Kaheawa Wind Power
Habitat Conservation Plan
FY 2020 Annual Report

Prepared for:
Kaheawa Wind Power, LLC
3000 Honoapiʻilani Highway
Wailuku, Hawaiʻi 96768

Prepared by:

TETRA TECH

Tetra Tech, Inc.
1750 SW Harbor Way, Suite 400
Honolulu, Hawaiʻi 96813

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Incidental Take License ITL-08/ Incidental Take Permit TE118901-0

EXECUTIVE SUMMARY

This report summarizes work performed by Kaheawa Wind Power, LLC (KWP I), owner of the Kaheawa Wind Power I Project (Project), during the State of Hawaiʻi fiscal year (FY) 2020 (July 1, 2019 – June 30, 2020) under the terms of the approved Habitat Conservation Plan (HCP). The HCP was approved in January 2006 and describes KWP I's compliance obligations under Project's state Incidental Take License (ITL-08) and federal Incidental Take Permit (TE118901-0). Species covered under the HCP include four federally and state-listed threatened and endangered species (Covered Species). The 20-turbine Project was constructed in 2005 and 2006 and has been operating since June 22, 2006.

Fatality monitoring at the Project in FY 2020 continued within search plots limited to cleared areas within 70-meters of each Wind Turbine Generator (WTG). Canine teams searched within each of the fatality monitoring search plots once per week year-round. Bias correction trials were conducted quarterly at the Project to measure the probability that a carcass would persist until the next search and the probability that an available carcass would be found by a canine search team. In FY 2020, mean probabilities of a carcass persisting until the next search were 0.96 (Hawaiian goose surrogates), 0.84 (bat surrogates) and 0.91(seabird surrogates); searcher efficiency exceeded 96 percent for Hawaiian goose, bat and seabird surrogates.

No fatalities of any of the Covered Species were found in FY 2020. Through FY 2020, the Project's total observed direct take of Covered Species has been 12 Hawaiian hoary bats, 28 Hawaiian geese, and eight Hawaiian petrels. The fatality estimates using the Evidence of Absence estimator at the upper 80 percent credibility level are 26 (Hawaiian hoary bat), 43 (Hawaiian goose), and 15 (Hawaiian petrel). Indirect take estimates for the Covered Species are four (Hawaiian hoary bat), two (Hawaiian goose), and four (Hawaiian petrel). Combining these values, there is an approximately 80 percent chance that cumulative take of Covered Species at the Project since the beginning of operations through FY 2020 was less than or equal to 30 for the Hawaiian hoary bat, 45 for the Hawaiian goose, and 19 for the Hawaiian petrel.

The bat acoustic monitoring program evolved during FY 2020. Initially, KWP I collected data at nine ground-based acoustic detectors distributed among Project WTGs. This number was reduced to five after an October 2019 wildfire destroyed monitoring equipment. Between July 2019 and June 2020, Hawaiian hoary bats were detected on 280 nights out of 1,853 (15.1 percent) detector-nights sampled. The seasonal pattern of detection rates was similar to previous years.

Mitigation commitments are ongoing. Baseline (Tier 1) mitigation obligations for the Hawaiian hoary bat were met prior to FY 2020 and current estimated take remains within Higher levels of take (Tier 2). Tier 2 mitigation will be complete in FY 2021 through funding of ecological research on Hawaiʻi Island. The Project's Hawaiian goose current estimate of take remains within Tier 1. Tier 1 mitigation has been funded and is ongoing as propagation efforts at the Haleakalā Ranch Hawaiian goose release pen. This release pen was funded in 2008 and constructed in 2011; in FY 2020 KWP I and DOFAW updated the Statement of Work and signed a Memorandum of

Understanding for continuing mitigation at Haleakalā Ranch. Proposed mitigation credit for fledgling production attributable to the Project has been described by DOFAW; however, KWP I believes that DOFAW's description undervalues the overall benefits of the mitigation funded by the Project to date, and is working with USFWS and DOFAW to develop consensus. Current estimated take of Covered Species that are seabirds remains within Tier 1. Tier 1 mitigation is on-going as implementation of a comprehensive plan for seabird colony management at Makamakaʻole. The Maui Nui Seabird Recovery Project is contracted to continue work at Makamaka`ole through the 2020 breeding season (including into the 2021 calendar year). KWP I continues to work with wildlife agencies to assess overall benefits of Project's seabird mitigation project. Makamakaʻole mitigation efforts produced five Newell's shearwater chicks in FY 2020 (2019 breeding season) in addition to other benefits.

KWP I communicated actively with USFWS and DOFAW throughout FY 2020. The communication was conducted through in-person meetings, conference calls, submittal of quarterly reports, and e-mail communications related to the Project's HCP. The purpose of these communications included required semi-annual HCP implementation meetings and focused discussions regarding mitigation funding and potential adjustments to mitigation strategies.

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1.0 Introduction

The Hawaiʻi Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW) and U.S. Fish and Wildlife Service (USFWS) approved the Kaheawa Wind Project I (Project) Habitat Conservation Plan (HCP) in 2006. Kaheawa Wind Power, LLC was issued a federal Incidental Take Permit (ITP; ITP- TE118901-0) from the U.S. Fish and Wildlife Service (USFWS) and a state Incidental Take License (ITL; ITL-08) from the Hawaiʻi Department of Land and Natural Resources (DLNR), Division of Forestry and Wildlife (DOFAW) for the Project in January of 2006. The ITP and ITL cover the incidental take of four federally and state-listed threatened and endangered species (referred to as the Covered Species) over a 20-year permit term.

The Covered Species include the:

- Hawaiian hoary bat or ʻōpeʻapeʻa (*Lasiurus cinereus semotus*);
- Hawaiian goose or nēnē (*Branta sandvicensis*);
- Hawaiian petrel or ʻuaʻu (*Pterodroma sandwichensis*); and
- Newell's shearwater or ʻaʻo (*Puffinus newelli*).

The HCP frames take levels and mitigation as Baseline Take and Higher Take. Hereafter, we refer to Baseline Take as Tier 1 and Higher Take as Tier 2.

The Project was constructed in 2005 and 2006 and was commissioned to begin operating on June 22, 2006. TerraForm Power, LLC (TerraForm) acquired the Project's LLC in 2016; the Project continues to be operated by KWP I. Brookfield Renewable Partners, LP acquired a majority stake in TerraForm in 2017.

On behalf of KWP I, Tetra Tech, Inc. (Tetra Tech) prepared this report to describe the work performed for the Project during the State of Hawaiʻi 2020 fiscal year (FY 2020; July 1, 2019 – June 30, 2020) pursuant to the terms and obligations of the approved HCP, ITL, and ITP. KWP I has previously submitted annual HCP progress reports for FY 2007 through FY 2019 to the USFWS and DOFAW (KWP I 2007, KWP I 2008, KWP I 2009, KWP I 2010, KWP I 2011, KWP I 2012, KWP I 2013, KWP I 2014, KWP I 2015, KWP I 2016, KWP I 2017,KWP I 2018, Tetra Tech 2019).

2.0 Fatality Monitoring

The Project has implemented a year-round intensive monitoring program to document downed (i.e., injured or dead) wildlife incidents involving Covered Species and other species at the Project since operations began in June 2006. In consultation with USFWS, DOFAW, and the ESRC, fatality searched areas have evolved over time from the start of operations through the initiation of the current approach established in April 2015. The last modifications were in response to the March 31, 2015 ESRC meeting wherein members agreed to "encourage the applicant to work with the statistical experts and researchers to develop an alternative more efficient and focused monitoring strategy which still meets the committees expressed preference for continuation of annual monitoring." The evolution of the searched areas in which fatality monitoring occurred (search plots) included:

- In June 2006, search plots were 180-meter by 200-meter rectangles centered on each of the Project's 20 wind turbine generators (WTG).
- In October 1, 2010, search plots were reduced to 73-meter radius circular plots centered on each WTG, except where steep slopes prohibited visual searching.
- In April 2015, search plots were reduced to the graded WTG pads and access roads that fall within a 70-meter radius circle centered on each of the Project's 14 WTGs (Figure 1).

In FY 2020, all 20 WTGs were searched for fatalities once per week. The FY 2020 mean search interval for all WTGs was 7.14 days (Standard Deviation = 0.95 days). The search plots were searched by a canine search team which included trained detector dog accompanied by a handler. If search conditions limited the use of dogs (e.g., weather, injury, availability of canine search team, etc.), search plots would have been visually surveyed by Project staff. All searches were conducted by canine teams in FY 2020; no visual searches occurred. In February 2020, one search period was not completed due to high winds over several days limiting the ability of the canine search team to safely and effectively perform searches at the Project.

Special precautions have been taken to eliminate any potential canine interactions with wildlife, with a focus on the Hawaiian goose. If Hawaiian geese were present nearby by, the canine handler was directed to immediately retrieve the dog and postpone or temporarily skip dog searches in favor of visual searches. Hawaiian geese were observed on October 23, November 6, 2019, and on January 2, February 26, March 7, and April 8, 2020. In each case, the handler moved the canine to a different WTG search area and returned to finish the disrupted search later in the day. No canine wildlife interactions were observed.

3.0 Carcass Persistence Trials

Four 28-day carcass persistence trials were conducted in FY 2020, once per quarter, using bat surrogates (black rats; *Rattus rattus*), seabird surrogates (wedge-tailed shearwaters; *Ardenna pacifica*) and Hawaiian goose surrogates (chickens; *Gallus gallus*). For FY 2020, the probability that a carcass persisted until the next search was 0.84 for all bat surrogate carcasses (95 percent Confidence Interval [CI] = 0.76, 0.90; N=20), 0.91 for seabird surrogates (95 percent CI = 0.74, 0.97; N=8), and 0.96 for Hawaiian goose surrogates (95 percent CI = 0.82, 0.99; N=8).

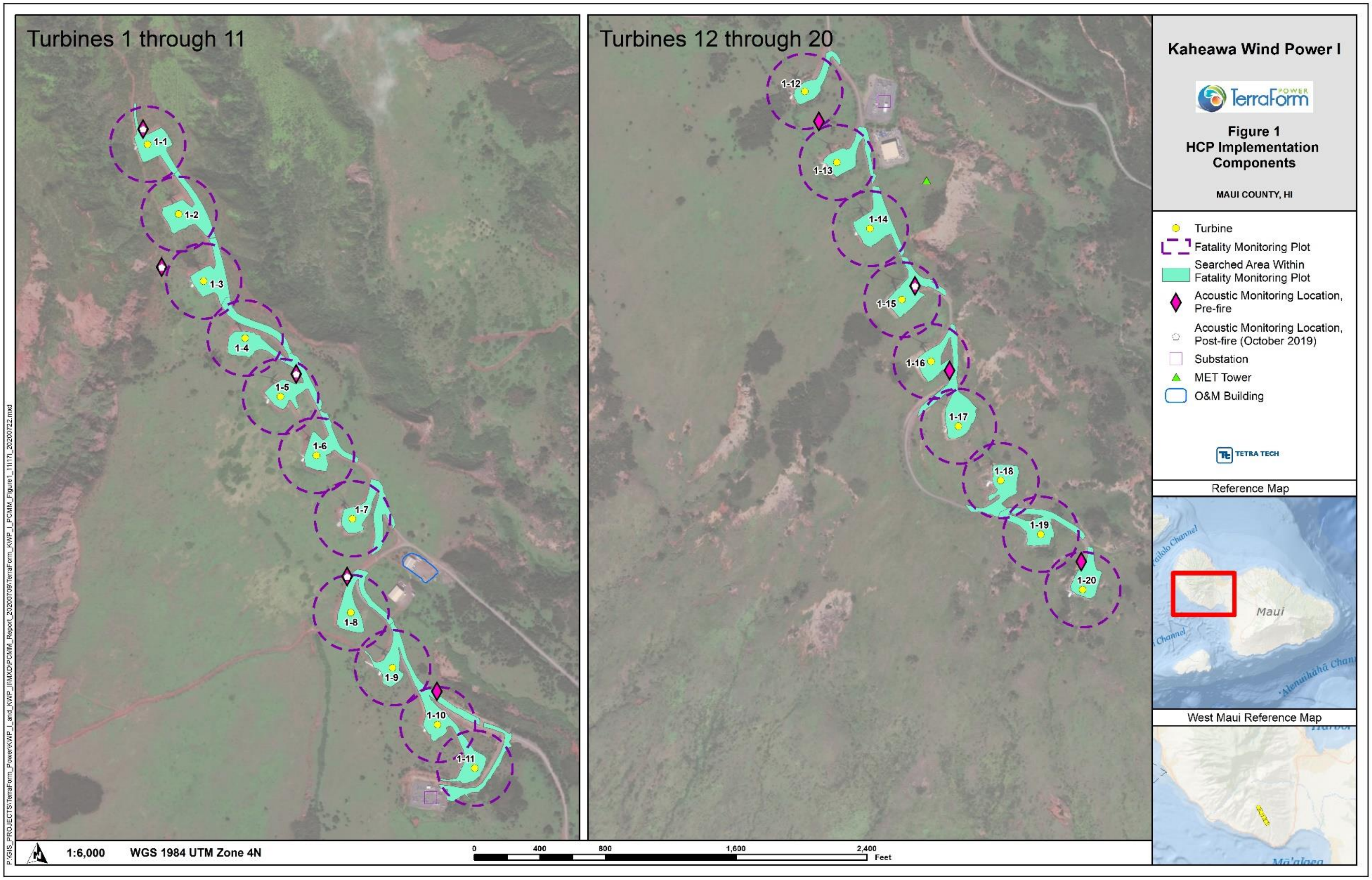

Figure 1. HCP Implementation Components

4.0 Searcher Efficiency Trials

A total of 56 searcher efficiency trials on 19 trial days were administered during FY 2020. Similar to the carcass persistence trials, large chickens were used as surrogates for Hawaiian goose, wedge-tailed shearwaters and other medium-sized birds collected under the Project's Special Purpose Utility Permit (MB22096C-0) were used as surrogates for Covered Seabird Species, and black rats as surrogates for bats. Searcher efficiency trials occurred throughout the year; 100 percent were conducted with canine search teams in FY 2020. Of the 56 trials placed, three bat surrogates were lost to predation. All other carcasses were available for detection. For FY 2020, the probability that a canine search team would find a carcass was 0.97 for bat surrogates (95 percent CI = 0.86, 0.997; N=32), 1.00 for Hawaiian petrel surrogates (95 percent CI = 0.83, 1.00; N=13), and 1.00 for Hawaiian goose surrogates (95 percent CI = 0.82, 1.00; N=12).

5.0 Vegetation Management

In order to maximize fatality monitoring efficiency and minimize impacts to native plants without compromising soil stability, KWP I performs vegetation management at the Project. Vegetation management activities have evolved over time, and account for Hawaiian goose nesting season restrictions:

- The vegetation management activities within the search plots were initially limited to between April 1 and October 31 to minimize risk during the Hawaiian goose nesting season.
- In November 2016, Stephanie Franklin of DOFAW-Maui verbally approved using hand management tools (spray packs and weed whackers) during the Hawaiian goose nesting season if the activity was within the current search area and did not disturb wildlife.
- In March 2017, Stephanie Franklin of DOFAW-Maui verbally approved the removal of Christmas berry (*Schinus terebinthifolius*) within 70 meters of the WTGs to reduce potential Hawaiian goose nesting habitat in the vicinity.

Vegetation management was implemented at the Project throughout FY 2020. Quarterly glyphosate-based herbicide treatments using a boom sprayer were applied to the cleared areas within each search plot, supplemented by weed whacking to maintain consistency of the extent of the cleared area within 70 meters of each WTG. In October 2019 (Quarter[Q] 2), a wildfire impacted the vegetation surrounding the Project, however the vegetation management program in place minimized the fire's impact to the search plots. Limited application of herbicide occurred in Q3 by spot treatment with a hand sprayer. On January 22, 2020, nest clearance surveys were conducted in conjunction with DOFAW prior to the application of herbicide using a boom sprayer to avoid exposing Hawaiian goose nests to the treatment. The regular vegetation management program resumed in Q4.

6.0 Scavenger Trapping

KWP I has implemented periodic scavenger trapping at the Project to extend carcass persistence times and contribute to a high probability of a carcass persisting until the next search. The scavenger trapping program at the Project was implemented during Q1 and Q2 of FY 2020. Due to logistical challenges, scavenger trapping was suspended during Q3 and Q4 of FY 2020. Scavenger trapping resumed in Q1 of FY 2021. Active trapping occurred at 15 turbines and included nine DOC250 body grip traps and 12 live traps. The trapping program documented the removal of 38 mongoose (*Herpestes auropunctatus*), one feral cat (*Felis cattus*) and one rat (*Rattus sp.*) in FY 2020. No non-target animals were trapped.

7.0 Documented Fatalities and Take Estimates

All observed downed wildlife were handled and reported in accordance with the Downed Wildlife Protocol provided by USFWS and DOFAW (USFWS and DOFAW 2019). No fatalities of Covered Species were found in FY 2020. No injured (live) downed wildlife were observed at the Project in FY 2020.

To calculate take estimates, the number of observed fatalities is scaled to account for fatalities that are not detected, or unobserved. Unobserved fatalities are the result of three primary factors:

- Carcasses may be scavenged before searchers can find them;
- Carcasses may be present, but not detected by searchers; and
- Carcasses may fall outside of the searched area.

Carcass persistence and searcher efficiency (bias correction; see Sections 3.0 and 4.0) measure the effect of the first two factors. The third factor, the number of carcasses that fall outside of the searched area, is dependent upon the proportion of the carcass distribution that is actually searched. The search area for fatalities at the Project has evolved over time; therefore, the proportion of the carcass distribution searched has varied; however, no changes to search plot dimensions have been made since FY 2016 (Section 2.0). Thus, the estimate of the density weighted proportion of the carcass distribution searched (Appendix 1) has remained the same as described in the FY 2017 annual report (KWP I 2017).

Cumulative take at an upper credible limit (UCL) of 80 percent was calculated for each Covered Species for which documented fatalities have occurred, per request of USFWS and DOFAW. The UCL is estimated from three components:

1. Observed direct take (ODT) during protocol (standardized) fatality monitoring;
2. Unobserved direct take (UDT); and
3. Indirect take.

The Evidence of Absence software program (EoA; Dalthorp et al. 2017), the agency-approved analysis tool for analyzing direct take, uses results from bias correction trials and ODT to generate a UCL of direct take (i.e., ODT + UDT). Direct take values from this analysis can be interpreted as: there is an 80 percent probability that actual direct take at the Project over the analysis period was less than or equal to the 80 percent UCL.

Indirect take calculations are based on the HCP and Agency guidance. Indirect take is estimated based on factors such as the breeding season in which fatalities are observed, sex, and age characteristics of Covered Species fatalities found at the Project, their associated life history characteristics as described in the Project's approved HCP, and current agency guidance (USFWS 2016 for Hawaiian hoary bats).

Additionally, EoA includes a module that allows users to project future estimates of mortality based on results of past fatality monitoring. Due to the inherent uncertainty of these projections (including the potential future contribution of indirect take) and the amplification of this uncertainty resulting from the use of the 80 percent UCL as the estimate of take for regulatory compliance, long term projections have limited utility. Nevertheless, they do help gauge the likelihood of permitted take exceedance, and may help operators in their mitigation planning, assuming future management and monitoring conditions can be reasonably estimated.

7.1 Hawaiian Hoary Bat

7.1.1 Estimated Take

A total of 12 Hawaiian hoary bat fatalities have been observed at the Project since monitoring began in June 2006, with no Hawaiian hoary bat fatalities detected in FY 2020. Of the 12 bats, nine were found inside of fatality search plots; three bat detections were excluded from inputs to EoA and are accounted for in the estimated take generated. All bat carcasses were transferred to the U.S. Geological Survey for genetic sexing. The observed Hawaiian hoary bat fatalities by fiscal year are listed in Table 1.

Table 1. Observed Hawaiian Hoary Bat Fatalities at KWP I Through FY 2020

Fiscal Year	Hawaiian Hoary Bat Observed Direct Take	Hawaiian Hoary Bat Incidental Fatality Observations	Total
2007	0	0	0
2008	0	0	0
2009	0	1	1
2010	0	0	0
2011	0	1	1
2012	0	0	0
2013	2	0	2

Fiscal Year	Hawaiian Hoary Bat Observed Direct Take	Hawaiian Hoary Bat Incidental Fatality Observations	Total
2014	4	0	4
2015	0	0	0
2016	0	0	0
2017	1	1	2
2018	1	0	1
2019	1	0	1
2020	0	0	0
Total	**9**	**3**	**12**

The estimated direct take (ODT + UDT) for the 12 Hawaiian hoary bat fatalities found between the start of fatality monitoring in June 2006 and end of FY 2020 (June 30, 2020) is less than or equal to 26 bats (80 percent UCL; Appendix 1). Therefore, EoA estimates 14 unobserved take in addition to the 12 observed take.

Indirect take is estimated to account for the potential loss of individuals that may occur indirectly as the result of the loss of an adult female through direct take during the period that females may be pregnant or supporting dependent young. The timing and sex of all observed fatalities (those observed in fatality monitoring as well as incidental to fatality monitoring) is used in the calculation of indirect take. Indirect take for the Project is calculated using the USFWS (2016) guidance as follows:

- The average number of pups attributed to a female that survive to weaning is assumed to be 1.8.
- The sex ratio of bats taken through UDT is assumed to be 50 percent female, unless there is substantial evidence (10 or more bats) to indicate a different sex ratio.
- The assessment of indirect take to a modeled UDT accounts for the fact that it is not known when the unobserved fatality may have occurred. The period of time from pregnancy to end of pup dependency for any individual bat is estimated to be 3 months. Thus, the probability of taking a female bat that is pregnant or has dependent young is 25 percent.
- The conversion of juveniles to adults is one juvenile to 0.3 adults.

Based on the USFWS guidance (USFWS 2016), the estimate of cumulative indirect take in FY 2020 is calculated as:

- **Total juvenile take calculated from observed female take (April 1 – September 15)**

  - 4 (observed females) * 1.8 (pups per female) = 7.2 juveniles[1]
- **Total juvenile take calculated from observed unknown sex take (April 1 – September 15)**
  - 0 (observed unknown sex) * 0.5 (assumed sex ratio) * 1.8 (pups per female) = 0 juveniles
- **Total juvenile take calculated from unobserved take**
  - 14 (unobserved direct take) * 0.5 (assumed sex ratio) * 0.25 (proportion of calendar year females could be pregnant or have dependent pups) * 1.8 (pups per female) = 3.2 juveniles
- **Total Calculated Juvenile Indirect Take** = 10.4 (7.2 + 0 + 3.2)
- **Total Adult Equivalent Indirect Take =** 0.3 (juvenile to adult conversion factor) * 10.4 = 3.1 (rounded up to 4)

Therefore, the estimated indirect take based on the UCL of Hawaiian hoary bat direct take at the Project is four adults.

The UCL for Project take of the Hawaiian hoary bat at the 80 percent credibility level is 30 adult bats (26 [estimated direct take] + 4 [estimated indirect take]). That is, there is an approximately 80 percent probability that cumulative take at the Project at the end of FY 2020 is less than or equal to 30 bats (Appendix 1).

7.1.2 Projected Take

KWP I projected Hawaiian hoary bat take through the end of the permit term using the fatality monitoring data collected through FY 2020. The objective of this analysis was to evaluate the potential for the Project to exceed the permitted take limit at the 80 percent UCL prior to the end of the permit term (Appendix 2). For this analysis, the detection probability for future years is assumed to match the estimated overall detection probability of FY 2018 through FY 2020, and the fatality rate is unaltered for all future years (rho=1). Because future indirect take is unknown and will potentially vary based on the timing of ODT, we assumed total indirect take for the Project over the permit term would be a maximum of eight adult equivalents (approximately 27 juveniles based on assumed Hawaiian hoary bat survival rates [USFWS 2016]), or 16 percent of the permitted take. Currently, the proportion of total take that is attributable to indirect take is roughly 13.3 percent (4 adult bat equivalents estimated from indirect take / 30 bats estimated combining the direct and indirect take), making the assumption of indirect take of eight adult bats to be upwardly conservative. Assuming eight adult bat equivalents are attributed to the Project as indirect take, the permitted direct take under the Project's ITP and ITL would be 42 bats (take of 50 bats permitted

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[1] DNA results have identified the sex of 11 of the 12 bat fatalities detected at the Project, confirming that six of the fatalities were female (Pinzari and Bonaccorso 2018, version 4.0 April 13,2020). Four of these were detected between April 1 and September 15.

by ITL and ITP minus take of eight bats estimated as attributed to indirect take = 42 bats estimated direct take maximum).

Based on the analysis described above and presented in Appendix 2, there is greater than an 86 percent chance that the 80 percent UCL of cumulative take will not exceed Tier 2 during the permit term. Specifically, the estimated direct take threshold of 42 exceeds more than 86 percent of the projected mortality estimates (Appendix 2). EoA calculated a median estimate of 20 years of Project operation without a direct take estimate exceeding 42 bats. Therefore, the Project is likely to remain below the permitted take limit of Hawaiian hoary bats for the permit term.

7.2 Hawaiian Goose

7.2.1 Estimated Take

A total of 28 Hawaiian goose fatalities attributable to the Project have been observed at the Project since monitoring began in June 2006; with no Hawaiian goose fatalities detected in FY 2020. Twenty-five of the 28 geese were found inside of fatality search plots and are used to estimate direct take. The observed Hawaiian goose fatalities by fiscal year are listed in Table 2.

Table 2. Observed Hawaiian Goose Fatalities at KWP I Through FY2020

Fiscal Year	Hawaiian Goose Observed Direct Take	Hawaiian Goose Incidental Fatality Observations	Total
2007	0	0	0
2008	2	1	3
2009	1	0	1
2010	1	0	1
2011	5	0	5
2012	1	0	1
2013	4	0	4
2014	3	0	3
2015	4	0	4
2016	1	0	1
2017	0	1	1
2018	1	1	2
2019	2	0	2
2020	0	0	0
Total	**25**	**3**	**28**

The estimated direct take (ODT + UDT) for the 25 Hawaiian goose fatalities (within the search area) found between the start of operation (June 5, 2006) and end of FY 2020 (June 30, 2020) is less than or equal to 43 geese (80 percent UCL; Appendix 1).

Indirect take is estimated to account for the potential loss of individuals that may occur as the result of the loss their parents. Both parents for the Hawaiian goose exhibit responsibility for care of young until fledging. The point during the breeding season when an adult is taken determines to what extent offspring may be affected. Indirect take was 3.93 juveniles (2.0 adults assuming a 0.8 annual survival rate and 3 years from fledging to adult; Appendix 3).

The Project may cause a net loss in productivity in the event that take outpaces the number of individuals produced from mitigation efforts. The lag between production of geese through mitigation efforts and the take of geese at the Project drives the estimates of lost productivity. Accrued lost productivity at a given point in time is calculated as the cumulative take less the number of individuals generated from mitigation efforts to date, and then adjusted by a factor of 0.1 to account for the probability that those unmitigated birds would have produced young (KWP I 2006). USFWS and DOFAW have agreed that the Project will not accrue lost productivity for Hawaiian goose take that occurred prior to calendar year 2011, the year the release pen was constructed. Six Hawaiian goose fatalities were documented at the Project prior to January 1, 2011.

DOFAW provided KWP I with Hawaiian goose fledgling data for Project-funded release efforts at the Haleakalā Ranch pen in July 2020. KWP I believes that accounting for mitigation credit undervalues the full extent of benefits the Project's mitigation efforts have produced and is working with USFWS and DOFAW to develop consensus on an approach to attribute mitigation credit for KWP I. Accrued lost productivity will be calculated in FY 2021 as more information becomes available.

The UCL for cumulative Project take of the Hawaiian goose at the 80 percent credibility level is 45 geese (43 [estimated direct take] + 2 [estimated indirect take]). That is, there is an approximately 80 percent probability that cumulative take at the Project at the end of FY 2020 is less than or equal to 45 adult geese (Appendix 1).

7.2.2 Projected Take

KWP I projected Hawaiian goose take through the end of the permit term using the fatality monitoring data collected through FY 2020. The objective of this analysis was to evaluate the potential for the Project to exceed the Tier 1 take limit (described as Baseline Take in the Project's HCP) at the 80 percent UCL prior to the end of the permit term (Appendix 2). As future indirect take is unknown and will potentially vary based on the timing of ODT, we assumed total indirect take for the Project over the permit term would be a maximum of three adult equivalents (approximately six juveniles based on an assumed Hawaiian goose survival rates from juvenile to adult of 0.512 [KWP I 2006]), or 5 percent of the Tier 1 take. Currently, the proportion of total take that is attributable to indirect take is 4.4 percent (2 adult goose equivalents estimated from indirect take/ 45 adult geese estimated, combining the direct and indirect take), making the assumption of three indirect take upwardly conservative. Assuming three adult Hawaiian geese are attributed to the Project as indirect take, the permitted direct take under Tier 1 of the Project's ITP and ITL would be 57 Hawaiian geese (take of 60 geese permitted by ITL and ITP for Tier 1 minus take of three geese estimated attributed to indirect take = 57 geese estimated direct take maximum).

Based on the analysis described above and presented in Appendix 2, there is a 22.2 percent chance that the 80 percent UCL of cumulative take will not exceed the Tier 1 take limit during the permit term. Specifically, the estimated direct take threshold of 57 exceeds 22.2 percent of the projected mortality estimates (Appendix 2). EoA calculated a median estimate of 20 years of Project operation without a direct take estimate exceeding 57 geese. Although the Project may exceed the Tier 1 permitted take limit within the permit term if no additional avoidance and minimization measures can be identified and implemented, the Tier 2 take (described as Higher Take in the Project's HCP) limit is 100. As with Tier 1 take, assuming 5 percent of the Tier 2 take limit is attributable to indirect take, authorized direct take under Tier 2 would be 95 Hawaiian geese (take of 100 geese permitted by ITL and ITP for Tier 1 minus take of five geese estimated to be attributed to indirect take = 95 geese estimated direct take maximum). A permitted direct take value of 95 exceeds 100 percent of the EoA projected mortality estimates (Appendix 2). KWP I has taken actions to minimize the threats to the Hawaiian goose and anticipates working with USFWS, DOFAW, and technical experts to further reduce risk (Section 10.0).

7.3 Hawaiian Petrel

7.3.1 Estimated Take

A total of eight Hawaiian petrel fatalities have been observed at the Project since monitoring began in June 2006; no Hawaiian petrel fatalities detected in FY 2020. Seven of the eight petrels were found inside of fatality search plots. The FY 2013 fatality was found outside of the designated search areas and is treated as an incidental observation. The observed Hawaiian petrel fatalities by fiscal year are listed in Table 3.

Table 3. Observed Hawaiian Petrel Fatalities at KWP I Through FY2020

Fiscal Year	Hawaiian Petrel Observed Direct Take	Hawaiian Petrel Incidental Fatality Observations	Total
2007	0	0	0
2008	1	0	1
2009	0	0	0
2010	0	0	0
2011	0	0	0
2012	2	0	2
2013	0	1	1

Fiscal Year	Hawaiian Petrel Observed Direct Take	Hawaiian Petrel Incidental Fatality Observations	Total
2014	1	0	1
2015	2	0	2
2016	0	0	0
2017	0	0	0
2018	0	0	0
2019	1	0	1
2020	0	0	0
Total	**7**	**1**	**8**

The estimated direct take (ODT + UDT) for the seven Hawaiian petrel fatalities found between the start of operation (June 5, 2006) and end of FY 2020 (June 30, 2020) is less than or equal to 15 petrels (80 percent UCL; Appendix 1). Appendix 1 presents the cumulative Hawaiian petrel direct take estimate based on results from the FY 2020 multi-year analysis from EoA.

Indirect take is estimated to account for the potential loss of individuals that may occur as the result of the loss their parents. Both parents for the Hawaiian petrel exhibit responsibility for care of young until fledging. The point during the breeding season when an adult is taken determines to what extent offspring may be affected. Indirect take was 11.33 juveniles (3.40 adults assuming a 0.3 survival rate from fledging to adult; Appendix 3).

The Project may cause a net loss in productivity if take outpaces the number of individuals produced from mitigation efforts. The lag between production of Hawaiian petrels through mitigation efforts and the take of petrels at the Project drives the estimates of lost productivity. Accrued lost productivity at a given point in time is calculated as the cumulative take less the number of individuals generated from mitigation efforts to date, and then adjusted by a factor of 0.15 to account for the probability that those unmitigated petrels would have produced young (KWP I 2006). Each year's lost productivity is accumulated until mitigation occurs for the estimated adult take.

KWP I is working with DOFAW and USFWS to quantify the benefits accrued through mitigation efforts at the Makamakaʻole Seabird Mitigation Site (Makamakaʻole) and on Lānaʼi. Based on reporting from the 2018 Hawaiian petrel breeding season on Lānaʼi (see FY 2019 annual report [Tetra Tech 2019]) and expected additional benefits from the 2019 breeding season, KWP I believes accrued lost productivity has been fully mitigated.

The UCL for cumulative Project take of the Hawaiian petrel at the 80 percent credibility level is 19 petrels (15 [estimated direct take] + 4 [estimated indirect take]). That is, there is an approximately 80 percent probability that cumulative take at the Project at the end of FY 2020 is less than or equal to 19 petrels.

7.3.2 Projected Take

KWP I projected Hawaiian petrel take through the end of the permit term using the fatality monitoring data collected through FY 2020. The objective of this analysis was to evaluate the potential for the Project to exceed the permitted take limit at the 80 percent UCL prior to the end of the permit term (Appendix 2). Because future indirect take is unknown and will potentially vary based on the timing of ODT, we assumed total indirect take for the Project over the permit term would be a maximum of nine adult equivalents (30 juveniles based on an assumed Hawaiian petrel survival rate of 0.3 from fledging to adult [KWP I 2006]), or 23.6 percent of the permitted take. Currently, the proportion of total take that is attributable to indirect take is 21.1 percent (four adult petrel equivalents estimated from indirect take/ 19 adult petrel estimated combining the direct and indirect take), making the assumption of nine indirect take conservative. Assuming nine adult Hawaiian petrel equivalents are attributed to the Project as indirect take, the permitted direct take under the Project's ITP and ITL would be 29 petrels (take of 38 petrels permitted by ITL and ITP minus the take of nine petrels estimated to be attributed to indirect take = 29 Hawaiian geese estimated direct take maximum).

Based on the analysis described above and presented in Appendix 2, there is more than a 98 percent chance that the 80 percent UCL of cumulative take will not be exceeded during the permit term. Specifically, the estimated direct take threshold of 29 exceeds more than 98 percent of the projected mortality estimates (Appendix 2). EoA calculated a median estimate of 20 years of Project operation without a direct take estimate exceeding 29 petrels. Therefore, the Project is likely to remain below the permitted take limit of Hawaiian petrels for the permit term.

7.4 Non-listed Species

Twelve bird fatalities representing five species and one undetermined species (juvenile dove) were documented at WTGs at the Project in FY 2020. One of the five species observed in FY 2020 is protected by the Migratory Bird Treaty Act (MBTA): Eurasian skylark (one bird; *Alauda arvensis*). Fatalities of four non-native introduced species without MBTA protection were also detected: gray francolin (three birds; *Francolinus pondicerianus*), warbling white-eye (3 birds; *Zosterops japonicus*), ring-necked pheasant (3 birds, *Phasianus colchicus*), and spotted dove (1 bird, *Spilopelia chinensis*). For a complete list of fatalities for FY 2020 see Appendix 4.

8.0 Wildlife Education and Observation Program

The wildlife education and observation program (WEOP) helps to ensure the safety and well-being of native wildlife in work areas and along site access roadways. The training provides useful information to assist staff, contractors, and visitors to be able to conduct their business in a manner consistent with the requirements of the HCP, Conditional Use Permit, land use agreements and applicable laws. Personnel are trained to identify Covered Species and other species of wildlife that may be found on-site and what protocol to follow, as determined in the HCP and through relevant agency guidance (e.g., USFWS and DOFAW 2019), when a downed wildlife is found. The trainees are also made aware of driving conditions and receive instruction on how to drive and act around wildlife. Records of wildlife observations by WEOP-trained staff are also used by the HCP program to identify the patterns of wildlife use of the site.

WEOP trainings were provided on November 4 and 5, 2019 and on February 19, 2020 at the Project, training total of 3 people in FY 2020. WEOP trainings will continue to be conducted on an as-needed basis to provide on-site personnel with the information they need to be able to respond appropriately in the event they observe a Covered Species or encounter downed wildlife while on-site.

9.0 Mitigation

The Project's mitigation requirements are described in Section 5.0 of the approved HCP (KWP I 2006).

9.1 Hawaiian Hoary Bats

9.1.1 Mitigation

Mitigation for Tier 1 take of 20 bats was funded in 2006 and completed. An HCP minor amendment approved by USFWS in October 2015 and DOFAW in January 2016 authorized take of up to an additional 30 Hawaiian hoary bats under Tier 2. A mitigation project that accounts for take of 15 of the authorized additional take of 30 bats began May 2017 and was completed in FY 2020 (Appendix 5; KWP I 2017). This mitigation project consists of Hawaiian hoary bat ecological research in East Maui, contracted to H.T. Harvey Ecological Consultants. The contract total cost was $750,000. KWP I is also partially funding another Hawaiian hoary bat ecological research project on Hawaiʻi Island contracted to the U.S. Geological Survey Hawaiian Hoary Bat Research Group that began in FY 2018 (Appendix 6). The Project contribution to this contract will total $750,000, and is expected to be completed in FY 2021. This research project provides mitigation benefits to account for the remaining 15 bats of Tier 2.

9.1.2 Acoustic Monitoring at the Project

As a voluntary measure (not required in the HCP), acoustic monitoring for bat activity at the Project has been conducted continuously beginning in August 2008. In October 2013 (FY 2014) nine Song Meter SM2BAT+ ultrasonic recorders (SM2) were deployed, replacing the Anabat SD2 bat detectors (Titley Electronics, Brendale, QLD, Australia). Each SM2 was equipped with one SMX-U1 ultrasonic microphone (Wildlife Acoustics, Maynard, MA, USA) positioned horizontally, facing southwest (away from the prevailing northeast trade winds), 6.5 meters above ground level. Eight SM2 units were deployed within 85 meters of the WTGs and was one SM2 unit was placed at the gulch edge of WTG-3 (Figure 1). SM2 units have been continuously used since October 2013. Because of differences in the equipment used, data collected in FY 2020 is only comparable to data collected between FY 2014 and FY 2019.

In October 2019 (FY 2020), the Pali brush fires burned across most of the Project destroying four SM2 units (WTGs: 10, 13, 16, and 20). Following the fire in FY 2020 (October 2019 to June 2020) five sites were monitored (WTGs 1, 5, 13, 15, and 20). Acoustic monitoring results are based on detection rates (nights with detections per detector night), which incorporate the level of monitoring effort. The change in the number of detectors, therefore, does not impact the analysis. A two-sample equal variance t-test was used to compare the complete FY 2020 data set to the post-fire monitoring locations and found no significant difference (P=0.954), therefore all data was included in the analysis.

The objective of monitoring is to better understand the annual and seasonal variations in bat activity across at the project. Analysis of variance (ANOVA) were used to test for differences in detection rates among FY 2015 and FY 2020. FY 2014 was excluded from the interannual analysis because it did not represent a full year sampling year and excluded months with the highest detection rates (July, August and September). A linear model (LM) was used to test for a change in detection rates across all sampling years, FY 2015 to FY 2020. Data was normalized using a log transformation. We examined the distribution of residuals from the LM to check this it did not violate assumptions of the model. All tests were 2-tailed, employed an alpha value of 0.05, and were conducted in R (R Core Team 2017). The characterization of Hawaiian hoary bat seasons corresponds approximately to Starcevich et al. 2019.

From FY 2015 through FY 2020 a significant increasing trend in nights with detections is observed. In FY 2020 Hawaiian hoary bats were detected on 280 nights out of 1,853 (15.1 percent; annual detection rate) detector-nights sampled. In FY 2020, detection rates were highest between the months of August and October during the lactation and post-lactation reproductive periods, with a peak in activity in the month of September (Figure 2). Lower detection rates were observed during the second half of the post-lactation and first half of the pre-pregnancy reproductive periods (Figure 2). A second increase in detection rates was observed in March and April at the end of the pre-pregnancy and beginning of the pregnancy reproductive periods (Figure 2). The temporal pattern of the detection rates in FY 2020 were similar to the detection rates observed in previous years (Figure 3). The annual detection rates in FY 2020 were marginally higher than the annual detection rates for FY 2019 (12.8 percent of detector-nights with detections, Tetra Tech 2019). Annual detections rates varied between all monitoring years, regardless of variation in the sampling effort; between FY 2015 and FY 2020 there was no significant difference in the annual detection rates (ANOVA: $F_{6,72} = 2.19$, $P > 0.065$; Table 4). Across the FY 2015 to FY 2020 monitoring years there is a significant increasing trend in the annual detection rate (LM: $R^2 = 7.0\%$; $F_{2,72} = 6.39$, $P < 0.015$; Figure 4).

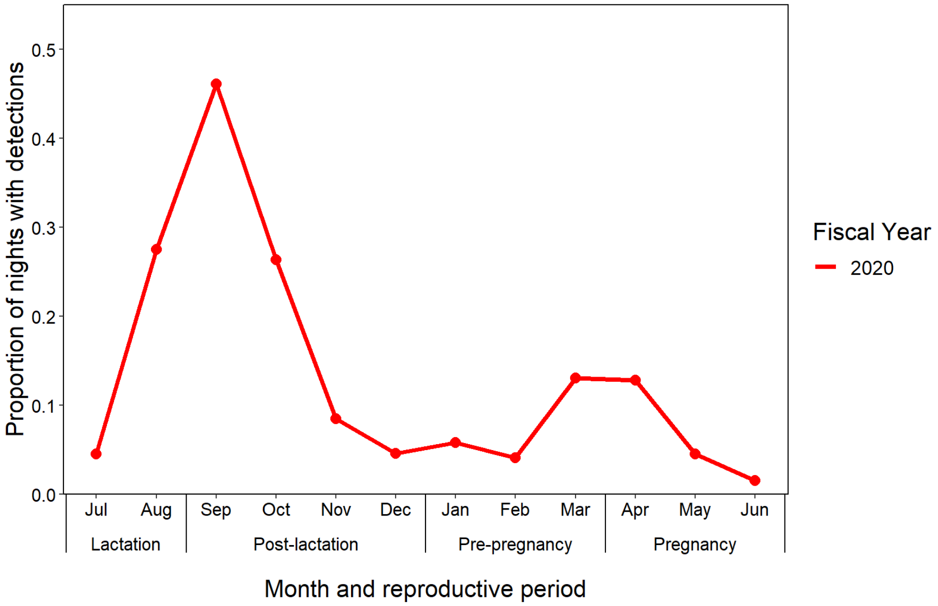

Figure 2. Monthly Detection Rates at KWPI in FY 2020 with Corresponding Reproductive Periods

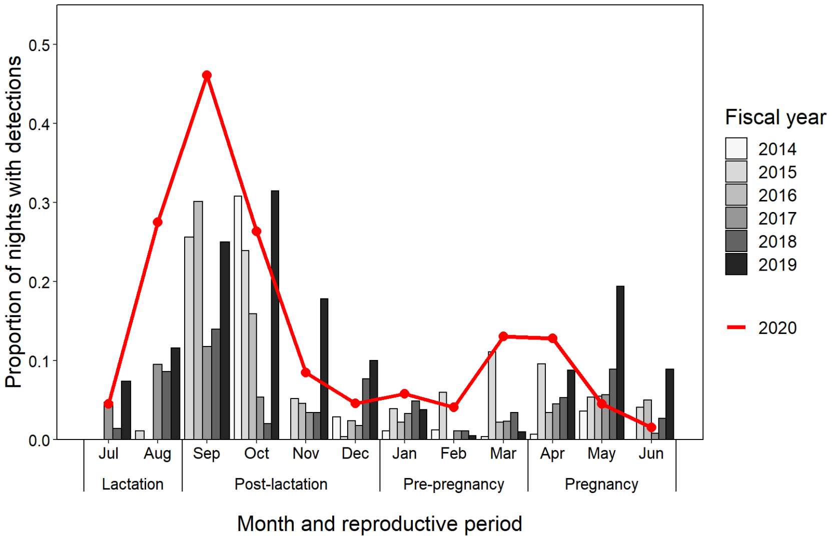

Figure 3. Monthly Bat Detection Rates at KWPI for FY 2014 to FY 2020 with Corresponding Reproductive Periods

Table 4. Number of Nights Sampled, Number of Detector-Nights with Detections and Proportion of Detector-Nights with Bat Detections Between FY 2014 and FY 2020

Dates	No. of Detector-Nights Sampled	No. of Detector-Nights with Detections	Proportion of Detector-Nights with Detection(s)
FY 2014 (October 2013 – June 2014)[1]	2,700	101	0.037
FY 2015 (July 2014 – June 2015)[1]	3,203	249	0.078
FY 2016 (July 2015 – June 2016)[1,2]	2,426	175	0.072
FY 2017 (July 2016 – June 2017)[1]	2,827	129	0.045
FY 2018 (July 2017 – June 2018)[1]	2,989	162	0.054
FY 2019 (July 2018 – June 2019)[1]	2,906	372	0.128
FY 2020 (July 2019 – June 2020)[3]	1,853	280	0.151

1. Number of detectors = 9.
2. Corrected estimates due to observed errors in detection rate calculations for 2016 Annual Report (KWP I 2016).
3. Detectors reduced from 9 to 5

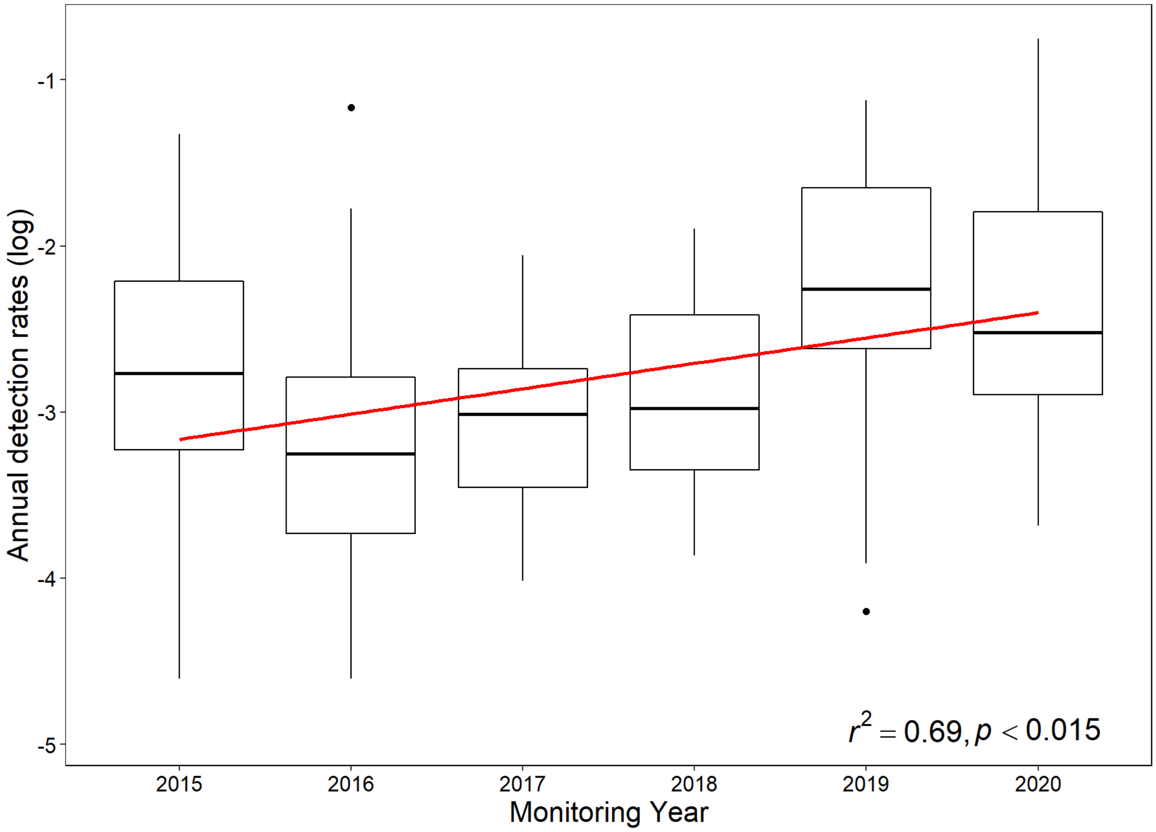

Figure 4. Annual Variation (Box Plots: Median, Interquartile Range and Outliers) and Trend (Red Line: Linear Regression) in Bat Detection Rates at KWPI from FY 2015 to FY 2020

9.2 Hawaiian Goose – Haleakalā Ranch Release Pen

As part of Project Hawaiian goose mitigation, the Project provided $264,000 to DOFAW to fund construction and management of the Haleakalā Ranch Hawaiian goose release pen in 2008. DOFAW completed construction of the release pen three years later. The remaining funds were used by DOFAW to perform fence maintenance, predator control, vegetation management, and monitoring at the Haleakalā Ranch pen over the nine years since construction. Hawaiian geese have been translocated from Kauaʻi to the Haleakalā Ranch pen since 2011, and several potential benefits have accrued based on the effects of these actions including production of fledglings and increases adult survival rates. Through FY 2020, 65 fledglings (subject to final FY 2020 numbers) have been produced in the pen from these translocated birds.

In FY 2019 and FY 2020, KWP I met with USFWS and DOFAW to better understand the past management of the Hawaiian goose release pen, improve accountability, and identify an approach to allow KWP I to meet its mitigation obligations for the Hawaiian goose. An updated Memorandum of Understanding was signed for managing the release pen program; KWP I provided standardized annual reporting forms to capture the annual activities occurring at each pen. In July 2020, DOFAW provided a letter describing proposed mitigation credit for fledgling production attributable to the Project; however, KWP I believes that accounting for mitigation credit undervalues the overall benefits the Project's mitigation efforts have produced and is working with USFWS and DOFAW to develop consensus. Once consensus is reached, KWP I will calculate accrued lost productivity and incorporate that information into an overall assessment of the Hawaiian goose mitigation status for the Project.

9.3 Seabirds

KWP I is committed to seabird protection and recovery on Maui and within Maui Nui. Although results at the Makamakaʻole Seabird Mitigation Site (Makamakaʻole) have suggested the potential for the site to support some reproduction of Newell's shearwaters, the Project is not on-track for fulfilling the Project's seabird mitigation needs. Therefore, it is the intent of KWP I to continue to work with DOFAW, USFWS, and seabird experts, to identify suitable alternatives to the Project's ongoing mitigation efforts at Makamaka'ole. KWP I believes adaptive management of this mitigation approach is required to achieve the goals laid out in the HCP.

9.3.1 Hawaiian Petrel and Newell's Shearwater- Makamakaʻole

Mitigation efforts at Makamaka'ole have been ongoing since construction of the two enclosures was completed on September 5, 2013. Mitigation efforts at Makamakaʻole involve predator monitoring and trapping, artificial burrow checks and monitoring using game cameras, seabird social attraction using decoys and sound systems, and ongoing maintenance of both enclosures. In the 2019 breeding season, which concluded in FY 2020, no Hawaiian petrel breeding was confirmed; however, monitoring results substantiated the production of five Newell's shearwaters fledglings were produced (Appendix 7, Appendix 8).

In Q2 of FY 2020, continued mitigation efforts at Makamakaʻole were contracted to Maui Nui Seabird Recovery Project (MNSRP) through the 2020 breeding season. Project staff are visiting the enclosures monthly with MNSRP to ensure consistent oversight. MNSRP along with Native Ecosystems Protection and Monitoring staff are working to maintain perimeter fencing. Weekly visits to Enclosures A and B are ongoing, checking burrows and game cameras for activity, completing vegetation management including clearing the outside perimeter and inside pathways and conducting predator control.

Seabird activity is assessed using game cameras, burrow scoping, checking for removal or displacement of toothpicks placed at burrow entrances, as well as checks for guano, feathers, and scent presence around burrows. Data collection for burrow activity began on May 22, 2020. As of July 2020, 18 burrows in Enclosure A have had Newell’s shearwater activity for at least one check, with 15 demonstrating consistent activity. In Enclosure B, seven burrows have had a mixture of Newell’s shearwater and Bulwer’s petrel (*Bulweria bulwerii*) activity with two demonstrating consistent activity.

9.3.2 Lāna’i Hawaiian Petrel Protection Project

For the 2019 Hawaiian petrel breeding seasons, KWP I worked with USFWS and DOFAW to adaptively manage Hawaiian petrel mitigation efforts in an interim fashion. As a result of this adaptive management, KWP I provided funding to Pūlama Lānaʻi in the amount of $33,142 to supplement Hawaiian petrel breeding colony protection efforts on Lāna’i.

Based on USFWS’s assessment in FY 2020, KWP I funded one year of mitigation efforts, aiding in the expansion of predator control for cats and rats into extremely dense petrel nesting areas on the island of Lānaʻi and improved monitoring in those areas to better understand the effects of predator control. In 2018, activities resulted in a net increase of 36 Hawaiian petrel fledglings over the calculated baseline. Activities and results are reported in the 2018 annual report (Appendix 5 in Tetra Tech 2019).

9.3.3 Newell’s Shearwater Survey - East Maui

Surveys of East Maui for potential additional mitigation sites was funded and completed in September 2015 (KWP I 2016). These surveys evaluated potential colony locations, estimated the numbers of birds present, assessed predator activity, and provided for management feasibility assessment.

10.0 Adaptive Management

In accordance with the HCP, the Project began implementing LWSC at all WTGs up to wind speeds of 5.0 m/s on July 29, 2014. LWSC is expected to reduce bat take (Section 7.12). LWSC was increased to 5.5 m/s on August 4, 2014 in response to bat take occurring at the Project and at the Kaheawa Wind Power II Project on March 13, 2013 and February 26, 2014. Curtailment at 5.5 m/s was in effect from sunset to sunrise, annually, from February 15 through December 15. The Project continues site-wide bat activity assessment via acoustic monitoring after the initial HCP-required monitoring period (Section 9.1).

The Project has previously implemented a variety of actions to minimize risk to the Hawaiian goose which continued in FY 2020. Safety measures to avoid interactions between Hawaiian goose and canine search teams have been identified and are implemented as needed. Additionally, scavenger trapping efforts implemented at the Project to improve persistence of carcasses during fatality monitoring have likely reduced the risk of predation of the Hawaiian goose. KWP I seeks to identify additional practicable actions to minimize the threats to the Hawaiian goose based on current projections of take, and will continue work with USFWS, DOFAW, and technical experts in FY 2021 to further reduce risk.

11.0 Agency Meetings, Consultations, and Visits

KWP I communicated actively with USFWS and DOFAW throughout FY 2020 through in-person meetings, conference calls, submittal of quarterly reports, and e-mail communications related to the Project's HCP. The purpose of these communications included required semi-annual HCP implementation meetings and focused discussions regarding mitigation funding, adjustments to the acoustic monitoring program, and adjustments to and mitigation credits for the Hawaiian goose and seabird mitigation programs. A summary of agency coordination follows in Table 5.

Table 5. Summary of Agency Coordination and Communication in FY 2020

Date	Communication	Participants
November 7, 2019	Annual HCP implementation review meeting (in person)	KWP I, Tetra Tech, USFWS, DOFAW
November 13, 2019	Submittal of FY2020 Q1 report	Submitted to DOFAW, USFWS by Tetra Tech
December 10, 2019	Submittal of a proposal for a revised bat monitoring program	Submitted to DOFAW, USFWS by Tetra Tech
December 18, 2019	Submittal of the final KWP I HCP FY 2019 annual report	Submitted to DOFAW, USFWS by Tetra Tech
December 30, 2019	Submittal of Makamakaʻole mitigation and future adaptive management report	Submitted to DOFAW, USFWS by Tetra Tech
January 8, 2020	Seabird mitigation adaptive management discussion	KWP I, Tetra Tech, USFWS, DOFAW
January 15, 2020	Annual HCP implementation review by ESRC	KWP I, Tetra Tech, ESRC
January 30, 2020	Submittal of FY 2020 Q2 report	Submitted to DOFAW, USFWS by Tetra Tech
April 23, 2020	Semi-annual HCP implementation review meeting (via conference call)	KWP I, Tetra Tech, USFWS, DOFAW

Date	Communication	Participants
April 29, 2020	Submittal of FY 2020 Q3 report	Submitted to DOFAW, USFWS by Tetra Tech
June 8, 2020	Submittal of an addendum to the proposal for a revised bat monitoring program	Submitted to DOFAW, USFWS by Tetra Tech
June 22, 2020	Submittal of Makamaka'ole Seabird Mitigation Site – 2019 breeding season summary memo in response to DOFAW request for further data support for fledglings at Makamaka`ole	Submitted to DOFAW, USFWS by Tetra Tech

12.0 Expenditures

Total HCP-related expenditures for the Project in FY 2020 were $525,300 (Table 6).

Table 6. HCP-related Expenditures at the Project in FY 2020

Category	Amount
Permit Compliance	$65,500
Fatality Monitoring	$53,700
Acoustic Monitoring for Bats	$19,800
Vegetation Management	$17,400
Scavenger Trapping	$5,000
Equipment and Supplies	$3,000
Staff Labor[1]	-
Makamakaʻole Mitigation Project	$251,600
Lāna'i Hawaiian Petrel Protection Project	
Tier 2 Bat Research Projects	$109,300
Total Cost for FY 2020	**$525,300**
1. Staff labor costs are included in the overall costs for each category	

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APPENDIX 1. DALTHORP ET AL. (2017) FATALITY ESTIMATION FOR HAWAIIAN HOARY BATS, HAWAIIAN GEESE AND HAWAIIAN PETRELS AT THE PROJECT THROUGH FY 2020

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Appendix 2a. Dalthorp et al. (2017) Fatality Estimation for Hawaiian Hoary Bats at Project Through FY 2020

Modelling Parameter		**Modelling Period**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**13**	**14**	**15 (current)**
FY		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dates	**Begin**	2006-01-01	2007-07-01	2008-07-01	2009-07-01	2010-07-01	2011-07-01	2012-07-01	2013-07-01	2014-07-01	2015-07-01	2016-07-01	2017-07-01	2018-07-01	2019-07-01
	End	2007-06-30	2008-06-30	2009-06-30	2010-06-30	2011-06-30	2012-06-30	2013-06-30	2014-06-30	2015-06-30	2016-06-30	2017-06-30	2018-06-30	2019-06-30	2020-06-30
Period Length (days)		545	365	364	364	364	365	364	364	364	365	364	364	364	365
% Year		1.5	1	1	1	1	1	1	1	1	1	1	1	1	1
LWSC		no	no	no	no	no	no	no	no	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s
Search Interval (days)		9	9	7	7	7	7	7	7	7	7	7	7	7	7
Number of Searches in Modelling Period		61	41	52	52	52	52	52	52	52	52	52	52	52	53
Observed Fatalities (X)		0	0	0	0	0	0	2	4	0	0	1	1	1	0
K		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	1	1	1	1	1
Canine Searches		No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
DWA[1]		1	1	1	1	1	1	1	1	1	0.4922	0.4922 or 0.573	0.573	0.573	0.573
g	**g**	0.445	0.442	0.501	0.45	0.505	0.345	0.414	0.484	0.217	0.44	0.524	0.459	0.368	0.466
	95% LCI	0.260	0.258	0.312	0.272	0.257	0.149	0.183	0.332	0.128	0.408	0.499	0.386	0.289	0.405
	95% UCI	0.638	0.636	0.69	0.634	0.752	0.574	0.669	0.638	0.321	0.472	0.549	0.533	0.45	0.529
B	**Ba**	11.21	11.06	12.70	12.37	7.145	6.089	5.894	19.23	14.76	407.9	816.1	80.67	50.35	115.3
	Bb	13.96	13.94	12.64	15.14	7.007	11.56	8.335	20.47	53.30	520.1	741.03	95.13	86.64	132.0
M*[2]		1	1	1	1	1	1	7	18	19	19	21	23	26	26

1. Where two values are represented, the searched area changed within the modeled period. Detection probability represents the cumulative detection for the year. See annual reports for details.
2. Cumulative value representing estimate of total direct take from the start of operations through the identified monitoring period at the 80 percent UCL.

Appendix 2b. Dalthorp et al. (2017) Fatality Estimation for the Hawaiian Goose at Project Through FY 2020

Modelling Parameter		**Modelling Period**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14 (current)**
FY		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dates	**Begin**	2006-01-01	2007-07-01	2008-07-01	2009-07-01	2010-07-01	2011-07-01	2012-07-01	2013-07-01	2014-07-01	2015-07-01	2016-07-01	2017-07-01	2018-07-01	2019-07-01
	End	2007-06-30	2008-06-30	2009-06-30	2010-06-30	2011-06-30	2012-06-30	2013-06-30	2014-06-30	2015-06-30	2016-06-30	2017-06-30	2018-06-30	2019-06-30	2020-06-30
Period Length (days)		545	365	364	364	364	365	364	364	364	365	364	364	364	365
% Year		1.5	1	1	1	1	1	1	1	1	1	1	1	1	1
LWSC		no	no	no	no	no	no	no	no	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s
Search Interval (days)		9	9	7	7	7	7	7	7	7	7	7	7	7	7
Number of Searches in Modelling Period		61	41	52	52	52	52	52	52	52	52	52	52	52	53
Observed Fatalities (X)		0	2	1	1	5	1	4	3	4	1	0	1	2	0
K		1	1	1	1	1	1	1	1	1	1	1	1	1	1
Canine Searches		No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
DWA[1]		0.95	0.95	0.95	0.95	0.95 or 0.7	0.7	0.7	0.7	0.7	0.29	0.29 or 0.35	0.35	0.35	0.35
g	**g**	0.923	0.923	0.928	0.928	0.773	0.678	0.666	0.683	0.691	0.284	0.327	0.344	0.339	0.33
	95% LCI	0.871	0.871	0.886	0.886	0.748	0.633	0.58	0.626	0.658	0.265	0.314	0.336	0.282	0.301
	95% UCI	0.962	0.962	0.961	0.961	0.797	0.72	0.748	0.737	0.722	0.302	0.341	0.352	0.399	0.359
B	**Ba**	120.8	120.8	162.5	162.5	889.3	299.4	79.75	183.9	548.7	661.2	1474.3	4420	84.70	337.8
	Bb	10.14	10.14	12.60	12.60	261.5	142.5	39.93	85.39	245.9	1671	3031	8438	165.3	686.5
M*[2]		0	2	4	5	11	13	18	23	28	32	34	37	42	43

1. Where two values are represented, the searched area changed within the modeled period. Detection probability represents the cumulative detection for the year. See annual reports for details.
2. Cumulative value representing estimate of total direct take from the start of operations through the identified monitoring period at the 80 percent UCL.

Appendix 2c. Dalthorp et al. (2017) Fatality Estimation for Hawaiian Petrel at Project Through FY 2020

Modelling Parameter		Modelling Period													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14 (current)
FY		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dates	Begin	2006-01-01	2007-07-01	2008-07-01	2009-07-01	2010-07-01	2011-07-01	2012-07-01	2013-07-01	2014-07-01	2015-07-01	2016-07-01	2017-07-01	2018-07-01	2019-07-01
	End	2007-06-30	2008-06-30	2009-06-30	2010-06-30	2011-06-30	2012-06-30	2013-06-30	2014-06-30	2015-06-30	2016-06-30	2017-06-30	2018-06-30	2019-06-30	2020-06-30
Period Length (days)		545	365	364	364	364	365	364	364	364	365	364	364	364	365
% Year		1.5	1	1	1	1	1	1	1	1	1	1	1	1	1
LWSC		no	no	no	no	no	no	no	no	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s	5.5 m/s
Search Interval (days)		9	9	7	7	7	7	7	7	7	7	7	7	7	7
Number of Searches in Modelling Period		61	41	52	52	52	52	52	52	52	52	52	52	52	53
Observed Fatalities (X)[1]		0	1	0	0	0	2	0	1	2	0	0	0	1	0
K		0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1	1	1	1	1
Canine Searches		No	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
DWA[2]		1	1	1	1	1 or 0.75	0.75	0.75	0.75	0.75	0.204	0.204 or 0.246	0.246	0.246	0.246
g	g	0.807	0.786	0.847	0.861	0.798	0.581	0.646	0.714	0.65	0.197	0.232	0.24	0.239	0.218
	95% LCI	0.602	0.593	0.717	0.706	0.752	0.431	0.511	0.668	0.555	0.18	0.221	0.203	0.196	0.192
	95% UCI	0.948	0.928	0.942	0.963	0.841	0.724	0.77	0.758	0.74	0.214	0.243	0.28	0.284	0.244
B	Ba	14.64	16.78	31.55	22.06	244.5	24.57	32.73	281.2	65.57	414.2	1272	114.8	85.20	210.7
	Bb	3.512	4.580	5.682	3.566	61.78	17.70	17.93	112.6	35.30	1690	4216	362.8	272.0	757.7
M*[3]		0	2	2	2	2	5	5	6	10	10	11	12	14	15

1. FY 2013 fatality was mistakenly included in previous analyses. Based on the contemporaneous fatality report, the carcass was recovered outside of the designated search plots.
2. Where two values are represented, the searched area changed within the modeled period. Detection probability represents the cumulative detection for the year. See annual reports for details.
3. Cumulative value representing estimate of total direct take from the start of operations through the identified monitoring period at the 80 percent UCL.

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APPENDIX 2. HAWAIIAN HOARY BAT, HAWAIIAN GOOSE AND HAWAIIAN PETREL 20-YEAR PROJECTED TAKE AT PROJECT IN FY 2020

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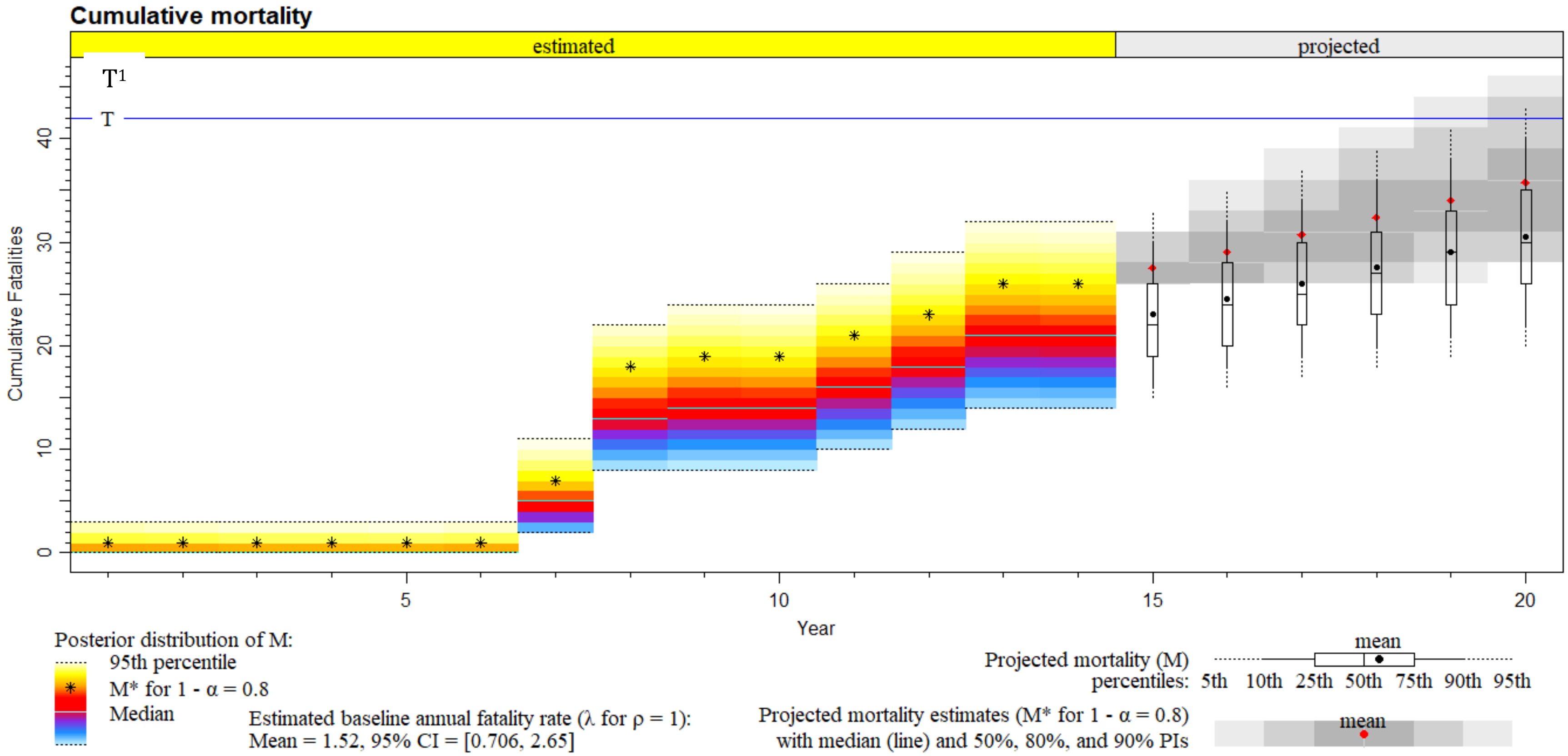
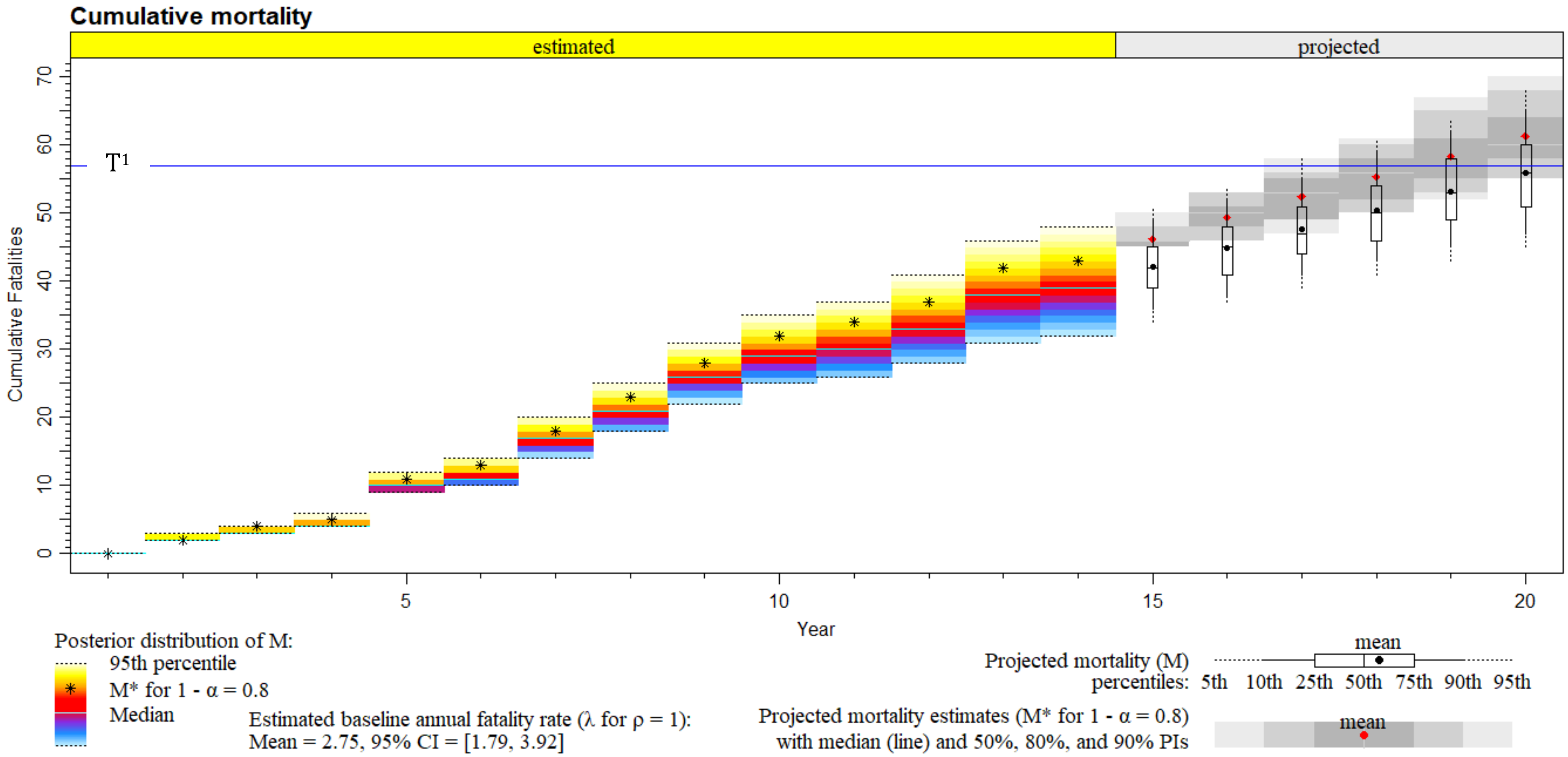
Figure 1. Projected Cumulative Mortality for the Hawaiian Hoary Bat at the Project



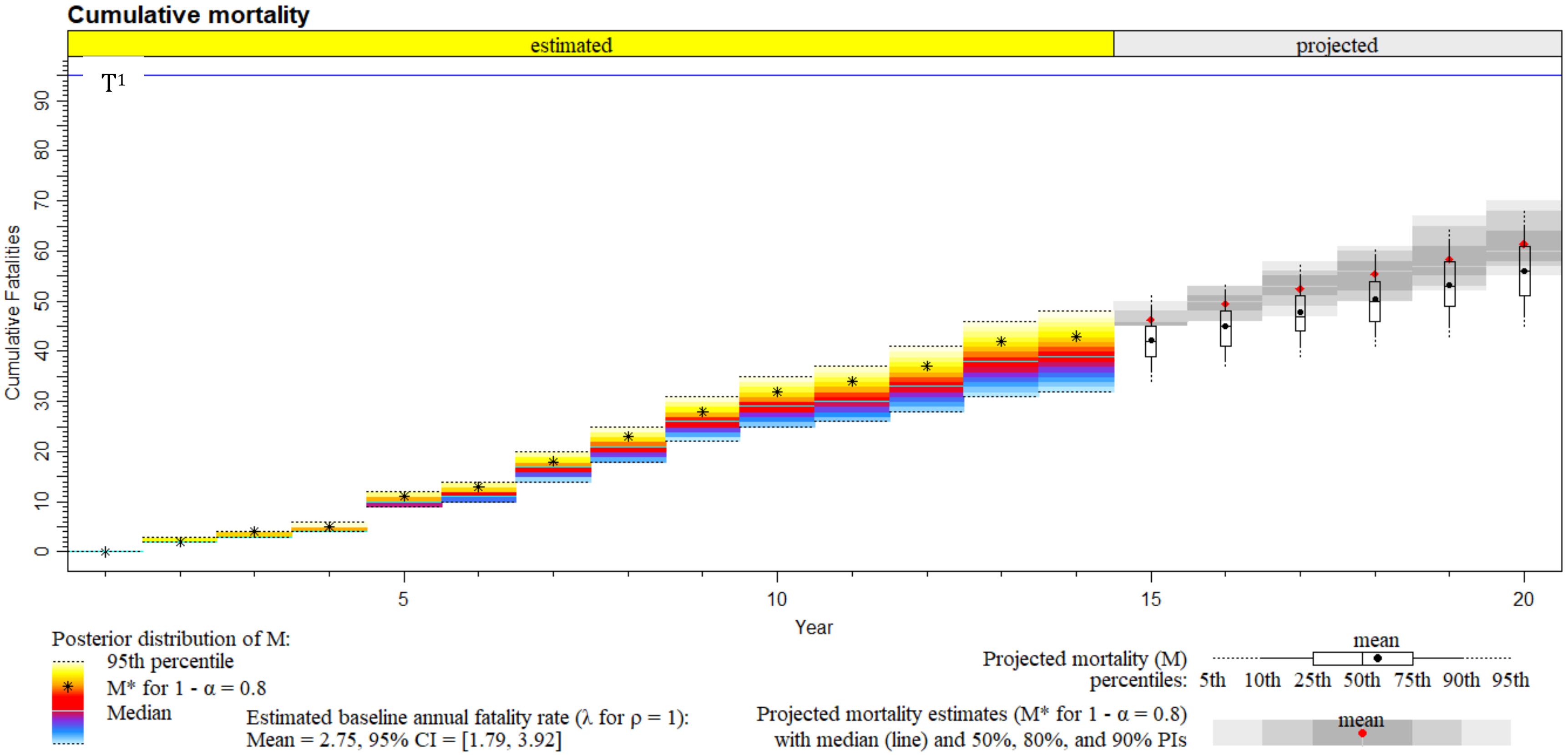
1. Permitted take for the Hawaiian hoary bat at the Project is 50; however, take as calculated from EoA only includes direct take. To account for indirect take in this figure, an approximate take threshold (T) of 42 is shown, representing authorized bat take (50) minus 8 adult equivalents of indirect take (16.0 percent of the authorized limit). Currently, the proportion of total take that is attributable to indirect take is 14.6 percent.

Figure 2b. Projected Cumulative Mortality for the Hawaiian Goose at the Project with Tier 1 Threshold



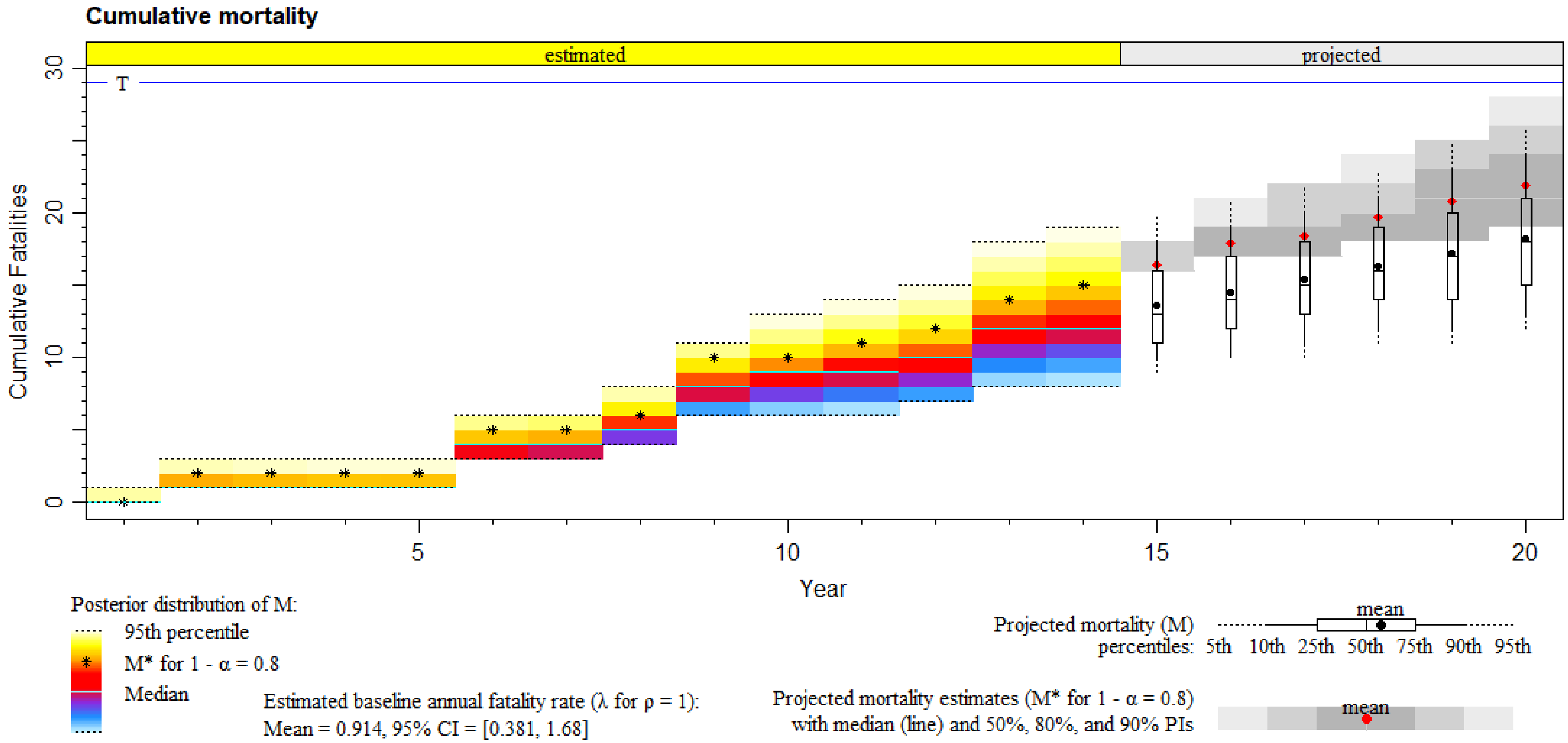
1. Permitted take for Tier 1 of the Hawaiian goose at the Project is 60; however, take as calculated from EoA only includes direct take. To account for indirect take in this figure, an approximate take threshold (T) of 57 is shown, representing permitted Hawaiian goose take (60) minus 3 adult equivalents of indirect take (5.0 percent of the requested authorized limit). Currently, the proportion of total take that is attributable to indirect take is 4.4 percent.

Figure 2b. Projected Cumulative Mortality for the Hawaiian Goose at the Project with Tier 2 Threshold



1 Permitted take for Tier 2 of the Hawaiian goose at the Project is 100; however, take as calculated from EoA only includes direct take. To account for indirect take in this figure, an approximate take threshold (T) of 57 is shown, representing permitted Hawaiian goose take (100) minus 5 adult equivalents of indirect take (5.0 percent of the requested authorized limit). Currently, the proportion of total take that is attributable to indirect take is 4.4 percent.

Figure 3. Projected Cumulative Mortality for the Hawaiian Petrel at the Project



1. Permitted take for the Hawaiian petrel at the Project is 38; however, take as calculated from EoA only includes direct take. To account for indirect take in this figure, an approximate take threshold (T) of 29 is shown, representing authorized petrel take (38) minus 9 adult equivalents of indirect take (23.6 percent of the authorized limit). Currently, the proportion of total take that is attributable to indirect take is 21.1 percent.

APPENDIX 3. INDIRECT TAKE FOR THE HAWAIIAN GOOSE AND HAWAIIAN PETREL AT PROJECT IN FY 2020

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Appendix 4a. Indirect Take for the Hawaiian Goose at the Project in FY 2020

Parameter	Description	Fiscal Year																	
		2007	2008	2009	2010	2011		2012	2013	2014		2015		2016	2017	2018	2019	2020	Total
A	Observed Take	0	3	1	1	3	2	1	4	2	1	3	1	1	1	2	**2**	**0**	**28**
B	Estimated Take Multiplier (43/28=1.54)	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	
C	Estimated Direct Take (A x B)	0.00	4.61	1.54	1.54	4.61	3.07	1.54	6.14	3.07	1.54	4.61	1.54	1.54	1.54	3.07	3.07	0.00	43.00
D	Observed Indirect Take Multiplier (Season Defined)	0.00	0.09	0.00	0.00	0.09	0.00	0.09	0.09	0.09	0.00	0.09	0.04	0.09	0.04	0.09	0.09	0.00	
E	Observed Indirect Take (C x D)	0.00	0.41	0.00	0.00	0.41	0.00	0.14	0.55	0.28	0.00	0.41	0.06	0.14	0.06	0.28	0.28	0.00	3.03
F	Unobserved Direct Take (C - A)	0.00	1.61	0.54	0.54	1.61	1.07	0.54	2.14	1.07	0.54	1.61	0.54	0.54	0.54	1.07	1.07	0.00	
G	Unobserved Indirect Take (F x 0.06)	0.00	0.10	0.03	0.03	0.10	0.06	0.03	0.13	0.06	0.03	0.10	0.03	0.03	0.03	0.06	0.06	0.00	0.90
Total Indirect Take (E + G; fledglings)																			**3.93**
Total Indirect Take (E + G)*0.512 (adults)																			**2.01**

Appendix 4b. Indirect Take for the Hawaiian Petrel at the Project in FY 2020

Parameter	Description	Fiscal Year																
		2007	2008	2009	2010	2011	2012		2013	2014	2015		2016	2017	2018	2019	2020	Total
A	Observed Take	0.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00	0.00	**8.00**
B	Estimated Take Multiplier (15/8=1.88)	0.00	1.88	0.00	0.00	0.00	1.88	1.88	1.88	1.88	1.88	1.88	0.00	0.00	0.00	1.88	0.00	
C	Estimated Direct Take (A x B)	0.00	1.88	0.00	0.00	0.00	1.88	1.88	1.88	1.88	1.88	1.88	0.00	0.00	0.00	1.88	0.00	**15.00**
D	Observed Indirect Take Multiplier (Season defined)		0.66				0.66	0.50	0.89	0.89	0.89	0.66				0.89		
E	Observed Indirect Take (A x D)	0.00	0.66	0.00	0.00	0.00	0.66	0.50	0.89	0.89	0.89	0.66	0.00	0.00	0.00	0.89	0.00	**6.04**
F	Unobserved Direct Take (C - A)	0.00	0.88	0.00	0.00	0.00	0.88	0.88	0.88	0.88	0.88	0.88	0.00	0.00	0.00	0.88	0.00	**7.00**
G	Unobserved Indirect Take (D x F)	0.00	0.58	0.00	0.00	0.00	0.58	0.44	0.78	0.78	0.78	0.58	0.00	0.00	0.00	0.78	0.00	**5.29**
Total Indirect Take (E + G) chicks/eggs																		**11.33**
Total Indirect Take (E + G) x 0.3 adults																		**3.40**
1. Productivity information for FY 2019 and FY 2020 is not yet available; values will be updated when data becomes available.																		

APPENDIX 4. DOCUMENTED FATALITIES AT THE PROJECT DURING FY 2020

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Species	**Date Documented**	**WTG**	**Distance to WTG (meters)**	**Bearing from WTG (degrees)**
Unknown Juvenile Dove	07-16-2019	7	15	319
Zosterops japonicus (Warbling White-Eye)	10-01-2019	7	4	349
Phasianus colchicus (Ring-necked Pheasant)	10-08-2019	19	65	64
Zosterops japonicus (Warbling White-Eye)	10-22-2019	13	10	95
Spilopelia chinensis (Spotted Dove)	11-20-2019	14	1	262
Francolinus pondicerianus (Gray Francolin)	01-14-2020	9	1	25
Francolinus pondicerianus (Gray Francolin)	02-04-2020	13	1	137
Francolinus pondicerianus (Gray Francolin)	03-17-2020	12	1	348
Phasianus colchicus (Ring-necked Pheasant)	04-21-2020	10	29	262
Phasianus colchicus (Ring-necked Pheasant)	05-12-2020	19	3	22
Alauda arvensis (Eurasian Skylark)[1]	05-12-2020	12	35	110
Zosterops japonicus (Warbling White-Eye)	06-02-2020	14	2	211

1. MBTA-protected species

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APPENDIX 5. HAWAIIAN HOARY BAT RESEARCH, MAUI

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H. T. HARVEY & ASSOCIATES
Ecological Consultants
50 years of field notes, exploration, and excellence

Hawaiian Hoary Bat Research, Maui
Final Report 2019

Project #3978-01

Prepared for:

Lily Henning
TerraForm Power
200 Liberty Street, 14th Floor
New York, NY 10281

Prepared by:

H. T. Harvey & Associates

April 2020

Abstract

This research project supports two of the goals presented by the Endangered Species Recovery Committee for the recovery of the federally and state endangered Hawaiian hoary bat (*Lasiurus semotus*): (1) conducting basic ecological research; and (2) identifying limiting factors to the population status of the species on Hawaiʻi. In support of basic ecological research, we determined habitat preferences through long-term acoustic monitoring; measured the foraging range (FR), core-use area (CUA) as measurements of home ranges, assessed relative prey availability in habitats of the study area; and determined the diets of bats based on the DNA barcoding of insect fragments from guano. To assist with identifying limiting factors to the population status of this species in Hawaii, we identified habitats that contained relatively low bat activity. A better understanding of these habitat preferences, home ranges, and diet is critical in determining how to restore habitat to better promote the recovery of this species.

The study area encompassed 34,226 hectares on the north-facing and windward slopes of Haleakala on the island of Maui, Hawaiʻi, and contained nine habitat types: agricultural vegetation, high-density developed, low-density developed, forest woodland low elevation, forest woodland upper elevation, grassland, gulch, shrubland, and sparse vesicular rock. From September 2017 through September 2018 we collected acoustic monitoring data with a sampling schematic utilizing nine bat detectors that were moved to new sites in the nine habitat types five times every other month. Thus, we installed bat detectors at 45 sites in the nine habitat types for a total of 315 deployments. We used the General Random Tessellation Stratified survey design to select the sites for acoustic monitoring across the nine habitat types. We determined the number of calls per night, the minutes with bat calls (call minutes), and the total number of feeding buzzes. After we finalized the habitat type definitions, we completed a trial power analysis of the first month's data and found differences in habitat use to be highly significant at a level of $\alpha = 0.05$ ($P < 0.0001$). This finding, which supported the alternative hypothesis of differences in habitat use by bats, gave us confidence to continue with our acoustic monitoring approach. We mist netted on 78 nights from June 2017 through September 2018 in three general areas: Haleakala National Park, Olinda Road, and Lower Kula to capture bats during summer and winter periods. Captured bats were radio-tracked using two or more handheld Yagi antennas to determine their locations through triangulation. Our team radio-tracked 16 bats on 109 nights during the mist netting period. We calculated the 95% kernel (FRs) and 50% kernel (CUAs) in R and determined mean ± SE 95% and 50% kernel areas for bats in our study. Additionally, we calculated the areas for the 95% and 50% kernel using the methods given in Bonaccorso et al. (2015) in order to attempt comparing the results of our kernel analysis of Maui bats and the bats from the Island of Hawaii. We sampled insects using extra tall blacklight traps in each of the nine habitat types for seven sampling periods from August 2017 through August 2018.

On the basis of the number of search calls and feeding buzzes in our acoustic data, bats spent more time foraging in gulch, low-density developed, and grassland habitats, although differences existed between months. Based on data from the 315 sites, we found habitat type to be highly significant at a level of $\alpha = 0.05$ ($P < 0.01$). The 50% kernel analysis determined that the mean CUA was 3,206±3,360 hectares and the mean 95% kernel

analysis for the foraging range was 12,905+13,857 hectares suggesting a very wide range of values among individuals. The mean long axis across the foraging range was 15.1+9.5 kilometers. The majority of guano samples were collected from adult males (n=7), followed by adult females (n=2) and subadult females (n=2). Bats ate primarily moths (68%), as well as flies (12%), termites (9%), crickets and katydids (5%), beetles (4%), and true bugs (2%). Insects eaten were both native and nonnative, and the dietary data suggest that bats were somewhat selective in prey species given the abundance of particular species found in the insect samples but not consumed. We found significant differences in the availability of prey based on the differences in the dry weights of insects collected in each of the habitat types from August 2017 through August 2018. The agricultural vegetation, grassland, and low-density developed habitats had the highest values for dry weight samples, followed by the gulch, shrubland, and sparse vesicular rock habitats. The lowest values for dry weight samples were from the forest woodland (low and upper elevation) and high-density developed habitats.

We identified a strong negative correlation between rainfall and the number of bat calls per night. To control for the effects of storm events we omitted nights when rainfall was greater than or equal to 5 millimeters from our dataset for the analysis. We found that bat activity was generally highest in gulch, low-density developed, and grassland habitats, and lowest in forest woodland habitats. Our findings contrast with the results of Hawaiian hoary bat studies on the island of Hawai'i, which found that bats foraged primarily in mature native and nonnative habitat, including macadamia nut (*Macadamia integrifolia*) orchards. Maui's forests comprised mostly monoculture nonnative forests (e.g., Monterey pine [*Pinus radiata*]) and only limited areas with native forest trees were present in our study area. We also found major differences between the CUAs and FRs for the bats we radio-tracked on Maui and the bats radio-tracked on the island of Hawaiʻi. Our mean CUA for bats on Maui was 3,700 hectares, and the CUA for bats on the island of Hawaiʻi was 25.5 hectares. Our data also suggest foraging flexibility in the species with the use of habitat types changing during different seasons.

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Tables

Appendices

List of Preparers

Ron Duke, M.A., President
Paul Conry, M.S., Senior Associate Ecologist
Dave S. Johnston, Ph.D., Associate Ecologist and Principal Investigator
Kristina M. Wolf, Ph.D., Ecologist II
Michele Childs, M.S., GIS Specialist
Brad Yuen, M.S., Field Biologist

In Collaboration with

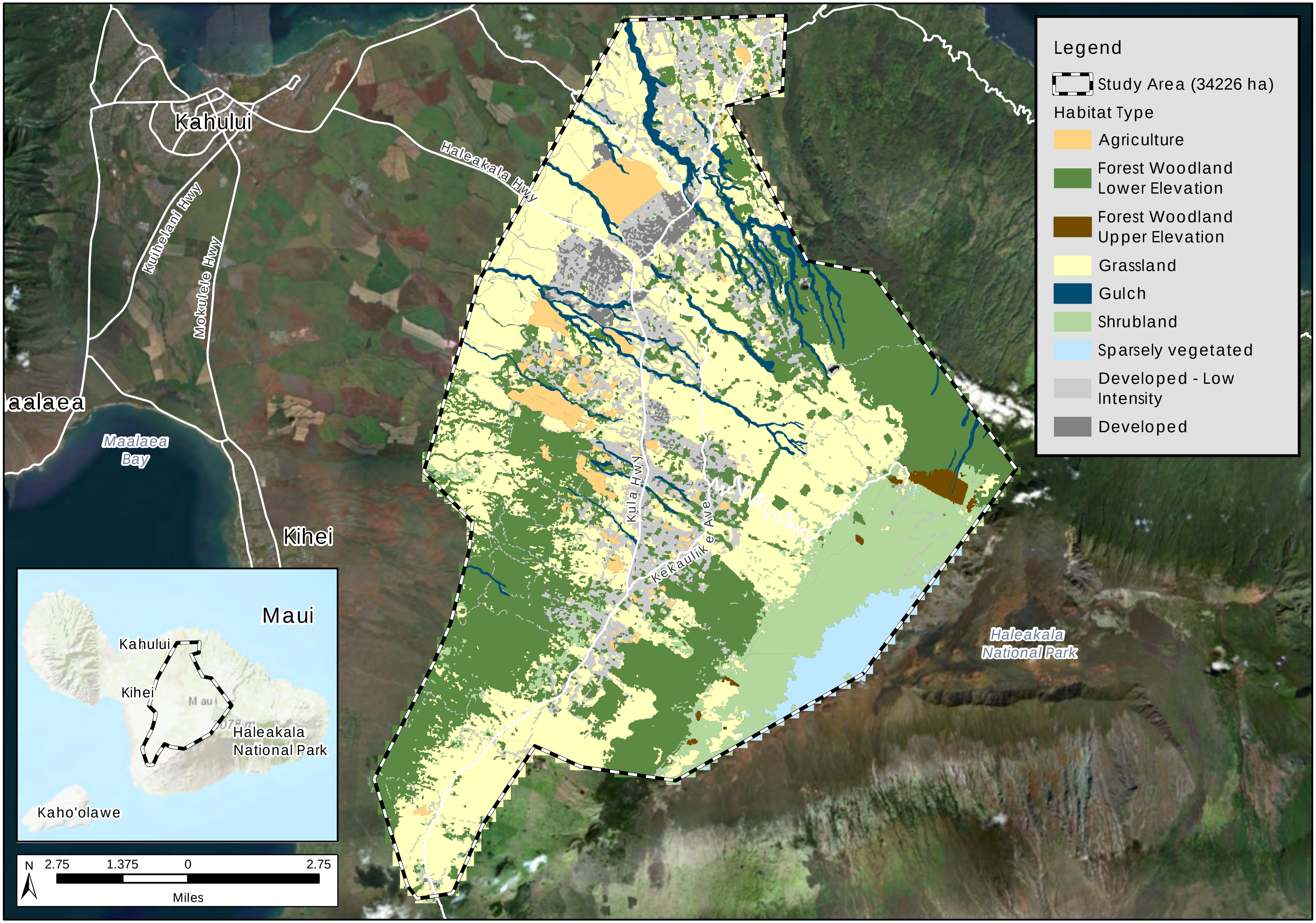
Elizabeth L. Clare, Ph.D., Senior Lecturer, Queen Mary University of London, London, UK
Matthew J. Medeiros, Ph.D., School of Life Sciences, University of Las Vegas, Nevada

Section 1. Background

This research project supports two of the goals presented by the Endangered Species Recovery Committee for the recovery of the Hawaiian hoary bat (*Lasiurus semotus*): (1) conducting basic ecological research; and (2) identifying limiting factors to the population status of the species on Hawaiʻi. In support of basic ecological research, we measured the foraging range, core-use area (CUA), and long axis of home ranges in our primary study area (Figure 1), and compared those data with the measurements of home ranges determined by U.S. Geological Survey (USGS) studies on the island of Hawaiʻi (Bonaccorso et al. 2015), and H. T. Harvey & Associates studies on Oahu (H. T. Harvey & Associates 2014). We are now using the scientific name *Lasiurus semotus* in recognition of the Hawaiian hoary bat as a unique species based on recent work by Simmons and Cirranello (2020).

We studied some of the potential limiting factors that influence populations of the Hawaiian hoary bat, namely whether there is suitable habitat and available food. In addition to determining if bats foraged in habitats in our study area, we also determined whether bats spent different amounts of time in various habitats over the course of four seasons. We were not able to study predation risks because too many of the roosts were located in inaccessible sites such as some of the gulches. Our multifaceted study provides the means to identify between 100 and 200 species of prey that are available to bats, determine which insect species the bats consume, and determine whether populations of the Hawaiian hoary bat are indeed limited by food resources in at least parts of their range. We anticipated that in our study area the availability of prey would not be uniformly distributed over space and time and that we would find areas that had limited potential food resources for the Hawaiian hoary bat. In a study in rural Missouri, where bats' home ranges encompassed fragmented habitats, Womack et al. (2013) found that bats' home range sizes may be influenced by the distribution of prey. Habitat fragmentation occurs throughout much of the Hawaiian Islands, including in our study area, and we therefore expected similar results—that bats' CUAs will be influenced by the fragmented nature of the suitable habitats.

The results of our basic ecological research were intended to help guide and assist conservation efforts leading to the recovery of the Hawaiian hoary bat. This report provides a synthesis of our research from the first 2 years (2017 and 2018) of field work and the 2019 analyses of data and DNA barcoding of prey found in bats' guano. Thus, this report provides valuable information on which habitats are used by the species at different times of the year, the size and locations of CUAs, and a list of insects that the bats are eating. By better understanding these metrics, important habitats can be conserved and restoration areas can include host plants of insects known to be eaten by the Hawaiian hoary bat.



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H. T. HARVEY & ASSOCIATES
Ecological Consultants

Figure 1. Study Area **and Habitats**
Ecology of the Hawaiian Hoary Bat (3978-0
December 2019

Section 2. Methods

2.1 Study Area and Habitat Descriptions

The study area consists of 34,226 hectares on the north-facing leeward and windward slopes of Haleakala extending to the summit on the island of Maui, Hawaiʻi (Figure 1). This study area was chosen because of the general accessibility of many areas by vehicular roads and pedestrian trails, the reasonable density of known bat records, and the diversity of habitats that extend from about 200 meters above Mean High Water (MHW) in the valley up to the Haleakala Ridge at about 3,000 meters MHW. Included in the study area are a variety of land covers, and with the exception of the category Gulch, were based on the latest published USGS land cover designations for Maui (Mair 2018). Gulch habitat was added as a separate habitat when we realized that bats were often concentrating their foraging behavior in some gulches, which had not been designated as a land cover by Mair (2018).

Table 1. Habitat Descriptions

Habitat Abbreviation	Name	Notes about the Habitat
AV	Agricultural Vegetation	small- to large-scale farms containing at least some planted crops and/or fruit trees, but not animal agriculture
DevH	High Density Develop	Makawao, Pukalani, Haliimaile, and a few densely populated areas of Kula (including within the larger school campuses).
DevL	Low Density Develop	Rural with manicured landscapes and a greater density of buildings and artificial lighting.
Fwl	Forest Woodland Low	Forest woodland less than 2,000 meters asl
FWU	Forest Woodland Upper	Forest woodland greater than 2,000 meters asl
Grass	Grassland	Habitat dominated with open grasslands
Gulch	Gulch	Incised geographical features with $\geq$ 100% slope and $\geq$ 10 meters deep
Shrub	Shrubland	Mostly contiguous growth $\leq$ 2 meters high
SV	Sparse Vesicular rock	Areas comprising mostly lava flows

2.2 Habitat Descriptions and Definitions

The habitat type ISNV (introduced semi-natural vegetation) described nearly all forested habitat types but was not a useful distinction from FW (forested woodland). Intact Native Forest was considered as a habitat type. However, too few sites were accessible for sampling because of their distance to vehicular access and because these areas comprised only a very small percentage of the forested areas within our study area. Therefore, we divided the forested areas into two groups, and the lower forests (FWL) in our study area consisted of Makawao Forest Reserve, Waihou Spring Forest Reserve and the surrounding forested areas, Kula Forest Reserve, and

Polipoli Spring State Recreation Area. The upper forests (FWU) consisted of Waikamoi, Hosmer's Grove, the forest behind the Park RM building and the eucalyptus (Eucalyptus sp.) grove at approximately 8,500 feet asl in Haleakala National Park. Grassland areas in our study area were somewhat constrained because we did not have access to Haleakala Ranch and Kaonoulu Ranch lands. We did not make a distinction between grazed and ungrazed grasslands but because many "pastures" in Hawaiʻi include trees; however, we did decide that there should be no, or very few trees within a grassland to use it as a sample site. For gulches, we positioned detectors on the edge of the gulch facing in, not blocked by vegetation so that they would have a vantage point into the gulch. Gulches were typically 30 meters deep and to be mapped as a habitat, this feature was not less than 10 meters deep from the top of bank to the bottom at a given point and with a slope of at least 100%. Shrub sites in our study area generally occurred in Haleakala National Park from the entrance station to just below the eucalyptus grove elevation (after which open areas become SV), along the lower elevation areas of Skyline Trail, and along Waipoli Road. SV in our study area only occurred in Haleakala National Park at the elevation of the eucalyptus grove and above, and in the upper elevation area along Skyline Trail.

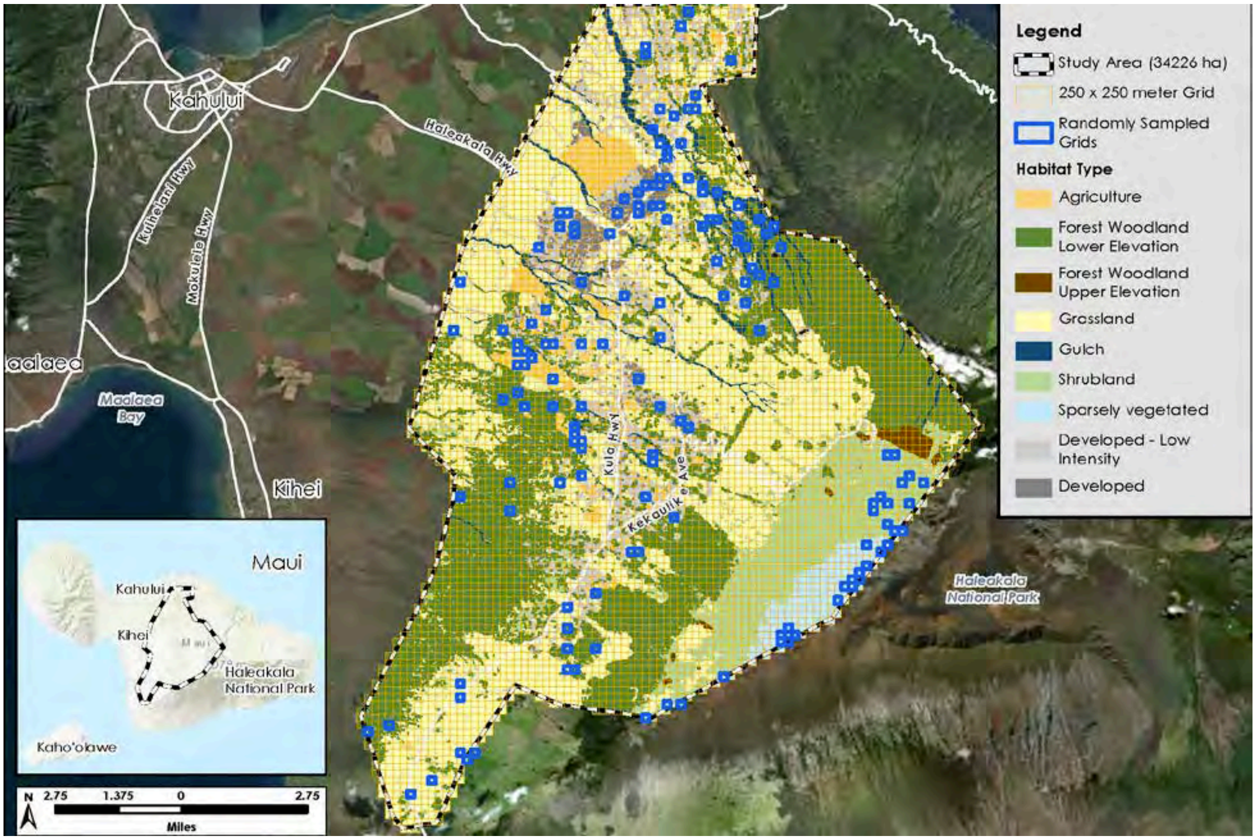


Figure 2. Study Area Showing Habitat Types, 250-meter Square Grid, and Randomly Sampled Sites.

2.3 Access to Private and Public Lands

Determining the land owners of 640 sample sites and gaining access to these sites was challenging. Many persons, especially Paul Conry of H. T. Harvey & Associates, Lance DeSilva of DOFAW, and Andrea Buckman of East Maui Watershed Collaborative. Through perseverance and a friendly approach we had great success working with agencies and private landowners. Additionally, staff have volunteered to do public outreach programs on the Hawaiian hoary bat through schools. This outreach has also helped with public perception and general acceptance of placing bat detectors on private lands. Thus, an enormous investment of non-billed time was made in the community to help gain access to private lands. Nonetheless, some large landowners chose not to allow access to non-conservation areas which limited our access to some portions of our study area.

2.4 Acoustic Monitoring and Modelling of Acoustic Data

From September 2017 through September 2018, we collected acoustic monitoring data with a sampling schematic utilizing nine bat detectors moved to new sites within each of the nine habitat types five times every other month. Bat detectors were left at each site for 3 nights. Thus, in each of the months of September and November 2017, and January, March, May, July, and September 2018, we deployed bat detectors at 45 sites in nine habitat types for a total of 315 deployments totaling 945 nights of bat detector data.

To control for temporal effects on bat activity, detectors in each habitat recorded simultaneously for 3 nights at each location from one hour before sunset until one hour after sunrise.

We used the General Random Tessellation Stratified survey design to select sites for acoustic monitoring across nine habitat types. A grid of 250-meter-square polygons were overlaid onto a map of habitats for the study area and sites were sampled based on a computer-generated random sampling (Figure 2). Accessible randomly selected sites were field-verified to determine that they met the criteria for each habitat type according to Table 1 before deploying acoustic monitoring equipment. In cases where sites did not meet these criteria or were inaccessible, the nearest accessible randomly selected sites meeting the habitat criteria were used.

Table 2. Criteria for Detector Deployment

Habitat	Minimum Criteria for Detector Deployment
AV	minimum of 100 square meters (m^2)of planted agriculture
DevH	minimum density of roads/buildings determined by GIS
DevL	maximum density of roads/buildings determined by GIS
FWL	forest and woodland low elevation/forest and woodland below 2,000 m elevation
FWU	forest and woodland upper elevation/forest and woodland above 2,000 m elevation
Grass	minimum of 100 m^2 of grazed or ungrazed pasture containing no/few trees/shrubs
Gulch	minimum of 10 m drop from edge to center of gulch
Shrub	minimum of 100 m^2 of landscape dominated by shrubs containing no/few trees
SV	minimum of 100 m^2 of bare or mostly bare rock

We used Song Meter SM4Bat FS (full spectrum) Bioacoustics Recorders (Wildlife Acoustics Inc., Maynard, Massachusetts, USA) bat detectors with SMM-U1 Ultrasonic Microphones. Audio recording settings were as follows: gain 12dB, 16 kiloHertz (kHz) high-pass filter off, sampling rate 256 kHz, minimum duration 1.5 milliseconds, no maximum duration, minimum trigger frequency 16 kHz, trigger level 12 dB, trigger window 3 seconds, max length 15 seconds. These settings differ from the recommended settings suggested by Gorresen et al. (2017) because many of the SM2Bat+ settings used in this reference are not available options on the newer SM4Bat models. Additionally, the SM4Bat FS equipped with the SMM-U1 microphone has superior sensitivity and signal-to-noise ratio compared with the older SM2Bat+ and SMX-US microphones. The 16 kHz high-pass filter was turned off because it actually cuts off calls at 20 kHz and social calls of the species are often below 16 kHz. The sampling rate was increased to 256 kHz because SD card capacity was not limiting, but increased fidelity of recordings would be of benefit for playback calls during mist netting. The max file duration was set to 15 seconds to be consistent with other recording protocols, including those using SD2 Anabat bat detectors (Titley Electronics, Australia).

All recorded files were manually analyzed in Avisoft Sound Analysis and Synthesis Laboratory (SASLab) Pro version 5.2 (Avisoft Bioacoustics, Berlin, DE). The settings used for analysis in SASLab were as follows: FFT Length 1024, frame 100%, Hamming window, and threshold intensity 50.

Recorded files were first analyzed for presence of bat echolocation pulses. To produce a standard, reliable method for quantifying bat activity without artificially increasing the importance of individual events containing many echolocation pulses, each file containing two or more bat echolocation pulses was classified as one bat call. Each file containing zero or one bat echolocation pulse was classified as no bat calls and removed from further analysis. Therefore we recorded the number of files (bat calls) containing two or more bat echolocation pulses. To further reduce inflation of activity caused by a single bat creating multiple bat calls within a short time frame, we removed duplicate calls timestamped with the same minute, so that each minute would either have one or zero calls. Thus, we also recorded the number of minutes with bat calls (call minutes). In addition to bat calls and call minutes, we also recorded the number of files with feeding buzzes (feeding buzzes). Because most bat acoustic studies in Hawaiʻi use the number of calls per night, we used this latter metric in our final statistical analyses of our data.

2.4.1 Statistical Analyses

With final definitions of our habitats we conducted a power analysis for the 250 x 250 meter squares to ensure that we would be able to compare habitat use among habitat types based on our sampling regime. With a sampling schematic utilizing 9 bat detectors moved to new sites within habitats over a 5-night period (a repeated measure), we found habitat to be highly significant at a significance level of $\alpha = 0.05$ ($P < 0.0001$). Utilizing generalized linear mixed model power simulation, our power to detect a difference between habitats with this sampling design was almost 100%, with a confidence interval of [99.63, 100] based on data from the month of July 2017 and the resulting 3,897 bat calls.

2.4.1.1 Dataset

Initially the 2017 dataset for acoustic dataset modelled well, but when the 2018 dataset was combined the model fell apart. To more efficiently proceed with the data analysis, we challenged some of our original assumptions that bat activity would not be adversely affected by precipitation events. In investigating the relationship between bat activity and precipitation, it became apparent that on nights when precipitation was high, bat activity was very low (Fig 3).

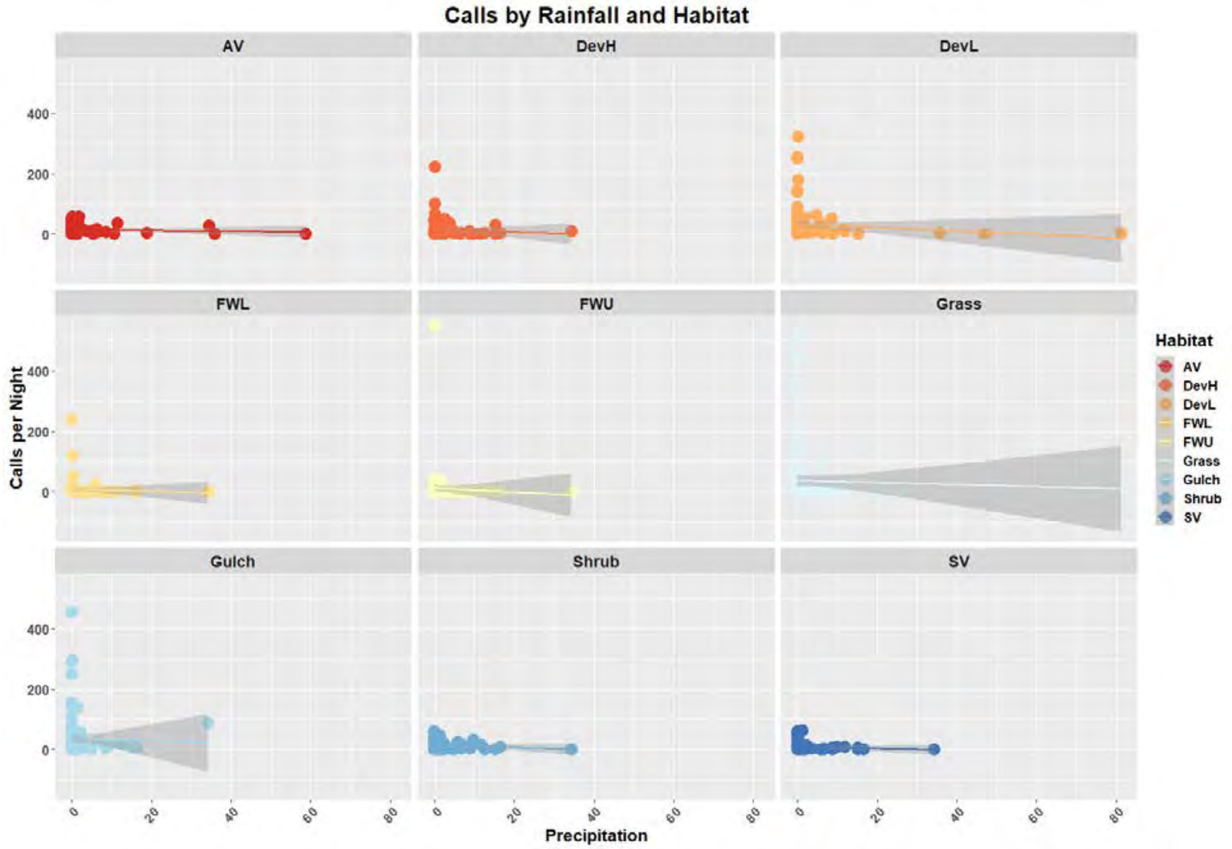


Figure 3. Relationship between Precipitation and the Nine Habitats in the Study Area.

Precipitation values in millimeters. Note that the number of calls/night drops to very low values after a few millimeters of precipitation.

Observations with any NA values were dropped from the analysis to encourage model convergence, and only the "max" values (the night with the highest number of bat call files out of the 3 nights of recording for each survey point) were retained in the final dataset, while any rows with precipitation higher than 5 millimeters were also removed. Original dataset contained 945 rows. The analysis dataset contained 283 rows. The resultant dataset had only 27 zeroes, as opposed to hundreds in the original dataset which was zero-inflated. The main issues in that dataset include non-normal distribution of the data, heterogeneity of variances among groups, potential for temporal autocorrelation, and an over dispersion in the response. The dataset is no longer zero-inflated.

When we removed data occurring when precipitation was greater than 5 millimeters, a better distribution of the points from left to right occurred, and we therefore removed the requirement to account for the effect of rainfall, at least when it is greater than 5 millimeters. Generally there are higher numbers of calls per night at lower precipitation levels, and the models worked better with this amount of spread in the data. Without removing nights with more than 5 millimeter of rainfall, the model resulted in a lack of model convergence or violations of modeling assumptions across a variety of modeling approaches.

We tested differences between the activity among the habitats by using a generalized linear model fit by maximum likelihood (LaPlace Approximation) with a negative binomial distribution (function glmer. nb, package lme 4; Bates et al. 2015), with date and site as random factors, and habitat as the fixed effect of interest. We added predictive parameters one at a time to the model, assessing the model fit and other model diagnostics after each run, including by checking patterns in the residuals overall and by predictor, testing normality of residual distribution and inspection of residual distribution plots, testing for collinearity among variables using variance inflation factors from the car package (Fox and Weisberg 2019) and by checking for model convergence and reasonable model estimates. To determine where significant differences existed across month and habitat combinations, we tested for differences between months within each habitat, and habitats within each month, using pairwise contrasts with a Tukey adjustment for comparing among estimates, by conditioning each factor type on the other (month on habitat, and habitat on month, respectively), with the emmeans package (Lenth 2016). Graphs and figures were generated using package ggplot2 (Wickham 2016).

2.5 Radio Tracking and Kernel Analysis

We mist netted for bat capture during summer 2017, winter 2017/2018, summer 2018, and winter 2018/2019. We used mist net sizes that varied from 2 meters by 3 meters (small) to 9 meters by 30 meters (macronets) that operate with a pulley system (Johnston 2000). At least three, and no more than five, mist nets were set. Additionally, a high definition acoustic lure (Ultra Sound Gate Player, Avisoft, Berlin, Germany) was used to help lure bats to nets. Each captured bat was weighed, the forearm length was measured, hair and tissue samples were taken, the sex, sexual condition, location, date of capture, and fur coloration were recorded. Each bat was outfitted with a BD-2T model radio-transmitter (Holohil Systems, Carp, Ontario, Canada). Radio-transmitters were calibrated for each transmitter to the nearest 0.001 MHz from about 1 meter from the ground. Fur between the shoulder blades was trimmed close to the skin and the transmitter was attached using Osto-Bond Skin Bond Latex Adhesive (Montreal Ostomy Inc., Vaudreuil-Dorion, Quebec, Canada). After allowing approximately 15 minutes for the adhesive to set, bats were released at the capture site. As radiotelemetry data on the night of capture would likely be influenced by the capture event, released bats were usually tracked for only a few minutes to obtain a bearing of disappearance or until roosting. This first night of data was not used to generate FRs and CUAs.

We used R-1000 Telemetry Receivers with hand-held 3- and 5-element Yagi antennas (Communications Specialists, Inc., Orange, California) to triangulate the locations of both roosting and moving bats. Triangulations were produced with two to three observers, each in a different GPS-recorded location, recording bearings in the direction of the strongest radiotelemetry signal strength using magnetic compasses. As Hawaiian hoary bats fly at high speeds and often change direction quickly, bearings used for each triangulation were always done simultaneously (within one second of each other). Because of the long curved slope of our study area, we were able to receive direct line-of-sight signals from 14-kilometer distances when pointing antennae downslope or upslope. Single-bearing determinations of location (Bonaccorso et al. 2015) were not used in our study.

Bonaccorso et al. (2015) used single-bearing determinations by calibrating signal strength (attenuation) and stated that this method is generally similar in accuracy to triangulations until a distance of 300 meters from the tracked bat. We chose the Upcountry region of Maui for the telemetry study in part because of the reasonable access throughout the area by public roads. However, it was infeasible for us to always be within 300 meters of the bat due to the lack of road infrastructure in some outlying areas of our study area and because of the speed at which the bats travel. Because we did not use attenuation to determine distance of a bat with a transmitter, we tracked bats from several kilometers (maximum of about 8 kilometers) away from receivers as long as the angles of the two or more observers were greater than or equal to 15°. Data based on observers with receivers less than 15° were not used to determine FRs and CUAs.

Only one bat was tracked at a time, and the nightly tracking period was based on the habits of the bat being tracked. Bats were tracked for their first foraging bout, which was generally 1.5–3 hours between 5:00 p.m. and midnight. Only one position was obtained each time a bat roosted, either by honing on to the signal or by triangulation. While flying, triangulations were attempted at not less than 3-minute intervals following the methods of Bonaccorso et al. (2015) to prevent autocorrelation of the positional data.

We entered grouped GPS and azimuth data for triangulations into LOAS 4.0.3.8 software (Ecological Software Solutions, Urnäsh, Switzerland) to plot the triangulated positions of bats. Triangulated positions generated using three bearings were validated through agreement between bi-angulated positions. Triangulated positions generated using two bearings were validated if the positions did not change markedly if either bearing were increased or decreased by 1° and verified using signal strength data recorded by the observers when available. Triangulated positions not meeting the validation criteria were eliminated from the dataset and not used in the kernel analysis. Bats with fewer than 25 qualifying fixes were not used for kernel analyses. Fixes determined by antennae with angles less than 15 degrees from each other were also not used for kernel analyses. We used the kernel UD function of the adehabitat HR package in R (Calenge 2006) to calculate the 95% kernel (FRs) and 50% kernel (CUAs). The smoothing parameter was set to "href" for this adehabitat HR package and a complete set of parameters is provided in Appendix A.

Because FRs and CUAs generated from our data were substantially larger than those determined for Hawaiian hoary bats on the island of Hawai'i, we also calculated these values using the same methods for kernel analysis used by Bonaccorso et al. 2015. Home ranges were assessed using Home Range Tools for ArcGIS 10 software. A least squares cross-validation was used to determine a smoothing parameter with minimum estimated error for fixed-kernel estimates (Rodgers et al. 2015). From these data we calculated minimum area probabilities for foraging range as the 95% fixed kernel. CUAs were defined by the 50% fixed kernel. A complete set of parameters is provided in Appendix A. Flight positions only (not roosting) were used to calculate foraging range and CUA. Bat locations were transposed on a map of Hawai'i using ArcGIS 10.7.1 software (Environmental

Systems Research Institute, Redlands, California). Habitat types for bats' radio telemetry coordinates within the FRs and CUAs were determined from base habitat maps.

2.6 Insect Sampling

We sampled insects using extra tall blacklight traps (BIOQUIP model 2805) at nine sites (one in each of the nine habitat types) for seven sampling periods: August and October/November 2017, and January, February/March, May, June/July, and August/September 2018.

In each sampling period, insect traps were deployed for one week, suspended approximately 2 meters above the ground. A 40% ethanol killing agent was used and each trap was powered by a 12-volt deep cycle marine battery. A photosensor switch was used to automatically turn insect traps on at night and off in the daytime to collect prey available to the Hawaiian hoary bat. Because little light penetrates the canopy in forest sites during the day, FWL and FWU insect traps were equipped with timer switches set for sunset and sunrise. On the third or fourth day after deployment, insects were strained and collected in ethanol, ethanol in light traps was replaced, and marine batteries were swapped out. After traps had run for 7 nights, insects were strained and collected in ethanol again, and traps retrieved.

2.6.1 Insect Identification and Quantifying Dry Weight

Because our primary purpose for collecting insects was to help identify which species the bats had foraged on, and we had collected tens of thousands of insects (i.e., too many to fully sort and identify), we gave priority to samples from habitats with the most bat activity for a given month. To obtain a representative set of insect species identifications at each high-priority sampling location, 50 insects were chosen randomly from each vial by drawing a line along the side of a closed vial with a marker, and then taking a vertical sample of the first 50 insects nearest to that line. The sampled insects were placed into glass dishes and sorted under a microscope. Insects were identified to lowest taxonomic order, which was usually family for non-Lepidoptera. For Lepidoptera, identification to genus or species was only carried out for males, whose genitalia allow for easier identification (wing pattern, labial palps, and other generic characters were destroyed during specimen collection). Dissections of male Lepidoptera were undertaken by first immersing specimens for 1 hour in simmering 10% potassium hydroxide, then subsequently soaking them in 50% ethanol, chlorozol black stain, 100% ethanol, and water, and mounting them on slides using polyvinyl alcohol fixative. Figure 4 is an example of one of the many prepared slides of male genitalia used to identify moths collected. This nonnative species, *Darna pallivitta,* (Limacodidae), was recently introduced to Hawaii.

Figure 4. Slide preparation of Male Genitalia of *Darna pallivitta* Used to Identify the Species.

To obtain the dry weights of the insect samples, the vial lids were unscrewed and the vials were set in a fume hood for one week, being gently stirred each day. The mass of each vial was recorded after 1 week, and its tare value (i.e., mass of an empty vial) was subtracted from the scale reading to calculate the dry weight of the samples.

2.6.2 Statistical Analysis of Dry Weights of Insect Samples per Habitat

We tested for temporal autocorrelation between months for the dry weights of insect samples using the Breusch-Godfrey test for serial correlation in software package ecm (Bansal 2019) and by inspecting the auto correlation function (acf) plot of model residuals in package and by inspecting the acf plot of model residuals in software package nlme (Pinheiro et al. 2018), but no patterns emerged and we failed to reject the null hypothesis that temporal autocorrelation does not exist in these data. We fit a negative binomial generalized linear model with a log link function from the MASS package (Venables and Ripley 2002) to accommodate overdispersion in the data and analyzed the impact of habitat and month on total dry weight of insect samples collected. The final model was selected based on model fit, satisfaction of model assumptions, and comparison of AIC (Akaike's Information Criterion) values between different models, with the model having the significantly lowest AIC score being the "best" model. The final model included both habitat and month, but no interaction of the two factors, as not 100% of habitats were successfully sampled in all months due to inclement weather.

We assessed model fit and other model diagnostics by checking patterns in the residuals (overall and by predictor), testing normality of residual distribution and inspection of residual distribution plots, testing for collinearity among variables using variance inflation factors from the car software package (Fox and Weisberg 2011) and by checking for model convergence and reasonable model estimates. The final model residuals were randomly distributed, and fitted estimates were positively correlated with the raw data, indicating good model fit.

To obtain model estimates of insect weight, we used the estimated marginal means (emmeans) (Searle et al. 1980) function from the emmeans software package in R (Lenth 2009) to generate estimated means for each group, adjusted for other factors in the model. To determine where significant differences existed across month and habitat combinations, we tested for differences between months and habitats using pairwise contrasts with a Tukey adjustment (Lenth 2009). Graphs and figures were generated using package ggplot2 (Wickham 2016).

2.7 DNA Extraction, Polymerase Chain Reaction, Library Prep and Sequencing:

Fecal samples were rinsed of storage media using sterile water and approximately half of the fecal material, was subjected to DNA extraction with QIAamp PowerFecal DNA kit (Qiagen) following manufacturer's protocol. For four fecal samples that were unsuccessfully extracted, a second extraction was performed, rinsing the fecal samples more thoroughly and increasing the two 4°C incubation steps from 5 minutes to 30 minutes. DNA was extracted with the QIAamp PowerFecal DNA kit according to the manufacturer's protocol.

DNA from all 11 extracts was amplified at two loci using two technical replicates for a total of 44 amplifications. We targeted the CO1 region with ZBJ-ArtF1c and ZBJ-ArtR2c primers (Zeale et al. 2010) and the 16S region with Coleop_16Sc and Coleop_16Sd (Epp et al. 2012) modified with adapters on the 5' end for the Illumina MiSeq platform (Illumina Corporation, San Diego, CA, USA). Conditions for PCR were 25 microliter (μL) reactions of 1X PCR gold buffer, 2.5 millimolar MgCl2, 0.8 millimolar deoxyribonucleotide triphosphate blend, 0.125 μL AmpliTaq Gold (Applied Biosystems, Foster City, CA, USA), 5g BSA (Sigma-Aldrich, St. Louis, MI, USA), 5 micromolar each primer (Integrated DNA Technologies, Coralville, IA, USA), and 3 μL of fecal DNA. PCR cycling parameters were: denaturation at 95°C for 10 minutes, followed by 35 cycles of 95°C for 30 seconds, 52°C for 30 seconds, and 72°C for 30 seconds, with a final elongation step of 10 minutes at 72°C. Amplification success was confirmed by running 5 μL of each sample on a 2% agarose gel (Sigma-Aldrich, St. Louis, MI, USA).

Initial PCR products with Illumina adapters were cleaned of unincorporated nucleotides with Agencourt AMPure XP beads (Beckman Coulter, Indianapolis, IN, USA). The cleaned products were labeled with unique combinations of forward and reverse indexes using a 50 μL second-step PCR, consisting of 25 μL KAPA HiFi HotStart taq (KAPA Biosystems, Wilmington, MA, USA), 5 μL each of Nextera XT v2 index forward and reverse primers (Illumina Corporation, San Diego, CA, USA), and 5 μL of initial PCR product. Cycling parameters were: denaturation at 95°C for 3 minutes, followed by 8 cycles of 95°C for 30 seconds, 55°C for 30 seconds, and 72°C for 30 seconds, with a final elongation step of 5 minutes at 72°C.

The indexed PCR products pooled to approximately equal molarities. Each pool was visualized and quantified on a Bioanalyzer (Agilent Technologies, Santa Clara, CA, USA) to ensure proper size and to calculate final loading concentration. Samples were diluted to 4 parts per million and combined with PhiX control DNA (Illumina Corporation, San Diego, CA, USA) at a ratio of 10% PhiX and then loaded onto a MiSeq Reagent Kit v2 500-cycle flow cell reading 175 bases paired-end, for sequencing at the University of Tennessee Genomics Core (Knoxville, TN, USA).

COI data analysis: The sequenced COI region was merged using custom scripts and the USEARCH method (Edgar 2010). Merged reads were uploaded to the mBRAVE platform (http://www.mbrave.net/). Length trimming was set at 30bp from the front end and 23bp from the reverse end to remove primers. We then filtered any read that was greater than 600bp. Primer masking was left off. We set the quality filters at MinQV=0, Min Length=90bp, Max Bases with Low QV (<20)=75%, Max Bases with Ultra Low QV (<10)=75%. The pre-clustering threshold was set to none and the ID distance threshold was set at 2%. We compared all reads to three established reference collections derived from the BOLD database:

- System reference library for insects consisting of 663,781 sequences representing 491,902 BINs (a cluster of related reference sequences which equates to a species) and 199,009 species designations.
- System reference library for non-arthropod invertebrates consisting of 69,983 sequences representing 42,990 BINs and 29,624 species designations.
- System reference library for non-insect arthropods consisting of 76,769 sequences representing 58,227 BINs and 23,254 species designations.

Data from the two technical replicates were pooled for analysis.

16S data analysis: The amplified 16S region was also merged using custom scripts and the USEARCH method (Edgar 2010). The merged reads were then analyzed using the QIIME2 platform, following the standard protocol for 16S sequence data (Bolyen et al. 2019). This involved quality control and filtering before generating a frequency table of unique sequences detected within each sample, using DADA2 (Callahan et al. 2016). The raw 50849 sequences were reduced to 8344 sequence variants at this step. Sequence variants are equivalent to 100% OTUs produced using other methods. These unique sequences were then identified by comparison to the reference data in NCBI GenBank using BLAST (Altschul et al. 1990).

Section 3. Results

3.1 Habitat Use Based on Acoustic Data

We recorded 17,408 bat calls, (15,382 calls per night and 12,650 call-minutes), 734 feeding buzzes, and 146 social calls between the dates of September 1, 2017 and September 30, 2018 located in nine habitats found on the study area. The conversion of total calls to number of calls per night is useful for long-term studies and is often used in acoustic studies of the Hawaiian hoary bat. The conversion of total calls to call-minutes is used to buffer the number of recordings of a single bat made in a short period of time because within one minute, calls are most frequently generated by a single bat (Miller 2001).

3.1.1 Modelling of bat calls per night

Based on the number of bat calls per night for all habitats over the course of the study, bats used Gulch, DevL, and Grass habitats more than other habitats overall (Figure 5). There is also more variance in Gulch, Grass, and DevL habitats. The higher the mean, the greater the variance. Moreover, we have different variances per group (Figure 5). By month, there is a general decrease in in calls per night from September 2017 to January 2018, and then increasing call minutes from March through September 2018 (Figure 6). Although that does not necessarily mean that there is an annual trend with only one year of data, September 2017 and September 2018 both had the highest calls per night and this is the expected trend based on other acoustic studies of the Hawaiian hoary bat (Bonaccorso et al. 2015, Gorreson et al. 2013) although we have only one year of data. September 2017 and 2018 were more alike in that they had the highest calls per night, but September 2017 had lower mean calls per night than September 2018. Using habitats as categories we found an interaction with month; and therefore, found habitat to be highly significant between habitats for specific months of the year (Figure 5, see Appendix B for estimates of means and standard errors, and Appendix C for a table of significant differences between habitats within each month). Table 3 provides examples of pairwise comparisons between habitat types showing significant, or near significant, bat use of some habitat types over others during different times of the year. In summary, the results (contrasts with Tukey adjustment, 0.95 confidence level; significance level of alpha=0.05) indicate that it is reasonable to conclude that there are significant differences between some habitats in some months, when rainfall is less than 5 millimeters. Appendix C shows a summary of significant differences between habitats over time.

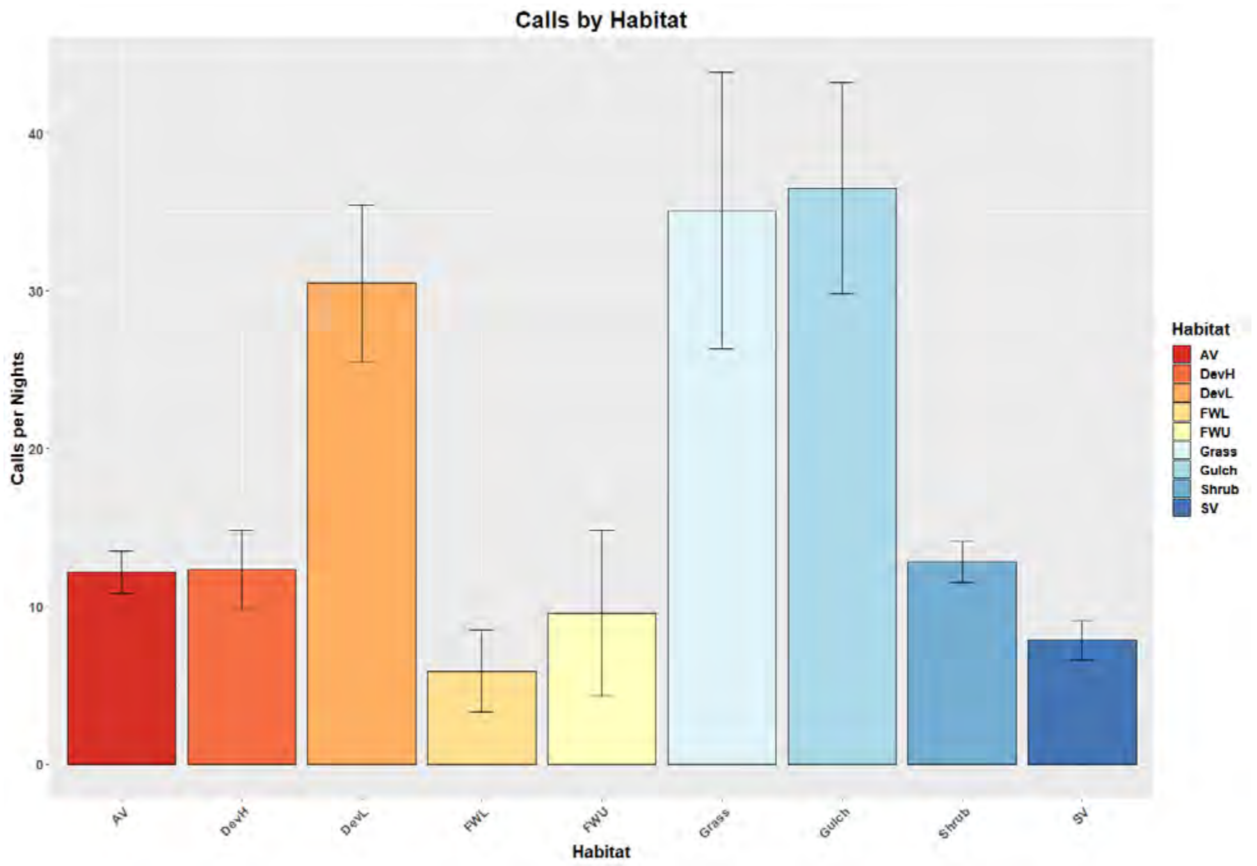


Figure 5. Differences in Bat Activity among Habitats within the Project Site Based on Raw Data

Bars show means and whiskers are one standard error of the mean. Gulch, Grassland, and Low Density Developed habitats had more bat calls/night overall than other habitats. Bat activity was least in the low and upper forested areas. Acronyms are as follows: AV = Agricultural Vegetation, DevH = High Density Developed, DevL = Low Density Developed, FWL = Forest Woodland Lower elevation (< 2000 meters above sea level), FWU = Forest Woodland Upper (≥ 2,000 meters above sea level), Grass = Grasslands, Gulch = Gulches, Shrub = Shrub lands, SV = Sparse Vesicular rock.

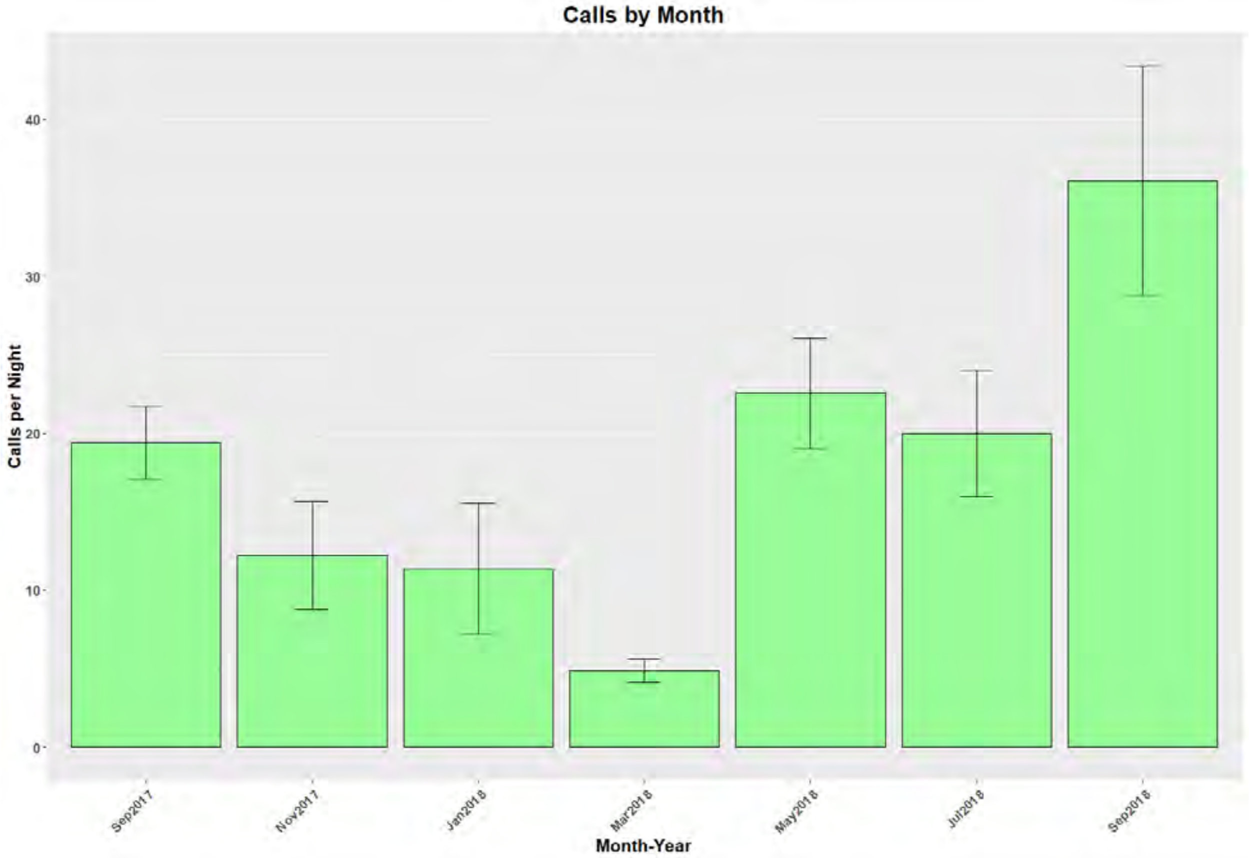


Figure 6. Differences in Bat Activity among Months Based on Raw Data.

Bars show means and whiskers are one standard error of the mean.

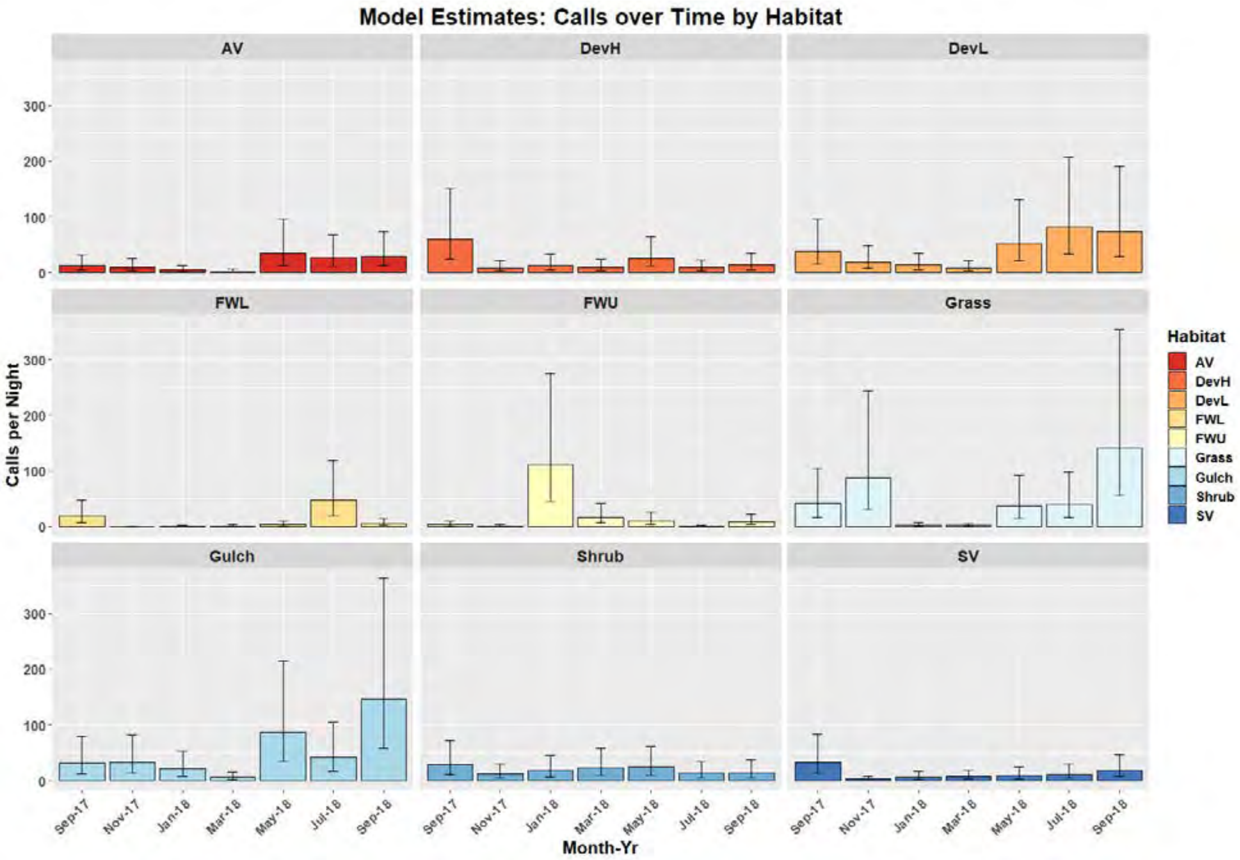


Figure 7. Differences in Bat Activity among Months Based on Raw Data.

Bars show means and whiskers are one standard error of the mean.

DevL, Gulch, and Grass show trends of greater activity during summer months. Higher values also show greater standard error. For all habitats during January, the highest amount of activity occurred in the FWU (forested areas above 2,000 meters). During summer months, FWL was little used although it was greater than the FWU.

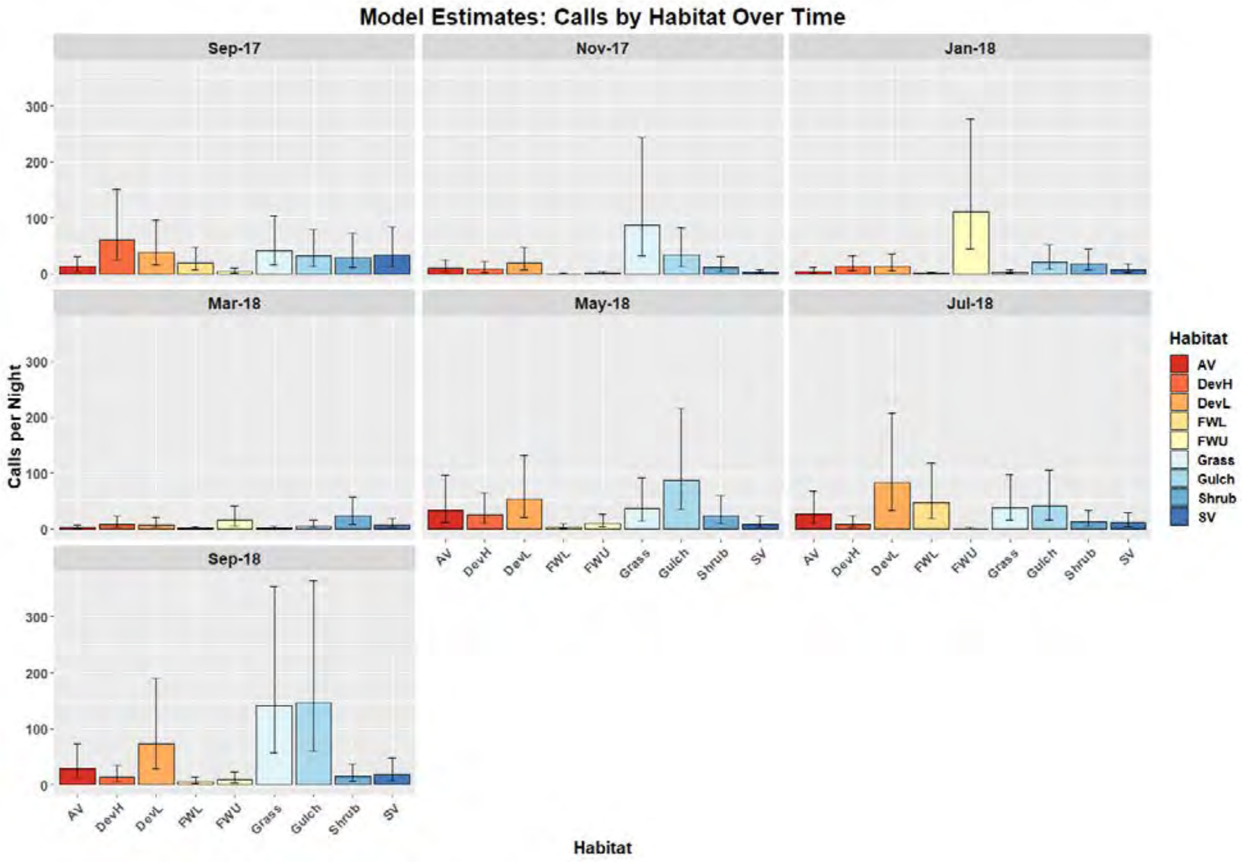


Figure 8. Model Estimates: Calls by Month, within Habitat.

Bars show means and whiskers are one standard error of the mean.

Table 3. Pairwise Comparisons of Habitat Types at Alpha = 0.05.[1]

Acoustic Monitoring Sample Month	Habitat(s) with Significantly Greater Amount of Activity	Habitat(s) with Significantly Less Amount of Activity
September 2017	DevL, DevH, Grass, Gulch, and SV	FWU
November 2017	Grass	DevH, FWL, FWU, and SV
	Gulch	FWL, FWU, and SV
	DevL	FWL and FWU
	AV, DevH, and Shrub	FWL
March 2018	FWU and Shrub	FWL
	Shrub	AV and Grass
May 2018	AV, DevL, Grass, and Gulch	FWL
	Gulch	FWU and SV
July 2018	AV, DevL, FWL, Grass, Gulch, Shrub, and SV	FWU
	DevL	DevH
September 2018	DevL, Grass, and Gulch	FWL
	Grass and Gulch	FWU
	Grass and Gulch	DevH
	Grass and Gulch	Shrub
	Gulch	SV

[1] Detailed statistics provided in Appendix C.

3.1.2 Model Diagnostics

We used a negative binomial distribution to model these data. A Shapiro test was applied to test for normality of the model residuals, and the results indicate that the residuals are normally distributed (W = 0.99) with no patterns emerging [Figure 9 (top)]. When the fitted values (model estimates) are plotted by the raw (actual) data there is a strong, positive relationship, indicating a good agreement between the model estimates and the actual data [Figure 9 (bottom)].

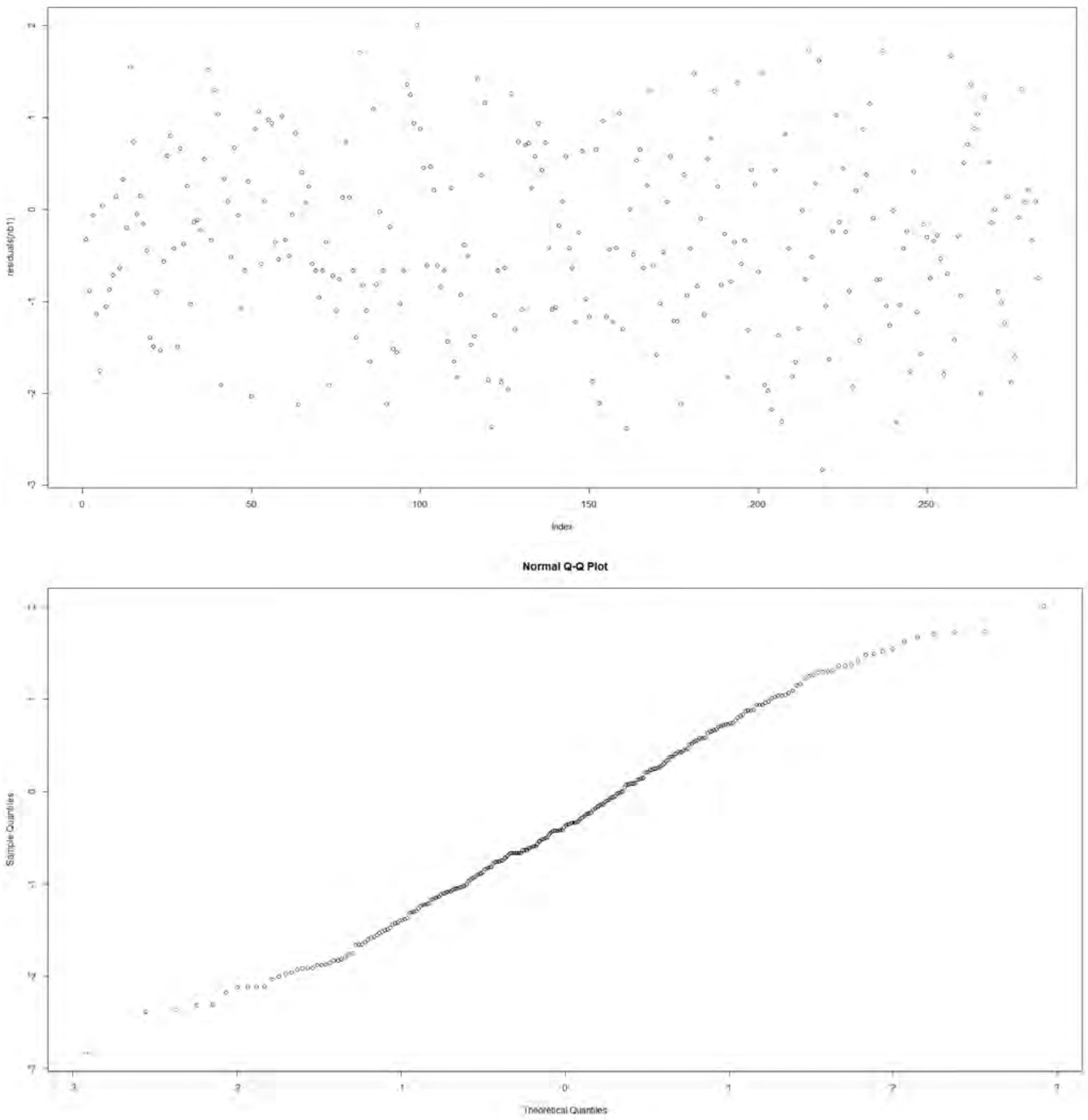


Figure 9. **Distribution of Model Residuals (Shapiro Test, W = 0.99). (Top) Model Qqnorm Plots. Showing a Strong Positive Relationship. (Bottom)**

3.1.3 Spatial Distribution of calls each night

Spatially these data are fairly well distributed. Figure 10 provides each night of data, including all 3 days of each deployment; and therefore, showing quite a bit of variation from one night to the next for the 3 nights. Areas without any acoustic monitoring are the result of a few large land owners who did not feel comfortable hosting the collection of bat acoustic data. The spatial distribution for calls each night for individual habitat types are provided in Appendix D.

Figure 10. Spatial Distribution of Bat Calls Based on 315 Locations among Nine Habitat Types from September 2017 through September 2018.

3.2 Results: Radio-tracking and Core Use Areas

Our capture success increased over time (Figure 11) possibly because of our increase in use of acoustic lures with locally recorded social calls. We mist netted on 78 nights from June 2017 through September 2018 (Figure 12). We initially used mainland hoary bat social calls and switched to Maui-specific Hawaiian hoary bat social calls and feeding buzzes as we recorded them during our acoustic surveys. The local social calls appeared to be much more effective as lures. Acoustic lures were most effective in September and October. Note that equal sampling effort did not occur in each month because after a bat was captured our nighttime hours were dedicated to radio-tracking that individual. Our mist netting effort was also biased during summer months partly because the rainy and windy weather during winter months prevented regular mist netting (Figure 12).

The mist netting areas consisted of 13 total capture sites in three broad regions: Haleakala National Park (summit district [n=3, Resource Management Office, 12-mile pool, Hosmer Grove]); Lower Kula–Naʻalae Road (n=2, a native plant nursery and rural property); Olinda/Piʻiholo Roads (n=9, Maui Forest Bird Recovery Project Office, Maui Forest Bird Recovery Project Cottage, Waihou Springs Reserve, five private residences, and Kamehameha Schools in Makawao). In total, we caught twenty bats composed of two subadult females, two subadult males, two adult females and sixteen adult males (Figure 13). Subadults are individuals that can fly but are less than one year old.

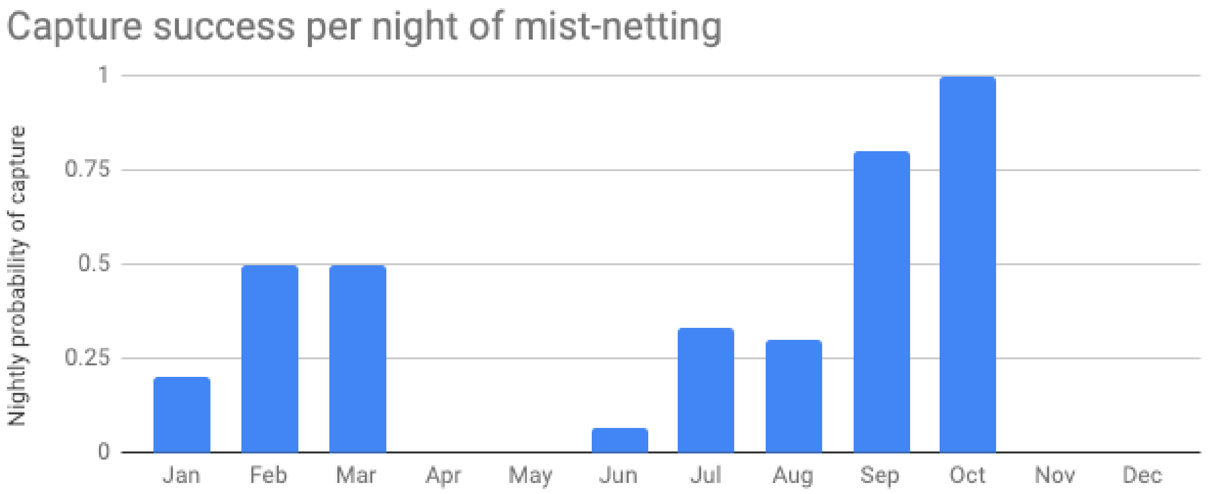


Figure 11. Probability of Capture Success per Night of Mist-netting Effort

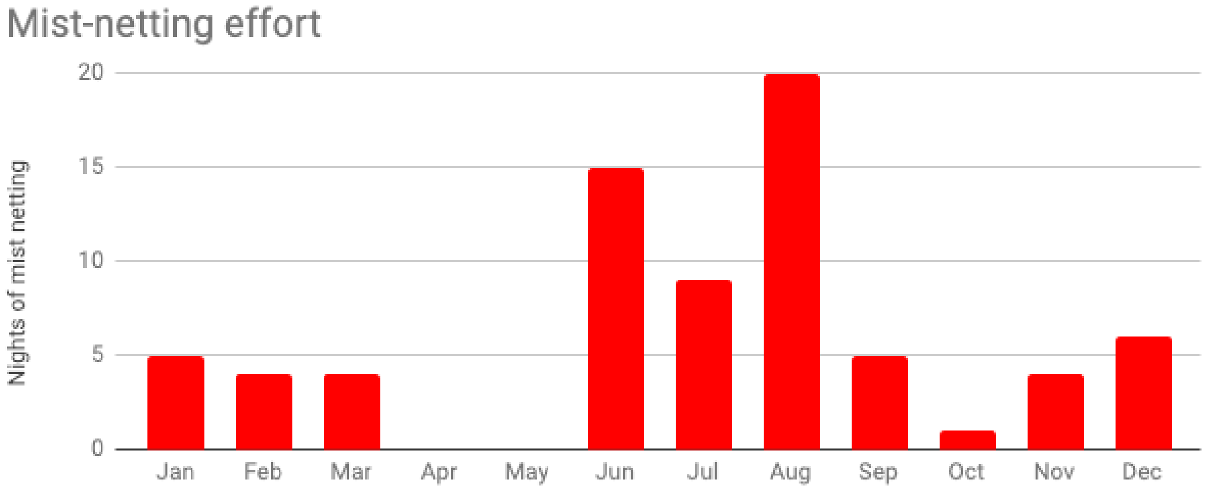


Figure 12. Mist Netting Effort for 2018.

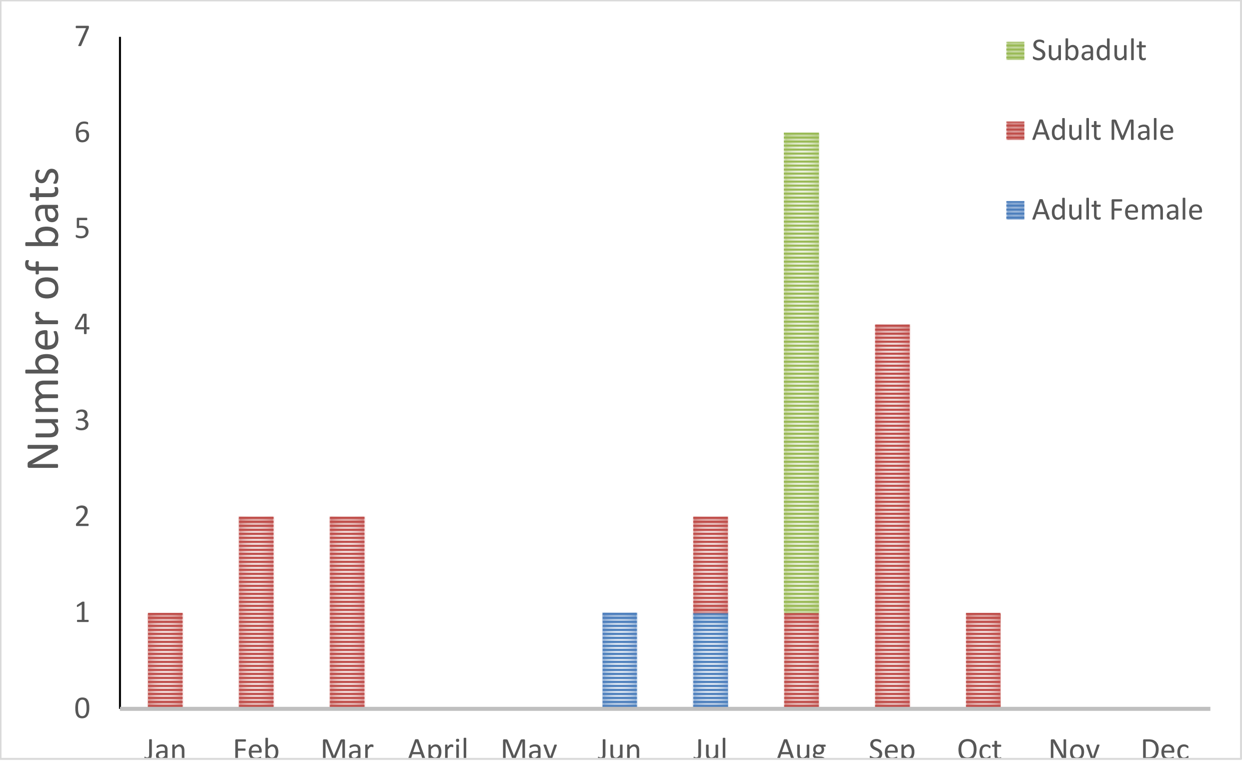


Figure 13. Pooled Data Showing the Distribution of Age Class and Sex from Mist Netting Effort

Seventy-eight nights of mist netting yielded 20 bat captures

Table 4. Summary of Mist Netting Effort

Season	Dates	Number of Valid Netting Nights	Hours * Net Meters^2	Total Bats Captured	Bats Captured with Use of Playback	Nights of Mist Netting to Capture Bat
Summer 2017	Jun 5 – Oct 2	30	12,052	7	4	4.3
Winter 2017/2018	Dec 29 – Mar 21	14	4,073	5	4	2.8
Summer 2018	Jun 4 – Sept 20	26	1,679	8	8	3.3
Winter 2018/2018	Nov 24 – Jan 8	8	569	0	0	N/A
	Total	**78**	**18,373**	**20**	**16**	**3.9**

Radiotelemetry. We radio-tagged a total of 16 bats and were able to sufficiently track the movements of 11 of these bats to map home range and CUAs. Table 6 provides data for the number of nights tracked, number of fixes, and other pertinent data for each bat tracked. Data for five bats were too limited to determine home range and another four bats were not fitted with radio-transmitters because of a late delivery of transmitters. We spent 109 nights tracking the movements of tagged bats. The 50% kernel (CUA) and 95% kernel (FR) ranged from the smallest (Bat 10, a mature male) at 2.76 ha for the CUA and 14.63 ha for the FR (STDEV x-axis 120.51, y-axis 66.54 and x/y ratio 1.81) to the largest (Bat 3, a subadult female) at 6,508.06 ha for the CUA and 24,878.93 ha for the FR (STDEV x-axis 5830.01, y-axis 1959.62 and x/y ratio 2.98).

Of the 11 bats whose home ranges we mapped, the mean 50% kernel CUA based on our kernel analysis methods was 2,914.39 hectares and 2,192.53 hectares based on methods used in the USGS studies (Figures 14 and 15) and the mean 95% kernel foraging range was 12,905.38 hectares based on our kernel analysis methods and 9,943.73 hectares based on the USGS studies (Figure 15). Because of huge differences in values for the CUAs and FRs, the standard deviations were 5,730 hectares and 23, 556 hectares, respectively, using our study methods. The mean longest length measurement based on our study methods is 6.86 kilometers and 15.1 kilometers for the CUAs and FRs, respectively. As seen in Table 5, we observed a high level of variability between individuals.

Table 5. Results for Kernel Analysis Based on H. T. Harvey & Associates and USGS Methods for Core Use Areas and Foraging Ranges

ID	%	Gender	Age	Length in km HTH	Hectare_ HTH	Month	Year	Hectare_ USGS	Difference for 50% kernel	Difference for 95% kernel
2	50	Male	Juv	1.77	235.80	Aug	2017	257.00	-21.20	
2	95	Male	Juv	5.56	1,263.30	Aug	2017	1,372.56		-109.26
3	50	Female	Juv	13.26	6,508.06	Aug	2017	231.93	6276.13	
3	95	Female	Juv	24.84	26,064.76	Aug	2017	1,185.83		24,878.93
4	50	Male	Ad	8.78	3,430.13	Sept	2017	2,106.94	1,323.19	
4	95	Male	Ad	22.48	18,503.88	Sept	2017	11,849.19		6,654.69
5	50	Male	Ad	3.72	574.57	Sept	2017	406.22	168.35	
5	95	Male	Ad	10.13	3,612.36	Sept	2017	2,694.69		917.66

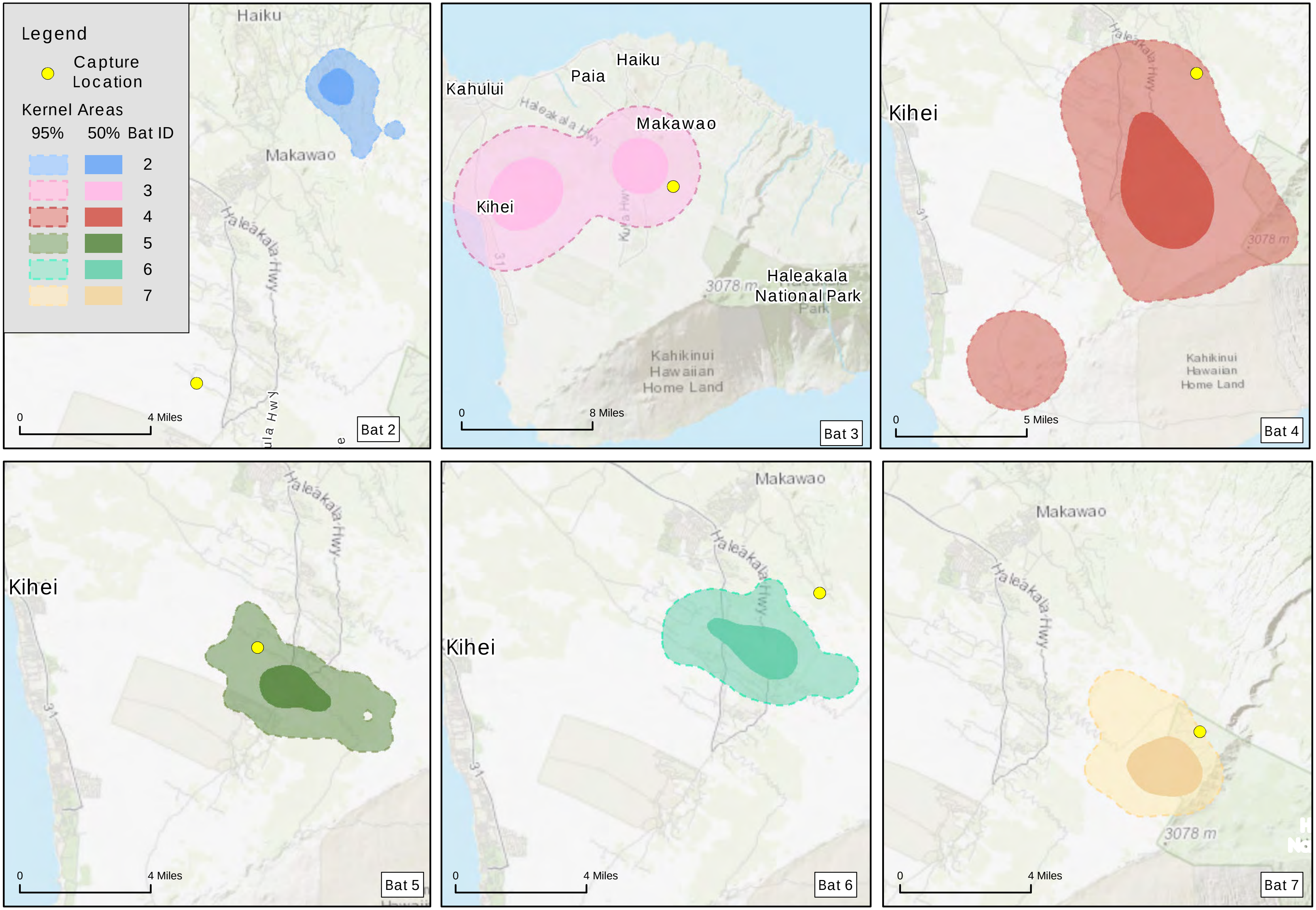
ID	%	Gender	Age	Length in km HTH	Hectare_ HTH	Month	Year	Hectare_ USGS	Difference for 50% kernel	Difference for 95% kernel
6	50	Male	Ad	4.85	793.64	Oct	2017	743.61	50.04	
6	95	Male	Ad	10.06	3,706.85	Oct	2017	3,638.68		68.16
7	50	Male	Ad	3.8	842.21	Jan	2018	1,088.48	-246.27	
7	95	Male	Ad	8.27	3,519.08	Jan	2018	4,508.76		-989.68
9	50	Male	Ad	11.05	3,531.15	Feb	2018	4,865.20	-1,334.06	
9	95	Male	Ad	16.51	12,398.30	Feb	2018	18,417.52		-6,019.21
10	50	Male	Ad	0.2	2.76	Mar	2018	1.63	1.14	
10	95	Male	Ad	0.62	14.63	Mar	2018	8.03		6.59
11	50	Male	Ad	3.76	970.67	Mar	2018	699.79	270.88	
11	95	Male	Ad	11.5	5,208.64	Mar	2018	4,083.70		1,124.94
12	50	Female	Ad	7.1	4,264.57	June	2018	4,275.03	-10.47	
12	95	Female	Ad	24.55	23,359.50	June	2018	23,306.52		52.98
20	50	Male	Ad	17.17	10,904.68	Sept	2018	9,441.99	1,462.70	
20	95	Male	Ad	31.1	44,307.91	Sept	2018	38,315.52		5,992.39

Notes: HTH = H. T. Harvey & Associates; USGS = U.S. Geological Survey; Ad = adult; Juv = juvenile

See Appendix E for individually mapped CUAs and foraging ranges based on H. T. Harvey & Associates and USGS kernel analysis methods, and Appendix F for detailed accounts of the movements of each radio-tagged bat.

Table 6. Summary of Tracking Success

Bat	Dates	Number of Tracking Nights	Number of Triangulated Fixes Used	Number of Day Roost Observations (Locations)	Number of Night Roost Observations (Locations)
1	Jul 16 – 19, 2017	2	3	0 (0)	0 (0)
2	Jul 27 – Aug 8, 2017	16	63	3 (1)	1 (1)
3	Aug 14 – 22, 2017	6	31	0 (0)	0 (0)
4	Sep 7 – 19, 2017	13	112	2 (1)	8 (4)
5	Sep 22 – Oct 1, 2017	10	128	2 (2)	6 (4)
6	Oct 2 – 8, 2017	7	65	2 (1)	3 (1)
7	Jan 10 – 18, 2018	7	59	2 (1)	1 (1)
9	Feb 20 – Mar 5, 2018	8	76	0 (0)	1 (1)
10	Mar 7 – 12, 2018	5	84	1 (1)	3 (1)
11	Mar 21 – Apr 1, 2018	5	52	1 (1)	2 (2)
12	Jun 19 – 25, 2018	6	54	1 (1)	0 (0)
20	Sep 18 – Oct 4, 2018	7	28	0 (0)	0 (0)
	Total	**92**	**755**	**14 (9)**	**25 (15)**



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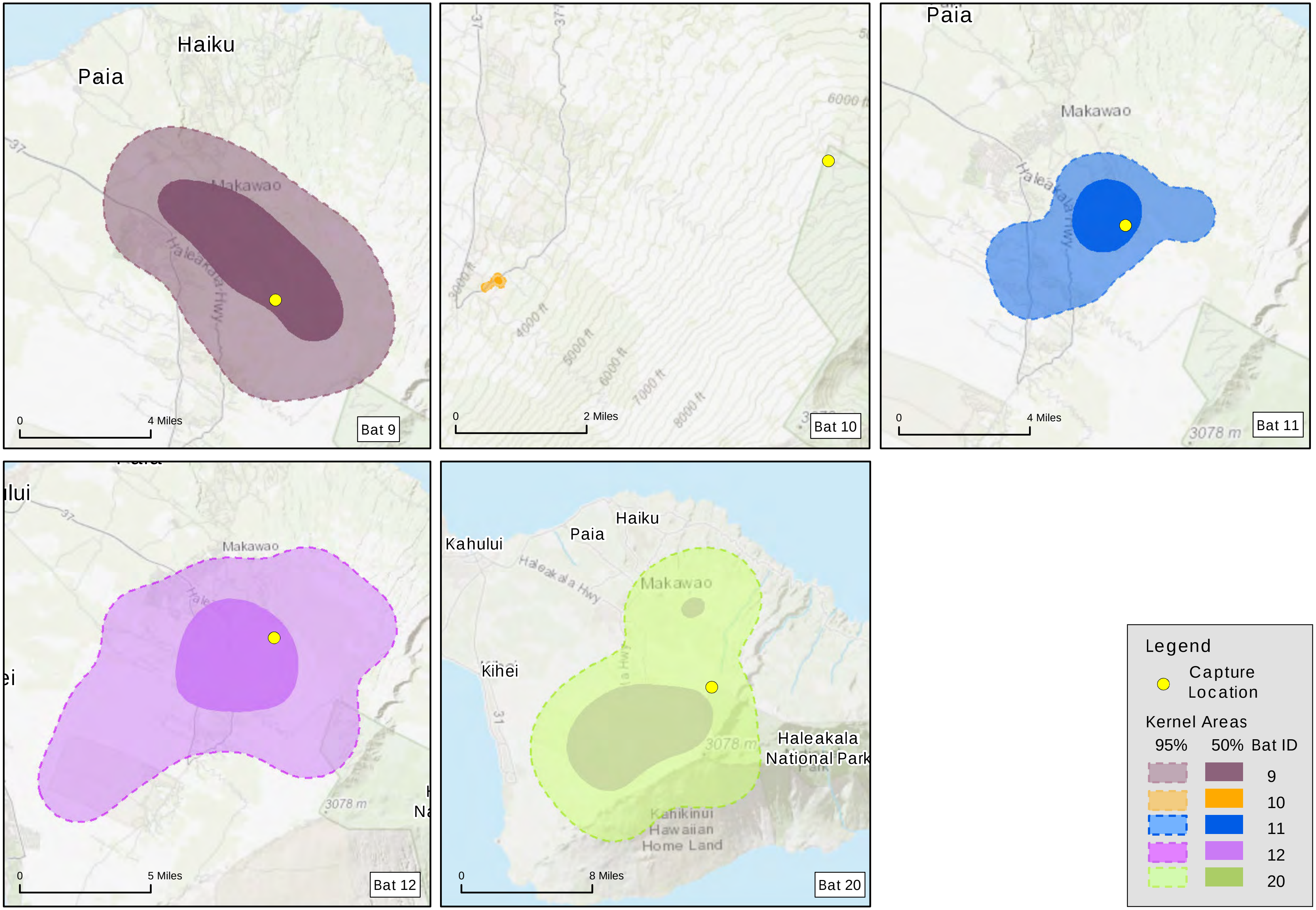
Appendix D. 95% and 50% Kernel Foraging and Core Areas per **Individual Bat (2-7)**

Ecology of the Hawaiian Hoary Bat (3978-01)
December 2019



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Appendix D. 95% and 50% Kernel Foraging and Core Areas per Individual Bat **(9 - 20)**

Ecology of the Hawaiian Hoary Bat (3978-01)
December 2019

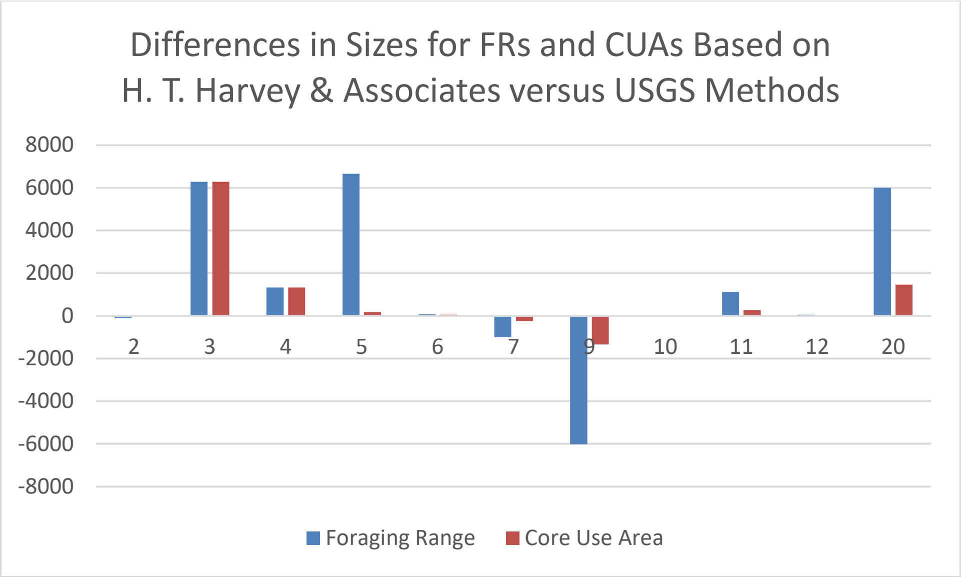

Figure 16. **Size Differences in the CUAs (50% kernel) and FRs (95% kernel) based on H. T. Harvey & Associates methods versus USGS methods.**

Although the mean sizes for the CUAs and FRs are larger when applying our study methods, the changes in size are dependent upon the individual bat. For example, Bat 3's FR is over 6,000 hectares larger when using our study methods compared with those in the USGS studies. Conversely, Bat 9's FA is over 6,000 hectares smaller when applying our study methods than it would be if the USGS methods were applied. The variation is likely attributable to different degrees of smoothing. The USGS methods tend to make smaller clusters of occupied space as opposed to our study methods, which tend to group small clusters of fixes. For example, Bat 3 shows a large FR and CUA based on our study methods whereas the USGS methods tend to make separate polygons of smaller areas resulting in a smaller FR and CUA (Figure 14).

On average, bats were tracked for 8 nights, thus the number of nights we collected data was quite small to be representative of the full range of their movements, even within a single season. Yet, even in these brief monitoring periods, we detected numerous long-range movements of approximately 16 kilometers and some of approximately 25 kilometers. Based on our study methods, the mean long axis for the CUA was 6.8±5.3 kilometers and the mean FR long axis was 15.06±9.5 kilometers.

In addition to measuring the number of bat calls in the nine habitat types to determine habitat use, we also looked at the distribution of habitat use based on the telemetry coordinates of location fixes. After pooling habitat data from the radiotelemetry fixes, we found that bats occurred in some habitats more than others. The data presented in Figure 17 suggest that at a confidence interval of 0.95 (alpha = 0.05) bats spent more time over low-density developed, forest woodland low elevation, and grassland habitat types. Although the bat calls/night data varied somewhat among these habitats for different months, the acoustic data imply that bats tend to spend more time in low-density developed, grassland, and gulch habitats, but not the forest woodland low elevation habitat. Interestingly, the gulch habitat type had only a single fix data point despite the acoustic data suggesting that it is an important habitat for the Hawaiian hoary bat. We found that the bats were typically undetectable with the radiotelemetry receiver when they were inside these deep gulches; however, individuals were detectable when they reemerged and flew over the forest and woodland low elevation habitat between gulches. Most of the radiotelemetry fixes in the forest and woodland low elevation habitat were situated at the edges of gulches and between gulches that were relatively close together.

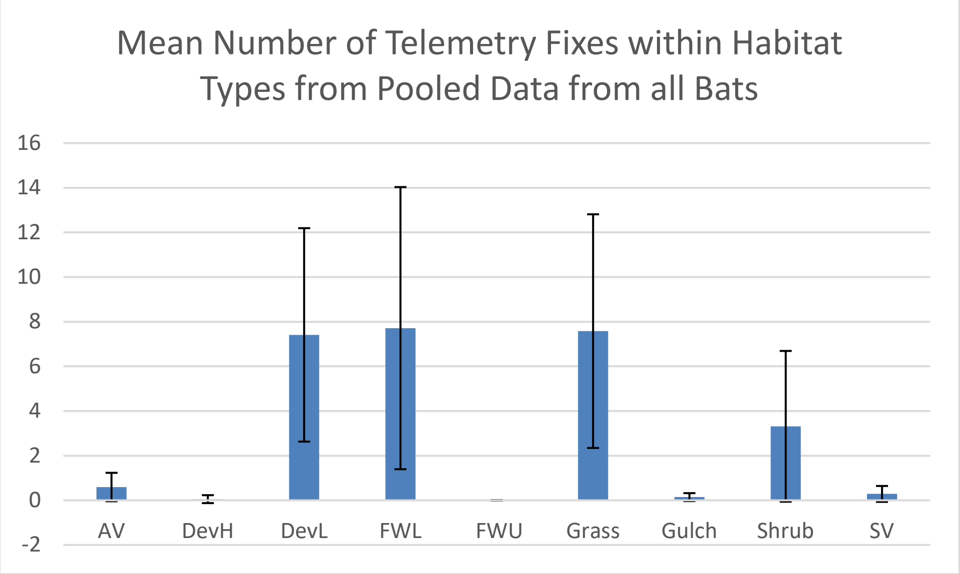

Figure 17. Habitat Use Based on Pooled Data from Radiotelemetry Fixes for 11 Bats.

Bars are mean estimates, and whiskers are 95% confidence intervals: AV (0.59), DevH (0.052), DevL (7.41), FWL (7.71), Grass (7.58), Gulch (0.14), Shrub (3.31) and SV (0.29). Acronyms are as follows: AV = Agricultural Vegetation, DevH = High Density Developed, DevL = Low Density Developed, FWL = Forest Woodland Lower elevation (< 2,000 meters above sea level), FWU = Forest Woodland Upper (≥ 2,000 meters above sea level), Grass = Grasslands, Gulch = Gulches, Shrub = Shrub lands, SV = Sparse Vesicular rock.

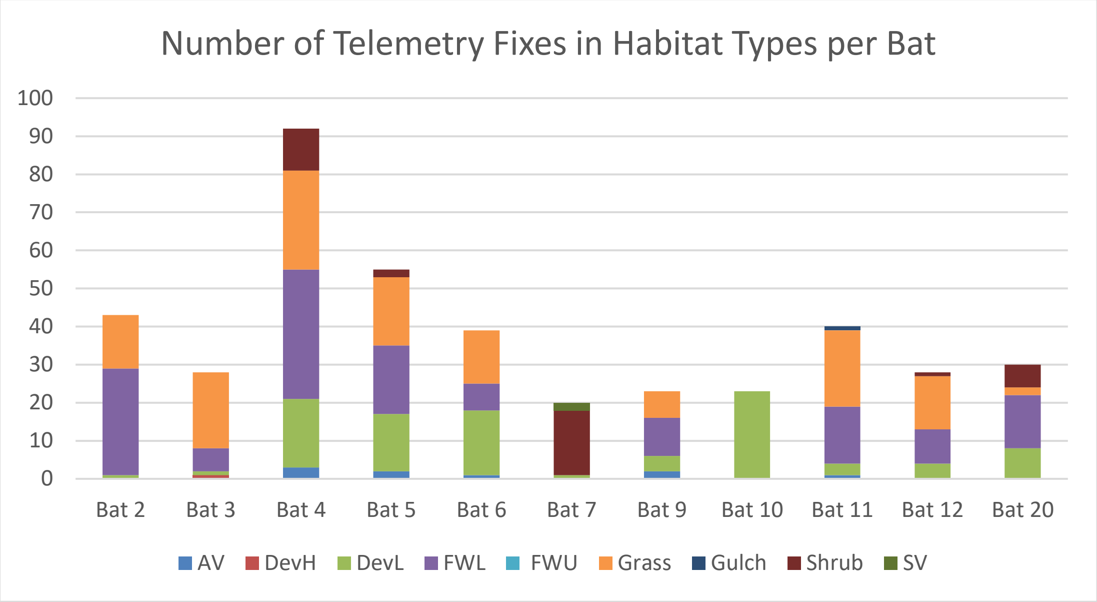

Figure 18. Number of Telemetry Fixes within Habitat Types per Bat.

Each bar represents the habitats used by each radio-tracked bat based on the telemetry fixes occurring in respective habitat types. Except for winter months, notice the similarities among bats caught in the same season. Bats 2 and 3 were radio-tracked during the summer of 2017; Bats 4, 5, and 6 were radio-tracked during the fall of 2017, Bats 7, 9, and 10 were radio-tracked during the winter of 2017-2018, Bats 11 and 12 were radio-tracked during the spring of 2018 and Bat 20 was radio-tracked during the fall of 2018. Appendix G provides each bat's telemetry fixes superimposed upon habitat maps with mean calls per night per habitat for the respective month each bat was radio-tracked.

We attempted multinomial logistic regression to predict habitat choice by bat, but that given the high number of habitat types and the relatively low number of samples, the model accuracy was only about 43%. However, Figure 18 provides a summary graph to show each bat's habitat use and the similarities among bats caught within the same season. Except during the winter season (Bats 7, 9, and 10), each season's bats use similar habitats. For example, Bats 2 (tracked in July) and 3 (tracked in August) spent most of their time in grasslands and forest woodland low elevation (which we believe represents gulches). Their CUAs do not overlap, but their FRs intersect. Bats 4 and 5 (both tracked in September) and Bat 6 (tracked in early October) show similar habitat use with forest woodland low elevation, grassland, and low-density developed as their primary habitats. Bat 7 was tracked in January and almost exclusively spent time in shrubland habitat found at high elevations (greater than 2,000 meters). Bat 9 was tracked in February and based on field observations and locations of fixes, spent most of its time in gulches; however, the fixes indicate the edges of the forest and woodland low elevation habitat. Bats 10, 11, and 12 were tracked in March but Bat 10 (tracked in early March) flew almost exclusively in low-density developed. Bats 11 and 12 were tracked in mid-March and late March, respectively, and foraged primarily in grassland, forest woodland low elevation (gulches) with less time foraging in low-density developed habitat. Bat 20 was tracked in September and used mostly forest woodland low elevation (gulches), low-density developed, and shrubland habitats. Appendix G provides the FR and CUA for each radio-tracked bat showing the distribution of fixes superimposed on the habitat map. Appendix G provides the FR and CUA with each bat's telemetry fixes superimposed upon base habitat maps with mean calls per night per habitat for the respective month each bat was radio-tracked. For example, Appendix G Bat 7 shows most of the telemetry fixes superimposed against the habitat map colored according to the mean calls per night for January 2018; Shrubland habitat had a mean of 13.5 calls/night and Forest Woodland Upper had a mean of 45 calls/night.

On October 1, 2017 between 6:02 p.m. and 6:06 p.m. a foraging bat that was about 25 meters above ground and presumed to be Bat 5, dive-bombed another bat three separate times as the second bat was commuting through the airspace. Physical contact between the two bats was not observed, although that same evening several bats were observed simultaneously within the same small area. The transmitter had just fallen off of Bat 5, so we could not determine whether both bats were males. However, the edges of the foraging ranges for Bat 5 and Bat 6 were close to the site of the observation and they were caught just 10 days apart. Both foraging ranges represent mostly low-density developed habitat. The two males had enlarged testis and well-developed spines on their penises, which are indicators of sexual maturity. The bats' FAs were from 0 to 0.89 kilometers apart for a distance of 11.4 kilometers, which suggested they may have been defending territories. This behavior was also mentioned in the telemetry study of hoary bats on the island of Hawaiʻi (Bonaccorso et al. 2015). The FAs for females and other males overlap considerably and do not suggest any separation of CUAs.

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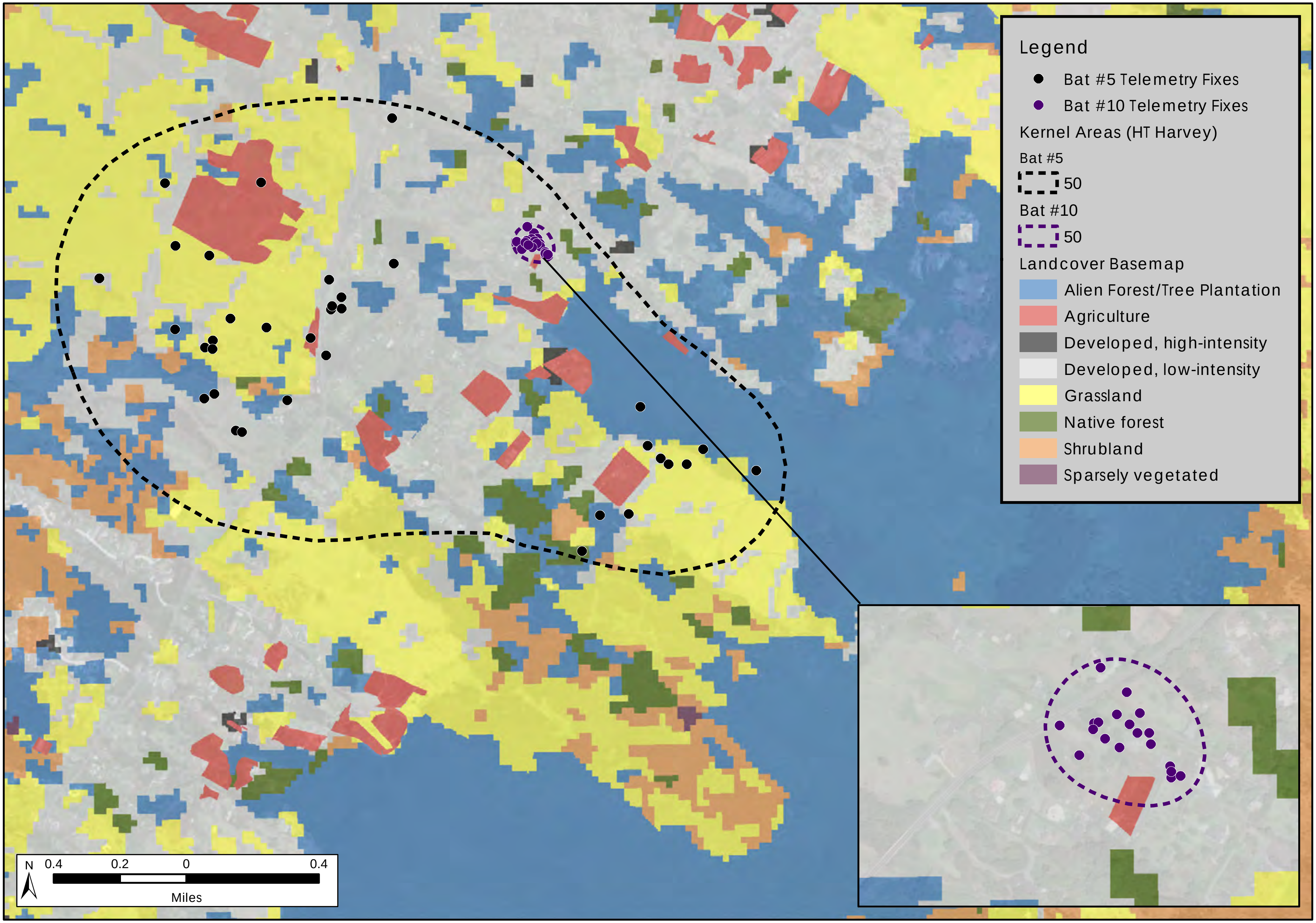

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Figure 19. 50% Kernel Areas for Bat #5 and Bat #10
Ecology of the Hawaiian Hoary Bat (3978-01)
April 2020

3.3 Diet: Insect Sampling, DNA Extraction from Guano Samples, and DNA Barcoding

During the 2017 and 2018 period of acoustic monitoring and radio telemetry, a total of 63 samples (9 habitats sampled every other month over a fourteen-month period) of insects were collected from within the study area. Additionally, guano samples were collected from approximately half of the bats captured (summer = 9, winter = 2). The majority of guano samples were collected from adult males (n=7), followed by adult females (n=2) and subadult females (n=2). Bats ate primarily moths although a small percentage of Orthopterans, coleaopterans, and isoterans were also eaten (Figure 17). The identification of insects in samples from habitats and the DNA barcoding of prey fragments found in guano samples was conducted in 2019.

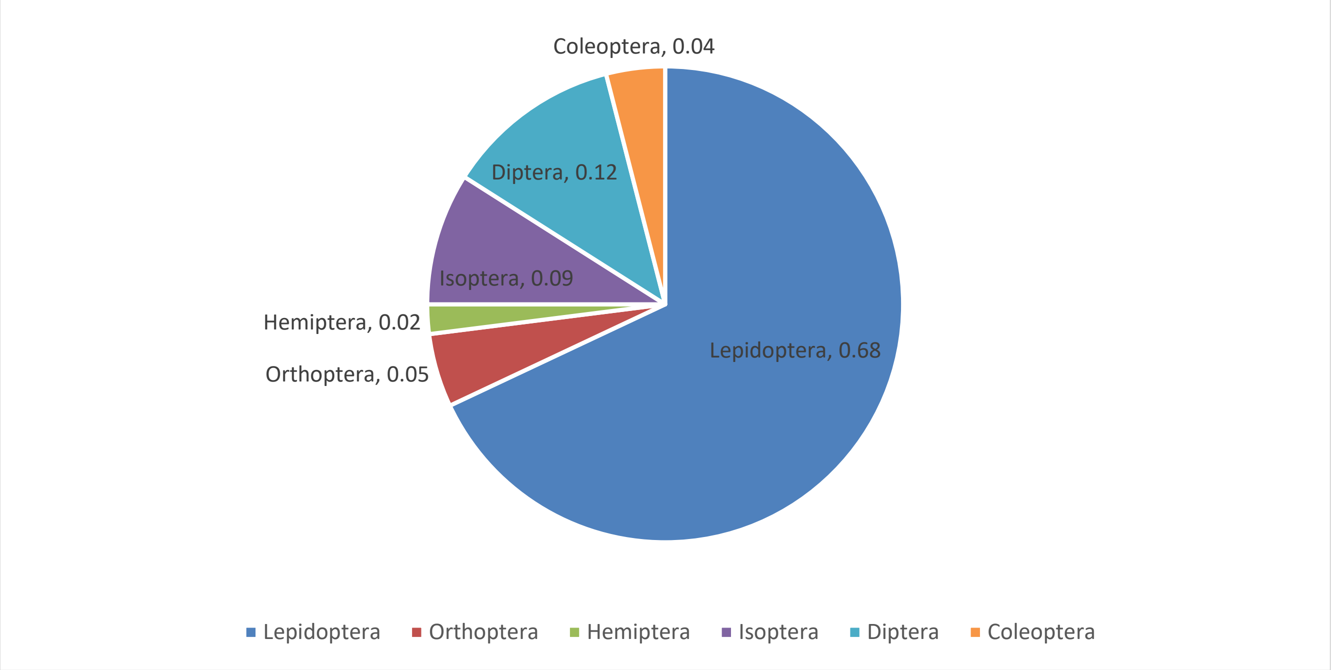

Figure 20. Percentage of Prey Items by Order for 11 Bats.

Percentages based on pooled data for numbers of species identified for each bat based on DNA extractions recovered from COI and 16S Data from 11 fecal samples. Table 6 provides a summary of the recovered COI and 16S data from these fecal samples.

3.3.1 Species based on DNA Extraction from guano samples

COI Data. We recovered sequences from 22 PCR reactions and pooled these to correspond to 11 fecal samples (Table 5). Negative PCR controls contained less than 200 reads and any identification was made with fewer than 30 assigned reads. Positive controls (mock communities) were analyzed and in these known mixes any identification with less than 200 reads was flagged as generating a false positive. Based on negative and positive controls we retained identifications with more than 200 assigned reads for further consideration and excluded those which did not meet these criteria (insufficient data). The vast majority of insects were moths including

Athetis thoracica, Peridroma saucia and *Perpetogramma licarsisalis* that were identified in five of the eleven guano samples while *Melipotis indomita* and *Mythimna unipucta* were found in three of the guano samples.

16S Data. The 16S reference data was very limited. As a consequence sequence identification was limited and made at a variety of taxonomic levels including a few noctuid and crambid moths. However, the 16S data identified other insect orders that were not identified by the COI data, namely Diptera including short palped crane flies (Limoniinae), blow flies (Calliphoridae), Isoptera including the termites Zootermopsis and Neotermes, and Orthoptera including field crickets (Gryllus) and katydids (Tettigoniidae). The introduced dung beetle (Digitonthophagus gazella) was also identified only in the 16s data.

Table 6. A summary of the Recovered COI and 16S Data from 11 Fecal Samples.

Sample	Reads[1] COI Data	Taxa Order	Taxa Identified	Geographic Agreement	Element or Vegetation
Bat 1	310000	Lepidoptera	*Herpetogramma licarsisalis*	Yes	grasses
		Lepidoptera	*Omiodes continuatalis*	Yes	grasses
		Lepidoptera	*Melipotis (indomita)*	Yes	*Prosopis*
		Lepidoptera	*Athetis (thoracica)*	Yes	generalist
		Lepidoptera	*Elaphria (nucicolora)*	Yes	generalist
		Lepidoptera	*Peridroma saucia*	Yes	generalist
		Orthoptera	*Trigonidomorpha sjostedti*	Yes	generalist
		Diptera	Tipulidae, Limoniinae*	Yes	freshwater detritus
		Isoptera	Neotermes*	Yes	wood
		Orthoptera	Tettigoniidae*	Yes	generalist
Bat 4	333900	Lepidoptera	*Herpetogramma licarsisalis*	Yes	grasses
		Lepidoptera	*Athetis (thoracica)*	Yes	generalist
		Lepidoptera	*Cryptophlebia illepida*	Yes	generalist
		Orthoptera	*Trigonidomorpha sjostedti*	Yes	many, incl. *Acacia koa*
		Diptera	Tipulidae, Limoniinae*	Yes	freshwater detritus
		Isoptera	*Zootermopsis**	Yes	wood
Bat 5	228394	Lepidoptera	*Herpetogramma licarsisalis*	Yes	grasses
		Lepidoptera	*Melipotis*	Yes	*Prosopis*
		Lepidoptera	*Peridroma saucia*	Yes	generalist
		Orthoptera	*Gryllus*	Yes	generalist
Bat 6	493882	Lepidoptera	*Herpetogramma licarsisalis*	Yes	grasses
		Lepidoptera	*Athetis (thoracica)*	Yes	generalist
		Lepidoptera	*Mythimna unipuncta*	Yes	generalist
		Diptera	Calliphoridae*	Yes	carrion and/or dung
		Diptera	Tipulidae, Limoniinae*	Yes	freshwater detritus
Bat 10	437496	Lepidoptera	*Hadenine*	Yes	generalist
		Lepidoptera	*Mythimna unipuncta*	Yes	
		Lepidoptera	*Peridroma saucia*	Yes	generalist

Sample	Reads[1] COI Data	Taxa Order	Taxa Identified	Geographic Agreement	Element or Vegetation
		Diptera	Calliphoridae*	Yes	carrion and/or dung
Bat 11	324361	Lepidoptera	*Hadenine*	Yes	
		Lepidoptera	*Mythimna unipuncta*	Yes	generalist
		Crambidae	*Spoladea (recurvalis)**	Yes	generalist
Bat 12	249839	Coleoptera		Yes	
		Lepidoptera	*Herpetogramma licarsisalis*	Yes	grasses
		Lepidoptera	*Athetis (thoracica*)	Yes	generalist
		Hemiptera	*Nezara viridula*	Yes	generalist, esp. legumes
		Lepidoptera	*Opogona sacchari*	Yes	generalist
		Lepidoptera	*Cryptophlebia illepida*	Yes	many, incl. *Acacia koa*
		Orthoptera	*Trigonidomorpha sjostedti*	Yes	generalist
		Coleoptera	*Digitonthophagus gazella**	Yes	dung
		Hemiptera	*Nezara viridula**	Yes	generalist
		Isoptera	*Neotermes**	Yes	wood
		Orthoptera	Oedipodinae*	Yes	generalist
		Orthoptera	*Gryllus**	Yes	
Bat 15	252774	Lepidoptera	*Herpetogramma licarsisalis*	Yes	Grasses
		Lepidoptera	*Melipotis*	Yes	*Prosopis*
		Lepidoptera	*Mompha*	Yes	Melastomataceae (expected)
		Lepidoptera	*Athetis*	Yes	generalist
		Orthoptera	*Chrysodeixis (eriosoma)*	Yes	generalist
		Orthoptera	*Euconocephalus**	Yes	generalist
		Orthoptera	*Trigonidomorpha sjostedti**	Yes	generalist
		Isoptera	*Neotermes**	Yes	wood
		Orthoptera	Tettigoniidae*	Yes	generalist
Bat 17		Diptera	Limoniinae*	Yes	freshwater detritus
		Isoptera	Neotermes*	Yes	wood
Bat 18	264369	Lepidoptera	*Cryptophlebia illepida*	Yes	many, incl. *Acacia koa*
		Diptera	Limoniinae*	Yes	freshwater detritus
		Isoptera	*Neotermes**	Yes	wood
Bat 20	311665	Hemiptera	*Gyponana*	Yes	plant sap
		Lepidoptera	*Peridroma saucia*	Yes	generalist

[1] Reads refers to the number of sequences retained for analysis, taxa identified is the genera and species identified by strict match to reference collections. Geographic agreement is a refinement based on which taxa are likely to be found in the sample area. Species determined by DNA barcoding but not known to occur in Hawaiʻi (e.g., *Pleuroprucha*, *Agrotis infusa*) were omitted. Species with an asterisk were determined by 16S; all others were determined by CO1. Species names in parentheses are the only Hawaiian representative of genera determined by DNA barcoding; thus, these species were not determined by DNA barcoding but rather, are provided here as the only known geographic representative of these genera.

3.3.2 Availability of Prey – Modelling of Dry Weights of Insect Samples by Habitat and Month

Differences among habitats. Raw data from the dry weights of insect samples suggest significant differences among habitats for the samples collected from August 2017 through August 2018 (Figure 21).

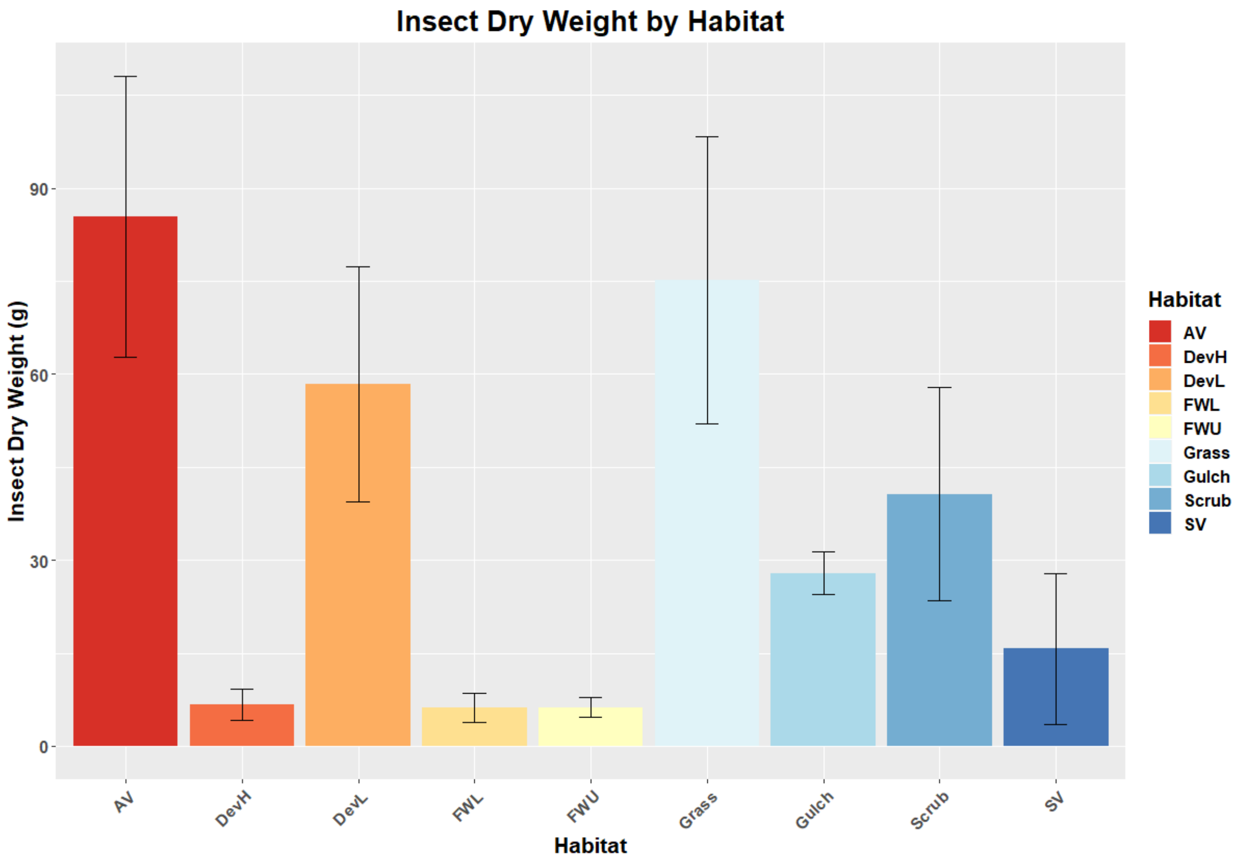

Figure 21. Raw Data for the Dry Weights in Grams of Insect Samples in Nine Habitats from August 2017 through August 2018.

Bars show means and whiskers are one standard error of each mean. AV = Agricultural Vegetation, DevH = High Density Developed, DevL = Low Density Developed, FWL = Lower Forest Woodland, FWU = Upper forest Woodland, Grass = Grassland, Scrub = Scrubland, and SV = Sparse Vesicular rock.

These values are different from model estimates shown in the below Figure 22 which has adjusted for the mean estimates based on the variance in the model and accounting for overdispersion in the dataset. The difference being that Model Estimates (Figure 22) are back-transformed from the log scale because the negative binomial regression (glm.nb) uses a log function, so the estimates on the response (i.e., measured) scale, have to be back-transformed while the statistical analyses are run on logged responses.

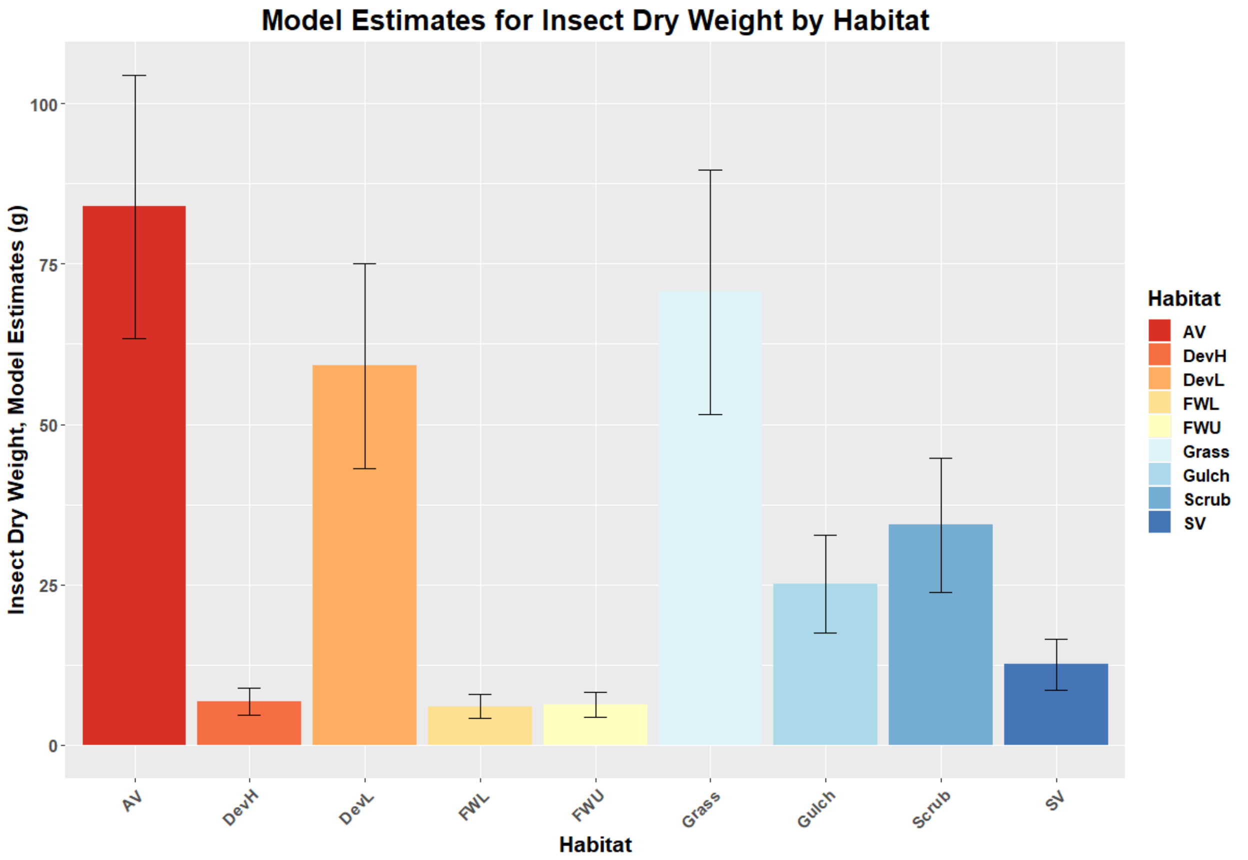

Figure 22. Model Dry Weights of Insect Samples by Habitat.

Bars are mean estimates, and whiskers are 95% confidence intervals generated from contrasts. AV = Agricultural Vegetation, DevH = High Density Developed, DevL = Low Density Developed, FWL = Lower Forest Woodland, FWU = Upper forest Woodland, Grass = Grassland, Gulch = Gulch, Scrub = Scrubland, and SV = Sparse Vesicular rock.

Modelling results (Tukey, 0.95 confidence; α = 0.05 significance level) indicate that it is reasonable to conclude that there are significant differences between some habitat types (Table 7).

Table 7. Pairwise Comparisons of Habitat Types at Alpha = 0.05.

Habitat Types with Significantly Greater Dry Weights of Insects	Habitat Type(s) with Significantly Less Dry Weight of Insects
DevL, Grass, AV, Gulch, and Scrub	FWL and FWU
Scrub, DevL, Grass, and AV	DevH
DevL, Grass, and AV	SV

AV = Agricultural Vegetation, DevH = High Density Developed, DevL = Low Density Developed, FWL = Lower Forest Woodland, FWU = Upper forest Woodland, Grass = Grassland, Gulch = Gulch, Scrub = Scrubland, and SV = Sparse Vesicular rock.

Differences among months. We could not detect significant differences between months sampled for the dry weights of insect samples. This is not to say that there are not differences between months. However, because of a few missing data, relatively small differences in the raw data, large variances, along with small sample size (maximum of one sample per month collected in each habitat type), it is likely impossible to discern differences.

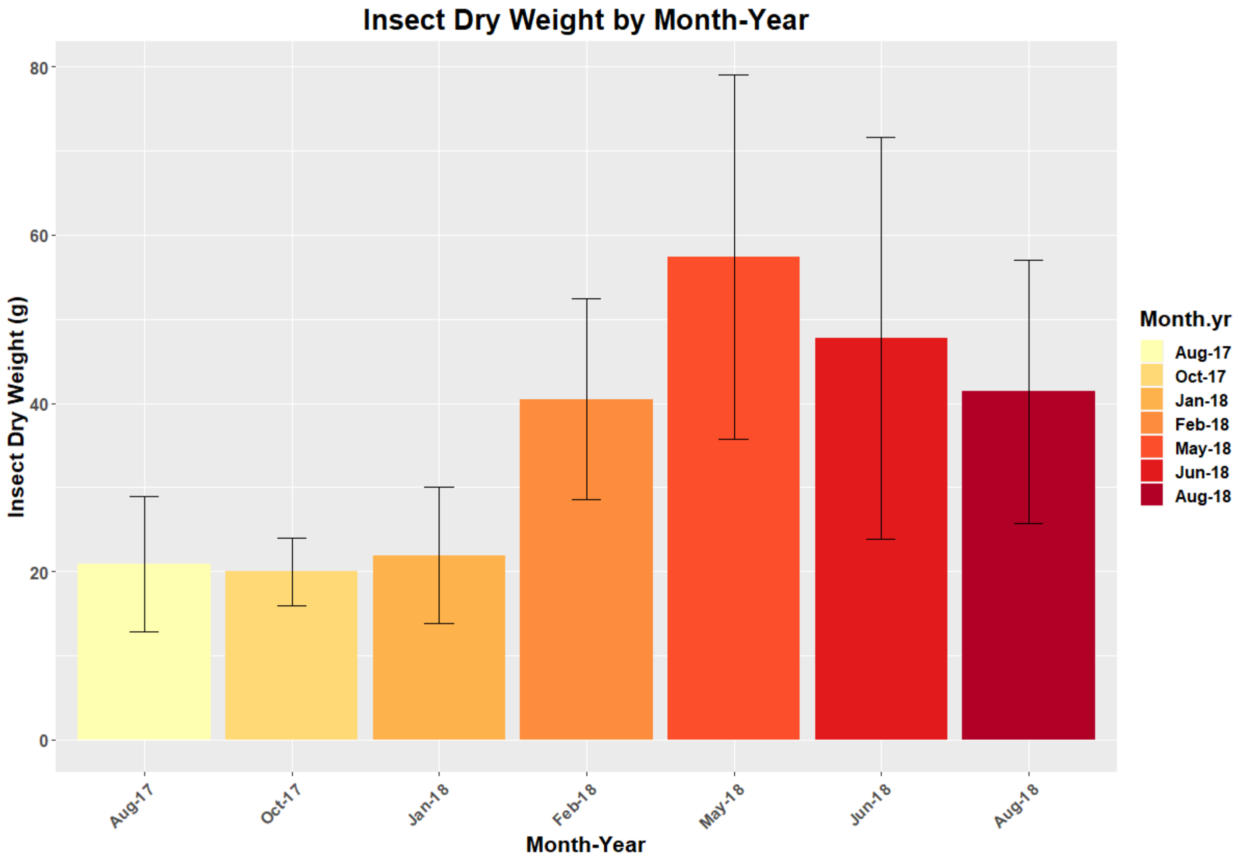

Figure 23. Raw Data for Dry Weights of Insect Samples during Seven sampling Months from Nine Habitat Types.

Bars show means and whiskers are one standard error of each mean.

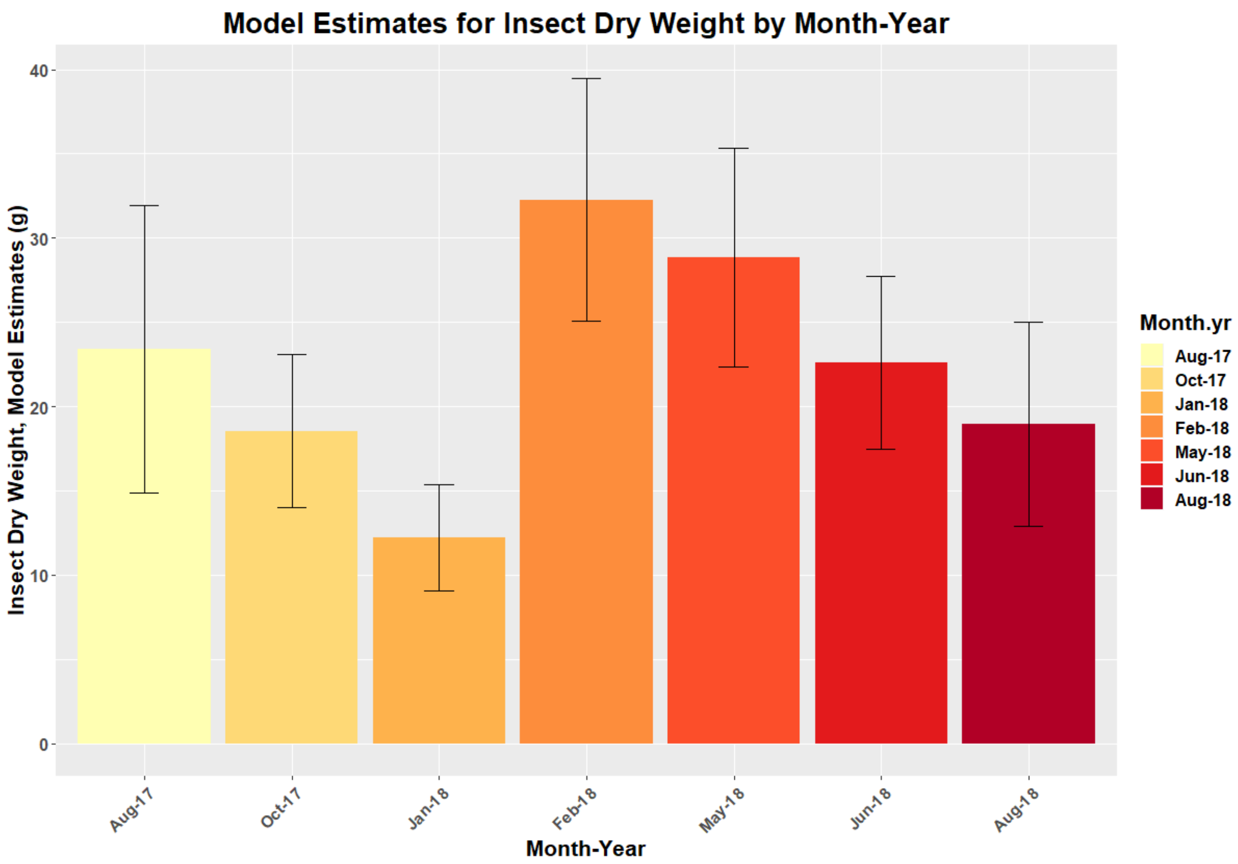

Figure 24. Modelled Dry Weights of Insect Samples by Month.

Values are adjusted based on the model, which calculates mean estimates on the basis of variance and other factors in the model and accounts for overdispersion in the dataset. Bars are mean estimates, and whiskers are 95% confidence intervals generated from contrasts.

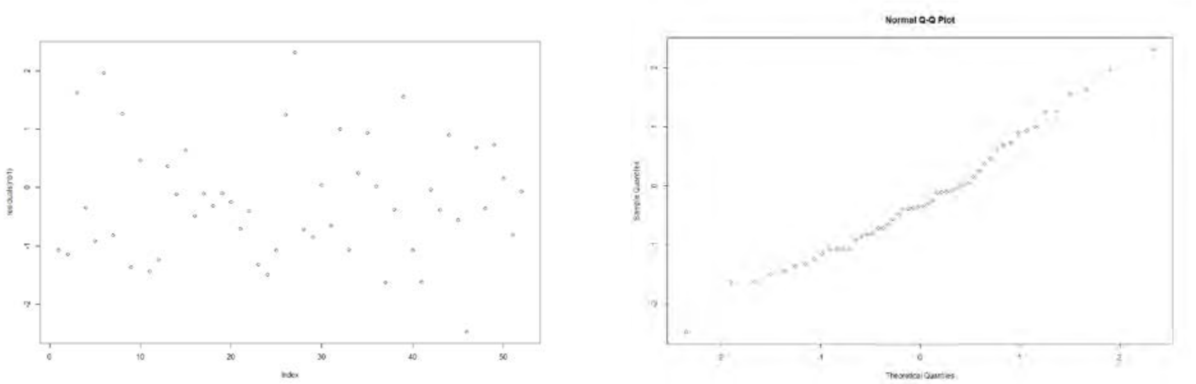

Figure 25. Distribution of Model residuals (Shapiro test, W = 0.99) (Left)
Model Qqnorm Plots Showing a Strong Positive Relationship. (Right)

We inspected the residuals factor (i.e., month and habitat type) and no evident patterns emerged, suggesting a valid model. When investigating residuals by habitat type and month, the residual spread is now much more homogeneous, which is an assumption of this model approach. A Shapiro test was applied to test for normality of the model residuals, and the results indicate that the residuals are normally distributed (W = 0.98, assumed normal because this value is greater than 0.95). The residuals appear to be sufficient and the fitted values plot looks good with no evident patterns. This finding is important because the residuals from the model fits should not be changing systematically in relation to a predictor in the model (this would be a violation of model assumptions). The fitted values (model estimates) plotted by the raw (actual) data have a strong, positive relationship, indicating good agreement between the model estimates and the actual data; this is also important for ensuring adequate model fit.

Appendix H provides the model output, model estimates (mean, standard error, and confidence interval), and the significant differences in dry insect weights between habitats and months.

Appendix I provides a list of species identified from samples

Correlation between Bat Activity and Dry Weights of Insect Samples. We could not examine interactions between bat activity per habitat and dry weights of insect samples per habitat because we collected only a single sample of insects in each habitat for each sample month. Further, several samples were missing because of collection difficulties due to storm events.

Section 4. Discussion

Bats primarily used gulches, grassland, and low density developed habitats. Gulches as a habitat for the Hawaiian hoary bat were unrecognized before this study as an important habitat feature for foraging although acoustic studies at Kawailoa Wind Farm on Oahu suggested that bats use gulches along with surrounding habitats (H. T. Harvey & Associates 2015). Further, base maps used for habitat investigations before this study did not separate gulches as a unique habitat. Bonaccorso et al. 2015 and Gorreson et al. 2013 encorporated gulches into the adjacent habitats (e.g., the wide gulches adjacent to native forests in Bonaccorso et al. 2015 were simply characterized as native forests). Thus, these earlier studies would likely have been shown gulches as an important habitat if the authors had separated out this geological feature. Because of our initial observations of bats concentrating inside gulch habitats of Maui, we separated these geographic areas out as a separate habitat type. Our initial observations suggested that bats were using gulches adjacent to all other habitat types. Because trade winds typically blow perpendicular to the gulches in our study area, these areas provide flying insects protection from the wind. We believe the concentration of bat activity and foraging in gulches is therefore likely because of the concentration of flying insects that find refuge from the wind, such as described by Verboom and Huitema (1997).

Based on the acoustic data, and suggested by the telemetry data, bats also spent significantly more time in grasslands, especially during the months of May through September, than most other habitats. Additionally, Bats 1, 2, 3, 4, 5, 6, 12, and 15 had all consumed the tropical webworm, *Herpotogramma licarsisalis*, an introduced moth specialized on grasses as their host species. Other bats, Bats 7, 8, 10, 11, and 12, were all caught early in the year (January through March) and did not have any evidence of this moth in their fecal pellets, possibly because their capture time was before this moth typically matured as an adult making it mostly unavailable as prey. Although we did not have enough samples of pastures to treat these as a subset of the grasslands, many pastures had high levels of bat activity based on acoustic data. In this study for Bat 12 and in Pinzari et al. (2019) the introduced African dung beetle (*Digitonthophagus gazella*) was also identified as a prey type and is found in active pastures throughout much of Hawaii. Additionally, the blow flies (Calliphoridae) that we found in guano from bats 6 and 10 may have also come from dung in pastures.

Low density development had significantly higher levels of bat activity based on our acoustic and telemetry data. Bats 4, 5, and 6 were caught in September and October, Bat 10 was caught in late March, and all show large portions of their time in low density development. We also found that these low density development habitats in the semi-rural communities surrounding Makawao and Kula had the second highest levels of insect mass based on our insect sampling. These areas were generally open and had a high diversity of nonnative plants and invertebrates likely providing ample prey bases. Schlaepfer (2018) suggested that some areas of nonnative introduced plants and animals, particulary in areas with cultivated landscapes, often have a richer species diversity than neighboring native habitats. We are not suggesting that the low density developed areas had higher biodiversities than native areas of Hawaii, but we are suggesting that this rural anthropogenic habitat is rich in biodiversity with high densities of insects and that bats appear to take advantage of this habitat within our study area.

For most months we found that bats spent significantly less time in forested habitats (forest woodland low and forest woodland upper) than any of the other seven habitats. We did not separate native forests from non-native forest because there were too few locations of native forest habitat where we could install bat detectors. Both forest habitat types (forest woodland lower and forest woodland upper) in our study area were composed of mostly nonnative forests. Nonetheless, native forests occurred and bats used native forests more than expected given the scant percentage of native forests. Of the forest woodland telemetry data, 81% of detections were over non-native forest lands as opposed to the 19% of detections over native forest lands while less than 10% of the forest habitat areas were native. Additionally, low density development, grassland, agricultural vegetation, gulch, and scrubland habitats all had significantly higher amounts of dry weights of insects compared to the forest habitats, and we observed very few moths and other flying insects in these nonnative forests while mist netting there. Figure 26 illustrates a monoculture mature Monterey pine (*Pinus radiata*) forest woodland low elevation habitat with little understory and low productivity for insects and bat activity. Monterey pine was one of several monotypic species of forest types found in forest woodland low elevation and forest woodland upper elevation habitats. We occasionally observed bats flying over forests, but these bats did not typically forage based on the limited circling behavior observed.

Figure 26. Monotypic Monterey pine stands within the forest woodland low elevation habitat.

Little understory occurred in monotypic Monterey pine habitat as well as in other monotypic species forested woodland low elevation and upper elevation areas. Such areas had significantly lower dry weights of insects and bat activity based on acoustic monitoring.

Unlike the acoustic data, habitat data derived from the radiotelemetry fixes suggests that bats spent significantly more time in forest woodland low elevation than in gulches. In fact, the gulch habitat type had only a single fix data point despite the acoustic data suggesting that it is an important habitat for the Hawaiian hoary bat. We found that the bats were typically undetectable with the radiotelemetry receiver when they were inside these deep gulches; however, individuals were detectable when they reemerged and flew over or through the forest woodland low elevation habitat between gulches. Most of the radiotelemetry fixes in the forest woodland low elevation habitat were situated at the edges of gulches and between gulches that were relatively close together. Further, gulches produced significantly more insects based on the dry weights of insects sampled at these habitats. Because gulches appear to provide an important habitat for the Hawaiian hoary bat on Maui, and because gulches tend to be less developable because of their steep terrain, we believe this habitat could play an important role in the conservation of habitats for this species.

Shrubland, occurring primarily at altitudes greater than 2,000 meters, appears to be an important habitat during winter months based on the acoustic data and telemetry data for habitat use. Bat 7 used these high altitude shrublands almost exclusively in February and forest woodland upper, also above 2,000 feet, had significantly higher acoustic activity in January. Thus, based on our acoustic and telemetry data, the importance of a specific habitat appears to change through seasons.

Based on bats' acoustic activity and telemetry fixes, suitable foraging habitat appear to be quite patchy in space and bats did not use several habitat types (e.g., development high density) much during most months of the year. Further, the prey availability based on the dry weights of insect samples suggest that prey were not equally available amoung habitats found in our study area or within a bat's FR. Because hoary bats regularly flew many kilometers every evening, and over some habitat types that were not primary habitats for bats, suggesting that certain habitats were not used, and not likely productive for foraging. Thus some habitats on Maui, such as developed high density and forest woodland low elevation habitats could be limiting factors for the species because of a paucity of insect prey, as in the case of Monterey pine forests.

In our study, bats clearly spent most of their time while foraging and commuting in primarily three habitat types, namely grassland, developed low density, and gulches but activity values and significance change for different seasons. Earlier studies of the Hawaiian hoary bat also suggest that this species uses not only native forests, but also eucalyptus plantations having mixed understories of trees and shrubs, suburban and urban areas with ornamental trees, grasslands, pastures, gorges, macadamia nut orchards and coastal bluffs (Tomich 1986; Jacobs 1993, Gorresen et al. 2013 and Bonaccorso et al. 2015. Thus, the habitats bats used in our study are not much different than habitats on other islands. The Bonaccorso telemetry study includes large areas of native forests which the bat has presumably evolved and adapted to. Thus it makes sense that the bats associated with native forests will tend to have smaller CUAs and FRs.

Alien habitats like some of the forest woodland low elevation habitats could be managed to include open areas with grassland to increase habitat for the Hawaiian hoary bat. Such open areas within forests appear to be productive foraging areas for the bat (Bonaccorso 2015) and lanes cut into the forest have also improved foraging opportunities. The cutting of lanes at the Ukoa Wetland designed by H. T. Harvey & Associates (2013) has significantly increased the bat occupancy of that restoration site based on preliminary data collected by TetraTech, Inc. (Christopher Todd, pers. comm.).

We totaled 92 nights of radio-tracking and had a total of 755 triangulated fixes to determine kernel analyses for home range sizes. Many fixes were not used when the timing of the bearings did not occur within one second of each other, could not be verified, or were from bats with less than 25 fixes. Further, we conservatively used only one telemetry position fix per three-minute periods to ensure independence of points while Bonaccorso et al. (2015) allowed for all positional points. Although our location data are fairly accurate, the number of nights we collected data on bats was quite small to be representative of the full range of their movements, even within a single season. Yet, even in this very brief monitoring period, we detected numerous long-range movements of approximately 16 kilometers. A limitation of using only two observers for bats that can fly fast (likely 60 miles per hour or more [Swartz pers. comm. 2019]) and use large home ranges is that it's often difficult to always have both observers at different wide angles to the bats to ensure accuracy. However, angles between observers less than 15 degrees were not used because fixes lose accuracy as bearings begin to converge. In such cases we did not include fixes and the lack of fixes in those instances would underestimate our home ranges. When compared to CUAs determined on the island of Hawai'i (Bonaccoso et al. 2015) our kernel analysis for Maui bats suggests CUAs averaged many times the size. Because of huge differences in mean sizes for the FRs and CUAs, we reanalyzed our data using the same parameters and smoothing values used for the telemetry data in the Bonaccorso et al. 2015 paper. As indicated in our results, and through this second analysis of our data, our kernel analyses averages of the Maui bats were slightly smaller but not consistently so. The telemetry study on Hawai'i was designed to require only one observer to collect data, and was also designed to limit the potential distance from the observer to the bat at 300 meters at which an error could occur. This limitation may have introduced a bias toward underestimating the distance between observer and bat and made it impossible to obtain a point on a bat further away than the maximum calibration distance of 300 meters.

Bats' CUAs described in the Bonaccorso et al. (2015) had much smaller areas that didn't typically overlap with each other whereas the bats in our study generally had much larger and more complex CUAs and FRs. At first glance, the bats in our study appear to have overlapping CUAs. However, when actual fixes within the CUAs, male bats do not typically overlap areas as was shown in the CUAs for Bats 5 and 10. Thus, male bats tended to separate their CUAs although sometimes at a fine scale. The bats in Bonaccorso et al. 2015 likely foraged in habitats with higher densities of prey whereas the bats in our study likely foraged in more separate patches scattered throughout what was descriped as the bats CUA and FR areas. When you examine the fixes of a given bat in our study, bats often foraged in one area and then flew over fairly large areas to then again forage and so on; taking advantage of heterogeneous habitats by selectively foraging in specific patches.

We believe this difference in mean sizes for FRs and CUAs could be due largely because the habitats bats used on the island of Hawai'i are quite different; the habitats for the Bonaccorso et al. (2015) study included more native vegetation and bats there may have foraged on higher densities of insects. This would reduce the amount of time and space needed for bats to forage. Several other studies suggest bats' foraging ranges and core use areas vary enormously between different geographic areas. For example, the core use areas for the Indiana bat (*Myotis sodalis*) was 145 hectares in Illinois (Menzel et al. 2005) and 1,137 hectares in Missouri (Womack et al. 2013). A sister taxon to hoary bats, the eastern red bat (*Lasiurus borealis*), had a mean core use area of 94 hectares in Mississippi (Elmore et al. 2005) and 1,357 hectares in Missouri (Amelon et al. 2014), a factor of over 14 times the size. Both in this study and in the Bonaccorso et al. 2015 study, mean CUAs and FRs were highly variable with a couple of outliers.

Bats appear to explore new areas, investing a certain percentage of their time explore new areas as a part of their routine. For example Bar 4 foraged primarily in developed low density habitats but then also spent time in shrub habitats at a higher elevation area, inside Haleakala Crater about 8 km away, and then in grassland about 16 km away from the center of its CUA, possibly as an exploratory behavior to discover new patches of prey.

We found that the Hawaiian hoary bat ate both native and nonnative insects. We also found that bats on Maui ate primarily moths, and rarely beetles, in contrast to bats on the Island of Hawaii that appeared to rely more on beetles at middle and lower elevations (Todd 2012). This study suggests that grassland habitat produces moths that are frequently eaten by the Hawaiian hoary bat, although some commonly found species of moths in our insect samples (e.g., native moths *Schrankia* sp. and *Orthommecyna* sp. of the same size as moths that were eaten) were not observed in the diets of bats for this study. This suggests bats were selective in their feeding habits, but our sample size of guano was comparatively small, and more samples should be analyzed for species contents before determining if bats showed preferences for prey species.

The changes in habitat use over time, the differences in home range sizes, and diets of bats between different Hawaiian Islands strongly suggests foraging flexibility in this species. We found that several commonly occurring habitats on Maui proved to be unproductive for the Hawaiian hoary bat. That said, we believe these habitats are limiting factors for the Hawaiian hoary bat on Maui. In particular, the alien forest woodland at low and upper elevations, could be used for restoration sites to improve and increase the amount of foraging habitat for this species. At a minimum, lanes and other clearings could be developed in these forests to provide better physical structure for foraging behavior. Further, these lanes and forest clearings should be planted with native grasses and shrubs that support moths commonly eaten by bats.   Other habitats, such as grassland habitat that produces numberous species of prey, could be augmented by clusters of appropriate native trees to improve upon the physical structure of the foraging habitat as well as provide potential roost trees.

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Appendix A. Parameters and Documentation for Kernel Analysis Method

1. Kernel Density Analysis (as per methods in Bonaccorso et al. 2015 p)

```
Start Time: 2/12/2020 3:37:43 PM
Input Data: CombinedFlyBats2020
Unique ID Field: Bat_id
Independence of observation indices:
System.Windows.Forms.ComboBox, Items.Count: 3, Count, Schoener, Swihart_Slade
2, 45, 0.5895, 0.25481
3, 28, 0.21031, 2.07054
4, 92, 0.53101, 2.48472
5, 55, 0.79848, 0.46162
6, 40, 1.18853, 0.51884
7, 25, 2.22128, -0.04386
9, 23, 0.87042, -0.0744
10, 23, 1.45613, 0.47087
12, 28, 0.73153, 1.77266
20, 32, 1.05162, 1.7071


Variances of x and y coordinates:
System.Windows.Forms.ComboBox, Items.Count: 3, Count, StdDev_X, StdDev_Y, Ratio(x:y)
2, 45, 707.68, 867.07, 0.82
3, 28, 5830.01, 1959.62, 2.98
4, 92, 2898.63, 3703.53, 0.78
5, 55, 1703.09, 1047.46, 1.63
6, 40, 1673.64, 922.23, 1.81
7, 25, 1265.22, 1390.46, 0.91
9, 23, 2752.8, 2530.32, 1.09
10, 23, 120.51, 66.54, 1.81
12, 28, 3893.36, 2604.4, 1.49
20, 32, 4311.18, 5567.71, 0.77


Kernel Settings
Kernel type: fixed
Bandwidth estimator: LSCV
Output Folder: N:\Projects3900\3978-01\shapefiles\Homerange\Telemetry_HRT_outputs
Raster Prefix name: kde
Raster Cell Size: 10
Scaling Factor: 10
Extent Setting: Full
Isopleths: 95, 50 (lines polygons  donuts )/n/nCase specific settings
Unique ID: 2
Sample Size: 45
Bandwidth: 462.843011245185
```

```
HREF (for reference): 419.621950358283
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde0
Kernel calculated successfully.
Volume: 9.99882822764607/10
Unique ID: 3
Sample Size: 28
Bandwidth: 222.123753795937
HREF (for reference): 2495.7725145611
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde1
Kernel calculated successfully.
Volume: 9.99876343723856/10
Unique ID: 4
Sample Size: 92
Bandwidth: 1009.14433185872
HREF (for reference): 1565.17151121943
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde2
Kernel calculated successfully.
Volume: 9.99875092294746/10
Unique ID: 5
Sample Size: 55
Bandwidth: 410.884557797558
HREF (for reference): 724.983780851449
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde3
Kernel calculated successfully.
Volume: 9.99881358658858/10
Unique ID: 6
Sample Size: 40
Bandwidth: 734.678314602725
HREF (for reference): 730.659686327921
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde4
Kernel calculated successfully.
Volume: 9.99874190209491/10
Unique ID: 7
Sample Size: 25
Bandwidth: 1016.6272740778
HREF (for reference): 777.386560181841
Bandwidth represents minimized LSCV
```

```
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde5
Kernel calculated successfully.
Volume: 9.99875121053928/10
Unique ID: 9
Sample Size: 23
Bandwidth: 2249.01245292563
HREF (for reference): 1567.80233734794
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde6
Kernel calculated successfully.
Volume: 9.99874252152107/10
Unique ID: 10
Sample Size: 23
Bandwidth: 37.2154834100862
HREF (for reference): 57.7207962932706
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde7
Kernel calculated successfully.
Volume: 9.99874878761319/10
Unique ID: 12
Sample Size: 28
Bandwidth: 1900.7367737047
HREF (for reference): 1900.7367737047
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde8
Kernel calculated successfully.
Volume: 9.99875282550947/10
Unique ID: 20
Sample Size: 32
Bandwidth: 2401.17823517117
HREF (for reference): 2794.50478344041
Bandwidth represents minimized LSCV
Columns, Rows:4208, 4755
Origin of the Raster (lower left x,y): 756076.7633, 2275647.189
Raster name: kde9
Kernel calculated successfully.
Volume: 9.99874486446701/10
Finish Time: 2/12/2020 4:27:14 PM
Processing Complete
 [RESCALE]
False
[kernel]
True
[form]
```

```
Gaussian (bivariate normal)
[lscv]
True
[bcv]
[href]
False
[manual]
False
[outfolder]
N:\Projects3900\3978-01\shapefiles\Homerange\Telemetry_HRT_outputs
[prefix]
kde
[cellsize]
10
[scaling]
10
[verbose]
True
[extent]
full
9781
[iso]
True
95, 50
True
True
True
[silent]
False
```

2. Kernel Density Analysis (as per original methods in R for this study)

```
# Analysis visualizing the kernel homerange distribution
library(readr)
library(sp)
library(adehabitatHR)
library(maptools)
library(rgdal)
library(raster)
library(ggplot2)
library(rworldmap)
library(mapproj)
library(ggmap)
library(Rmisc)
library(ggthemes)
library(leaflet)
library(ggsn)
library(g.data)
library(grid)
```

```
#_________________GET THE DATA
IN_____________________________________________________________________________________
setwd("C:/Users/kjonasson/Desktop/Telemetry Data/Fixes/")
# Get the files names
files = list.files(path="C:/Users/kjonasson/Desktop/Telemetry Data/Fixes/", pattern="*.csv")
# First apply read.csv, then rbind
data = do.call(rbind, lapply(files, function(x) read.csv(x, stringsAsFactors = FALSE)))
# X&Y Estimates are UTMs (Output from the LOAS program)
addinfo <- subset(data[, c(3,4)])
i= 7
# Get capture data
setwd("C:/Users/kjonasson/Desktop/")
capture <- read.csv("capture.csv")
capture <- capture[i,]
#capture <- read.csv("G:/Work Products/Active Projects/3978, HI Hoary Bat Research/01,
Maui/FieldData/MistNetting/CaptureData.csv")

# quick plot of the points
plot(data$X_Estimate, data$Y_Estimate, asp = 1)


#_________________GET THE DATA IN SPATIAL DATA FRAME
_______________________________________________________________________

prj <- '+proj=utm +zone=4 +datum=WGS84' #need for next step, don't delete
sp <- SpatialPointsDataFrame(coordinates(cbind(data$X_Estimate, data$Y_Estimate)), data = addinfo,
                             proj4string = CRS(prj))

#plot the mean center of the data
mc <- apply(sp, 2, mean)


# Note: if you want more information, like animal id, you'll need to make this into a SpatialPonitsDataFrame
# another quick plot
plot(sp, pch = 19, cex = .5, axes=TRUE)


kd <- kernelUD(sp[,"Bat_id" ], h="href", grid=150) # the "Bat_id" is super important to pull out thee bats
image(kd)

#_________________ CREATING THE SPATIAL POLYGONS DATA FRAME
______________________________________________________________
kd_names <- c("Bat 2", "Bat 3", "Bat 4", "Bat 5", "Bat 6", "Bat 9", "Bat 10", "Bat 12", "Bat 16")
ud_50 <- lapply (kd, function(x) try(getverticeshr(x,50)))
# This code dpesn't work, but it's OK because the row names are appropriate

sapply(1:length(ud_50), function(i){
  row.names(ud_50[[i]]) <<- kd_names[i] # two arrows because it's a superassignment ... inside [[]]
  })
```

```
sdf_poly <- Reduce(rbind,ud_50)
sdf_poly

df <- fortify (sdf_poly)
g <- ggplot(df, aes(x=long, y=lat, fill = id, group=group))+
  geom_polygon(alpha=0.4)+
  coord_equal()+
  theme_void()
g



#________________ VISUALIZE IN GGPLOT
__________________________________________________________________

# first convert to longitude and latitude
sp2 <- spTransform(sp, CRS('+proj=longlat'))
plot(sp2, axes=TRUE)
sp3 <- as.data.frame(sp2) # this has fly and roost
sp3$Bat_id <- as.character(sp3$Bat_id)
colnames(sp3) <- c("Bat_id", "FlyRoost", "lon", "lat")
fly <- subset(sp3, FlyRoost=="Fly")
roost <- subset(sp3, FlyRoost=="Roost")


sdf_poly_latlong <- spTransform(sdf_poly, CRS('+proj=longlat +datum=WGS84'))a
plot(sdf_poly_latlong, axes=TRUE)
sdf_poly_latlong<- fortify(sdf_poly_latlong)

# Work around for mapping
HImap.df <- ggmap(get_stamenmap(rbind(as.numeric(paste(geocode_OSM("Maui")$bbox))), zoom = 12))

bb <- attr(HImap.df, "bb")
bb2 <- data.frame(long=unlist(bb[c(2,4)]), lat=unlist(bb[c(1,3)]))
scale <- data.frame(lat= c(-156.25,-156.4), lon=c(20.625,20.625))

scalebar = function(x,y,w,n,d, units="km"){
  # x,y = lower left coordinate of bar
  # w = width of bar
  # n = number of divisions on bar
  # d = distance along each division

  bar = data.frame(
    xmin = seq(0.0, n*d, by=d) + x,
    xmax = seq(0.0, n*d, by=d) + x + d,
    ymin = y,
    ymax = y+w,
    z = rep(c(1,0),n)[1:(n+1)],
    fill.col = rep(c("black","white"),n)[1:(n+1)])

  labs = data.frame(
    xlab = c(seq(0.0, (n+1)*d, by=d) + x, x),
```

```
    ylab = c(rep(y-w*1.5, n+2), y-3*w),
    text = c("0","5","10","15","20","25 km", "")
  )
  list(bar, labs)
}

sb = scalebar(-156.5, 20.625, 0.005, 4, 0.048092, "km" )

# Mapping
HImap.df <- get_map(location = c(long = -156.33, lat= 20.79),
                    maptype="satellite",
                    source="google",
                    zoom=11,
                    color="color")

bb <- attr(HImap.df, "bb")
bb2 <- data.frame(long=unlist(bb[c(2,4)]), lat=unlist(bb[c(1,3)]))
scale <- data.frame(lat= c(-156.25,-156.4), lon=c(20.625,20.625))

scalebar = function(x,y,w,n,d, units="km"){
  # x,y = lower left coordinate of bar
  # w = width of bar
  # n = number of divisions on bar
  # d = distance along each division

  bar = data.frame(
    xmin = seq(0.0, n*d, by=d) + x,
    xmax = seq(0.0, n*d, by=d) + x + d,
    ymin = y,
    ymax = y+w,
    z = rep(c(1,0),n)[1:(n+1)],
    fill.col = rep(c("black","white"),n)[1:(n+1)])

  labs = data.frame(
    xlab = c(seq(0.0, (n+1)*d, by=d) + x, x),
    ylab = c(rep(y-w*1.5, n+2), y-3*w),
    text = c("0","5","10","15","20","25 km", "")
  )
  list(bar, labs)
}

sb = scalebar(-156.5, 20.625, 0.005, 4, 0.048092, "km" )



# Pulling out the areas of these polygons is a shit ton of work
ud_95[[5]] # give the home range in ha (look up mcp that will tell units in and out of the function)
# The below no longer works with the type of object i have :(
# hr2 <- round( ud_95[[2]], digits=2)
```

```
# Plot with  no fixes
p1 <- ggmap(HImap.df, extent="panel")+
  geom_polygon(data=sdf_poly_latlong, aes(x = long, y = lat, group=group, fill = id), alpha=0.6)+ # need
group=group so the polygons make sense

  geom_rect(data=sb[[1]], aes(xmin=xmin, xmax=xmax, ymin=ymin, ymax=ymax, fill=z), inherit.aes=F,
            show.legend = F,  color = "black", fill = sb[[1]]$fill.col) +
  geom_text(data=sb[[2]], aes(x=xlab, y=ylab, label=text), inherit.aes=F, show.legend = F, size=3,
color="white")+
  labs(title = "Homeranges of bats tracked from Jul 28 - Oct 7, 2017", x="Longitude", y="Latitude")+
  theme(plot.margin = margin(1, 1, 1, 1, "cm"), legend.position = "bottom", legend.justification = "left")+
  scale_fill_discrete(name="95% Kernel ", labels= c("Bat 2  1,263.30 ha","Bat 3  26,064.76 ha","Bat 4
19,213.87 ha","Bat 5  4,000.17 ha","Bat 6  3,706.85 ha" ))+
  guides(fill=guide_legend(nrow=5,byrow=TRUE, title.position = "top"))+
  coord_cartesian()+
  north(data=bb2, location="topright", symbol = 10)

p1

pdf(paste("C:/Users/kjonasson/Desktop/Telemetry Data/HomerangePlots/AllBats.pdf", sep=""),
    width=7, height=9, paper = "letter")
 p1
dev.off()

#i <- i+1 # increase the counter so you go to the next bat

#}

# Plot with fixes

g_legend<-function(a.gplot){
  tmp <- ggplot_gtable(ggplot_build(a.gplot))
  leg <- which(sapply(tmp$grobs, function(x) x$name) == "guide-box")
  legend <- tmp$grobs[[leg]]
  legend
}

legends <- list(g_legend(p2 + geom_point(data=fly, aes(color = "black" ))),
                g_legend(p2 + geom_point(data=roost, aes(lon, lat, shape="FlyRoost"), pch=19, color="red",
show.legend = TRUE)
                         +  scale_fill_discrete(name="  ") +
                           guides(fill=guide_legend(nrow=5,byrow=TRUE, title.position = "top"))

                         )
                         )


library(gridExtra)
grid.arrange(p2  + guides(color = 'none'),
             do.call(arrangeGrob, legends), nrow = 1, widths = c(0.8, 0.2))
```

```
# Just the map
p2 <- ggmap(HImap.df, extent="panel")+
  geom_blank()+
  #geom_polygon(data=sdf_poly_latlong, aes(x = long, y = lat, group=group, fill = id), alpha=0.6,
show.legend = F)+ # need group=group so the polygons make sense
  #geom_point(data=fly, aes(lon, lat), col="black", show.legend=F)+
  #geom_point(data=roost, aes(lon, lat), col="red")+
  #geom_point(data=capture, aes(Long, Lat), col="black", pch=23, fill="white", size=2)+
  geom_rect(data=sb[[1]], aes(xmin=xmin, xmax=xmax, ymin=ymin, ymax=ymax, fill=z), inherit.aes=F,
            show.legend = F,  color = "black", fill = sb[[1]]$fill.col) +
  geom_text(data=sb[[2]], aes(x=xlab, y=ylab, label=text), inherit.aes=F, show.legend = F, size=3,
color="white")+
  labs(title = "Homeranges of bats tracked from Jul 28 - Oct 7, 2017", x="Longitude", y="Latitude")+
  theme(plot.margin = margin(1, 1, 1, 1, "cm"), legend.position = "bottom", legend.justification = "left")+
  scale_fill_discrete(name="95% Kernel ", labels= c("Bat 2  1,263.30 ha","Bat 3  26,064.76 ha","Bat 4
19,213.87 ha","Bat 5  4,000.17 ha","Bat 6  3,706.85 ha" ))+
  guides(fill=guide_legend(nrow=5,byrow=TRUE, title.position = "top"))+
  coord_cartesian()+
  north(data=bb2, location="topright", symbol = 10)

p2

# Just the homerange
p_hr <- ggmap(HImap.df, extent="panel")+
  geom_polygon(data=sdf_poly_latlong, aes(x = long, y = lat, group=group, fill = id), alpha=0.6,
show.legend = T)+ # need group=group so the polygons make sense
  scale_fill_discrete(name="95% Kernel ", labels= c("Bat 2  1,263.30 ha","Bat 3  26,064.76 ha","Bat 4
19,213.87 ha","Bat 5  4,000.17 ha","Bat 6  3,706.85 ha" ))+
  guides(fill=guide_legend(nrow=5,byrow=TRUE, title.position = "top"))+
  theme(legend.position = "bottom")
p_hr

# Just the fly
p_fly <- ggmap(HImap.df, extent="panel")+
  geom_point(data=fly, aes(x=lon, y=lat, shape=FlyRoost), col="black")+
  scale_shape_manual(values=19, guide = guide_legend(nrow=1, title.position = "top")) +
  theme(legend.position = "bottom", legend.title=element_blank(), legend.key = element_rect(colour =
"transparent", fill = "white"))
p_fly

# Just the roost
p_roost <- ggmap(HImap.df, extent="panel")+
  geom_point(data=roost, aes(x=lon, y=lat, shape=FlyRoost), col="red")+
  scale_shape_manual(values=19, guide = guide_legend(nrow=1, title.position = "top")) +
  theme(legend.position = "bottom", legend.title=element_blank(), legend.key = element_rect(colour =
"transparent", fill = "white"))
p_roost

# Just the capture site
p_cap <- ggmap(HImap.df, extent="panel")+
  geom_point(data=capture, aes(x=Long, y=Lat, shape=LED), col="black", fill="white", size=2)+
  scale_shape_manual(values=23, guide = guide_legend(nrow=1, title.position = "top")) +
```

```
  theme(legend.position = "bottom", legend.title=element_blank(), legend.key = element_rect(colour =
"transparent", fill = "white"))
p_cap

pdf(paste("C:/Users/kjonasson/Desktop/Telemetry Data/HomerangePlots/AllBats_fixes.pdf", sep=""),
    width=7, height=9, paper = "letter")
p2
dev.off()
```

Appendix B. Contrast Estimates by Habitat and Month

```
> emmeans(nb1, pairwise ~ Month | Habitat, type = "response")
$emmeans
Habitat = AV:
 Month    response     SE  df asymp.LCL asymp.UCL
 Jan2018     4.508  2.284 Inf    1.6701     12.17
 Jul2018    26.865 12.679 Inf   10.6523     67.75
 Mar2018     2.270  1.265 Inf    0.7612      6.77
 May2018    34.344 18.024 Inf   12.2777     96.07
 Nov2017     9.760  4.731 Inf    3.7743     25.24
 Sep2017    12.209  5.860 Inf    4.7657     31.28
 Sep2018    28.966 13.630 Inf   11.5172     72.85

Habitat = DevH:
 Month    response     SE  df asymp.LCL asymp.UCL
 Jan2018    12.744  6.122 Inf    4.9705     32.67
 Jul2018     8.965  4.358 Inf    3.4580     23.24
 Mar2018     9.174  4.501 Inf    3.5070     24.00
 May2018    25.545 12.046 Inf   10.1376     64.37
 Nov2017     8.310  4.051 Inf    3.1964     21.61
 Sep2017    60.479 28.243 Inf   24.2163    151.04
 Sep2018    13.208  6.325 Inf    5.1667     33.77

Habitat = DevL:
 Month    response     SE  df asymp.LCL asymp.UCL
 Jan2018    13.523  6.469 Inf    5.2951     34.54
 Jul2018    82.830 38.606 Inf   33.2242    206.50
 Mar2018     7.896  3.945 Inf    2.9656     21.02
 May2018    52.675 24.620 Inf   21.0747    131.66
 Nov2017    18.813  8.923 Inf    7.4257     47.66
 Sep2017    38.128 17.880 Inf   15.2087     95.59
 Sep2018    72.843 35.656 Inf   27.9084    190.12

Habitat = FWL:
 Month    response     SE  df asymp.LCL asymp.UCL
 Jan2018     0.419  0.350 Inf    0.0814      2.15
 Jul2018    47.184 22.094 Inf   18.8459    118.14
 Mar2018     1.032  0.670 Inf    0.2889      3.68
 May2018     3.425  1.789 Inf    1.2300      9.54
 Nov2017     0.194  0.215 Inf    0.0223      1.70
 Sep2017    18.713  8.879 Inf    7.3832     47.43
 Sep2018     5.145  2.655 Inf    1.8711     14.15

Habitat = FWU:
 Month    response     SE  df asymp.LCL asymp.UCL
 Jan2018   110.793 51.556 Inf   44.5057    275.81
 Jul2018     0.598  0.448 Inf    0.1377      2.59
 Mar2018    16.341  7.776 Inf    6.4298     41.53
 May2018    10.134  4.904 Inf    3.9252     26.16
 Nov2017     1.514  0.883 Inf    0.4832      4.75
 Sep2017     3.569  1.846 Inf    1.2947      9.84
 Sep2018     8.685  4.226 Inf    3.3470     22.54

Habitat = Grass:
 Month    response     SE  df asymp.LCL asymp.UCL
 Jan2018     2.273  1.243 Inf    0.7783      6.64
 Jul2018    39.109 18.332 Inf   15.6060     98.01
 Mar2018     1.976  1.126 Inf    0.6471      6.04
 May2018    36.422 17.086 Inf   14.5228     91.34
 Nov2017    87.604 45.625 Inf   31.5656    243.13
```

```
 Sep2017   41.327 19.362 Inf   16.4981    103.52
 Sep2018  140.576 66.313 Inf   55.7672    354.36

Habitat = Gulch:
 Month   response     SE  df asymp.LCL asymp.UCL
 Jan2018   20.572  9.739 Inf    8.1345     52.03
 Jul2018   41.721 19.569 Inf   16.6378    104.62
 Mar2018    5.994  2.986 Inf    2.2583     15.91
 May2018   86.492 40.295 Inf   34.7068    215.54
 Nov2017   33.057 15.528 Inf   13.1651     83.00
 Sep2017   31.865 14.974 Inf   12.6857     80.04
 Sep2018  146.166 67.959 Inf   58.7602    363.59

Habitat = Shrub:
 Month   response     SE  df asymp.LCL asymp.UCL
 Jan2018   17.567  8.346 Inf    6.9236     44.57
 Jul2018   13.523  6.495 Inf    5.2752     34.67
 Mar2018   22.937 10.835 Inf    9.0871     57.89
 May2018   24.133 11.394 Inf    9.5657     60.88
 Nov2017   11.806  5.678 Inf    4.5994     30.30
 Sep2017   28.721 13.516 Inf   11.4191     72.24
 Sep2018   14.435  7.016 Inf    5.5679     37.42

Habitat = SV:
 Month   response     SE  df asymp.LCL asymp.UCL
 Jan2018    6.428  3.180 Inf    2.4379     16.95
 Jul2018   11.489  5.549 Inf    4.4587     29.61
 Mar2018    7.194  3.544 Inf    2.7392     18.89
 May2018    9.218  4.481 Inf    3.5548     23.90
 Nov2017    2.668  1.426 Inf    0.9356      7.61
 Sep2017   33.231 15.606 Inf   13.2373     83.42
 Sep2018   18.595  8.822 Inf    7.3377     47.12

Confidence level used: 0.95
Intervals are back-transformed from the log scale
```

Contrast Tests for Significant Differences
Differences between Habitats within a Month-Yr

```
$contrasts
Month = Jan2018:
 contrast         ratio       SE  df z.ratio p.value
 AV / DevH     3.54e-01 2.47e-01 Inf  -1.488  0.8614
 AV / DevL     3.33e-01 2.32e-01 Inf  -1.578  0.8172
 AV / FWL      1.08e+01 1.05e+01 Inf   2.433  0.2660
 AV / FWU      4.07e-02 2.80e-02 Inf  -4.657  0.0001
 AV / Grass    1.98e+00 1.48e+00 Inf   0.919  0.9920
 AV / Gulch    2.19e-01 1.52e-01 Inf  -2.191  0.4117
 AV / Shrub    2.57e-01 1.78e-01 Inf  -1.960  0.5718
 AV / SV       7.01e-01 4.96e-01 Inf  -0.501  0.9999
 DevH / DevL   9.42e-01 6.39e-01 Inf  -0.088  1.0000
 DevH / FWL    3.04e+01 2.93e+01 Inf   3.545  0.0118
 DevH / FWU    1.15e-01 7.69e-02 Inf  -3.233  0.0334
 DevH / Grass  5.61e+00 4.08e+00 Inf   2.368  0.3015
 DevH / Gulch  6.19e-01 4.18e-01 Inf  -0.710  0.9987
 DevH / Shrub  7.25e-01 4.90e-01 Inf  -0.475  0.9999
 DevH / SV     1.98e+00 1.37e+00 Inf   0.992  0.9867
 DevL / FWL    3.23e+01 3.11e+01 Inf   3.610  0.0093
 DevL / FWU    1.22e-01 8.14e-02 Inf  -3.153  0.0428
 DevL / Grass  5.95e+00 4.32e+00 Inf   2.456  0.2540
 DevL / Gulch  6.57e-01 4.42e-01 Inf  -0.624  0.9995
 DevL / Shrub  7.70e-01 5.19e-01 Inf  -0.388  1.0000
 DevL / SV     2.10e+00 1.45e+00 Inf   1.081  0.9770
 FWL / FWU     3.78e-03 3.61e-03 Inf  -5.834  <.0001
 FWL / Grass   1.84e-01 1.84e-01 Inf  -1.695  0.7501
 FWL / Gulch   2.04e-02 1.95e-02 Inf  -4.056  0.0016
 FWL / Shrub   2.38e-02 2.29e-02 Inf  -3.889  0.0032
 FWL / SV      6.51e-02 6.32e-02 Inf  -2.814  0.1113
 FWU / Grass   4.87e+01 3.50e+01 Inf   5.415  <.0001
 FWU / Gulch   5.39e+00 3.57e+00 Inf   2.538  0.2139
 FWU / Shrub   6.31e+00 4.19e+00 Inf   2.771  0.1241
 FWU / SV      1.72e+01 1.17e+01 Inf   4.194  0.0009
 Grass / Gulch 1.10e-01 7.99e-02 Inf  -3.047  0.0588
 Grass / Shrub 1.29e-01 9.37e-02 Inf  -2.824  0.1083
 Grass / SV    3.54e-01 2.61e-01 Inf  -1.410  0.8943
 Gulch / Shrub 1.17e+00 7.85e-01 Inf   0.236  1.0000
 Gulch / SV    3.20e+00 2.19e+00 Inf   1.700  0.7471
 Shrub / SV    2.73e+00 1.87e+00 Inf   1.466  0.8712

Month = Jul2018:
 contrast         ratio       SE  df z.ratio p.value
 AV / DevH     3.00e+00 2.03e+00 Inf   1.619  0.7945
 AV / DevL     3.24e-01 2.15e-01 Inf  -1.696  0.7490
 AV / FWL      5.69e-01 3.78e-01 Inf  -0.848  0.9954
 AV / FWU      4.50e+01 3.98e+01 Inf   4.299  0.0006
 AV / Grass    6.87e-01 4.57e-01 Inf  -0.564  0.9998
 AV / Gulch    6.44e-01 4.28e-01 Inf  -0.662  0.9992
 AV / Shrub    1.99e+00 1.34e+00 Inf   1.020  0.9841
 AV / SV       2.34e+00 1.58e+00 Inf   1.258  0.9431
 DevH / DevL   1.08e-01 7.29e-02 Inf  -3.303  0.0267
 DevH / FWL    1.90e-01 1.28e-01 Inf  -2.460  0.2518
 DevH / FWU    1.50e+01 1.34e+01 Inf   3.033  0.0612
 DevH / Grass  2.29e-01 1.55e-01 Inf  -2.182  0.4173
 DevH / Gulch  2.15e-01 1.45e-01 Inf  -2.276  0.3570
 DevH / Shrub  6.63e-01 4.53e-01 Inf  -0.601  0.9996
 DevH / SV     7.80e-01 5.35e-01 Inf  -0.362  1.0000
 DevL / FWL    1.76e+00 1.16e+00 Inf   0.851  0.9952
 DevL / FWU    1.39e+02 1.22e+02 Inf   5.590  <.0001
 DevL / Grass  2.12e+00 1.40e+00 Inf   1.136  0.9688
```

```
 DevL / Gulch  1.99e+00 1.31e+00 Inf   1.036  0.9824
 DevL / Shrub  6.13e+00 4.10e+00 Inf   2.706  0.1453
 DevL / SV     7.21e+00 4.84e+00 Inf   2.942  0.0791
 FWL / FWU     7.90e+01 6.97e+01 Inf   4.946  <.0001
 FWL / Grass   1.21e+00 8.00e-01 Inf   0.283  1.0000
 FWL / Gulch   1.13e+00 7.49e-01 Inf   0.186  1.0000
 FWL / Shrub   3.49e+00 2.34e+00 Inf   1.864  0.6390
 FWL / SV      4.11e+00 2.76e+00 Inf   2.101  0.4728
 FWU / Grass   1.53e-02 1.35e-02 Inf  -4.732  0.0001
 FWU / Gulch   1.43e-02 1.27e-02 Inf  -4.805  0.0001
 FWU / Shrub   4.42e-02 3.93e-02 Inf  -3.506  0.0135
 FWU / SV      5.20e-02 4.64e-02 Inf  -3.317  0.0255
 Grass / Gulch 9.37e-01 6.22e-01 Inf  -0.097  1.0000
 Grass / Shrub 2.89e+00 1.94e+00 Inf   1.582  0.8151
 Grass / SV    3.40e+00 2.29e+00 Inf   1.819  0.6693
 Gulch / Shrub 3.09e+00 2.07e+00 Inf   1.679  0.7597
 Gulch / SV    3.63e+00 2.44e+00 Inf   1.916  0.6024
 Shrub / SV    1.18e+00 8.01e-01 Inf   0.239  1.0000

Month = Mar2018:
 contrast         ratio       SE  df z.ratio p.value
 AV / DevH     2.47e-01 1.84e-01 Inf  -1.883  0.6258
 AV / DevL     2.87e-01 2.15e-01 Inf  -1.667  0.7666
 AV / FWL      2.20e+00 1.88e+00 Inf   0.922  0.9918
 AV / FWU      1.39e-01 1.02e-01 Inf  -2.692  0.1505
 AV / Grass    1.15e+00 9.15e-01 Inf   0.174  1.0000
 AV / Gulch    3.79e-01 2.83e-01 Inf  -1.299  0.9319
 AV / Shrub    9.90e-02 7.23e-02 Inf  -3.164  0.0414
 AV / SV       3.16e-01 2.35e-01 Inf  -1.551  0.8313
 DevH / DevL   1.16e+00 8.11e-01 Inf   0.215  1.0000
 DevH / FWL    8.89e+00 7.23e+00 Inf   2.687  0.1523
 DevH / FWU    5.61e-01 3.84e-01 Inf  -0.843  0.9955
 DevH / Grass  4.64e+00 3.49e+00 Inf   2.044  0.5126
 DevH / Gulch  1.53e+00 1.07e+00 Inf   0.609  0.9996
 DevH / Shrub  4.00e-01 2.73e-01 Inf  -1.344  0.9182
 DevH / SV     1.28e+00 8.87e-01 Inf   0.350  1.0000
 DevL / FWL    7.65e+00 6.26e+00 Inf   2.486  0.2385
 DevL / FWU    4.83e-01 3.34e-01 Inf  -1.052  0.9806
 DevL / Grass  4.00e+00 3.02e+00 Inf   1.830  0.6623
 DevL / Gulch  1.32e+00 9.29e-01 Inf   0.390  1.0000
 DevL / Shrub  3.44e-01 2.37e-01 Inf  -1.548  0.8324
 DevL / SV     1.10e+00 7.70e-01 Inf   0.133  1.0000
 FWL / FWU     6.31e-02 5.09e-02 Inf  -3.429  0.0176
 FWL / Grass   5.22e-01 4.51e-01 Inf  -0.753  0.9980
 FWL / Gulch   1.72e-01 1.41e-01 Inf  -2.150  0.4391
 FWL / Shrub   4.50e-02 3.61e-02 Inf  -3.860  0.0036
 FWL / SV      1.43e-01 1.17e-01 Inf  -2.382  0.2935
 FWU / Grass   8.27e+00 6.14e+00 Inf   2.844  0.1027
 FWU / Gulch   2.73e+00 1.88e+00 Inf   1.456  0.8757
 FWU / Shrub   7.12e-01 4.77e-01 Inf  -0.506  0.9999
 FWU / SV      2.27e+00 1.56e+00 Inf   1.198  0.9572
 Grass / Gulch 3.30e-01 2.49e-01 Inf  -1.466  0.8713
 Grass / Shrub 8.62e-02 6.38e-02 Inf  -3.311  0.0261
 Grass / SV    2.75e-01 2.07e-01 Inf  -1.715  0.7372
 Gulch / Shrub 2.61e-01 1.79e-01 Inf  -1.955  0.5751
 Gulch / SV    8.33e-01 5.84e-01 Inf  -0.260  1.0000
 Shrub / SV    3.19e+00 2.18e+00 Inf   1.699  0.7475

Month = May2018:
 contrast         ratio       SE  df z.ratio p.value
 AV / DevH     1.34e+00 9.48e-01 Inf   0.420  1.0000
 AV / DevL     6.52e-01 4.58e-01 Inf  -0.609  0.9996
 AV / FWL      1.00e+01 7.43e+00 Inf   3.113  0.0483
 AV / FWU      3.39e+00 2.42e+00 Inf   1.710  0.7408
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 AV / Grass    9.43e-01 6.64e-01 Inf -0.083  1.0000
 AV / Gulch    3.97e-01 2.79e-01 Inf -1.316  0.9268
 AV / Shrub    1.42e+00 1.00e+00 Inf  0.500  0.9999
 AV / SV       3.73e+00 2.67e+00 Inf  1.839  0.6562
 DevH / DevL   4.85e-01 3.22e-01 Inf -1.090  0.9758
 DevH / FWL    7.46e+00 5.25e+00 Inf  2.855  0.0999
 DevH / FWU    2.52e+00 1.70e+00 Inf  1.368  0.9098
 DevH / Grass  7.01e-01 4.66e-01 Inf -0.533  0.9998
 DevH / Gulch  2.95e-01 1.96e-01 Inf -1.840  0.6551
 DevH / Shrub  1.06e+00 7.06e-01 Inf  0.085  1.0000
 DevH / SV     2.77e+00 1.88e+00 Inf  1.505  0.8536
 DevL / FWL    1.54e+01 1.08e+01 Inf  3.899  0.0031
 DevL / FWU    5.20e+00 3.50e+00 Inf  2.450  0.2568
 DevL / Grass  1.45e+00 9.57e-01 Inf  0.557  0.9998
 DevL / Gulch  6.09e-01 4.02e-01 Inf -0.752  0.9980
 DevL / Shrub  2.18e+00 1.45e+00 Inf  1.175  0.9618
 DevL / SV     5.71e+00 3.85e+00 Inf  2.585  0.1929
 FWL / FWU     3.38e-01 2.41e-01 Inf -1.523  0.8449
 FWL / Grass   9.40e-02 6.60e-02 Inf -3.367  0.0217
 FWL / Gulch   3.96e-02 2.77e-02 Inf -4.613  0.0001
 FWL / Shrub   1.42e-01 9.99e-02 Inf -2.773  0.1235
 FWL / SV      3.72e-01 2.65e-01 Inf -1.387  0.9030
 FWU / Grass   2.78e-01 1.88e-01 Inf -1.898  0.6150
 FWU / Gulch   1.17e-01 7.87e-02 Inf -3.192  0.0380
 FWU / Shrub   4.20e-01 2.84e-01 Inf -1.283  0.9364
 FWU / SV      1.10e+00 7.54e-01 Inf  0.138  1.0000
 Grass / Gulch 4.21e-01 2.78e-01 Inf -1.309  0.9291
 Grass / Shrub 1.51e+00 1.00e+00 Inf  0.618  0.9995
 Grass / SV    3.95e+00 2.67e+00 Inf  2.034  0.5194
 Gulch / Shrub 3.58e+00 2.38e+00 Inf  1.925  0.5966
 Gulch / SV    9.38e+00 6.32e+00 Inf  3.325  0.0249
 Shrub / SV    2.62e+00 1.77e+00 Inf  1.420  0.8904

Month = Nov2017:
 contrast         ratio       SE  df z.ratio p.value
 AV / DevH     1.17e+00 8.07e-01 Inf  0.234  1.0000
 AV / DevL     5.19e-01 3.52e-01 Inf -0.968  0.9887
 AV / FWL      5.02e+01 6.06e+01 Inf  3.244  0.0323
 AV / FWU      6.44e+00 4.89e+00 Inf  2.458  0.2528
 AV / Grass    1.11e-01 7.93e-02 Inf -3.085  0.0526
 AV / Gulch    2.95e-01 1.99e-01 Inf -1.808  0.6772
 AV / Shrub    8.27e-01 5.64e-01 Inf -0.279  1.0000
 AV / SV       3.66e+00 2.64e+00 Inf  1.798  0.6840
 DevH / DevL   4.42e-01 3.00e-01 Inf -1.202  0.9563
 DevH / FWL    4.27e+01 5.16e+01 Inf  3.108  0.0490
 DevH / FWU    5.49e+00 4.17e+00 Inf  2.242  0.3785
 DevH / Grass  9.49e-02 6.76e-02 Inf -3.303  0.0267
 DevH / Gulch  2.51e-01 1.70e-01 Inf -2.041  0.5145
 DevH / Shrub  7.04e-01 4.82e-01 Inf -0.513  0.9999
 DevH / SV     3.12e+00 2.25e+00 Inf  1.571  0.8206
 DevL / FWL    9.68e+01 1.16e+02 Inf  3.801  0.0046
 DevL / FWU    1.24e+01 9.33e+00 Inf  3.354  0.0226
 DevL / Grass  2.15e-01 1.51e-01 Inf -2.185  0.4154
 DevL / Gulch  5.69e-01 3.80e-01 Inf -0.845  0.9955
 DevL / Shrub  1.59e+00 1.08e+00 Inf  0.690  0.9989
 DevL / SV     7.05e+00 5.04e+00 Inf  2.735  0.1357
 FWL / FWU     1.28e-01 1.60e-01 Inf -1.643  0.7812
 FWL / Grass   2.22e-03 2.71e-03 Inf -5.001  <.0001
 FWL / Gulch   5.88e-03 7.06e-03 Inf -4.276  0.0006
 FWL / Shrub   1.65e-02 1.99e-02 Inf -3.406  0.0190
 FWL / SV      7.29e-02 8.95e-02 Inf -2.133  0.4506
 FWU / Grass   1.73e-02 1.35e-02 Inf -5.193  <.0001
 FWU / Gulch   4.58e-02 3.43e-02 Inf -4.121  0.0013
 FWU / Shrub   1.28e-01 9.69e-02 Inf -2.718  0.1414
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 FWU / SV      5.68e-01 4.49e-01 Inf -0.716  0.9986
 Grass / Gulch 2.65e+00 1.86e+00 Inf  1.390  0.9018
 Grass / Shrub 7.42e+00 5.26e+00 Inf  2.828  0.1073
 Grass / SV    3.28e+01 2.45e+01 Inf  4.681  0.0001
 Gulch / Shrub 2.80e+00 1.88e+00 Inf  1.532  0.8407
 Gulch / SV    1.24e+01 8.81e+00 Inf  3.539  0.0120
 Shrub / SV    4.43e+00 3.18e+00 Inf  2.069  0.4950

Month = Sep2017:
 contrast         ratio       SE  df z.ratio p.value
 AV / DevH     2.02e-01 1.35e-01 Inf -2.391  0.2885
 AV / DevL     3.20e-01 2.15e-01 Inf -1.699  0.7477
 AV / FWL      6.52e-01 4.40e-01 Inf -0.633  0.9994
 AV / FWU      3.42e+00 2.41e+00 Inf  1.744  0.7189
 AV / Grass    2.95e-01 1.98e-01 Inf -1.819  0.6693
 AV / Gulch    3.83e-01 2.57e-01 Inf -1.429  0.8868
 AV / Shrub    4.25e-01 2.86e-01 Inf -1.273  0.9391
 AV / SV       3.67e-01 2.47e-01 Inf -1.492  0.8597
 DevH / DevL   1.59e+00 1.05e+00 Inf  0.698  0.9988
 DevH / FWL    3.23e+00 2.15e+00 Inf  1.763  0.7071
 DevH / FWU    1.69e+01 1.18e+01 Inf  4.064  0.0016
 DevH / Grass  1.46e+00 9.67e-01 Inf  0.576  0.9997
 DevH / Gulch  1.90e+00 1.26e+00 Inf  0.968  0.9887
 DevH / Shrub  2.11e+00 1.40e+00 Inf  1.124  0.9708
 DevH / SV     1.82e+00 1.20e+00 Inf  0.905  0.9928
 DevL / FWL    2.04e+00 1.36e+00 Inf  1.067  0.9788
 DevL / FWU    1.07e+01 7.45e+00 Inf  3.395  0.0197
 DevL / Grass  9.23e-01 6.11e-01 Inf -0.122  1.0000
 DevL / Gulch  1.20e+00 7.94e-01 Inf  0.270  1.0000
 DevL / Shrub  1.33e+00 8.81e-01 Inf  0.427  1.0000
 DevL / SV     1.15e+00 7.61e-01 Inf  0.207  1.0000
 FWL / FWU     5.24e+00 3.68e+00 Inf  2.361  0.3056
 FWL / Grass   4.53e-01 3.02e-01 Inf -1.188  0.9591
 FWL / Gulch   5.87e-01 3.92e-01 Inf -0.797  0.9970
 FWL / Shrub   6.52e-01 4.35e-01 Inf -0.641  0.9994
 FWL / SV      5.63e-01 3.76e-01 Inf -0.860  0.9949
 FWU / Grass   8.63e-02 6.02e-02 Inf -3.512  0.0132
 FWU / Gulch   1.12e-01 7.82e-02 Inf -3.135  0.0453
 FWU / Shrub   1.24e-01 8.68e-02 Inf -2.983  0.0704
 FWU / SV      1.07e-01 7.50e-02 Inf -3.195  0.0377
 Grass / Gulch 1.30e+00 8.60e-01 Inf  0.392  1.0000
 Grass / Shrub 1.44e+00 9.55e-01 Inf  0.548  0.9998
 Grass / SV    1.24e+00 8.25e-01 Inf  0.329  1.0000
 Gulch / Shrub 1.11e+00 7.38e-01 Inf  0.156  1.0000
 Gulch / SV    9.59e-01 6.37e-01 Inf -0.063  1.0000
 Shrub / SV    8.64e-01 5.74e-01 Inf -0.219  1.0000

Month = Sep2018:
 contrast         ratio       SE  df z.ratio p.value
 AV / DevH     2.19e+00 1.47e+00 Inf  1.170  0.9628
 AV / DevL     3.98e-01 2.71e-01 Inf -1.352  0.9153
 AV / FWL      5.63e+00 3.94e+00 Inf  2.471  0.2462
 AV / FWU      3.34e+00 2.26e+00 Inf  1.781  0.6952
 AV / Grass    2.06e-01 1.38e-01 Inf -2.364  0.3038
 AV / Gulch    1.98e-01 1.31e-01 Inf -2.448  0.2578
 AV / Shrub    2.01e+00 1.36e+00 Inf  1.028  0.9833
 AV / SV       1.56e+00 1.04e+00 Inf  0.664  0.9992
 DevH / DevL   1.81e-01 1.25e-01 Inf -2.486  0.2386
 DevH / FWL    2.57e+00 1.81e+00 Inf  1.338  0.9200
 DevH / FWU    1.52e+00 1.04e+00 Inf  0.614  0.9995
 DevH / Grass  9.40e-02 6.33e-02 Inf -3.512  0.0132
 DevH / Gulch  9.04e-02 6.03e-02 Inf -3.603  0.0096
 DevH / Shrub  9.15e-01 6.25e-01 Inf -0.130  1.0000
 DevH / SV     7.10e-01 4.79e-01 Inf -0.508  0.9999
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 DevL / FWL    1.42e+01 9.96e+00 Inf  3.765  0.0052
 DevL / FWU    8.39e+00 5.81e+00 Inf  3.068  0.0552
 DevL / Grass  5.18e-01 3.45e-01 Inf -0.987  0.9871
 DevL / Gulch  4.98e-01 3.38e-01 Inf -1.027  0.9834
 DevL / Shrub  5.05e+00 3.43e+00 Inf  2.381  0.2944
 DevL / SV     3.92e+00 2.68e+00 Inf  1.993  0.5483
 FWL / FWU     5.92e-01 4.21e-01 Inf -0.737  0.9983
 FWL / Grass   3.66e-02 2.54e-02 Inf -4.761  0.0001
 FWL / Gulch   3.52e-02 2.45e-02 Inf -4.811  0.0001
 FWL / Shrub   3.56e-01 2.52e-01 Inf -1.462  0.8732
 FWL / SV      2.77e-01 1.94e-01 Inf -1.830  0.6621
 FWU / Grass   6.18e-02 4.20e-02 Inf -4.098  0.0014
 FWU / Gulch   5.94e-02 4.00e-02 Inf -4.198  0.0009
 FWU / Shrub   6.02e-01 4.15e-01 Inf -0.737  0.9983
 FWU / SV      4.67e-01 3.17e-01 Inf -1.121  0.9713
 Grass / Gulch 9.62e-01 6.39e-01 Inf -0.059  1.0000
 Grass / Shrub 9.74e+00 6.54e+00 Inf  3.390  0.0200
 Grass / SV    7.56e+00 5.07e+00 Inf  3.014  0.0645
 Gulch / Shrub 1.01e+01 6.82e+00 Inf  3.435  0.0172
 Gulch / SV    7.86e+00 5.22e+00 Inf  3.106  0.0493
 Shrub / SV    7.76e-01 5.28e-01 Inf -0.372  1.0000

P value adjustment: tukey method for comparing a family of 9 estimates
Tests are performed on the log scale
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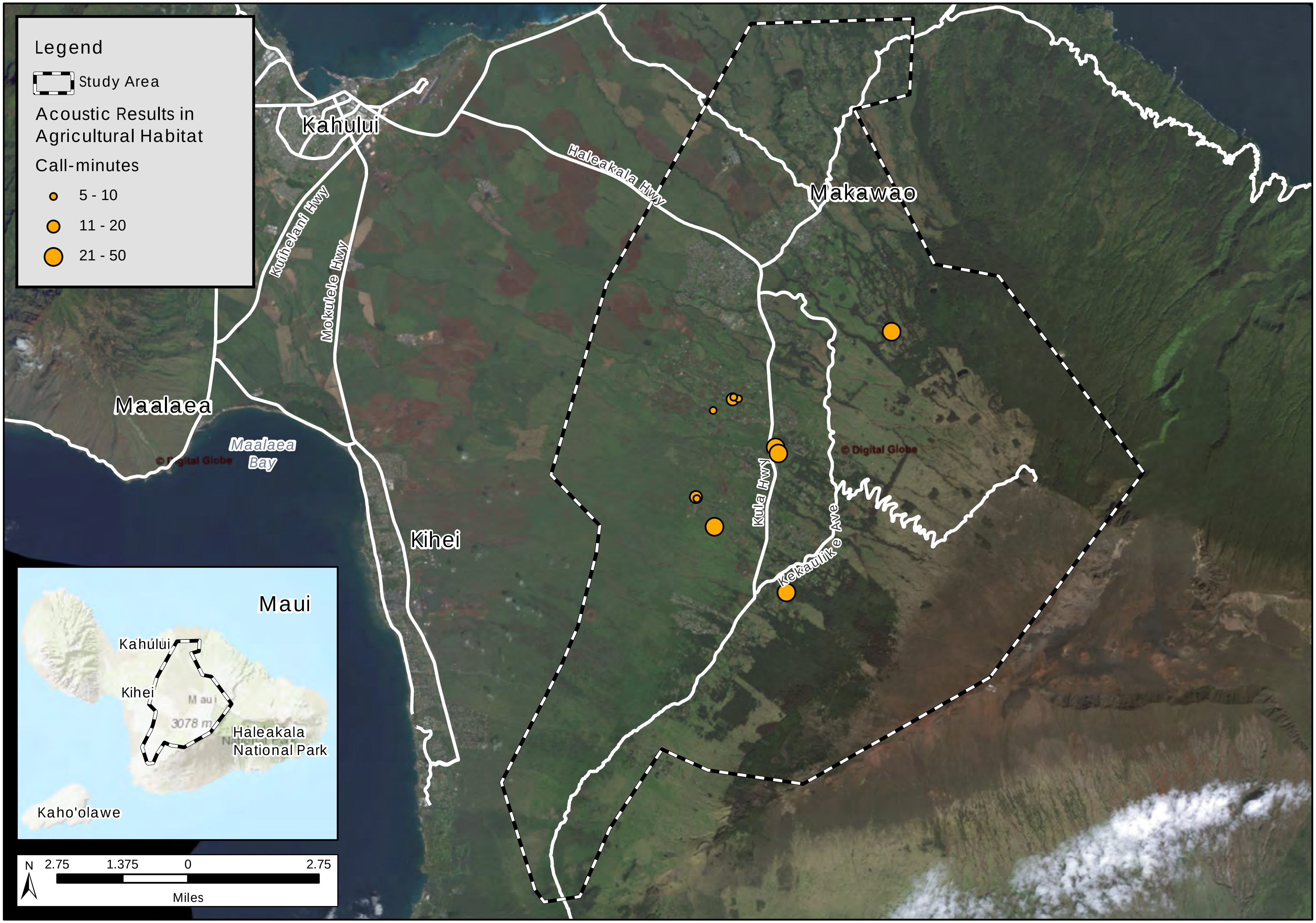
Appendix C. Significant Differences between Habitats by Month

Month	**Habitat 1**					**Habitat 2**					**Significance and Test Statistics**				
	Type	***Mean est***	***SE***	***LCL***	***UCL***	***Type***	***Mean est***	***SE***	***LCL***	***UCL***	***Sign. Difference***	***ratio***	***SE***	***z.ratio***	***p.value***
Sep-17	DevH	60.48	28.24	24.22	151.04	FWU	3.57	1.85	1.29	9.84	DevH > FWU	16.90	11.80	4.06	0.0016
	FWU	3.57	1.85	1.29	9.84	Grass	41.33	19.36	16.50	103.52	Grass > FWU	0.09	0.06	-3.51	0.0132
	DevL	38.13	17.88	15.21	95.59	FWU	3.57	1.85	1.29	9.84	DevL > FWU	10.70	7.45	3.40	0.0197
	FWU	3.57	1.85	1.29	9.84	SV	33.23	15.61	13.24	83.42	SV > FWU	0.11	0.08	-3.20	0.0377
	FWU	3.57	1.85	1.29	9.84	Gulch	31.87	14.97	12.69	80.04	Gulch > FWU	0.11	0.08	-3.14	0.0453
Nov-17	FWL	0.19	0.22	0.02	1.70	Grass	87.60	45.63	31.57	243.13	Grass > FWL	0.00	0.00	-5.00	<.0001
	FWU	1.51	0.88	0.48	4.75	Grass	87.60	45.63	31.57	243.13	Grass > FWU	0.02	0.01	-5.19	<.0001
	Grass	87.60	45.63	31.57	243.13	SV	2.67	1.43	0.94	7.61	Grass > SV	32.80	24.50	4.68	0.0001
	FWL	0.19	0.22	0.02	1.70	Gulch	33.06	15.53	13.17	83.00	Gulch > FWL	0.01	0.01	-4.28	0.0006
	FWU	1.51	0.88	0.48	4.75	Gulch	33.06	15.53	13.17	83.00	Gulch > FWU	0.05	0.03	-4.12	0.0013
	DevL	18.81	8.92	7.43	47.66	FWL	0.19	0.22	0.02	1.70	DevL > FWL	96.80	116.00	3.80	0.0046
	Gulch	33.06	15.53	13.17	83.00	SV	2.67	1.43	0.94	7.61	Gulch > SV	12.40	8.81	3.54	0.012
	FWL	0.19	0.22	0.02	1.70	Shrub	11.81	5.68	4.60	30.30	Shrub > FWL	0.02	0.02	-3.41	0.019
	DevL	18.81	8.92	7.43	47.66	FWU	1.51	0.88	0.48	4.75	DevL > FWU	12.40	9.33	3.35	0.0226
	DevH	8.31	4.05	3.20	21.61	Grass	87.60	45.63	31.57	243.13	Grass > DevH	0.09	0.07	-3.30	0.0267
	AV	9.76	4.73	3.77	25.24	FWL	0.19	0.22	0.02	1.70	AV > FWL	50.20	60.60	3.24	0.0323
	DevH	8.31	4.05	3.20	21.61	FWL	0.19	0.22	0.02	1.70	DevH > FWL	42.70	51.60	3.11	0.049
Jan-18	FWL	0.42	0.35	0.08	2.15	FWU	110.79	51.56	44.51	275.81	FWU > FWL	0.00	0.00	-5.83	<.0001
	FWU	110.79	51.56	44.51	275.81	Grass	2.27	1.24	0.78	6.64	FWU > Grass	48.70	35.00	5.42	<.0001
	AV	4.51	2.28	1.67	12.17	FWU	110.79	51.56	44.51	275.81	FWU > AV	0.04	0.03	-4.66	0.0001
	FWU	110.79	51.56	44.51	275.81	SV	6.43	3.18	2.44	16.95	FWU > SV	17.20	11.70	4.19	0.0009
	FWL	0.42	0.35	0.08	2.15	Gulch	20.57	9.74	8.13	52.03	Gulch > FWL	0.02	0.02	-4.06	0.0016
	FWL	0.42	0.35	0.08	2.15	Shrub	17.57	8.35	6.92	44.57	Shrub > FWL	0.02	0.02	-3.89	0.0032
	DevL	13.52	6.47	5.30	34.54	FWL	0.42	0.35	0.08	2.15	DevL > FWL	32.30	31.10	3.61	0.0093
	DevH	12.74	6.12	4.97	32.67	FWL	0.42	0.35	0.08	2.15	DevH > FWL	30.40	29.30	3.55	0.0118

Month	Habitat 1					Habitat 2					Significance and Test Statistics				
	Type	***Mean est***	***SE***	***LCL***	***UCL***	***Type***	***Mean est***	***SE***	***LCL***	***UCL***	***Sign. Difference***	***ratio***	***SE***	***z.ratio***	***p.value***
	DevH	12.74	6.12	4.97	32.67	FWU	110.79	51.56	44.51	275.81	FWU > DevH	0.12	0.08	-3.23	0.0334
	DevL	13.52	6.47	5.30	34.54	FWU	110.79	51.56	44.51	275.81	FWU > DevL	0.12	0.08	-3.15	0.0428
Mar-18	FWL	1.03	0.67	0.29	3.68	Shrub	22.94	10.84	9.09	57.89	Shrub > FWL	0.05	0.04	-3.86	0.0036
	FWL	1.03	0.67	0.29	3.68	FWU	16.34	7.78	6.43	41.53	FWU > FWL	0.06	0.05	-3.43	0.0176
	Grass	1.98	1.13	0.65	6.04	Shrub	22.94	10.84	9.09	57.89	Shrub > Grass	0.09	0.06	-3.31	0.0261
	AV	2.27	1.27	0.76	6.77	Shrub	22.94	10.84	9.09	57.89	Shrub > AV	0.10	0.07	-3.16	0.0414
May-18	FWL	3.43	1.79	1.23	9.54	Gulch	86.49	40.30	34.71	215.54	Gulch > FWL	0.04	0.03	-4.61	0.0001
	DevL	52.68	24.62	21.07	131.66	FWL	3.43	1.79	1.23	9.54	DevL > FWL	15.40	10.80	3.90	0.0031
	FWL	3.43	1.79	1.23	9.54	Grass	36.42	17.09	14.52	91.34	Grass > FWL	0.09	0.07	-3.37	0.0217
	Gulch	86.49	40.30	34.71	215.54	SV	9.22	4.48	3.55	23.90	Gulch > SV	9.38	6.32	3.33	0.0249
	FWU	10.13	4.90	3.93	26.16	Gulch	86.49	40.30	34.71	215.54	Gulch > FWU	0.12	0.08	-3.19	0.038
	AV	34.34	18.02	12.28	96.07	FWL	3.43	1.79	1.23	9.54	AV > FWL	10.00	7.43	3.11	0.0483
Jul-18	DevL	82.83	38.61	33.22	206.50	FWU	0.60	0.45	0.14	2.59	DevL > FWU	139.00	122.00	5.59	<.0001
	FWL	47.18	22.09	18.85	118.14	FWU	0.60	0.45	0.14	2.59	FWL > FWU	79.00	69.70	4.95	<.0001
	FWU	0.60	0.45	0.14	2.59	Grass	39.11	18.33	15.61	98.01	Grass > FWU	0.02	0.01	-4.73	0.0001
	FWU	0.60	0.45	0.14	2.59	Gulch	41.72	19.57	16.64	104.62	Gulch > FWU	0.01	0.01	-4.81	0.0001
	AV	26.87	12.68	10.65	67.75	FWU	0.60	0.45	0.14	2.59	AV > FWU	45.00	39.80	4.30	0.0006
	FWU	0.60	0.45	0.14	2.59	Shrub	13.52	6.50	5.28	34.67	Shrub > FWU	0.04	0.04	-3.51	0.0135
	FWU	0.60	0.45	0.14	2.59	SV	11.49	5.55	4.46	29.61	SV > FWU	0.05	0.05	-3.32	0.0255
	DevH	8.97	4.36	3.46	23.24	DevL	82.83	38.61	33.22	206.50	DevL > DevH	0.11	0.07	-3.30	0.0267
Sep-18	FWL	5.15	2.66	1.87	14.15	Grass	140.58	66.31	55.77	354.36	Grass > FWL	0.04	0.03	-4.76	0.0001
	FWL	5.15	2.66	1.87	14.15	Gulch	146.17	67.96	58.76	363.59	Gulch > FWL	0.04	0.02	-4.81	0.0001
	FWU	8.69	4.23	3.35	22.54	Gulch	146.17	67.96	58.76	363.59	Gulch > FWU	0.06	0.04	-4.20	0.0009
	FWU	8.69	4.23	3.35	22.54	Grass	140.58	66.31	55.77	354.36	Grass > FWU	0.06	0.04	-4.10	0.0014
	DevL	72.84	35.66	27.91	190.12	FWL	5.15	2.66	1.87	14.15	DevL > FWL	14.20	9.96	3.77	0.0052
	DevH	13.21	6.33	5.17	33.77	Gulch	146.17	67.96	58.76	363.59	Gulch > DevH	0.09	0.06	-3.60	0.0096

Month	**Habitat 1**					**Habitat 2**					**Significance and Test Statistics**				
	Type	***Mean est***	***SE***	***LCL***	***UCL***	***Type***	***Mean est***	***SE***	***LCL***	***UCL***	***Sign. Difference***	***ratio***	***SE***	***z.ratio***	***p.value***
	DevH	13.21	6.33	5.17	33.77	Grass	140.58	66.31	55.77	354.36	Grass > DevH	0.09	0.06	-3.51	0.0132
	Gulch	146.17	67.96	58.76	363.59	Shrub	14.44	7.02	5.57	37.42	Gulch > Shrub	10.10	6.82	3.44	0.0172
	Grass	140.58	66.31	55.77	354.36	Shrub	14.44	7.02	5.57	37.42	Grass > Shrub	9.74	6.54	3.39	0.02
	Gulch	146.17	67.96	58.76	363.59	SV	18.60	8.82	7.34	47.12	Gulch > SV	7.86	5.22	3.11	0.0493

Appendix D. GIS Spatial relationships of calls each night for acoustic monitoring.



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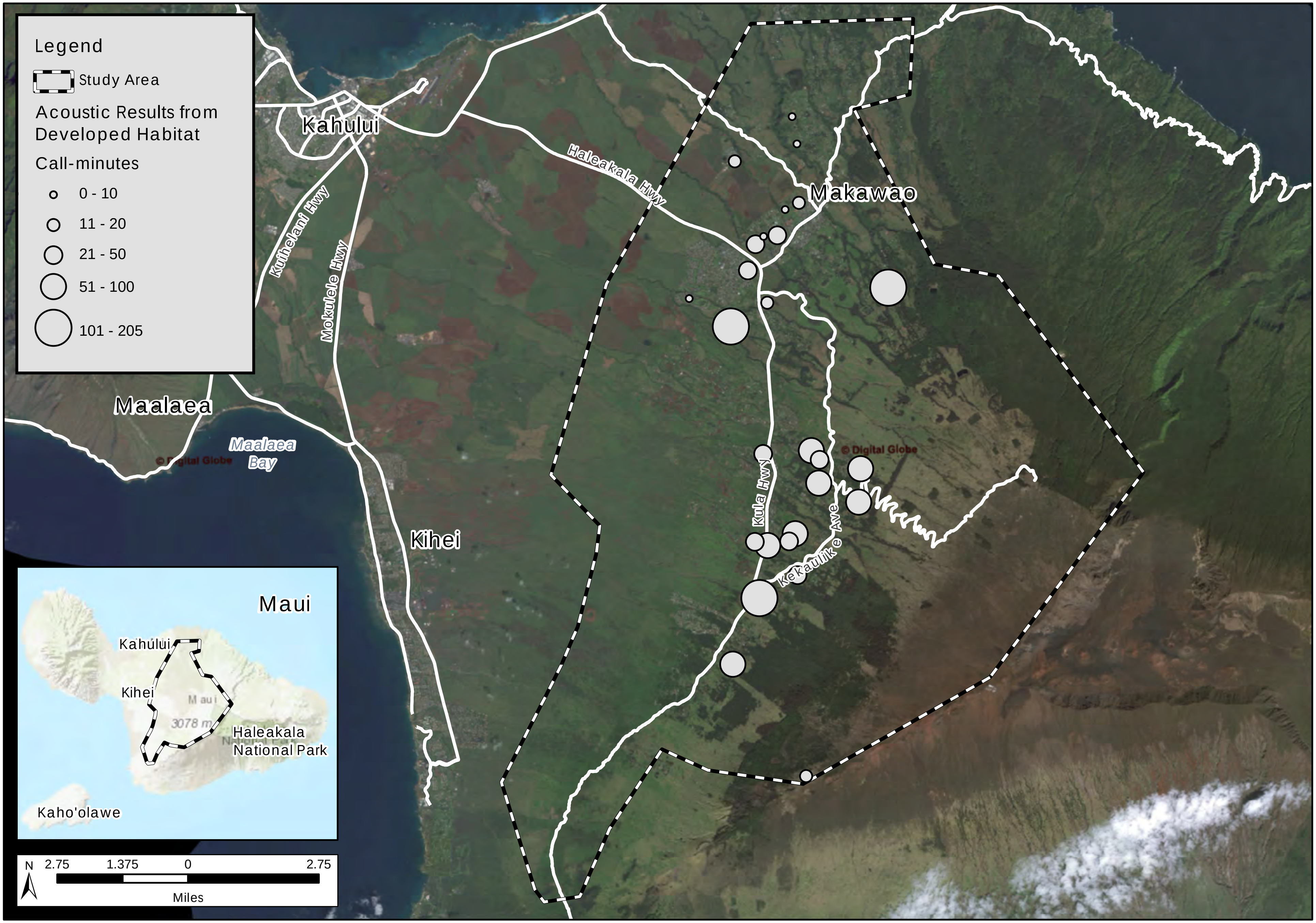
Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2018



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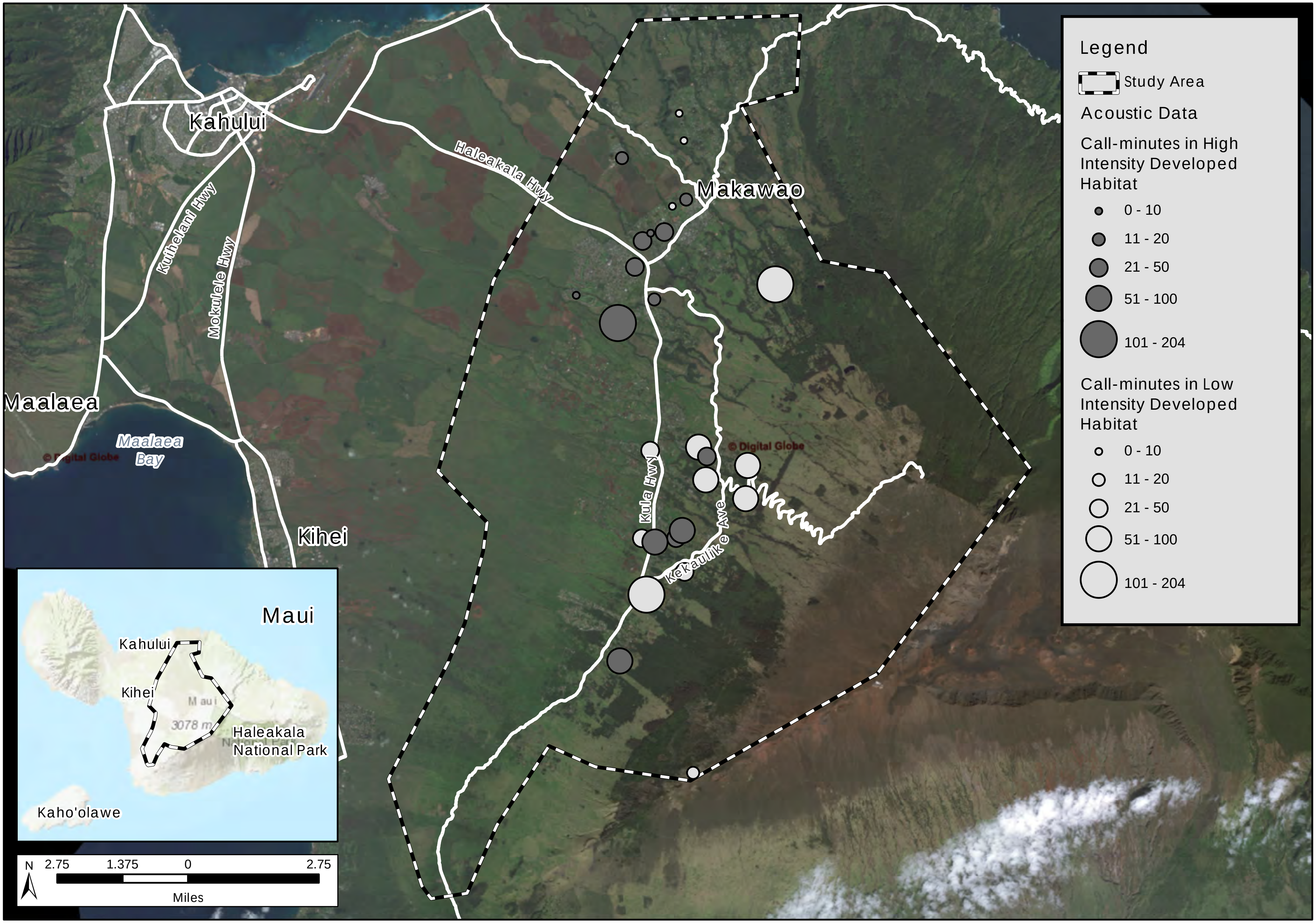
Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2018



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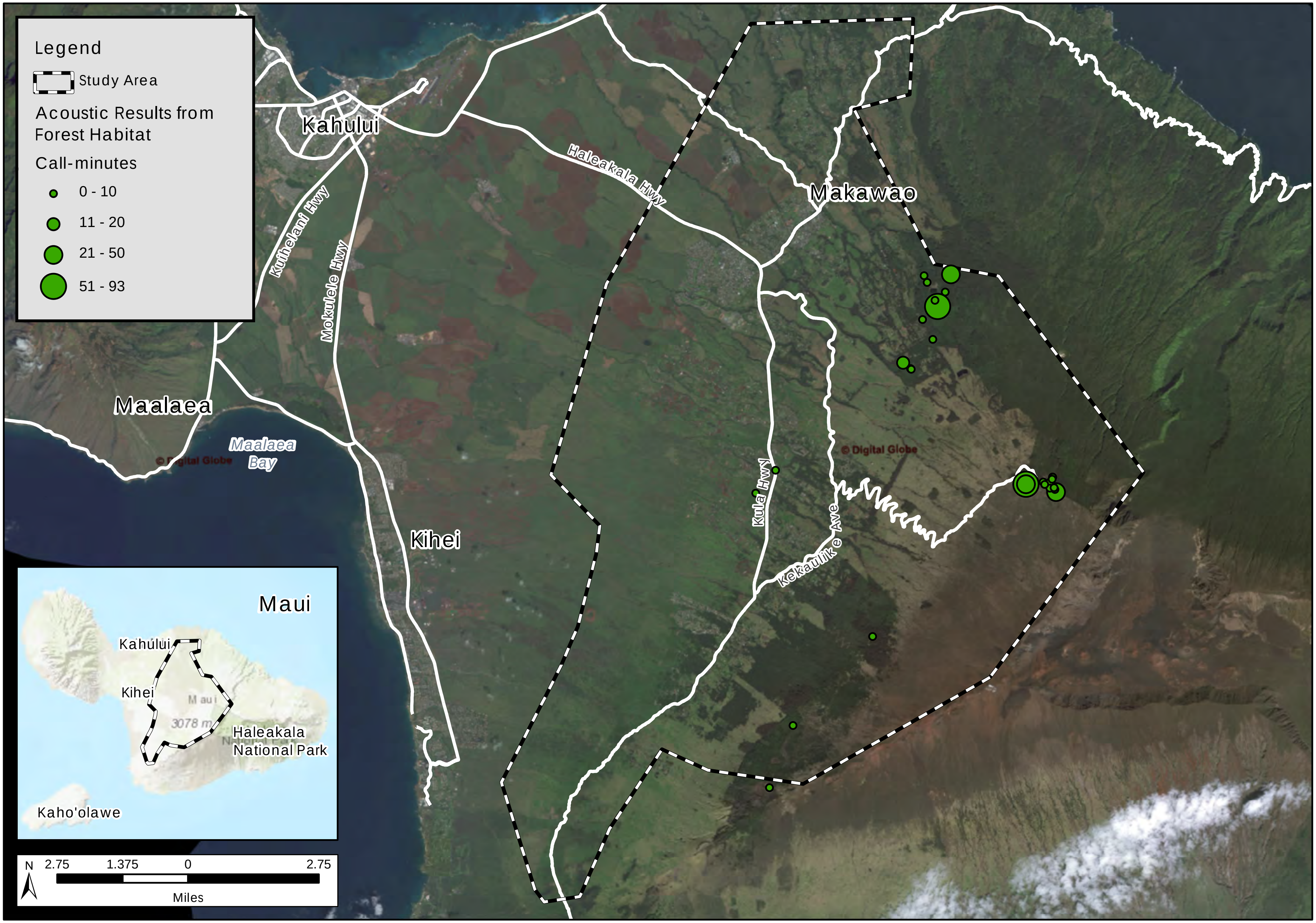
Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2018



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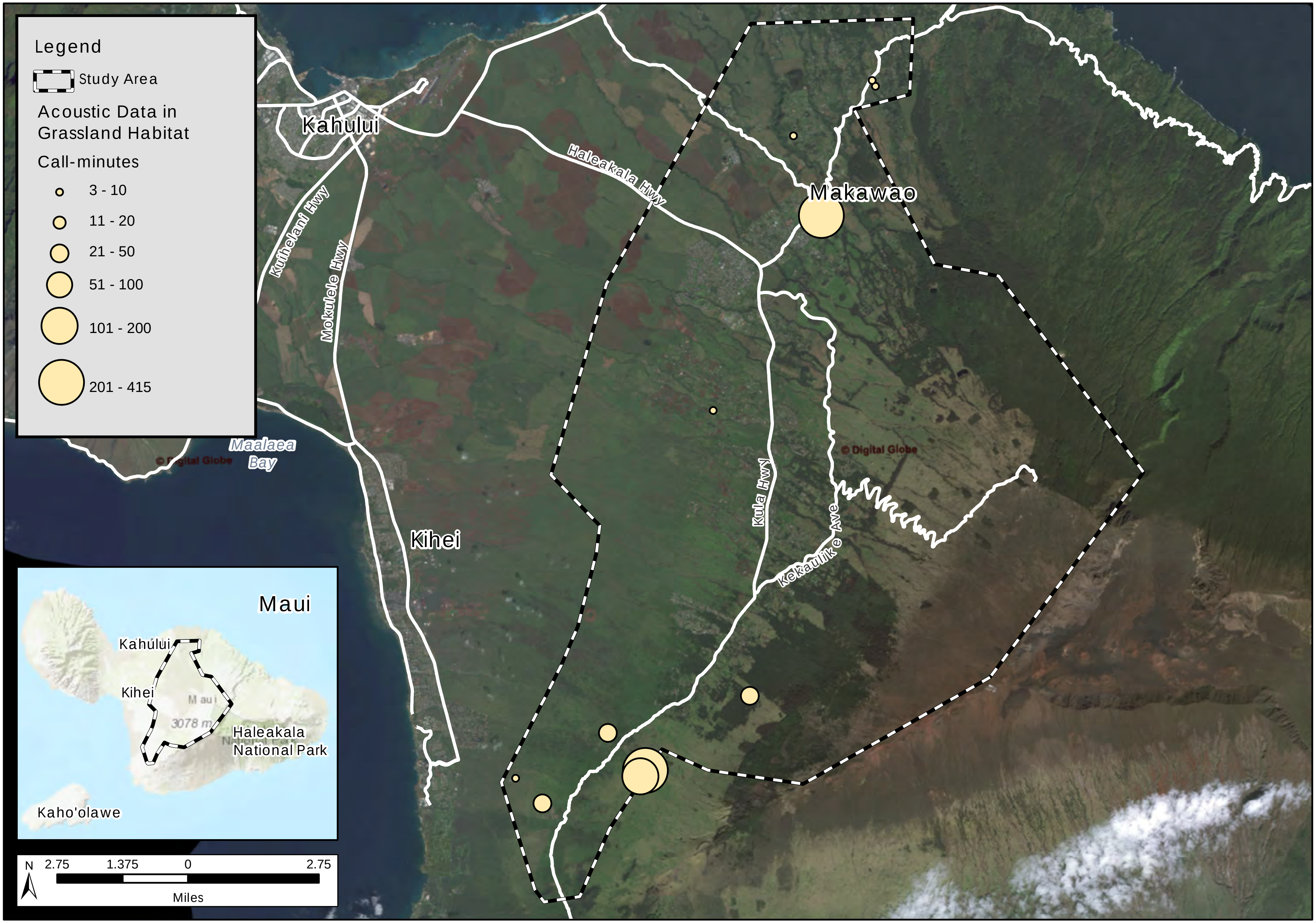
Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2018



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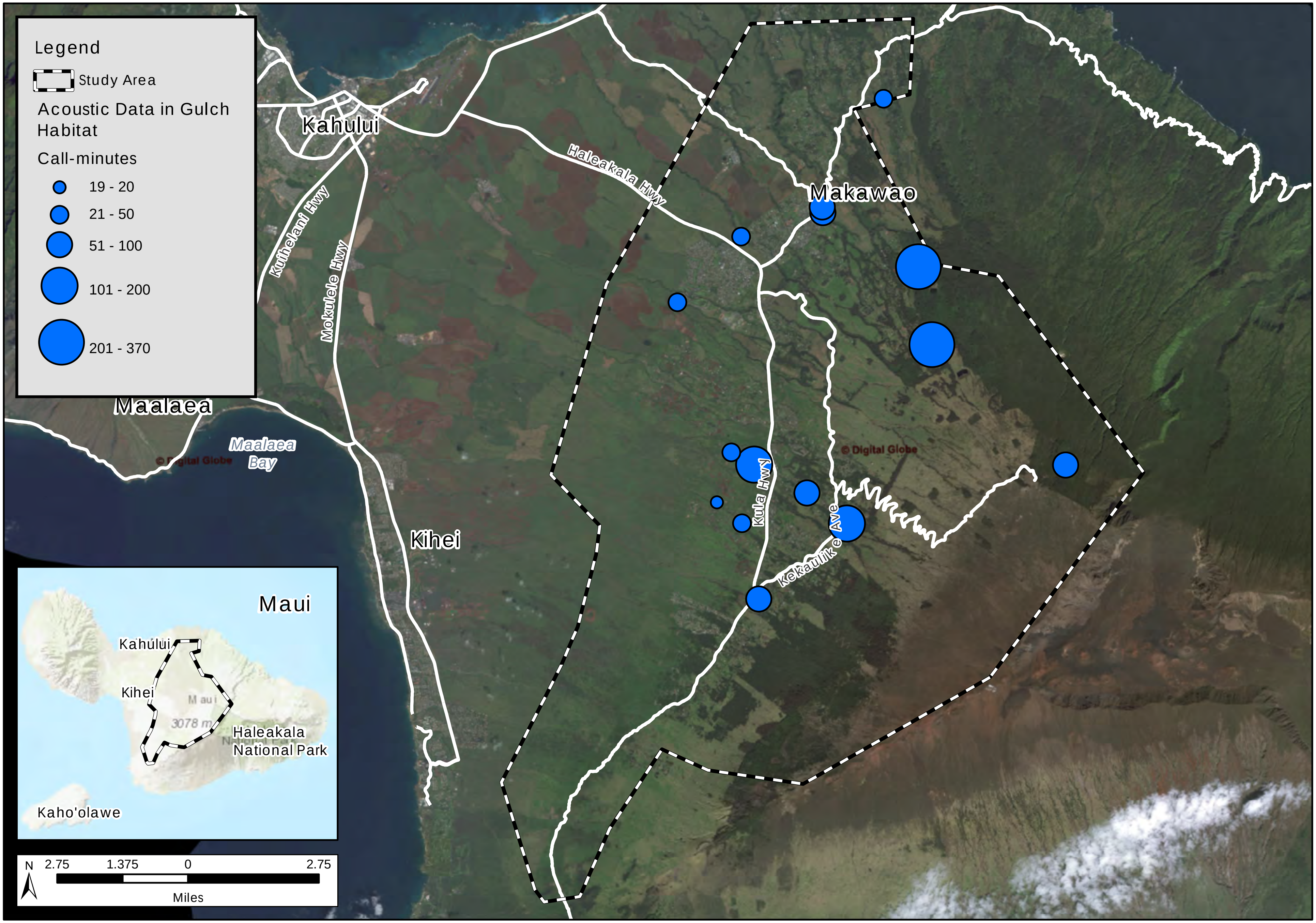
Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2018



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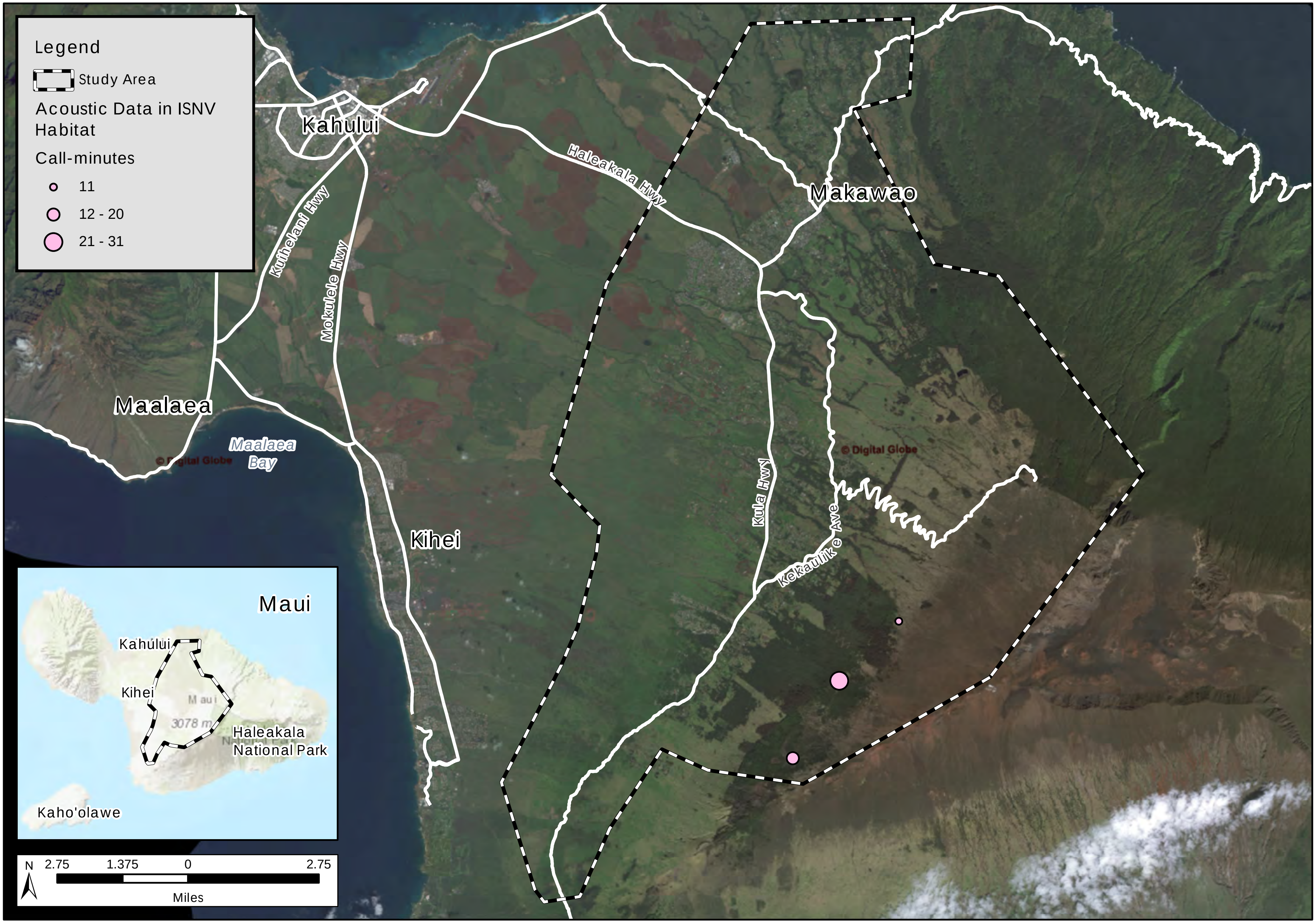
Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)
February 2018



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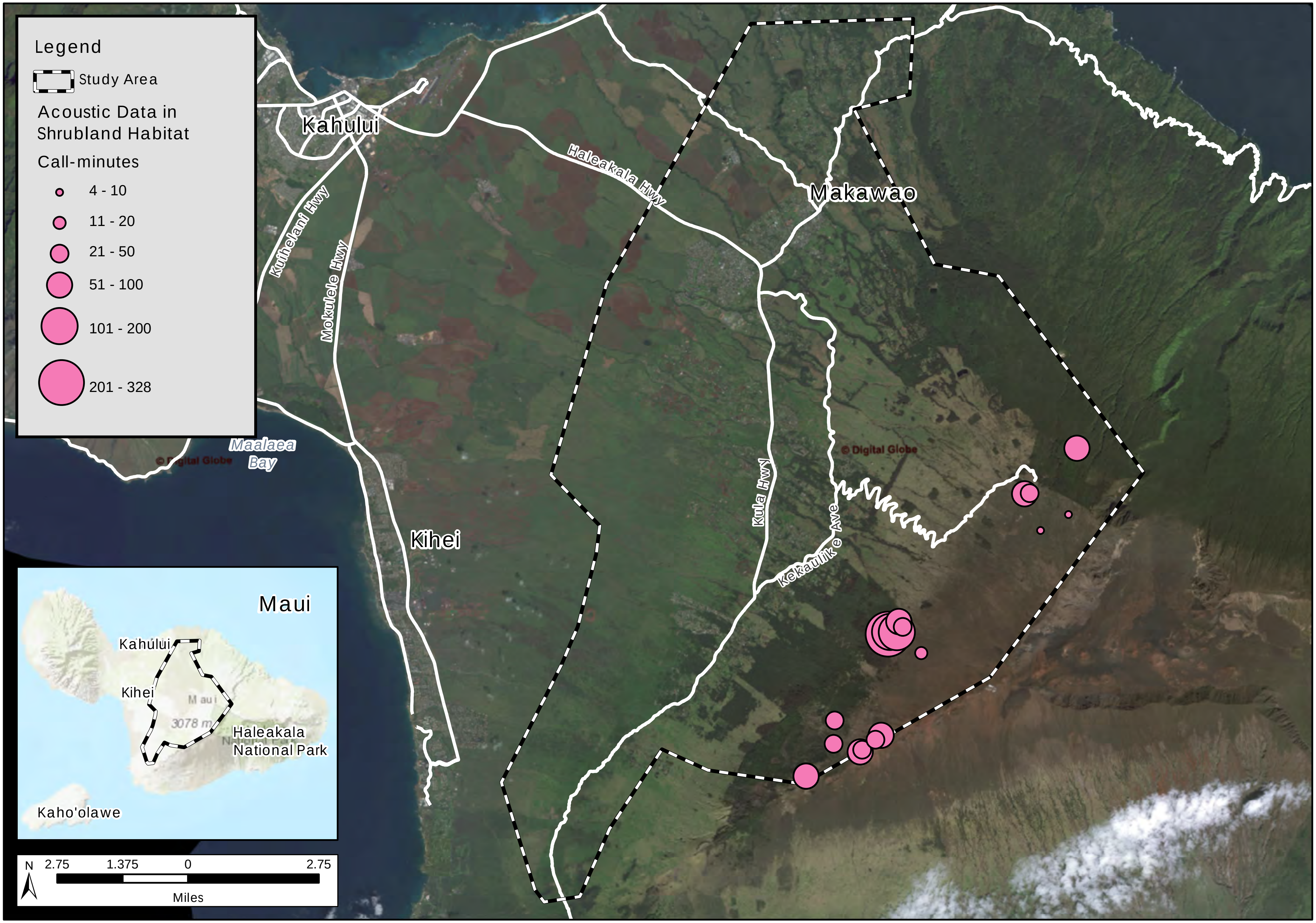
Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2018



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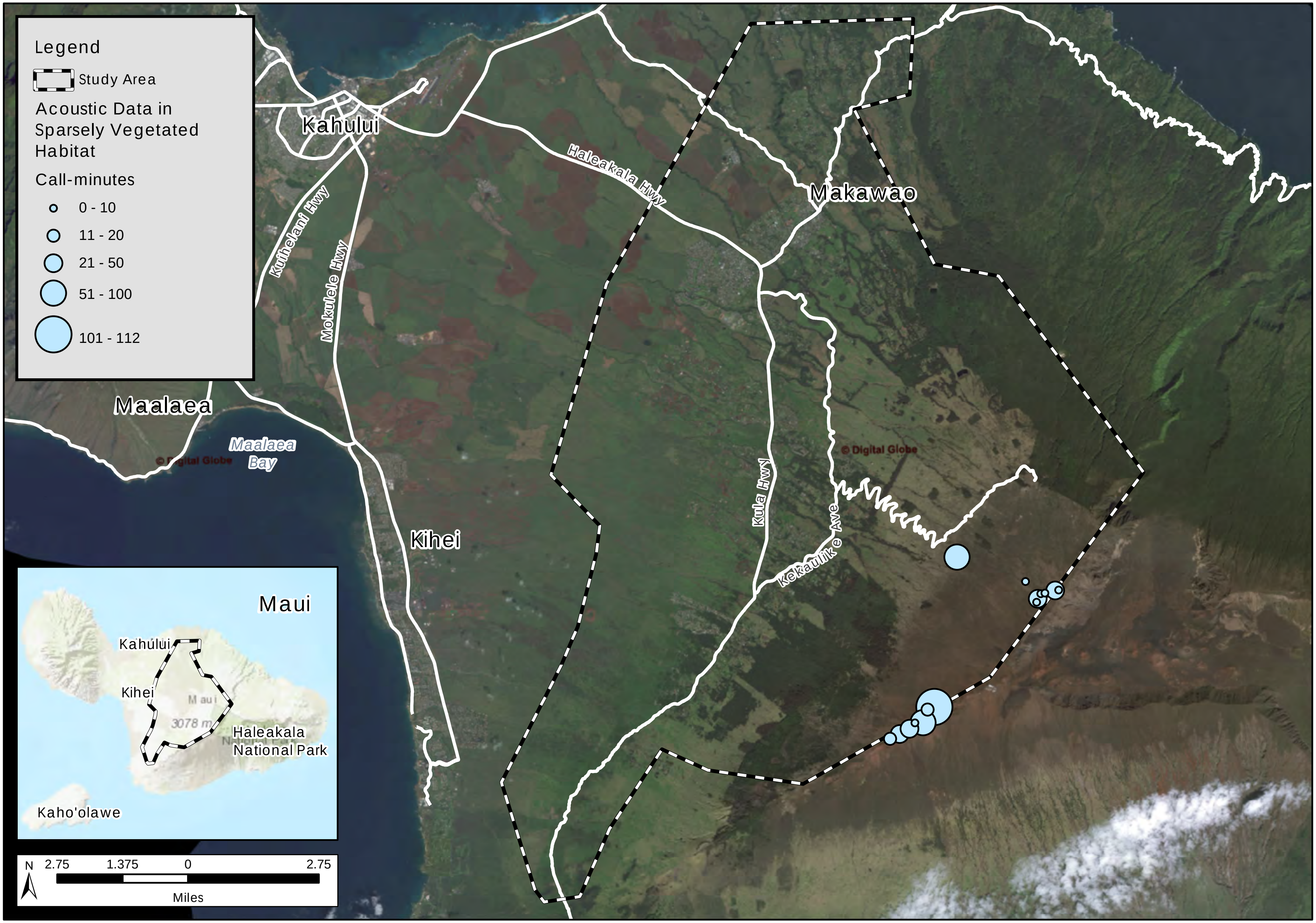
Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2018



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Acoustic Data Summary by Habitat

Ecology of the Hawaiian Hoary Bat (3978-01)
February 2018

Appendix E. Individual 50% Kernel (Core Use Areas) and 95% Kernel (Foraging Areas) for Individual Bats

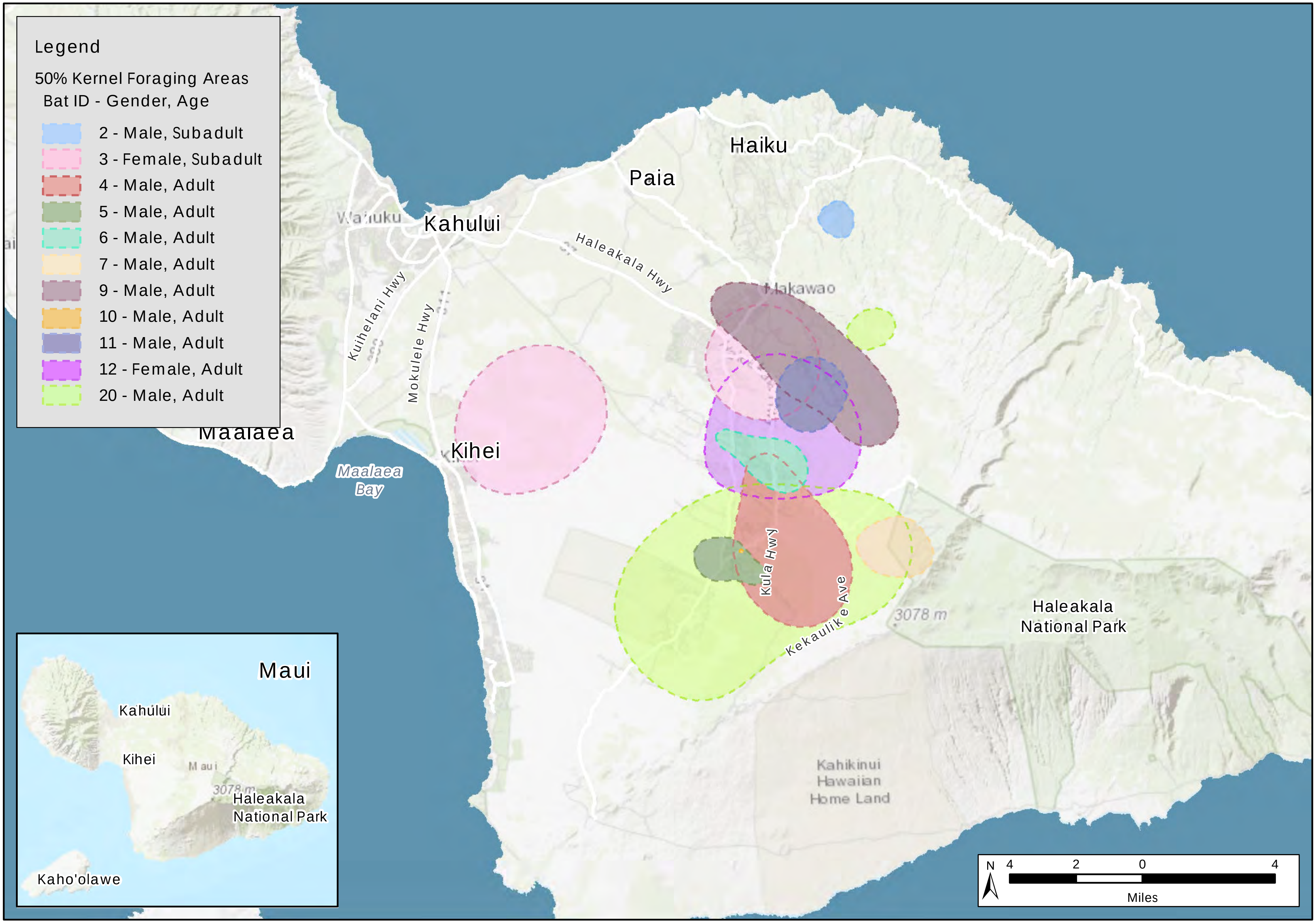

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Figure 11. Core Use Areas (50% Kernel**)**

Ecology of the Hawaiian Hoary Bat(3978-01)

August 2019

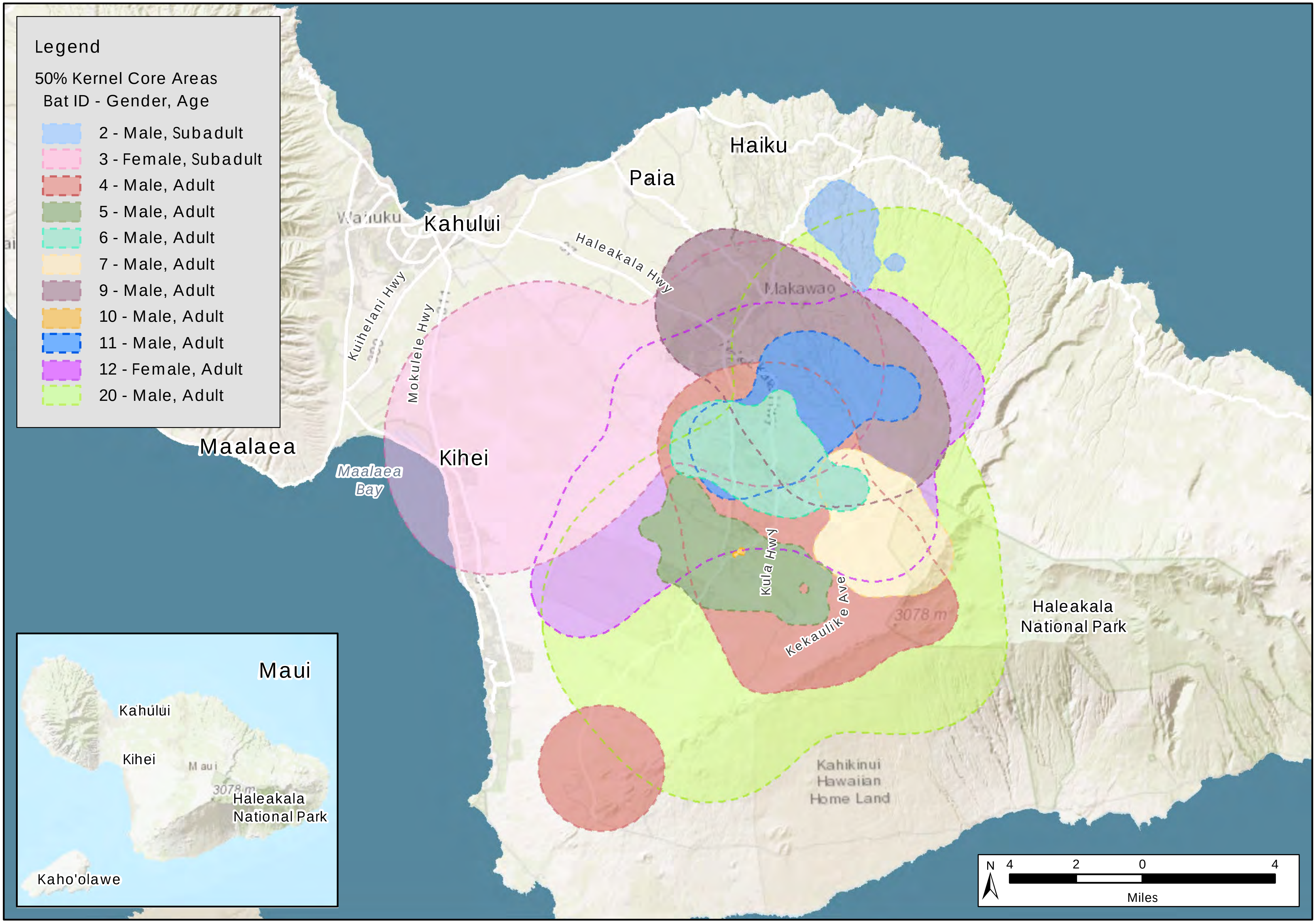

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Figure 12. Foraging Areas **(95% Kernel)**

Ecology of the Hawaiian Hoary Bat (3978-01) August 2019

Appendix F. Movement Accounts of each Radio-Tagged Bat

Bat 01, adult female, was captured in west Kula on July 16, 2017 and telemetry fixes were only obtained on one night, during which she flew south from Kula toward Keokea. Her roost was never located and because of the limited number of data points, no core use area was determined.

Bat 02, subadult male, was captured in west Kula on July 27, 2017 and tracked as he foraged from approximately 7:00 pm until 9:30 pm on six nights between August 1 and 7, 2017. He roosted and foraged within the forested gulches of Haiku. His foraging range was approximately 10 miles from his capture location in Kula. His homerange likely extended considerably further eastward, as telemetry signal was often lost in that direction during tracking, and was eventually lost in that direction completely. The 95% kernel area (foraging range) was calculated at 3,122 acres and the 50% kernel (CUA) was 583 acres.

Bat 03, subadult female, was captured near the entrance to Waihou Spring Trail on August 14, 2017 and tracked as she foraged from approximately 7:30 pm until 10:30 pm on two nights and from approximately 7:30 pm until 12:00 am on one night between August 15 and 17, 2017. She roosted in a forested gulch less than a mile from Makawao and foraged both in the gulch where her day roost was located and over cane fields up to 9 miles away. The 95% kernel area was 64,406 acres and the 50% kernel area was 16,081 acres.

Bat 04, adult male, was captured near the entrance to Waihou Spring Trail on September 7, 2017 and tracked as he foraged from approximately 6:00 pm until 9:30 pm on seven nights between September 8 and 18, 2017. He roosted in multiple gulches in Kula and foraged over a large area in the mixed forest and pasture of leeward Haleakala, approximately four miles away from his day roosts. On one night, he flew an additional nine miles to spend two hours in Ulupalakua before heading back. No part of this additional area in his foraging range made it into his 50% kernel CUA. The 95% kernel area was 45,721 acres and the 50% kernel area was 8,476 acres.

Bat 05, adult male, was captured in west Kula on September 22, 2017 and tracked as he foraged from approximately 6:30 pm to 8:00 pm on six nights between September 23 and 28, 2017. He roosted in multiple nonnative trees, all adjacent to roads in Kula. His day- and night-roost trees were within his foraging range and he appeared to forage primarily over a complex low-density developed landscape. The 95% kernel area was 8,926 acres and the 50% kernel area was 1,420 acres.

Bat 06, adult male, was captured near the entrance to Waihou Spring Trail on October 2, 2017 and tracked as he foraged from approximately 6:00 pm until 8:30 pm on four nights between October 3 and 7, 2017. He used a stand of silk oaks (*Grevillea robusta*) in northwest Kula for both day and night roosts and foraged over a large area approximately 3 miles away from his roost. His foraging range included both a low-density developed landscape and forested pasture. The 95% kernel area was 9,160 acres and the 50% kernel area was 1,961 acres.

Bat 07, adult male, was captured over a pond just upslope of Haleakala National Park Headquarters on January 10, 2018 and tracked as he foraged from approximately 7:00 pm to 9:00 pm on six nights between January 11 and January 16, 2018. He roosted in the forest downslope of Haleakala National Park and slowly weaved his way upslope and into the National Park each evening. His foraging range included shrub, pasture, and gulches at forest edges, and his core-use area was mainly high-elevation shrubland and gulches. On Jan 11, his signal was lost after the bat flew through Haleakala Crater and no triangulations could be obtained. The last signal on bat 07 showed the bat leaving the National Park and flying westerly where continued tracking was not possible. The 95% kernel area was 8,696 acres and the 50% kernel area was 2,081 acres.

Bat 08, adult male, was captured outside of the forest adjacent to the Haleakala National Park Entrance Station on February 2, 2018. He was searched for, but his signal was never located.

Bat 09, adult male, was captured near the entrance to Waihou Spring Trail on February 20, 2018 and tracked as he foraged from approximately 6:30 pm until 8:30 pm on seven nights between February 23 and March 2, 2018. He roosted in Haiku, but flew directly to the area around Makawao to forage. His foraging range appeared to consist primarily of forest, forested gulches, and forest clearings. Although his foraging range includes the highly developed portions of Makawao, all positions of the bat in the town were on the outskirts, which suggests that he was avoiding the urban center and foraging in the low density population fringes of the town. The 95% kernel area was 30,636 acres and the 50% kernel area was 8,726 acres.

Bat 10, adult male, was captured outside of the forest adjacent to the Haleakala National Park Entrance Station on March 7, 2018 at 7:45 pm. Although he was caught early in the night, he had already fed and produced guano that included recognizable bits of beetle chitin. He was tracked as he foraged from approximately 7:30 pm to 9:00 pm on three nights (March 9, 10, and 11, 2018). He day roosted in a loquat tree (*Eriobotrya japonica)* next to a house in a low-density developed part of south Kula. Each night that he was tracked, he foraged in a very small area near his roost which appeared abundant with scarab beetles. Although he stayed in a very small part of his range during the window of time when he was tracked, the entirety of his calculated foraging range was approximately 5 miles from his capture site. The 95% kernel area was 36 acres and the 50% kernel area was 7 acres.

Bat 11, adult male, was captured near the entrance to Waihou Spring Trail on March 21, 2018 and tracked as he foraged from approximately 7:00 pm until 8:30 pm on three nights between March 22 and March 29, 2018. He roosted in, or near to, Waihou Spring Forest Reserve, but foraged south of it, over a large section of the pastures east of Haleakala Highway. Based on the rapid attenuations in telemetry signals observed while tracking bat 11, we believe that much of his foraging time was spent at gulches and possibly very dense treelines. The area of the 95% kernel foraging range calculated for bat 11 was acres and the area of the 50% kernel CUA was acres. The 95% kernel area was 12,871 acres and the 50% kernel area was 2,399 acres.

Bat 12, adult female, was captured near the entrance to Waihou Spring Trail on June 19, 2018 and tracked as she foraged from approximately 7:30 pm until 8:30 pm on the nights of June 20 – 23, and from approximately 7:30 pm until 9:30 pm on the night of June 24, 2018. Roosting signal could not be detected during the daytime, despite first flying signal emerging in north Kula, just south of Makawao, suggesting that she roosted in a nearby gulch. She foraged in and around multiple gulches in Kula, both upslope and downslope of Haleakala Highway. On the night of June 24, 2018, she flew a slow 40-minute circuit around her CUA, presumably foraging, or looking for a place to forage, briefly foraged in a gulch within her CUA, then left her previous foraging range completely, heading downslope from south Kula in the direction of Wailea. The 95% kernel area was 57,721 acres and the 50% kernel area was 10,538 acres.

Bat 13, adult male, was captured near the entrance to Waihou Spring Trail on July 17, 2018. He was searched for, but his signal was never detected.

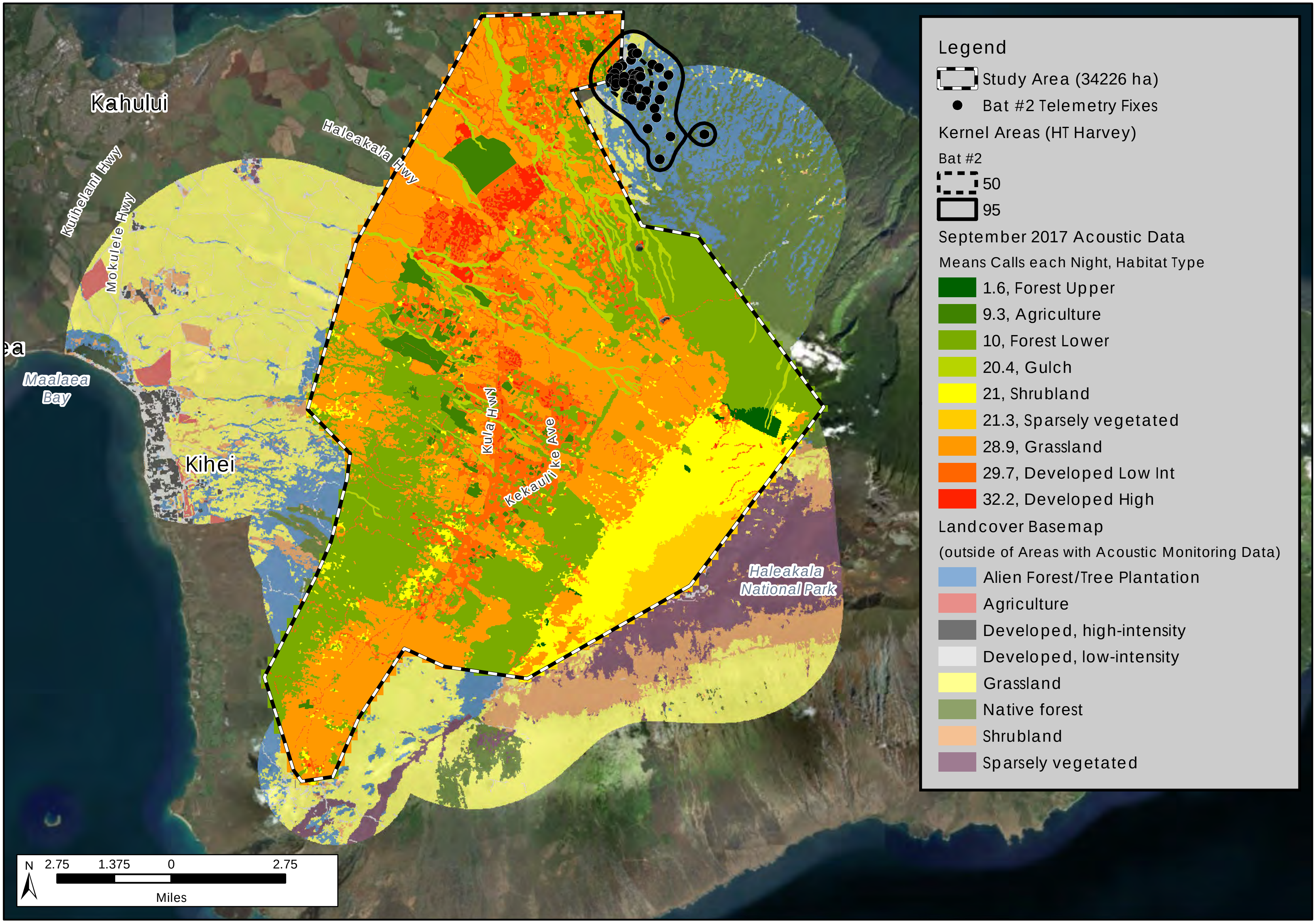
Bat 14, subadult male, was captured near the entrance to Waihou Spring Trail on August 5, 2018. Two single bearings were obtained on August 6, 2018 at 7:14 and 7:19 PM of the bat heading southward east of Haleakala Highway. Signal was never located again after this.

Bats 15 through 18 were not radio-tagged because we were waiting for the manufacturer to send us additional radio tags. Nonetheless, guano was recovered from these bats that was used in the diet studies.

Bat 19, subadult male, was captured near the entrance to Waihou Spring Trail on September 2, 2018. Bat 15 could only be faintly heard for a few minutes each night while leaving its roost north of Haleakala National Park with no better vantage points to track from.

Bat 20, adult male, was captured outside of the forest adjacent to the Haleakala National Park Entrance on September 18, 2018 and tracked as he foraged from approximately 7:30 pm to 9:00 pm on five nights between September 23 and October 3, 2018. Although his day-roost was never located, it is likely that he roosted near to, or within, Polipoli Spring State Recreation Area based on triangulations obtained just after he left his roost each evening. Each night after leaving his roost, bat 20 followed a similar routine, foraging initially in Keokea and South Kula before rapidly moving to another area: the forested area near Waihou Spring Trail on two nights and near the capture site in Haleakala National Park on two nights. The area of the 95% kernel foraging range calculated for bat 20 was acres and the area of the 50% kernel CUA was acres. The 95% kernel area was 200,597 acres and the 50% kernel area was 48,762 acres.

Appendix G. Foraging Range and Core Use Areas with the Distribution of Telemetry Fixes Superimposed on the Study Area Habitat Map



N:\Projects3900\3978-01\Figures\Home Range Report\Bat2 over Acoustic Habs.mxd

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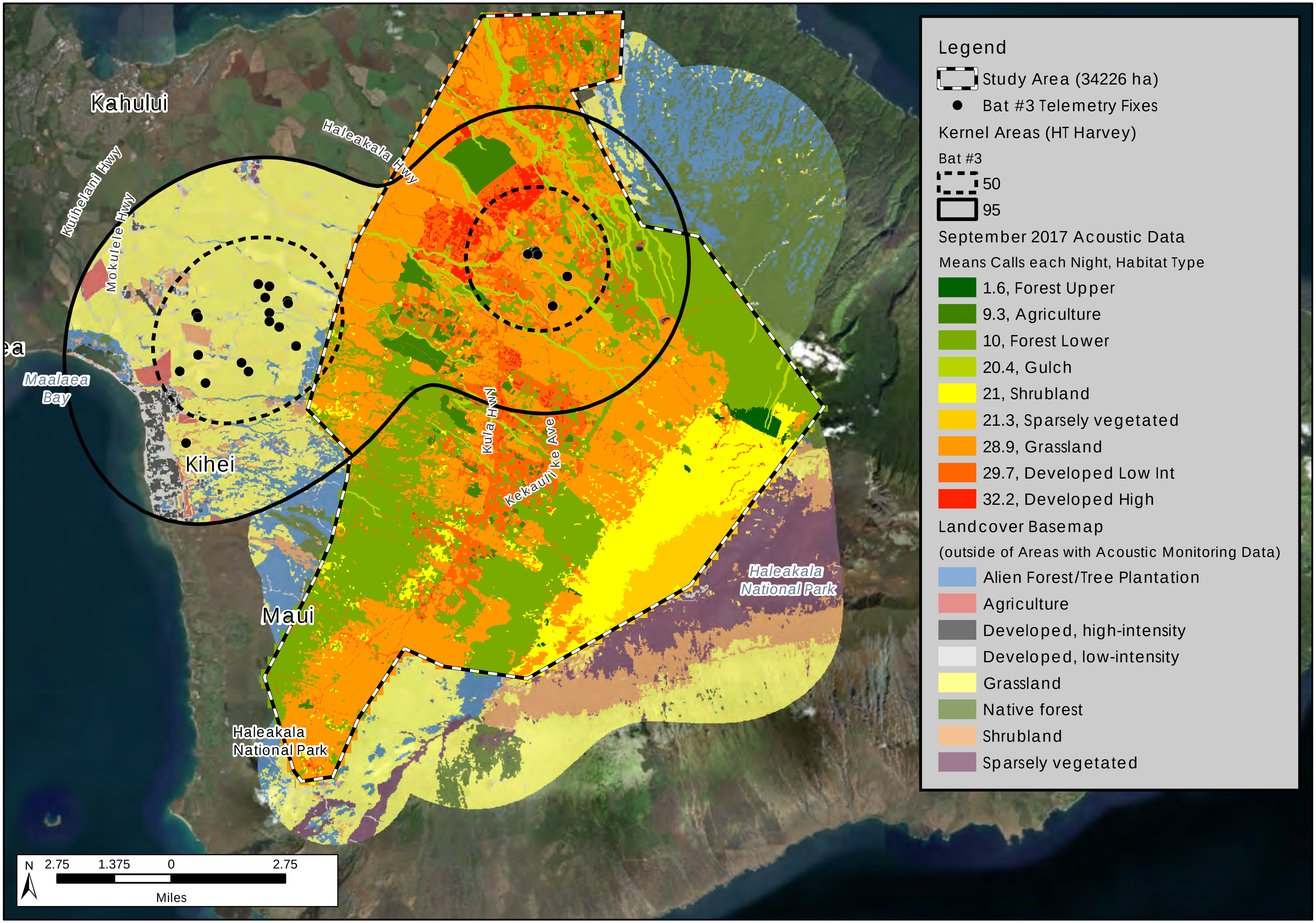
Bat #2 Telemetry Over September 2017 Acoustic Monitoring Data

Ecology of the Hawaiian Hoary Bat (3978-01)
February 2020



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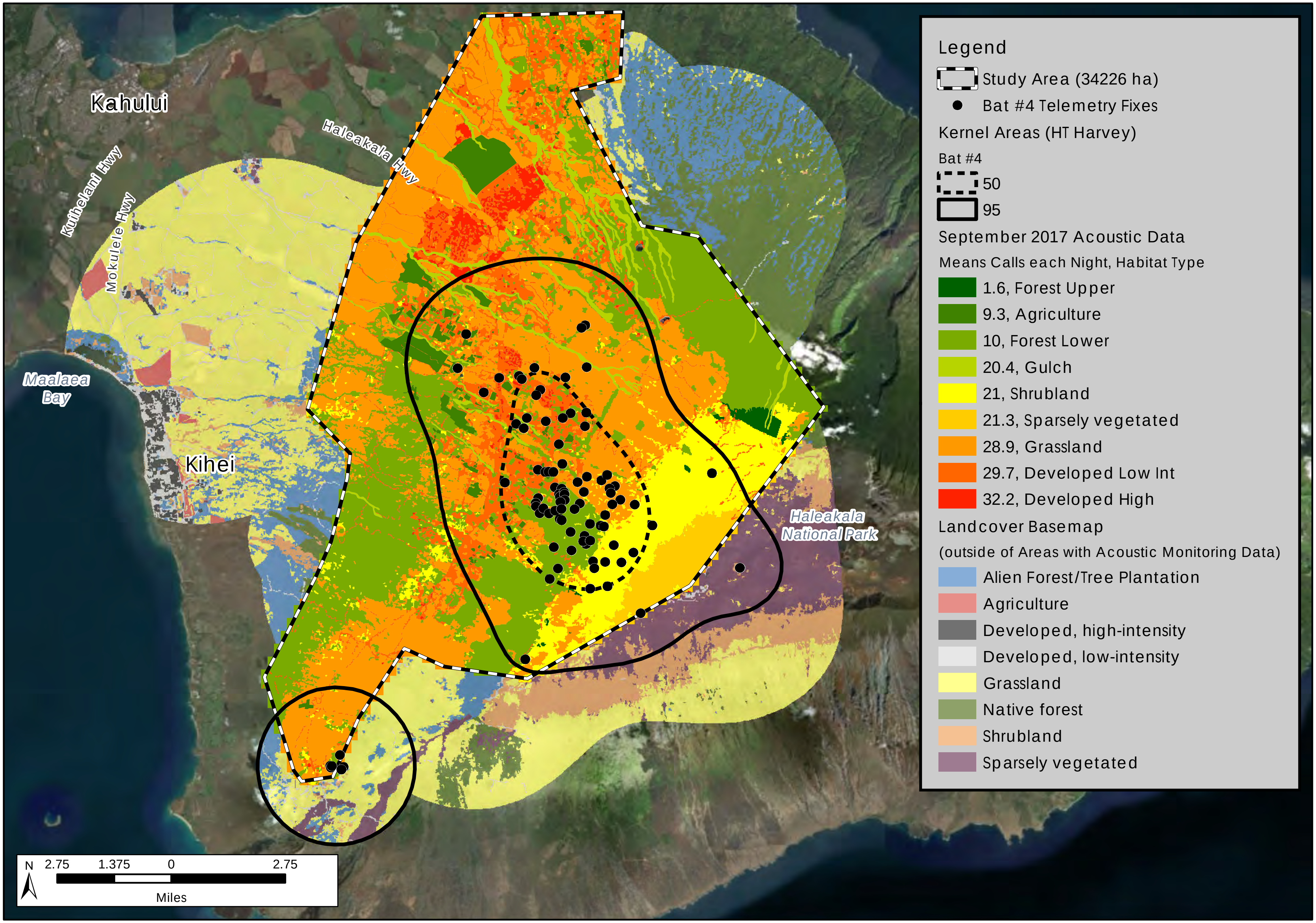
Bat #3 Telemetry Over Acoustic Data per Habitat for September 2017

Ecology of the Hawaiian Hoary Bat (3978-01)
February 2020



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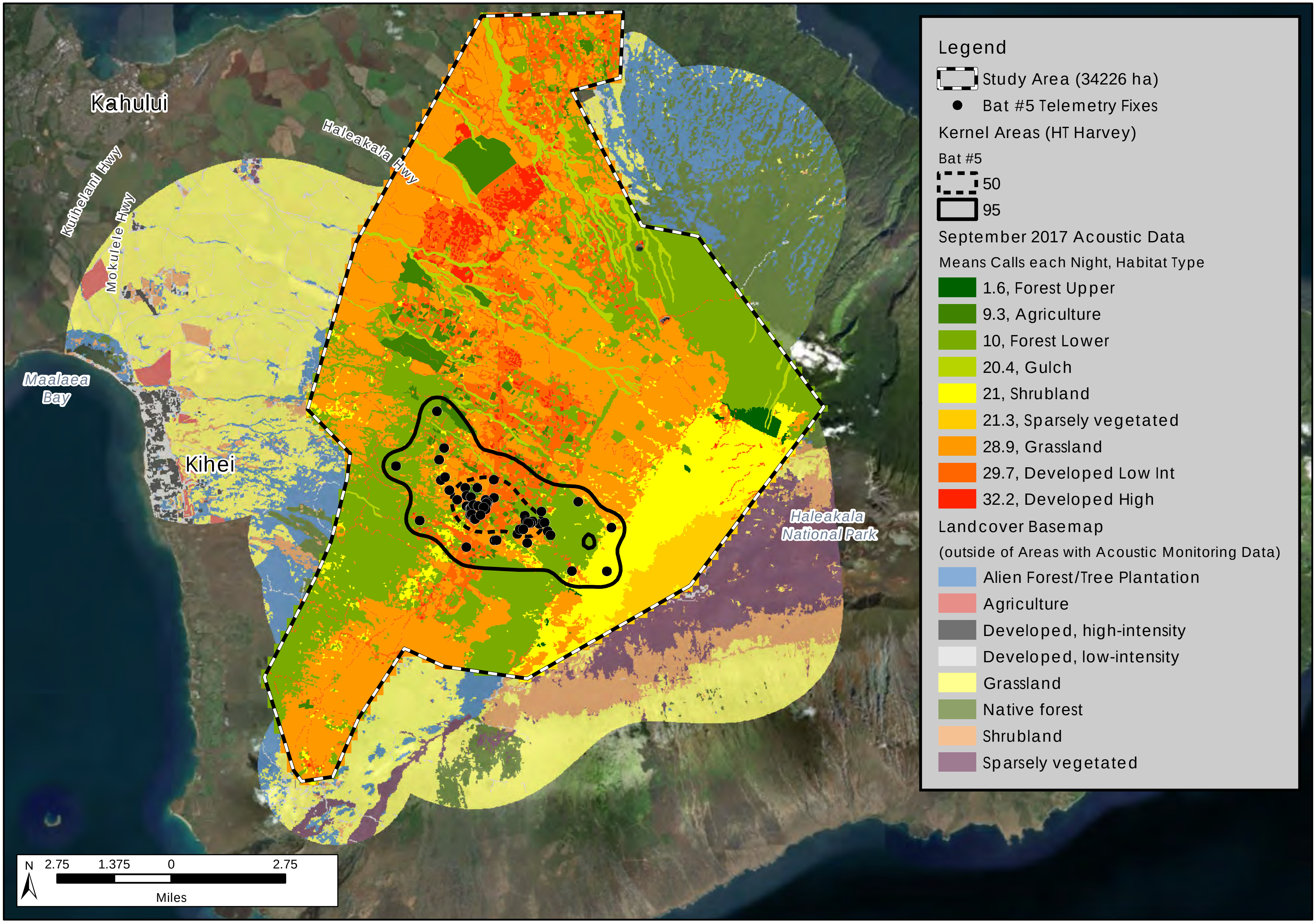
Bat #4 Telemetry Over September 2017 Acoustic Monitoring Data
Ecology of the Hawaiian Hoary Bat (3978-01)
February 2020



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Bat #5 Telemetry Over September 2017 Acoustic Monitoring Data

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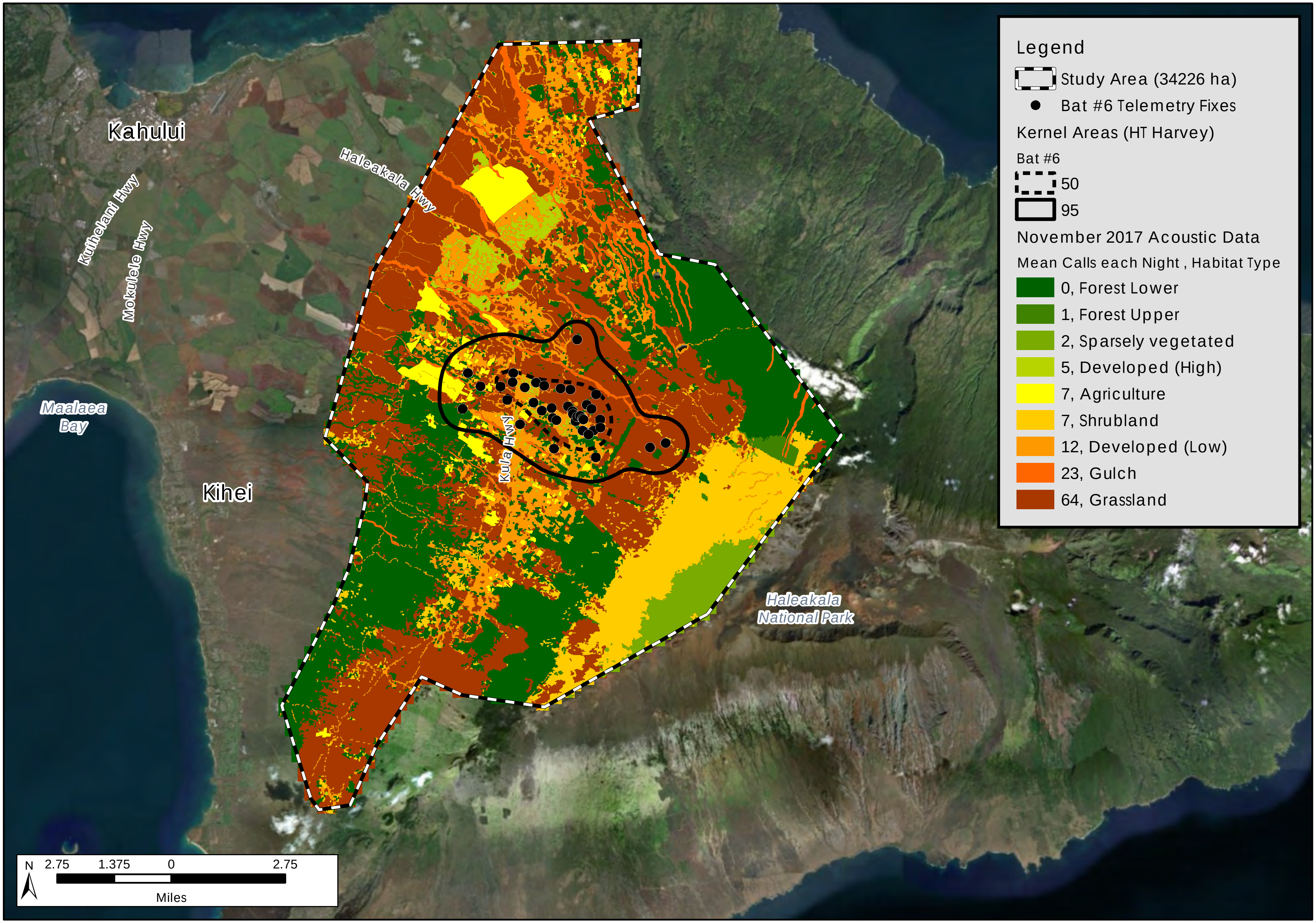
February 2020



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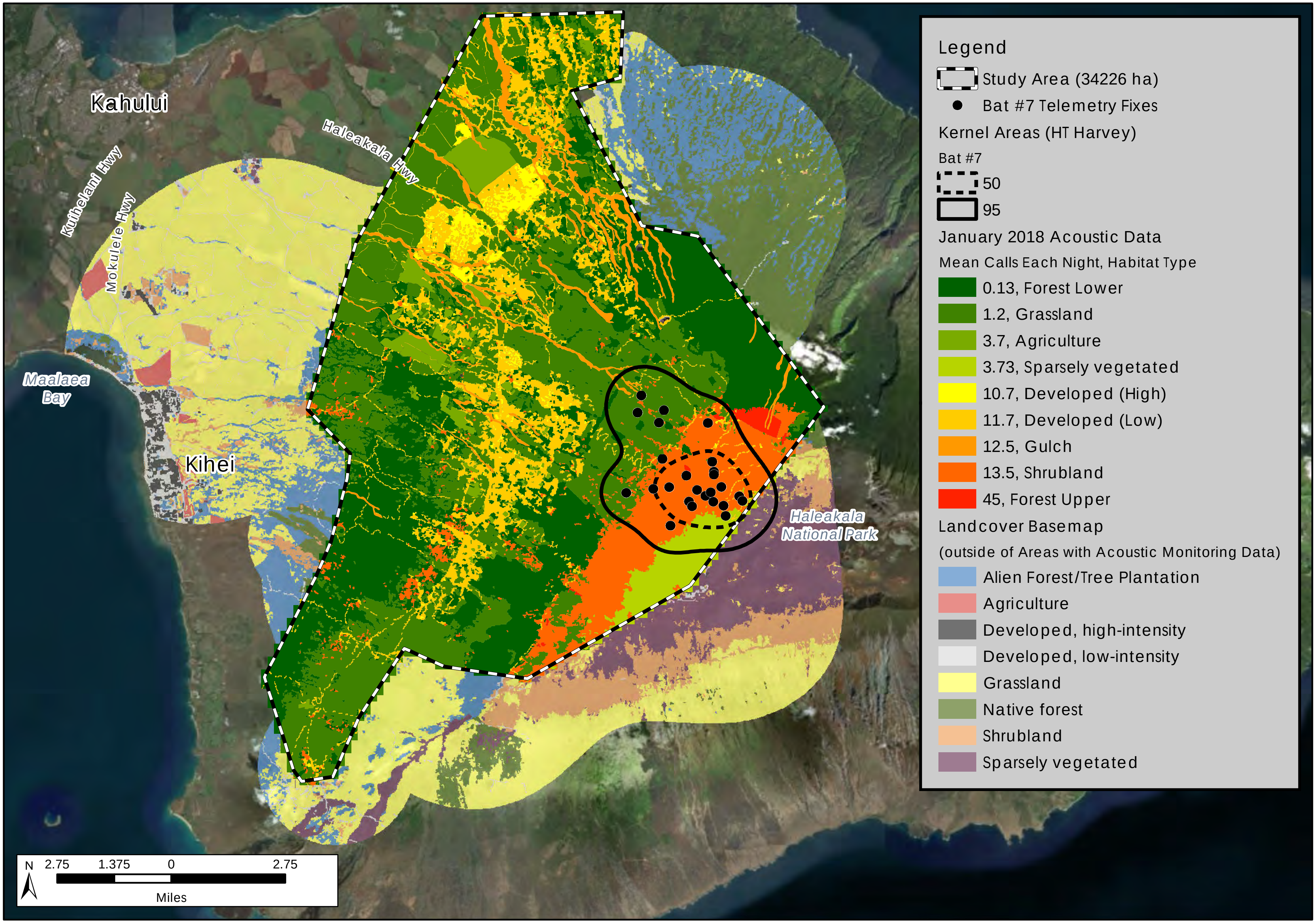
Bat #6 Telemetry Over November 2017 Acoustic Monitoring Data

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2020



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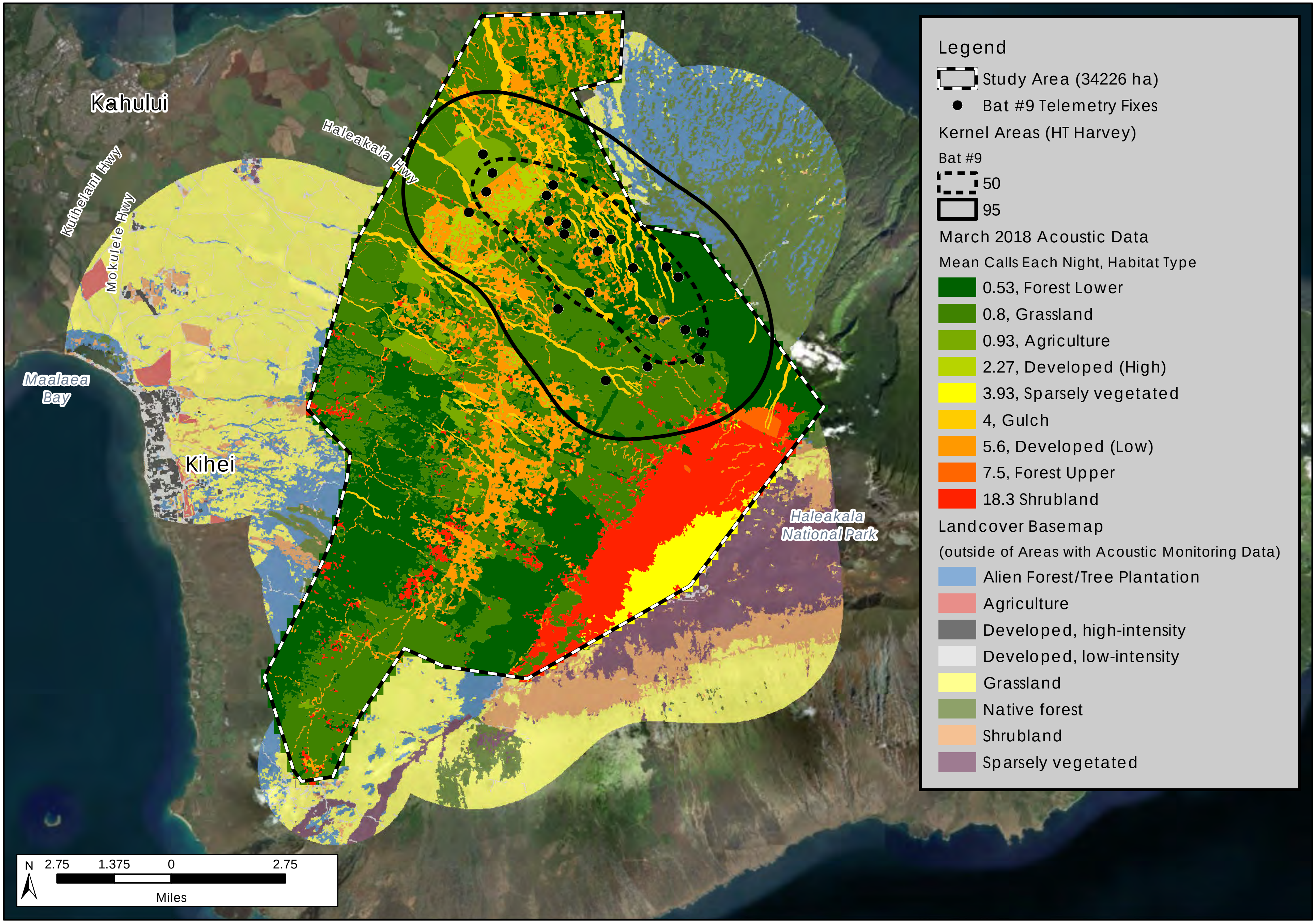
Bat #7 Telemetry Over January 2018 Acoustic Monitoring Data
Ecology of the Hawaiian Hoary Bat (3978-01)
February 2020



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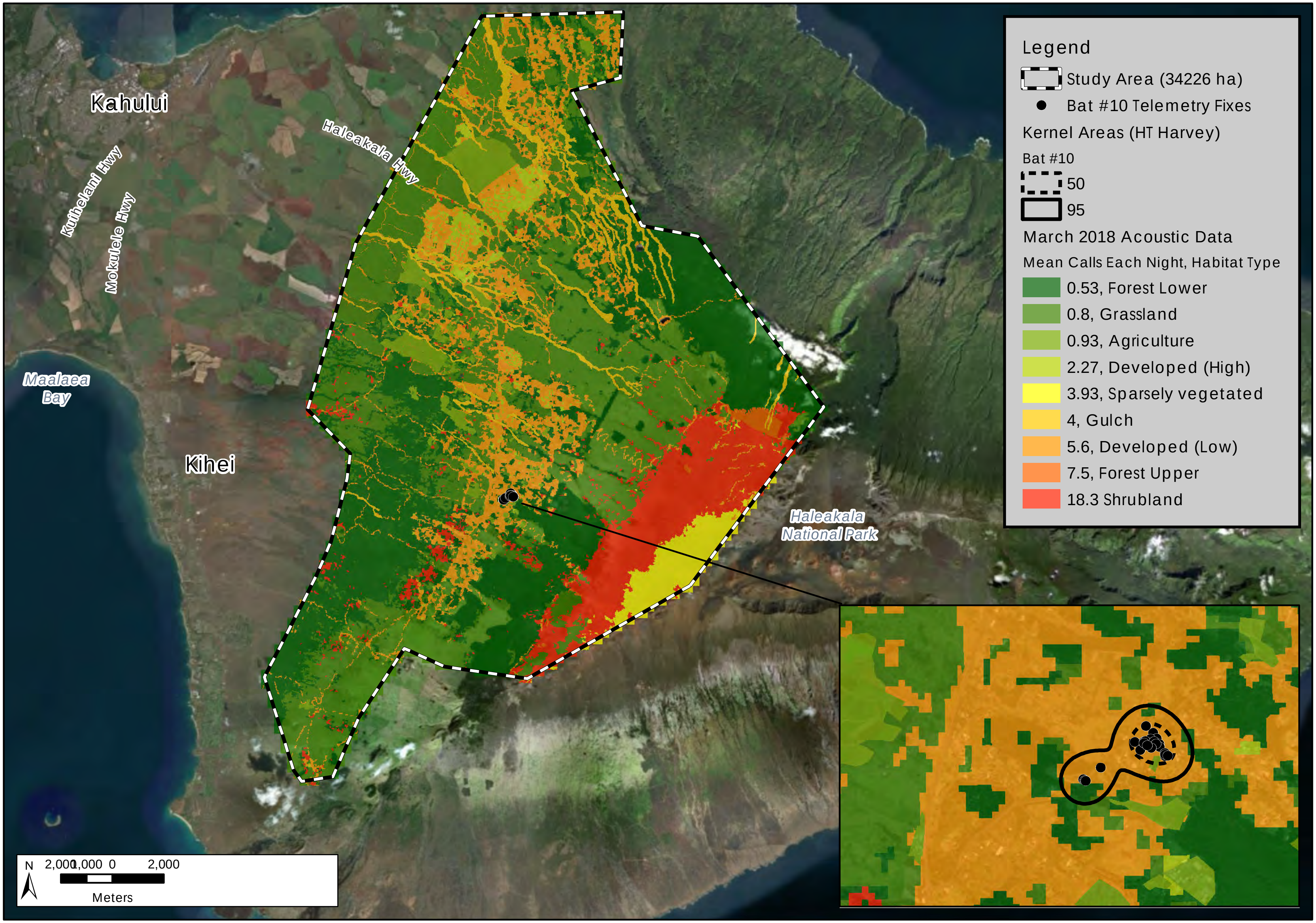
Bat #9 Telemetry Over March 2018 Acoustic Monitoring Data

Ecology of the Hawaiian Hoary Bat (3978-01)
February 2020



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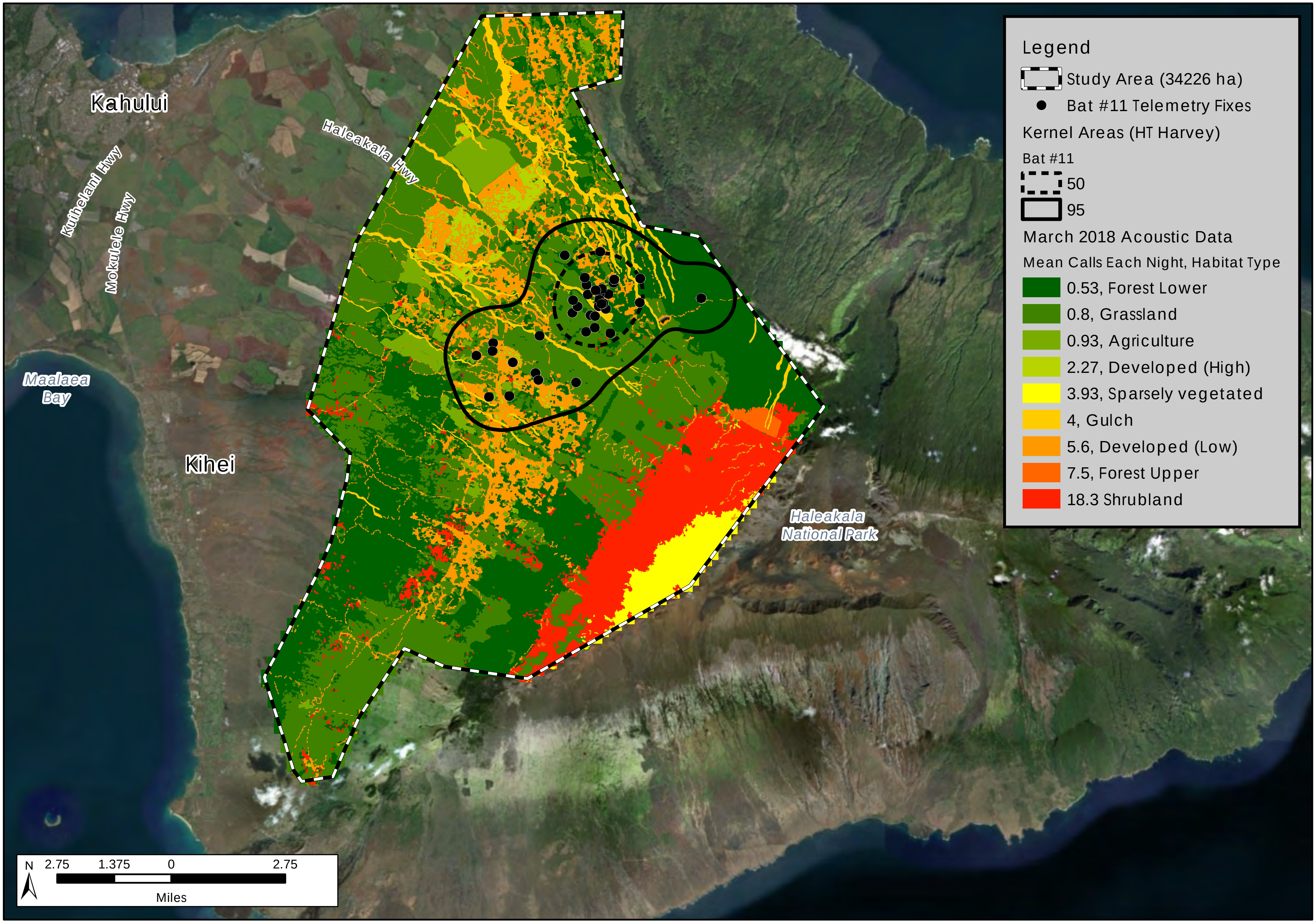
Bat #10 Telemetry Over March 2018 Acoustic Monitoring Data

Ecology of the Hawaiian Hoary Bat (3978-01)

February 2020



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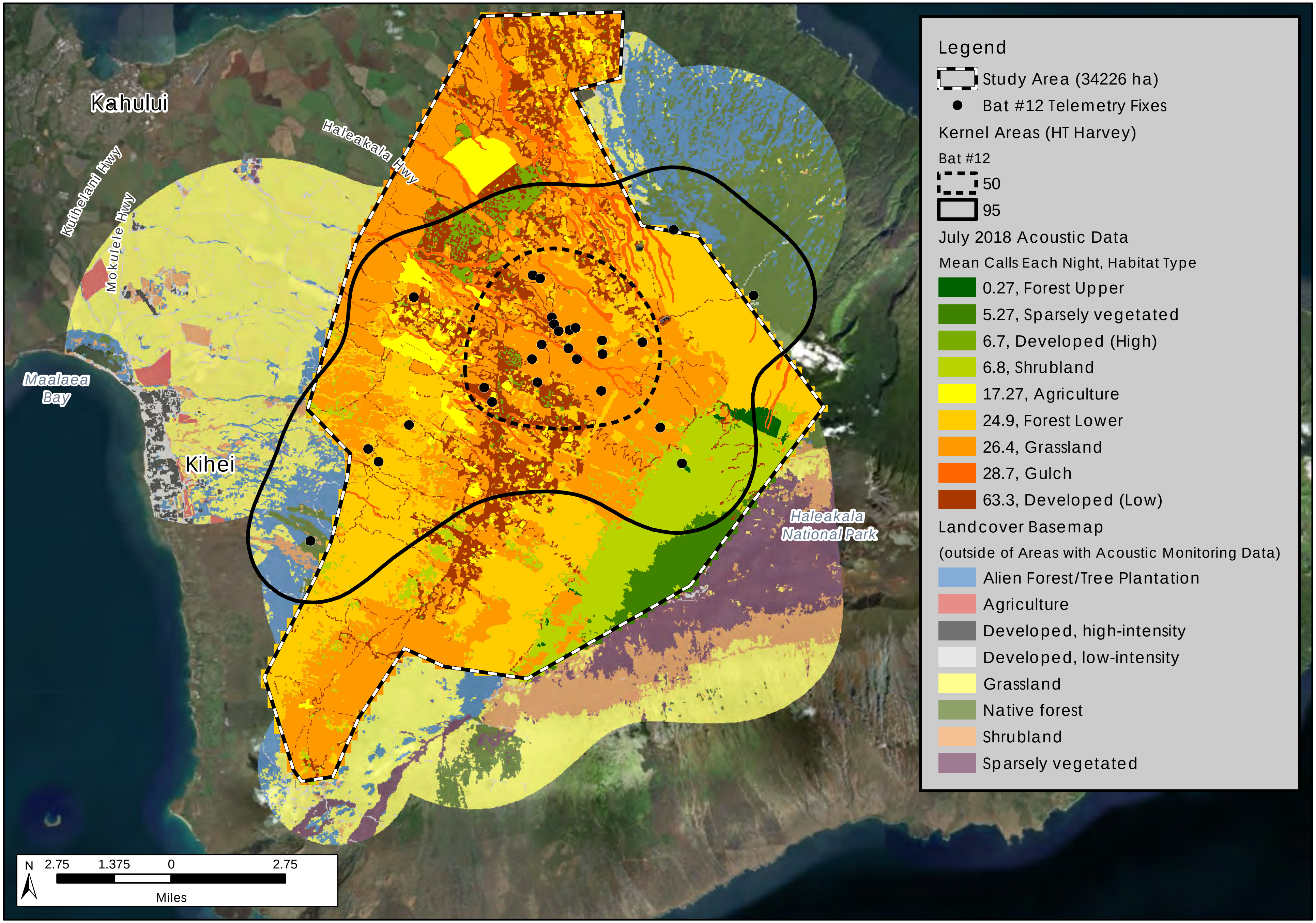
Bat #11 Telemetry Over March 2018 Acoustic Monitoring Data

Ecology of the Hawaiian Hoary Bat (3978-01)
February 2020



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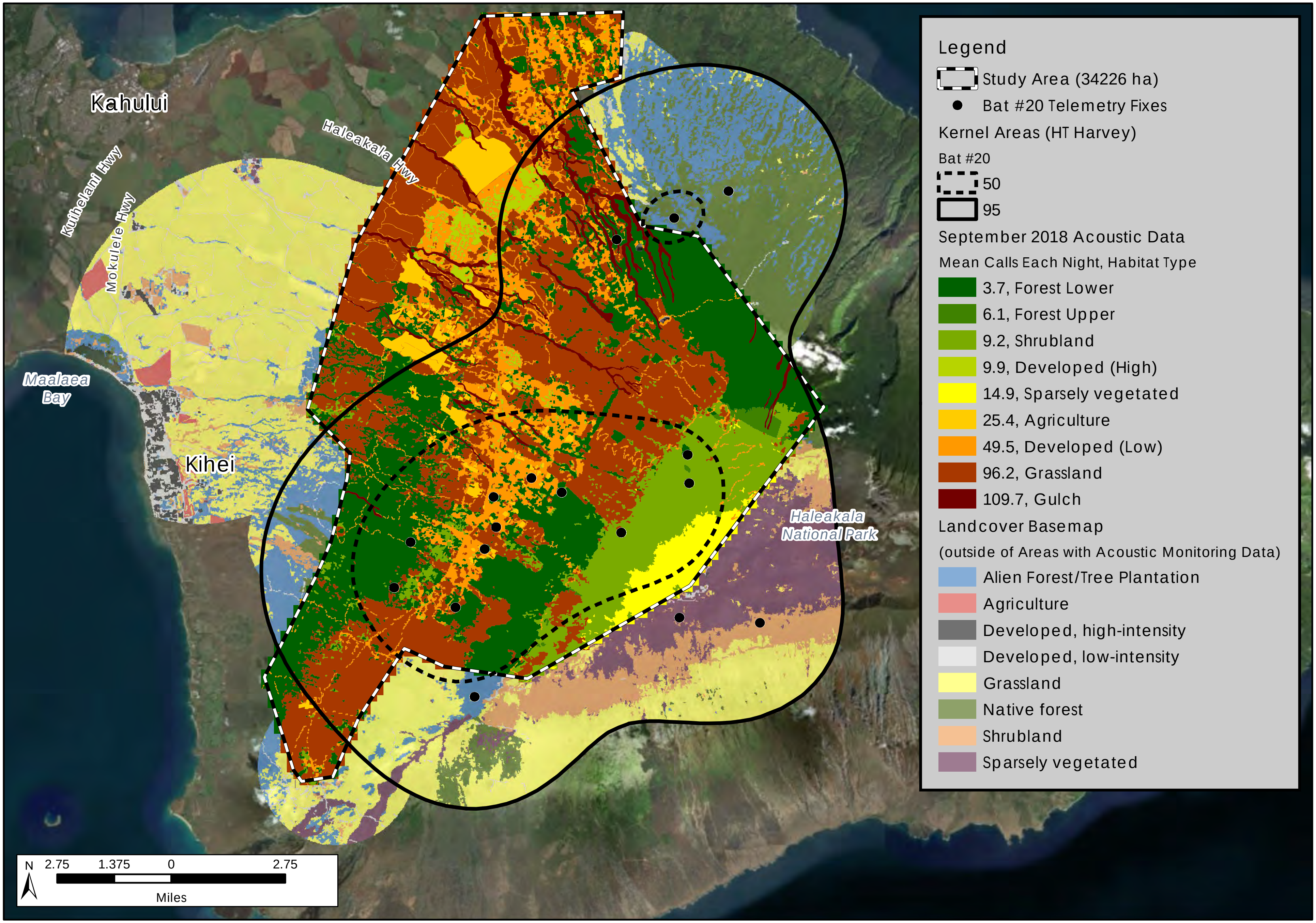
Bat #12 Telemetry Over July 2018 Acoustic Monitoring Data
Ecology of the Hawaiian Hoary Bat (3978-01)
February 2020



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Bat #20 Telemetry Over September 2018 Acoustic Monitoring Data
Ecology of the Hawaiian Hoary Bat (3978-01)
February 2020

Appendix H. Model Output, Model Estimates, and the Significant Differences in Dry Insect Weights between Habitats and Months

By Month, across all habitats

```
  Month.yr N Dry.weight.per.sample       sd        se        ci
1   Aug-17 4              20.84500 16.07773  8.038865 25.583258
2   Oct-17 8              19.97500 11.36709  4.018873  9.503124
3   Jan-18 8              21.91875 22.95523  8.115901 19.191057
4   Feb-18 9              40.45111 35.88806 11.962687 27.586007
5   May-18 9              57.42222 64.91973 21.639912 49.901726
6   Jun-18 9              47.74000 71.57901 23.859670 55.020498
7   Aug-18 5              41.39400 35.04634 15.673198 43.515774
```

By Habitat, across all Months

```
  Habitat N Dry.weight.per.sample        sd        se        ci
1      AV 7             85.357143 59.906785 22.642636 55.404535
2    DevH 6              6.696667  6.079216  2.481830  6.379746
3    DevL 6             58.433333 46.485596 18.977665 48.783642
4     FWL 6              6.235000  5.847953  2.387417  6.137050
5     FWU 6              6.255000  3.862366  1.576804  4.053304
6   Grass 6             75.216667 56.788077 23.183635 59.595432
7   Gulch 5             27.920000  7.526420  3.365917  9.345285
8   Scrub 5             40.660000 38.425161 17.184254 47.711139
9      SV 5             15.720000 27.162419 12.147403 33.726598
```

Modeled Results

Model Output

```
glm.nb(formula = Dry.weight.per.sample ~ Month.yr + Habitat,
    data = Insect, link = "log", init.theta = 2.480127055)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.4781  -0.9515  -0.3527   0.3910   2.3101

Coefficients:
               Estimate Std. Error z value Pr(>|z|)
(Intercept)     4.51501    0.40753  11.079  < 2e-16 ***
Month.yrOct-17 -0.23320    0.44203  -0.528  0.59780
Month.yrJan-18 -0.64849    0.45197  -1.435  0.15134
Month.yrFeb-18  0.32149    0.42772   0.752  0.45227
Month.yrMay-18  0.20907    0.42842   0.488  0.62554
Month.yrJun-18 -0.03461    0.43020  -0.080  0.93587
Month.yrAug-18 -0.21093    0.48809  -0.432  0.66563
HabitatDevH    -2.51973    0.39201  -6.428 1.30e-10 ***
HabitatDevL    -0.35045    0.36409  -0.963  0.33578
HabitatFWL     -2.62682    0.39425  -6.663 2.69e-11 ***
```

```
HabitatFWU     -2.59594    0.39643  -6.548 5.82e-11 ***
HabitatGrass   -0.17238    0.36343  -0.474  0.63528
HabitatGulch   -1.20487    0.38943  -3.094  0.00198 **
HabitatScrub   -0.89419    0.38966  -2.295  0.02174 *
HabitatSV      -1.89866    0.40269  -4.715 2.42e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(2.4801) family taken to be 1)

    Null deviance: 172.285  on 51  degrees of freedom
Residual deviance:  54.537  on 37  degrees of freedom
AIC: 447.58

Number of Fisher Scoring iterations: 1


              Theta:  2.480
          Std. Err.:  0.542

 2 x log-likelihood:  -415.575
```

Model Estimates: Mean, SE, and CI Estimates

Habitat

Response = in this table is the back-transformed “mean estimate”.
SE = one standard error of the mean
LCL = lower confidence interval, UCL = upper CI (95%)

```
Habitat response    SE  df asymp.LCL asymp.UCL
AV         83.91 20.45 Inf     52.05     135.3
DevH        6.75  2.07 Inf      3.70      12.3
DevL       59.11 15.99 Inf     34.78     100.4
FWL         6.07  1.88 Inf      3.30      11.1
FWU         6.26  1.96 Inf      3.39      11.5
Grass      70.63 19.04 Inf     41.64     119.8
Gulch      25.15  7.64 Inf     13.86      45.6
Scrub      34.31 10.43 Inf     18.91      62.3
SV         12.57  4.03 Inf      6.70      23.6

Results are averaged over the levels of: Month.yr
Confidence level used: 0.95
Intervals are back-transformed from the log scale

Month.yr response   SE  df asymp.LCL asymp.UCL
Aug-17       23.4 8.52 Inf     11.46      47.8
Oct-17       18.5 4.53 Inf     11.47      29.9
Jan-18       12.2 3.15 Inf      7.38      20.3
Feb-18       32.3 7.21 Inf     20.82      50.0
May-18       28.8 6.48 Inf     18.56      44.8
Jun-18       22.6 5.15 Inf     14.46      35.3
Aug-18       18.9 6.08 Inf     10.10      35.5

Results are averaged over the levels of: Habitat
Confidence level used: 0.95
Intervals are back-transformed from the log scale
```

Significant Differences

Habitat

Pairwise Comparisons – in all of the below combinations, if the z-ratios are > 0, the habitat on the left had higher insect weights than the habitat on the right; if z-ratio < 0, then the habitat on the left had lower insect weights than the habitat on the right. Significant differences are in red, and shown in the summary below that by differences in letters. Underlined are “borderline” significant (just over p = 0.05).

```
$contrasts
 contrast        ratio     SE  df z.ratio p.value
 AV / DevH     12.4253 4.8708 Inf   6.428  <.0001
 AV / DevL      1.4197 0.5169 Inf   0.963  0.9891
 AV / FWL      13.8297 5.4524 Inf   6.663  <.0001
 AV / FWU      13.4091 5.3158 Inf   6.548  <.0001
 AV / Grass     1.1881 0.4318 Inf   0.474  0.9999
 AV / Gulch     3.3363 1.2993 Inf   3.094  0.0512
 AV / Scrub     2.4454 0.9529 Inf   2.295  0.3451
 AV / SV        6.6769 2.6887 Inf   4.715  0.0001
 DevH / DevL    0.1143 0.0470 Inf  -5.277  <.0001
 DevH / FWL     1.1130 0.4860 Inf   0.245  1.0000
 DevH / FWU     1.0792 0.4745 Inf   0.173  1.0000
 DevH / Grass   0.0956 0.0392 Inf  -5.719  <.0001
 DevH / Gulch   0.2685 0.1143 Inf  -3.089  0.0519
 DevH / Scrub   0.1968 0.0842 Inf  -3.800  0.0046
 DevH / SV      0.5374 0.2362 Inf  -1.413  0.8933
 DevL / FWL     9.7412 4.0212 Inf   5.514  <.0001
 DevL / FWU     9.4450 3.8370 Inf   5.527  <.0001
 DevL / Grass   0.8369 0.3130 Inf  -0.476  0.9999
 DevL / Gulch   2.3500 0.9640 Inf   2.083  0.4851
 DevL / Scrub   1.7224 0.6891 Inf   1.359  0.9130
 DevL / SV      4.7030 1.9414 Inf   3.750  0.0055
 FWL / FWU      0.9696 0.4279 Inf  -0.070  1.0000
 FWL / Grass    0.0859 0.0354 Inf  -5.954  <.0001
 FWL / Gulch    0.2412 0.1048 Inf  -3.274  0.0294
 FWL / Scrub    0.1768 0.0772 Inf  -3.970  0.0023
 FWL / SV       0.4828 0.2163 Inf  -1.625  0.7911
 FWU / Grass    0.0886 0.0359 Inf  -5.974  <.0001
 FWU / Gulch    0.2488 0.1091 Inf  -3.173  0.0403
 FWU / Scrub    0.1824 0.0783 Inf  -3.961  0.0024
 FWU / SV       0.4979 0.2198 Inf  -1.580  0.8162
 Grass / Gulch  2.8081 1.1503 Inf   2.520  0.2219
 Grass / Scrub  2.0582 0.8222 Inf   1.807  0.6777
 Grass / SV     5.6197 2.3166 Inf   4.188  0.0009
 Gulch / Scrub  0.7330 0.3130 Inf  -0.728  0.9984
 Gulch / SV     2.0013 0.8777 Inf   1.582  0.8150
 Scrub / SV     2.7304 1.1706 Inf   2.343  0.3162

Results are averaged over the levels of: Month.yr
P value adjustment: tukey method for comparing a family of 9 estimates
Tests are performed on the log scale

  Habitat  response       SE  df asymp.LCL asymp.UCL .group
4     FWL  6.067549 1.880776 Inf  2.574654  14.29906   a
5     FWU  6.257839 1.956725 Inf  2.635568  14.85849   a
2    DevH  6.753348 2.074078 Inf  2.888373  15.79011   ab
9      SV 12.567486 4.028984 Inf  5.178511  30.49944   abc
7   Gulch 25.151061 7.643971 Inf 10.852480  58.28860    bcd
```

```
8   Scrub 34.314789 10.433189 Inf 14.801598  79.55254      cd
3    DevL 59.105081 15.986960 Inf 27.974302 124.87928       d
6   Grass 70.625781 19.039499 Inf 33.510404 148.84933       d
1      AV 83.912140 20.447505 Inf 42.771536 164.62461       d
```

Month

```
$contrasts
 contrast        ratio    SE  df z.ratio p.value
 Aug-17 / Oct-17 1.263 0.558 Inf  0.528  0.9985 
 Aug-17 / Jan-18 1.913 0.864 Inf  1.435  0.7830 
 Aug-17 / Feb-18 0.725 0.310 Inf -0.752  0.9892 
 Aug-17 / May-18 0.811 0.348 Inf -0.488  0.9990 
 Aug-17 / Jun-18 1.035 0.445 Inf  0.080  1.0000 
 Aug-17 / Aug-18 1.235 0.603 Inf  0.432  0.9995 
 Oct-17 / Jan-18 1.515 0.537 Inf  1.172  0.9048 
 Oct-17 / Feb-18 0.574 0.190 Inf -1.678  0.6311 
 Oct-17 / May-18 0.643 0.213 Inf -1.334  0.8358 
 Oct-17 / Jun-18 0.820 0.273 Inf -0.596  0.9970 
 Oct-17 / Aug-18 0.978 0.395 Inf -0.055  1.0000 
 Jan-18 / Feb-18 0.379 0.129 Inf -2.847  0.0665 
 Jan-18 / May-18 0.424 0.145 Inf -2.511  0.1551 
 Jan-18 / Jun-18 0.541 0.186 Inf -1.787  0.5568 
 Jan-18 / Aug-18 0.646 0.263 Inf -1.075  0.9356 
 Feb-18 / May-18 1.119 0.354 Inf  0.355  0.9998 
 Feb-18 / Jun-18 1.428 0.455 Inf  1.117  0.9232 
 Feb-18 / Aug-18 1.703 0.665 Inf  1.363  0.8216 
 May-18 / Jun-18 1.276 0.408 Inf  0.762  0.9884 
 May-18 / Aug-18 1.522 0.596 Inf  1.073  0.9360 
 Jun-18 / Aug-18 1.193 0.469 Inf  0.449  0.9994 

Results are averaged over the levels of: Habitat 
P value adjustment: tukey method for comparing a family of 7 estimates 
Tests are performed on the log scale 

  Month.yr response       SE  df asymp.LCL asymp.UCL .group
3   Jan-18 12.23084 3.150644 Inf  6.128040  24.41129      a
2   Oct-17 18.52742 4.534281 Inf  9.608809  35.72402      a
7   Aug-18 18.94460 6.077498 Inf  8.011407  44.79836      a
6   Jun-18 22.59740 5.150401 Inf 12.260355  41.64991      a
1   Aug-17 23.39331 8.521339 Inf  8.803963  62.15914      a
5   May-18 28.83312 6.479326 Inf 15.778538  52.68859      a
4   Feb-18 32.26351 7.209087 Inf 17.716229  58.75597      a
```

Appendix I. List of species identified from samples from specific habitats

Jar Code	Specimen ID	Abundance	Order	Family	Genus	Species	Sort Date	Greater than 10mm?
Maui_06/2018_FWL	HHB-00001	5	Coleoptera			*Morphospecies* [1]	9/11/2018	
Maui_06/2018_FWL	HHB-00002	1	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	9/11/2018	
Maui_06/2018_FWL	HHB-00003	1	Lepidoptera	Crambidae	*Eudonia*	*Eudonia?* [1]	9/11/2018	
Maui_06/2018_FWL	HHB-00004	4	Isoptera				9/12/2018	
Maui_06/2018_FWL	HHB-00005	1	Lepidoptera				9/12/2018	
Maui_06/2018_FWL	HHB-00006	1	Lepidoptera				9/12/2018	
Maui_06/2018_FWL	HHB-00007	1	Lepidoptera				9/12/2018	
Maui_06/2018_FWL	HHB-00008	1	Lepidoptera	Erebidae	*Schrankia*	*altivolans*	9/13/2018	
Maui_06/2018_FWL	HHB-00009	1	Lepidoptera				9/14/2018	
Maui_06/2018_FWL	HHB-00010	1	Lepidoptera	Geometridae	*Scotorythra*	*euryphaea*	9/14/2018	
Maui_06/2018_FWL	HHB-00011	1	Homoptera	Psocoptera	*Caeciliidae*		9/14/2018	
Maui_06/2018_FWL	HHB-00012	1	Lepidoptera	Torticidae			9/14/2018	
Maui_06/2018_FWL	HHB-00013	1	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	9/14/2018	
Maui_06/2018_FWL	HHB-00014	1	Lepidoptera	Cosmopterigidae	*Hyposmocoma*		9/14/2018	
Maui_06/2018_FWL	HHB-00015	7	Coleoptera	Elateridae			9/19/2018	
Maui_06/2018_FWL	HHB-00016	15	Coleoptera	Curculionidae			9/19/2018	
Maui_06/2018_FWL	HHB-00017	6	Coleoptera	Carabidae			9/19/2018	
Maui_06/2018_FWL	HHB-00018	6	Coleoptera	Staphylinidae			9/19/2018	
Maui_06/2018_FWL	HHB-00019	22	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	9/19/2018	
Maui_06/2018_FWL	HHB-00020	1	Lepidoptera	Tortricidae	*Epiphyas*	*postvittana*	9/19/2018	
Maui_06/2018_FWL	HHB-00021	2	Lepidoptera				9/19/2018	
Maui_06/2018_FWL	HHB-00022	1	Lepidoptera				9/19/2018	
Maui_06/2018_FWL	HHB-00023	1	Lepidoptera	Crambidae	*Orthomecyna*	*exigua exigua*	9/19/2018	
Maui_06/2018_FWL	HHB-00024	1	Lepidoptera	Tortricidae	*Amorbia*	*emigratella*	9/19/2018	
Maui_06/2018_FWL	HHB-00025	1	Lepidoptera	Crambidae	*Eudonia*		9/20/2018	

Jar Code	**Specimen ID**	**Abundance**	**Order**	**Family**	**Genus**	**Species**	**Sort Date**	**Greater than 10mm?**
Maui_06/2018_FWL	HHB-00026	1	Lepidoptera	Cosmopterigidae	*Hyposmocoma (Euperissus)*		9/20/2018	
Maui_06/2018_FWL	HHB-00027	7	Homoptera	Cicadellidae			9/20/2018	
Maui_06/2018_FWL	-	67	Lepidoptera	less than 16mm			9/11/2018	
Maui_06/2018_FWL	HHB-00028	7	Diptera				9/24/2018	
Maui_06/2018_FWL	HHB-00029	1	Hemiptera				9/24/2018	
Maui_06/2018_FWL	HHB-00030	1	Lepidoptera	Cosmopterigidae	*Hyposmocoma*		9/24/2018	
Maui_06/2018_FWL	HHB-00031	1	Lepidoptera	Crambidae	*Orthomecyna*	*exigua exigua*	9/24/2018	
Maui_06/2018_FWL	HHB-00032	1	Lepidoptera	Erebidae	*Schrankia*	*altivolans*	9/24/2018	
Maui_06/2018_FWL	HHB-00033	1	Lepidoptera	Crambidae	*Orthomecyna*	*exigua exigua*	10/9/2018	
Maui_06/2018_FWL	-	44	Lepidoptera	female greater than 16mm			9/11/2018	
Maui_06/2018_FWL	HHB-00034	1	Lepidoptera	Crambidae	*Omiodes*		10/9/2018	
Maui_06/2018_FWL	HHB-00035	1	Lepidoptera	Erebidae	*Schrankia*	*altivolans*	10/9/2018	
Maui_06/2018_FWL	HHB-00036	1	Lepidoptera	Crambidae	*Orthomecyna*	*exigua exigua*	10/9/2018	
Maui_06/2018_FWL	HHB-00037	1	Hemiptera	Pentatomidae			10/9/2018	
Maui_06/2018_FWL	HHB-00038	1	Araneae				10/11/2018	
Maui_06/2018_FWL	HHB-00039	1	unknown				10/11/2018	
Maui_06/2018_FWL	HHB-00040	1	Lepidoptera	Erebidae	*Schrankia*	*altivolans*	10/15/2018	
Maui_06/2018_FWL	HHB-00041	1	Lepidoptera	Crambidae	*Herpetogramma*	*licarsisalis*	10/15/2018	
Maui_06/2018_FWL	HHB-00042	1	Lepidoptera	Crambidae	*Orthomecyna*	*exigua exigua*	10/15/2018	
Maui_06/2018_FWL	HHB-00043	1	Lepidoptera	Crambidae	*Orthomecyna*	*exigua exigua*	10/15/2018	
Maui_06/2018_FWL	HHB-00044	1	Lepidoptera	Tortricidae	*Amorbia*	*emigratella*	10/24/2018	
Maui_06/2018_FWL	HHB-00045	1	Hymenoptera	Ichneumonidae			10/24/2018	
Maui_01/2018_AV3/5	HHB-00046	23	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	6/17/2019	
Maui_01/2018_AV3/5	HHB-00047	12	Lepidoptera	less than 10mm			6/17/2019	
Maui_01/2018_AV3/5	HHB-00048	4	Coleoptera			*Morphospecies* [2]	6/18/2019	

Jar Code	Specimen ID	Abundance	Order	Family	Genus	Species	Sort Date	Greater than 10mm?
Maui_01/2018_AV3/5	HHB-00049	5	Lepidoptera	female greater than 10mm			6/18/2019	
Maui_01/2018_AV3/5	HHB-00050	1	Coleoptera			*Morphospecies* ^{1}	6/18/2019	
Maui_01/2018_AV3/5	HHB-00051	2	Diptera				6/18/2019	
Maui_01/2018_AV3/5	HHB-00052	1	Lepidoptera	Tineidae	*Decadarchis*	*flavistriata?*	6/18/2019	
Maui_01/2018_AV3/5	HHB-00053	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	6/18/2019	
Maui_01/2018_AV3/5	HHB-00054	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	6/18/2019	
Maui_02/2018_SV1/2	HHB-00055	50	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	6/20/2019	
Maui_01/2018_DevL1/4	HHB-00056	1	Coleoptera	Carabidae			6/21/2019	
Maui_01/2018_DevL1/4	HHB-00057	19	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	6/21/2019	
Maui_01/2018_DevL1/4	HHB-00058	1	Hymenoptera	Ichneumonidae			6/21/2019	
Maui_01/2018_DevL1/4	HHB-00059	11	Lepidoptera	less than 10mm			6/21/2019	
Maui_01/2018_DevL1/4	HHB-00060	8	Diptera	less than 5mm			6/21/2019	
Maui_01/2018_DevL1/4	HHB-00061	1	Lepidoptera	Crambidae	*Eudonia*		6/21/2019	
Maui_01/2018_DevL1/4	HHB-00062	5	Lepidoptera	female greater than 10mm			6/21/2019	
Maui_01/2018_DevL1/4	HHB-00063	1	Lepidoptera	Crambidae	*Eudonia*		6/21/2019	
Maui_01/2018_DevL1/4	HHB-00064	1	Coleoptera			*Morphospecies* ^{1}	6/21/2019	
Maui_01/2018_DevL1/4	HHB-00065	2	Coleoptera			*Morphospecies* ^{2}		
Maui_02/2018_Gulch2/2	HHB-00066	19	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00067	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00068	7	Lepidoptera	less than 10mm			6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00069	3	Lepidoptera	female greater than 10mm			6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00070	1	Lepidoptera				6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00071	10	Diptera	less than 5mm			6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00072	1	Heteroptera	Miridae			6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00073	4	Homoptera	*Ciccadellidae?, Psyllidae*			6/23/2019	

Jar Code	Specimen ID	Abundance	Order	Family	Genus	Species	Sort Date	Greater than 10mm?
Maui_02/2018_Gulch2/2	HHB-00074	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00075	1	Coleoptera	Lyctidae			6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00076	1	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	6/23/2019	
Maui_02/2018_Gulch2/2	HHB-00077	1	Lepidoptera	Crambidae	*Herpetogramma*	*licarsisalis*	6/23/2019	
Maui_07/2017_NativeNursery1/1	HHB-00078	6	Coleoptera	Scarabeidae			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00079	2	Coleoptera	Scolytinae			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00080	2	Coleoptera	Carabidae			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00081	16	Lepidoptera	less than 10mm			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00082	1	Neuroptera	Chrysopidae			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00083	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00084	5	Lepidoptera	female greater than 10mm			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00085	4	Coleoptera	Staphylinidae			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00086	11	Heteroptera	Lygaeidae			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00087	1	Coleoptera	Elateridae			6/26/2019	
Maui_07/2017_NativeNursery1/1	HHB-00088	1	Lepidoptera	Noctuidae	*Amyna*	*natalis*	6/26/2019	
Maui_11/2018_FWU1/1	HHB-00089	9	Lepidoptera	less than 10mm			6/27/2019	n
Maui_11/2018_FWU1/1	HHB-00090	8	Lepidoptera	female greater than 10mm			6/27/2019	y
Maui_11/2018_FWU1/1	HHB-00091	18	Diptera				6/27/2019	n
Maui_11/2018_FWU1/1	HHB-00092	10	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	6/27/2019	y
Maui_11/2018_FWU1/1	HHB-00093	1	Lepidoptera	Tortricidae	*Bactra*		6/27/2019	
Maui_11/2018_FWU1/1	HHB-00094	1	Lepidoptera	Crambidae	*Eudonia*		6/27/2019	
Maui_11/2018_FWU1/1	HHB-00095	1	Lepidoptera	Pterophoridae	*Stenoptilodes*		6/27/2019	
Maui_11/2018_FWU1/1	HHB-00096	1	Lepidoptera	Crambidae	*Eudonia*		6/27/2019	
Maui_11/2018_FWU1/1	HHB-00097	1	Lepidoptera	Crambidae	*Eudonia*		6/27/2019	
Maui_10/2017_Grass2/2	HHB-00098	2	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	6/28/2019	y

Jar Code	Specimen ID	Abundance	Order	Family	Genus	Species	Sort Date	Greater than 10mm?
Maui_10/2017_Grass2/2	HHB-00099	4	Coleoptera	Scarabeidae			6/28/2019	y
Maui_10/2017_Grass2/2	HHB-00100	5	Coleoptera	Scolytinae			6/28/2019	both
Maui_10/2017_Grass2/2	HHB-00101	16	Coleoptera			*Morphospecies* ^{2}	6/28/2019	n
Maui_10/2017_Grass2/2	HHB-00102	2	Coleoptera	Staphylinidae			6/28/2019	n
Maui_10/2017_Grass2/2	HHB-00103	3	Coleoptera	Carabidae			6/28/2019	both
Maui_10/2017_Grass2/2	HHB-00104	6	Diptera				6/28/2019	n
Maui_10/2017_Grass2/2	HHB-00105	3	Lepidoptera	less than 10mm			6/28/2019	n
Maui_10/2017_Grass2/2	HHB-00106	1	Coleoptera	Silphidae?			6/28/2019	n
Maui_10/2017_Grass2/2	HHB-00107	2	Heteroptera	Lygeidae			6/28/2019	n
Maui_10/2017_Grass2/2	HHB-00108	3	Hymenoptera	Braconidae			6/28/2019	n
Maui_10/2017_Grass2/2	HHB-00109	1	Homoptera	Cicadellidae			6/28/2019	n
Maui_10/2017_Grass2/2	HHB-00110	1	Lepidoptera	Limacodidae	*Darna*	*pallivitta*	6/28/2019	y
Maui_10/2017_Grass2/2	HHB-00111	1	Acari				6/28/2019	n
Maui_08/2017_DevH1/1	HHB-00112	4	Heteroptera	Pentatomidae			7/5/2019	y
Maui_08/2017_DevH1/1	HHB-00113	7	Coleoptera	Elateridae			7/5/2019	y
Maui_08/2017_DevH1/1	HHB-00114	14	Coleoptera	Carabidae			7/5/2019	n
Maui_08/2017_DevH1/1	HHB-00115	11	Coleoptera	Scarabeidae			7/5/2019	y
Maui_08/2017_DevH1/1	HHB-00116	6	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	7/5/2019	y
Maui_08/2017_DevH1/1	HHB-00117	1	Heteroptera				7/5/2019	n
Maui_08/2017_DevH1/1	HHB-00118	2	Coleoptera	Staphylinidae			7/5/2019	n
Maui_08/2017_DevH1/1	HHB-00119	1	Lepidoptera	female greater than 10mm			7/5/2019	y
Maui_08/2017_DevH1/1	HHB-00120	2	Diptera				7/5/2019	n
Maui_08/2017_DevH1/1	HHB-00121	1	Coleoptera				7/5/2019	y
Maui_08/2017_DevH1/1	HHB-00122	1	Lepidoptera	Crambidae	*Herpetogramma*	*licarsisalis*	7/5/2019	y
Maui_08_2018_DevL3/4	HHB-00123	7	Heteroptera				7/24/2019	n

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Maui_08_2018_DevL3/4	HHB-00124	1	Lepidoptera	Crambidae	*Omiodes*		7/24/2019	y
Maui_08_2018_DevL3/4	HHB-00125	1	Lepidoptera	Crambidae	*Eudonia*		7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00126	1	Lepidoptera				7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00127	1	Homoptera	Delphacidae			7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00128	14	Lepidoptera	female			7/24/2019	both
Maui_08_2018_DevL3/4	HHB-00129	1	Coleoptera			*morphospecies* [1]	7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00130	8	Coleoptera			*morphospecies* [2]	7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00131	1	Coleoptera	Carabidae			7/24/2019	y
Maui_08_2018_DevL3/4	HHB-00132	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	7/24/2019	y
Maui_08_2018_DevL3/4	HHB-00133	1	Lepidoptera	Crambidae	*Eudonia*		7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00134	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00135	1	Lepidoptera	Crambidae	*Eudonia*		7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00136	1	Lepidoptera	Cosmopterigidae	*Hyposmocoma*	*nr. malornata*	7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00137	1	Lepidoptera	Pyralidae	*Ephestiodes*		7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00138	1	Lepidoptera	Crambidae	*Eudonia*		7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00139	2	Coleoptera	Staphylinidae			7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00140	1	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	7/24/2019	y
Maui_08_2018_DevL3/4	HHB-00141	2	Coleoptera	Elateridae			7/24/2019	y
Maui_08_2018_DevL3/4	HHB-00142	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00143	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	7/24/2019	n
Maui_08_2018_DevL3/4	HHB-00144	1	Lepidoptera	Crambidae	*Eudonia*		7/24/2019	n
Maui_08_2018_DevL4/4	HHB-00145	1	Mantodea	Mantidae			7/25/2019	y
Maui_08_2018_DevL4/4	HHB-00146	1	Coleoptera	Cerambycidae			7/25/2019	y
Maui_08_2018_DevL4/4	HHB-00147	15	Heteroptera				7/25/2019	various sizes
Maui_08_2018_DevL4/4	HHB-00148	1	Coleoptera	Scarabeidae			7/25/2019	y

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Maui_08_2018_DevL4/4	HHB-00149	2	Coleoptera	Carabidae			7/25/2019	y
Maui_08_2018_DevL4/4	HHB-00150	6	Coleoptera			*morphospecies* [2]	7/25/2019	n
Maui_08_2018_DevL4/4	HHB-00151	1	Diptera				7/25/2019	n
Maui_08_2018_DevL4/4	HHB-00152	1	Homoptera	Delphacidae			7/25/2019	n
Maui_08_2018_DevL4/4	HHB-00153	1	Isoptera				7/25/2019	y
Maui_08_2018_DevL4/4	HHB-00154	10	Lepidoptera	female			7/25/2019	various sizes
Maui_08_2018_DevL4/4	HHB-00155	1	Heteroptera	Pentatomidae			7/25/2019	y
Maui_08_2018_DevL4/4	HHB-00156	4	Coleoptera	Elateridae			7/25/2019	y
Maui_08_2018_DevL4/4	HHB-00157	1	Lepidoptera	Crambidae	*Orthomecyna*		7/25/2019	n
Maui_08_2018_DevL4/4	HHB-00158	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	7/25/2019	n
Maui_08_2018_DevL4/4	HHB-00159	2	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	7/25/2019	n
Maui_08_2018_DevL4/4	HHB-00160	1	Lepidoptera	Pyralidae	*Ephestiodes*		7/25/2019	n
Maui_08_2018_DevL4/4	HHB-00161	1	Lepidoptera				7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00162	14	Lepidoptera	female			7/25/2019	various sizes
Maui_08_2018_DevL1/4	HHB-00163	5	Coleoptera			*morphospecies* [2]	7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00164	5	Coleoptera	Elateridae			7/25/2019	y
Maui_08_2018_DevL1/4	HHB-00165	1	Coleoptera	Staphylinidae			7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00166	1	Blattodea				7/25/2019	y
Maui_08_2018_DevL1/4	HHB-00167	1	Lepidoptera	Pyralidae	*Unadilla*	*bidensana?*	7/25/2019	y
Maui_08_2018_DevL1/4	HHB-00168	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00169	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00170	1	Lepidoptera	Pyralidae	*Ephestiodes*		7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00171	1	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	7/25/2019	y
Maui_08_2018_DevL1/4	HHB-00172	5	Coleoptera	Carabidae			7/25/2019	various sizes

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Maui_08_2018_DevL1/4	HHB-00173	9	Heteroptera				7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00174	1	Isoptera				7/25/2019	y
Maui_08_2018_DevL1/4	HHB-00175	1	Coleoptera			*morphospecies*[3]	7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00176	1	Lepidoptera	Crambidae	*Eudonia*		7/25/2019	n
Maui_08_2018_DevL1/4	HHB-00177	1	Coleoptera	Scarabeidae			7/25/2019	y
Maui_08_2018_DevL1/4	HHB-00178	1	Coleoptera				7/25/2019	n
Maui_01_2018_FWU1/1	HHB-00179	15	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	8/20/2019	y
Maui_01_2018_FWU1/1	HHB-00180	1	Neuroptera	Hemerobiidae			8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00181	5	Diptera	Tipulidae?			8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00182	6	Diptera	Culicidae?			8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00183	16	Lepidoptera	female			8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00184	1	Diptera	Ephydridae?			8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00185	1	Lepidoptera	Carposinidae	*Carposina*	*inscripta*	8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00186	1	Lepidoptera	Crambidae	*Eudonia*		8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00187	1	Lepidoptera	Carposinidae	*Carposina*	*gracillima*	8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00188	1	Lepidoptera	Carposinidae	*Carposina*	*inscripta*	8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00189	1	Lepidoptera	female			8/20/2019	n
Maui_01_2018_FWU1/1	HHB-00190	1	Lepidoptera	Crambidae	*Eudonia*		8/20/2019	n
Maui_08/2017_DevL1/1	HHB-00191	1	Lepidoptera	Geometridae	*Scotorythra*		8/22/2019	y
Maui_08/2017_DevL1/1	HHB-00192	17	Coleoptera	Elateridae			8/22/2019	y
Maui_08/2017_DevL1/1	HHB-00193	9	Lepidoptera	female			8/22/2019	various sizes
Maui_08/2017_DevL1/1	HHB-00194	1	Homoptera	Delphacidae			8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00195	3	Psocoptera				8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00196	1	Coleoptera	Scarabeidae			8/22/2019	y
Maui_08/2017_DevL1/1	HHB-00197	6	Coleoptera				8/22/2019	n

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Maui_08/2017_DevL1/1	HHB-00198	1	Isoptera				8/22/2019	y
Maui_08/2017_DevL1/1	HHB-00199	3	Homoptera	Psyllidae			8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00200	1	Hymenoptera	Braconidae			8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00201	1	Coleoptera	Carabidae			8/22/2019	y
Maui_08/2017_DevL1/1	HHB-00202	1	Lepidoptera				8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00203	1	Lepidoptera	Cosmopterigidae	*Hyposmocoma*		8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00204	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00205	1	Lepidoptera	Cosmopterigidae	*Hyposmocoma*		8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00206	1	Lepidoptera	Torticidae	*Cydia*		8/22/2019	n
Maui_08/2017_DevL1/1	HHB-00207	1	Lepidoptera				8/22/2019	n
Maui_03/2018_FWU1/1	HHB-00208	8	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	9/3/2019	y
Maui_03/2018_FWU1/1	HHB-00209	1	Hymenoptera	Ichneumonidae			9/3/2019	y
Maui_03/2018_FWU1/1	HHB-00210	24	Lepidoptera	female			9/3/2019	various sizes
Maui_03/2018_FWU1/1	HHB-00211	1	Diptera	Tipulidae			9/3/2019	y
Maui_03/2018_FWU1/1	HHB-00212	3	Diptera				9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00213	1	Lepidoptera	Pterophoridae			9/3/2019	y
Maui_03/2018_FWU1/1	HHB-00214	1	Coleoptera	Staphylinidae			9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00215	1	Psocoptera				9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00216	1	Lepidoptera	Crambidae	*Udea*		9/3/2019	y
Maui_03/2018_FWU1/1	HHB-00217	1	Lepidoptera	Crambidae	*Eudonia*		9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00218	1	Lepidoptera	Tortricidae	*Epiphyas*	*postvittana*	9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00219	1	Lepidoptera	Crambidae	*Eudonia*		9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00220	1	Lepidoptera	Crambidae	*Eudonia*		9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00221	1	Lepidoptera	Crambidae	*Udea*		9/3/2019	y

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Maui_03/2018_FWU1/1	HHB-00222	1	Lepidoptera	Crambidae	*Eudonia*		9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00223	1	Lepidoptera	Geometridae	*Scotorythra*		9/3/2019	y
Maui_03/2018_FWU1/1	HHB-00224	1	Lepidoptera	Carposinidae	*Carposina*		9/3/2019	n
Maui_03/2018_FWU1/1	HHB-00225	1	Lepidoptera	Crambidae	*Udea*		9/3/2019	n
Maui_10/2017_Gulch3/3	HHB-00226	17	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	9/9/2019	y
Maui_10/2017_Gulch3/3	HHB-00227	1	Coleoptera			*morphospecies* [1]	9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00228	1	Lepidoptera	Crambidae	*Eudonia*		9/9/2019	y
Maui_10/2017_Gulch3/3	HHB-00229	2	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00230	16	Lepidoptera	female			9/9/2019	various sizes
Maui_10/2017_Gulch3/3	HHB-00231	1	Diptera				9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00232	2	Coleoptera	Staphylinidae			9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00233	1	Psocoptera				9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00234	1	Coleoptera	Carabidae			9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00235	1	Coleoptera			*morphospecies* [3]	9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00236	1	Lepidoptera	Geometridae	*Scotorythra*		9/9/2019	y
Maui_10/2017_Gulch3/3	HHB-00237	1	Lepidoptera	Torticidae	*Cydia*		9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00238	1	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	9/9/2019	y
Maui_10/2017_Gulch3/3	HHB-00239	1	Lepidoptera	Crambidae	*Orthomecyna*		9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00240	1	Lepidoptera	male			9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00241	1	Lepidoptera	Cosmopterigidae	*Hyposmocoma*		9/9/2019	n
Maui_10/2017_Gulch3/3	HHB-00242	1	Lepidoptera	Torticidae	*Amorbia*	*emigratella*	9/9/2019	n
Maui_10/2017_Gulch1/3	HHB-00243	10	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	10/8/2019	y
Maui_10/2017_Gulch1/3	HHB-00244	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00245	12	Lepidoptera	female			10/8/2019	both
Maui_10/2017_Gulch1/3	HHB-00246	1	Lepidoptera	Erebidae	*Schrankia*	*altivolans*	10/8/2019	n

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Maui_10/2017_Gulch1/3	HHB-00247	1	Coleoptera	Carabidae			10/8/2019	y
Maui_10/2017_Gulch1/3	HHB-00248	4	Coleoptera	Scarabeidae			10/8/2019	y
Maui_10/2017_Gulch1/3	HHB-00249	3	Coleoptera	Elateridae			10/8/2019	y
Maui_10/2017_Gulch1/3	HHB-00250	1	Homoptera	Delphacidae			10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00251	2	Diptera	multiple families			10/8/2019	less than 2mm
Maui_10/2017_Gulch1/3	HHB-00252	1	Coleoptera	Scolytinae			10/8/2019	less than 2mm
Maui_10/2017_Gulch1/3	HHB-00253	3	Coleoptera	multiple families			10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00254	1	Lepidoptera	Erebidae	*Schrankia*	*altivolans*	10/8/2019	y
Maui_10/2017_Gulch1/3	HHB-00255	1	Lepidoptera	Crambidae	*Udea*		10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00256	1	Lepidoptera	Crambidae	*Orthomecyna*	*exigua exigua*	10/8/2019	y
Maui_10/2017_Gulch1/3	HHB-00257	1	Lepidoptera	Crambidae	*Omiodes*		10/8/2019	y
Maui_10/2017_Gulch1/3	HHB-00258	1	Lepidoptera	Crambidae	*Herpetogramma*	*licarsisalis*	10/8/2019	y
Maui_10/2017_Gulch1/3	HHB-00259	1	Lepidoptera	male			10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00260	1	Lepidoptera	Tineidae	*Tinea*	*despecta?*	10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00261	1	Lepidoptera	Crambidae	*Orthomecyna*	*exigua exigua*	10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00262	1	Lepidoptera	Crambidae	*Udea*		10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00263	1	Lepidoptera	Erebidae	*Schrankia*	*altivolans*	10/8/2019	n
Maui_10/2017_Gulch1/3	HHB-00264	1	Lepidoptera				10/8/2019	n
Maui_10/2017_Grass1/2	HHB-00265	18	Coleoptera	Scarabeidae			10/10/2019	y
Maui_10/2017_Grass1/2	HHB-00266	16	Coleoptera			*morphospecies*[4]	10/10/2019	n
Maui_10/2017_Grass1/2	HHB-00267	1	Coleoptera	Carabidae			10/10/2019	y
Maui_10/2017_Grass1/2	HHB-00268	1	Hymenoptera				10/10/2019	y
Maui_10/2017_Grass1/2	HHB-00269	5	Lepidoptera	female			10/10/2019	both

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Maui_10/2017_Grass1/2	HHB-00270	1	Lepidoptera	Noctuidae	*Agrotis*		10/10/2019	y
Maui_10/2017_Grass1/2	HHB-00271	2	Coleoptera				10/10/2019	n
Maui_10/2017_Grass1/2	HHB-00272	1	Diptera	Ephydridae			10/10/2019	n
Maui_10/2017_Grass1/2	HHB-00273	4	Coleoptera	Staphylinidae			10/10/2019	n
Maui_10/2017_Grass1/2	HHB-00274	1	Coleoptera			*morphospecies*[3]	10/10/2019	n
Maui_08/2018_DevL2/4	HHB-00275	4	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	10/14/2019	y
Maui_08/2018_DevL2/4	HHB-00276	1	Lepidoptera	Crambidae	*Omiodes*		10/14/2019	y
Maui_08/2018_DevL2/4	HHB-00277	9	Lepidoptera	female			10/14/2019	y
Maui_08/2018_DevL2/4	HHB-00278	1	Lepidoptera	Noctuidae	*Megalographa*	*biloba*	10/14/2019	y
Maui_08/2018_DevL2/4	HHB-00279	4	Coleoptera	Elateridae			10/14/2019	y
Maui_08/2018_DevL2/4	HHB-00280	3	Coleoptera	Staphylinidae			10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00281	12	Coleoptera			*morphospecies*[4]	10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00282	3	Heteroptera	Lygaeidae			10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00283	2	Heteroptera	Cydnidae			10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00284	1	Coleoptera				10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00285	1	Lepidoptera	Tortricidae	*Cryptophlebia*	*illepida*	10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00286	3	Lepidoptera	Crambidae	*Eudonia*		10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00287	1	Lepidoptera	Hyposmocoma			10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00288	1	Coleoptera	Scolytinae			10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00289	1	Coleoptera	Scarabeidae			10/14/2019	y
Maui_08/2018_DevL2/4	HHB-00290	1	Coleoptera	Curculionidae			10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00291	1	Acari				10/14/2019	n
Maui_08/2018_DevL2/4	HHB-00292	1	Lepidoptera	Noctuidae	*Agrotis*		10/14/2019	y
Maui_06/2018_FWU1/1	HHB-00293	5	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	10/23/2019	y
Maui_06/2018_FWU1/1	HHB-00294	39	Diptera	Tipulidae			10/23/2019	y

Jar Code	Specimen ID	Abundance	Order	Family	Genus	Species	Sort Date	Greater than 10mm?
Maui_06/2018_FWU1/1	HHB-00295	4	Lepidoptera	female			10/23/2019	both
Maui_06/2018_FWU1/1	HHB-00296	1	Lepidoptera	male			10/23/2019	y
Maui_06/2018_FWU1/1	HHB-00297	1	Lepidoptera	Crambidae	*Eudonia*		10/23/2019	y
Maui_01/2018_Grass1/3	HHB-00298	6	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	10/23/2019	y
Maui_01/2018_Grass1/3	HHB-00299	1	Coleoptera	Elateridae			10/23/2019	y
Maui_01/2018_Grass1/3	HHB-00300	7	Coleoptera	Scarabeidae			10/23/2019	y
Maui_01/2018_Grass1/3	HHB-00301	25	Lepidoptera	female			10/23/2019	both
Maui_01/2018_Grass1/3	HHB-00302	1	Heteroptera	Lygaeidae			10/23/2019	n
Maui_01/2018_Grass1/3	HHB-00303	4	Coleoptera			*morphospecies* [4]	10/23/2019	n
Maui_01/2018_Grass1/3	HHB-00304	2	Coleoptera	Carabidae			10/23/2019	y
Maui_01/2018_Grass1/3	HHB-00305	1	Diptera	Ephydridae?			10/23/2019	n
Maui_01/2018_Grass1/3	HHB-00306	1	Lepidoptera	Crambidae	*Orthomecyna*		10/23/2019	n
Maui_01/2018_Grass1/3	HHB-00307	1	Lepidoptera	Autostichidae	*Stoeberhinus*	*testaceus*	10/23/2019	n
Maui_01/2018_Grass1/3	HHB-00308	1	Lepidoptera	Crambidae	*Herpetogramma*	*licarsisalis*	10/23/2019	y
Maui_01/2018_DevL3/4	HHB-00309	23	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	10/24/2019	y
Maui_01/2018_DevL3/4	HHB-00310	2	Coleoptera			*morphospecies* [4]	10/24/2019	n
Maui_01/2018_DevL3/4	HHB-00311	14	Lepidoptera	female			10/24/2019	both
Maui_01/2018_DevL3/4	HHB-00312	1	Lepidoptera	Geometridae	*Scotorythra*		10/24/2019	y
Maui_01/2018_DevL3/4	HHB-00313	2	Diptera				10/24/2019	n
Maui_01/2018_DevL3/4	HHB-00314	2	Lepidoptera	Crambidae	*Eudonia*		10/24/2019	n
Maui_01/2018_DevL3/4	HHB-00315	1	Lepidoptera	male			10/24/2019	n
Maui_01/2018_DevL3/4	HHB-00316	1	Lepidoptera	Crambidae	*Udea*		10/24/2019	n
Maui_01/2018_DevL3/4	HHB-00317	1	Lepidoptera	Crambidae	*Orthomecyna*		10/24/2019	n
Maui_01/2018_DevL3/4	HHB-00318	1	Lepidoptera	Noctuidae	*Agrotis*		10/24/2019	y
Maui_01/2018_DevL3/4	HHB-00319	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	10/24/2019	y

Jar Code	Specimen ID	Abundance	Order	Family	Genus	Species	Sort Date	Greater than 10mm?
Maui_01/2018_DevL3/4	HHB-00320	1	Lepidoptera	male			10/24/2019	y
Maui_08/2018_FWU1/1	HHB-00321	3	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	10/28/2019	y
Maui_08/2018_FWU1/1	HHB-00322	2	Lepidoptera	Geometridae	*Scotorythra*		10/28/2019	y
Maui_08/2018_FWU1/1	HHB-00323	19	Lepidoptera	female			10/28/2019	y
Maui_08/2018_FWU1/1	HHB-00324	1	Coleoptera	Scarabeidae			10/28/2019	y
Maui_08/2018_FWU1/1	HHB-00325	9	Diptera	Tipulidae			10/28/2019	n
Maui_08/2018_FWU1/1	HHB-00326	3	Diptera				10/28/2019	n
Maui_08/2018_FWU1/1	HHB-00327	1	Lepidoptera	Tortricidae	*Bactra*	*straminea*	10/28/2019	n
Maui_08/2018_FWU1/1	HHB-00328	1	Lepidoptera	Tortricidae	*Epiphyas*	*postvittana*	10/28/2019	n
Maui_08/2018_FWU1/1	HHB-00329	1	Lepidoptera				10/28/2019	n
Maui_08/2018_FWU1/1	HHB-00330	1	Lepidoptera	male			10/28/2019	n
Maui_08/2018_FWU1/1	HHB-00331	1	Lepidoptera	Crambidae	*Udea*		10/28/2019	n
Maui_08/2018_FWU1/1	HHB-00332	2	Hymenoptera	Ichneumonidae			10/30/2019	y
Maui_08/2018_FWU1/1	HHB-00333	1	Neuroptera	Hemerobiidae			10/30/2019	y
Maui_08/2018_FWU1/1	HHB-00334	1	Lepidoptera	Crambidae	*Eudonia*		10/30/2019	n
Maui_08/2018_FWU1/1	HHB-00335	1	Lepidoptera	Crambidae	*Udea*		10/30/2019	y
Maui_08/2018_FWU1/1	HHB-00336	1	Lepidoptera	Crambidae	*Udea*		10/30/2019	y
Maui_08/2018_FWU1/1	HHB-00337	1	Lepidoptera	Crambidae	*Udea*		10/30/2019	y
Maui_08/2018_FWU1/1	HHB-00338	1	Lepidoptera	Pterophoridae	*Stenoptilodes*		10/30/2019	y
Maui_02/2018_Gulch1/2	HHB-00339	24	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	11/16/2019	y
Maui_02/2018_Gulch1/2	HHB-00340	3	Diptera	Drosophilidae?	*Drosophila?*		11/16/2019	n
Maui_02/2018_Gulch1/2	HHB-00341	6	Diptera				11/16/2019	n
Maui_02/2018_Gulch1/2	HHB-00342	1	Heteroptera				11/16/2019	n
Maui_02/2018_Gulch1/2	HHB-00343	6	Lepidoptera	female			11/16/2019	both
Maui_02/2018_Gulch1/2	HHB-00344	2	Coleoptera			*morphospecies* 4	11/16/2019	n

Jar Code	Specimen ID	Abundance	Order	Family	Genus	Species	Sort Date	Greater than 10mm?
Maui_02/2018_Gulch1/2	HHB-00345	1	Heteroptera	Pentatomidae			11/16/2019	y
Maui_02/2018_Gulch1/2	HHB-00346	1	Homoptera				11/16/2019	n
Maui_02/2018_Gulch1/2	HHB-00347	1	Diptera	Syrphidae			11/16/2019	n
Maui_02/2018_Gulch1/2	HHB-00348	1	Lepidoptera	male			11/16/2019	n
Maui_02/2018_Gulch1/2	HHB-00349	1	Lepidoptera	Noctuidae	*Spodoptera*	*exigua*	11/16/2019	y
Maui_02/2018_Gulch1/2	HHB-00350	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	11/16/2019	y
Maui_02/2018_Gulch1/2	HHB-00351	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	11/16/2019	y
Maui_02/2018_Gulch1/2	HHB-00352	1	Lepidoptera	Geometridae	*Macaria*	*abydata*	11/16/2019	y
Maui_10/2017_Gulch2/3	HHB-00353	14	Lepidoptera	Noctuidae	*Mythimna*	*unipuncta*	11/22/2019	y
Maui_10/2017_Gulch2/3	HHB-00354	4	Coleoptera	Scarabeidae			11/22/2019	y
Maui_10/2017_Gulch2/3	HHB-00355	3	Coleoptera	Staphylinidae			11/22/2019	both
Maui_10/2017_Gulch2/3	HHB-00356	1	Coleoptera	Scolytinae			11/22/2019	n
Maui_10/2017_Gulch2/3	HHB-00357	4	Coleoptera	Elateridae			11/22/2019	y
Maui_10/2017_Gulch2/3	HHB-00358	1	Coleoptera			*morphospecies* ^{4}	11/22/2019	n
Maui_10/2017_Gulch2/3	HHB-00359	1	Lepidoptera	Torticidae	*Cryptophlebia*	*illepida*	11/22/2019	n
Maui_10/2017_Gulch2/3	HHB-00360	1	Heteroptera	Cydnidae			11/22/2019	n
Maui_10/2017_Gulch2/3	HHB-00361	1	Coleoptera			*morphospecies* ^{3}	11/22/2019	n
Maui_10/2017_Gulch2/3	HHB-00362	3	Lepidoptera	Crambidae	*Eudonia*		11/22/2019	both
Maui_10/2017_Gulch2/3	HHB-00363	10	Lepidoptera	female			11/22/2019	both
Maui_10/2017_Gulch2/3	HHB-00364	2	Isoptera				11/22/2019	y
Maui_10/2017_Gulch2/3	HHB-00365	1	Lepidoptera	Crambidae	*Orthomecyna*		11/22/2019	n
Maui_10/2017_Gulch2/3	HHB-00366	1	Lepidoptera	Torticidae	*Amorbia*	*emigratella*	11/22/2019	n
Maui_10/2017_Gulch2/3	HHB-00367	1	Lepidoptera	Crambidae	*Herpetogramma*	*licarsisalis*	11/22/2019	y
Maui_10/2017_Gulch2/3	HHB-00368	1	Lepidoptera	Crambidae	*Herpetogramma*	*licarsisalis*	11/22/2019	y
Maui_10/2017_Gulch2/3	HHB-00369	1	Lepidoptera	Crambidae	*Herpetogramma*	*licarsisalis*	11/22/2019	y

Morphospecies [1] = Coleoptera: Curculionidae: Scolytinae (subfamily)
Morphospecies [2] = Coleoptera: Scarabeidae (unidentified species 1)
Morphospecies [3] = Coleoptera: (tiny species from an unidentified family)
Morphospecies [4] = Coleoptera: Scarabeidae (unidentified species 2)

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APPENDIX 6. HAWAI'I ISLAND HAWAIIAN HOARY BAT ECOLOGICAL RESEARCH PROJECT ANNUAL REPORT

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Hawaiian Hoary Bat Conservation Biology: Movements, Roosting Behavior, and Diet

Agreement # 17WSTAAZB005541

Annual Report

Summary of Research Activities through July 2020

27 July 2020

Prepared by:

USGS-Pacific Island Ecosystems Research Center, Kilauea Field Station, P.O. Box 44, Hawaii National Park, HI 96718

Hawaii Cooperative Studies Unit, University of Hawaii at Hilo, P.O. Box 44, Hawaii National Park, HI 96718

The Hawaiian Hoary Bat Conservation Biology project is designed to advance understanding of key aspects of endangered Hawaiian hoary bat (*Lasiurus cinereus semotus*) ecology and population biology. Key components of the study include:

- Roost fidelity and characterization
- Maternal roost ecology and mother-pup behavior
- Habitat use
- Diet analysis using molecular techniques
- Insect prey selection and availability
- Insect prey-host plant associations
- Movements throughout the annual cycle
- Banking of tissue and fur collection for genetic and pesticide studies (outside scope of this study)

Study preparation and design

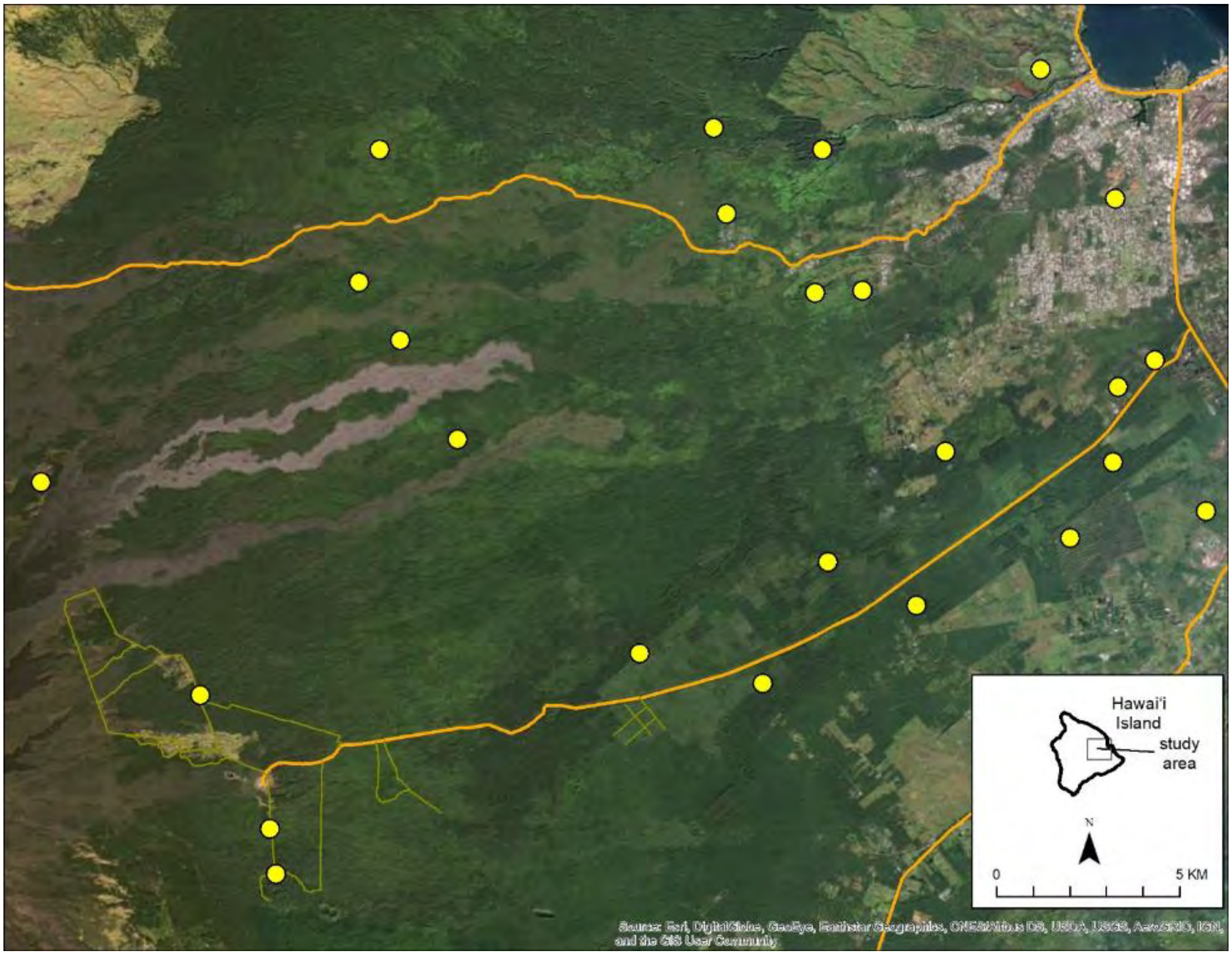
This USGS-led study is being conducted in collaboration with several researchers with the University of Hawaii at Hilo – Hawaii Cooperative Studies Unit.

Significant permitting and land access requirements were addressed during the initial phase of the project. State of Hawaii Department of Land and Natural Resources – Division of Forestry and Wildlife (HI DLNR-DOFAW) has granted permits for access and special use in several Forest Reserves and Natural Area Reserves, and Laupahoehoe Hawaii Experimental Tropical Forest. The US Fish and Wildlife Service has granted a special use permit for the Hakalau Forest National Wildlife Refuge. A native invertebrate collection permit has been granted by HI DLNR-DOFAW. Additionally, State and Federal permits for the capture, handling, and sampling of Hawaiian hoary bats have been renewed. The USDA Forest Service - Institute for Pacific Islands Forestry and the University of Hawaii College of Tropical Agriculture and Human Services have granted permission to station automated telemetry receiver stations on their properties. All permits are being renewed annually.

The study area spans much of the east side of Hawaii Island (Figure 1). Eight fixed sampling sites have been selected for regularly scheduled bat mist netting and insect collections; these sites are sampled three times per year (approximately 4-month interval between visits). Four fixed sites are located at high elevation (above 1000 m asl) and four at low elevation (below 600 m asl). The fixed sample sites include native and exotic forests, orchards, pastures, and mixed habitats. Sampling cycles are divided by breeding cycle phase: non-reproductive (December-March), pregnancy/pupping (April-July), post-lactation/fledging (August-November). Additional bat mist netting efforts are conducted at a variety of sites that span a range of habitat types in east Hawaii.

Effect of Covid-19 pandemic on study

Bat capture efforts were paused mid-March through early June 2020 due to the Covid-19 pandemic. During this time a number of field and lab tasks that could be conducted without the handling of bats and while maintaining social distancing continued relatively uninterrupted and data processing continued. After careful evaluation of conditions on the island of Hawaii, implementation of enhanced sanitation protocols, acquisition of personal protective equipment, and personnel training in the proper use of N95 respirators, bat captures resumed in early June 2020. We will continue to monitor and evaluate conditions and adjust efforts as needed for safety.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1. Mist nest sites in the Wailuku watershed of east Hawaii Island. For clarity, map excludes several net sites in the Laupahoehoe Natural Area Reserve (20 km to north).

Capture effort

Bat mist netting was conducted during 155 nights from 14 May 2018 to 24 July 2020 (2018: 36, 2019: 87, 2020: 32); bats were captured on 57 of these nights (Figure 2). Eighty-six individuals were captured and from all individuals tissue and hair samples were collected and morphometric measurements and reproductive status recorded. All bats were marked with unique color-coded bands. Radio-telemetry tags were affixed to 81 individuals. Additionally, six individuals were captured twice, four of which were radio-tagged twice.

Figure 2. Mist nest set up to capture Hawaiian hoary bats (left) and captured bat (right).

Roost ecology

Roost ecology studies were a primary focus of field efforts during years one and two of the project. Once individuals are captured and radio-tagged, efforts to track the individual to a day roost tree commence within one day. Dense forest vegetation and a limited road network creates extremely difficult conditions for tracking individuals to their day roost resulting in significant effort devoted to this work. Radio telemetry (Figure 3) has been used to date to track a total of 22 bats to a day roost tree; an additional 32 bats have been tracked to the forest stand of their day roost (Figure 4). Three maternity roosts were confirmed in 2019 and three in 2020, and the number of pups is evaluated by repeat observations at each maternity roost (Figure 5). The maternity roosts have been monitored on a weekly basis using acoustic and thermal video recordings to obtain information on roost fidelity, the time of roost emergence/return, the within-night frequency and duration of foraging flights, time to pup fledging, and presence of potential predators (Figure 5). Regular monitoring of select non-maternity roosts is also being conducted to check for returning individuals to document fidelity and identify opportunities for video monitoring (Figure 6). Where possible, roost fidelity of bats with active radio tags is monitored using an automated receiver station near the roost (Figure 3). Data from these systems have been collected and downloaded at 21 tree or stand-level roosts since May 2019, when the system was first used.

Roost trees are identified to species and characteristics are measured (e.g., height, dbh, percent canopy cover, etc.). To date, roost tree metrics have been collected at 31 trees. Stand-level characteristics (e.g., stand height, dominant tree, understory, etc.) for an additional 39 locations (72 total) were derived from a combination of satellite and airborne imagery and ground measurements. For the data compiled for the 2018-2019 period of monitoring, trees used by roosting bats were primarily comprised of non-native plantation or invasive species, although native *Metrosideros polymorpha* was also used. Other preliminary tree and stand metric results and metadata are publicly available through the USGS

ScienceBase Catalog, https://doi.org/10.5066/P9R95UYT (Montoya-Aiona et al. 2019). A metadata viewer is available for download: https://github.com/usgs/fort-pymdwizard/releases.

Figure 3. Radio telemetry effort to located day roost tree (left). Automated receiver station used to measure roost fidelity (middle). Thermal imager used for searches for roosting bats (right).

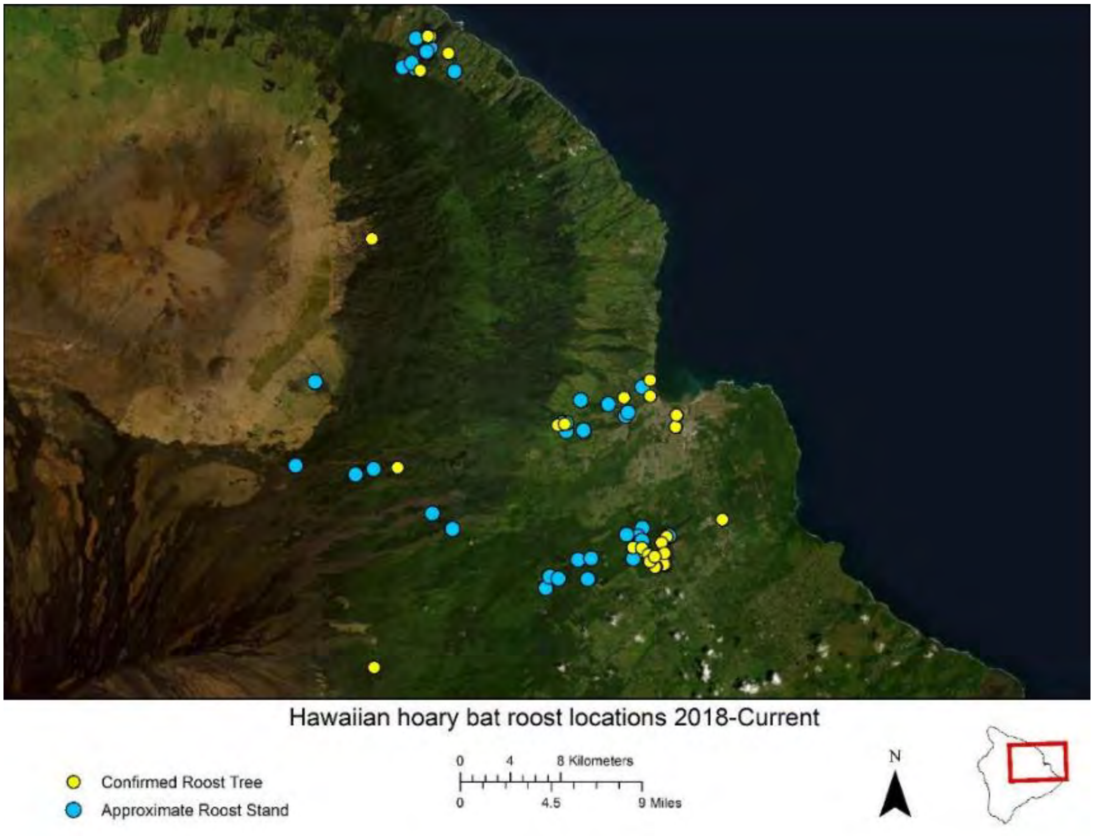


Figure 4. Confirmed and approximate Hawaiian hoary bat roost locations, 2018 – June 2020.

Figure 5. Thermal video camera deployment at maternity roost (left). A mother Hawaiian hoary bat with two pups observed during maternity roost monitoring (right).

Figure 6. Example of a mother-pup Hawaiian hoary bats at roost (left). Adult male Hawaiian hoary bat observed during roost fidelity monitoring (right).

Diet studies

Diet studies were also a focus during years one and two of the study. Studies of diet are focused on three primary lines of research: prey selection (comparison of availability with what is in fecal samples and comparison between sexes), seasonal and elevational comparisons, and host-plant associations with diet species.

Insect collection commenced in February 2019. Nocturnal flying insects are collected using light traps (Figure 7) run at each fixed collection site concurrently with mist netting. Insect collection is conducted during two nights in each sampling cycle (i.e., 16 nights per cycle). Insects are categorized by size class and identified to the highest possible taxonomic classification; this lab work is underway (Figure 7). Additionally, DNA extracted from potential prey items have been and will continue to be submitted for genetic meta-barcoding to establish a reference library of potential bat prey items.

To identify bat prey, genetic meta-barcoding of guano samples is being conducted, and a bioinformatics approach used to match bat prey items in with the reference library (above) and public databases (see Pinzari et al. 2019). To date, 59 guano samples have been collected. Lab work to begin analysis of these samples commenced in early 2020 and is on-going (Figure 7). Genetic barcoding of potential insect prey commenced in June 2020 and is on-going.

Collection of caterpillars from vegetation at the fixed sampling sites commenced in March 2020 and is on-going (Figure 8). A combination of rearing caterpillars to adult form and genetic meta-barcoding of the caterpillars will be used to link the collections with bat diet. Host plants of bat prey are being identified using these collections and in-depth literature search and cataloging of insect host plants in Hawaii.

Figure 7. Insect collection using UV light trap (left). Potential bat prey collected and identified (middle). Hawaiian hoary bat guano sample being prepared for genetic meta-barcoding (right).

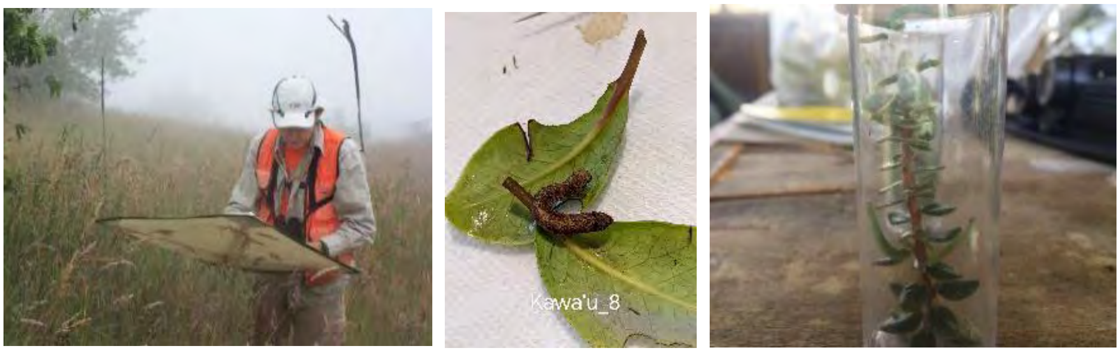


Figure 8. Caterpillar collection from vegetation to identify host plants of potential Hawaiian hoary bat prey (left). Caterpillars collected with host plant material (middle and right).

Movements

Study of Hawaiian hoary bat movements were limited in year one and two of the study; increased effort on this objective is planned in year three. A network of 20-30 ft masts with antennas and radio receivers that function as automated telemetry systems across a broad section of the Hilo watershed is still undergoing testing. Technical issues with the effectiveness of radio receivers for this system have occurred, and extensive testing of receivers continues. Five stations have been installed. Once operational, the receiver systems should allow for a better understanding of the distances traveled and elevational migrations made by bats within a night and within the approximately two- to three-week period that a radio tag is active. By the end of 2020 a determination will be made if efforts to track long distance movements will be shifted to ground-based tracking methods. Additional movement information is documented when possible, including site fidelity and seasonality of re-captured bats (*n* = 6) and the distance between capture and roost locations (Figure 9).

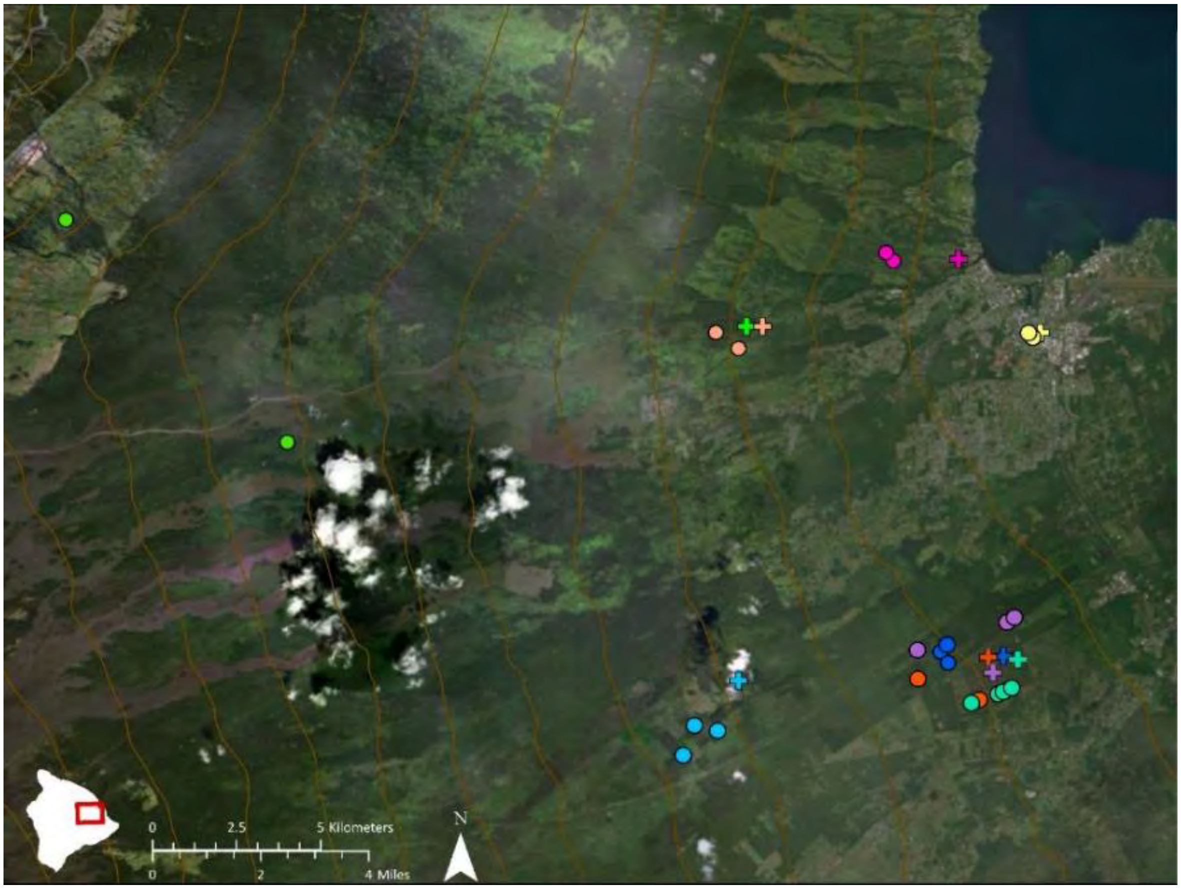


Figure 9. Net sites (cross symbols) relative to roost locations (circles) for captured bat (grouped by color) (data as of March 2020).

Future research efforts

We plan to continue field work and data collection across east Hawaii through mid-year 2021 including regular efforts to capture, collect samples, and radio-tag bats. Tracking individuals to roost trees and data collection at roost trees will continue to be a focus of field efforts during 2020. Diet studies including aerial nocturnal insect collection and caterpillar collection to identify bat prey host plants will also continue to be a focus of field studies through the end of 2020. During late 2020 and early 2021 we expect to increase efforts to track long-distance movements using the automated telemetry system supplemented with ground tracking. Data analysis and report writing is planned for 2021.

References

Montoya-Aiona, K. M., F. A. Calderon, S. P. Casler, K. N. Courtot, P. M. Gorresen, and J. P. S. Hoeh. 2020. Hawaii Island, Hawaiian hoary bat roosting ecology and detection 2018-2019. U.S. Geological Survey data release, https://doi.org/10.5066/P9R95UYT.

Pinzari, C., T. Zinn, R. W. Peck, D. Gross, K. Montoya-Aiona, K. Brinck, P. M. Gorresen, and F. Bonaccorso. 2019. Hawaiian hoary bat (*Lasiurus cinereus semotus*) activity, diet, and prey availability at the Waihou Mitigation Area, Maui. Hawai`i Cooperative Studies Unit Technical Report HCSU-TR090, University of Hawai'i at Hilo, Hilo, Hawaiʻi. Available: http://hdl.handle.net/10790/4638.

APPENDIX 7. MAKAMAKA‘OLE SEABIRD MITIGATION AREA 2019 ANNUAL REPORT

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H. T. HARVEY & ASSOCIATES

Ecological Consultants

50 years of field notes, exploration, and excellence

Makamaka'ole Seabird Mitigation Project
2019 Final Report

Project #3978-02

Prepared for:

Lily Henning
TerraForm Power
200 Liberty Street, 14th Floor
New York, NY 10281

Prepared by:

H. T. Harvey & Associates

January 2020

Executive Summary

The following report contains a summary of the work that H. T. Harvey & Associates performed at the Makamaka'ole Seabird Mitigation Project area during spring-fall 2019, including the seabirds' breeding season, and includes a comprehensive assessment of project performance, success criteria, challenges and future needs. We also present findings and recommendations, for both Newell's shearwaters (*Puffinus newelli)* and Hawaiian petrels *(Pterodroma sandwichensis)*, as they relate to Makamaka'ole and its capacity to provide long-term net conservation benefits by expanding the science and understanding of the ecology, breeding biology, and restorative capacities of both of these ESA-listed species.

Actions being implemented at Makamaka'ole are intended to partially satisfy mitigation obligations for the endangered Hawaiian petrel and threatened Newell's shearwater. Mitigation measures involve the establishment of viable colonies of these species, including predator exclusion fencing, removal and ongoing control of predators, and social attraction to facilitate seabird recruitment and breeding at artificially constructed nesting burrows. The report also includes an assessment of overall project performance to date and presents several scenarios that contemplate next steps and expectations of success going forward. In its sixth year, Makamaka'ole has demonstrated the capacity to provide favorable conditions leading to recruitment and nest site establishment, primarily thus far by Newell's shearwaters. In 2019, following a number of alterations in procedures, nest box use increased from 9-10 in June to 22 nest boxes eventually receiving documented visitation by the end of July. Seventeen of these exhibited consistent visitation by Newell's shearwaters and were monitored through October, while 5 nest boxes were only visited on a few occasions for the first time in 2019. Five of these 17 nests produced chicks that successfully fledged between mid-September and approximately October 15, 2019. These successful fledglings represent the first Newell's shearwater fledglings raised in an artificially constructed nesting colony in Hawaii using social attraction. The project site has also attracted at least one individual, or pair, of dark petrels believed to be Bulwer's petrel *Bulweria bulwerii*. While close fly-bys have occurred, Hawaiian petrels have not been documented landing, prospecting, or attempting to establish nest sites at the mitigation area since 2017.

In general, we conducted management activities on site regularly. Repeated procedures that we employed included: switching camera SD cards weekly; performing fence inspections and vegetation clearing along fencelines and around culverts bi-weekly; monitoring and maintaining the trapping grids and bait stations weekly and monthly, respectively; and barn owl control measures 1-2 nights per week. Vegetation (grass) was trimmed in front of burrows during most camera data card rotations. This was required more frequently depending on the amount of guano deposited at burrow entrances, which resulted in substantial nutrient influx and promoted accelerated growth rate.

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Appendices

List of Preparers

Gregory Spencer, Senior Wildlife Ecologist

Brad Yuen, Wildlife Ecologist

David Ainley, Senior Wildlife Ecologist

Scott Terrill, Senior Wildlife Biologist and Principal

Section 1.0 Introduction

In the fall of 2013, following several years of data collection, feasibility assessment studies, conceptual design and scientific peer review, two approximately 1.8 hectare predator resistant, fenced enclosures were constructed to begin the Makamaka'ole Seabird Mitigation Project. Enclosures were designed to provide nesting habitat largely free of predators for two ESA-listed species: the Newell's shearwater (*Puffinus newelli)* and Hawaiian petrel (*Pterodroma sandwichensis*). In 2013, most of the emphasis was focused on site rejuvenation following fence construction, establishing trapping grids, predator removal, completing the initial installment of roughly 30 artificial burrows inside each enclosure, placing models, and activating the sound playback systems that broadcast calls of Newell's shearwaters (Enclosure A) and Hawaiian petrels (Enclosure B).

By 2015 (Year 2 of project implementation) the number of artificial burrows installed inside each enclosure had reached the initial goal of 50. The sound playback system was managed to attract Newell's shearwaters and Hawaiian petrels in 2015, and both species were documented landing and visiting nest boxes, sometimes concurrently. In 2016, most of the seabird activity observed was limited to Newell's shearwaters and a small dark petrel species, believed to be Bulwer's petrel *Bulweria bulwerii*. It is referred to as such in this report, though by laying an egg in February 2019, it's actual identity was called into question, as the species is supposed to be a summer breeder in Hawaii; Bulwer's petrel activity was almost entirely limited to a cluster of three burrows in Enclosure B. In 2017, Hawaiian petrels, Newell's shearwaters, and Bulwer's petrels were observed visiting nest sites in the aforementioned cluster in Enclosure B and Newell's shearwaters were active at two burrows in Enclosure A. That year, four eggs (three reported to be Newell's shearwaters' and one presumably laid by a Bulwer's petrel) were produced, but did not hatch and were later collected. Newell's shearwater activity increased in 2018 when five nesting sites were visited and occupied for various lengths of time in Enclosure A, and four were visited in Enclosure B (in addition to documented visitation at the naturally excavated burrow cavity referred to as the "uluhe" burrow) (Table 1).

A significant amount of information is contained in previous annual reports detailing management activities associated with the project (Kaheawa Wind Power 2013, 2014, 2015, 2016, 2017, and 2018). We reviewed these reports and developed a timeline for each burrow that exhibited activity, based on previous monitoring, to display the progression of colony establishment and formulate preliminary expectations, in terms of potential breeding performance, in 2019. We also deduced the need for and implemented important refinements to enhance the recruitment capacity of both seabird species, and these actions resulted in a substantial increase in the number of nest sites visited by seabirds. Moreover, five nest sites produced Newell's shearwater chicks that appear to have successfully fledged. This represents the first case in Hawaii in which social attraction has led not just to nesting recruitment, but also successful reproduction among endangered seabirds. The specific actions that were implemented and how these are attributed to the successes observed in 2019 are discussed below

Table 1. Sequence of Nest Site Visitation, Presence of Egg Material, and Newell's Shearwater Chicks Presumed Produced at the Makamaka'ole Seabird Mitigation Site, 2013–2019

Enclosure A				Enclosure B			
Year	Nests Visited	# Eggs	# Chicks	Year	Nests Visited	# Eggs	# Chicks
2013	0	0	0	2013	0	0	0
2014 (1)	0	0	0	2014 (1)	1	0	0
2015 (2)	0	0	0	2015 (2)	1[a]	0	0
2016 (3)	1	0	0	2016 (3)	4	0	0
2017 (4)	3	3	0	2017 (4)	3	1	0
2018 (5)	5	2	0	2018 (5)	5	2	0
2019 (6)	15	3	3	2019 (6)	2	3	2

[a] The single nest visited in Enclosure B in 2015 was a presumed Bulwer's petrel observed in the vicinity of several burrows clustered near one of the speaker horns.

Notes: Numbers in parentheses indicate the project implementation year; Nests visited indicates the number of nest boxes that received visitation that was considered consistent (> 3 weeks); Enclosures A and B were established for Newell's shearwaters and Hawaiian petrels, respectively; # eggs includes intact eggs and egg shell fragments and/or egg membrane material present.

Section 2.0 Work Performed in 2019

2.1 Mitigation Site Inspections and Nest Box Preparation

In anticipation of seabird site use, in February and early March 2019, we conducted pre-season field site assessments, nesting box inspections and preparations, fence inspections, inventory and provisioning of project components such as traps and bait-stations, evaluation of the performance of the audio playback system, and the production of new and enhanced call playback sequences in an effort to achieve more effective representations of both species. Once birds began arriving and visiting nest sites, we installed high performance covert IR game cameras to monitor seabird visitation and activities and managed habitat in the vicinity of burrows and active burrow clusters.

We mobilized resources and personnel and initiated fence inspections of Enclosures A and B before the anticipated arrival of shearwaters and petrels to identify any breaches or portions of the fence infrastructure in need of immediate repairs. In early March, H. T. Harvey & Associates ecologists David Ainley, Brad Yuen, Gregory Spencer, and Spencer Engler, formerly a field biologist with TerraForm Power, performed inspections of all nest boxes in both enclosures. We opened each box, examined the contents, and evaluated the condition of each nest box lid. Contents within the nest boxes were carefully inspected to evaluate the presence of feathers and nest material, composition of the nesting substrate, and general conditions inside the nest boxes. We shifted gravel to form nesting "bowls," when one was not evident, to reduce the potential for eggs to be accidentally rolled out of nest chambers during incubation. Moreover, photos and reports from previous years indicated egg breakage in some eggs and to further guard against this, we also removed any large rocks. We also added small amounts of grass to pad the substrate. Finally, we repositioned models so as not to appear to be guarding burrow entrances (and subsequently on occasion moved them to new positions). During our initial nest box inspections at Enclosure A in early March, we encountered four nest boxes that contained feathers and eight that contained pieces of grass, twigs, and tips of grassy vegetation, pulled into the boxes by occupants, and that corroborated records of past visitation. In Enclosure B, we observed feathers in five nest boxes. One small egg was discovered intact inside a well-prepared nest bowl in nest box B-50 (Figure 1). Based on its small size, we concluded that it had been laid by the Bulwer's petrel that has been steadily active at this nest box for most of the entire preceding year, as indicated by game camera photographs.

2.2 Fence Inspections and Repairs

Fence inspections were conducted regularly to guard against intrusion of alien mammals. These inspections consisted of walking and hiking the perimeter and inner edges and inspecting the structural components including mesh and skirt, posts and braces, hood, brackets, overlap sections, and overall structural integrity to identify wear and needed repairs. We also monitored erosion, particularly where terrain is steep, looking for signs of developing rills or new drainage corridors. Eroded gullies might allow predator entrance into the enclosures. We did not identify any significant erosion concerns but recognize the potential for sheeting flow to move through the area, especially during or following periods of heavy rainfall.

Figure 1. Egg Observed at B-50 during Pre-Season Nest Box Inspections in Early March, 2019, and Believed to Belong to Bulwer's Petrel (or Related Species)

Until early August 2019, most interim repairs were limited to patching and plugging small holes, cracks, or crevices that sometimes form around the margins of the culverts. Numerous older brackets contain rust, and while quite a few have been replaced, especially in the lower sections of the enclosures (mostly Enclosure A), many brackets remain in need of replacement. We replaced some brackets based on the severity of rust and corrosion indicating a need for immediate repairs. The mesh on the windward (east) upper side of Enclosure A contains a substantial amount of rusted brackets and there are portions of the mesh that have become severely rusted. High winds in August caused mesh failure on two joining panels and we installed two new 25-foot long sections of mesh over the entire worn portion to ensure that any further disintegration of the original meshing would not result in a breach (Figures 2 and 3). Similarly, we replaced several brackets in this section to reinforce the connection to the adjacent hood.

Although the interim repairs have performed well, another wind event in December 2019 caused one of the upright fence posts to break, resulting in the separation of at least one bracket and damage to the hood (Figure 4). In fact, the damaged section of hood separated from its attachment points and is hanging free of the fence structure, threatening further damage and potential for unwanted breaches. Interim repairs to correct this damage are in progress and recommendations for additional fence repairs needs are outlined below.

Figure 2. Fence Damage Caused by Excessive Rust Detected in August 2019

Figure 3. Fence Repairs Implemented in August 2019

Figure 4. Damaged Section of Fence Detected in December, 2019

2.3 Erosion Management

We did not observe any significant erosion issues in 2019. Soils were saturated in the early weeks of project management, but steadily improved throughout the season. When rainfall was consistent, or surface runoff evident, we examined areas where runoff appeared heaviest and traced adjacent sources of runoff to ensure that new rills were not forming outside of previously installed erosion control features (water bars, flow deflectors). We systematically looked for any evidence of sediment flow and/or slumping of mud or other debris to ensure that there was no accumulation along the fences, especially in the steep and lower sections.

2.4 Culverts

Culverts were installed in 2013 as components of the original fence designs to manage and direct storm water flow at four discharge points along the lower sections of the fenced enclosures. Three are located at Enclosure A and one was installed along the lower margin of Enclosure B. We used hand tools and weed-whackers to regularly clear vegetation from around the culverts and aprons to ensure unimpeded storm water flow downslope, which also enabled culverts to be inspected for wear, needed repairs, and evidence of digging or cracks that might facilitate small mammal ingress, mostly around the grouted margins. We frequently inspected the four culverts and reduced the vegetation around them. We used care in applying spot treatments of Round-

Up to inhibit weed regeneration around the grouted margins of the culverts. We only applied herbicide around the culverts during dry periods when rainfall was absent or forecast to be negligible.

2.5 Vegetation and Invasive Weed Control

The terrain within the enclosures is densely covered by mostly perennial herbaceous vegetation. We did not consider vegetation to present significant issues and did not observe the emergence of any new types of noxious or invasive weeds. By far, the majority of the ground-cover management that we performed in 2019 was intended to open up and maintain a cleared corridor along the fencelines. Facilitated by weed-whackers and hand tools (machete), regular clearing helped to provide easy access along the perimeter inside and outside each fenced enclosure, helped reduce seed dispersal, and enabled the partially buried fence skirt to be inspected for wear, signs of digging by unwanted mammals, or breaches of any kind. In order to properly inspect and repair the margins of the culverts, vegetation control around these features was necessary and was performed routinely. Maintenance of habitat around the burrow groups entailed trimming back grasses and small shrubs, by hand, to enhance the visibility of models, burrow entrances, and the field of view for the covert IR game cameras. We also targeted the removal of particularly unwanted weeds, such as clidemia *Clidemia hirta* and *Tibouchina* spp., and we removed several of these plants at the root, bagged and disposed of these off site. Benefits of this approach were indicated by expansion of uluhe fern *Dicranopteris linearis* and other native plants within the enclosures, thereby contributing to habitat improvements within the management area. Uluhe fern is often associated with nesting areas of the shearwaters and petrels at lower altitudes (i.e. Lanai, Kauai). We also conducted monthly spot treatments of *Clidemia* and *Tibouchina* using Round-Up. Monitoring of vegetation focused on detecting the spread of unwanted species such as molasses grass *Melinis minutiflora* and guava *Psidium* spp, to ensure that early detection would facilitate future actions can be taken to limit encroachment of these unwanted species along the fencelines and other portions of the management area.

Section 3.0 Predator Control

3.1 Rodents and Mongoose

The predator control program implemented at Makamaka'ole specifically targeted the exclusion of predators such as rats *Rattus* spp., cats *Felis catus*, mongoose *Herpestes auropunctatus*, and feral pigs *Sus scrofa*, all of which are known to harm or kill burrowing seabirds. Measures focused on removal and ongoing control of rats and included trapping to intercept any mongoose that might find a way into the fenced enclosures. No mongoose have been documented inside either of the enclosures since the project began in 2013-2014, although many were trapped immediately adjacent to fences outside. Traps were placed to actively dispatch rats and mongoose within a buffer extending several meters outside the fences. DOC-200 traps (New Zealand Department of Conservation) and Victor snap traps were used for mongoose and rats, respectively. These traps were secured within wooden boxes designed to exclude seabirds and non-target species. In 2019, we removed 37 mongoose from outside-the-fence buffer areas, whereas ten rats were trapped inside: nine in Enclosure A and one in Enclosure B; and an additional ten were removed from the buffer (Table 2). Three mice were removed from inside Enclosure A.

Table 2. Rodent and Mongoose Trapping Results in Each Enclosure by Target Species and Location (April 1 to November 22, 2019)

Location	Trap	Enclosure	Mongoose	Rat	Mouse
Outside	DOC	A	19	1	0
		B	17	1	0
	Snap	A	0	5	0
		B	1	3	0
Inside	DOC	A	0	0	0
		B	0	0	0
	Snap	A	0	9	3
		B	0	1	0
Total			**37**	**20**	**3**

In addition to trapping, we provisioned and checked bait stations (24 per enclosure in an approximate grid) loaded with Ramik Mini-Bars (active ingredient 0.005% diphacinone) every two weeks for signs of consumption by rats and to ensure bait freshness. Although the bait used is mold- and moisture-resistant, it generally needed replacement after a period of six to ten weeks, depending on the weather conditions and placement within the grid. Thus far, all bait replacement was deemed necessary due to molding with no bait bars chewed by rodents by more than approximately 25%. Overall, most bait checked and replaced had not shown evidence of consumption by rats, with the same bait boxes generally showing evidence of consumption from check to check.

3.2 Tracking-Tunnel Surveys

We performed three quarterly tracking-tunnel surveys to sample rodent and mongoose presence. Surveys were conducted 21-25 March, 3-7 June, and September 26-30; Table 3). Each survey consisted of deploying 40 tracking tunnels and cards in each enclosure over a 96 hour exposure period (n=20 per treatment, 2 treatments; treatment exposure time = 24 hours for rodents, 72 hours for mongoose). As in previous years, no mongoose activity was detected in either enclosure in 2019, while some amount of rodent activity was detected in both enclosures.

Table 3. Estimates of Rodent and Mongoose Activity Levels in Each Enclosure Using Tracking Tunnel Cards Expressed as Percent Activity (March 1, 2018 to September 30, 2019)

Predator	Month	Enclosure A	Enclosure B
Mongoose	March	0	0
	June	0	0
	September	0	0
Rat/Mouse	March	20	0
	June	10	0
	September	30	60

Note: Activity levels are expressed as percent, averaged among all cards used in the trial for a given treatment period. Trials are performed quarterly; percent activity functions as a proxy index of relative presence.

These results indicate very low to negligible levels of rodents early in the year, and high probability that mongoose remained completely absent inside both enclosures. However, we did note an increase in the presence of rodents, as evidenced by the activity levels seen in September, in both enclosures. An increase in rodent activity on tracking tunnel surveys beginning in late summer and continuing into winter is also consistent with what was observed in previous years and suggests that rodents are probably exhibiting seasonal fluctuation in abundance.

Despite the seasonal increase in rat activity evident in tracking-tunnel surveys, there was little evidence of increased bait consumption at bait stations. Because of this, we also suspect that the current bait station system may not be entirely adequate. When rodents are exposed to poison baits, some individuals consume a lethal quantity, but others consume a sublethal quantity and after surviving the ill-effects, may develop an aversion to the bait (Prakash 1988). In this way, some rats may have developed an aversion to the diphacinone-based bait within the enclosures and are thereby experiencing higher than expected survival. This scenario is supported by information we obtained from the Vector Control Branch (Hawaii Department of Health) and the U.S. Department of Agriculture. These organizations recommended changing the type of toxin used on a rotational basis to reduce the likelihood of aversion and also of tolerance to any one type of control agent.

3.3 Barn Owls

Our initial work on managing the threat presented by Barn owls was limited to observations in the vicinity of the hunting zone, to learn about presence, activity and habits of Barn owls when we could observe them, and to coordinate on control. We also conducted surveillance for owls while making observations of seabirds at night, mostly from the stable, elevated platform in the uppermost corner of enclosure B, and along the road near the preferred hunting area. We observed barn owls on at least 5 occasions at Makamaka'ole in 2019. At the preferred hunting area, we attracted individual owls on two separate occasions to recorded call playbacks of distressed small mammals (mice and voles).

H. T. Harvey & Associates obtained a new Wildlife Control Permit with the Division of Forestry and Wildlife, issued at the end of June 2019. Active owl-control efforts began on July 12th. This involved playing a recording associated with a decoy. We hunted actively on three occasions but no owls were shot or removed from the project area in 2019.

Section 4.0 Social Attraction and Nesting Colony Establishment

4.1 Sound Playback System

Three sound playback systems were used at Makamaka'ole in 2019. Each system entails one Xplod 350 watt 2/1 Channel Power Amplifier housed in a weather-resistant case and powered by a 12-volt battery charged by solar panels. Each power amplifier can accommodate up to eight speaker horns under the current configuration. The playback systems at Makamaka'ole, from the original start of the project, were intended to broadcast only Newell's shearwater calls in Enclosure A and only Hawaiian petrel calls in Enclosure B. Early in the season, we were surprised to learn that the recorded playback sequence being broadcast in Enclosure A since 2018 was a mix of Newell's shearwater and Hawaiian petrel. We quickly made a new recording sequence containing only the calls of Newell's shearwaters and this new sequence was used for the duration of the 2019 season. In early July, upon installing additional speakers (see below), and upon testing the revised system, we reevaluated the recording sequence being played in enclosure B and, although this track contained only Hawaiian petrels, we found it to lack clarity and deemed that it needed to be replaced. The re-installed playback sequence for Hawaiian petrels was derived from recordings made on Lanai'hale and was provided by the Cornell Lab of Ornithology (Macaulay Library). These calls generally resemble, in our opinion, those made by petrels at Makamaka'ole. Thus, we considered them to be well suited given the proximity, and shared ecological setting with the petrels breeding on Lanai. There is the possibility that some Makamaka'ole recruits could be from that population. Each of the three systems were configured to play from sundown to sunrise and each had been on this playback regime, non-stop, since the end of the 2018 breeding season. In 2019, we discontinued playbacks at the end of October, which is long past when new potential recruits would have been visiting and calling.

At the beginning of 2019, two large 50 watt speaker horns (TOA Electronics) were being run on each amplifier. In early July, to spread the sound sources, we replaced the horn drivers in the 50 watt horns and added four additional 30 watt speakers to the existing arrays in each enclosure (eight new speaker horns). We chose to increase speaker coverage on the basis of our observation that visited nest boxes where close to existing speaker horns. We concluded that by installing additional horns we might increase the number of active burrows, spread over a wider area.

The Newell's shearwaters, as noted, have been using nest boxes that are closest to the speaker horns (i.e. the source of the broadcast), i.e. within 1-3 meters. Upon adding new speakers, which basically was an informed hunch, we were pleased that within days additional nest boxes began to be visited by seabirds in Enclosure A. This confirmed our suspicion that we could manipulate recruitment through strategic placement of horns. By expanding the sound system, though not in a systematic manner (we were just experimenting) we significantly expanded the distribution and number of active burrows. These adjustments clearly helped to advance the attraction of new recruits to nest at Makamaka'ole, in the process contributing important insights that will prove useful in the future.

4.2 Nest Site Monitoring

In March, we evaluated the distribution and posture of seabird models, considering that prospecting shearwaters and petrels may be sensitive to the position of decoys relative to nest sites. To mitigate the possibility that models were positioned in a way that could be interpreted by recruits to be guarding a respective burrow entrance, we rearranged models in both enclosures, increased the distance between models and burrow entrances. Periodically, we adjusted the postures and orientations of individual models throughout the season.

In the recently completed nesting season, the first Newell's shearwaters began arriving and visiting burrows on about April 8, 2019. Visitation increased gradually thereafter, and apparently reached a stable maximum by June. Shortly after the system upgrades were accomplished in early July, we observed a nearly three-fold increase in the number of active nest sites being visited by Newell's shearwaters, mostly in Enclosure A. Eventually, 22 nest boxes were being visited by shearwaters by the end of July. Seventeen of these exhibited consistent visitation by Newell's shearwaters and were monitored through October, while 5 nest boxes were only visited on a few occasions for the first time in 2019. Five of these 17 nests produced chicks that successfully fledged between mid-September and mid-October (Table 4).

4.3 Camera Deployments and Data Review

We monitored visitation and activities of mostly Newell's shearwaters at all active nest sites using primarily the professional quality Reconyx covert IR game cameras (*HyperFire* and *HyperFire 2*, Reconyx, Inc., Holmen, Wisconsin), as well as some older digital trail cameras having similar IR-illumination capacity manufactured by Moultrie. These cameras are motion triggered, capturing high quality digital monochrome photos using a nighttime infrared illuminator and are custom programmed to function according to a specific set of operational parameters that maximize data acquisition and quality. Although both types of cameras perform these functions, the Reconyx proved to be superior in terms of meeting project performance criteria. Burrows were selected for camera monitoring based on initial indications of toothpick displacement at burrow entrances, as well as the appearance of fresh guano. Grass outside burrows was trimmed by hand and regularly maintained to enhance the quality of the photos and reduce unwanted triggering by wind moving the vegetation (below).

The cameras are designed for securing to a stationary object and can depict areas several meters wide. We made every effort to install one camera at each active nesting burrow at Makamaka'ole in 2019 using a wooden stake in a position that allowed the entrance of the nesting burrow to be under continuous surveillance (Figure 5). In some cases, depending on the amount of activity and number of birds visiting a given site, we repositioned cameras to observe more area in the immediate vicinity of the entrance while, at others, the camera looked directly at the entrance itself (Figures 6 and 7). Reducing unwanted triggering by trimming weeds and grass in the foreground is important and also helps to enhance the quality of the images and our interpretation of the activities recorded. This was done very carefully, especially when birds were suspected of being present inside the nest box during the day, in order to minimize any disturbance. Camera data cards were switched and reviewed at least weekly and slight changes in the position of cameras were sometimes made, as needed.

Table 4. Timeline of Nest Site Visitation and Breeding Parameters Exhibited by Newell's Shearwaters at the Makamaka'ole Seabird Mitigation Project Area in 2019

Burrow	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
A-11 [a]	NESH							🟧	🟧		
A-12 [a]	NESH							🟧	🟧	🟧 9/20	
A-13 [a]	NESH				Upgrades installed →			🟧	🟧	🟧 9/20	
A-14 [a]	NESH							🟧	🟧	🟧	🟧 10/ 5
A-18 [a]	NESH							🟧	🟧		
A-20 [a]	NESH							🟧	🟧		
A-21 [a]	NESH							🟧	🟧		
🟦 A-22 [b, c]	NESH							🟧	🟧	🟧	🟧 10/14
A-24 [a]	NESH							🟧	🟧	🟧 9/24	
A-25 [b]	NESH				🟧	🟧	🟧	🟧	🟧	🟧	🟧 10/5
🟦 A-26 [b, c, d]	NESH				🟧	🟧	🟧	🟧	🟧	🟧	🟧 10/5
A-42 [a]	NESH							🟧	🟧		
🟦 A-43 [b, d, e]	NESH				🟧	🟧	🟧	🟧	🟧	🟧	🟧 10/14
A-48 [a]	NESH					🟧	🟧	🟧	🟧	🟧	🟧 10/14
A-50 [a]	NESH							🟧	🟧	🟧 9/20	
🟦 B-22 [b, d]	NESH				🟧	🟧	🟧	🟧	🟧	🟧 9/5	
🟦 B-50 [b, e]	NESH				🟧	🟧	🟧	🟧	🟧	🟧	🟧 10/7

[a] Probable non-breeders in 2019.

[b] Downy feathers present in nest box.

[c] Chick presence confirmed visually.

[d] Egg shell fragments and/or membrane present.

[e] Intact egg present; A-43 (intact NESH egg, relay); B-50 (NESH egg roll out, relay).

Notes: NESH = Newell's shearwater 🟧; dates in cells indicate the date birds last seen at burrow and, blue shaded burrows indicate chick produced 🟦.

Data obtained with game cameras were entered into a data base, useful in characterizing the activities of seabirds associated with active nesting burrows. Behavioral changes observed over the course of the season were useful indicators of breeding status and the relative likelihood that pairs were involved. Such behaviors can indicate breeding, incubation, and/or chick provisioning, or whether birds visiting specific nest sites may have been simply prospecting or establishing their claim on nest sites that would be used for breeding in subsequent seasons.

Figure 5. **Reconyx HyperFire 2 Camera Monitoring an Active Newell's Shearwater Nesting Burrow at Makamaka'ole in 2019**

Figure 6. **A Pair of Newell's Shearwaters Active at One of the Burrows in Enclosure B; the Camera was Positioned at this Site to Capture a Broader Field of View**

Figure 7. Newell's Shearwaters Documented at an Artificial Burrow in Mid-July, 2019 using the Reconyx HyperFire Camera Aimed Directly into the Burrow Passage

4.4 Searches for Active Nesting Burrows, Inside and Outside of the Protective Enclosures

In the long term, we expect that shearwaters (and petrels) will eventually dig their own burrows, especially once a high proportion of nest boxes become used. Therefore, we performed searches for the presence of active nests and signs of burrowing and prospecting by both Newell's shearwaters and Hawaiian petrels inside and outside of both enclosures, in addition to nest box use. While on site and working inside the enclosures we frequently moved around in areas containing dense understory habitat that would be suitable for nesting. We carefully examined and searched areas, independently and as a team, coordinating observations, in an effort to achieve consistency in our searches for signs of burrow excavation and nesting.

So far, we have not found any burrows or signs of active prospecting outside of the immediate management areas, defined as the areas where the sound system and artificial burrows are situated, within the exclosures. Outside the fenced enclosures, the modest investigations we have done within ten meters of the fencelines, thus far, have not yielded any active nesting burrows or promising signs of prospecting or excavation, by any seabird species. Nor have we found any carcasses that predators outside the exclosures would have left upon predating prospecting birds. We know of one site in Enclosure B, not a nest box (i.e. the "uluhe" burrow), that was prospected, partially excavated, and was routinely visited by both Newell's shearwaters and Hawaiian petrels in past years. This site is located immediately adjacent to one of the 50 watt horns and less than one meter from

B-22, one of the most active burrows in this enclosure. No substantive activity was documented at the uluhe site in 2019 (see Section 5.2).

In Enclosure A, we discovered that Newell's shearwaters were actively prospecting at least one site in close proximity to one of the large 50-watt horns, a few meters behind one of the more active burrows in this portion of the new colony (A-26). We directed considerable attention to monitoring this site, deploying a camera for several weeks, and we regularly searched for additional nest-site prospecting in the surrounding area. We concluded that, although some excavation was occurring, there was no nest established in 2019. Any places that birds may be exploring or beginning to tunnel or excavate are areas that we have inspected carefully. In that way, we can be sure that we are accounting for all nesting activity attributable to our management actions.

While it is important to understand how the project might affect the distribution of nest sites beyond the immediate range of the management area, based on our observations, we have learned that there is a strong spatial correlation between the source of sound playback broadcasts and nest site selection. Concerns expressed about the capacity of the project's social attraction mechanism to result in birds establishing nest sites outside of the enclosures, where they may be exposed to predation, do not appear to be valid at this time. As the colony grows and expands, however, a corresponding increase in the effective radius of calling may eventually result in greater probability that birds will establish nest sites beyond the core management area. Such a development may require the project to expand management actions to ensure the needed protection from threats associated with predation exposure.

Section 5.0 Overall Assessment of Seabird Productivity and Trends in Recruitment Dynamics

5.1 Newell's Shearwaters

The first Newell's shearwaters arrived at Makamaka'ole and began entering burrows on approximately April 8 2019. By the end of June there were eight nest sites being visited; that number increased to about 22 by mid-July. We attribute the nearly three-fold increase in the number of nesting burrows being visited by Newell's shearwaters, in part, to the modifications we made to the playback system and digital call playback sequences. Re-positioning models may also have been involved. Apparently, there has been a 'surplus' of birds being attracted by the call playbacks, but which owing to the territoriality of nest box occupants, have not been encouraged to land. However, there may be other factors that contributed to this increase. For example, in 2018, a second pulse of activity in both enclosures occurred in roughly mid-August, indicated by disturbed toothpicks and some guano deposits (4 nest boxes in Enclosure A and 3 in Enclosure B). Data and observations gathered since project inception indicate that this new colony has been experiencing a stepwise advancement over time. In fact, eight of the nest boxes visited by Newell's shearwaters in 2019 have been active sites for 1-3 previous seasons and four of these (A-26, A-43, B-50, and B-22) have contained eggs each year since 2017 (B-22 first egg in 2018). By installing several new horns in proximity to unused burrows, we believe that we helped to overcome territoriality by existing nest box occupants, thus helping to facilitate the expansion of prospecting opportunities, indicated by the temporal cascade of visitation and subsequent nest site activity that we observed in 2019.

We continued to monitor the visitation and activities of Newell's shearwaters carefully, noting that visitation remained consistent at most nest sites until the end of August, when activity at some of the sites diminished. The drop off was consistent with the expected departure of non-breeders toward the end of the egg period. Song meters (Wildlife Acoustics) used elsewhere indicate a reduction in calling at that time. However, several nests remained active, indicating to us that some of these nesting burrows may have contained chicks being provisioned by parents. On September 4, we used a burrow scope equipped with an LED lamp rosette to examine the contents of several burrow boxes. The burrow scope, which came with the project, was sub-optimal for this purpose since it was not equipped with IR capacity and was difficult to maneuver inside the passage. We did observe a bird (presumably a chick) in nest A-26, but the bird moved out of the view of the burrow scope lens and we were not able to manipulate the scope to get a clearer view. By September, our analysis of camera-derived data indicated a group of five to eight burrows that likely contained chicks, based on the consistency of visitation and behaviors being exhibited by adults, such as food delivery (Figure 8).

On October 10, when it became evident that game camera data alone would not be sufficient to unequivocally confirm chick presence, we opened and examined the eight nest boxes that most likely contained chicks (plus an additional seven nest boxes that were still very active during much of 2019). Anticipating the presence of chicks at these eight nest sites, we coordinated with the Maui Nui Seabird Recovery Project, which we were informed possessed permits for banding Newell's shearwaters and Hawaiian petrels. Our hope was to band chicks prior to fledging. To our surprise, we found no chicks in the eight nest boxes examined. Unsatisfied, we returned two days later to conduct a more thorough evaluation of the contents of each nesting burrow. We carefully inspected the contents, including the inner surfaces of the nest boxes, nesting materials, and substrate on the floor of the nest boxes. We discovered evidence for the presence of chicks, including downy feathers and down filaments (i.e. filoplume-like), egg shell fragments, egg membrane, and indication that at least two pairs of birds layed a second egg which presumably hatched a chick that fledged (A-43 and B-50). One of the nest boxes (A-22) that we inspected on the second day did in fact contain a chick, which apparently was occupying the nest passageway and not the nest box, and thus was not visible to us on the first inspection (Figure 9). In total, strong evidence indicated that five shearwaters fledged from the site in 2019.

5.2 Hawaiian Petrels

Hawaiian petrels have not been observed actively visiting any burrows at Makamaka'ole since 2017, when there were one or more birds associated with the "uluhe" burrow and B-22, both in Enclosure B. In 2016, after it first appeared that Hawaiian petrels had stopped landing to prospect and visit potential nesting burrows during the period when the mixed recorded sequences were playing, the call playback sequence was apparently returned to species-specific calls being broadcast in the two respective enclosures, and indeed Hawaiian petrels were observed on the ground, briefly, in 2017. As our data and observations indicate, the quality and character of the recorded call playback sequences are very important. Prior to July 2019, we thought it problematic to expect both species to establish equally successful nesting colonies intermixed or in close proximity given the more aggressive behavior exhibited by Newell's shearwaters. Newell's shearwaters have responded favorably to audio playback of the species' recorded calls, and as indicated by the camera data, may, at times, fiercely protect a chosen nest site (Figure 10).

Hawaiian petrels and Newell's shearwaters both visited the "uluhe" burrow in 2017, but petrels have not been documented there since. The reasons for their absence are unclear but may relate to several factors including competition with Newell's shearwaters, social attraction response sensitivity, habitat or other variables (including ecological processes at sea). In an effort to better understand factors most influencing the recruitment capacity of Hawaiian petrels and to evaluate whether petrels might exhibit response patterns similar to Newell's shearwaters, we refined the recorded call playback sequence and broadcast the new recordings from 4 additional speaker horns beginning in early July, 2019.

Figure 8. An Adult Newell's Shearwater Delivering Food to a Chick at the Entrance to Burrow A-22 at the Makamaka'ole Seabird Mitigation Area, September 20, 2019

Figure 9. Newell's Shearwater Chick at Rest Shortly before Fledging from Artificial Nest Box A-22 at the Makamaka'ole Seabird Mitigation Area, October 2019

Figure 10. Newell's Shearwater, Possibly a Male, Exhibiting Territoriality

An interesting event cycle occurred in Enclosure B approximately five weeks after the system upgrades were implemented in early July, 2019. On August 14 we discovered that 11 of the burrows in Enclosure B had received visitation, including the "uluhe" burrow, indicated by toothpick displacement and fresh guano. Given that Hawaiian petrels have not been detected landing and exploring burrows in this area since 2017, the observation was a welcome surprise. At that time, we took pictures and inspected the entrances of each burrow where toothpicks had been displaced (indicative of birds passing through the entrance) and then replaced the toothpicks. Two days later, on August 16, three of these burrows were visited again, indicated by toothpick displacement. At the time, all of our covert IR game cameras were in place monitoring other active burrows. Therefore, we determined which of those boxes were least likely to contain active breeding, and redeployed three cameras in Enclosure B in an effort to document the species that was newly exploring the burrows. Unfortunately, the pattern of visitation at burrows in Enclosure B became highly variable and, because we didn't have enough cameras to deploy at each of these newly visited burrows, we were unable to document species. The fact that visitation in Enclosure B rapidly diminished was not a surprise because, based on the breeding season phenology exhibited by Hawaiian petrels, colony attendance by pre-breeding birds would be expected to have already started to decrease for the season (Simons 1985).

The wave of visitation we observed in Enclosure B indicates to us that these birds may have been Hawaiian petrels, for several reasons. First, the system in Enclosure B is only playing Hawaiian petrel calls. The Newell's shearwaters that occupy burrows B-22 and B-50 began establishing these sites in 2015-2016 and are well-stablished. However, there has been no further effort exhibited by Newell's shearwaters to establish nest sites in this enclosure since that time, despite the significant concurrent increases evident in Enclosure A. Second, the response by seabirds in Enclosure B (and Enclosure A) coincided closely with the installation of additional speaker horns, playing species-specific calls. This is important, and encouraging, because the systems in each enclosure are species-specific with the objective being to minimize interspecific competition and maximize reproductive capacity for each species. One of the burrows that was visited in the initial wave of visits in August, the "uluhe" burrow, has a history of visitation beginning with Newell's shearwaters in 2016 and including both species at this site in 2017. All of the nest boxes that showed signs of visitation were adjacent to newly installed speaker horns, consistent with the pattern we observed in Enclosure A.

Notwithstanding the promising recruitment success in Enclosure A with Newell's shearwaters along with the active nest sites at B-22 and B-50, we did not observe nor confirm any new prospecting or nest site establishment by Newell's shearwaters in Enclosure B in 2019. Hawaiian petrels continue to be present based on nighttime observations of birds in flight over the area.

Section 6.0 Conclusions and Recommendations

6.1 2019 Breeding Performance

Based on the monitoring of nest-site visitation and evidence collected at nest sites in 2019, we conclude that five nest sites occupied by Newell's shearwaters produced young, which successfully fledged between mid-September and mid-October. Of the 22 total burrows that received visitation in 2019, 17 of these were visited consistently through September-October, while an additional 5 burrows were visited inconsistently, for periods lasting no more than three weeks, and are presumed to have been early prospectors. By the time the surge in nest site visitation occurred, consistent with the system upgrades (more speakers, recorded call playback refinement, rearrangement of decoys, etc.) in July, with the exception of burrow A-22, it was probably too late in the summer for new eggs to be laid. Seven nests remained active most of the season with visitation extending into early to mid-October. We observed a very small amount of feather material inside A-25 that resembled down. However, based on the criteria we applied in confirming successful fledgling production, we deemed this evidence to be insufficient to confirm a likely fledged chick. The late increase in nest box visitation is expected of subadults seeking to establish nests for use in subsequent seasons.

Although Hawaiian petrels were not directly observed landing and visiting nest sites in 2019, the evidence of late season visitation in Enclosure B indicates to us that at the very least this species may well have exhibited a renewed interest once the improvements we undertook were accomplished.

6.1.1 Recommendations

- Add an additional four 30 watt speaker horns to the sound playback array in Enclosure B in 2020 and begin broadcasting calls of Hawaiian petrels 2-3 weeks before initiating call playbacks of Newell's shearwaters in Enclosure A. This considers the fact that Newell's shearwaters appear to have reached a stage in site recruitment in which they will continue to return to their nest sites even in the absence of artificial social cues, at least initially, and may provide an initial advantage for first time prospecting Hawaiian petrels to initiate nest site establishment ahead of Newell's shearwaters.
- Acquire new sound recordings of Hawaiian petrels at the Makamaka'ole site, Haleakala, and/or the island of Lanai to improve call playback quality and consistency with local call dialects; phase these recordings into the playback sequences by March-April, 2020.
- Obtain a new burrow scope equipped with IR capacity and plan to open and inspect nest boxes in late August, in order to confirm the presence of chicks and ensure that birds are banded well in advance of anticipated fledging dates.

6.2 Nest Box Design

The nest boxes at Makamaka'ole were installed initially in accord to experience with petrels in New Zealand, and with little consideration for possible differences in how Newell's shearwaters and Hawaiian petrels might utilize the structures. There was little reason at the time to believe that design attributes would have any measurable effect on nest site establishment and breeding performance for these two species, given the success of similar efforts in New Zealand (where principal consultant, Steve Sawyer, conducted similar work). However, we observed a significant amount of variability in the behavior of the Hawaiian species at different nest sites, and this became increasingly evident as the season progressed, especially during the chick provisioning period. Some of this variability included how much time birds spent at the entrances, outside the burrows, resting inside the lower portion of the burrow passages, or whether birds quickly entered burrows and did not emerge again until they departed the site. On the other hand, these differences in behavior may have been related to differences in configurations of the burrow structures. For example, the adult birds that occupied A-22 frequently performed many of their exchanges with the chick near the entrance, indicating to us that the chick may have spent considerable time inside the burrow passage rather than inside the nest box. There is also the possibility that the temperature was lower inside the passage, which is insulated by substrate; not every nest box contained an insulated cover in 2019. This is further indicated by the fact that we did not initially observe the chick at A-22 when we opened the box for the first time in October, but discovered its presence two days later. This led to the idea that perhaps Newell's shearwaters may not require nor necessarily prefer as long a passage that existing design offered between the burrow entrance and the nest box chamber. In contrast, burrow A-43 contained a somewhat steeper gradient between the entrance and the nest box chamber and the nest box also was equipped with an insulated cover. This nest box contained copious amounts of feathers and guano, indicating the chick and the adults probably spent considerable time inside the box. We believe that in the near future some modifications of nest boxes in both enclosures may be warranted to understand better the effects of these potential factors.

6.2.1 Recommendations

- Consider modifying the burrow passages on some of the burrows in Enclosure A by shortening the length of the passage and/or adjusting the angle between the entrance and the nest box.
- Construct and install insulated nest box covers to bring temperatures in the nest box chamber in alignment with the temperatures inside the passage, or alternatively, install newly fabricated nest boxes partially below ground level, allowing the nesting chambers to approximate subsurface temperatures.
- Replace worn nest boxes with newly fabricated nest boxes and install these (and any refinements in the burrow passages) well before the first birds are expected to arrive in late March-early April. In this way, the nest site and adjacent ground cover and habitat would have time to recover sufficiently from disturbances to the substrate resulting from these modifications.

6.3 Predator Control

Control of predators needs to remain as an important component for the long term success of the Makamaka'ole project. This is especially true as the seabird populations within the exclosures increase, and become more attractive especially to owls. Adaptive measures should be used whenever changes that might affect success are identified. One of the more apparent examples we observed in 2019 relates to the seasonal variability in rodent activity inside the enclosures. As discussed, we believe there is reason to suspect that, although density of rodents is very low most of the year, there is a seasonal uptick that occurs in late summer through fall. Combined with some degree of habituation or aversion to trap baits (peanut butter, nuts, coconut, etc.) and possibly the development of aversion to Ramik bars containing diphacinone, it may be necessary to explore rotational alternatives to address the latter.

6.3.1 Recommendations

- Explore the use of a secondary formulation of diphacinone or use of an alternative agent if deemed warranted to deal with the potential of aversion in rodents that may reside inside the enclosures and obtain approval by the U.S. Fish and Wildlife Service and the Hawaii Division of Forestry and Wildlife for a change in protocol for the use of a secondary rotational or alternative agent that can be applied within the scope of the management plan to control rodents.
- Remove all caches of materials associated with initial fence construction which remain inside the enclosures, such as bags of sand, lumber, tarps, and any items that may provide shelter for rodents.
- Invite the expertise of two Barn owl control experts with whom we established communication in 2019, to visit the site, and advise on most effective management methods and approach to efficiently address the issue of Barn owl control at Makamaka'ole going forward.

6.4 Fence Maintenance

Both fenced enclosures have been in place for nearly seven years and certain portions are beginning to wear out. The areas affected most at this time are in the upper windward sections, where salt-laden air carried by the prevailing trade winds and rainfall is more frequent and the steepness of the terrain increases. The wear is most apparent in the meshing and bases of wooden uprights, and there are numerous hood brackets that have rusted and should be replaced concurrent with other repairs. Some of the repair work is considered proactive in order to avoid later damage or failures while other actions that are necessary should address immediate repair priorities. Some immediate repairs are being performed on an interim level, while other measures should include replacement and reconstruction of specific structural features in anticipation of the 2020 season.

We will provide a supplemental assessment that will detail and better characterize fence damage observed to date and quantify the fence maintenance and repair needs for both enclosures so that planning for these needed actions can commence. It is likely that mesh needn't be as high as it is currently, and thus could also reduce costs associated with replacement. But that option needs to be considered further before being introduced.

6.5 Important Considerations

The addition of more speaker horns should enhance recruitment capacity of seabirds at Makamaka'ole. Rather than deliver one call sequence for the entire season, we believe there is merit in considering the phasing in of playback sequences that better represent petrel call variability that occurs as the season progresses. Given the present status and trends being observed with Newell's shearwater recruitment in Enclosure A, increasing the attractiveness of Enclosure B for Hawaiian petrels may well demonstrate that petrels are able to become established, without compromising or reducing the overall performance trajectory of Newell's shearwaters. We are looking forward to determining whether this will be true. Meanwhile we expect accelerated growth of Newell's shearwater occupation in Enclosure A.

The number of active Newell's shearwater burrows, and especially the dramatic 2019 increase, is impressive, as after a slow start, these results indicate an acceleration toward meeting mitigation targets, for this species, consistent with the models developed to guide the initial permitting process; such models predicted the likely success of the Makamaka'ole project to achieve its goals (H. T. Harvey & Associates 2011a and 2011b). Given the sudden jump from partial success to a season in which several nests produced young, we believe that the alterations that we introduced were involved. This is one of the only projects anywhere, and certainly in Hawaii, in which demographic models constructed prior to conservation action are being tested in real time. We believe it will be instructive to revisit those demographic models and examine the degree to which the project is on a track, based on theory, toward correctly predicting performance of seabird populations assisted by management actions. The number of active Newell's shearwater burrows at Makamaka'ole, following a dramatic increase in 2019, is now within the rather broad modeled 20-70 active burrow range used to estimate net benefit (number of birds produced) under the reasonable (preferred) starting point scenario (H. T. Harvey & Associates 2011a). Whether the Hawaiian petrels at Makamaka'ole will likewise catch up, following revised management actions, remains to be seen.

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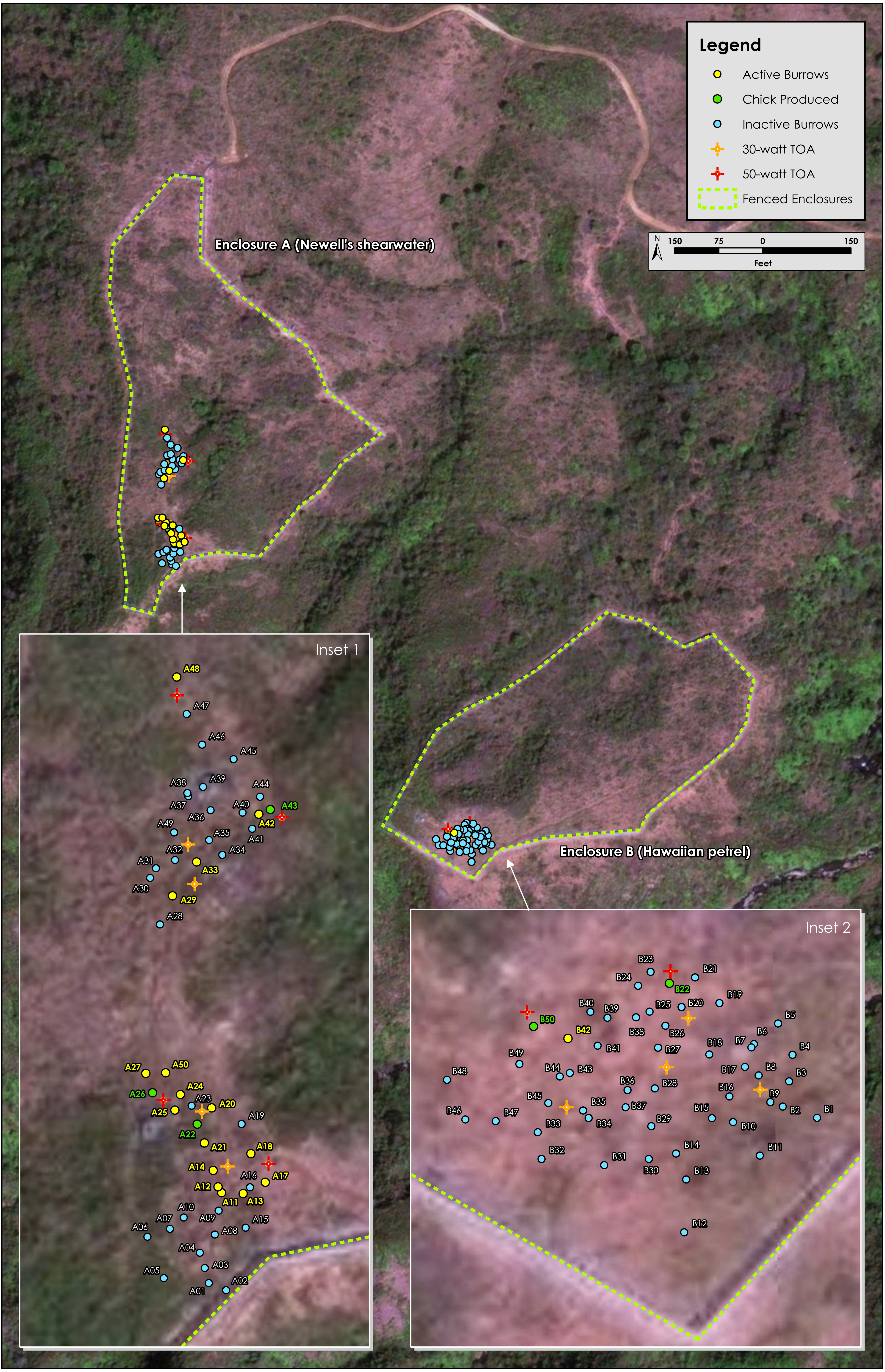
Appendix A. Distribution of Active, Inactive, and Chick Producing Burrows at Makamaka’ole in 2019



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H. T. HARVEY & ASSOCIATES
Ecological Consultants

Appendix A. Distribution of Active, Inactive, and Chick Producing Burrows at Makamaka'ole in 2019

Makamaka'ole Seabird Mitigation (3978-02)

January 2020

Appendix B. Summary of Nocturnal Avian Surveillance at the Makamaka’ole Seabird Mitigation Project through July 2019

Date	Day	Time	Location	Objective	Summary
2/21/19	Thursday	Dusk, early evening (18:30-20:45)	Enclosure B deck.	Observe the airspace for barn owls; evaluate for hunting and general reconnaissance.	Broad area can be seen including much of adjacent Maka valley and enclosure B; not preferred for hunting owls due to immediate proximity to encl. No owls observed.
2/22/19	Friday	Dusk, early evening (18:30-20:10)	Along the road near the enclosure B trail spur.	Surveillance scanning for owls moving through the upper gulches, approaching from lower pastures, or other movement patterns and timing of arrival.	No owls observed; mostly overcast, light rain late.
3/20/19	Wednesday	Late afternoon through early evening (17:30-20:00)	Enclosure B deck; casual observations from points along the access road.	Surveillance scans to detect owls – first arrivals and movement and early season seabird arrivals.	No owls observed. Few HAPE. Broken clouds, no precip.
3/21/19	Thursday	Dusk, early evening (18:00-20:00)	Along the road near the enclosure B trail spur; adjacent to established hunting site.	Surveillance scanning for owls moving through the upper gulches, approaching from lower pastures, or other movement patterns and timing of arrival.	On site discussion of hunting procedures; surveillance in 5-10 minute segments from road, overlook, and across adjacent forested pastures. No Barn owls observed.
4/3/19	Wednesday	Dusk, early evening (18:30-20:00)	Along the road near the enclosure B trail spur.	Surveillance scanning for owls moving through the upper gulches, approaching from lower pastures, or other movement patterns and timing of arrival.	No owls observed. Very dark, mostly overcast, intermittent drizzle late.
4/4/19	Thursday	Dusk, early evening (18:30-20:00)	Hunting location below enclosure B spur.	Deploy audio and visual attraction cues (small rodent distress calls, battery-operated	One Barn owl detected at about 19:15; approached from lower gulch – flew directly to the lure

Date	Day	Time	Location	Objective	Summary
				lure); observe owl response.	and sound playback source; departed quickly in response to observers; no further observations. Very dark conditions, overcast, no precip.
4/18/19	Thursday	Dusk, early evening (18:30-20:00)	Enclosure B deck; casual observations from points along the access road.	Mostly observe activity of seabirds; secondary surveillance for presence of Barn owls.	HAPE and few NESH; no owls. Weather mostly fair, light wind, no precip.
4/19/19	Friday	Dusk, early evening (18:30-20:00)	Enclosure B deck; casual observations from points along the access road.	Mostly observe activity of seabirds; secondary surveillance for presence of Barn owls.	HAPE and few NESH; no owls. Light wind, occasional gusts, no precip.
4/23/19	Tuesday	Dusk, early evening (18:30-20:30)	Enclosure B deck.	Mostly observe activity of seabirds and effort to observe any birds landing near nest boxes or adjacent areas; secondary surveillance for presence of Barn owls.	HAPE and several NESH; no owls. Light wind, occasional gusts, and light precip late.
4/26/19	Friday	Dusk, early evening (18:30-20:30)	Enclosure B deck; casual observations from points along the access road.	Mostly observe activity of seabirds; secondary surveillance for presence of Barn owls.	HAPE and several NESH; no owls. Light wind, 50% overcast.
5/16/19	Thursday	Dusk, early evening (18:30-20:30)	Hunting location below enclosure B spur and well below road.	Deployed audio attraction cues (two separate types of small rodent distress calls).	Set up audio playback in two separate locations (snag and road berm) to widen broadcast; one owl call heard; no owls observed.
5/30/19	Thursday	Dusk, early evening (18:30-20:30)	Enclosure B deck	Comprehensive assessment from high point in the management area to evaluate landscape structure relative to hunting position; surveillance for owls and seabirds after sundown.	Seabirds active; no owls observed.
7/2/19	Tuesday	Dusk, early evening	Enclosure B deck and road outcropping	Surveillance for owls and seabirds after sundown.	Seabirds active; no owls observed.

Date	Day	Time	Location	Objective	Summary
		(18:45-20:30)			
7/12/19	Friday	Early evening	Hunting location below enclosure B spur and well below road.	Set up attractive lure, sound playback (distressed vole and mouse).	No owls approached or observed; seabirds present and calling during flyovers.
7/15/19	Monday	Early evening	Hunting location below enclosure B spur and well below road.	Set up attractive lure, sound playback (distressed vole and mouse).	No owls approached or observed; seabirds present and calling during flyovers.
7/19/19	Friday	Early evening	Hunting location below enclosure B spur and well below road.	Set up attractive lure, sound playback (distressed vole and mouse).	No owls approached or observed; seabirds present and calling during flyovers.
7/20/19	Saturday	Early evening (18:45-20:00)	Along the road above Makamaka'ole Stream	General seabird and owl reconnaissance	Several petrels and Newell's — several Newell's heard above the sound playback near A.

Appendix C. Nest Box Inspection Photos for Active Burrows in 2019

Nest Box A-11 Contents on October 10, 2019 Consisted of Sparse Nesting Material with Little Evidence of Activity Inside the Nest Box by Shearwaters

Nest Box A-12 Contents on October 10, 2019 Consisted of a Small Amount of Nesting Material, Feathers, and Dried Guano. No Eggshell, Membrane, or Down was Found

Nest box A-13 contents on October 10, 2019 consisted of nesting material and feathers. No eggshell, membrane, or down was found.

Nest Box A-14 Contents on October 10, 2019 Consisted of a Small Amount of Nesting Material and Feathers. No Eggshell, Membrane, or Down was Found

Nest Box A-18 Contents on October 10, 2019 Consisted of a Small Amount of Nesting Material and Feathers. Some Larger Stones were Excavated and Moved to the Center of the Nest by the Birds. No Eggshell, Membrane, or Down was Found

Nest Box A-20 Contents on October 10, 2019 Consisted of Copious Nesting Material and Some Feathers. No Eggshell, Membrane, or Down was Found

Nest Box A-21 Contents on October 10, 2019 Consisted of a Small Amount of Nesting Material, Some Feathers, and Guano. No Eggshell, Membrane, or Down was Found.

Newell's Shearwater Chick was Discovered in Nest Box A-22 on October 14, 2019. The Nest Box also Contained a Small Amount of Nesting Material, Some Feathers, Guano, and Sparse Down. No Eggshell or Membrane was Found

Nest Box A-24 Contents on October 10, 2019 Consisted of Nesting Material and Feathers. No Eggshell, Membrane, or Down was Found

Nest Box A-25 Contents on October 10, 2019 Consisted of Nesting Material, Feathers, and Few Small Down-Like Feathers. No Eggshell or Membrane was Found

Nest Box A-26 Contents on October 14, 2019 Consisted of Nesting Material, Feathers, Down, Eggshell Fragments, and Membrane

Nest Box A-42 Contents on October 10, 2019 Consisted of Nesting Material and Feathers. No Eggshell, Membrane, or Down was Found

Nest Box A-43 Contents on October 10, 2019 Consisted of Copious Nesting Material, Feathers, a Complete Intact Egg, Eggshell Fragments from a Second Egg, and Down Scattered throughout the Nest Bowl

Nest Box A-48 Contents on October 10, 2019 Consisted of Nesting Material and Feathers. No Eggshell, Membrane, or Down was Found

Nest Box B-22 Contents on October 11, 2019 Consisted of Nesting Material, Feathers, Down, and Eggshell Membrane

Nest Box B-50 Contents on October 11, 2019 Consisted of Nesting Material, Feathers, and Down. No Eggshell or Membrane was Found

Nest B-50 Entrance Passageway Margin Inside the Nest Box Encrusted in Down on October 16, 2019

APPENDIX 8. SUPPLEMENTAL MAKAMAKA’OLE 2019 BREEDING SEASON MEMORANDUM

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TETRA TECH

MEMO

To:	Lasha Salbosa, U.S. Fish and Wildlife Service Lauren Taylor, State of Hawai'i Division of Forestry and Wildlife
From:	Tetra Tech, Inc.
Date:	June 2020
Correspondence #:	TTCES-PTLD-2020-081
Subject:	Makamaka'ole Seabird Mitigation Site – 2019 Breeding

1.0 Introduction

TerraForm Power, LLC (TerraForm) owns and operates the Kaheawa Wind Power I, LLC (KWP I) and Kaheawa Wind Power II, LLC (KWP II) facilities at Kaheawa Pastures, West Maui. In accordance with the state- and federally approved Habitat Conservation Plans (HCPs) for both projects, a final mitigation plan was approved in January 2012 to establish seabird nest sites protected by two separate predator-resistant enclosures (KWP I 2006, SWCA 2011). These nest sites are intended to attract Hawaiian petrels (*Pterodroma sandwichensis*) and Newell's shearwaters (*Puffinus newelli*), and to provide a net conservation benefit to mitigate for the estimated take of both species at KWP I and KWP II. Together, the two nest site enclosures are known as the Makamaka`ole Seabird Mitigation Site (Makamaka'ole) and encompass approximately 7.9 acres.

On September 5, 2013, KWPI and KWPII completed construction of the two enclosures at Makamaka'ole. The first documentation of Newell's shearwater and Hawaiian petrel at Makamaka'ole occurred in 2014. Beginning in 2017 and in each year thereafter, Newell's shearwater attempted to nest, producing three or more eggs observed per year. The first Newell's shearwater fledging success at Makamaka'ole was documented in 2019.

During the semiannual HCP implementation meeting with the U.S. Fish and Wildlife Service (USFWS) and the State of Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife (DOFAW) (collectively, "the agencies"), DOFAW requested additional documentation of reproductive success beyond that provided in the Makamaka'ole Seabird Mitigation Project 2019 Final Report (H.T. Harvey 2019), an annual report provided to the agencies in April 2020. This memo therefore serves as a supplement to that annual report, clarifies interpretation of results, and provides additional context relevant to the determination of successful fledging.

2.0 Methods

2.1 Statewide Standards for Fledging Success

Evaluation of success for the Makamaka’ole is described in the KWP II HCP (SWCA 2011); however, the HCP did not include descriptions of specific definitions for determining nesting activity and burrow fledging success. The monitoring methods and assessment criteria used at Makamaka’ole in the 2019 season report are consistent with monitoring methods and assessment criteria used throughout the state of Hawaii (Simons 1985, Haleakalā National Park 2019, Tetra Tech 2018, Chen et al. 2019, DOFAW 2020). Since fledging success is determined by monitoring burrow activity, multiple monitoring methods are used at Makamaka’ole to document burrow activity and fledging success and the collective dataset is evaluated to assess burrow activity and fledging success (described below in Section 2.2). Statewide the assessment of fledging success is determined by the number of burrows active during the fledging period of September and October where there are no indications of depredation. Signs of an active burrow include the following:

1. Weekly burrow visitation by adults
    a. Feathers
    b. Scent
    c. Toothpick movement
    d. Droppings
    e. Tracks
    f. Game camera activity
2. Evidence of breeding
    a. Egg or egg fragments
    b. Down feathers
    c. Chick observations
    d. Parental feeding of chicks

Evidence that suggests a burrow did not produce a fledged chick may include one or more of the following:

1. Evidence of chick mortality
    a. Documented predation
    b. Chick remains observed
2. Occupied by non-breeding adults
    a. Absence of signs of nesting as defined above
    b. Infrequent visitation
    c. Early departure from the colony, before September or October

2.2 Site-Specific Considerations for Makamaka’ole

During colony establishment, seabirds are sensitive to disturbance. Disturbance of breeding individuals could have substantial detrimental impacts, prompting outcomes including nest and site abandonment. Therefore, the desire for monitoring to be as comprehensive as possible must be balanced against the disturbance it may cause. At Makamaka’ole, establishment of the colony was and remains the highest priority. This entails minimizing human-made noise and minimizing disturbance such as burrow scoping, opening burrow boxes, and banding until late in the breeding season at the potential expense of additional documentation.

The conclusions reached by the ecologists managing Makamaka’ole (see the Results section below) represent the combined evidence as described above. Any single line of evidence may not be sufficient to determine the outcome of a burrow, but the use of multiple methods provides multiple opportunities to recognize signs of both successful fledging young and failed nesting attempts. Late-season activity is the strongest indicator of breeding activity because non-breeding individuals typically depart the colony prior to the fledging period. In the absence of evidence of chick mortality, the presence of a chick, indicated by observation, egg fragments, down, or daily adult visitation late in the breeding season, are indicative of successful fledging. The uncertainty in monitoring comes as a result of prioritizing colony establishment. The outcome of the burrows may not be known with certainty, but the evaluation of success at Makamaka’ole is consistent with methods and criteria used elsewhere for measuring fledging success of seabirds, including at mitigation sites.

3.0 Results

Observations from the 2019 breeding season indicate that five Newell’s shearwaters fledged from the Makamaka’ole. Table 1 describes multiple lines of evidence that support the determination of fledging success from the on-site ecologist. For completeness, we have included data associated with the assessment of Burrow Number A-25 because this burrow showed several lines of evidence suggesting the possible production of young.

Table 1. Evidence of Newell’s Shearwater Fledging Success from Burrow Monitoring at the Makamaka’ole Seabird Mitigation Site in 2019

Burrow Number	Active in Previous Season(s)	Weekly Adult Visitation[1]	Chick Observed	Evidence of Breeding	Evidence of Possible Nest Failure	Final Status
A-22	No	July–October 14	Yes	Down, Guano, Nest Material, No Egg	None	Successfully Fledged
A-25	No	April–October 5	No	Possible Down, Guano, Nest Material, No Egg	None	Non-breeder/ Failed
A-26	Yes	April–October 5	Yes	Down, Guano, Nest Material, Egg Fragments	None	Successfully Fledged
A-43	Yes	April–October 14	No	Down, Guano, Nest Material, Egg Fragments	Second egg observed in burrow	Successfully Fledged
B-22	Yes	April–September 5	No	Down, Guano, Nest Material, Egg Fragments	None	Successfully Fledged
B-50	Yes	April–October 7	No	Down, Guano, Nest Material, No Egg	None	Successfully Fledged

1 Documentation of activity is determined by one or more of the following: game camera observations, toothpick activity, scent, guano, feathers, tracks, or other signs of activity.

4.0 Revised Procedures

The lessons learned from prior years of management at Makamaka’ole will improve monitoring and decrease uncertainty in the future. Changes to the field methods and management of data collected as the result of these lessons include:

- Modifications to game camera use:
    - Position game cameras to capture burrow entrances. Through the breeding season, Newell’s shearwater chicks did not exit the tunnels; therefore, capturing mid-season activity may necessitate photos capturing tunnel entrances where possible.
    - Monitoring requirements may be different for different times of year, requiring cameras to be moved as appropriate for breeding phenology and project needs. When cameras are placed close to burrows, non-animal triggering of game cameras is reduced, and details such as burrow entrances can be captured; however, seabirds sometimes move rapidly past the cameras, resulting in movements being missed. Moving cameras further from the burrows results in the camera being triggered by grass and shadow movement, but allows for the capture of a larger area.
- Burrow examination:
    - Using a burrow scope to examine the tunnel will provide additional evidence of the presence or absence of a chick since they may remain in the burrow entrance tunnel if boxes are opened.
    - Burrows that produced chicks vary in the type and quantity of evidence (down, egg fragments, or otherwise), and multiple lines of evidence must be used to determine fledging success where single observations do not clearly document success or failure. Adjustments to game camera deployment, the timing of late-season burrow checks, and possible use of burrow scopes should increase the confidence in nesting success assessments.
- Data review:
    - Subcontractor data will be reviewed and compiled monthly to ensure data transfer and that appropriate documentation of nesting success are collected and shared.

5.0 Conclusions

Makamaka’ole has demonstrated the success of predator control and social attraction for the Newell’s shearwater. During the 2019 breeding season, five Newell’s shearwater nests showed burrow activity patterns consistent with successful fledging based on assessment criteria used to evaluate mitigation success at other sites in Hawai’i. The continued growth of the colony as shown by the increasing number of Newell’s shearwaters illustrates that the cautious approach to monitoring has had a negligible impact on nesting seabirds. TerraForm has provided documentation of the evidence used to support these successes and will provide additional documentation from H.T. Harvey, if available. Based on Tetra Tech’s review of the standards applied to measure fledging success at other similar projects, the evidence presented in the 2019 Final Report’s conclusions (H.T. Harvey 2019), and supplemented in this memo, is consistent with the standards used to measure fledging success throughout the state.

Tetra Tech is working with the Maui Nui Seabird Recovery Project to ensure that the lessons learned from 2019 are applied to work being performed in 2020. TerraForm expects that the application of these lessons will improve the documentation of fledging success in 2020.

6.0 Literature Cited

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