# MODELING FORAGING HABITAT SUITABILITY OF THE HAWAIIAN HOARY BAT

A Proposal Prepared for State of Hawaii Endangered Species Committee

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## SUMMARY

The purpose of the proposed study is to apply and test a combination of sampling methods — videography, echolocation and insect sampling — to improve assessments of occurrence and foraging habitat suitability for the Hawaiian hoary bat (*Lasiurus cinereus semotus*). In addition to providing preliminary measurements of bat activity and behavior, the data collected during the study will be used for a power analysis to calculate the necessary sampling effort for future studies of population trend and bat response to habitat restoration.

**Budget Requested from the Bat Mitigation Research Fund by USGS: $143,542**
**Budget Match Provided Courtesy of USGS: $27,870**

## GOALS

The goal of this proposal is to relate bat occurrence and frequency of feeding events to insect abundance. Solitary foliage-roosting bats such as the Hawaiian hoary bat typically roost alone or in small family groups throughout the year. In the past, information on the status of these species has been based on anecdotal accounts of mass migrations, swarming events, or historical capture and collection records. Quantitative measures of population size and trend for tree-roosting bat species have faced the difficulty of detecting sparsely distributed and cryptic individuals at locations where samples of occurrence frequently yield low encounter rates (Carter et al. 2003).

Where overall detection probability is high, metrics such as those produced by occupancy analysis can provide reliable assessments of distribution and trend (e.g., Gorresen et al. 2008, 2013). However, where detection probabilities are low, occupancy analysis produces estimates that are imprecise and positively biased (McKann et al. 2013). Additionally, acoustic sampling may yield low rates of detection because the method can miss a high proportion of locally present bats (e.g., Gorresen et al. 2015, *In prep*.), thereby underestimating bat prevalence and complicating site-specific assessments of trend, habitat use or risk (Weller 2008). Power analysis of occupancy models that specifically applied low detection probabilities (such as that expected or known for Oʻahu from samples limited only to acoustic detection methods) demonstrated that the necessary sampling effort for monitoring trends would not be practical or feasible (Western EcoSystems Technology 2015). Other simulation studies have also shown that power to detect change in occupancy status over time is generally low unless sampling effort is large or detection rates are moderately high (Joseph et al. 2006, Pollock 2006).

The proposed study will apply and test a combination of sampling methods — videography, echolocation and insect trapping — to more directly determine bat occurrence and activity than previous approaches that relied solely on acoustic detection. By integrating multiple detection methods we will improve the metrics on which subsequent assessments of population status depend. In addition to demonstrating the multiple sampling approach, the study will provide the data needed for a power analysis to quantify the resources needed to meet specific monitoring goals in subsequent studies of bat population trend and response to habitat restoration.

Similarities between the 2015 USGS study (Gorresen et al. 2015) and the proposed study include the location and an analytical method. For reasons of accessibility and equipment security, the proposed study may be conducted at the same location (Kawailoa Wind Power) that was used for the 2015 study. Also, both the 2015 study and the proposed study assess the association of bat presence with meteorological and habitat variables using occupancy analysis.

However, the objectives of the 2015 and the proposed study differ in a number of ways. Because occupancy analyses do not perform well when detection rates are low (as observed for acoustic-only data from Oʻahu), the proposed study aims to incorporate videographic detections (in addition to acoustics) to greatly increase the bat detection rate. In the 2015 study, bats were observed by thermal video at more than ten times the rate of concurrent acoustic samples.

The proposed study will also apply a multi-state occupancy model that is more informative than simple models of presence and (presumed) absence. These states will include the occurrence of bat feeding behavior, as well as bat presence without observed feeding, and bat absence. In addition to meteorological and habitat variables, the proposed study will also include in occupancy models measures of insect abundance (this variable was not used in the 2015 study).

## OBJECTIVES

The 2015 USGS study demonstrated the limits of modeling the occupancy of wide-raging animals such as bats when using only acoustic data. However, the study also provided a baseline for the expected detection rates from acoustic and video sampling efforts, which we now propose to integrate along with feeding observations into a single model of foraging habitat suitability. The joint incorporation of these two sources of data, as well as predictor variables such as insect abundance, is expected to improve overall occupancy model results. These results include a determination of how closely bat use of an area is related to insect abundance.

The objective — regional occupancy estimates with a focus on bat feeding behavior — that is to be accomplished as part of the proposed study directly addresses several research priorities. The proposed analyses may be used to assess foraging habitat use and the extent to which bat distribution may be limited by foraging habitat quality and insect availability. As such, the outputs from the pilot study are applicable to research priorities "*Basic research: Document distribution*" (1.a) and "*Identify limiting factors: Determine relationship of distribution to suitable habitat*" (2.a.ii). The method is also relevant to monitoring trends for subsequent studies that involve periodic sampling over time, and this application addresses "*Research and development: Develop methods for assessing long term population trends*" (3.a). Improved occupancy analysis methods can also be applied to comparative analyses of the response of locally resident bats to management (e.g. between sites that serve as control and treatment sites for mitigation actions that include habitat restoration). Finally, the video-derived encounter rates recorded as part of the proposed study will also be used to produce density estimates if random encounter models (REM) are shown to be an effective approach (see the separate proposal "Testing a novel model to estimate bat density and population size").

## TASKS AND ACTIVITIES

Bat occurrence is often closely associated with insect abundance. For example, Lee and McCraken (2005) found that diets of Brazilian free tailed bats (*Tadarida brasiliensis*) were closely correlated to patterns of emergence and availability of noctuid moths. Todd (2012) determined bat vocalization rates to be significantly and positively associated with moths, the most abundant taxa consumed in this and other studies of the Hawaiian hoary bat (Belwood and Fullard 1984, Jacobs 1999). The correlation of insect and bat detections by video were also observed to be moderately high at a wind energy facility on Oʻahu (Gorresen et al. 2015). In that study, nightly bat and insect detections demonstrated similar episodic peaks and dips over the 6-month sampling period, and insect occurrence generally exhibited a bimodal within-night pattern similar to that of bats (i.e., peaking after sunset and again before sunrise).

Hawaiian hoary bats are not likely to be limited by the amount of tree cover in most regions because most locations have trees that can serve for short-term use as a night-roost in proximity to foraging habitats (i.e., a bat flying at 11 m/s can cover 10 kilometers in just over 15 minutes). Prey availability is likely to be the primary factor that determines bat occurrence and activity in an area. As such, we propose to incorporate insect sampling as a predictive variable in models of bat occupancy and as an index of foraging habitat quality.

Thermal videography will be used to determine bat occurrence and relative activity since it provides less ambiguous measurements than acoustic methods alone. Compared to acoustic samples, the higher rates of detection provided by videography is expected to allow for occupancy models to be effectively applied to the estimation of bat prevalence and its association with variables such as insect abundance.

Acoustic recording of bat echolocation will be also used concurrently with videography to identify vocalization specific to the close-range targeting of insect prey. Whereas the detection of all bats calls will be used (along with videography) to determine bat presence, a subset of acoustic samples that focus exclusively on terminal phase-type calls ("feeding buzz"; Griffin et al. 1960) will be used to quantify active insect pursuit and capture. For the detection of this type of activity, the exclusion of calls indicative of bats simply searching for prey or commuting past sampled habitats is expected to reduce the sample variability used to infer habitat suitability. Finally, the abundance of insect prey will be evaluated to provide an index of foraging habitat quality and as a potential correlate of bat presence at a site.

The data will be analyzed with occupancy models that estimate the proportion of sample units occupied by a species (MacKenzie et al. 2006). Recent advances in occupancy models allow for the estimation of multiple occupancy states which are more informative than simple models of presence and absence (Nichols et al. 2007, MacKenzie et al. 2009, Bailey et al. 2014). Multi-state occupancy models have relevance to conservation and habitat management because they allow the investigator to consider a range of biologically relevant states. The multi-state approach also accounts for different detection probabilities by state (arising from either inherent difference in detection between different occupancy states or for the use of different survey methods). In this case we will differentiate among states derived from three types of observations: <u>unoccupied</u> sites (i.e., no bats detected), occupied sites at which <u>no feeding</u> by bats was detected, and occupied sites at which <u>feeding</u> was detected.

## OUTPUTS

The data outputs of this proposed study will include regional occupancy estimates from which trend can be assessed and differences between regions may be compared. More importantly, the study will serve as a demonstration of a combined sampling approach that focuses on the suitability of a region as foraging habitat for the Hawaiian hoary bat.

## OUTCOMES

USGS and HCSU project staff will be available to advise state, federal and private organizations about the application of the informational outputs described above. This can be accomplished by technical assistance meetings, conference presentations, workshops, and the publication of technical reports and peer reviewed scientific publications.

## MATERIALS AND METHODS

The proposed pilot study will apply three methods to measure bat occurrence, the frequency of feeding events, and available insect prey.

Bat occurrence will be sampled using surveillance cameras equipped with 10 mm lenses (Axis Q1932-E, Axis Communications, Lund, Sweden). These cameras image in the "thermal" spectrum of infrared light (approx. 9000−14000 nm) and require no supplemental illumination. Equipped with a 10 mm lens, the 640 by 480 pixel camera resolution provides a 54 m wide by 41 m high field of view at a distance of 50 m (broadening at greater distances). Video imagery will be processed using custom-written code and matrix-based statistical software (Mathworks) to automatically detect animals flying through the video scenes. All detections will be visually reviewed and characterized as to identity (bat, bird, insect) and proximity.

Bat echolocation at each sampling site will be recorded with Song Meter 4 Bat ultrasonic detectors (Wildlife Acoustics, Concord, MA), each equipped with a SMM-U1 microphone oriented towards the air-space imaged by video cameras. Recordings will be processed with the program CallViewer (version 18; Skowronski and Fenton 2008) to identify and characterize bat call pulses. All files (inclusive of those classed as "noise") will be visually inspected as sonograms to ensure that designations do not include false positives (files misidentified as containing bat calls) or false negatives (files with missed pulses). Sonograms from files with identifiable bat calls will be used to identify terminal-phase calls.

The abundance of insects that may act as prey for bats will be sampled at each site with a Malaise trap (MegaView Science). Trapped insects will be collected following each site visit and oven dried to produce measures of dry weight biomass. As a demonstration of a relatively low-cost, short-term survey approach, the proposed study will not attempt to identify insect species taxa (bat diet and available insect prey is more intensively evaluated in a separate proposal "Hawaiian hoary bat movements and roosting behavior").

The availability of insects that may act as prey for bats will be sampled at each site with UV light trapping (specifically the Leptrap shown below; http://leptraps.com/lighttraps.htm). It will be equipped with a timer or light sensor so that it only operates to attract insects at night; this will minimize inclusion of daytime active insects in the samples. The trap will include a beetle separator and a cap to protect the set-up from rain. The trap will be powered by a 12-volt battery in its own enclosure. Trapped insects will be collected following each site visit and sorted to taxonomic order and size category. Samples will subsequently be oven dried to produce measures of dry weight biomass. However, the topic of bat diet and available insect prey at lower taxon levels will be more closely evaluated in a separate proposal ("Hawaiian hoary bat movements and roosting behavior") and in another HHB study to be conducted on Maui at the end of this year.

For this pilot study, we will fit single-season multi-state occupancy models wherein habitat characteristics, meteorological conditions, and available insect prey are evaluated individually and jointly as potential predictors of bat occurrence and feeding activity. Habitat characteristics will include several of the more important landscape metrics identified in the 2015 study (elevation, and wind exposure). Likewise, important meteorological conditions such as nightly wind speed and moon illumination will be used in occupancy models. Insect abundance (measured as dry weight biomass and number per order) will also be incorporated as a quantitative variable affecting occupancy. A suite of competing models comprised of single variables and a combination of variables will be fit to the data and ranked in terms of explanatory power. As an example, a model with a particular predictor (Lepidoptera biomass) is compared to other models without this variable, to determine its particular significance and relative effect on bat presence and feeding activity. Additive terms for additional variables (e.g., elevation) and interaction terms (e.g., wind and moon illumination) will also be incorporated. The multi-state occupancy models are to be developed as described by MacKenzie et al (2009) (also see [http://www.mbr-pwrc.usgs.gov/software/doc/presence/presence.html#multi_state](http://www.mbr-pwrc.usgs.gov/software/doc/presence/presence.html#multi_state)).

To simplify model parameters and the minimize sampling effort needed for precise estimates, sample sites will be chosen to be as similar as possible, limited to open settings with no visible forest cover in the video camera field-of-view so as to eliminate its effect on bat detection. Predictors such as nightly precipitation and wind speed recorded at nearby sources will be used to incorporate weather conditions.

Given the observed bat encounter histories (of both occurrence and terminal-phase type vocalizations) we will use Monte Carlo simulation to estimate the sampling effort needed to meet a range of monitoring goals. In this method the observed data is randomly sampled, then perturbed to incorporate the change or trend we wish to detect. The statistical test is conducted on the simulated data, and the process is repeated. The proportion of tests with statistically significant results is an estimate of the power to detect the desired change or trend.

To assess for differences in occupancy or detection probability between regions, we would fit a model with an additional covariate indicating the region. If this augmented model has significantly more explanatory power we conclude that the parameters are different between regions, and the coefficient of the region covariate estimates the magnitude of the difference. Testing for differences between years can be done similarly. To look for trends over time, year is included as a continuous covariate, and if doing so improves model explanatory power we can conclude there is a change over time.

These occupancy models can be fit in either a maximum-likelihood or a Bayesian framework. The latter has advantages for trend detection. The posterior distribution of the rate of change over time can be subject to equivalency testing (Camp et al. 2008) to evaluate the strength of evidence that a population is increasing, decreasing, or stable within the definitions of a quantified monitoring goal.

Possible monitoring goals to be evaluated in this study may include the detection of differences in occupancy rate between geographic regions and years; for example, “the ability to detect a 20% change in occupancy between two sites with 90% confidence allowing for a 10% type I error rate.” A potential trend monitoring goal might be “the ability to detect a net change of 40% over a 10-year period” with the same numerical goals for confidence and error rate.

Sampling will be scheduled for the lactation period (mid-June to August) of the reproductive season, a period shown by previous fieldwork to have a relatively high acoustic detection probability (Gorresen et al. 2015). Sampling effort will consist of 4 sites monitored concurrently for 4-night intervals. Sampling will rotate among sites in the study area (currently planned for the Kawailoa Wind Power facility in the leeward region of the northern Koʻolau Mountains), with up to 20 sites visited within a 5-week period (Figure 1).

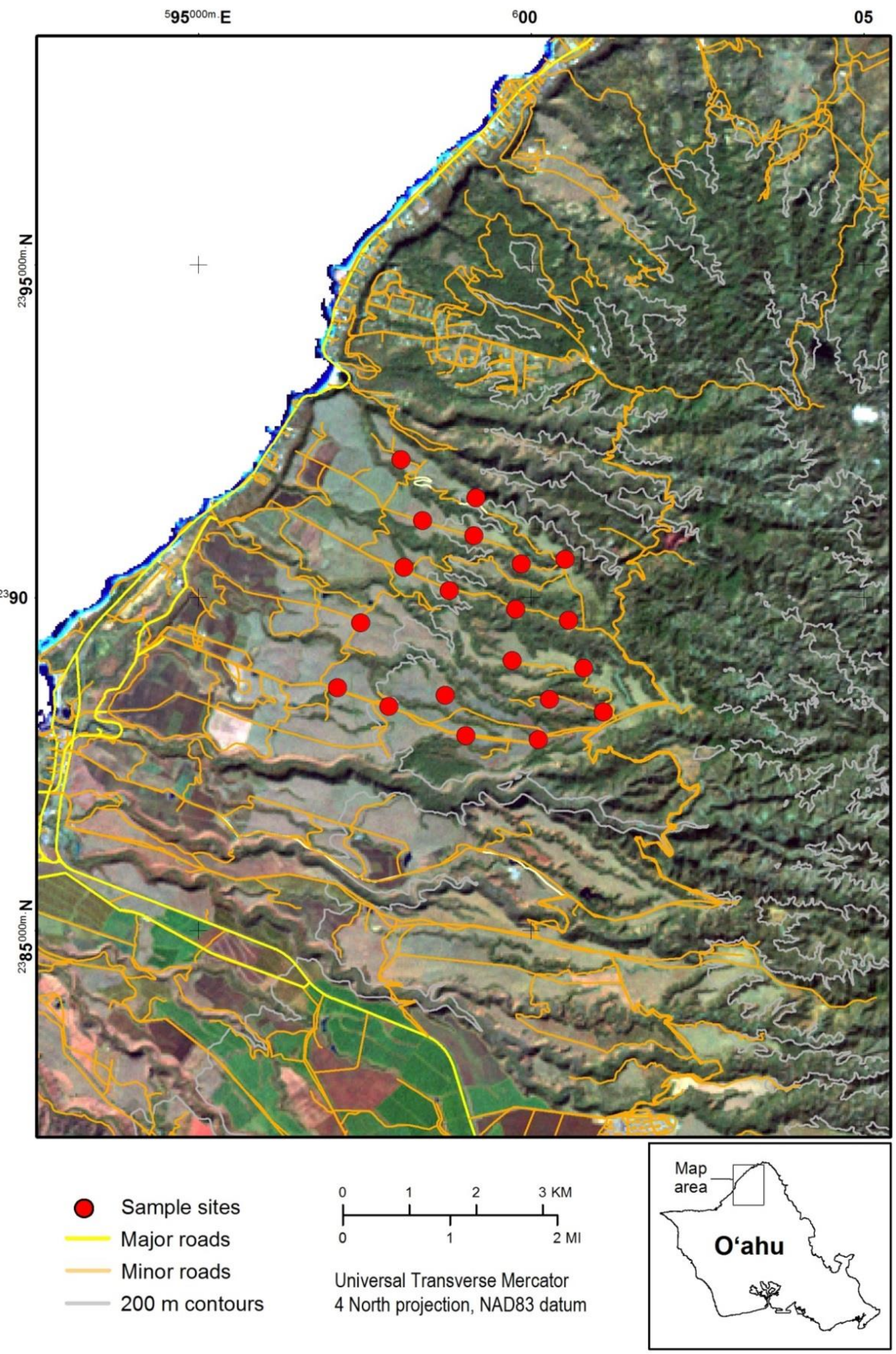


Figure 1. Proposed sample sites in the northern Koʻolau Mountains, Oʻahu.

## TIMETABLE AND MILESTONES

The proposed schedule is centered on field time in mid-June to July, but may be adjusted as needed by several weeks in either direction. Depending on the timing of funding, fieldwork may be started as early as 2017. A draft publication will be available 6 months from the conclusion of fieldwork. Data distribution and documentation (metadata) through USGS ScienceBase (https://www.sciencebase.gov/about/) will be concurrently available with the resulting study publication.

| Task | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
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| permits and authorizations | | | | | | | | | | | | |
| field time | | | | | | | | | | | | |
| data analysis | | | | | | | | | | | | |
| report writing | | | | | | | | | | | | |
| data management and delivery | | | | | | | | | | | | |
| preparation of publications | | | | | | | | | | | | |

## PERMITS AND AUTHORIZATIONS

Access will be coordinated with the Kawailoa Wind Power facility operated by SunEdison. USGS-PIERC and HCSU have an IACUC protocol for observational studies approved by the University of Hawaiʻi at Hilo.

## MONITORING AND EVALUATION

The project manager will be involved in all aspects of the proposed research and be in frequent contact with the Principal Investigator. A summary of the initial survey results of will be available immediately after the fieldwork. Subsequent progress on data analysis and writing will be provided by the Principal Investigator or Project Manager at request.

## ORGANIZATIONS AND KEY PERSONNEL

The applicant organizations include the USGS Pacific Island Ecosystems Research Center (PIERC) and the Hawaiʻi Cooperative Studies Unit (HCSU) of the University of Hawaiʻi at Hilo.

Dr. Bonaccorso will serve as **Principal Investigator**. Dr. Bonaccorso has 45 years of global experience in field biology and research on bats including 11 years of field work on hoary bats in Hawaiʻi. He has 8 peer reviewed publications in major journals involving wildlife telemetry and over 50 publications overall in animal ecology, and has a Ph.D. from the University of Florida.

Marcos Gorresen will serve as the **Project Manager** (University of Hawaiʻi at Hilo, HCSU, Kilauea Field Station, PO Box 44, Hawaiʻi National Park, HI 96718; Telephone: 808-985-6407 Fax: 808-967-8568 Email: mgorresen@usgs.gov). Mr. Gorresen has 22 years of global experience in vertebrate biology and quantitative ecology including 14 years of field and statistical modeling work on hoary bats in Hawaiʻi. He has authored over 30 peer-reviewed publications, and has a M.S. from Texas Tech University.

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