along a steep gulch. I observed a number of my sites close to gulches which had multiple nights where a bat or multiple bats circled the microphone allowing me to record feeding buzzes, indicating active foraging. While these nightly events counted a one positive nightly detection in the occupancy model (1), they occurred a number of times at multiple different sites along the gulch. This indicates that the gulch habitat is important to the bats and future research should include it as a specific habitat type.

It has been noted that Hawaiian hoary bats have a seasonal difference in detectability where they become vocally cryptic and much harder to detect from October through March, with a significant decline from December to March (Gorresen et al. 2015, Starecvich et al. 2020). This time period corresponds with the post-lactation reproductive period (September-December) and pre-pregnancy reproductive period (January-March) (Menard 2001). Since I sampled the period that corresponds with most significant reduction in detectability, I would assume that the four months sampled would be relatively similar. Thus, I believe that my statistically significant difference in detectability between months was due to reduced sampling in the month of December and not a difference in detection between months. In future studies, this concern could be resolved by extending the study to two years, allowing a longer sampling period to establish a baseline outside of the post-lactation (September - December), pre-pregnancy (January - March) time frame.

Additionally, in order to make future research more robust and to be able to determine which factors influence bat detection and occupancy in HWA, the variables wind speed, insect biomass and species, canopy cover, forest clutter, temperature and rainfall should be collected at each site and input into the occupancy models.

Management Implications

DOFAW is currently in planning phase one of their management plan for the HWA. This involves seeking public input on development options for HWA. Some of the proposed future projects are increasing horseback riding trails, hiking trails, building campgrounds, planting a cultural garden for public use and potentially removing the paperbark and albizia forests in order to plant native koa and sandalwood. Increasing the number of trails, both horseback riding and hiking, should not impact Hawaiian hoary bat occupancy across Helemano as bats have been found to utilize corridors and the edges of corridors, such as along hiking trails and roads, for hunting and flying through dense forest (Hein et al. 2009, Bonaccorso et al. 2015). Depending on where the campgrounds are placed, tree removal might be necessary. Since the Hawaiian hoary bat is a solitary, foliage roosting bat that indiscriminately roosts in both native and non-native tree species that range from 1-9 m above the ground, care should be taken when removing trees (USFWS 1998, Gorresen et al. 2013). This is especially true when removing a number of trees in a given timeframe as this increases the likelihood of removing one that potentially has a day roosting bat. It is also important to note that Hawaiian hoary bats have been found roosting in paperbark so care should be taken when thinking about removing the paperbark grove (M. Gorresen, personal communication, May 1, 2020). I recommend that before any tree is removed a thermal imaging FLIR camera, that is able to pick up the bat's body heat be used. I also recommend cutting trees down slowly and carefully so that if a bat is disturbed it has the opportunity to fly away unharmed. Care should especially be taken during the months of April-August when the female bats are pregnant and when she has her pups (Menard, 2001). While these precautions can be challenging, costly and time consuming, they are necessary to make sure no bats are hurt in the tree removal process.

Lastly, a cultural garden, as long as no pesticides are being used, should not impact the bat. If pesticides are in use, care should be taken as it has been speculated that pesticide use could be a factor in population decline and individual death (USFWS 1998).

Future Work

Due to the small number of detections resulting in a relatively small sample size, I had few statistically significant results. This may be due to the bats not having a preference between habitat types. However, to be able to say that with certainty a power analysis should be run. This will also allow me to determine if more detectors are needed for future research. I plan to run this analysis in the coming months and include it in the report for DOFAW. In addition, a detailed study plan outlining study length, area use, and covariates will be created in the hopes that this project will continue. By continuing the study, DOFAW will get a stronger Hawaiian hoary bat habitat use baseline with the potential to see season differences. In addition, if DOFAW continues to monitor the bats in HWA before, during, and after the restoration activities, they will be able to see if restoring areas has an impact on the bat's habitat use, and thus be able to say if they had a positive, negative or neutral impact on the bats.

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