Kawailoa Wind Project Habitat Conservation Plan
FY 2022 Annual Report

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EXECUTIVE SUMMARY

This report summarizes work performed by Kawailoa Wind, LLC (Kawailoa Wind), owner of Kawailoa Wind Project (Project), during the State of Hawaiʻi fiscal year 2022 (FY 2022; July 1, 2021 – June 30, 2022) under the terms of the approved Habitat Conservation Plan (HCP), dated October 2011, and the approved HCP Amendment, dated September 2019, as well as pursuant to the obligations contained in the Project's state Incidental Take License (ITL; ITL-14 Amended) and federal Incidental Take Permit (ITP; TE-59861A-1). The Project was constructed in 2011 and 2012, and commissioned to begin operating on November 2, 2012. Species covered under the HCP and HCP Amendment include seven state- and federally listed threatened or endangered species, as well as one state-listed endangered species.

Fatality monitoring at the Project continued throughout FY 2022 at all wind turbine generators (WTG). On January 3, 2022, turbine search areas were expanded from 35-meter radius circular search areas centered on each turbine to 55-meter radius circular search areas centered on each turbine, and the search interval was decreased from twice a week to once a week. Starting January 24, 2022, roads out to 75-meters surrounding each turbine were also included in the new search areas. The mean search interval from July 1, 2021 to December 31, 2021 (Q1 – Q2) for WTGs was 3.5 days. The mean search interval from January 3, 2022 to June 30, 2022 (Q3 – Q4) was 7.0 days. The mean search interval for the two meteorological towers in FY 2022 was 7.1 days.

Four 28-day carcass persistence trials were conducted in FY 2022, using 60 bat surrogates and 12 medium-sized bird carcasses. For FY 2022, the probability and 95% confidence interval that a bat surrogate carcass persisted until the next search was 0.78 (0.67 – 0.87) during Q1 – Q2 and 0.61 (0.50 – 0.71) during Q3 – Q4, respectively. The probability that a medium-size bird carcass persisted until the next search was 0.97 (0.84 – 1.00) during Q1 – Q2 and 0.91 (0.68 –0.98) during Q3 – Q4. Scavenger trapping resumed at the Project in Q4 of FY 2022.

Searcher efficiency trials were conducted over 24 trial days with 79 trial carcasses in FY 2022. The overall searcher efficiency in FY 2022 for bat surrogate (N = 69) was 0.94 (0.83 – 0.99) during Q1 – Q2 and 0.97 (0.87 – 0.98) during Q3 – Q4, respectively. For medium-sized birds (N = 10) searcher efficiency was 1.00 (0.67 –1.00) during Q1 – Q2 and 1.00 (0.56 –1.00) during Q3 – Q4.

Two HCP Covered Species fatalities were observed in FY 2022; one Hawaiian hoary bat (*Lasiurus cinereus semotus*) was found on December 14, 2021 at WTG 16, and a second Hawaiian hoary bat fatality was found on March 24, 2022 at WTG 20. These were the first Hawaiian hoary bat fatalities observed at the Project since October 2018 (FY 2019). The Project's total observed bat take from operations through FY 2022 is 42 bats. The fatality estimate for non-incidental observed bats using the Evidence of Absence estimator (Dalthorp et al. 2017) at the upper 80 percent credibility level is 93 bats and the total indirect take for this estimate is 9 adult bat equivalents. Combining these values, there is an approximately 80 percent chance that actual take of Hawaiian hoary bats at the Project is less than or equal to 102 adult bats. Per U,S, Fish and Wildlife Service (USFWS) input, this total is estimated using no adjustment to the annual rho value for years when deterrents were operational, despite a demonstrated 95 percent confidence that risk to bats has been significantly reduced through the installation of bat deterrents at the Project. Kawailoa Wind continues to work with USFWS to ensure that demonstrated benefits from the deployment of bat deterrents are appropriately incorporated into the estimate of Project take. This estimate falls within the Tier 4 bat take request (which is up to 115 bats). Mitigation for Tier 4 take was completed in 2018.

Fifty bird fatalities representing twelve non-listed species were found at the Project in FY 2022. This includes the following birds that are protected by the Migratory Bird Treaty Act: three white-tailed tropic birds (*Phaethon lepturus*), two Pacific golden-plover (*Pluvialis fulva*), one cattle egret (*Bubulcus ibis*), one house finch (*Haemorhous mexicanus*), and one mourning dove (*Zenaida macroura*).

Mitigation for the Hawaiian hoary bat continued in FY 2022. Four permanent ground-based ultrasonic bat detectors were managed at the Project at WTGs 1, 10, 21, and 25. Hawaiian hoary bats were detected 266 of 1,217 (21.9 percent) detector-nights sampled throughout the 2022 Bat Sampling Period. The ʻUkoʻa Wetland mitigation program for Tier 1 mitigation continued for waterbirds and bats through FY 2022 including invasive vegetation control, predator control and monitoring, fence monitoring and maintenance, bat acoustic monitoring, and insect sampling. During the 2022 Bat Sampling Period, Hawaiian hoary bats were detected on 559 nights out of 2,430 detector-nights sampled (23.0 percent). Insect sampling was completed at ʻUkoʻa and results will be provided in the next annual report.

Hawaiian hoary bat research projects conducted by the U.S. Geological Survey and WEST Consultants for Tier 2 and 3 bat mitigation continued. Final invoices for these projects were paid in FY 2022. The remainder of Tier 3 bat mitigation was completed in FY 2019 with the acquisition of the Waimea Native Forest. Tier 4 bat mitigation was completed in FY 2019 with the acquisition of the Helemano Wilderness Area. Kawailoa Wind continues to plan for Tier 5 mitigation.

Mitigation for waterbirds continued at ʻUkoʻa Wetland, despite no observed take of these species at the facility. In total, 11 Hawaiian common gallinule (*Gallinula chloropus sandvicensis*) fledglings have been recorded at ʻUkoʻa since monitoring began following management. No evidence of Hawaiian stilt (*Himantopus mexicanus knudseni*) or Hawaiian coot (*Fulica alai*) breeding has been observed at ʻUkoʻa Wetland despite years of ongoing management. Kawailoa Wind is having ongoing discussions with the agencies regarding adaptive management of waterbird mitigation.

No Hawaiian petrel (*Pterodroma sandwichensis*) fatalities were observed in FY 2022. The estimated cumulative Project take is below the authorized take limit. Mitigation for the take of Hawaiian petrel was completed in FY 2021. In response to a contested case settlement, Kawailoa Wind provided additional funds to conduct research related to Hawaiian petrels on Oʻahu in FY 2022.

Mitigation for Newell's shearwater (*Puffinus newelli*) was completed in FY 2015. Pueo/Hawaiian short-eared owl (*Asio flammeus sandwichensis*) mitigation was completed in FY 2017.

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

The Habitat Conservation Plan (HCP) for the Kawailoa Wind Project (Project) was approved by the Hawaiʻi Division of Forestry and Wildlife (DOFAW) in 2012 (SWCA 2011; the 2011 HCP). On December 8, 2011, the U.S. Fish and Wildlife Service (USFWS) issued Kawailoa Wind, LLC (Kawailoa Wind) a federal incidental take permit (ITP) for the Project, and DOFAW issued a state incidental take license (ITL) on January 6, 2012. The original ITP and ITL cover the incidental take of six state- and federally listed threatened or endangered species, as well as one state-listed endangered species (referred to as the Covered Species) over a 20-year permit term.

In September 2019, Kawailoa Wind submitted a final HCP Amendment to USFWS and DOFAW to request an increase in the amount of Hawaiian hoary bat/ʻopeʻapeʻa (*Lasiurus cinereus semotus*) take, and add the endangered Hawaiian petrel/ ʻuaʻu (*Pterodroma sandwichensis*) as a Covered Species (Tetra Tech 2019). Kawailoa Wind received an amended ITP from USFWS on September 4, 2019. An amended ITL was issued by DOFAW on February 26, 2021, and signed by Kawailoa Wind on March 30, 2021. The Project's Covered Species are listed in Table 1.

Table 1. Covered Species

Common and Hawaiian Names	Scientific Names
Hawaiian coot, ʻalae keʻokeʻo	*Fulica alai*
Hawaiian duck, koloa maoli	*Anas wyvilliana*
Hawaiian common gallinule, ʻalae ʻula	*Gallinula chloropus sandvicensis*
Hawaiian stilt, aeʻo	*Himantopus mexicanus knudseni*
Hawaiian petrel,ʻuaʻu	*Pterodroma sandwichensis*
Newell's shearwater, ʻaʻo	*Puffinus newelli*
Hawaiian hoary bat, ʻopeʻapeʻa	*Lasiurus cinereus semotus*
Hawaiian short-eared owl, pueo	*Asio flammeus sandwichensis*

Project construction occurred in 2011 and 2012, and was commissioned to begin operating in November 2012. The Project is owned and operated by Kawailoa Wind, a wholly-owned subsidiary of DESRI IV, LLC, which is an investment fund managed by D.E. Shaw Renewable Investments, LLC.

This report summarizes work performed for the Project during the State of Hawaiʻi 2022 fiscal year (FY 2022; July 1, 2021–June 30, 2022) pursuant to the terms and obligations of the 2011 HCP (SWCA 2011), HCP Amendment (Tetra Tech 2019), and amended ITL and ITP.

2.0 Fatality Monitoring

All 30 wind turbine generators (WTGs) were searched for fatalities throughout FY 2022; however, the search parameters changed in January 2022 due to a contested case settlement. The revised fatality monitoring protocol was approved by USFWS and DOFAW in September 2021 and November 2021, respectively.

From July 1, 2021, to December 31, 2022 (Q1 and Q2 of FY 2022), turbine search plots consisted of a 35-meter radius circular plot centered on each WTG, and searches occurred twice per week. There were no unsearchable areas or rock-lined swales within the 35-meter radius search plots. During this search protocol, the mean search interval for WTGs was 3.5 days (standard deviation [SD] = 0.5 days).

On January 3, 2022, WTG search areas were expanded from 35-meter radius circular search areas centered on each WTG to 55-meter radius circular search areas centered on each WTG. Less than 4 percent of the expanded search radius are designated as unsearchable due to safety concerns; these unsearchable areas are incorporated into the take analysis. Starting January 24, 2022, roads out to 75-meters surrounding each WTG were also included in the new search areas. The new search areas are searched for fatalities once per week. This new fatality monitoring protocol will be implemented for 2 years. During this revised search protocol (January 3, 2022–June 30, 2022, or Q3 and Q4 of FY 2022), the mean search interval was 7.0 days (SD = 0 days).

In FY 2022, the search areas were searched by trained dogs accompanied by their handlers. In previous years when conditions limited the use of dogs (e.g., weather, injury, availability of canine search team, etc.), search plots were visually surveyed by Project staff; however, canine teams conducted 100 percent of the WTG searches in FY 2022. Vegetation within the search areas is managed (e.g., mowed) to maximize searcher efficiency (see Section 4.0).

In addition to the WTGs and surrounding roads, the two unguyed meteorological (met) towers were searched approximately once per week within a 50-meter radius plot centered on the two met towers. No changes have been made to the search protocol for the met towers since the Project began operations. There are no unsearchable areas within the met tower search plots. In FY 2022, the mean search interval for met towers was 7.1 days (SD = 2.5 days).

3.0 Bias Correction

3.1 Carcass Persistence Trials

Four 28-day carcass persistence trials were conducted in FY 2022 using bat surrogates (black rat; *Rattus rattus*) and wedge-tailed shearwater (*Ardenna pacifica*) carcasses. Wedge-tailed shearwaters are medium-sized birds that are suitable surrogates for the listed bird species covered in the 2011 HCP and HCP Amendment (see Table 1). Due to the change in search area beginning in Q3 of FY

2022, bias correction statistics are calculated separately for the two search strategies. Results for FY 2022 are provided in Table 2, including results by vegetation class.

Table 2. Carcass Persistence and Searcher Efficiency Trial Results in FY 2022

Quarter	Size	Vegetation Class	Total Trials		Mean (95% Confidence Interval)	
			SEEF[1]	CPT[1]	SEEF (Proportion Detected)[2]	Probability of Persistence to the Next Search (*r*)[2, 3]
Q1 – Q2	Rat Surrogate	Short	24	25	0.92 (0.76 – 0.98)	0.82 (0.69 – 0.91)
		Medium	11	5	1.00 (0.80 – 1.00)	0.58 (0.23 – 0.84)
		Combined	35	30	0.94 (0.83 – 0.99)	0.78 (0.67 – 0.87)
	Medium Bird	Short	5	5	1.00 (0.62 – 1.00)	0.93 (0.61 – 0.99)
		Medium	1	1	1.00 (0.15 – 1.00)	NA[1]
		Combined	6	6	1.00 (0.67 – 1.00)	0.97 (0.84 – 1.00)
Q3 – Q4	Bat Surrogate	Short	28	29	0.96 (0.85 – 1.00	0.62 (0.52 – 0.72)
		Medium	6	1	1.00 (0.67 – 1.00)	NA[1]
		Combined	34	30	0.97 (0.87 – 0.98)	0.61 (0.50 – 0.71)
	Medium Bird	Short	4	5	1.00 (0.56 – 1.00)	0.94 (0.65 – 0.99)
		Medium	0	1	NA[1]	NA[1]
		Combined	4	6	1.00 (0.56 – 1.00)	0.91 (0.68 – 0.98])

1. SEEF = Searcher efficiency; CPT = Carcass Persistence Trials; NA = Not Available, sample size too small to calculate.
2. Estimates and confidence interval calculated using Dalthorp et al. (2017) single-year module.
3. The estimate of r is reported in lieu of carcass persistence time, as r provides a more informative portrayal of the effect of carcass persistence on fatality estimates than carcass persistence time, incorporating information from the carcass persistence distribution and the search interval in a single variable. Estimates and confidence interval for r calculated using Dalthorp et al. (2017) single-year module.

3.2 Searcher Efficiency Trials

Tetra Tech personnel (non-searchers) administered 79 searcher efficiency trials on 24 trial days during FY 2022. Similar to the carcass persistence trials, wedge-tailed shearwaters were used as surrogates for listed bird species, and black rats were used as surrogates for bats. Searcher efficiency trials occurred throughout the year. Vegetation category (short vs. medium) of the search plot was documented at the time the carcasses were placed and when they were found.

As with carcass persistence statistics, due to the change in search area beginning in Q3 of FY 2022, searcher efficiency statistics are calculated separately for the two search strategies. Results for FY 2022 are provided in Table 2, including results by vegetation class.

4.0 Vegetation Management

Vegetation in the search plots consists mainly of Guinea grass (*Megathyrsus maximus*), Bermuda grass (*Cynodon dactylon*), and a mixture of common low-growing weedy plants. All search plots around the WTGs and met towers are mowed regularly to increase visibility during fatality searches. Plots are mowed to a height of 3 to 4 inches, depending on the type of mower used. Plots are mowed roughly every 2 to 4 weeks. Herbicides were also used in FY 2022 to control vegetation in some of the outer portions of the new WTG search areas. The frequency of vegetation management varies depending on rainfall, time of year, type of vegetation cover, and cattle presence.

Cattle grazing has occurred on the Kamehameha Schools lands on which the Project is located since prior to construction. Domestic cattle are rotated periodically throughout portions of the Project, and graze vegetation under several of the turbines. Cattle periodically graze at WTGs 1 – 3 and WTGs 16 – 26. The specific locations and number of cows present throughout the year depends on several factors, including forage, water availability, and landowner operations. A small herd of feral cattle roam also throughout WTGs 4 – 15. No cattle are present at WTGs 27 – 30. Because Kawailoa Wind is not the landowner, the Project does not have control over cattle use in the area.

5.0 Scavenger Trapping

Trapping is responsive to Project needs and carcass persistence times are monitored quarterly throughout the fiscal year. Mean carcass persistence times calculated at the end of each quarter exceeded the search interval (3.5 days) in Q1 – Q2 of FY 2022; as a result, no trapping was conducted. Due to the increase in the search interval in January 2022 and the associated reduction in the probability of carcass persistence until the next search (Table 2), the Project resumed trapping in Q4 of FY 2022. Mongoose and cats were targeted by deploying 16 DOC 250 lethal traps. In FY 2022, 12 mongoose and one rat were trapped at the Project. Additional traps are being purchased and will be deployed in FY 2023.

6.0 Documented Fatalities and Take Estimates

Two Hawaiian hoary bat fatalities were found in FY 2022 (Table 3). Both fatalities were found within the older 35-meter search areas. The ultrasonic acoustic deterrents (UAD) at each WTG were functional when the fatalities were observed. These were the first Hawaiian hoary bat fatalities observed at the Project since October 2018 (FY 2019). All observed, downed wildlife were handled and reported in accordance with the most recent Downed Wildlife Protocol. Both bat carcasses were transferred to U.S. Geological Survey (USGS) for genetic testing.

No other listed species fatalities were observed in FY 2022. All non-listed fatalities observed at the Project during FY 2022 are listed in Appendix 1.

Table 3. Observed Hawaiian Hoary Bat Fatalities at the Project in FY 2022

Age	Sex[1]	Date Documented	WTG	Distance to WTG (meters)	Bearing from WTG (degrees)
Adult	Male	December 14, 2021	16	15	253
Adult	Female	March 24, 2021	20	22	304
1. Genetic sexing results from Pinzari and Bonaccorso 2018.					

6.1 Hawaiian Hoary Bat

Two Hawaiian hoary bat fatalities were documented during FY 2022 (Table 3, Appendix 1). The total take estimate for the Hawaiian hoary bat is based on fatality monitoring data and bias correction data from the start of operation (November 2012) through the end of FY 2022 (June 2021). An upper credible limit (UCL) of take is estimated from three components: (1) observed direct take (ODT) during protocol (standardized) surveys, (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 UCL of direct take (i.e., ODT + UDT). The USFWS and DOFAW have requested that these calculations be reported at the 80 percent UCL. 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. Associated indirect take is estimated based on observations of the temporal distribution of Covered Species fatalities at the Project and agency guidance regarding life history characteristics of the associated Covered Species.

A total of 42 Hawaiian hoary bat fatalities have been observed at the Project since operations began on November 2, 2012. The highest number of annual bat fatalities (9) was observed in FY 2014 and 2015. Two of the total 42 observed bats were found outside of fatality search plots and classified as incidental observations. Table 4 presents the cumulative take estimate (direct take + indirect take) by FY since operations began. Direct take is estimated using the EoA estimator at the 80 percent UCL (Dalthorp et al. 2017). Indirect take is calculated using USFWS (2016) guidance.

Table 4. Hawaiian Hoary Bat Fatalities by Fiscal Year and Cumulative Take Estimates

Fiscal Year	Number of Observed Fatalities[1]	Cumulative Take Estimate[2]
2013	4	11
2014	9	26
2015	9	38
2016	4	49
2017	2	60
2018	5	73
2019	5	89

Fiscal Year	Number of Observed Fatalities[1]	Cumulative Take Estimate[2]
2020	0	94 [3]
2021	0	97 [3]
2022	2	102 [3]
Total	**40**	**102** [3]

1. Does not include bat fatalities found outside of the search areas (i.e., 2 incidental observations).

2. Cumulative take represents the 80 percent upper credible limit of cumulative direct take estimated from the Evidence of Absence estimator (Dalthorp et al. 2017) plus the associated indirect take calculated using USFWS (USFWS 2016) guidance.

3. The installation of acoustic deterrents represents an inflection point in the bat fatality rate, reducing the risk to bats. Based on results from 3 years of monitoring, there is a 95 percent probability that the risk to bats of operating with deterrents is reduced by at least 46.7 percent of operating without deterrents under similar low wind speed curtailment regimes. Per agency guidance, rho has not been adjusted for FY 2020 - 2022 to account for this benefit as USFWS conducts additional review of use of a modified rho value.

The estimated direct take (ODT + UDT) for the 42 Hawaiian hoary bat fatalities found between the start of operation (November 2, 2012) and end of FY 2022 is less than or equal to 93 bats (80 percent UCL; Appendix 2). Because 2 of the 42 observed bat fatalities were found outside of the search areas (i.e., were incidental observations), 40 fatalities were used in the direct take analysis, and the 2 incidental observations are accounted for in the estimated value of UDT. The two incidental observations were found in FY 2013 and FY 2016. UDT is estimated at 51 (93 bats 80 percent UCL – 42 bats ODT).

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. Indirect take for the Project is calculated using the October 2016 USFWS 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 45 percent female based on the 42 bats assessed by USGS from the Project.
- 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 methodology (2016), the estimate of cumulative indirect take in FY 2022 is calculated as:

- **Total juvenile take calculated from observed female take (April 1 – September 15)**
  - 10 (observed females) * 1.8 (pups per female) = 18 juveniles

- **Total juvenile take calculated from observed unknown sex take (April 1 – September 15)**
  - 0 (observed unknown sex) * 0.45 (sex ratio observed at Kawailoa Wind)* 1.8 (pups per female) = 0 juveniles
- **Total juvenile take calculated from unobserved take**
  - 51 (unobserved direct take) * 0.45 (sex ratio observed at Kawailoa Wind) * 0.25 (proportion of calendar year females could be pregnant or have dependent pups) * 1.8 (pups per female) = 10.3 juveniles
- **Total Calculated Juvenile Indirect Take** = 28.7 (18 + 0 + 10.3)
- **Total Adult Equivalent Indirect Take =** 0.3 (juvenile to adult conversion factor) * 28.3 = 8.5

Therefore, the estimated indirect take based on the UCL of Hawaiian hoary bat direct take at the Project is nine adult bats (rounded up from 8.5).

The UCL for Project take of the Hawaiian hoary bat at the 80 percent credibility level is 102 adult bats (93 estimated direct take + 9 estimated indirect take)[1]. That is, there is an approximately 80 percent probability that actual take at the Project at the end of FY 2022 is less than or equal to 102 bats. This estimate falls within the Tier 4 bat take authorization detailed in the HCP Amendment, which has a total take request of 115 bats. The approved HCP Amendment addressed the exceedance of the previously authorized bat take limit (Tiers 1-3) through the identification of additional avoidance and minimization measures, as well as additional compensatory bat mitigation (Tetra Tech 2019).

The minimization measures associated with the HCP Amendment demonstrate a statistically significant reduction in the fatality rate. This reduction warrants the application of an appropriate rho value in the EoA model. A comparison of the fatality rates before and after the application of minimization measures associated with the HCP Amendment shows the fatality rate is reduced from an average of 11.15 bats per year in FY 2013 – 2019 estimated by EoA to an average of 2.25 bats per year in FY 2020 – 2022 (Figure 1). A test for misspecification of rho in EoA demonstrates that application of a rho value of 1 in FY 2020 – 2022 is overestimated (p value = 0.00094). Using an annual rho value of 0.533, the test for misspecification exceeds the threshold of 0.05 (p value = 0.050). The estimate of a rho of 0.533 is statistically supported as a maximum value by EoA (α = 0,05) and is highly conservative (assumes lower deterrent effectiveness than suggested by available data) because of the use of 95 percent confidence level. This demonstration of deterrent effectiveness was measurable in the first year of deployment (Tetra Tech 2020), has been sustained over three years of operation, and is robust enough to demonstrate benefits despite the observation of two bat fatalities in FY 2022. Based on the strength and resilience of these measured benefits, the use of an adjusted rho is appropriate. However, per USFWS input, no adjustment to rho has been

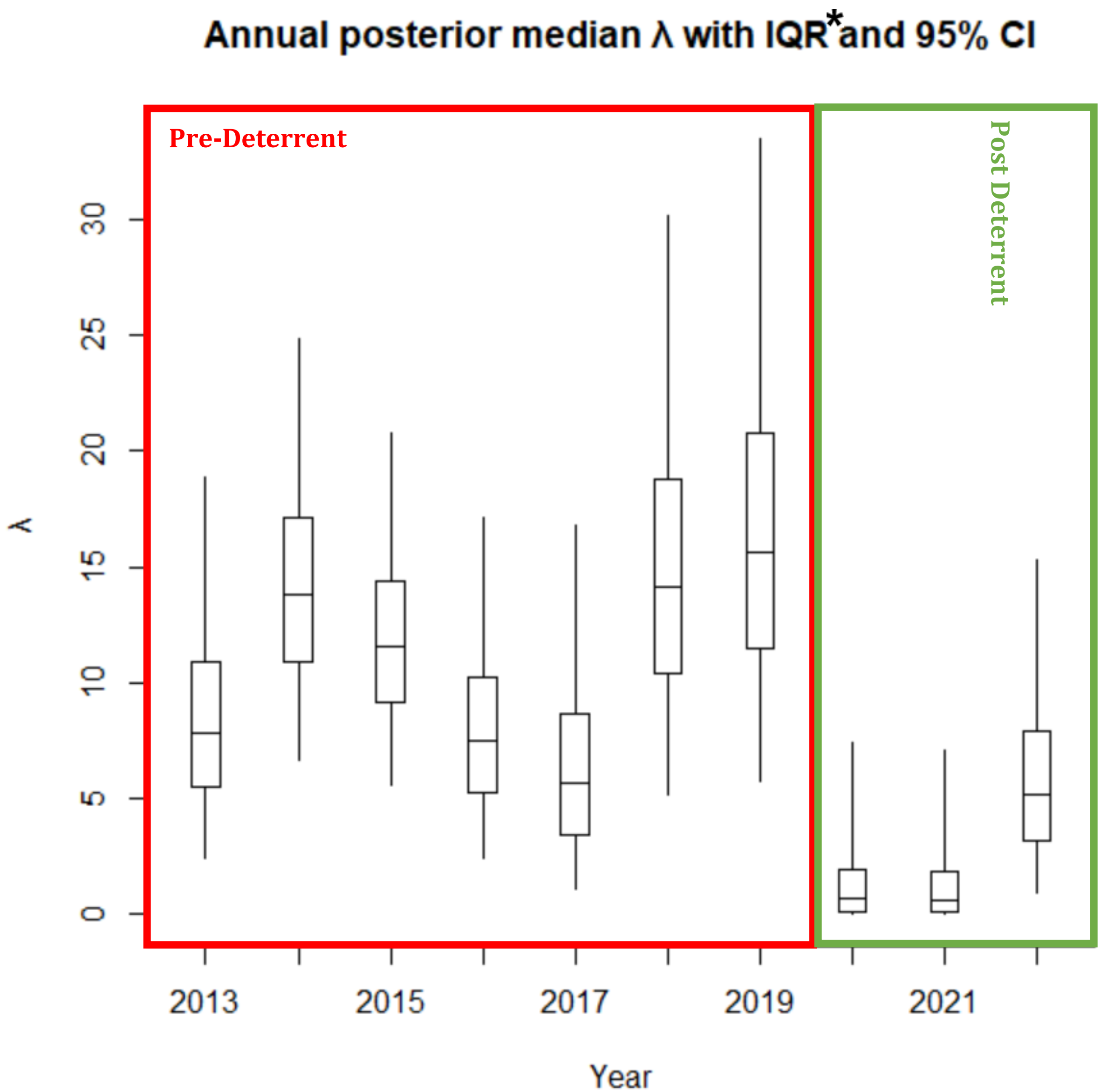
[1] This total is estimated using no adjustment to the annual rho value of 1.0 for years when deterrents were operational.

applied in these analyses. Kawailoa Wind continues to work with USFWS to ensure that the measurable benefits from deployment of this minimization measures are appropriately accounted for in the take analyses.

Kawailoa Wind described methods for determining a conservative rho value in the FY 2020 and 2021 annual reports (Tetra Tech 2020, Tetra Tech 2021) and has continued discussions with the agencies to allow incorporation of a modified rho into take analyses. Ultimately, the assessment of rho in the post-UAD installation period is expected to incorporate ongoing fatality monitoring results in the post-UAD period and an unbiased estimate of the deterrent benefit. The inclusion of additional years will increase statistical rigor to accurately assess changes in rho given the observed inter-annual variability. The rho value applied for periods with the current minimization measures would be re-evaluated annually to adjust for additional information until Kawailoa Wind, USFWS, and DOFAW have sufficient evidence for application of a standardized rho value representing the reduction in fatalities associated with deterrents. The details of the rho analysis demonstrating the effectiveness of deterrents with data through FY 2022 are provided in Appendix 3.

A take projection can be generated with EoA and with methods outlined in the HCP Amendment to estimate the likelihood of staying within the permitted take within the permit term. The take projection is strongly influenced by the rho value as outlined in the preceding paragraphs. If no adjustment to rho is used, the median take projection at the end of the ITP term (December 2031) is 179 bats (Interquartile Range [IQR]: 166, 195). Given the use of a rho value of 0.533 post-UAD, the median take projection at the end of the ITP term (December 2031) is 142 bats (Interquartile Range [IQR]: 133, 152). Either value would be well below the total take authorization of 220 bats. However, both methods of projection are likely to overestimate project impacts because the take rate prior to deterrent installation heavily impacts the projection. Alternatively to this approach using EoA with a selected estimate of relative risk of post-UAD versus pre-UAD periods, the HCP Amendment specifies a comparison of the current take estimate and the current take rate to total authorized take over the permit term to determine if adaptive management is warranted. This method can also be used to evaluate take rates on an ongoing basis. EoA estimated the take rate at the Project in FYs 2020 – 2022 is 2.25 bats per year; extrapolating from the current direct take estimate (using a rho of 1), and the current take rate the Project estimates a direct take total of 114.4 bats at the end of the ITP term (93 bats estimated by EoA in FY 2022 + 2.25 bats per year * 9.5 years remaining in the permit term).

The Project's current ratio of indirect take to direct take indicates the estimated indirect take is 9.1 percent of the direct take estimate (8.50 adult bat equivalents estimated in FY 2022 / 93 bats estimated from direct take). When an estimate of indirect take of 10.5 adult bat equivalents (9.1 percent * 114.4 bats estimated from direct take) is added to the direct take estimate, the estimated take is 124.9 adult bat equivalents (114.4 bats estimated through direct take + 10.5 bats estimated through indirect take) in December 2031. This indicates that while the Project may stay below the Tier 4 maximum of 115 bats through the permit term (the impacts of the modified search strategy and the actual number of observed bats in the future are uncertain), there is a reasonable probability that it will surpass this value. Nevertheless, both the EoA and HCP methods of generating take projections indicate the Project will stay below the total HCP Amendment take estimates (up to Tier 6) through the permit term.



*Interquartile Range

Figure 1. EoA Estimated Hawaiian Hoary Bat Fatality Rates by Year at the Project

6.2 Hawaiian Petrel

Although no Hawaiian petrel fatalities were observed in FY 2022, the species is the only other HCP Covered Species previously observed as a fatality at the Project; thus, a take estimate is calculated. The Hawaiian petrel was added as an HCP Covered Species through an amendment to the HCP and issuance of amended permits in 2019 (ITP in September 2019 and ITL in February 2021)[2]. Therefore, there is a distinction between Project estimated take and the level of take occurring under the authorized permits and the amended HCP. To address this issue, estimated take over the period of Project operations was analyzed first. Following this analysis, a ratio was applied of the portion of the Project's operations under which the Hawaiian petrel was an HCP Covered Species to identify the estimated take for the purposes of tracking take with respect to the applicable regulatory permits.

Table 5 summarizes the total estimated Hawaiian petrel take through FY 2022. Input values for the multi-year analysis are provided in Table 6.

Table 5. Eighty Percent Upper Credible Limit (UCL) Estimate of Cumulative Hawaiian Petrel Take through FY 2022

A: Observed Direct Take[1]	B: Incidental Observed Take[2]	C: 80% UCL of Estimated Direct Take[3]	D: UDT (C –A – B)	E: Estimated Indirect Take (Chicks/Eggs)[4]
0	2	1	NA	2

1. Observed direct take used in Evidence of Absence analysis based on FY 2013 – FY 2022 data.
2. Fatalities occurred outside of the defined search area and were not used in Evidence of Absence analysis.
3. Multi-year Evidence of Absence analysis (Dalthorp et al. 2017) based on FY 2013 – FY 2022 data.
4. Overall indirect take for the Project is calculated based on parameters described in Appendix 16 of the HCP Amendment and rounded up to the nearest integer (Tetra Tech 2019).

Table 6. Input Values for Multi-Year Analysis of Hawaiian Petrel Take through FY 2022

Year[1]	Weight	Search Fatalities[2]	Ba	Bb	$\hat{g}$	$\hat{g}$ 95% Confidence Interval
FY 2013	0.67	0	347.5	34.45	0.910	0.879 –0.936
FY 2014	1	0	126.3	23.51	0.843	0.781 –0.897
FY 2015	1	0	398.7	221.4	0.643	0.605 –0.680
FY 2016a	0.33	0	393.4	209.6	0.652	0.614 –0.690
FY 2016b	0.67	0	1437	4968	0.224	0.214 –0.235
FY 2017	1	0	496.6	1734	0.223	0.206 –0.240
FY 2018	1	0	5.721	22.19	0.205	0.080 –0.370
FY 2019	1	0	140.0	426.5	0.247	0.213 –0.283
FY 2020	1	0	978.7	3056	0.243	0.229 – 0.256
FY 2021	1	0	1698	5298	0.243	0.233 – 0.253
FY 2022	1	0	201.2	448.2	0.310	0.275 – 0.346

[2] Based on input from the regulatory agencies and species experts, take of the Hawaiian petrel was not anticipated during the development of the original HCP.

Year[1]	Weight	Search Fatalities[2]	Ba	Bb	$\hat{g}$	$\hat{g}$ 95% Confidence Interval
1. Year data for FY 2013 – 2017 are taken from Appendix 16 in the HCP Amendment (Tetra Tech 2019). 2. Two Hawaiian petrel fatalities have been found at the site (July 21, 2017, and August 20, 2018), both occurred outside of the systematic search areas and therefore were not included in the Evidence of Absence analysis.						

Based on biological parameters presented in Appendix 16 of the HCP Amendment (Tetra Tech 2019), the estimate of cumulative indirect take through FY 2022 is calculated as follows:

Estimate of direct adult take:

Greater of observed adult direct take (2) and estimated direct take using Evidence of Absence (1) = **2** adults

Proportion of adults that breed:

Both observed fatalities occurred May – August. The estimate of the percent of adults breeding in the colony at this time is = **0.89**

Parental contribution:

Breeding adults produce 1 chick/pair and are dependent on both adults during May – August = **100 percent**

Reproductive success:

Average reproductive success = **0.63**

Total chick/egg indirect take

Calculated as (2*0.89*1.00*0.63) **= 1.12**

Therefore, the estimated indirect take based on the estimate of Hawaiian petrel direct take at the Project is **2 chicks/eggs** (rounded up from 1.12).

The UCL for cumulative Project take of the Hawaiian petrel over the period of Project operations is **2 adult and 2 chicks/eggs**.

As noted above, from a regulatory perspective, take of the Hawaiian petrel has only been permitted for a portion of the Project's operations. To measure take against the authorized take limit we apply a proportion of the time the Project has operated with permits authorizing incidental take of the Hawaiian petrel to the estimate for the entire period of Project operation and round up to calculate the estimate of take for the purposes of tracking take in comparison to the authorized take limit. For the purposes of this analysis, the Project has operated from November 2012 through June 2022 (9.67 years) and the Project has been operating under a permit (ITP or ITL) authorizing incidental take of the Hawaiian petrel from September 2019 to June 2022 (2.83 years).

Estimated adult Hawaiian petrel take under permit = (2.83/9.67)*2 = **0.56**

Estimated chick/fledging Hawaiian petrel take under permit = (2.83/9.67)*1.12 = **0.33**

Rounding up, the cumulative Project take of Hawaiian petrels as measured against the authorized take limit are **1 adult and 1 chick/egg**. This estimate is below the authorized take limit of 19 adults and 5 chicks/eggs.

6.3 Non-listed Species

Fifty bird fatalities representing twelve different non-listed species were documented at WTGs at the Project in FY 2022 (see Table 7). No fatalities have been observed at either of the two met towers. Five of the species observed in FY 2022 are protected by the Migratory Bird Treaty Act. Appendix 1 provides a complete list of fatalities for FY 2022.

Table 7. Non-listed Bird Fatalities Documented at the Project in FY 2022

Species	Common Name	No. of Observed Fatalities in FY 2022
Acridotheres tristis	Common Myna	2
Bubulcus ibis[1]	Cattle Egret	1
Estrilda astrild	Common Waxbill	20
Francolinus francolinus	Black Francolin	1
Geopelia striata	Zebra Dove	7
Haemorhous mexicanus[1]	House Finch	1
Lonchura punctulata	Scaly-breasted Munia	3
Phaethon lepturus[1]	White-tailed Tropicbird	3
Pluvialis fulva[1]	Pacific Golden-Plover	2
Spilopelia chinensis	Spotted Dove	5
Zenaida macroura[1]	Mourning Dove	1
Zosterops japonicus	Warbling White-eye	4
1. Species protected by the Migratory Bird Treaty Act.		

7.0 Wildlife Education and Observation Program

Wildlife Education and Observation Program (WEOP) trainings continue to be conducted on an as-needed basis to provide on-site personnel and visitors with the information they need to be able to respond appropriately in the event they observe a listed species or encounter a fatality while on site. Twenty-four WEOP trainings were conducted in FY 2022.

8.0 Mitigation

The Project's current mitigation requirements are described in Section 7.6 of the 2011 HCP (SWCA 2011) and Section 7 of the HCP Amendment (Tetra Tech 2019).

8.1 Hawaiian Hoary Bats

For the Hawaiian hoary bat, mitigation is required based on where the estimated Project take falls with respect to tiers identified in the 2011 HCP and HCP Amendment. As stated above, the Project is currently in Tier 4 bat take.

During FY 2022, acoustic bat surveys continued at the Project (see Section 8.1.1) and management activities and acoustic bat surveys for Tier 1 mitigation continued at ʻUkoʻa Wetland (see Section 8.1.2). USFWS and DOFAW approved bat research projects for Tiers 2/3 mitigation were completed in FY 2022 (see Section 8.1.3). In previous fiscal years, Kawailoa Wind contributed funds toward the acquisition of Waimea Native Forest to fulfill remaining obligations for Tier 3 (see Section 8.1.4), and contributed funds toward the purchase and long-term protection of the Helemano Wilderness Area for Tier 4 mitigation (see Section 8.1.5). Kawailoa Wind is continuing planning for Tier 5 bat mitigation should it be required during the Project's permit term (see Section 8.1.6).

8.1.1 On-site Acoustic Surveys

Following commitments outlined in the 2011 HCP (SWCA 2011), bat activity was intensively monitored at 42 sites (30 WTGs at ground and nacelle, and 12 gulch detectors) across the Project during the first 3 years of systematic fatality monitoring (beginning in August of 2013, FY 2014). Having identified no significant correlation with acoustic bat activity that could inform curtailment during the required intensive acoustic monitoring period (April 2012 to November 2015), Kawailoa Wind reduced the acoustic monitoring effort at the Project in the second quarter of FY 2017 to four permanent ground-based units located at WTGs 1, 10, 21, and 25 (Figure 2). These locations were randomly chosen after eliminating detectors with high or low detection rates. Currently, each monitoring site consists of one song meter SM2BAT+ ultrasonic recorder (SM2) equipped with one SMX-U1 ultrasonic microphone (Wildlife Acoustics, Maynard, MA, USA) positioned 6.5 meters above ground level.

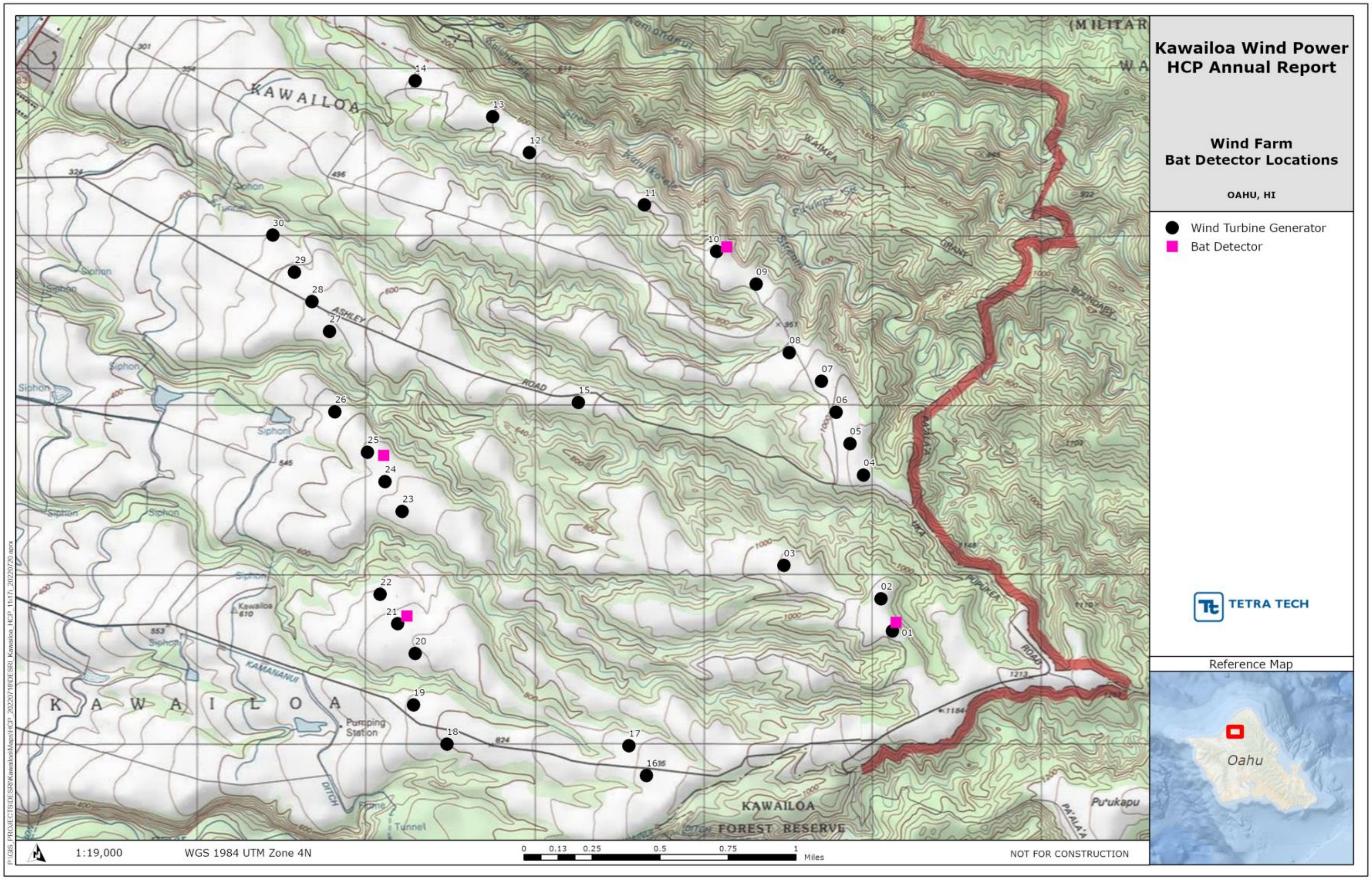


Figure 2. Four Permanent Bat Acoustic Detector Locations at the Project in FY 2022

Beginning in FY 2021, the analysis and reporting period for bat acoustic data was changed to June 1 to May 31 (rather than July 1– June 30). The change in the bat acoustic data period was made to allow adequate time for data review and analysis. The sampling period for this FY 2022 report is from June 1, 2021 to May 31, 2022. All previous sampling years have been adjusted to reflect this same sampling period (June to May; hereafter referred to as the Bat Sampling Period).

The objective of acoustic monitoring is to better understand the annual and seasonal variations in bat activity at the Project. Analysis of variance (ANOVA) and Tukey's honest significance difference (Tukey's HSD) were used to test for differences in detection rates between the 2014 and 2022 Bat Sampling Periods. A linear model (LM) was used to test for a change in detection rates across all monitoring years. Data were normalized using an Ordered Quantile Normalization transformation (ORQ). The distribution of residuals from the LM were examined to check for violations of model assumptions. All tests were 2-tailed, employed an alpha value of 0.05, and were conducted in the program R version 4.1.2 (R Core Team 2022).

Hawaiian hoary bats were detected on 266 of 1,217 (21.9 percent) detector-nights sampled throughout the 2022 Bat Sampling Period (June 2021 – May 2022). The annual detection rate during the 2022 Bat Sampling Period was marginally higher than the annual detection rate in the 2021 Bat Sampling Period (20.7 percent; Table 8), although not significant (Tukey's HSD: $P > 0.998$). Annual detection rates varied between all years (Table 8); however, only differences between 2014 and 2018, 2014 and 2019, 2014 and 2021, and 2014 and 2022 were significant (ANOVA: $F_{8,97} = 2.78$, $P < 0.008$; Tukey's HSD: 2014–2018, $P < 0.048$; 2014–2019, $P < 0.021$; 2014–2021, $P < 0.033$; 2014 – 2022, $P < 0.022$).

Table 8. Number of Nights Sampled, Number of Nights with Detections, and Proportion of Nights with Bat Detections at Permanent Detectors from June 2013 through May 2022

Bat Sampling Period	No. of Nights Sampled	No. of Nights with Detections	Proportion of Nights with Detections
FY 2014 (June 2013 — May 2014)	1,211	82	0.068
FY 2015 (June 2014 — May 2015)	1,021	144	0.141
FY 2016 (June 2015 — May 2016)	1,321	213	0.161
FY 2017 (June 2016 — May 2017)	1,355	180	0.133
FY 2018 (June 2017 — May 2018)	1,451	280	0.193
FY 2019 (June 2018 — May 2019)	1,249	300	0.240
FY 2020 (June 2019 — May 2020)	1,272	169	0.133
FY 2021 (June 2020 — May 2021)	1,437	298	0.207
FY 2022 (June 2021 — May 2022)	1,217	266	0.219
Note: FY 2013 not included due to minimal number of detector-nights compared to other years.			

Across all years (2014 to 2022), there is a significant increasing trend in the annual detection rates (LM: R^2 = 9.01%; $F_{1,104}$ = 11.4, $P < 0.001$; Figure 3). If the 2014 Bat Sampling Period is removed, there is still an increasing trend in the annual detection rates, although not significant (LM: R^2 = 2.20%; $F_{1,92}$ = 3.09, P = 0.082). The low r-squared value of this trend suggests that little of the variation is explained by the linear model (i.e., year). This could be an indication of inherent inter-annual variation, or the importance of variables not included in the model.

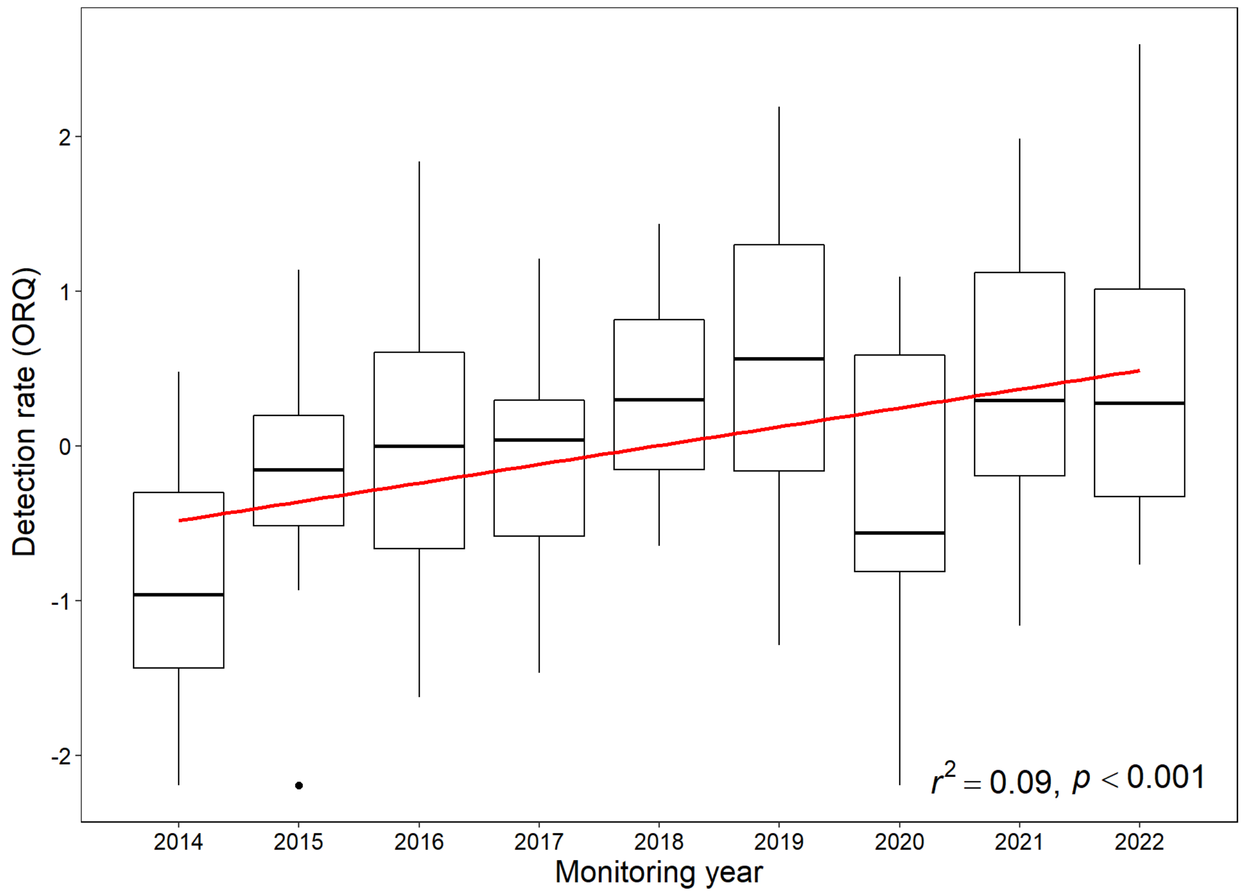


Figure 3. Box-plot Fitted with a Linear Regression Showing the Increasing Trend in the Detection Rate at the Project between FY 2014 and FY 2022.

Note: Annual Detection Rates were Transformed using an Ordered Quantile Normalization Transformation (ORQ).

During the 2022 Bat Sampling Period, elevated detection rates were observed during the lactation (mid-June through August) and early post-lactation (September) reproductive periods[3]. A decline in detection rates occurred shortly after the transition to the post-lactation (September to mid-December) reproductive period. Lower detection rates were observed from October of the post-lactation reproductive period to March of the pre-pregnancy reproductive period (mid-December to mid-March) with a slight increase during the month of January. Following March of the pre-pregnancy reproductive period, detection rates increased in April and May of the pregnancy reproductive period (mid-March to mid-June; Figure 4).

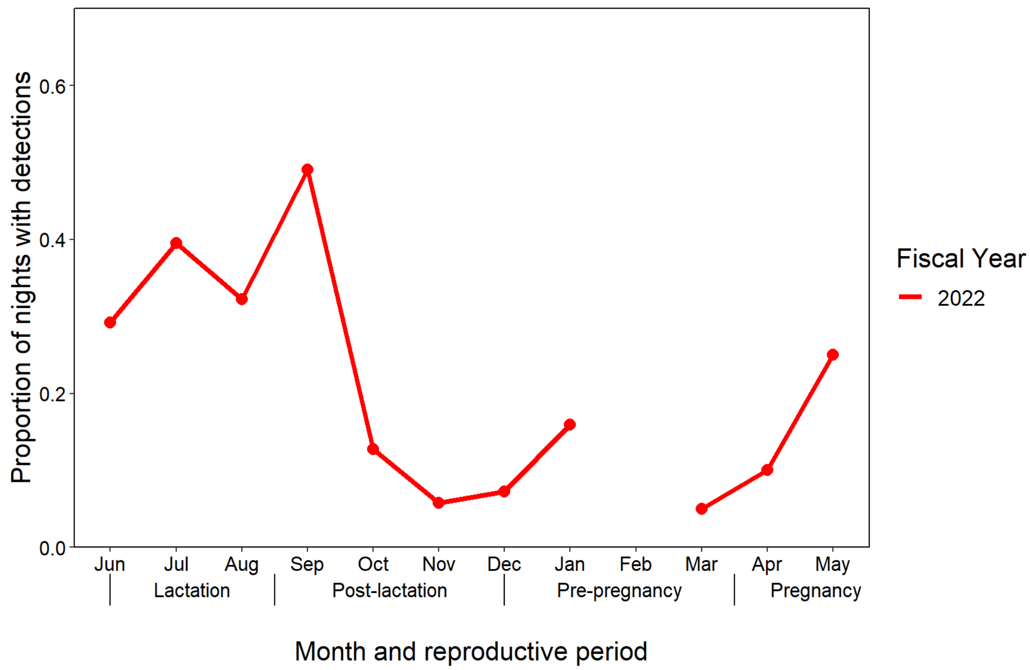


Figure 4. Monthly Detection Rates at Kawailoa in FY 2022 with Corresponding Reproductive Periods.

Note: No data was collected during February 2022.

The temporal patterns in detection rates during the 2022 Bat Sampling Period were relatively similar to detection rates observed in previous sampling years (Figure 5). The general temporal pattern in the detection rates observed at the Project has also been reported in other acoustic monitoring studies at other low elevation sites on Oʻahu (Thompson and Starcevich 2021) and Hawaiʻi Island (Todd 2012).

[3] Reproductive periods correspond approximately with reproductive periods as defined by Gorresen et al. (2013).

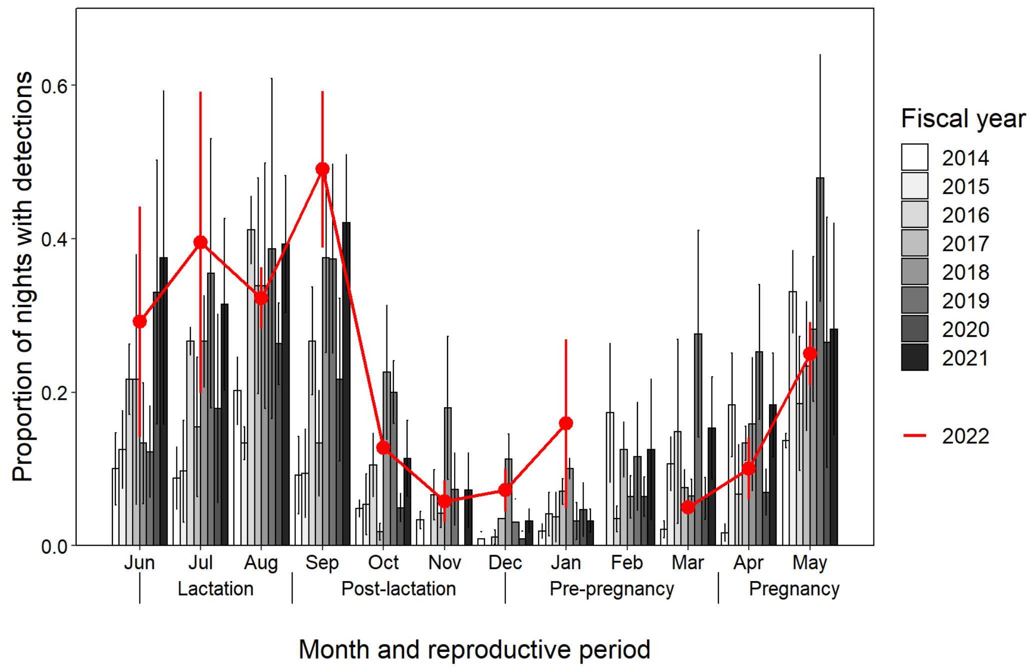


Figure 5. Monthly Bat Detection Rates at Kawailoa for FY 2014 to FY 2022 with Corresponding Reproductive Periods.

Note: No data was collected during February 2022.

The variation in detection rates across the four permanent detector sites is shown in Figure 6. In general, WTG-25 recorded higher detection rates than the other sites, except during the post-lactation reproductive period when WTG-21 recorded the highest detector rate of the sites. The seasonal patterns in observed detection rates were similar among detector sites WTG-1, 10, and 25, although the level of detection rate varied slightly. Detection rates at sites WTG-1, 10, and 25 increased during the lactation (July and August) and early post-lactation reproductive period, peaking in September. Detection rates declined in October and remained at lower rates throughout the remainder of the post-lactation period. There was a second smaller peak in detection rates at the beginning of the pre-pregnancy period followed by a decline that lasted until May of the pregnancy reproductive period (Figure 6). The seasonal trend in detection rates at site WTG-21 was similar to the other sites with a month delay. Detection rates at WTG-21 did not begin to increase until the end of lactation reproductive period (August) and peaked in October of the post-lactation reproductive period.

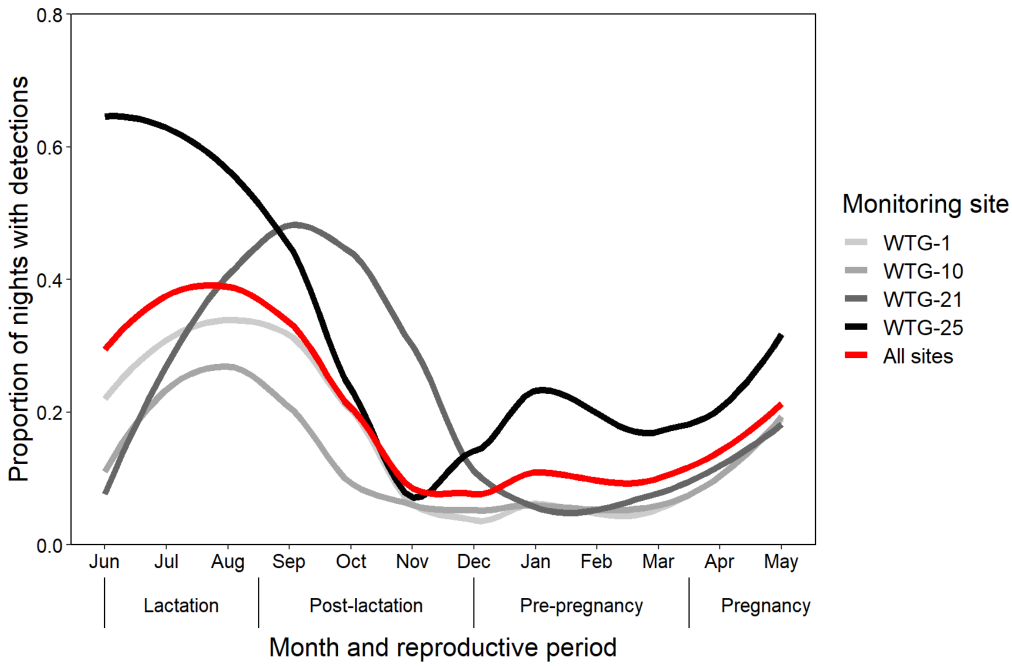


Figure 6. Site-Specific Variation in Detection Rates for Each Month of FY 2022 with Corresponding Reproductive Periods.

Note: Trend Lines are fitted with Loess smoothing curve

8.1.2 ʻUkoʻa Wetland (Tier 1)

Mitigation for bats and waterbirds continued at ʻUkoʻa Wetland during FY 2022. In FY 2016 (March 2016), USFWS and DOFAW provided written confirmation permitting adaptive management for the original bat and waterbird mitigation proposed at ʻUkoʻa Wetland. This included the following:

1. Reduction from 40 acres of vegetation removal to assumed open water areas, as outlined in Figure 2 of the approved ʻUkoʻa Wetland Hawaiian Hoary Bat Mitigation Management Plan (H. T. Harvey and SWCA 2014);
2. Omit replanting of natives with assumption of natural recruitment after invasive plant species are removed;
3. Omit mosquitofish removal component; and
4. Tie success criteria for bats to completion of all other management and monitoring components instead of increased bat activity.

In FY 2022, activities associated with Tier 1 bat mitigation at ʻUkoʻa Wetland included invasive vegetation removal, predator control, monitoring predator presence, fence monitoring and maintenance, bat acoustic monitoring, and insect sampling and analysis. Additional details for each are provided below.

8.1.2.1 Invasive Vegetation Removal

In FY 2022, Hapa Landscaping conducted maintenance visits to remove any areas of water hyacinth (*Eichhornia crassipes*) or other invasive vegetation that regenerated in the previously cleared open water area including water lettuce (*Pistia stratiotes*) and California grass (*Urochloa mutica*). Quarterly scheduled visits were modified as needed to accommodate staff schedules and avoid disturbing Hawaiian common gallinule nests and chicks in the area. Figure 7 shows a representative photograph of the open water as a result of this ongoing maintenance.

Figure 7. Open Water Resulting from Ongoing Removal of Invasive Vegetation at ʻUkoʻa Wetland in FY 2022.

Note: Photo Taken in June 2022.

8.1.2.2 Predator Control and Monitoring Predator Presence

The Project contracts Grey Boar Wildlife Services, LLC (Grey Boar) to conduct predator and ungulate removal at ʻUkoʻa Wetland, as well as to monitor and repair the fence. Predator control first began at ʻUkoʻa Wetland in June 2014 (FY 2014). The number and types of predators trapped at ʻUkoʻa Wetland from FY 2014 to FY 2022 is shown in Table 9. In FY 2022, a total of 176 predators were removed from ʻUkoʻa Wetland including 48 pigs, 105 mongoose, and 23 rats (Grey Boar 2021a, Grey Boar 2021b, Grey Boar 2022a, Grey Boar 2022b). The following trap types are used throughout at ʻUkoʻa Wetland in FY 2021: four pig corral and two pig box traps, 100 GoodNature A24s, 12 live cages, and 50 Doc-250s. Pigs continue to move into the fenced area at ʻUkoʻa Wetland due to trespassers cutting the fence.

Table 9. Predators Trapped at ʻUkoʻa Wetland from FY 2014 to FY 2022

Predator	FY 2014[1]	FY 2015[2]	FY 2016[2]	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
Rats	30	92	77	18	24	12	25	35	23
Cats	15	22	7	2	10	2	3	2	0
Mongoose	224	190	204	96	160	136	168	173	105
Mice	21	23	6	1	3	0	0	0	0
Pigs	51	56	20	103	29	42	7	9	48
Dogs	0	0	0	0	1	0	0	0	0
Total Predators Removed	**341**	**383**	**314**	**220**	**227**	**192**	**203**	**219**	**176**

1. In FY 2014, trapping only occurred for 1 month (June 2014).
2. No trapping occurred at ʻUkoʻa Wetland from April 2016 to November 2016.

Tracking tunnels are generally set out quarterly to assess the presence of rodents, mongoose, and cats within the wetland. Overall, tracking tunnel data since 2014 (see Figure 8) shows a general reduction in predator presence, specifically mongoose and rats, since the predator program was initiated.

In FY 2022 tracking tunnels were set out in September 2021, December 2021, March 2022, and June 2022. Twenty-five tracking tunnels were used to detect predator presence in FY 2022. The cards were baited with fish paste and collected one day after setting. Tracks were then counted and recorded. Percent activity (number of cards with tracks divided by total number of cards set out) during FY 2022 is shown in Table 10. Rat activity varied between zero and 11.1 percent, mongoose activity varied between zero and 7.4 percent, mice activity varied between zero and 11.1 percent, and cat activity was tracked at zero for all of FY 2022.

Table 10. Percent Predator Activity Based on Tracking Tunnels at ʻUkoʻa Wetland during FY 2022

Date	Rats	Mongoose	Mice	Cats
September 26, 2021	11.1%	7.4%	11.1%	0.0%
December 18, 2021	0.0%	0.0%	3.7%	0.0%
March 18, 2022	8.0%	0.0%	0.0%	0.0%
June 18, 2022	8.0%	0.0%	0.0%	0.0%

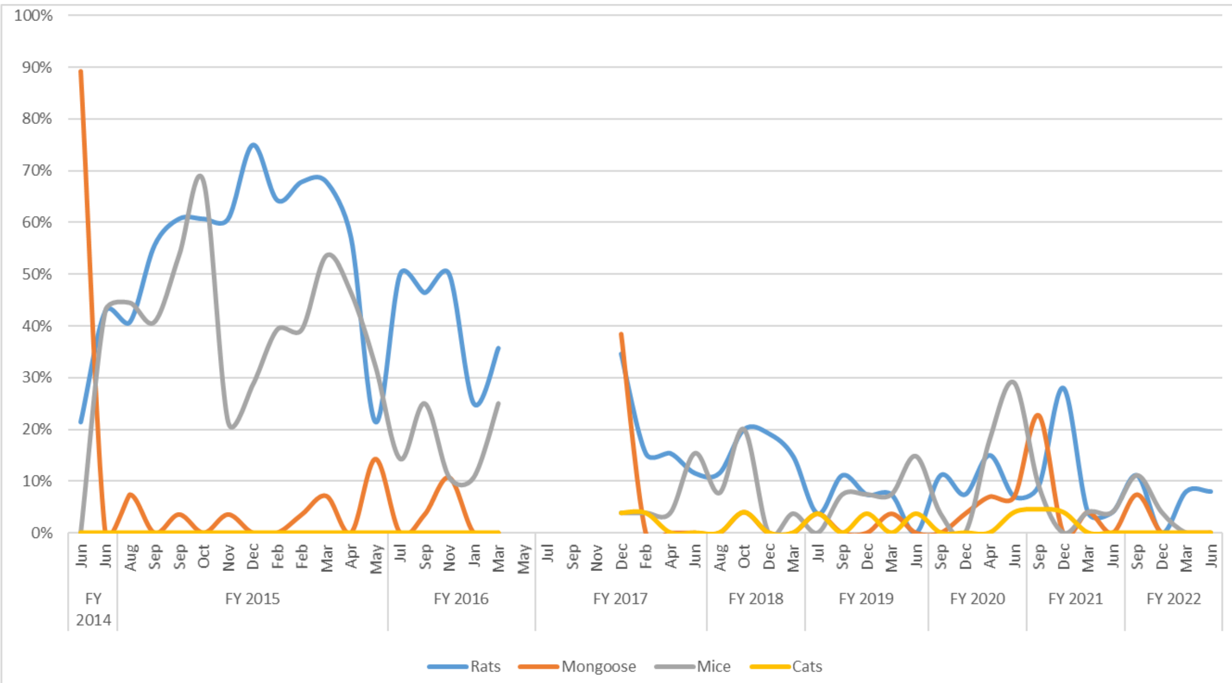


Figure 8. Percent Activity of Tracking Tunnels from FY 2014 to FY 2022

Source: Grey Boar 2022b.

8.1.2.3 Fence Monitoring and Maintenance

Fence inspections were conducted by Grey Boar while checking predator control traps. The fence was visually inspected for any signs of ungulate disturbance, damage, or vandalism. During FY 2022, several sections of fence were repaired. The main cause of fence damage continues to be trespassers.

8.1.2.4 Bat Lanes

Oahu Tree Works, LLC finished bat lane construction in December 2017 (FY 2018). No bat lane maintenance was needed in FY 2022. Bat lane maintenance last occurred in March 2021 and will likely occur in Q1 of FY 2023. Figure 9 shows an example of the current state of the bat lanes since the last maintenance visit. In total, there are 16 bat lanes within 10 zones throughout ʻUkoʻa Wetland (Figure 10).

Figure 9. Bat Lane at ʻUkoʻa Wetland

Photo Taken in June 2022.

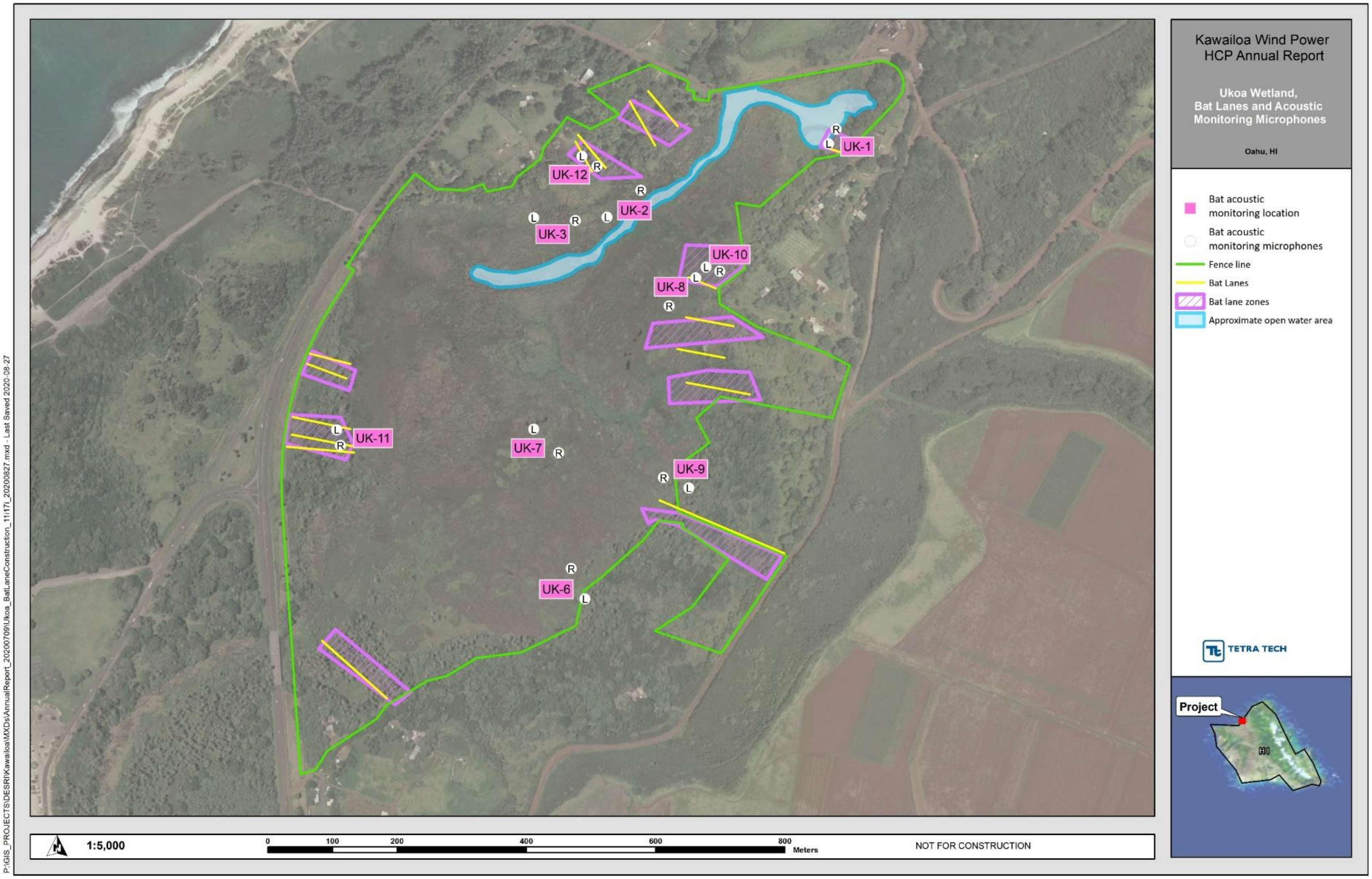


Figure 10. Bat Lanes and Bat Acoustic Detector Microphones at ‘Uko‘a Wetland

8.1.2.5 Bat Acoustic Surveys at ʻUkoʻa

In June 2017, following the removal of invasive vegetation at the open water areas of ʻUkoʻa Wetland and construction of bat lanes, 10 Song Meter SM2BAT+ acoustic recorders (Wildlife Acoustics, Maynard, MA, USA) (hereafter referred to as SM2) were deployed at locations previously monitored between 2012 to 2015 (see Figure 9). The SM2s deployed in June 2017 are similar to those used in previous sampling years to maintain consistency. Each SM2 is equipped with two SMX-U1 ultrasonic microphones (Wildlife Acoustics, Maynard, MA, USA) positioned between 3 and 6.5 meters above ground level.

The proportion of detector-nights containing a single bat pass (any call file containing two or more bat echolocation pulses; Gannon et al. 2003) was used as a measure to quantify bat activity. The sampling period and methods used to analyze bat acoustic data at ʻUkoʻa Wetland are the same as those used for acoustic data at the Project (see Section 8.1.1).

During the 2022 Bat Sampling Period (June 2021 – May 2022), Hawaiian hoary bats were detected on 559 nights out of 2,430 detector-nights sampled (23.0 percent). The annual detection rate in the 2022 Bat Sampling Period was similar to the annual detection rate during the previous sampling year (19.3 percent) (see Table 11).

As shown in Table 11 annual detection rates have varied across sampling years; significant differences in annual detection rates occurred between 2014 and 2016 (ANOVA: $F_{9,91} = 3.94$, $P < 0.001$; Tukey's HSD: $P < 0.048$), 2014 and 2020 (Tukey's HSD: $P < 0.002$), 2014 and 2021 (Tukey's HSD: $P < 0.013$), and 2014 and 2022 (Tukey's HSD: $P < 0.002$). Across all monitoring years there is a significant increase in the annual detection rates (LM: $R^2 = 17.6\%$; $F_{1,99} = 22.36$, $P < 0.001$; Figure 11). There are some inconsistencies in sampling periods for some of the monitoring years. Sampling in the 2012 and 2016 Bat Sampling Periods only occurred during the pregnancy and lactation reproductive periods, which have higher rates of detections, and sampling in 2015 did not occur during the months of November and December, which typically have lower rates of detection.

Detection rates in the 2022 Bat Sampling Period peaked (0.50) during the lactation reproductive period (August) followed by a decline in the detection rate at the onset of the post-lactation reproductive period (September to November; Figure 12). Following November, detection rates increased during the pre-pregnancy reproductive period with a second peak (0.23) in January. Detection rates declined in February, with the lowest detections rates (0.02) in March of pre-pregnancy reproductive period. Detection rates increased again in April of the pregnancy reproductive period with a third peak (0.27) occurring in May (Figure 12). The temporal patterns in the detection rates for the 2022 Bat Sampling Period are similar to the detection rates observed at ʻUkoʻa Wetland in previous sampling years (Figure 13).

Table 11. Number of Nights Sampled, Number of Nights with Detections, and Proportion of Nights with Bat Detections at ʻUkoʻa Wetland from April 2012 to May 2022

Bat Sampling Period	Before or After Vegetation Removal	No. of Nights Sampled	No. of Nights with Detections	Proportion of Nights with Detections
FY 2012 (April – May 2012)	Before	142	18	0.127
FY 2013 (June 2012 –May 2013)	Before	2,036	191	0.094
FY 2014 (June 2013 – May 2014)	Before	2,694	100	0.037
FY 2015 (June 2014 – May 2015)	Before	2,552	175	0.069
FY 2016 (June – October 2015)	Before	1,211	218	0.180
FY 2018 (June 2017 – May 2018)	After	3,248	444	0.137
FY 2019 (June 2018 – May 2019)	After	3,391	506	0.149
FY 2020 (June 2019 – May 2020)	After	3,339	650	0.195
FY 2021 (June 2020 – May 2021)	After	3,182	613	0.193
FY 2022 (June 2021 – May 2022)	After	2,430	559	0.230

Notes:
2017 Sampling Period not included due to minimal number of detector-nights compared to other years; no detectors were deployed from November 2015 to May 2017. Beginning FY 2021, the time period for analyzing and reporting bat acoustic data (referred to as the Bat Sampling Period) was changed to June 1–May 31 rather than the FY (July 1–June 30) to allow adequate time for data review and analysis. All previous sampling years have been adjusted to reflect this same sampling period.

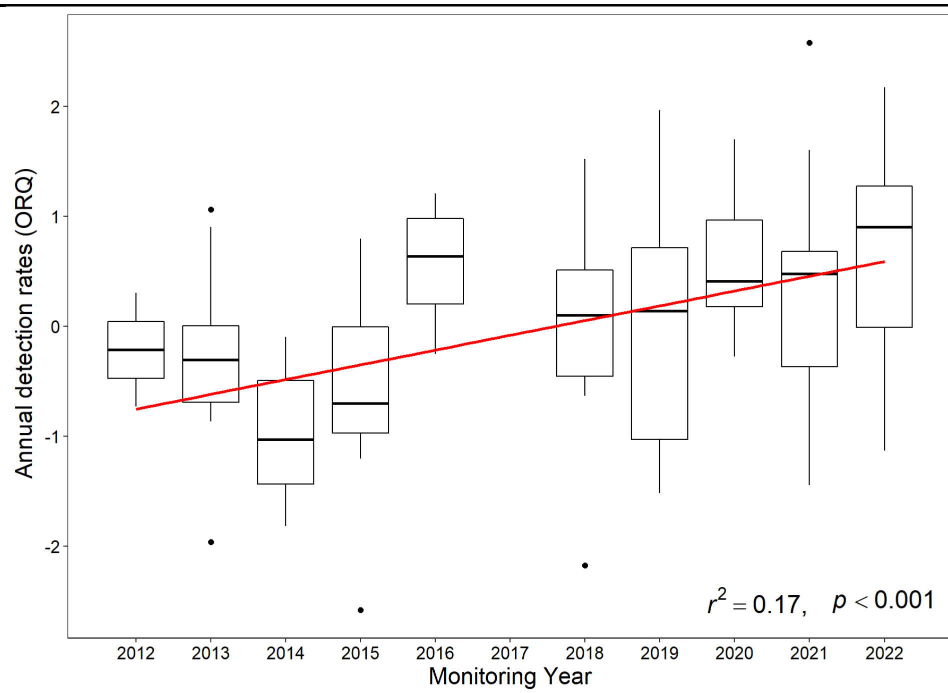


Figure 11. Box-plot Fitted with a Linear Regression Showing the Increasing Trend in the Annual Detection Rates at the Project between 2012 and 2022 Sampling Periods

Note: Annual Detection Rates were Transformed using an Ordered Quantile Normalization Transformation (ORQ).

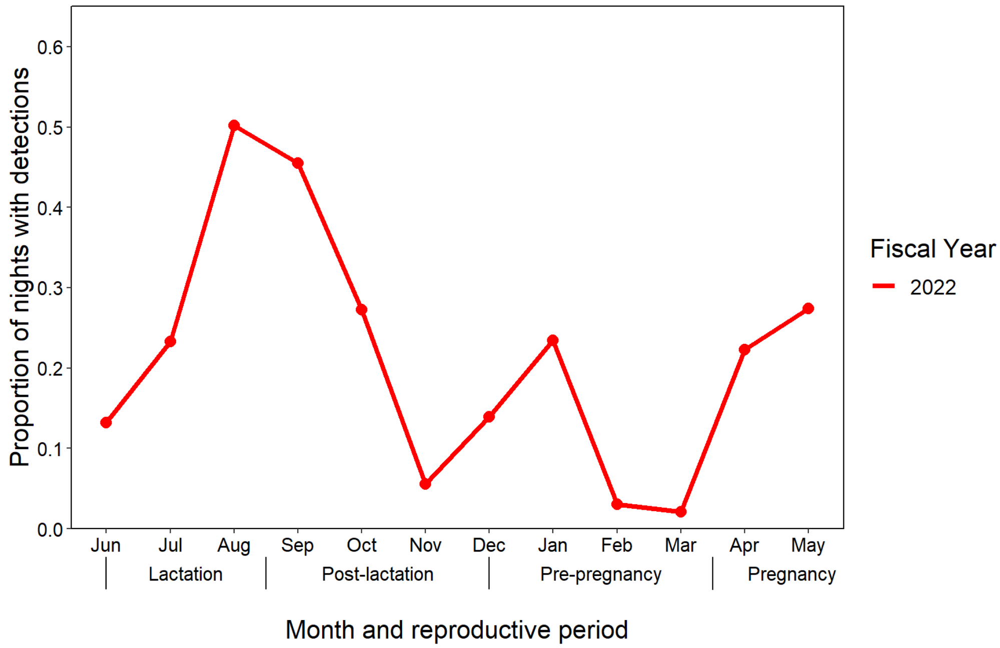


Figure 12. Monthly Bat Detection Rates at ʻUkoʻa Wetland during 2022 Bat Sampling Period (June 2021–May 2022) with Corresponding Reproductive Periods

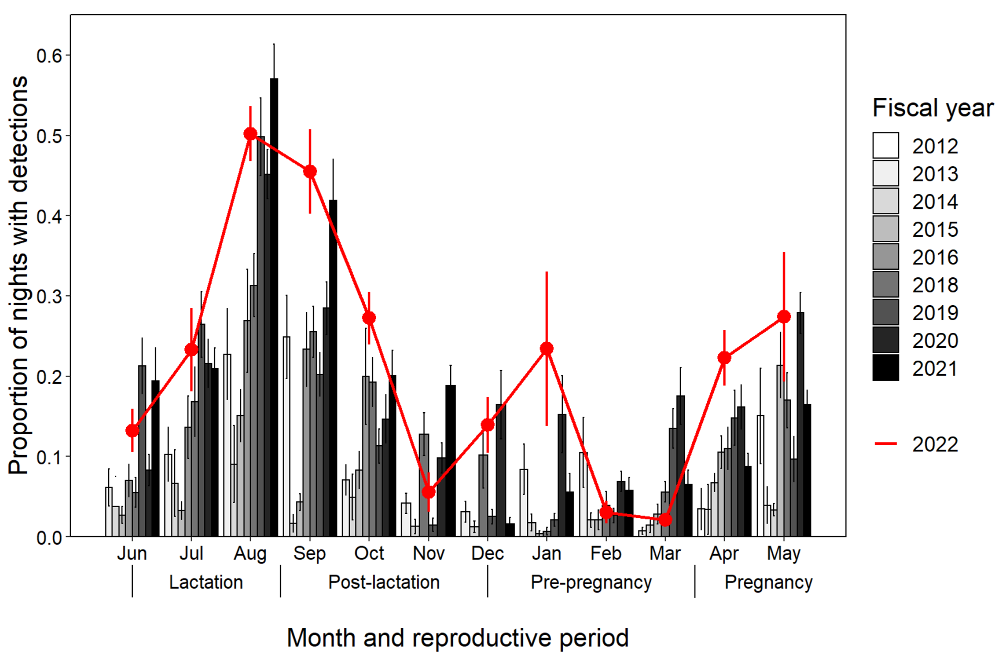


Figure 13. Monthly Bat Detection Rates at ʻUkoʻa Wetland for 2014 to 2022 Bat Sampling Periods with Corresponding Reproductive Periods

Comparison of detection rates for each month before (2012 to 2016 Sampling Period) and after (2018 to 2022 Sampling Period) management was implemented at ʻUkoʻa Wetland indicate an increase in the detection rates for several of the months throughout the year (Figure 14). In addition to observed increases in monthly detection rates, there was also an observed increase in the mean proportion of nights with feeding buzzes recorded at several of the monitoring sites after management was implemented (Figure 15). A feeding buzz is classified as a burst of pulses at a very high rate with less than 11 milliseconds between pulses (Griffin et al. 1960) and are indicative of foraging behaviors. Monitoring sites UK-1, UK-2, UK-6, UK-11, and UK-12 had the greatest observed increase following management activities (Figure 15). The observed increases in the detection rates and feeding buzzes are a positive indication for the effects of management but may correlate with factors other than the invasive plant species removal or bat lane installation.

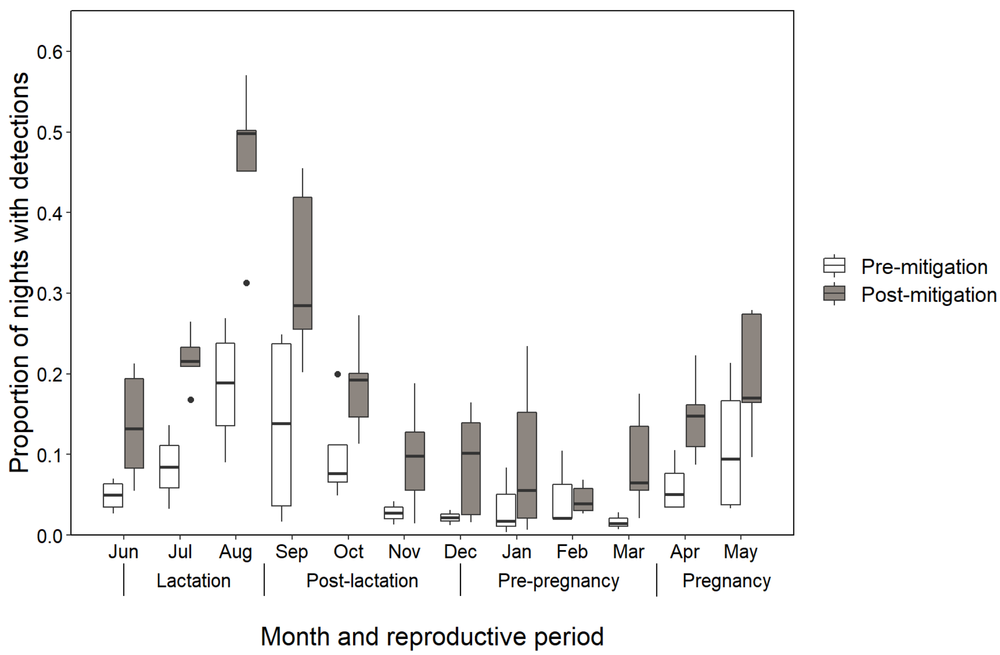


Figure 14. Box-plot Identifying the Median, Lower (Q1) and Upper (Q3) Quartiles, Whiskers (IQR*1.5), and Outliers for Monthly Bat Detection Rates at ʻUkoʻa Wetland Before (2012 – 2016 Sampling Period) and After (2018– 2022 Sampling Period) Invasive Vegetation Removal and Bat Lane Construction

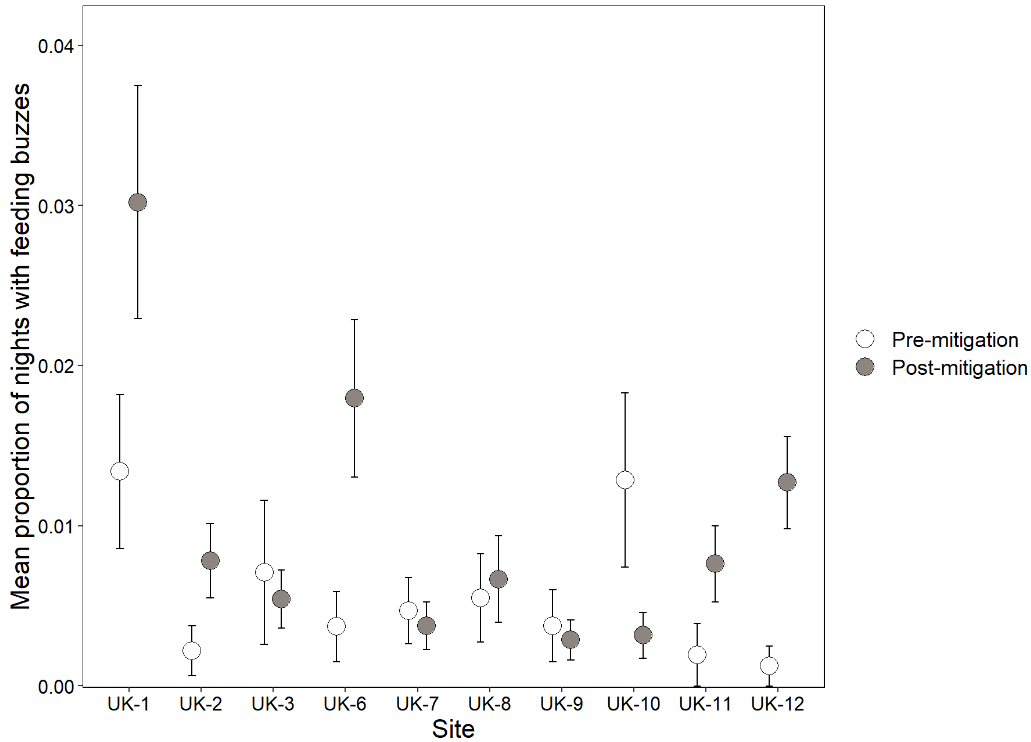


Figure 15. Mean and Standard Error for the Proportion of Feeding Buzzes for each monitoring site at ʻUkoʻa Wetland Before (2012 – 2016 Sampling Period) and After (2018-2022 Sampling Period) Management

8.1.2.6 Insect Sampling & Assessment

In 2014 and 2015, First Wind biologists sampled insects at 10 traps throughout ʻUkoʻa Wetland as part of bat mitigation. Several Endangered Species Recovery Committee (ESRC) members requested Kawailoa Wind conduct a follow-up insect assessment to compare bat prey availability prior to and after management activities at ʻUkoʻa Wetland. DOFAW and USFWS approved Kawailoa Wind's methods for conducting a follow-up insect assessment in April and May 2021, respectively. These methods are included in Appendix 5.[4] The purpose of the 2021 insect sampling is to evaluate current Hawaiian hoary bat prey availability at ʻUkoʻa Wetland and compare the results to insect sampling conducted in 2014 and 2015. It is important to note that although the management activities conducted at ʻUkoʻa Wetland (e.g., clearing vegetation over open water, creating foraging lanes through forested areas) have the potential to change insect populations, it is not possible to attribute any observed changes to the management activities given unrelated annual variability in insect populations.

[4] Methods for this study were slightly modified from Appendix 5 to include one additional emergent trap in the open water area based on discussions with USFWS in May 2021.

Insect sampling was conducted in June, July, August, and September 2021 using 10 traps throughout ‘Uko‘a Wetland. All traps were set out from sunset to sunrise for 3 to 5 consecutive nights each month (similar to 2014 and 2015). Trap types and number of sampling events are shown in Table 12, and 2021 trap locations are shown in Figure 16. Sampling methods employed in 2021 were similar to 2014/2015 sampling methods; however, minor modifications were made to the methodology because of 1) alterations in wetland management activities that were conducted, 2) alterations in site conditions (e.g., water levels and vegetation types), and 3) input from entomologists and Hawaiian hoary bat experts. Sampling in 2021 was conducted during dry weather as much as possible and was timed around the new moon of each month.

All 2021 samples were sorted and identified by entomologist Paul Krushelnycky. Between June and September 2021, nearly 17,700 insect taxa were collected in the samples. A report is currently being drafted to include: a list of insect taxa collected in 2014, 2015, and 2021; a comparison on the species and relative abundance of insects sampled in previous years compared to 2021; and a discussion on how the samples relate to Hawaiian hoary bat prey. This report will be included in the FY 2023 annual report.

Table 12. Insect Trap Types and Sampling Events in 2021

Trap ID	Trap Type	Habitat	No. of Nights Sampled per Month				Total Nights Sampled
			June	**July**	**Aug**	**Sept**	
Up10	Townes-style Malaise	Ground Upland	5	5	5	5	20
UpDOT	Townes-style Malaise	Ground Upland	5	5	5	5	20
Wet1[1]	Townes-style Malaise	Ground Wetland	5	5	5	5	20
Wet2[1]	Townes-style Malaise	Ground Wetland	5	5	5	5	20
WaterKayak	Aquatic Emergence	Open Water	5	5	5	5	20
WaterRoad[2]	Aquatic Emergence	Open Water	5	5	5	5	20
Light9	Universal Black Light	Ground Upland	3	3	3	3	12
Light 12	Universal Black Light	Ground Upland	3	3	3	3	12
Air12	Air Intercept	Air Upland	5	5	5	5	20
AirDOT	Air Intercept	Air Upland	5	5	5	5	20

1. Trap location slightly shifted in 2021 to sample habitat similar to sites surveyed in 2014/2015 (*Bacopa monieri* dominated flats surrounded by bulrush and *Plusher*).

2. 2014/2015 trap location abandoned due to routinely low water levels; based on discussions with USFWS, Kawailoa Wind agreed to deploy an additional emergent trap in a different open water area that was not sampled in 2014/2015.

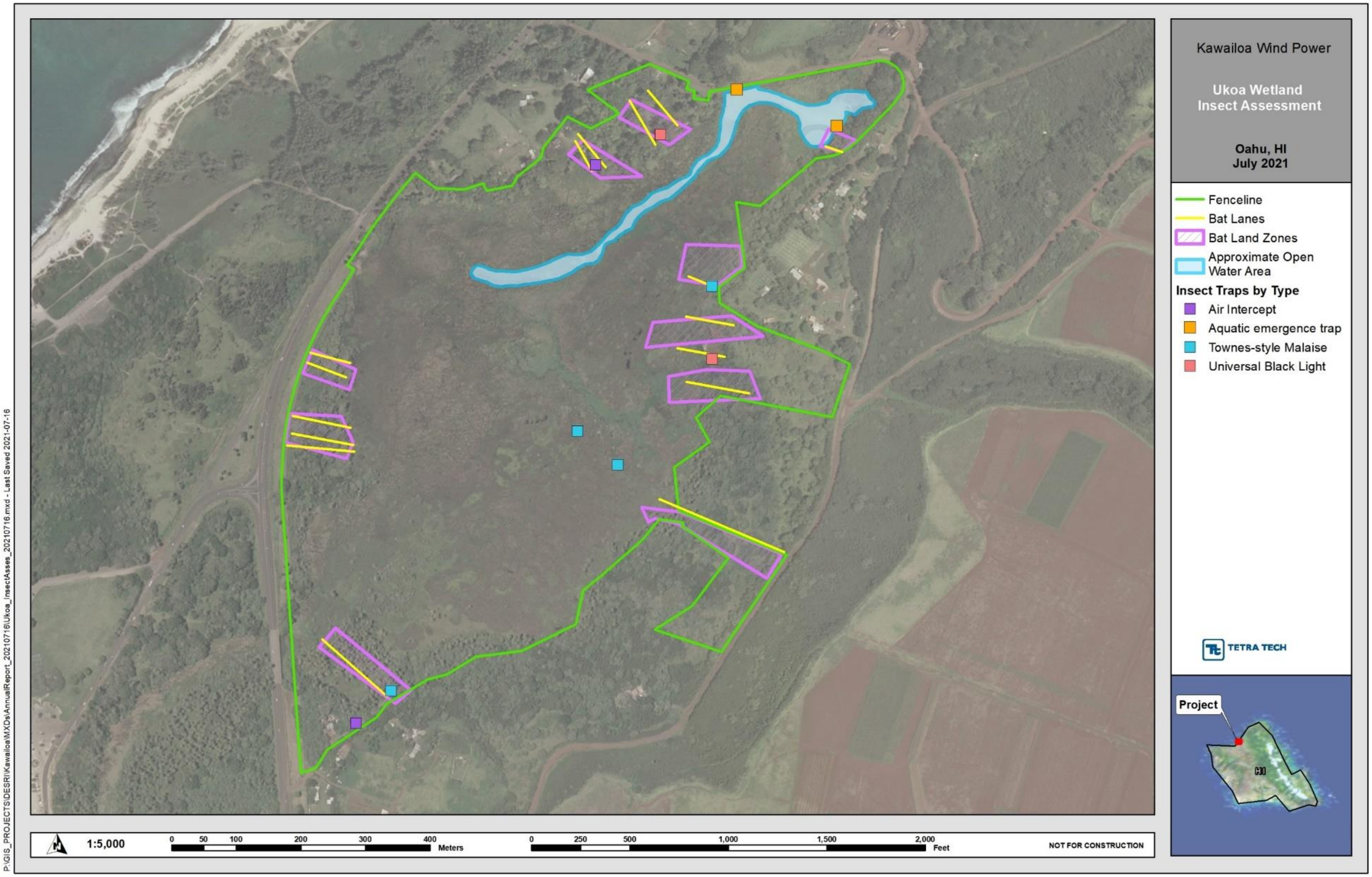


Figure 16. 2021 Insect Trap Locations at ʻUkoʻa Wetland

8.1.3 Studies (Tier 2/3)

In FY 2017, Kawailoa Wind contracted WEST Consultants (WEST) and the USGS to conduct three multi-year studies as Tier 2/3 Hawaiian hoary bat mitigation. These studies were recommended to Kawailoa Wind by USFWS and DOFAW. The total funding for the three projects is over $1.6 million.

One of the USGS research projects (Modeling Foraging Habitat Suitability) was completed in FY 2019 and the research was published in *PLOS ONE* (Gorresen et al. 2018). During FY 2022, Kawailoa Wind continued to fund the WEST project and the second USGS genetics study. Final invoices for both studies were paid in FY 2022. A summary of the work completed for these studies during FY 2022 is provided below.

USGS' *Hawaiian Hoary Bat Conservation Genetics*: The objectives of this study were to improve the understanding of the genetic diversity of the Hawaiian hoary bat, identify bat prey items, and identify the sex of bat carcasses and any sex-specific food habits. Data on these topics will help inform conservation planning and improve bat habitat restoration efforts. In FY 2022, all lab work and data analysis for this study was completed, and Kawailoa Wind provided all funds. The following journal manuscripts were drafted in FY 2022 and are awaiting publication:

- Genetic diversity, structure, and effective population size of an endangered, endemic hoary bat, 'ōpe'ape'a, across the Hawaiian Islands.
- Hawaiian Islands Hawaiian hoary bat sample collection information, mitochondrial COI sequence data, microsatellite genotypes, 2005-2020.

WEST's *Oahu Hawaiian Hoary Bat Occupancy and Distribution Study*: The goal of WEST's multi-year study was to examine the distribution and seasonal occupancy of the Hawaiian hoary bat on O'ahu. The island-wide, randomized block, multi-season monitoring study design can be used to estimate island-wide trends in occupancy. Field data collection for the study spanned roughly four years, beginning in late spring 2017 and concluding in early fall 2021. Throughout FY 2022, WEST:

- Continued data downloads and processing from deployed detectors;
- Managed and analyzed data, and conducting modeling;
- Removed detectors that will not be monitored for an additional (5th) year; and
- Drafted the Final Report (Thompson and Starcevich 2022; see Appendix 6).

As stated above, Kawailoa paid the remaining funding obligations for this research project in FY 2022. WEST received additional funds from various sources to continue monitoring a subset of the deployed detectors after the completion of the 4th year. Kawailoa has committed to providing up to $10,000 to support continued monitoring during a 5th year (ending August 2022). This funding is outside the Tier 2/3 mitigation obligations, which are now complete.

8.1.4 Waimea Native Forest (Tier 3)

Funding the above-listed Tier 2/3 studies left an outstanding obligation of $353,702 for Tier 3 bat mitigation. To fulfill the remaining uncommitted funding obligation, Kawailoa Wind provided $353,702 to Trust for Public Land (TPL) in December 2019 (FY 2019) to contribute to the acquisition of the Waimea Native Forest. The acquisition was completed, and ownership of the parcel was transferred to DOFAW in December 2019; therefore, Tier 3 Hawaiian hoary bat mitigation is complete.

8.1.5 Helemano Wilderness Area (Tier 4)

As described in the HCP Amendment (Tetra Tech 2019), Tier 4 Hawaiian hoary bat mitigation included contributing $2,750,000 to TPL toward the purchase and long-term protection of the nearly 2,900-acre Helemano Wilderness Area (HWA). Kawailoa Wind provided these funds to TPL in October 2018, and ownership of the HWA was transferred from TPL to DOFAW in 2018. The area became the Helemano Section of the ʻEwa Forest Reserve in March 2021. A draft management plan was completed. In FY 2022, DOFAW conducted the following: outplanted native species; performed road maintenance and road repair; controlled vegetation along road corridors; fence maintenance; cleared vegetation to create corridors to increase bat foraging habitat; and cleared 5 acres and conducted site preparation for an experimental seed orchard (R. Peralta/DOFAW, pers. comm, July 2022).

8.1.6 Tier 5 Mitigation

As outlined in the HCP Amendment, Tier 5 bat mitigation will consist of implementation of one or a combination of the following: 1) contributing funding to acquire property that will protect bat roosting and foraging habitat in perpetuity, and/or 2) conduct bat habitat management/restoration to improve bat foraging and/or roosting habitat at the Central Koʻolau area, HWA, Waimea Native Forest, or similar sites (Tetra Tech 2019). In accordance with the mitigation planning requirements under the HCP Amendment, a Site-Specific Mitigation Implementation Plan for Tier 5 mitigation was submitted to USFWS and DOFAW on May 1, 2020. However, Kawailoa Wind has continued planning for Tier 5 mitigation and is exploring new options as potential sites for Tier 5 mitigation utilizing information from recent research and other management/restoration projects.

8.2 Waterbirds

As stated above, USFWS and DOFAW provided written confirmation permitting adaptive management for the original waterbird mitigation. Some activities completed for waterbird mitigation at ʻUkoʻa Wetland (e.g., invasive vegetation removal, predator control, fence maintenance) overlap with bat mitigation requirements and are summarized in Section 8.1.2 above.

Tetra Tech conducts waterbird surveys at ʻUkoʻa Wetland as part of the required mitigation. Comprehensive weekly waterbird surveys began at ʻUkoʻa Wetland in January 2017 following invasive vegetation removal in the open water area and have continued annually throughout FY 2022 (Table 13). In FY 2022, waterbird surveys were conducted weekly from July 2021 to September 2021 and between December 2022 to June 2022. A total of 38 waterbird surveys were completed in FY 2022. A qualified biologist conducted surveys at nine point count (PC) stations set up in the vicinity of the open water and in areas with previous waterbird sightings (Figure 17). Independent waterbird observations are also recorded while walking between stations. The detailed protocols for these surveys are provided in the FY 2017 Annual Report (Tetra Tech 2017).

In addition to the weekly surveys, a biologist conducts waterbird surveys prior to any invasive vegetation control (see Section 8.1.2.1). The purpose of these surveys is to identify if listed waterbird nests or chicks are present in the vicinity of the planned work area. If present, control work is modified to avoid and minimize impacts to endangered Hawaiian waterbirds.

Results of the waterbird monitoring are detailed in the sections below. Waterbirds at ʻUkoʻa are not banded; therefore, assessments of changes on an individual basis is not possible. Although successful reproduction of Hawaiian common gallinule has been documented at ʻUkoʻa Wetland, no evidence of Hawaiian stilt or Hawaiian coot breeding has been observed despite years of ongoing management. As a result of minimal observed breeding events at the site (particularly for stilts and coots), Kawailoa Wind is having ongoing discussions with USFWS and DOFAW regarding adaptive management of waterbird mitigation and potentially shifting the mitigation site.

8.2.1 Hawaiian Common Gallinule

In FY 2022, gallinule (either adults, chicks, or fledglings) were observed on 36 out of the 38 survey dates. Gallinule were recorded at six out of the nine PC stations (Figure 18). Average monthly gallinule detections for FY 2022 are summarized in Table 13 and shown in Figure 19.

Gallinule detections have generally decreased since comprehensive waterbird surveys began in 2017 (Table 13); however, detections increased in FY 2022 compared to the low detections in FY 2020 and FY 2021. The removal of water hyacinth in the open water area has altered habitat available to gallinule at ʻUkoʻa Wetland.

Table 13 also summarizes the number of observed gallinule breeding efforts. Two gallinule breeding events were observed in FY 2022. The event observed in December 2021 resulted in the successful fledging of two gallinule. The second event was observed in June 2022 so the outcome of this breeding effort has yet to be determined; as of June 30, 2022, two gallinule chicks were still present. Both breeding events in FY 2022 were observed in the areas around PC3. All breeding observed during the last 3 years has been along the open water. In total, 11 gallinule fledglings have been recorded since surveys began in FY 2017. Although no waterbird take has been recorded at Kawailoa to date, the Project is required to replace 20 gallinule fledglings.

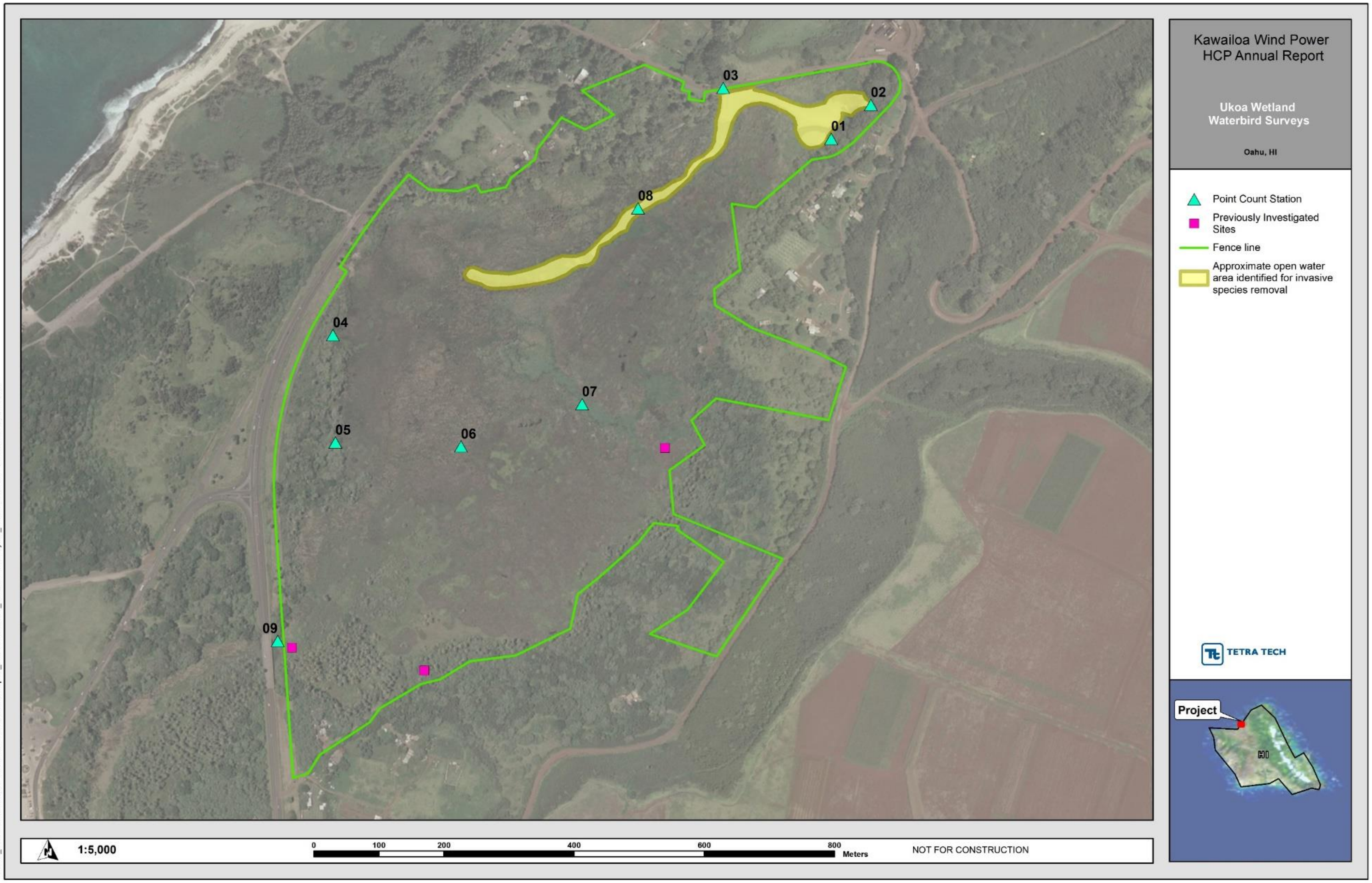


Figure 17. Waterbird Point Count Station Locations at ‘Uko‘a Wetland

Table 13. Average Number of Hawaiian Common Gallinule Detected per Survey by Fiscal Year

Sampling Period	No. of Waterbird Surveys	Average No. of Adults Detected per Survey	Average No. of Chicks Detected per Survey	Average No. of Fledglings Detected per Survey	Total No. of Breeding Efforts Observed	No. of Failed Breeding Efforts Observed	Total No. Fledged
FY 2017 (Aug 2016-Dec 2016)[1]	N/A	N/A	N/A	N/A	3	0	5
FY 2017 (Jan 2017–June 2017)	25	5.7	0.8	1.0	4	2	3
FY 2018 (July 2017–June 2018)	38	4.1	0.4	0.0	6	6	0
FY 2019 (July 2018–June 2019)	41	3.0	0.4	0.0	4	4	0
FY 2020 (July 2019–June 2020)	40	1.9	0.1	0.0	3	3	0
FY 2021 (July 2020–June 2021)	40	2.2	0.4	0.1	1	0	1
FY 2022 (July 2021–June 2022)	38	3.0	0.4	0.3	1	0	2
Total No. Hawaiian Common Gallinule Fledglings							**11**
1. FY 2017 is divided into 2 parts because comprehensive waterbird surveys at PC stations began in January 2017 and detections in late 2016 were incidental to other monitoring that occurred during vegetation removal in the open water areas.							

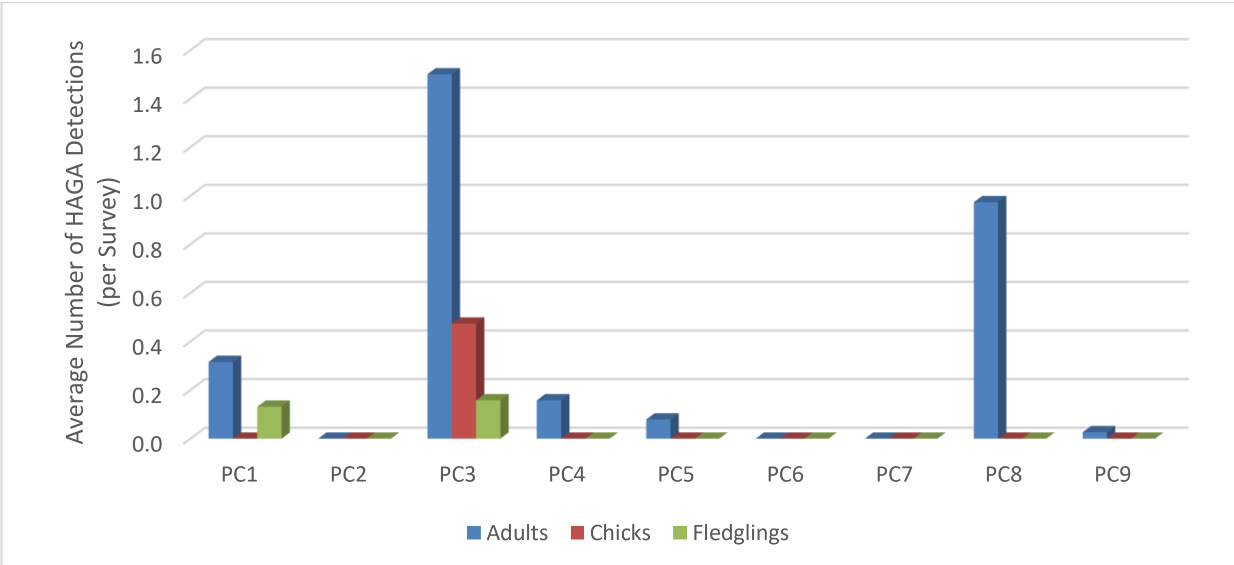


Figure 18. Average Number of Hawaiian Common Gallinule (HAGA) Detections per Survey at Point Count Stations in FY 2022

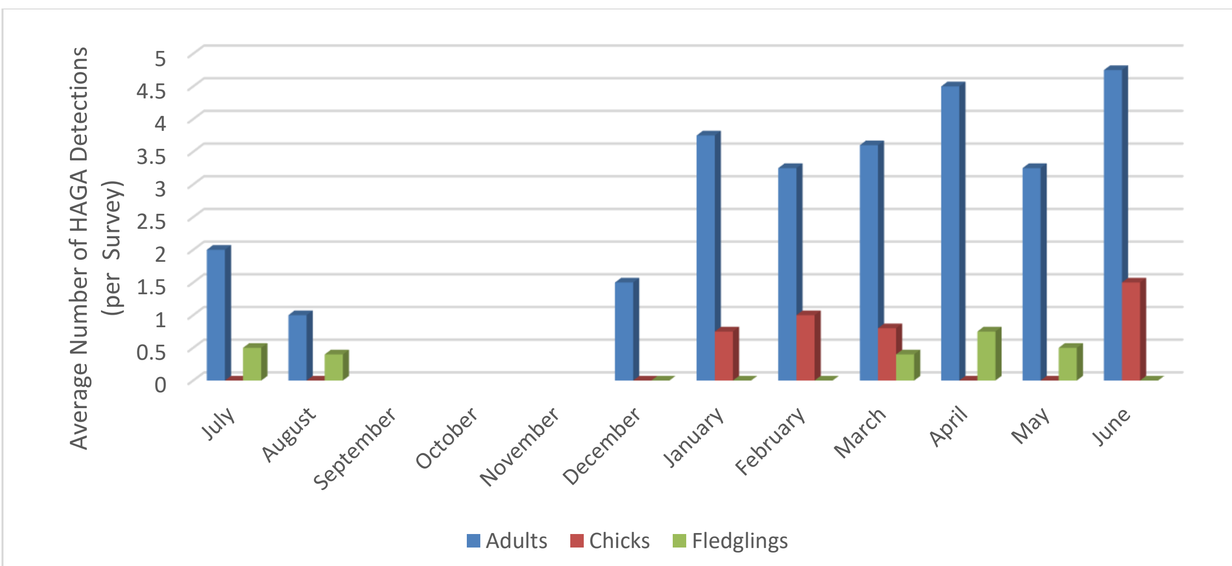


Figure 19. Average Number of Hawaiian Common Gallinule (HAGA) Detections by Month (per Survey) at Point Count Stations in FY 2022

8.2.2 Hawaiian Stilt

In FY 2022, two Hawaiian stilts were observed on a single survey date (June 7, 2021) flying over areas of ʻUkoʻa Wetland. This was the first stilt observation since March 2020. As shown in Table 14, Hawaiian stilt detections have decreased since comprehensive surveys began in January 2017. No Hawaiian stilt nests, chicks, or evidence of reproductive activity have been observed at ʻUkoʻa Wetland since comprehensive surveys began. Although no take of Hawaiian stilts has been recorded at Kawailoa to date, the Project is required to replace 24 stilt fledglings.

Table 14. Average Number of Hawaiian Stilts Detected per Survey and Proportion of Surveys with at Least One Detection by Fiscal Year

Sampling Period	No. of Surveys	Average No. of Adults Detected per Survey	Proportion of Surveys with at Least One Detection
FY 2017 (January 2017–June 2017)	25	0.68	0.24
FY 2018 (July 2017–June 2018)	38	0.71	0.29
FY 2019 (July 2018–June 2019)	41	0.15	0.05
FY 2020 (July 2019–June 2020)	40	0.13	0.07
FY 2021 (July 2020–June 2021)	40	0.00	0.00
FY 2022 (July 2021–June 2022)	38	0.05	0.03

8.2.3 Hawaiian Coot

Since comprehensive waterbird surveys begin in January 2017, only one Hawaiian coot has been detected during the surveys; a single adult Hawaiian coot was recorded in March 2017. Although no waterbird take has been recorded at Kawailoa to date, the Project is required to replace 20 coot fledglings.

8.3 Seabirds

8.3.1 Newell's Shearwater

Tier 1 mitigation for Newell's shearwater was completed in FY 2015.

8.3.2 Hawaiian Petrel

As stated in Section 1.0, the Hawaiian petrel was added as a Covered Species in the HCP Amendment (Tetra Tech 2019). To mitigate for impacts to this species, Kawailoa funded one year of monitoring and predator control at the Hanakāpīʻai and Hanakoa seabird colonies within the Hono O Nā Pali Natural Area Reserve on Kauaʻi in 2020. Final reports from Kauaʻi Endangered Seabird

Recovery Project (Raine et al. 2020) and Hallux Ecosystem Restoration LLC (Dutcher and Pias 2021) for this mitigation project were included in the FY 2021 Annual Report. The reports confirmed Kawailoa Wind's mitigation obligations for the Hawaiian petrel are complete.

8.4 Hawaiian Short-eared Owls or Pueo

Mitigation for the Hawaiian short-eared owl (or pueo) was completed in FY 2017.

9.0 Other Compliance Items

In response to a contested case settlement, Kawailoa Wind provided $250,000 to Pacific Rim Conservation in October 2021 to carry out research related to Hawaiian petrels on O‘ahu. The goal of this project is to determine whether Hawaiian petrels detected in previous surveys are prospecting or breeding on O‘ahu. To accomplish this goal, the project's objectives are:

- Deploy 6-11 song meters at strategic locations across O‘ahu where bird have been previously detected;
- Visit each song meter bi-monthly to maintain equipment and retrieve data for rapid analysis; and
- Conduct on the ground auditory surveys weekly to locate possible burrows.

In April 2022, Pacific Rim deployed 12 automated acoustic recording units (song meters) in suitable locations on the island (six units in the ‘Ewa Forest Reserve and two units at Mt Ka‘ala). Data is retrieved bi-monthly and provided to Conservation Metrics for analysis. In May and June 2022, 70 auditory ground surveys were conducted at the ‘Ewa Forest Reserve and at Mt Ka‘ala for listed seabirds. During these surveys two Hawaiian petrels and eight unknown seabirds were detected, all at Mt Ka‘ala. The funds from Kawailoa will be used to survey for the remainder of the 2022 breeding season, as well as the 2023-2026 Hawaiian petrel breeding seasons (L. Young/Pacific Rim, per. comm., July 2022).

10.0 Adaptive Management

Kawailoa Wind is committed to the ongoing implementation of operational avoidance and minimization measures described in the 2011 HCP and HCP Amendment. Kawailoa Wind has been evaluating options to reduce the risk to bats since Project operations began in 2012. Kawailoa Wind implemented multiple adaptive management steps to understand and reduce the risk to the Hawaiian hoary bat in previous fiscal years including modifying the low wind speed curtailment (LWSC) regime, implementing innovative approaches to post-construction mortality monitoring, and supporting development of the latest technologies that could reduce WTG collision risk to bats. Details on the Project's adaptive management are provided in previous annual reports (Tetra Tech

2018, Tetra Tech 2019, Tetra Tech 2020, Tetra Tech 2021) and the HCP Amendment (Tetra Tech 2019).

As outlined in the FY 2021 Kawailoa Annual Report (Tetra Tech 2021), Kawailoa Wind returned to a 10-minute rolling average on April 3, 2021. Kawailoa continued to operate under the 10-minute rolling average LWSC regime for all of FY 2022.

Kawailoa Wind installed acoustic deterrents at all 30 Project WTGs in May and June 2019. Deterrent functionality is monitored remotely to ensure the systems are functioning properly. Deterrent units (DU) and deterrent unit controllers (DUC) that are identified as underperforming are replaced as soon as possible based on manufacturer recommendations. Each WTG is installed with five DUs, each having overlap in coverage in the deterred airspace. The result of a single DU failure is less than one-fifth of the rotor swept area. If one DU is deficient, a WTG has adequate coverage across the rotor swept area due to redundancy provided by the other four DUs. Kawailoa Wind and NRG work together to install replacements as quickly as feasible. Based on data provided by NRG, the total sitewide deterrent availability for the Project was 98.8 percent in FY 2022.

11.0 Collection Permits

Annual reports for the Project's federal and state collection permits were submitted in Q2 of FY 2022. The USFWS special purpose utility permit (MB22099C-0) expired March 31, 2022. The renewal application was submitted to USFWS on March 24, 2022. The State's Protected Wildlife Permit (Permit No. WL19-33) was renewed on February 10, 2021 (Permit No. WL21-05) and will expire on February 10, 2023.

12.0 Agency Meetings, Consultations, and Visits

Kawailoa Wind and Tetra Tech participated in six virtual meetings with USFWS and DOFAW staff in FY 2022, as well as one ESRC meeting. This includes the following:

- August 9, 2021 – Consulted with DOFAW on alternative waterbird mitigation sites
- September 8, 2021 – Consulted with DOFAW on alternative waterbird mitigation sites
- September 21, 2021 – Consulted with USFWS and DOFAW regarding adaptive management modifications to search monitoring strategy
- September 24, 2021 – Consulted with DOFAW on alternative waterbird mitigation sites
- October 28, 2021 – USFWS and DOFAW semi-annual meeting
- February 3, 2022 – ESRC FY 2021 annual report review
- May 11, 2022 – USFWS and DOFAW semi-annual meeting

13.0 Expenditures

Total HCP-related expenditures for the Project in FY 2022 were approximately $853,800 (Table 15).

Table 15. Estimated HCP-Related Expenditures at the Project in FY 2022.

Category	Amount
Permit Compliance	$113,400
Facility Vegetation Management	$158,500
Fatality Monitoring	$119,200
ʻUkoʻa Wetland Mitigation Compliance	$118,500
Pacific Rim Seabird Research & Coordination	$251,880
Tier 2/3 Bat Research Projects	$88,600
Tier 5 Bat Mitigation Preparation	$3,720
Total Cost for FY 2022	**$853,800**

14.0 Literature Cited

Dalthorp, D., M. Huso, and D. Dail. 2017. Evidence of absence (v2.0) software user guide: U.S. Geological Survey Data Series 1055, 109 p., https://doi.org/10.3133/ds1055.

Dutcher, A. and K. Pias. 2021. Hanakāpīʻai – Hanakoa 2020 Final Report. Hallux Ecosystem Restoration LLC. Prepared for Kawailoa Wind, LLC.

Gannon, W. L., R. E. Sherwin, S. Haymond. 2003. On the importance of articulating assumptions when conducting acoustic studies of habitat use by bats. Wildlife Society Bulletin 31:45-61.

Gorresen, P.M., Bonaccorso, F., Pinzari, C., Todd, C., Montoya-Aiona, K. and Brinck, K. 2013. A Five Year Study of Hawaiian Hoary Bat (*Lasiurus cinereus semotus*) Occupancy on the Island of Hawaii. Hawai'i Cooperative Studies Unit. Technical Report HCSU-041.

Gorresen, P.M., K.W. Brinck, M.A. DeLisle, K. Montoya-Aiona, C.A. Pinzari, F.J. Bonaccorso. 2018. Multi-state occupancy models of foraging habitat use by the Hawaiian hoary bat (*Lasiurus cinereus semotus*). PLoS ONE 13(10): e0205150. Available at: https://doi.org/10.1371/journal.pone.0205150.

Grey Boar (Grey Boar Wildlife Services LLC). 2021a. Ukoa Predator Control Program. 3rd Quarter Report 2021. Prepared for Kawailoa Wind LLC.

Grey Boar. 2021b. Ukoa Predator Control Program. 4th Quarter Report 2021. Prepared for Kawailoa Wind LLC.

Grey Boar. 2022a. Ukoa Predator Control Program. 1st Quarter Report 2022. Prepared for Kawailoa Wind LLC.

Grey Boar. 2022b. Ukoa Predator Control Program. 2nd Quarter Report 2022. Prepared for Kawailoa Wind LLC.

Griffin, D.R., F.A. Webster, and C.R. Michael. 1960. The echolocation of flying insects by bats. Animal Behavior 8:141-154.

H. T. Harvey and SWCA (H. T. Harvey and Associates and SWCA Environmental Consultants). 2014. ʻUkoʻa Wetland Hawaiian Hoary Bat Mitigation Management Plan. Prepared for First Wind. Approved by USFWS and DOFAW 2014.

Pinzari, C.A. and Bonaccorso, F.J., 2018, Hawaiian Islands Hawaiian Hoary Bat Genetic Sexing 2009-2020 (ver. 7.0, June 2022): U.S. Geological Survey data release, https://doi.org/10.5066/P9R7L1NS.

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/

Raine, A.F. J. Rothe, S. Driskill, and S. Rossiter. 2020. Monitoring of Endangered Seabirds at Hanakāpīʻai and Hanakoa, Annual Report 2020. Kauaʻi Endangered Seabird Recovery Project (KESRP), Pacific Cooperative Studies Unit (PCSU), University of Hawaiʻi and Division of Forestry and Wildlife (DOFAW).

SWCA (SWCA Environmental Consultants). 2011. Kawailoa Wind Power Habitat Conservation Plan. Prepared for Kawailoa Wind Power. Dated October 2011.

SWCA. 2012. ʻUkoʻa Wetland Management Plan for Waterbirds 2012 – 2032. Prepared for First Wind. Approved by USFWS and DOFAW 2012.

Tetra Tech (Tetra Tech, Inc.). 2017. Kawailoa Wind Power Habitat Conservation Plan, FY 2017 Annual Report.

Tetra Tech. 2018. Kawailoa Wind Power Habitat Conservation Plan, FY 2018 Annual Report.

Tetra Tech. 2019. Kawailoa Wind Power Habitat Conservation Plan Amendment.

Tetra Tech. 2020. Kawailoa Wind Power Habitat Conservation Plan, FY 2020 Annual Report.

Tetra Tech. 2021. Kawailoa Wind Power Habitat Conservation Plan, FY 2021 Annual Report.

Thompson, J. and L.A. Starcevich. 2021. Oahu Hawaiian Hoary Bat Occupancy and Distribution Study. Project Update and Third Year Analysis. Dated May 2021. Prepared for: Hawaii Endangered Species Research Committee.

Thompson, J. and L.A. Starcevich. 2022. Oahu Hawaiian Hoary Bat Occupancy and Distribution Study, Final Report. Dated July 2022. Prepared for: Hawaii Endangered Species Research Committee.

Todd, C.M. 2012. Effects of Prey Abundance on Seasonal Movements of the Hawaiian Hoary Bat (*Lasiurus cinereus semotus*). ProQuest. Presented to the faculty of the Tropical Conservation Biology and Environmental Science Graduate Program University of Hawaiʻi at Hilo.

USFWS (U.S. Fish and Wildlife Service). 2016. Wildlife agency guidance for calculation of Hawaiian hoary bat indirect take. USFWS Pacific Islands Field Office. Honolulu, HI. October 2016.

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Appendix 1. Documented Fatalities at the Project during FY 2022

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Species[1]	Date Documented	WTG	Distance to WTG (meters)	Bearing from WTG (degrees)
Lonchura punctulata (Scaly-breasted Munia)	7/6/2021	18	33	164
Estrilda astrild (Common Waxbill)	7/8/2021	09	2	166
Spilopelia chinensis (Spotted Dove)	7/13/2021	24	2	208
Zosterops japonicus (Warbling White-eye)	7/13/2021	05	3	300
Acridotheres tristis (Common Myna)	8/17/2021	17	1	201
Lonchura punctulata (Scaly-breasted Munia)	8/27/2021	22	7	8
Geopelia striata (Zebra Dove)	8/31/2021	29	1	18
Bubulcus ibis (Cattle Egret)	9/27/2021	03	40	205
Phaethon lepturus (White-tailed Tropicbird)	9/27/2021	16	16	40
Haemorhous mexicanus (House Finch)	10/26/2021	19	3	310
Pluvialis fulva (Pacific Golden-Plover)	10/28/2021	06	20	160
Geopelia striata (Zebra Dove)	11/16/2021	29	1	46
Geopelia striata (Zebra Dove)	11/16/2021	28	1	356
Zosterops japonicus (Warbling White-eye)	11/16/2021	28	26	216
Phaethon lepturus (White-tailed Tropicbird)	11/26/2021	24	25	255
Geopelia striata (Zebra Dove)	11/30/2021	23	1	19
Estrilda astrild (Common Waxbill)	12/7/2021	16	20	160
Estrilda astrild (Common Waxbill)	12/7/2021	27	24	48
Estrilda astrild (Common Waxbill)	12/7/2021	22	1	55
Estrilda astrild (Common Waxbill)	12/7/2021	18	1	20
Estrilda astrild (Common Waxbill)	12/7/2021	17	13	320
Estrilda astrild (Common Waxbill)	12/9/2021	07	20	304
Estrilda astrild (Common Waxbill)	12/9/2021	03	15	122
Estrilda astrild (Common Waxbill)	12/9/2021	10	20	150
Estrilda astrild (Common Waxbill)	12/9/2021	10	17	290
Estrilda astrild (Common Waxbill)	12/9/2021	09	29	112
Estrilda astrild (Common Waxbill)	12/9/2021	09	28	268
Estrilda astrild (Common Waxbill)	12/9/2021	07	15	352
Estrilda astrild (Common Waxbill)	12/9/2021	05	34	320
Estrilda astrild (Common Waxbill)	12/9/2021	15	9	340
Estrilda astrild (Common Waxbill)	12/9/2021	15	35	80
Estrilda astrild (Common Waxbill)	12/9/2021	07	42	348
Geopelia striata (Zebra Dove)	12/9/2021	12	1	60
Geopelia striata (Zebra Dove)	12/9/2021	10	1	306

Species[1]	Date Documented	WTG	Distance to WTG (meters)	Bearing from WTG (degrees)
Lonchura punctulata (Scaly-breasted Munia)	12/9/2021	11	31	284
Estrilda astrild (Common Waxbill)	12/14/2021	25	25	96
Estrilda astrild (Common Waxbill)	12/14/2021	25	38	58
Geopelia striata (Zebra Dove)	12/14/2021	28	1	326
Lasiurus cinereus semotus (Hawaiian Hoary Bat)	12/14/2021	16	15	253
Phaethon lepturus (White-tailed Tropicbird)	12/16/2021	25	71	350
Zosterops japonicus (Warbling White-eye)	12/21/2021	23	18	320
Spilopelia chinensis (Spotted Dove)	2/1/2022	14	2	286
Pluvialis fulva (Pacific Golden-Plover)	2/22/2022	12	36	116
Spilopelia chinensis (Spotted Dove)	2/24/2022	22	3	290
Spilopelia chinensis (Spotted Dove)	3/1/2022	14	2	210
Spilopelia chinensis (Spotted Dove)	3/11/2022	27	1	182
Zosterops japonicus (Warbling White-eye)	3/17/2022	20	51	292
Zenaida macroura (Mourning Dove)	3/18/2022	23	32	220
Francolinus francolinus (Black Francolin)	3/24/2022	18	1	60
Lasiurus cinereus semotus (Hawaiian Hoary Bat)	3/24/2022	20	22	304
Acridotheres tristis (Common Myna)	6/2/2022	20	43	238
Estrilda astrild (Common Waxbill)	6/7/2022	08	3	10
Species protected by the Migratory Bird Treaty Act are highlighted in gray. Species protected by the Endangered Species Act are highlighted in yellow.				

Appendix 2.
Dalthorp et al. (2017) Fatality Estimation for Hawaiian hoary bats at Project through FY 2022

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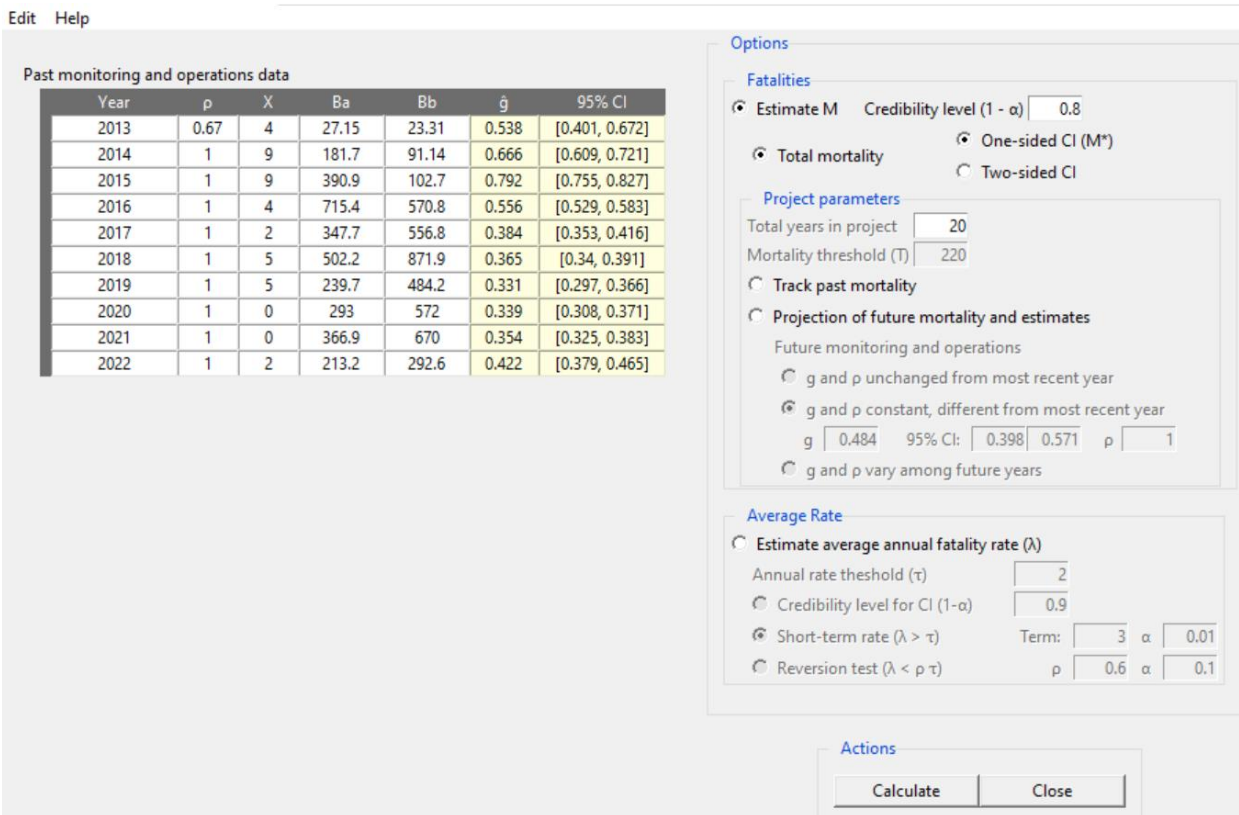
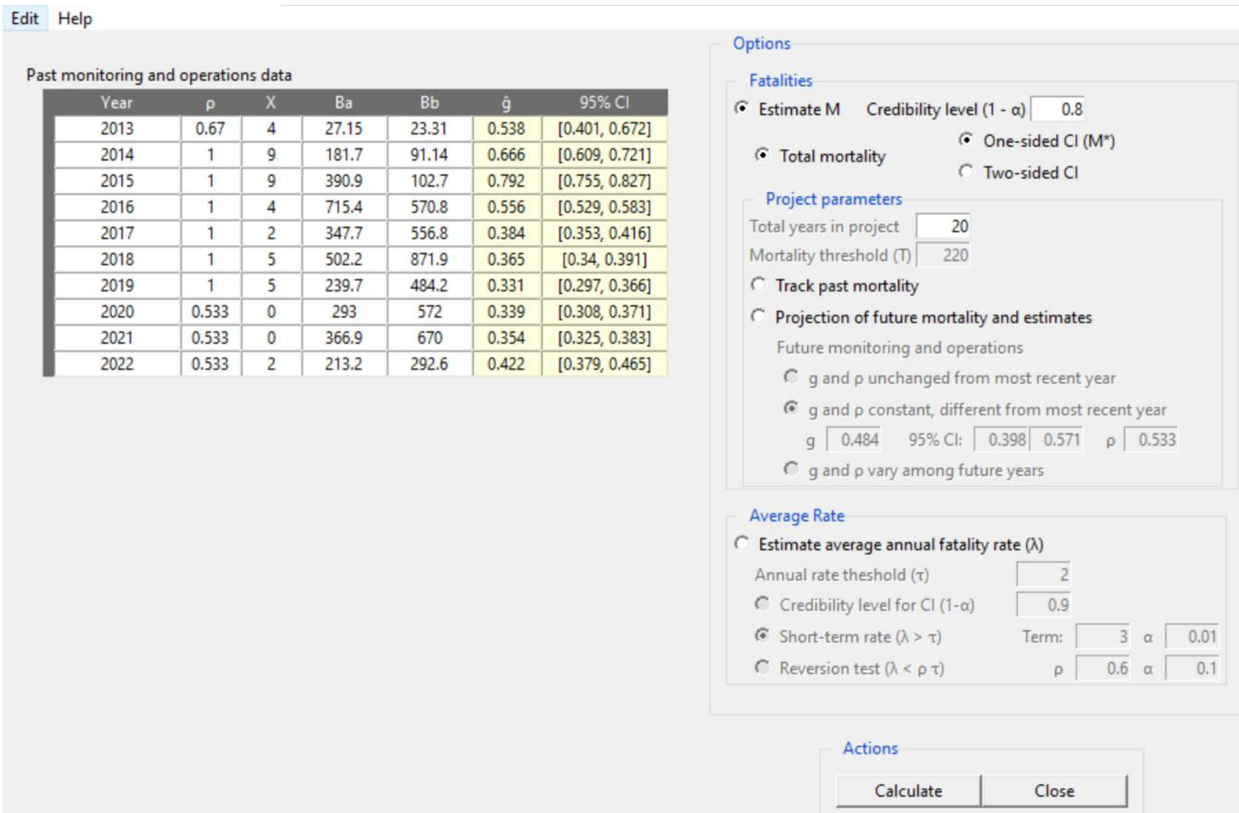
Figure 1. Dalthorp et al. (2017) Fatality Estimation for Hawaiian Hoary Bats at Project through FY 2022 with No Rho Adjustment.[5]



Year	ρ	X	Ba	Bb	ĝ	95% CI
2013	0.67	4	27.15	23.31	0.538	[0.401, 0.672]
2014	1	9	181.7	91.14	0.666	[0.609, 0.721]
2015	1	9	390.9	102.7	0.792	[0.755, 0.827]
2016	1	4	715.4	570.8	0.556	[0.529, 0.583]
2017	1	2	347.7	556.8	0.384	[0.353, 0.416]
2018	1	5	502.2	871.9	0.365	[0.34, 0.391]
2019	1	5	239.7	484.2	0.331	[0.297, 0.366]
2020	1	0	293	572	0.339	[0.308, 0.371]
2021	1	0	366.9	670	0.354	[0.325, 0.383]
2022	1	2	213.2	292.6	0.422	[0.379, 0.465]

[5] Rho represents the portion of a year represented for each line of data. Year 2013 represents a partial year (November 2012 – June 2013) because the Project began operations in November; all remaining years represent a full fiscal year.

Figure 2. Dalthorp et al. (2017) Fatality Estimation for Hawaiian Hoary Bats at Project through FY 2022 with Rho Adjustment.[4, 6]



Year	ρ	X	Ba	Bb	ĝ	95% CI
2013	0.67	4	27.15	23.31	0.538	[0.401, 0.672]
2014	1	9	181.7	91.14	0.666	[0.609, 0.721]
2015	1	9	390.9	102.7	0.792	[0.755, 0.827]
2016	1	4	715.4	570.8	0.556	[0.529, 0.583]
2017	1	2	347.7	556.8	0.384	[0.353, 0.416]
2018	1	5	502.2	871.9	0.365	[0.34, 0.391]
2019	1	5	239.7	484.2	0.331	[0.297, 0.366]
2020	0.533	0	293	572	0.339	[0.308, 0.371]
2021	0.533	0	366.9	670	0.354	[0.325, 0.383]
2022	0.533	2	213.2	292.6	0.422	[0.379, 0.465]

[6] The methodology and calculation of the adjusted rho value is provided in Appendix 3.

Figure 3. Posterior Distribution: Dalthorp et al. (2017) Fatality Estimation for Hawaiian Hoary Bats at Project for FY 2022 with No Rho Adjustment

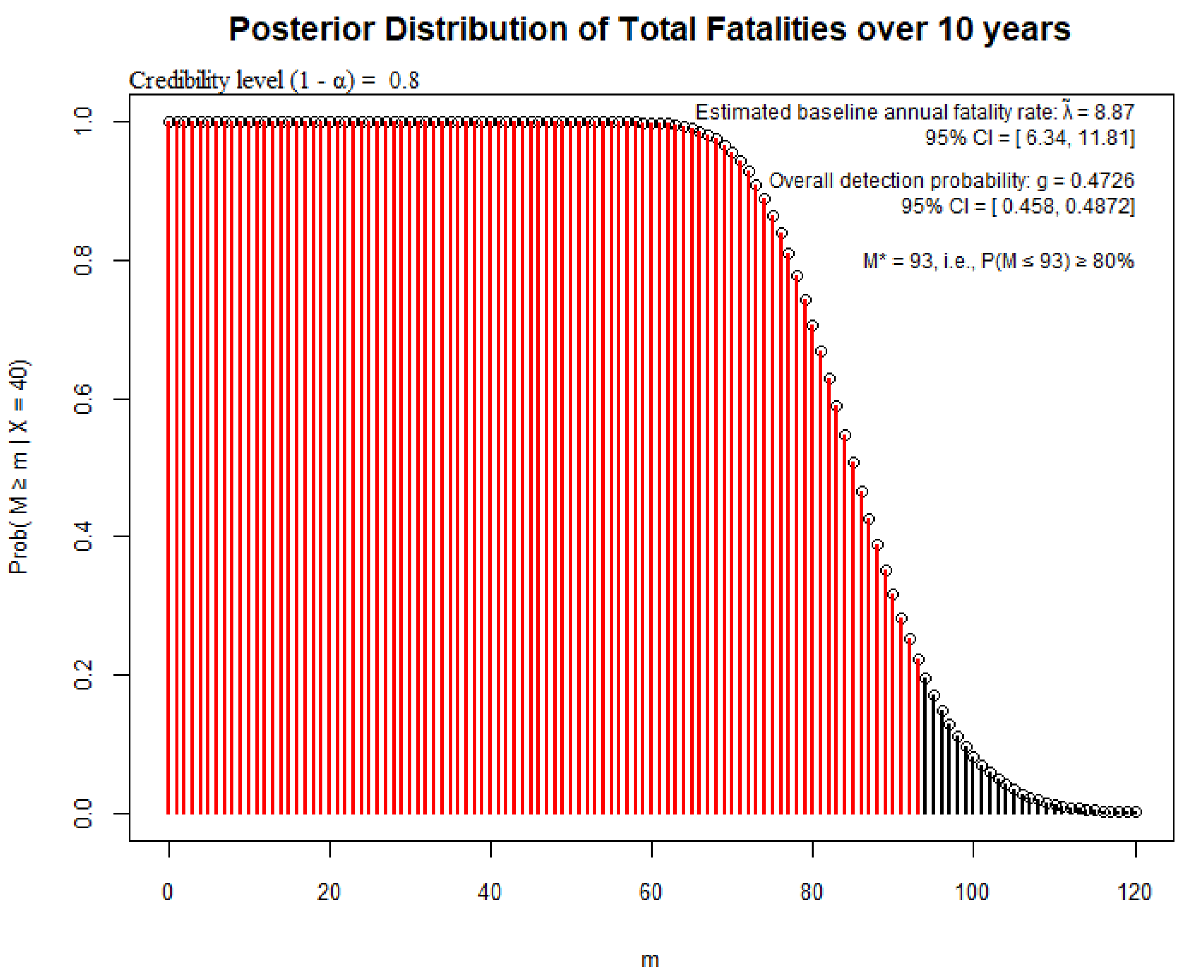
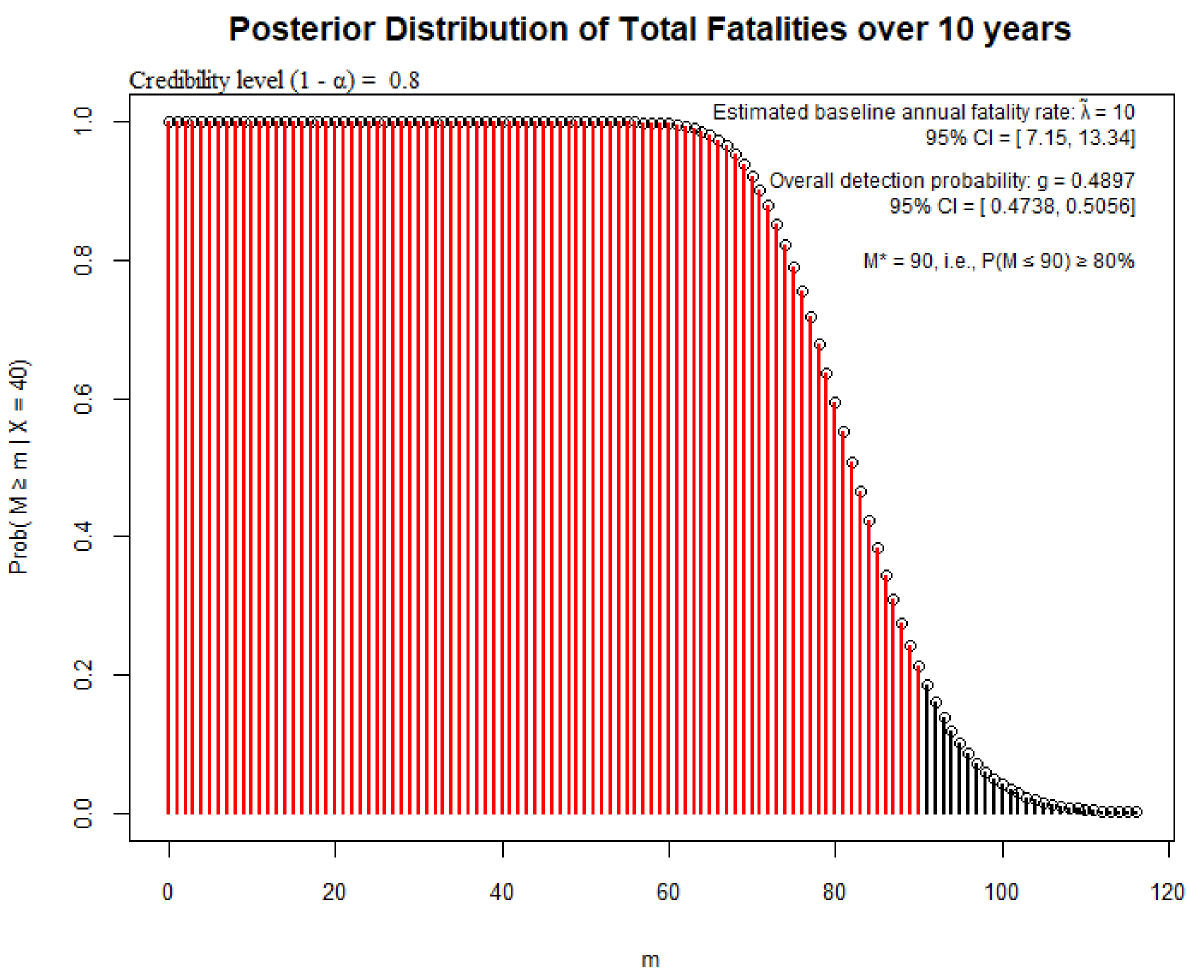


Figure 4. Posterior Distribution: Dalthorp et al. (2017) Fatality Estimation for Hawaiian Hoary Bats at Project for FY 2022 with Rho Adjustment[7]



[7] The methodology and calculation of the adjusted rho value is provided in Appendix 3.

Appendix 3.
Methodology for Determining an Appropriate Rho Value

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In May and June 2019, Kawailoa Wind, LLC (Kawailoa Wind) installed ultrasonic acoustic deterrents (UAD) at all 30 wind turbine generators (WTG) at the Kawailoa Wind Project (Project). The installation of UADs is correlated with a reduction in fatality rates for mainland hoary bats (Weaver et al. 2019) and is a minimization measure encouraged by the U.S. Fish and Wildlife Service (USFWS) and Hawai'i Division of Forestry and Wildlife (DOFAW) to reduce the risk to Hawaiian hoary bats at the Project.

The effectiveness of UADs on the Hawaiian hoary bat is not known, but evidence from monitoring at the Project suggests the Hawaiian hoary bat fatality rate is reduced at the Project after installation of UADs. The effectiveness of UADs for mainland hoary bats at Los Vientos Wind Farm in Texas was found to be 78.3 percent (95% confidence interval [CI]: 61.5–95.1%) reduced relative to WTGs without UADs active. Differences in site conditions and the species-specific responses led to uncertainty if this reduction will be replicated at the Project. Additionally, the Project has implemented low wind speed curtailment at 5 meters per second (m/s) with a 0.2 m/s hysteresis, further reducing the risk to bats relative to the study at Los Vientos.

The Evidence of Absence (EoA) software program incorporates a parameter called rho (ρ), which adjusts the expected fatality rate. A rho value of 1 is typically used when assessing compliance with authorized take limits. The use of a rho value of 1 assumes the risk is the same from year to year. Rho has also been used to account for the proportion of the year covered by search parameters, such as the partial year of fatality monitoring at the Project's start in fiscal year (FY) 2013 and the change in search areas that occurred in FY 2016. The EoA user's manual (Dalthorp et al. 2017) describes rho as follows:

> The assumed relative mortality rate is ρ. If there are no changes in operations and no reason to suspect mortality rates varied systematically from year to year, then $\rho=1$ each year. However, if operations or ecological conditions change, the ρ parameter should be adjusted to reflect changes. For example, if a site is expanded by 20% in year 3, then $\rho=1$ for years 1 and 2 as a baseline and $\rho=1.2$ in year 3 would be appropriate. Or if minimization measures that are expected to reduce fatalities by 30% are implemented in year 3, then $\rho=1$ for years 1 and 2, and $\rho=0.7$ for year 3.

To test if the fatality rate is reduced, Tetra Tech used EoA to compare fatality rates and check for misspecification in rho. In other words, "Does the fatality monitoring data provide evidence that minimization measures have reduced the risk to bats?" To compare the fatality rate in each year, Tetra Tech used the multi-year module of EoA to compare the fatality rates. The fatality rates (lambda[λ]) for each year are shown in Table 1 and Figure 1. These illustrate that the interquartile ranges are non-overlapping, although the 95 percent confidence intervals overlap.

To test if the rho value is appropriately specified before and after installation of UADs, each period was grouped as a single period in the multi-years module of EoA and tested for misspecification of rho using the multi-year module of EoA. For the pre-UAD period, rho = 1 for each full year; the rho for a partial year is calculated as the proportion of the year involved. The rho for the post-UAD period will begin with rho=1 for all years (i.e., after 4 years, rho=4). For multiple years, the rho value for the post-UAD period is represented by the equation: rho * years of monitoring. In practice this would be assumed to be the same for all years. For example, if after year four, the cumulative rho value of 0.5 for the post-UAD period (2020-2024) is indicated by the EoA test for misspecification of rho, the annual rho value would be 0.5/4 years, or 0.125. Similarly, if a rho value of 4 is indicted by the EoA test for misspecification of rho for the same period (2020-2024), the rho value would be 1 for all years (4 rho/4 years = 1 rho/year).

November 2012-June 2019, which correlates with FY 2013-2019, represents the pre-UAD period, and July 2019-June 2022, which correlates with FY 2020-2022, represents the post-UAD installation period. The cumulative detection probability for each period was calculated using EoA to group the years (FY 2013-2019, and FY 2020-2022) and provide a cumulative detection probability. For each period, the observed fatalities were summed to calculate the total observed fatalities for the period. The pre-deterrent period therefore represents the pooled data from FY 2013 to FY 2019 including: rho which represents the years of monitoring from November 2012-June 2019 or 6.67 years, the sum of observed bat fatalities (38 bats), and the cumulative detection probability from November 2012 to June 2019 (0.518). The post-deterrent period represents the pooled data from FY 2020 to FY 2022 including: rho which represents the years of monitoring from July 2019 – June 2022 or 3 years, the sum of observed bat fatalities (2 bats), and the cumulative detection probability from July 2019 to June 2022 (0.371). The inputs are provided in Table 2.

Comparing the fatality monitoring data before and after UADs demonstrates that fatality rates are overestimated after installation of UADs if the same rho is used for both periods. At a rho value of 3 (annual rho of 1), the test for misspecification returns a significant result when testing for a p value less than 0.05 (p value =0.00094); the EoA outputs for this trial are shown in Figure 2. The rho value was decreased incrementally by 0.05 until the p value for the test of misspecification of rho exceeded a p value of 0.05. The first rho value with a test of misspecification p value greater than 0.05 (p value= 0.05006) was found when the combined rho FY 2020 – FY 2022 = 1.6 (a 0.533 annual rho) or a 46.7 percent reduction in the annual fatality rate after installation of UADs; the EoA outputs for this trial are shown in Figure 3. Therefore, Project data suggest 95 percent confidence that Hawaiian hoary bat risk at the Project is reduced by at least 46.7 percent through the use of UADs.

As shown in Figure 1, fatality rates can vary significantly from year to year. Kawailoa Wind, USFWS, and DOFAW will need to continue to evaluate the results of fatality monitoring to ensure the rho value is appropriately specified. The methods outlined here represent the means by which an appropriate rho value will be determined, and which are consistent with the recommended methodology outlined in the USFWS Programmatic Environmental Impact Statement (USFWS 2019), which states:

> All projects start off with using $\rho = 1$. If an additional minimization such as raising the cut in speed (see Appendix D) or deterrents are implemented, the rho-value is still kept at 1 until tests on assumed weights indicate that there may be a difference in fatality rates. This may require several years of deploying the minimization action before any difference can be supported by the test on the rho-value. If the tests do confirm a change in the fatality rates between periods beyond a reasonable doubt, a rho-value can be put in place, retroactively,

for the periods in which the minimization action was deployed, if approved by the Service. The tests can be rerun to determine if the rho value continues to be reasonable. Note, however, that the actual rho-value is not calculated by the model and may never be known. The best that can be done is to maintain testing of the rho value being used to see if it is reasonable.

An appropriate rho value needs to be incorporated in the Project EoA assessment to account for the reduced risk to bats from the installation of UADs at the Project. An appropriate rho value will have sufficient years of supporting data for both pre- and post-minimization effectiveness to statistically account for inter-annual variability in the observed take rate. Once a final rho value is determined, the final rho will be applied to all years in which UADs are active.

Table 1. Fatality Rates for Each Year of Project Operation

Year	Observed Fatalities	Detection Probability	Fatality Estimate at the 80% Credible Level	Median Fatality Estimate	Fatality Estimate 95% CI	Lambda	Lambda 95% CI
2013	4	0.538	10	7	[4,14]	8.588	[2.486, 18.83]
2014	9	0.666	16	13	[10,20]	14.30	[6.669, 24.87]
2015	9	0.792	13	11	[9,15]	12.01	[5.619, 20.79]
2016	4	0.556	10	7	[4,12]	8.097	[2.427, 17.14]
2017	2	0.384	8	5	[2,12]	6.520	[1.081, 16.78]
2018	5	0.365	19	14	[7,26]	15.08	[5.215, 30.13]
2019	5	0.331	21	15	[7,28]	16.68	[5.749, 33.44]
2020	0	0.339	2	0	[0,4]	1.481	[0.001433, 7.448]
2021	0	0.354	1	0	[0,4]	1.416	[0.001433, 7.123]
2022	2	0.421	8	5	[2,11]	5.955	[0.9859, 15.34

Table 2. Inputs for the Test of Misspecification of Rho

Year	P (rho)	X (Observed Fatalities)	Ba (Shape)	Bb (Scale)	ĝ (Detection Probability)	95% CI
2013 – 2019	6.67	38	1356	1262	0.518	[0.499, 0.537]
2020 – 2022	3 or 1.6	2	812.3	1375	0.371	[0.351, 0.392]

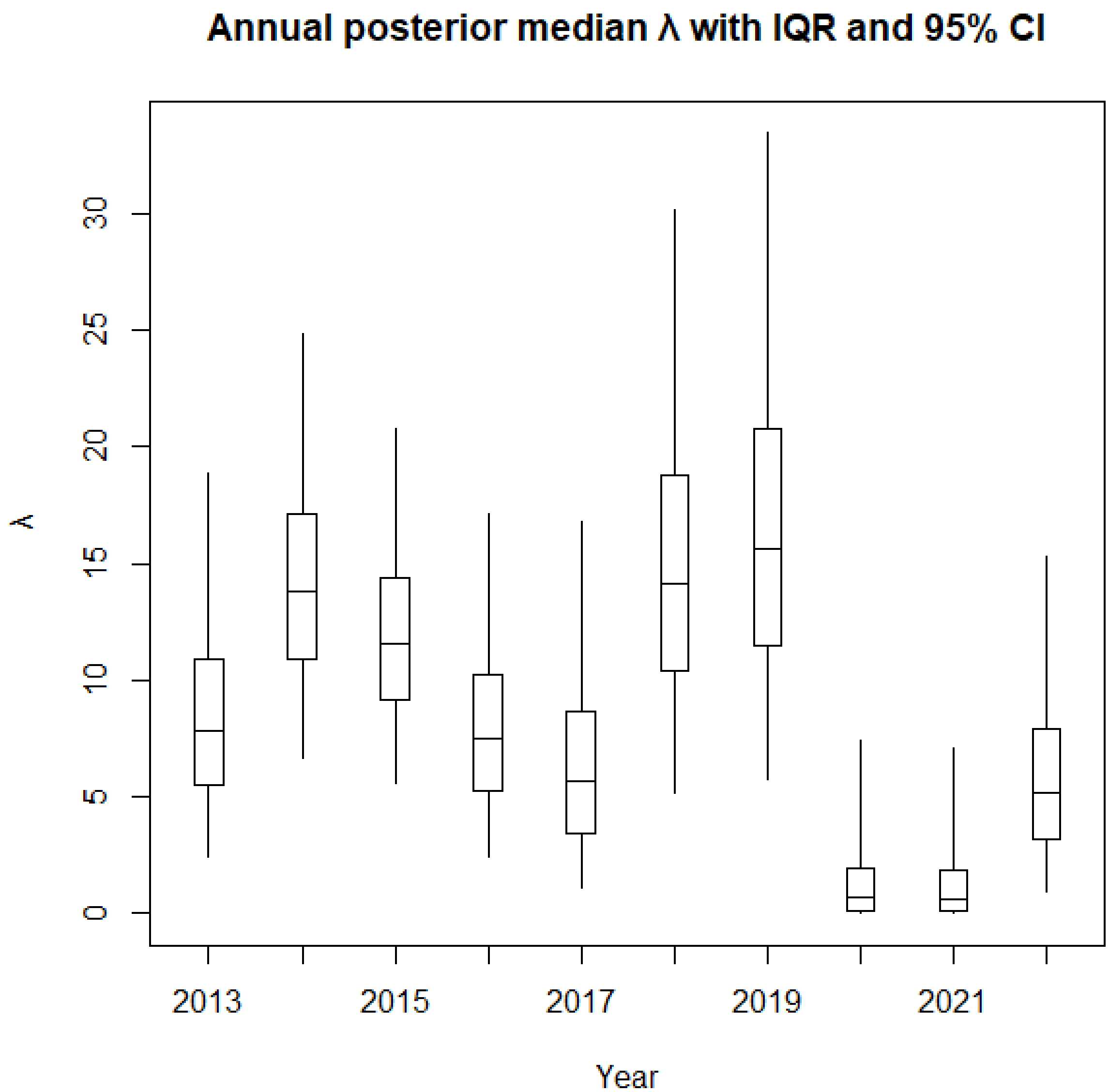

Figure 1. Annual Hawaiian Hoary Bat Fatality Rates Estimated by EoA for the Project at the 80 Percent Credible Level

```
Summary statistics for mortality estimates through 2 years
------------------------------------
Results

M* = 93 for 1 - a = 0.8, i.e., P(M <= 93) >= 80%
Estimated overall detection probability: g = 0.472, 95% CI = [0.458, 0.487]
   Ba = 2116.6, Bb = 2363.2
Estimated baseline fatality rate (for rho = 1): lambda = 8.867, 95% CI = [6.34, 11.8]

Cumulative Mortality Estimates
                                              mean
Year          X    g     M*  median  95% CI  lambda       95% CI
FY2013-2019  38 0.518   81    73    [59, 91]  74.37   [52.64, 99.84]
FY2020-2022  40 0.472   93    85    [68, 106]  85.75   [61.3, 114.3]


Annual Mortality Estimates
                                              mean
Year          X    g     M*  median  95% CI  lambda       95% CI
FY2013-2019  38 0.518   81    73    [59, 91] 74.3700   [52.6400, 99.8400]
FY2020-2022   2 0.371    9     6    [2, 13] 6.7390   [1.1190, 17.3100]


Test of assumed relative weights (rho) and potential bias
              Fitted rho
Assumed rho     95% CI
   6.67     [7.739, 9.507]
      3     [0.161, 1.929]

p = 0.00094 for likelihood ratio test of H0: assumed rho = true rho
Quick test of relative bias: 1.064

================================================================================
Input
Year (or period)  rho    X    Ba     Bb   ghat    95% CI
FY2013-2019      6.670  38   1356   1262 0.518 [0.499, 0.537]
FY2020-2022      3.000   2  812.3   1375 0.371 [0.351, 0.392]
```

Figure 2. Testing for Misspecification of Rho with a Rho Value of 3

```
Summary statistics for mortality estimates through 2 years
------------------------------------
Results

M* = 90 for 1 - a = 0.8, i.e., P(M <= 90) >= 80%
Estimated overall detection probability: g = 0.49, 95% CI = [0.474, 0.506]
   Ba = 1853, Bb = 1931.8
Estimated baseline fatality rate (for rho = 1): lambda = 10.01, 95% CI = [7.15, 13.3]

Cumulative Mortality Estimates
                                              mean
Year          X    g     M*  median  95% CI  lambda      95% CI
FY2013-2019  38 0.518   81    73     [59, 91]  74.37   [52.64, 99.84]
FY2020-2022  40 0.490   90    82     [65, 101]  82.75   [59.15, 110.3]


Annual Mortality Estimates
                                              mean
Year          X    g     M*  median  95% CI  lambda      95% CI
FY2013-2019  38 0.518   81    73     [59, 91] 74.3700   [52.6400, 99.8400]
FY2020-2022   2 0.371    9     6     [2, 13] 6.7390   [1.1190, 17.3100]


Test of assumed relative weights (rho) and potential bias
              Fitted rho
Assumed rho     95% CI
   6.67      [6.679, 8.150]
    1.6      [0.119, 1.584]

p = 0.05006 for likelihood ratio test of H0: assumed rho = true rho
Quick test of relative bias: 1.027

================================================================================
Input
Year (or period)  rho    X    Ba     Bb   ghat    95% CI
FY2013-2019      6.670  38   1356   1262 0.518 [0.499, 0.537]
FY2020-2022      1.600   2  812.3   1375 0.371 [0.351, 0.392]
```

Figure 3. Testing for Misspecification of Rho with a Rho Value of 1.6 (Annual Rho of 0.533)

Literature Cited:

Dalthorp, D., M. Huso, and D. Dail. 2017. Evidence of absence (v2.0) software user guide: U.S. Geological Survey Data Series 1055. 109 p. https://doi.org/10.3133/ds1055.

USFWS (U.S. Fish and Wildlife Service). 2019. Final Programmatic Environmental Impact Statement Addressing the Issuance of Incidental Take Permits for Four Wind Energy Projects in Hawaiʻi. U.S. Department of the Interior, Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office. July.

Weaver, S., and I. Castro-Arellano. 2019. Studying Behavior and Testing Strategies to Reduce Impact of Wind Energy on Bats in Texas. Final Performance Report. Prepared for the State Wildlife Grant Program, Texas.

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Appendix 4.
Dalthorp et al. (2017) Fatality Estimation for Hawaiian Petrels at Project through FY 2022

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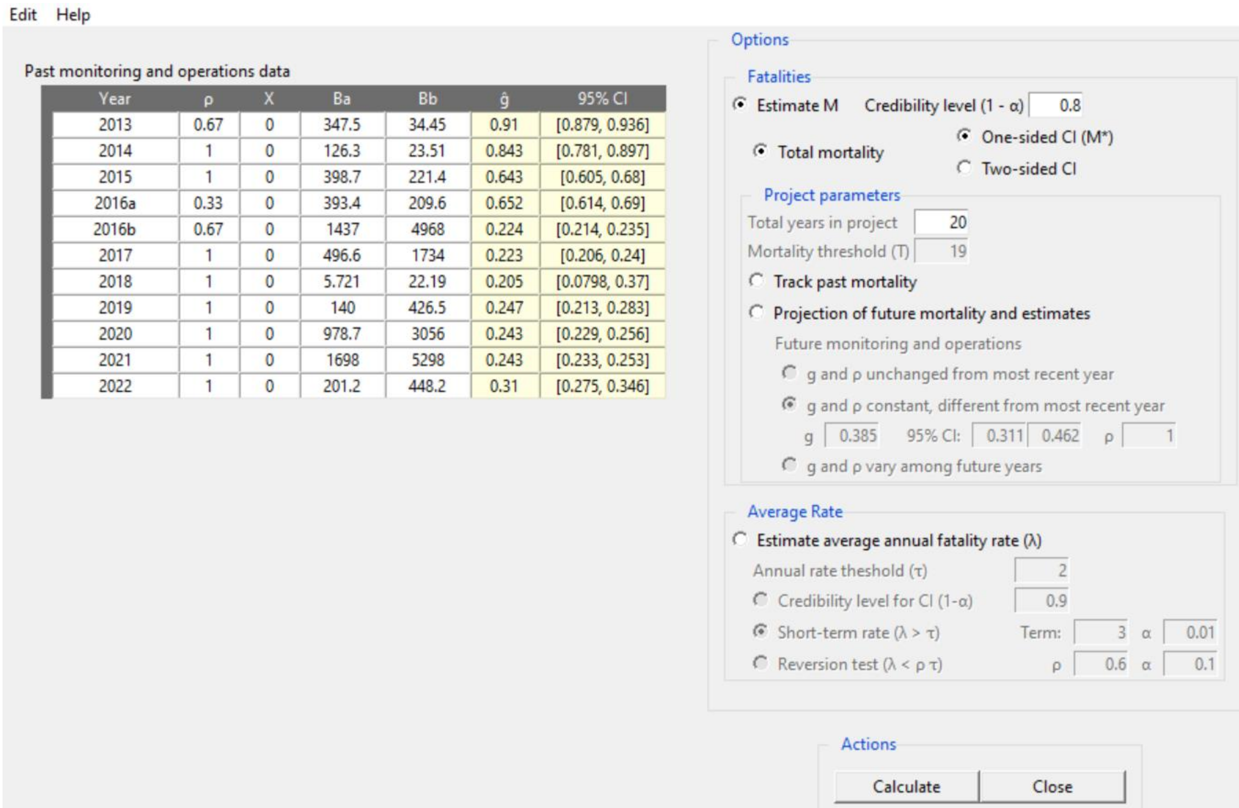
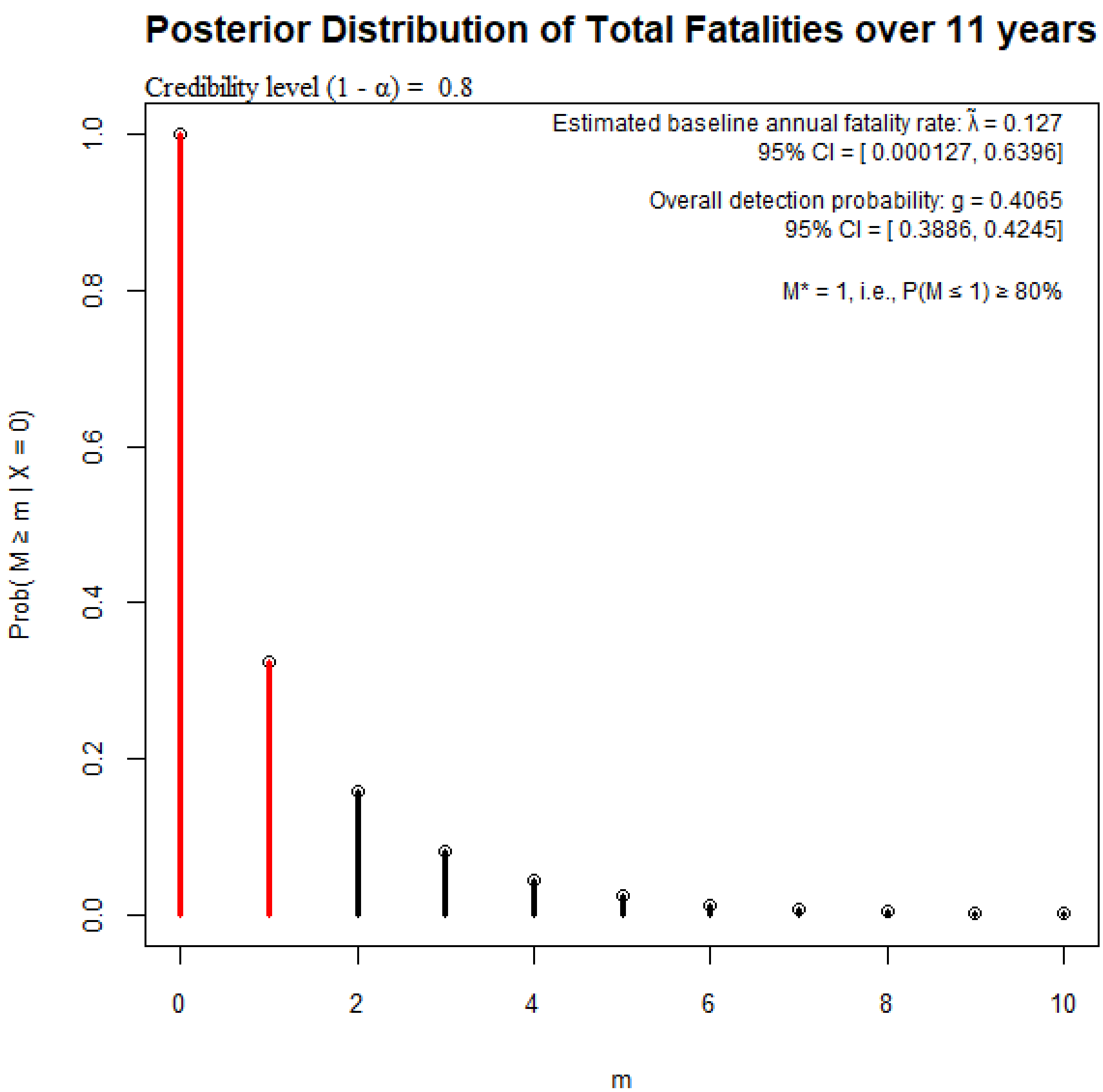
Figure 1. Dalthorp et al. (2017) Fatality Estimation for Hawaiian Petrels at Project through FY 2022.[8]



[8] Rho represents the portion of a year represented for each line of data. FY 2013 represents a partial year (November 2012 – June 2013) because the Project began operations in November. In FY 2016 the search strategy was changed, so the analysis period is broken into two components. All remaining years represent a full fiscal year.

Figure 2. Posterior Distribution: Dalthorp et al. (2017) Fatality Estimation for Hawaiian Petrels at Project for FY 2022.



Appendix 5.
2021 ‘Uko‘a Wetland Insect Assessment Methods

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KAWAILOA WIND

‘UKO‘A WETLAND INSECT ASSESSMENT METHODS (2021)

Revised April 17, 2021

Introduction

The ‘Uko‘a Wetland Hawaiian Hoary Bat Mitigation Management Plan (dated August 2014) states that the purpose of the Kawailoa Wind insect assessment is to measure changes in availability of bat prey at ‘Uko‘a Wetland through insect sampling (H.T. Harvey and SWCA 2014). It lists “relative increases in numbers of available insect prey” as a measure of success for mitigation activities. In 2014 and 2015, First Wind biologists sampled insects at 10 traps throughout ‘Uko‘a Wetland. During several Endangered Species Recovery Committee (ESRC) meetings, committee members have requested Kawailoa Wind conduct a follow-up insect assessment to compare bat prey availability prior to and after management activities at ‘Uko‘a Wetland. However, it is important to note that although the management activities conducted at ‘Uko‘a Wetland (e.g., clearing vegetation over open water, creating foraging lanes through forested areas) have the potential to change insect populations, it is not possible to attribute any observed changes to the management activities given unrelated annual variability in insect populations.

The purpose of the 2021 insect sampling is to evaluate current Hawaiian hoary bat prey availability at ‘Uko‘a Wetland and compare the results to insect sampling conducted in 2014 and 2015. In 2021, prey availability will be measured by sampling insects using methods similar to those used in the assessments conducted by First Wind biologists in 2014 and 2015. However, minor modifications to the methodology are being proposed because of 1) alterations in wetland management activities that were conducted and 2) input from entomologists and Hawaiian hoary bat experts. This will be the final insect sampling Kawailoa Wind will conduct at ‘Uko‘a Wetland and fulfills the follow-up monitoring requirement identified in the HCP.

Field & Laboratory Methods

Between June and September 2021, a total of 9 traps will be distributed throughout ‘Uko‘a Wetland. Trap locations are shown in Figure 1 and summarized in Table 1. Traps will be deployed in the same general locations as the trap locations used during the 2014 and 2015 surveys. The second aquatic emergent trap (WaterHwy) will be removed from the 2021 survey because this site is now dry.

Table 1. Trap types and locations.

Trap ID	Trap Type	# of Bottles	Habitat	UTM's NAD 83	
Up10	Townes-style Malaise trap	1	Ground upland	593881	2389359
WetIn	Townes-style Malaise trap	1	Ground wetland	593779	2389354
WetOut	Townes-style Malaise trap	1	Ground wetland	593722	2389327
UpDOT	Townes-style Malaise trap	1	Ground upland	593375	2388716
WaterKayak	Aquatic emergence trap	1	Open water	594065	2389590
Light 9	Universal black light trap	-	Ground upland	593872	2389230
Light 12	Universal black light trap	-	Ground upland	593792	2389577
Air12	Air intercept trap	2	Air upland	593692	2389530
AirDOT	Air intercept trap	2	Air upland	593321	2388666

All traps will be set out from sunset to sunrise for 3 to 5 consecutive nights each month (similar to 2014 and 2015). During the 2014/2015 survey sampling events varied from 3 to 5 consecutive nights across all traps types due to weather events, trap malfunction, and abundance of insects collected. Notably, the protocol was altered in June 2015 to sample for 3 consecutive nights (rather than 5 nights) at both universal black light traps to reduce the sorting and identification effort involved with large samples collected. To compare 2021 results to the previous years, the same number of sampling nights will be conducted per month at the various traps (see Table 2). Each sample will be collected daily within one hour of sunrise. Sampling will be conducted during dry weather as much as possible and will be timed around the new moon of each month.

Table 2. Trap types and sampling events per month.

Trap ID	Trap Type	June	July	August	September	Total No. Sampling Nights
Up10	Townes-style Malaise trap	5	5	5	5	20
WetIn	Townes-style Malaise trap	5	5	5	5	20
WetOut	Townes-style Malaise trap	5	5	5	5	20
UpDOT	Townes-style Malaise trap	5	5	5	5	20
WaterKayak	Aquatic emergent trap	5	5	5	5	20
Light 9	Universal black light trap	3	3	3	3	12
Light 12	Universal black light trap	3	3	3	3	12
Air12	Air intercept trap	5	5	5	5	20
AirDOT	Air intercept trap	5	5	5	5	20

In 2014 and 2015, samples of day flying mosquitoes were collected at all traps except for light traps. Day samples will not be collected during the 2021 survey because mosquitofish removal was omitted from the management activities at ‘Uko‘a Wetland with agency approval. However, day sample of mosquitoes will be collected at the 1 emergent trap that will be run for 24 hours per sample, but will not be distinguishable from mosquitoes collected at night.

Townes-style Malaise traps

Four Townes-style lightweight Malaise traps (Bioquip Products Inc., Compton, California, United States) will be deployed to collect low flying insects. Two malaise traps will be deployed in the uplands (Up10 and UpDOT) and two malaise traps will be deployed in the interior of the wetland (WetIn and WetOut) similar to 2014/2015 (Figures 2-4). These tent-like mesh traps intercept insects that fly close to the ground and trap a wide variety of insects, particularly Lepidopterans (moths) and Dipterans (flies). The collecting bottles for the malaise traps will be furnished with enough denatured alcohol to last the sampling period. Denatured alcohol will act as both the killing agent and the preservative.

Universal black light traps

Two universal black light funnel traps equipped with a 12 watt U-shaped black light (Bioquip Products Inc., Compton, California, United States) will be deployed in the uplands (Light9 and Light12; Figures 5-6). Light traps utilize ultraviolet light to attract night-flying insects and are particularly effective at collecting Lepidopterans and Coleopterans. Universal black light traps will be placed a minimum distance of 80 meters from all bat detector microphones to avoid attracting insects, and therefore bats, to the detector sampling area. The black light traps will be run off one 12-volt battery which will be connected to solar panels for recharging during the day. Ammonium carbonate will be used as a killing agent. Nightly samples will be collected in 5-gallon elastic-top paint strainers or similar mesh bags, tied, labeled, and placed in the freezer for preservation. Black light traps will be brought in from the field between samples to reduce likelihood of theft.

Air intercept traps

Two land and air intercept traps with Malaise trap bottom collectors (Bioquip Products Inc., Compton, California, United States) will be suspended from a tree branch or pole in the uplands (Air12 and AirDOT) approximately 4 meters above ground level (measured from the top of the trap) (Figure 7). These traps are designed to collect higher flying insects, particularly Coleoptera, which will drop into collection tubes upon hitting the trap. Each suspended trap has a collection bottle at the top and a second collection bottle at the bottom. Bottom collection bottles will be modified to allow water, but not captured insects, to escape during rain events. The collecting bottles for the air intercept traps will each be furnished with enough denatured alcohol to last the sampling period. Denatured alcohol will act as both the killing agent and the preservative.

Aquatic emergence trap

One Aquatic Emergence Trap (Bioquip Products Inc., Compton, California, United States) will be deployed in the open water area (see Figures 1 and 8) to capture aquatic emergent insects. This trap will run 24 hours per day, and the windows on the Emergence Trap will be left open between samples so captured insects could escape. The other sampling location of the second emergence trap used in 2014/2015 (WaterHwy) will not be used in this current assessment because this location was often dry during the 2014/2015 surveys resulting in inconsistent and minimal sampling.

Sorting and Identification

At the completion of each sampling period, all samples will be transferred to mason jars or whirl packs, labeled, frozen or dried (as appropriate) and delivered to entomologist Dr. Paul Krushelnycky for sorting and identification. All insects between 3 and 25 millimeters in length, which represent the size class of typical prey items consumed by Hawaiian Hoary bats (Jacobs, 1999; Todd, 2012; Pinzari et al. 2019), will be identified to the greatest taxonomic precision practical (generally Order and Family) and counted.

Reporting

After all samples are collected, a report will be drafted to include a list of insect taxa collected in 2014, 2015, and 2021. This report will include a size range of each taxa collected and a discussion on the relative abundance of insects sampled in previous years compared to samples collected in 2021.

Literature Cited

Gorresen, P.M., K.W. Brinck, M.A. DeLisle, K. Montoya-Aiona, C.A. Pinzari, and F.J. Bonaccorso. 2018. Multi-state occupancy models of foraging habitat use by the Hawaiian hoary bat (*Lasiurus cinereus semotus*). PLoS ONE 13(10): e0205150. https://doi.org/10.1371/journal.pone.0205150.

H.T. Harvey and SWCA (H. T. Harvey and Associates and SWCA Environmental Consultants). 2014. ‘Uko‘a Wetland Hawaiian Hoary Bat Mitigation Management Plan. Prepared for First Wind. Approved by USFWS and DOFAW 2014.

Jacobs, D.S. 1999. The diet of the insectivorous Hawaiian hoary bat (*Lasiurus cinereus semotus*) in an open and a cluttered habitat. *Canadian Journal of Zoology*, *77*(10), 1603–1608. https://doi.org/10.1139/z99-110.

Todd, C.M. 2012. Effects of prey abundance on seasonal movements of the Hawaiian hoary bat *(Lasiurus cinereus semotus)*. University of Hawai’i at Hilo.

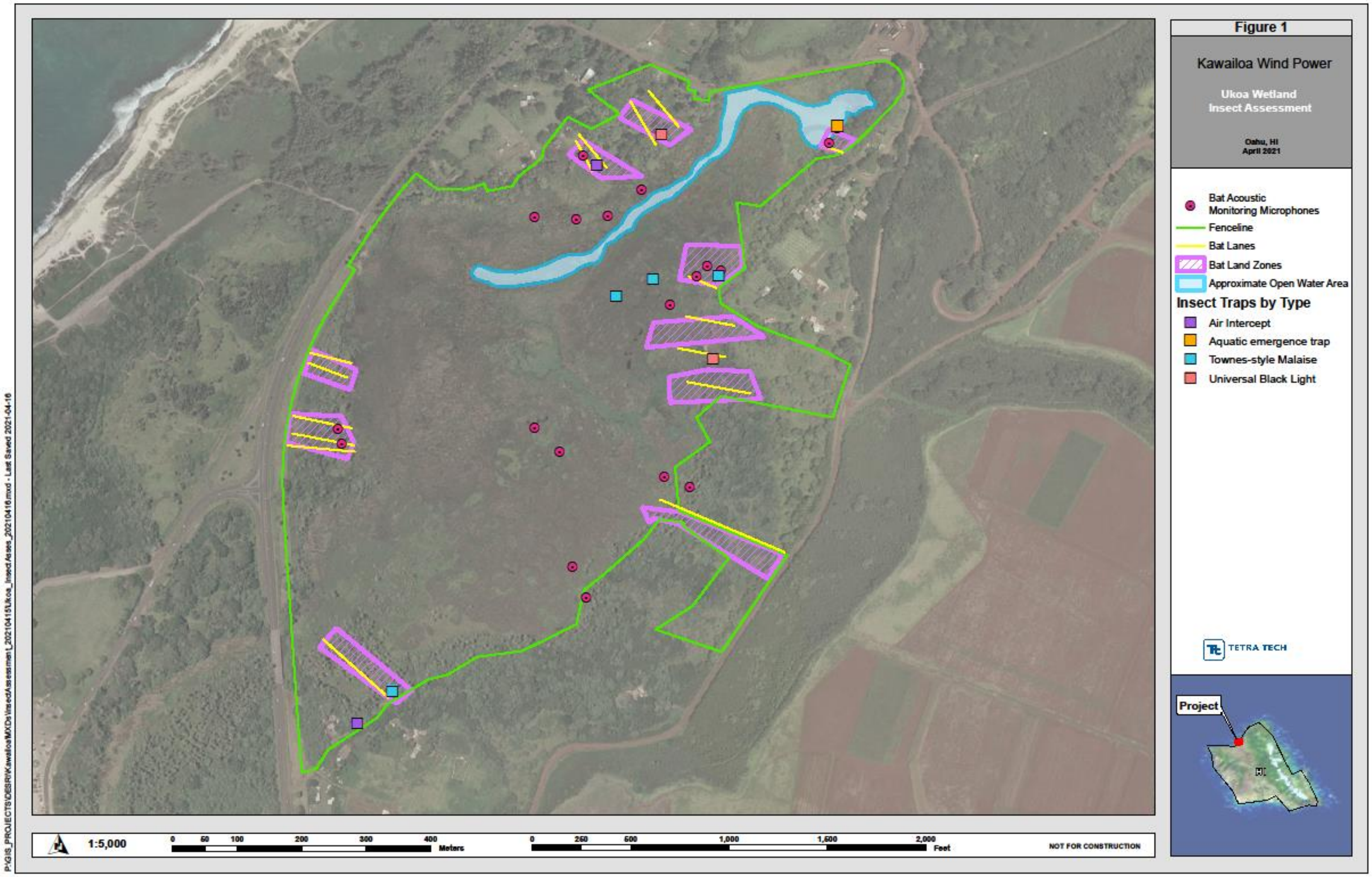

Figure 1. Insect trap locations for the 2021 ‘Uko‘a Wetland Insect Assessment.

Figure 2. WetOut, a Townes-style Malaise trap deployed in the ‘Uko‘a Wetland interior during the 2014/2015 surveys.

Figure 3. WetIn, a Townes-style Malaise trap deployed in the ‘Uko‘a Wetland interior during the 2014/2015 surveys.

Figure 4. UpDOT, a Townes-style Malaise trap deployed in the uplands at the south tip of ʻUkoʻa Wetland during the 2014/2015 surveys.

Figure 5. Light12, a universal black light trap deployed in the uplands in the northwestern region of the wetland during the 2014/2015 surveys.

Figure 6. Light9, a universal black light trap deployed in the uplands of the eastern region of ʻUkoʻa Wetland during the 2014/2015 surveys.

Figure 7. AirDOT, an air intercept trap suspended from a kiawe tree branch along the fence line at the south tip of ʻUkoʻa Wetland during the 2014/2015 surveys.

Figure 8. WaterKayak, an Aquatic Emergence Trap, that floated on open water in the northeastern corner of ʻUkoʻa Wetland during the 2014/2015 surveys.

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Appendix 6.
Oahu Hawaiian Hoary Bat Occupancy and Distribution Study Project Final Report (Thompson and Starcevich 2022)

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Oahu Hawaiian Hoary Bat

Occupancy and Distribution Study

Final Report

Prepared for:

Hawaii Endangered Species Research Committee

Prepared by:

Joel Thompson and Leigh Ann Starcevich

Western EcoSystems Technology, Inc.
2725 Northwest Walnut Boulevard
Corvallis, Oregon 97330

July 18, 2022

WEST

EXECUTIVE SUMMARY

In response to a request for proposals issued by Hawaii's Endangered Species Recovery Committee (ESRC) in 2016, Western EcoSystems Technology, Inc. (WEST) developed a five-year study proposal to assess Hawaiian hoary bat (HAHOBA) distribution and occupancy across the island of Oahu. The study was developed to allow for island-wide inference and used an equiprobable generalized random tessellation stratified sample of grid cells for the placement of acoustic bat detectors across Oahu.

Field data collection spanned a roughly four-year period, beginning in late spring 2017 and concluding in early fall 2021. Wildlife Acoustics Song Meter SM4Bat (SM4) full spectrum bat detectors were deployed for all data collection conducted by WEST. Acoustic detectors were deployed within selected grid cells with microphones placed approximately 10 feet (three meters) above ground. Detectors were left in the field year round at the location of original placement and programmed to record data from approximately one hour prior to sunset to approximately one hour after sunrise. Detectors were visited on a regular basis to download data and assess functionality. Acoustic recordings were processed with the Kaleidoscope Pro 5 software package (Wildlife Acoustics) to remove noise (i.e., non-bat) files and convert the full-spectrum call files to zero-cross files. A bat biologist with training and experience in acoustic bat call analysis then reviewed all call files identified as bats to ensure they contained a minimum of two distinct pulses and to confirm the recording was consistent with that of a HAHOBA.

Acoustic detection data were examined using a dynamic occupancy analysis for correlated detections to obtain estimates of occupancy and detection rates. Occupancy and detection rates of HAHOBA on Oahu were modeled from nightly detector data. Multi-season dynamic occupancy models, which account for site-level extinction (the probability an occupied site will be unoccupied the next season) and local colonization (the probability an unoccupied site will be occupied the next season), were implemented to model trends in occupancy rates over time. Site-level covariates representing human population density, elevation, the percentage of trees, forest height, and land cover type in each grid cell were examined as predictors of occupancy.

Trends in occupancy were estimated in two ways: the mean annual proportional trend was calculated as the mean of the set of one-year proportional changes, and the net trend was calculated as the difference in occupancy in the first and last years divided by the first year occupancy estimate. The proportion of operating detectors with detections and 5-day moving averages of the daily proportions of detectors with detections were used to further examine the movement of bats over the course of the year.

The final dataset included data from 88 detectors, of which 86 of which were located in randomly selected cells and used in the occupancy analyses. The dataset spanned the period June 8, 2017, through the night of October 31, 2021 (the Study Period). At least one bat detection (i.e., bat call) was recorded during the Study Period at 84 (95%) of the 88 detectors monitored. The number of detector nights sampled by site during the Study Period ranged from 106 to 1,537 and 30,469

HAHOBA detections were recorded. The number of site-level detections ranged from zero to 6,083 during the Study Period. The mean number of site-level detections per detector night ranged from zero to 5.40 and the proportion of detector nights with detections ranged from zero to 0.45 during the Study Period. Detections were more widespread across Oahu during the post-lactation season relative to the other seasons.

The final model for the lactation season described occupancy as positively associated with the mean grid cell elevation and negatively associated with the indicator of any wet forest/grassland/shrub land cover in the cell. Estimated occupancy rates during the lactation season increased slightly during the Study Period, from 0.61 to 0.65. The final model for the post-lactation season contained no site-level covariates as predictors of site occupancy. Estimated occupancy rates during the post-lactation season increased slightly during the Study Period, from 0.75 to 0.81. The final model for the pre-pregnancy season contained a positive effect of mean grid cell elevation and a negative effect of the proportion of wet forest/grassland/shrub land cover. Estimated occupancy rates during the pre-pregnancy season increased during the Study Period, from 0.40 to 0.50. While occupancy estimates showed slight increases during the lactation, post-lactation, and pre-pregnancy seasons, the trend estimates during these seasons were not substantially different from zero. The final model for the pregnancy season contained a positive effect for elevation and negative effects for proportion of wet forest/grassland/shrub land cover and human population density within each grid cell. Estimated occupancy rates during the pregnancy season increased during the Study Period, from 0.31 to 0.46 and the trend estimates were substantially different from zero.

Occupancy rates varied by season, with the highest occupancy estimates observed in the lactation and post-lactation seasons and the lowest occupancy rates observed during the pre-pregnancy and pregnancy seasons. Bat occurrence (as indicated by the proportion of detectors with detections) expanded spatially over the pregnancy and lactation seasons, peaked near the beginning of the post-lactation season, and then contracted through the remainder of the post-lactation season to its most spatially restricted period during the pre-pregnancy. Occupancy rates exhibited slight but significant increasing trends in both mean and net proportional trends during the pregnancy season. Occupancy estimates during the other seasons had slight upward trajectories over the Study Period, but trends were not significant. Given the consistency in results across seasons and years, the HAHOBA occupancy rate for Oahu appeared stable to slightly increasing over the Study Period.

No habitat covariates were identified as significant predictors of site occupancy during the post-lactation season when the HAHOBA population appeared most dispersed across Oahu and occupancy rates were highest. The broader distribution and increased occupancy rates during this period could be indicative of a broader distribution of adult bats across the island or the dispersal of young-of-the-year bats recently added to the population or versus. Effects of elevation were positive and of similar magnitude for the three seasons incorporating site-level covariates in the occupancy model (lactation, pre-pregnancy, and pregnancy). The proportion of wet forest/grassland/shrub land cover was negatively associated with occupancy during these three seasons, with the negative effect increasingly pronounced in the pre-pregnancy and pregnancy seasons. Mean monthly Oahu precipitation measured at weather stations between 1920 and 2012 ranged from 5.4 to 6.7 in (13.7 to 17.0 cm) per month from November through April, and from 3.1 to 4.6 in (7.9 to 11.7 cm) per month from May through October, defining distinct wet (November through April) and dry (May through October) periods on Oahu. Predicted HAHOBA occupancy across Oahu suggests that the drier mid-elevations are more consistently occupied throughout the year, while the leeward and more arid areas of the island are preferred during the rainy period, occurring principally during the pre-pregnancy season. Therefore, the HAHOBA distribution is most contracted during the wet period, when dry or mesic habitats appear to be preferred over wet habitats.

A power analysis was conducted to assess the sample size of detectors needed to detect 10% or 15% annual trends in lactation-season occupancy rates over a 10-year period. This prospective power analysis indicates that changes in occupancy over a 10-year period could be detected with reasonable power with a sample of 20–30 detectors. If a monitoring program were to be implemented over a longer term, we would suggest that the smaller samples would provide the best basis for inference if spatial balance and the probabilistic selection process used in this study were maintained so that the sampled population matches the target population as closely as possible. A fifth year of field data are being collected for a subsample of 40 of the 88 detectors reported on herein, which will be used to complete an updated analysis of trends in occupancy over a 5-year period.

STUDY PARTICIPANTS

Joel Thompson	Project Manager / Senior Biologist
Leigh Ann Starcevich	Senior Statistician
Erica Adamczyk	Field Biologist / Acoustic Analyst
David Young	Senior Reviewer
Mysti Martin	GIS Technician
Jeanette Haddock	Technical Editor
Kristina Hammond-Rendon	Bat Biologist / Acoustic Reviewer

ACKNOWLEDGEMENTS

The authors would like to acknowledge Kawailoa Wind LLC for funding this multi-year study and the Hawaii Endangered Species Research Committee (ESRC) and ESRC Bat Subcommittee for their ongoing support of this Project throughout its duration. Inputs from the Bat Subcommittee members prior to, during, and post study have been especially helpful and greatly appreciated. We offer special thanks to Marcos Gorresen and Corrina Pinzari of the Hawaii Cooperative Studies Unit and James Jacobi of the USGS for their collaborative nature and willingness to discuss anything from sample locations to statistical analyses at various times along the way. We are grateful to all the agencies and private entities who provided access to sample locations across the island. While too many to mention, many private businesses and/or landowners graciously provided safe locations and unimpeded access to detectors, without which the randomized nature of the study could have been substantially compromised. In addition to the private entities, DLRN-DOFAW, the City & County of Honolulu, Hawaii State Parks, Hawaiian Electric, Department of Defense, and USFWS all provided access to multiple sites each and courteously facilitated access as needed, providing the bulk of survey locations across the island. Special thanks goes out to Matthew Burt of the Army Natural Resource Center, who not only aided in access to US Army sites, but also proved extremely helpful with locating non-DOD access sites. Mitch Craig, Adam Young, Jenny Taylor, and Jacob Dutton also deserve special thanks for their assistance with site access and data sharing for detectors already deployed within our sample cells. Beyond these collaborators, the authors especially thank Erica Adamczyk for her positive mindset and tireless efforts hiking the hills of Oahu to deploy, troubleshoot, and collect data from the 80+ acoustic detectors, as well as her efforts to organize and analyze the copious amounts of data they produced. It is due to the collaborative nature of all those involved that this island-wide study was a success, especially during the trying times of the COVID-19 pandemic, which impacted so many during the span of this study. THANK YOU to all involved.

REPORT REFERENCE

Thompson, J. and L. A. Starcevich. 2022. Oahu Hawaiian Hoary Bat. Occupancy and Distribution Study. Final Report. Prepared for Hawaii Endangered Species Research Committee. Prepared by Western EcoSystems Technology, Inc. Corvallis, Oregon. July 18, 2022

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

In response to a request for proposals issued in 2016 by Hawaii's Endangered Species Recovery Committee (ESRC), Western EcoSystems Technology, Inc. (WEST) developed a 5-year study proposal to investigate the distribution and seasonal occupancy of Hawaiian hoary bat (HAHOBA; *Lasiurus cinereus semotus*) on the island of Oahu. The proposal was discussed during two meetings with the ESRC Bat subcommittee in January and February 2017, leading to a finalized study plan that focused on HAHOBA distribution and occupancy across the island of Oahu, in its entirety. The initial objectives of the study were to 1) provide information on bat occupancy, distribution, and detection probabilities for the island of Oahu, 2) examine seasonal changes in distribution by estimating seasonal changes in occupancy, and 3) collect data that could be used to assess HAHOBA habitat use relationships. The initial objectives were maintained throughout the study, with no substantial deviations to study design or data collection occurring over the four years of field studies.

Field data collection spanned a roughly 4-year period, beginning in late spring 2017 and concluding in early fall 2021. This final report is based on an updated analysis of the cumulative dataset spanning June 2017 to October 2021 (the Study Period). In this report, we describe the sampling design and methods used to collect and analyze the data and summarize the results and occupancy analysis through the fourth year of field studies. The report concludes with recommendations for concluding the study and future analysis, as well as thoughts on ways to continue the study in a meaningful, refined, and cost-effective manner.

This report represents the final analysis of data collected under the contractual obligations resulting from the 2016 ESRC request for proposals. As such, the data and analysis results presented herein supersede those presented in prior interim reports (e.g., Starcevich et al. 2019, 2020; Thompson and Starcevich 2021) and should be considered final as they relate to the full study conducted under obligation to the ESRC. However, an extension of the study was funded by several entities in early 2022 to collect additional data from a subset of sample locations, which will be incorporated into an updated analysis and report focused on annual trends in bat occupancy over a 5-year period.

METHODS

Sampling Design

The study design was developed to allow for island-wide inference. A sampling frame of 787 grid cells was developed in a geographic information system by overlaying a grid of 0.8-square mile (2.3-square kilometer) cells across the island of Oahu. To allow for island-wide inference, no areas on Oahu were omitted from the sampling frame except for small nearshore islands. From the grid of 787 cells, an equiprobable generalized random tessellation stratified sample (Stevens and Olsen 2003, 2004) of 100 grid cells was selected for the placement of acoustic bat detectors (Figure 1). An oversample of 150 grid cells was selected to provide an extra set of spatially balanced sites to use if cells within the main sample could not be surveyed for some reason (e.g., inaccessibility due to safety issues, landowner denial of access).

Field Data Collection

Wildlife Acoustics Song Meter SM4Bat (SM4) full spectrum bat detectors fitted with model SMM-U1 (U1) ultrasonic microphones (Wildlife Acoustics, Inc., Concord, Massachusetts) were initially deployed for all data collection conducted by WEST. However, the U1 microphones began to malfunction in significant numbers in spring 2019. Based on the recommendations of the manufacturer, the U1 microphones were replaced with Wildlife Acoustics' newer SMM-U2 (U2) ultrasonic microphones. New U2 microphones were deployed throughout the summer and fall of 2019. The microphone type was recorded for each detector so that microphone effects could be examined as a covariate in detection probability models. Data collected by cooperating entities (e.g., Kuhuku Wind Project) and included in our analyses was collected using older Wildlife Acoustics full spectrum bat detectors (e.g., SM3Bat) outfitted with U1 microphones.

The SM4 detectors are small, measuring roughly eight inches (in) tall by five in wide by three in deep (20 centimeters [cm] tall by 13 cm wide by eight cm deep) and are fully self-contained (Figure 2). Some of the detectors located in easily accessible areas with relatively high risk of theft or vandalism were operated on internal batteries to minimize their detectability and potential vandalism or theft, while most detectors utilized a small external battery and accompanying solar panel as a power source (Figure 2).

Detectors were attached to existing structures (e.g., fence posts, light poles) or newly installed t-posts, via attachment of a 10-foot (ft; 3-meter [m]) length of 0.75 in (1.9 cm) diameter metal conduit used to extend the microphone approximately 10 ft above ground (Figure 2). In some cases, the 10-ft pole was supported by small guy wires. The detector, and external battery and solar panels (when used), were mounted low on the pole with the microphone mounted at the top of the pole (Figure 2). In some developed areas, units were contained in a small toolbox and placed on top of an appropriately sized outbuilding (approximately 10 ft above ground).

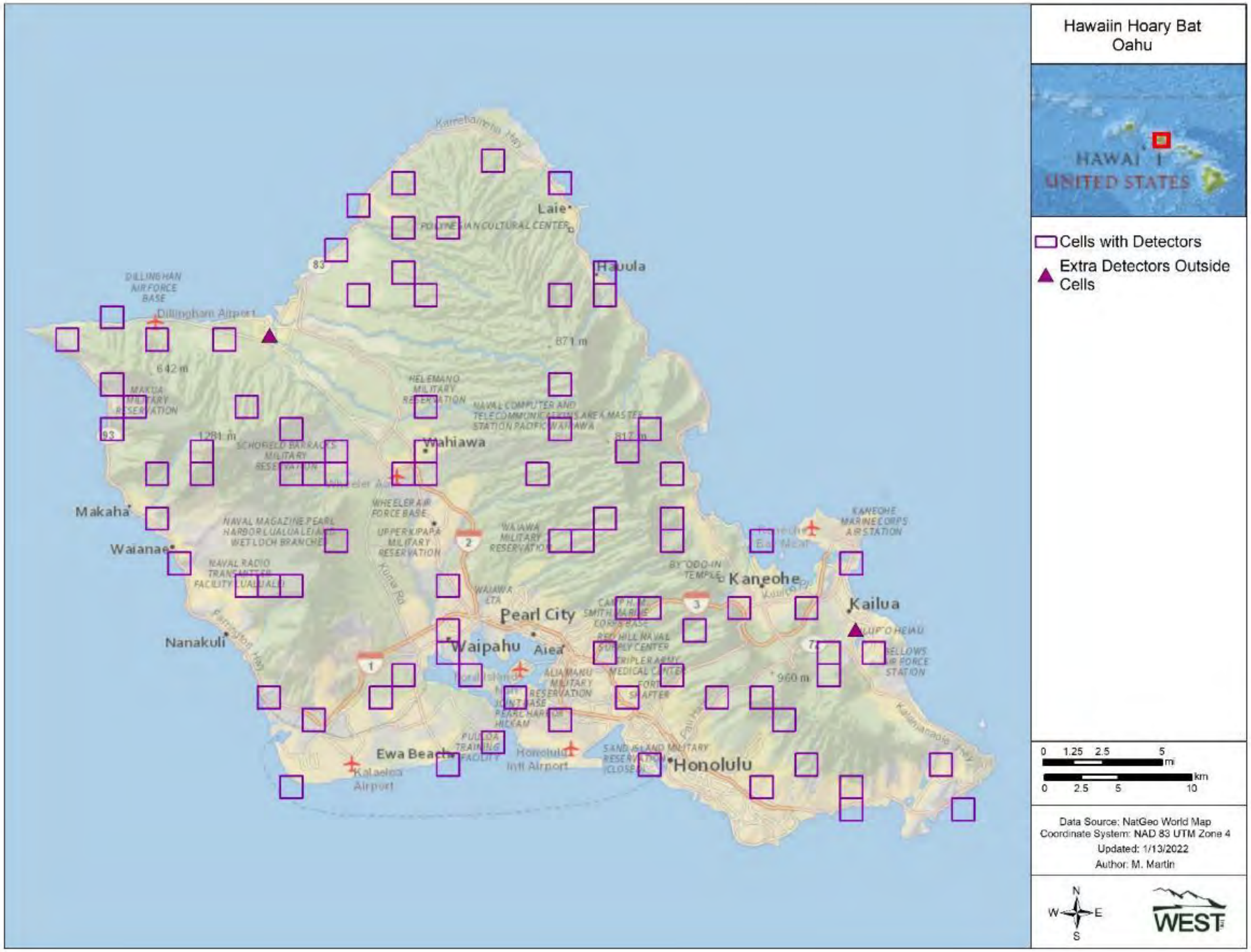


Figure 1. Equiprobable generalized random tessellation stratified sample of 100 grid cells used for initial study design of the island-wide occupancy study of Hawaiian hoary bats on Oahu.

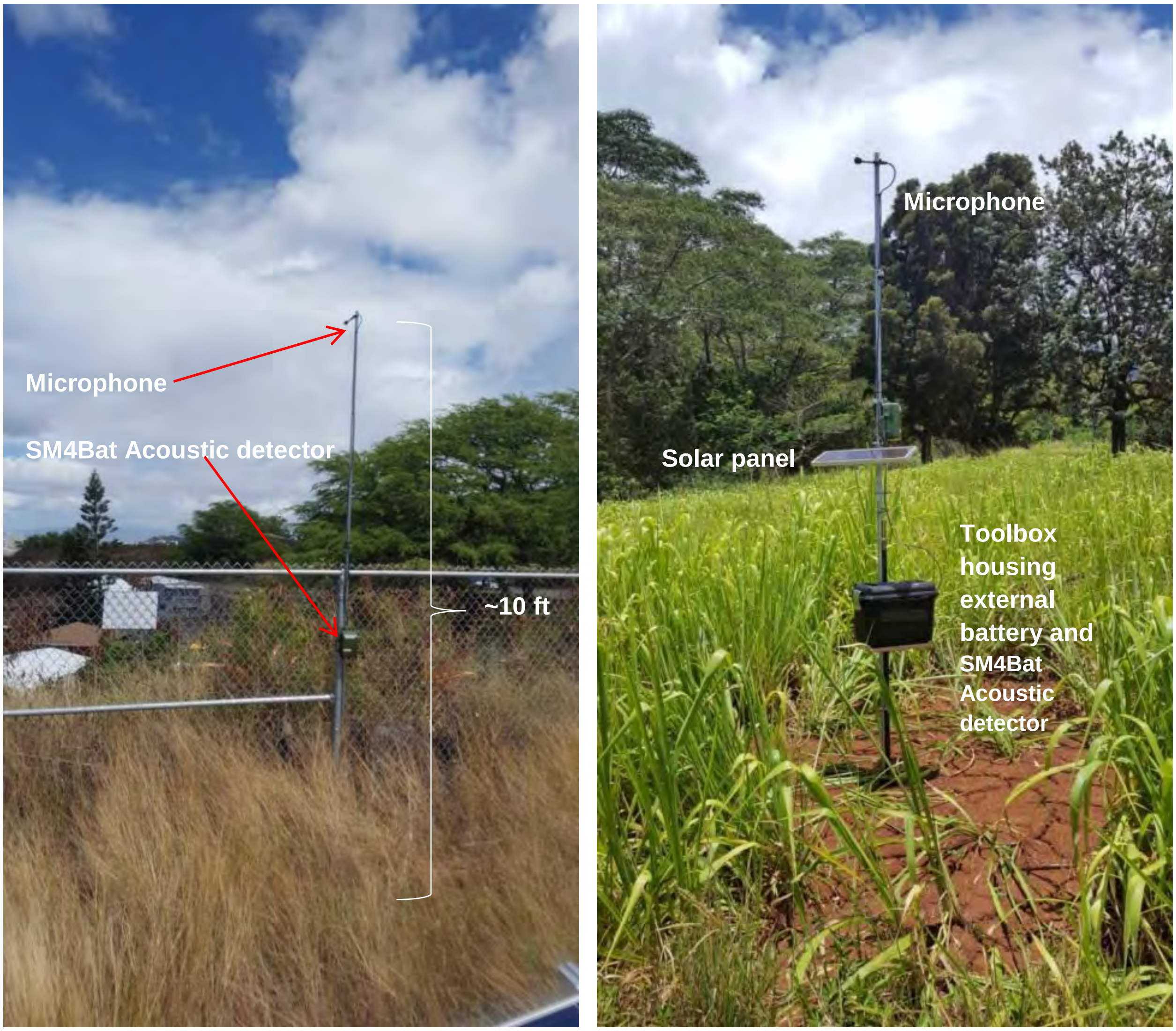


Figure 2. Examples of commonly used set-ups of the Wildlife Acoustics SM4Bat detectors used in the Hawaiian hoary bat Occupancy and Distribution Study on Oahu.

Acoustic detectors remained in the field year round at the location of original placement. Detectors were programmed to operate nightly, from approximately one hour prior to sunset to approximately one hour after sunrise. Within the SM4 Detector Configurator, the following settings were selected: detector sample rate of 192 kilohertz (kHz); gain of 12 decibels (dB); minimum signal duration of 1.5 milliseconds; maximum signal duration off; minimum trigger frequency of 10 kHz; trigger level of 12 dB; and trigger window of three seconds. Detectors were visited regularly to swap data cards and inspect the units for proper function. Detectors were checked once seven to 14 days after initial deployment to ensure proper function and data collection, followed by less frequent checks. At sites with external power sources, detectors were checked every one to two months, while remote sites requiring helicopter access sometimes extended more than two months between checks. At sites where the detectors were powered by internal batteries, units were checked more frequently (e.g., every 10 to 14 days on average). However, throughout much of 2020 and 2021, status checks were more sporadic due to the COVID-19 pandemic and resulting restrictions on access to parks, trails, helicopter use, and travel in general.

Call Analysis

To expedite call analysis, acoustic recordings were processed with the Kaleidoscope Pro 5 software package (Wildlife Acoustics 2019) to remove noise (i.e., non-bat) files and convert the full-spectrum call files to zero-cross files. For all files classified as containing a bat echolocation call, a bat biologist with training and experience in acoustic bat call analysis manually reviewed the zero-cross call files in program Analook (Titley Scientific) to ensure calls contained a minimum of two distinct pulses, and to confirm the recording was consistent with that of a HAHOBA. Manual review of all recorded bat calls by a bat biologist helped minimize the potential for false positives to be included in the final dataset. Social calls and feeding buzzes were noted during the manual review process for later assessment of behavioral activity at sites. A subset of noise files was also examined to ensure detectors were functioning properly when several consecutive nights without recordings occurred.

Occupancy Modeling

Acoustic detection data were examined using a dynamic occupancy analysis for correlated detections to obtain estimates of occupancy and detection rates. In the dynamic occupancy model for correlated detections, the detection probability is modeled conditional on both site occupancy and species availability. Occupancy and detection rates of HAHOBA on Oahu were modeled from nightly detector data, with the modeling approach informed by previous analyses (Starcevich et al. 2019, 2020; Thompson and Starcevich 2021). Multi-season dynamic occupancy models (MacKenzie et al. 2006), which account for site-level extinction (the probability an occupied site will be unoccupied the next season) and local colonization (the probability an unoccupied site will be occupied the next season), were implemented to model trends in occupancy rates. For comparability, reproductive seasons were defined consistent with those used by Gorresen et al. (2013, as adapted from Menard 2001) and used to define seasons within which closure was assumed. The reproductive seasons were defined as lactation (mid-June to August), post-lactation (September to mid-December), pre-pregnancy (mid-December to March), and pregnancy (April to mid-June). While these seasons were generally aligned with the reproductive cycle of HAHOBA, their purpose in this analysis was to define discrete seasons for analysis, not to suggest that the reproductive cycle of all HAHOBA are strictly aligned with these periods.

The multi-season dynamic occupancy model (MacKenzie et al. 2006) yields estimates of rates of occupancy (Ψ), detection (p), local extinction (ε), and local colonization (γ). The models we examined assumed closure within each reproductive season and modeled the local colonization and extinction rates as equal across all years. To relax the assumption of independent detections, the correlated detection model (Hines et al. 2014) was applied to account for the rate of local presence, the probability in which a species may temporarily emigrate from an occupied site and be unavailable for detection. Local presence was modeled conditionally on site occupancy and whether the species was locally present during the previous time period (θ_1) or not locally available at the previous time period (θ_0). The probability of detection (p) was modeled conditionally on local presence for the current and previous sampling occasion.

Previous analyses (Starcevich et al. 2019, 2020) applied the join count chi-square test (Wright et al. 2016) to evaluate the independence of nightly detection data within each reproductive season and year. The join count test compares the number of detections in consecutive time periods (temporal "joins") to an expected number based on the assumption of independence. Temporal correlation among detections violates the assumption of independent detections required for standard occupancy modeling. Failure to account for temporal correlation may result in variance underestimation, leading to narrow confidence intervals and inappropriately small p-values that indicate a significant effect when none exists. When temporal correlation is present, detection occasions may be separated in time to avoid temporal correlation (Wright et al. 2016). Previous analyses applied the join count test to data sets obtained from systematic random samples of detector nights taken by site at various intervals to determine the appropriate temporal spacing of detector nights. However, a small simulation of 25 iterations indicated that the correlated detection model adequately accounted for temporal correlation based on observed 95%-credible interval (CRI) coverage of 96% for Ψ and θ_0, 100% CRI coverage for θ_1 and *p*, and 92% CRI coverage for ε and γ. The slight under coverage for the dynamic occupancy parameters was considered negligible, and the full data set of consecutive nights was used for occupancy modeling.

All modeling was conducted in R (R Development Core Team 2021). The dynamic occupancy model for correlated detections (Hines et al. 2014) was applied in a Bayesian context with the *rjags* package (Plummer 2019). Modeling was conducted independently by reproductive season to estimate occupancy model parameters and the effects of site-level covariates for each season. We assumed uniform (0, 1) priors for all unknown probability parameters and vague Gaussian priors (Normal [0, 5]) for regression parameters. Three parallel Monte Carlo Markov chains were used, each sampling for 50,000 iterations after burn-in and adaptation phases of 5,000 iterations. Model diagnostics included convergence checks, trace plot review, and posterior predictive checking (Gelman et al. 2013). Site-level covariates (Table 1) representing human population density, elevation, the percentage of trees, forest height, and land cover type in each grid cell were examined as predictors of occupancy. Covariate effects were treated as correlated when more than one covariate was included in the model. Microphone type was used as a covariate for the detection probability model to account for any differences in detection rates potentially resulting from use of different microphone models (U1 or U2).

Model selection was conducted with the spike and slab approach (Mitchell and Beauchamp 1988). Spike and slab modeling is analogous to a LASSO method where all covariates are initially considered and unimportant covariates are assigned regression coefficients near zero. All site-level covariates were included in the model for initial occupancy, and posterior inclusion probabilities measured the importance of each covariate in the occupancy model. Covariates with posterior inclusion probabilities of 0.5 or more were included in the final occupancy model. The final model assumed correlated regression coefficients, but highly correlated covariates were excluded for model parsimony. A reduced model including only the important covariates was used for final inference so that interpretable credible intervals could be obtained.

Table 1. Site-level covariates for occupancy modeling.

Site-level Covariate	Description
PopSqMi	Human population per square mile (mi) in each grid cell
PopSqMiClass	0 if population density <64.60 people per square mi, 1 otherwise
Elev	Mean site elevation in meters (m) in each grid cell
ElevClass	0 if elevation <144.62 m, 1 otherwise
PctTrees	Percent tree cover in grid cell
PctTreesClass	0 if percent tree cover <20.68, 1 otherwise
ForestHt_std	Standard deviation of forest height within grid cell
PropDry	Proportion of dry forest, grassland, or shrubland
PropDryClass	0 if PropDry=0, 1 if PropDry >0
PropMes	Proportion of mesic forest, grassland, or shrubland
PropMesClass	0 if PropMes=0, 1 if PropMes >0
PropWet	Proportion of wet forest, grassland, or shrubland
PropWetClass	0 if PropWet=0, 1 if PropWet >0

Trend was estimated in two ways: the mean annual proportional trend was calculated as the mean of the set of one-year proportional changes, and the net trend was calculated as the difference in occupancy in the first and last years divided by the first year occupancy estimate. The two-sided test for trend in occupancy was assessed by determining if the 95%-CRI for the mean proportional trend contained zero or the net proportional trend contained one, both of which indicate no substantial trend in occupancy. For example, a proportional trend (either the mean annual trend or the net trend over the monitoring period) of 0.08 implies an increase of 8% over the monitoring period, and a proportional trend of -0.08 is interpreted as an 8% decline in occupancy over the monitoring period.

The movement of bats over the course of the year was calculated as the proportion of operating detectors with detections and 5-day moving averages of the daily proportions of detectors with detections. Only nights with at least 20 operational detectors were used for occupancy modeling, which removed roughly the first two weeks of the study, and the data set was truncated to end August 31, 2021.

Power Analysis

The results of the occupancy analysis were used to inform an analysis of the power to detect an annual trend in occupancy over time. The power to detect annual linear trends of 10% and 15% in the occupancy rate over 10 years was assessed for sample sizes of 20, 40, 60, and 80 sites per year. A Monte Carlo simulation generated 500 populations with known occupancy, detection, and correlated detection parameters for the lactation season, and one of two trend levels was applied to each population. The correlated detection dynamic occupancy model (Hines et al. 2014) was applied to each simulated data set. The proportion of times that the 95%-CRI did not contain zero approximated the power of the two-sided test of a non-zero trend.

RESULTS

Detectors were deployed as access to sample sites was obtained, which resulted in a staggered start to data collection across sample sites. The first detectors were deployed in June 2017, with the initial deployment of detectors continuing through May 2018. Given the timing of initial detector deployments, the survey year is defined as beginning in the lactation season and extending through the end of the pregnancy season to reflect the timing of this study. For example, survey year 2017 spans the period June 15, 2017–June 14, 2018. While the initial goal was to deploy 100 detectors across Oahu, we were unable to achieve the goal of 100 detectors in Year 1 using the probabilistic sampling design. Land access was the most common reason for delay in getting units deployed within sequentially selected cells, with lack of suitable sample sites also causing some cells to be excluded from consideration. Land access issues were most often associated with cells mostly owned and/or managed by larger private landowners who would not grant access, or from whom we could not get a response to our request for access. In some cases, otherwise accessible cells lacked safely accessible sample sites or simply lacked a suitable location to mount or locate a detector. As a result of the various access issues, we extended our sample effort to include 19 of the oversample cells.

In total, WEST placed 86 acoustic detectors in the field, with 84 of the 86 located in randomly selected grid cells and two placed opportunistically at sites not within randomly selected cells (Figure 3). One other randomly selected grid cell was located in the Kuhuku Wind Project, which contained two detectors maintained and monitored by Kuhuku Wind Project personnel. One of the two Kuhuku detectors was randomly selected and the data included in our study dataset. In addition, data were incorporated into our final dataset from one detector monitored over a roughly 2-year period by the US Geological Survey (USGS) as a part of a larger study on Marine bases across Oahu (Pinzari et al. 2021), as this detector was located in one of the initial sample cells selected from the generalized random tessellation stratified sample. Due to vandalism and repeated theft, detectors at two locations (Ewa Beach Park and Malekahana State Park) were dropped from the sample relatively early (July 2018 and March 2019, respectively) in the Study Period, after at least two detectors and associated equipment were lost at each location. Of the two detectors not placed in randomly selected cells, one was located at a residence in Waialua and initially used as a test site, and the other was placed at Hamakua Ponds at the request of Department of Forestry and Wildlife staff. Data from these two detectors are reported, but the data were not used in the occupancy analyses. For the final analysis reported on herein, data were used from the 86 detectors located in randomly selected grid cells (84 deployed by WEST, Site-069 maintained by Kuhuku Wind, and Site-042 maintained by USGS).

Because detectors were placed in the field as access permissions were obtained, the temporal distribution of data varied among detectors. As such, seasonal data sets during the first year differ in the number of detectors that contributed data, as well as the number of nights contributed by individual detectors. While raw counts of bat calls are provided, due to the variability in sampling effort (i.e., the amount of time detectors were in the field) during the various years/seasons, the adjusted metrics of call counts/detector night and frequency of occurrence, not raw counts, were (and should be) used when making comparisons across seasons or years. The following sections and appendices provided summary tables and figures presenting both raw counts and adjusted metrics in space and through time. A data visualization tool (*HAHOBA_Study.html*) is available as a supplement to this report, allowing for additional spatial and temporal sorting and display of the various datasets presented herein.

Detector Data

Total Detections

The final dataset spanned the period June 8, 2017, through the night of October 31, 2021 (the Study Period). Although the final date of data collection varied among detectors, 75% of detectors remained in the field through at least the end of July 2021. At least one bat detection (i.e., bat call) was recorded during the Study Period at 84 (95%) of the 88 (86 within randomly selected cells plus the two not in randomly selected cells) detectors monitored. The number of detector nights sampled by site during the Study Period ranged from 106 to 1,537 (Table 2), and 30,469 HAHOBA detections were recorded across all sites. The number of site-level detections ranged from zero to 6,083 during the Study Period (mean=346 detections, median=34 detections; Table 2).

Detections per Detector Night

The mean number of site-level detections per detector night ranged from zero to 5.40 among sites for all years combined during the Study Period (Table 2, Figure 4), with a maximum of 4.37 in Year 1, 5.19 in Year 2, 6.49 in Year 3, and 6.57 in Year 4 (Appendices A1–A4). Detections were more widespread across Oahu during the post-lactation season relative to the other seasons Appendices A5–A8).

Proportion of Detector Nights

The proportion of detector nights with detections ranged from zero to 0.45 (Table 2; Figure 5) across all seasons and sites for the Study Period, with annual variability from zero to 0.52 in Year 1, zero to 0.37 in Year 2, zero to 0.60 in Year 3, and zero to 0.46 in Year 4 (Appendices B1–B4). The proportion of detector nights with detections demonstrated seasonal patterns similar to those of mean detections per detector night, with a higher frequency of detections during the post-lactation season relative to the other seasons (Appendix B5–B8).

Feeding Buzzes and Social Calls

Feeding buzzes (n=1,485) were identified from call files recorded at 40 detectors, and social calls (n=129) from files recorded at 13 detectors (Figure 6). The presence of feeding buzzes and social calls is reported only for informational purposes. These two call types were treated the same as all other calls in the occupancy analyses.

Table 2. Total detections, total detector nights, mean detections per night, and proportion of nights with detections by site from June 8, 2017 to October 31, 2021.

Site ID	Site Name	Detections	Nights with Detections	Detector Nights[2]	Mean Detections Per Detector Night	Proportion of Detector Nights with Detections
Site-000	Goodale Tribe[1]	43	40	849	0.0506	0.0471
Site-002	TTHTT	39	35	1,157	0.0337	0.0303
Site-004	Army Nat Res	53	48	1,486	0.0357	0.0323
Site-006	Waihee Res	7	6	950	0.0074	0.0063
Site-008	Ewa Beach Park[3]	0	0	106	0	0
Site-009	Waianae HS	28	26	1,055	0.0265	0.0246
Site-011	Burn Camp	114	86	1,372	0.0831	0.0627
Site-013	KAW Gate	1,467	337	1,291	1.1363	0.2610
Site-016	Radar Hill Rd	32	28	980	0.0327	0.0286
Site-018	Dillingham Air	171	82	1,311	0.1304	0.0625
Site-020	Wahiawa botanical	25	23	1,438	0.0174	0.0160
Site-021	Lualualei 1	448	228	1,368	0.3275	0.1667
Site-022	Kahana Wedding	18	14	1,279	0.0141	0.0109
Site-023	Waimea Valley	975	387	1,344	0.7254	0.2879
Site-024	Ft Shafter	15	13	1,392	0.0108	0.0093
Site-025	Schofield	450	276	1,436	0.3134	0.1922
Site-026	Kawainiui	1	1	1,343	0.0007	0.0007
Site-029	KAW Rd	165	132	1,117	0.1477	0.1182
Site-030	Sacred Falls	3	3	1,182	0.0025	0.0025
Site-031	Plantation Village	7	7	1,351	0.0052	0.0052
Site-032	Nuuanu Watershed	1	1	1,316	0.0008	0.0008
Site-033	Camp Erdman	167	115	1,488	0.1122	0.0773
Site-034	Barbers Point	38	30	1,224	0.0310	0.0245
Site-035	Helemano	90	80	1,422	0.0633	0.0563
Site-036	Kroc Center	17	14	1,341	0.0127	0.0104
Site-038	Moanalua Trail	1	1	1,392	0.0007	0.0007
Site-039	Pupukea	4,237	389	1,310	3.2344	0.2969
Site-040	Hickham AFB	0	0	1,237	0	0
Site-041	Schofield 3	1,208	455	1,386	0.8716	0.3283
Site-042	042 USGS	1	1	676	0.0015	0.0015
Site-043	Manana Trail 1	6	6	1,350	0.0044	0.0044
Site-044	Royal Hawaiian Golf	7	6	1,297	0.0054	0.0046
Site-046	Poamoho	24	22	1,342	0.0179	0.0164
Site-048	Chaminade Univ.	38	29	1,524	0.0249	0.0190
Site-049	Lualualei NAVY	80	64	1,368	0.0585	0.0468
Site-050	HECO Kahe Point	6	4	905	0.0066	0.0044
Site-053	Kumaipo LZ	6,083	504	1,127	5.3975	0.4472
Site-054	Anchor Church	8	8	1,199	0.0067	0.0067
Site-055	Schofield Waikane	48	38	1,207	0.0398	0.0315
Site-057	McCarthy Field	304	220	1,483	0.2050	0.1483
Site-058	Kailua Heights	7	6	1,199	0.0058	0.0050
Site-059	Moanalua Red Hill	11	10	1,301	0.0085	0.0077
Site-060	Hawaii Loa Booster	23	23	1,316	0.0175	0.0175
Site-061	Mt Kaala	696	453	1,488	0.4677	0.3044
Site-064	Kamehameha Res	36	29	931	0.0387	0.0311
Site-065	Makua Valley	93	64	1,320	0.0705	0.0485
Site-066	Wheeler	93	84	1,430	0.0650	0.0587
Site-067	Honouliuli FR	77	55	1,015	0.0759	0.0542
Site-068	Waikane Valley	4	3	748	0.0053	0.0040

Table 2. Total detections, total detector nights, mean detections per night, and proportion of nights with detections by site from June 8, 2017 to October 31, 2021.

Site ID	Site Name	Detections	Nights with Detections	Detector Nights[2]	Mean Detections Per Detector Night	Proportion of Detector Nights with Detections
Site-069	MitchDetector	7	5	1,496	0.0047	0.0033
Site-070	Iroquois Pt	63	49	1,268	0.0497	0.0386
Site-071	Makaha Res	75	51	1,224	0.0613	0.0417
Site-072	Waihee Wells	0	0	1,207	0	0
Site-073	Kipapa North Fence	0	0	271	0	0
Site-074	Hawaii Loa	74	46	1,316	0.0562	0.0350
Site-075	Peerson	4,023	561	1,380	2.9152	0.4065
Site-076	Kaipapau FR	42	15	902	0.0466	0.0166
Site-077	Manana Trail 2	10	10	1,372	0.0073	0.0073
Site-078	Sand Island	7	7	1,315	0.0053	0.0053
Site-079	Makua Ridge	971	358	1,433	0.6776	0.2498
Site-081	KAW 2	160	113	1,215	0.1317	0.0930
Site-083	Lualualei 2	217	122	1,119	0.1939	0.1090
Site-084	Aiea Loop Ridge	8	8	1,201	0.0067	0.0067
Site-085	Kaw 1	119	103	1,331	0.0894	0.0774
Site-087	Schofield 1	207	161	1,394	0.1485	0.1155
Site-088	Kawainui Marsh 1	1	1	1,263	0.0008	0.0008
Site-089	Waiawa Snot	19	13	1,334	0.0142	0.0097
Site-090	Kau Crater Trail	1	1	1,341	0.0007	0.0007
Site-093	Pouhala Marsh	7	7	1,061	0.0066	0.0066
Site-094	Manoa Falls	8	6	1,485	0.0054	0.0040
Site-095	Kuaokala Game Area	2,819	165	1,309	2.1536	0.1261
Site-097	Malaekahana SP	152	14	509	0.2986	0.0275
Site-098	West Loch Golf	17	16	1,068	0.0159	0.0150
Site-100	Heeia State Park	9	8	1,537	0.0059	0.0052
Site-101	Pupukea Paumalu	805	329	1,132	0.7111	0.2906
Site-102	Pearl Harbor	22	19	1,262	0.0174	0.0151
Site-103	Schofield Forest	1,270	312	1,456	0.8723	0.2143
Site-105	Aiea Loop Trail 1	237	64	1,438	0.1648	0.0445
Site-106	Puu Pia Trail	2	2	1,179	0.0017	0.0017
Site-109	Central Oahu Park	18	16	1,140	0.0158	0.0140
Site-110	Halone Blowhole	40	27	1,261	0.0317	0.0214
Site-111	YMCA Waianae	46	36	679	0.0677	0.0530
Site-112	Barbers Point	1	1	1,102	0.0009	0.0009
Site-113	Hauula Dist. Park	10	7	1,124	0.0089	0.0062
Site-114	Waipio Soccer	3	3	1,168	0.0026	0.0026
Site-115	Waianae Valley	1,250	165	1,318	0.9484	0.1252
Site-119	Makua Cave	280	140	1,082	0.2588	0.1294
Site-999	Hamakua Pond[1]	4	4	979	0.0041	0.0041

1. Denotes subjectively selected grid cells.

2. Denotes nights that the detector was functional.

3. Denotes data from a single season only.

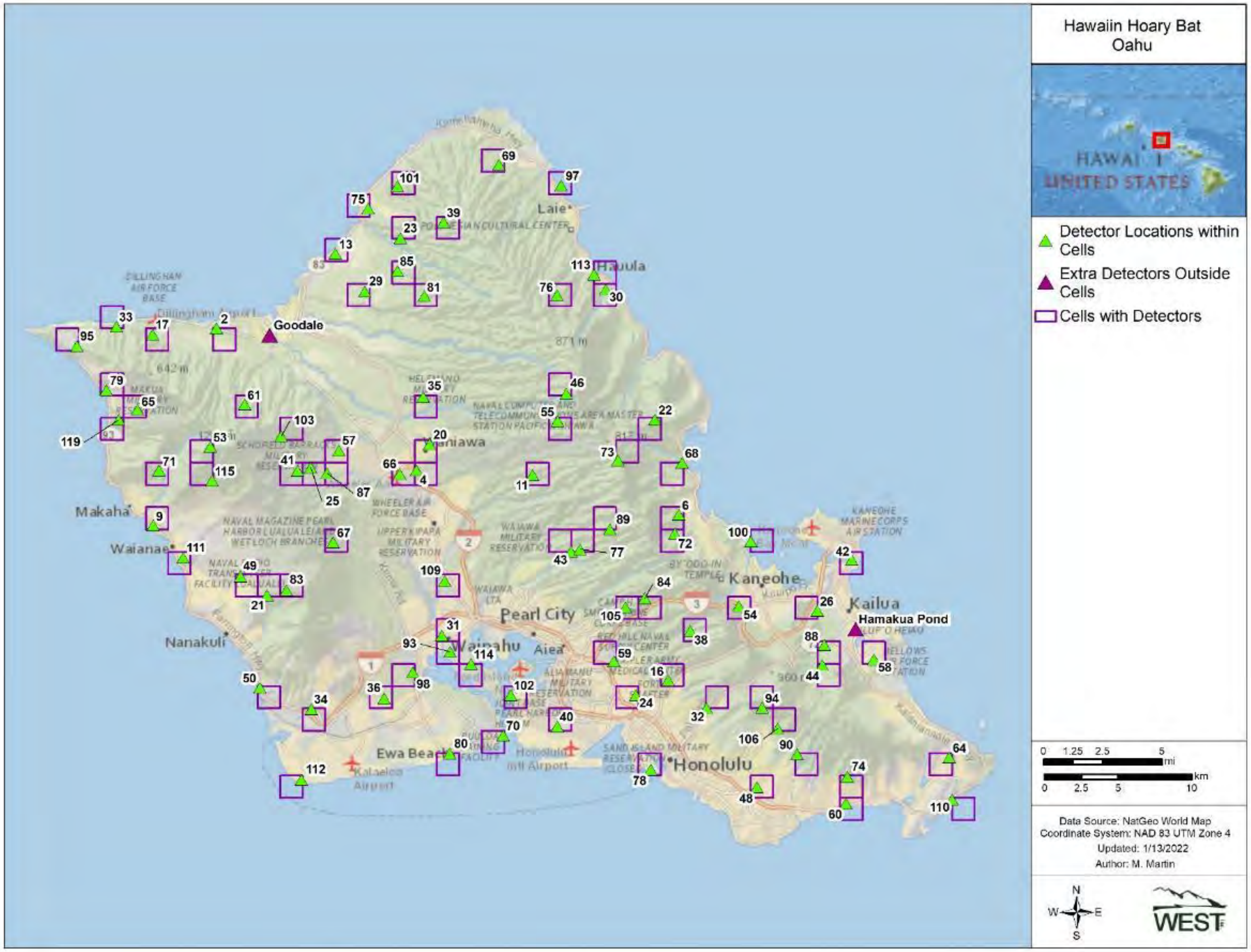


Figure 3. Distribution of acoustic bat detectors used in the island-wide occupancy study of Hawaiian hoary bats on Oahu. Site identification numbers provided for each sample location.

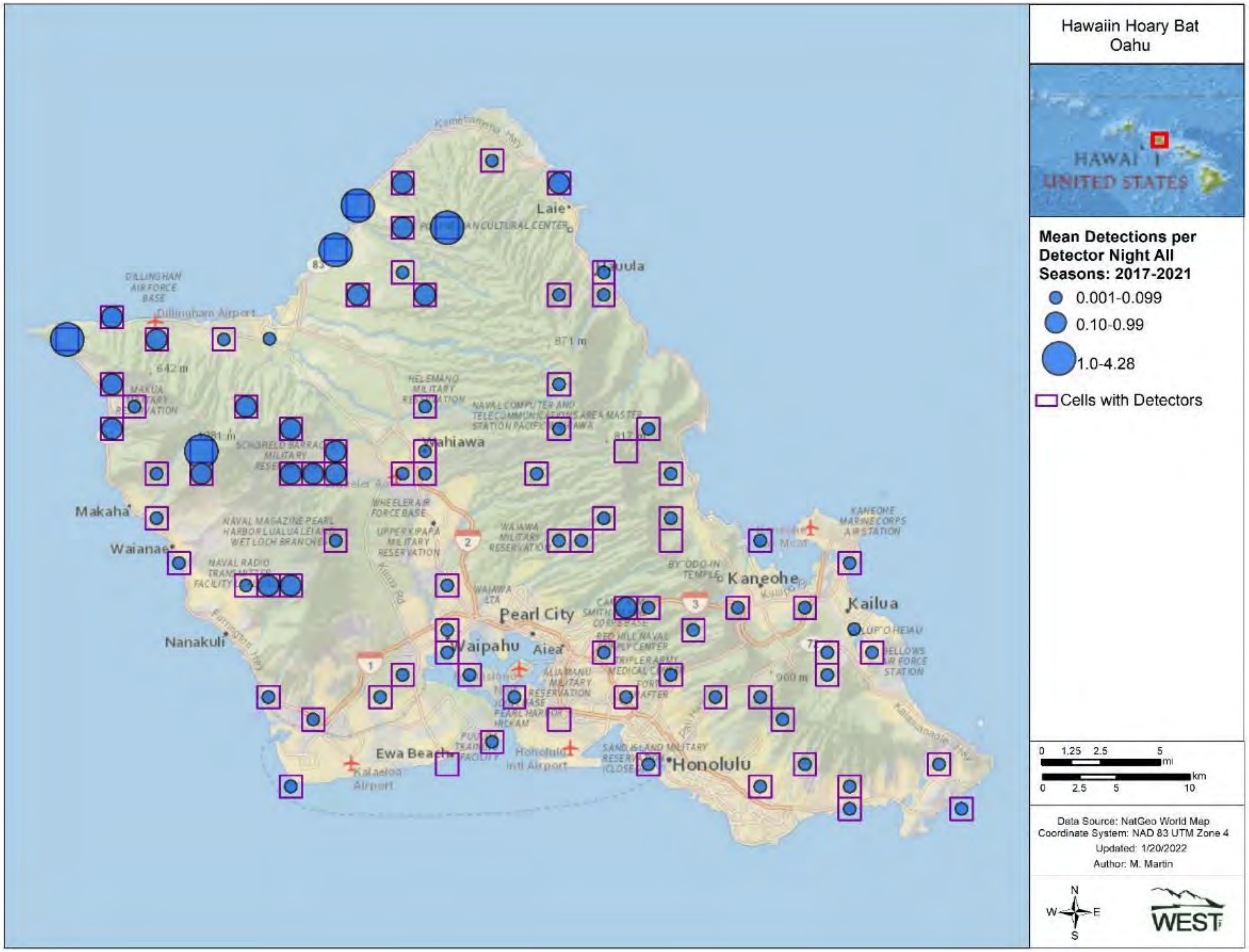


Figure 4. Mean detections per night by site between June 8, 2017 and October 31, 2021.

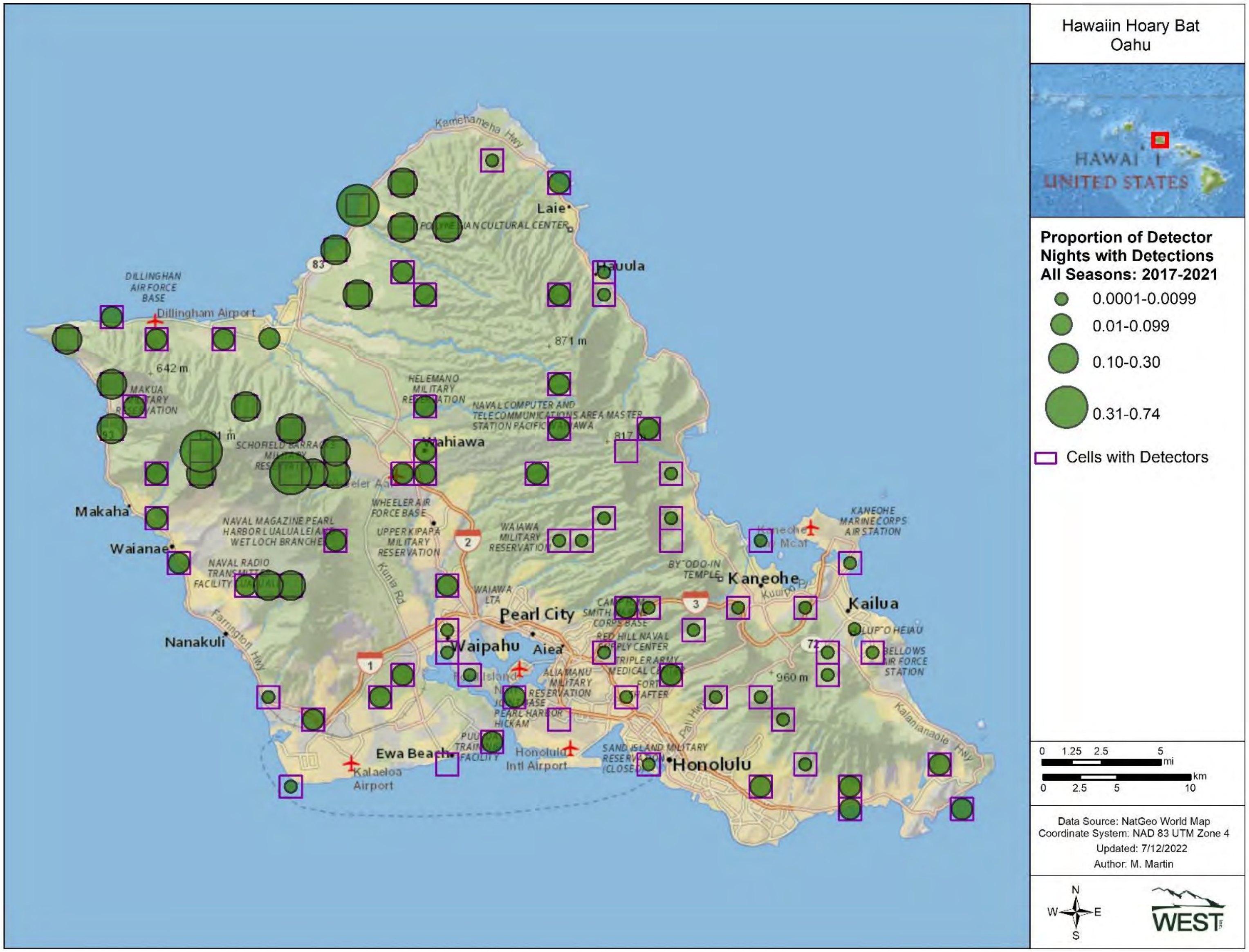


Figure 5. Proportion of nights with detections by site between June 8, 2017 and October 31, 2021.

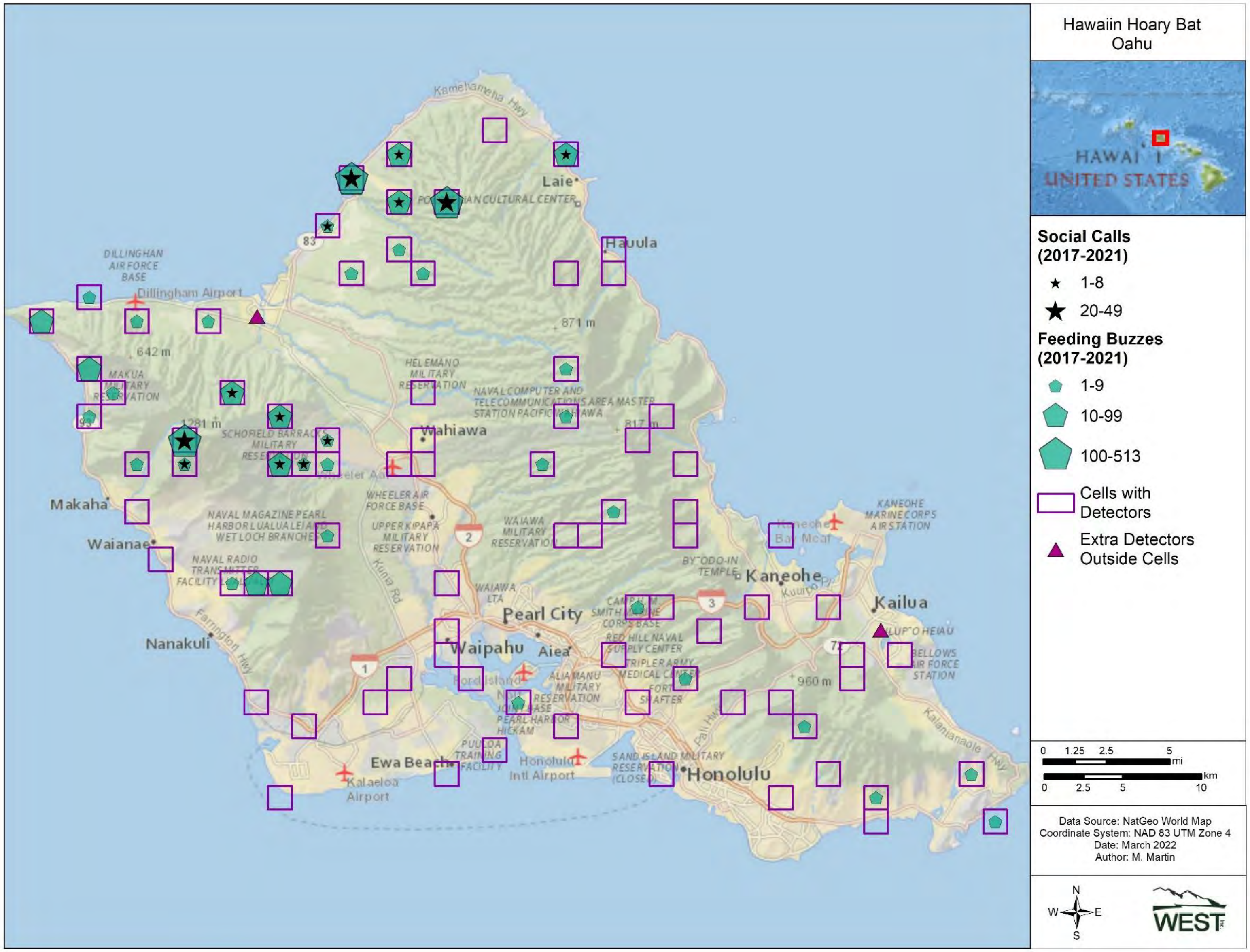


Figure 6. Distribution of feeding buzzes and social calls recorded between June 8, 2017 and October 31, 2021.

Occupancy Modeling

Site-level covariates (Table 3) used to model occupancy included human population per square mile (US Census Bureau 2019), mean elevation of the grid cell in meters (USGS 2017), the percentage of the grid cell covered in tree-dominated land cover classes (LANDFIRE 2017), and the standard deviation of tree height in each grid cell. Several site-level covariates were also discretized into a two-level category of low/high based on the median value and are indicated as covariates ending in "Class." To improve model convergence, human population density was scaled to density per thousand people, and elevation was scaled to hectometers (100 m [328 ft]). The distribution of each of the site-level covariates, with the exception of forest height standard deviation, was skewed right with a high proportion of values near zero (Table 3, Figures 7 and 8).

Table 3. Summary statistics for site-level covariates for all grid cells in the sampling frame and the subset of grid cells in the sample.

	Sampling Frame			Sample		
Site-level Covariate	**Mean**	**Median**	**Range**	**Mean**	**Median**	**Range**
PopSqMi (number/mile^2)	1,390.5	64.6	0–33,319.9	1,114.3	188.4	0–13,759.0
Elev (meters)	188.9	141.4	0–896.7	187.2	144.6	0.1–643.1
PctTrees (%)	37.3	20.7	0–99.8	37.9	24.5	0–99.1
ForestHt_std	4.2	4.1	0–12.8	4.4	4.5	0.4–9.0
PropDry (%)	19.8	3.7	0–99.9	0.2	0	0–1.0
PropMes (%)	22.3	0	0–99.6	0.2	0	0–1.0
PropWet (%)	14.8	0	0–100	0.1	0	0–1.0

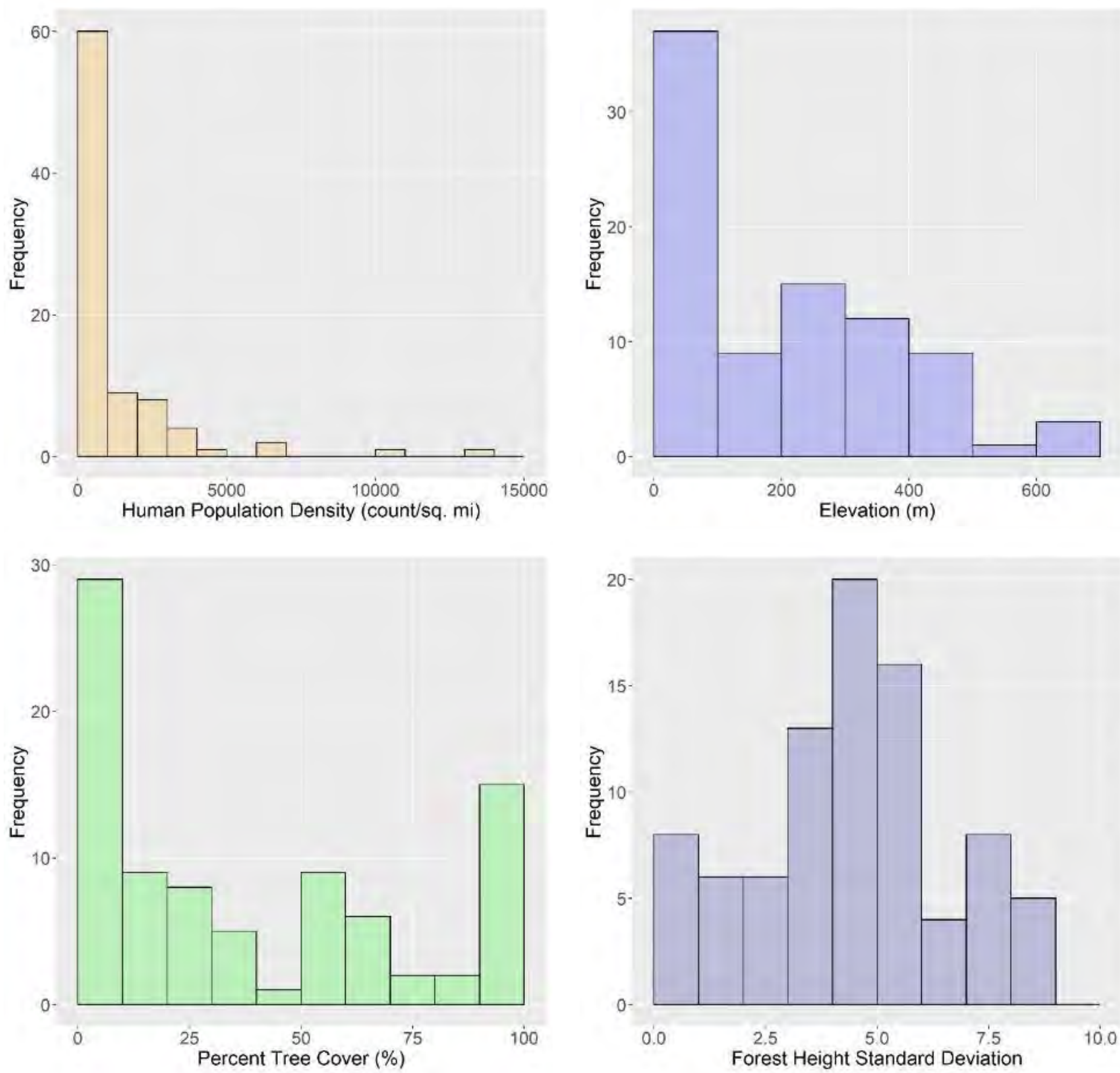


Figure 7. Distribution of site-level covariates measuring grid cell human population density, mean elevation, percent tree cover, and the standard deviation in forest height.

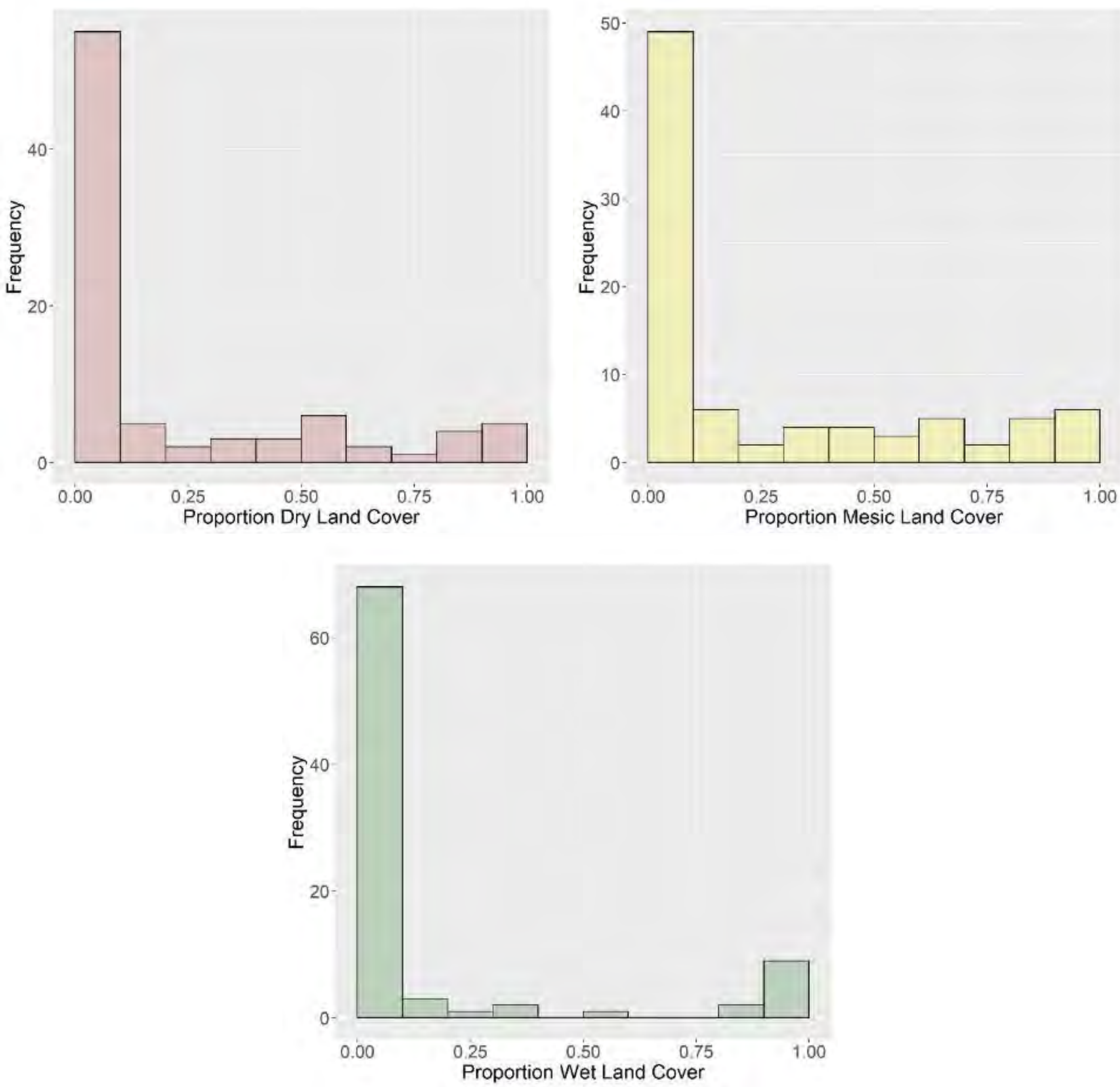


Figure 8. Distribution of site-level covariates measuring grid cell proportions of forest, grassland, or shrubland classified as dry, mesic, or wet.

Model parameters are defined in Table 4. Intercept-only models were used to model local extinction and local colonization. The final models for each reproductive season are provided in Tables 5–8.

Table 4. Occupancy model parameters for the multi-season dynamic occupancy model for correlated detections (Hines et al. 2014).

Parameter	Description
psi	Occupancy rate.
theta0	Probability the species is available at a survey occasion given the site is occupied and the species **was not** available at the previous survey occasion.
theta1	Probability the species is available at a survey occasion given the site is occupied and the species **was** available at the previous survey occasion.
gam	Probability a site not occupied during a given season is colonized during the next season.
eps	Probability a site occupied during a given season is not occupied during the next season.
p	Probability a species is detected given the site is occupied and the species is currently available.

The final model for the lactation season (Table 5) described occupancy as positively associated with the mean grid cell elevation and negatively associated with the indicator of any wet forest/grassland/shrub land cover in the cell. Estimated occupancy rates during the lactation season (Table 9, Figure 9) increased slightly during the Study Period, from 0.61 (95%-CRI: 0.50, 0.74) to 0.65 (95%-CRI: 0.55, 0.74). However, the trend estimates were not substantially different from zero, as evidenced by the 95%-CRI on the occupancy estimates (Table 5), the mean proportional trend (0.01, 95%-CRI: -0.05, 0.08) for which the CRI overlapped zero, and the net proportional trend (1.07, 95%-CRI: 0.82, 1.36) for which the CRI overlapped one. The estimated detection probability (Table 10, Figure 10) for the U1 microphone (0.44, 95%-CRI: 0.40, 0.48) was slightly higher than for the U2 microphone (0.38, 95%-CRI: 0.35, 0.42) during the lactation season (difference in detection rates: 0.05, 95%-CRI: 0.02, 0.09).

The final model for the post-lactation season (Table 6) contained no site-level covariates as predictors of site occupancy. Estimated occupancy rates during the post-lactation season increased slightly during the Study Period (Table 9, Figure 9), from 0.75 (95%-CRI: 0.63, 0.87) to 0.81 (95%-CRI: 0.74, 0.88). However, the trend estimates were not substantially different from zero, as evidenced by the 95%-CRI on the occupancy estimates (Table 6), mean proportional trend (0.02, 95%-CRI: -0.02, 0.08), and net proportional trend (1.09, 95%-CRI: 0.91, 1.32). Detection probabilities (Table 10, Figure 10) were modeled by microphone type (Table 6, Figure 10), with slightly higher detection for the U2 microphone (0.34, 95%-CRI: 0.32, 0.36) than the U1 microphone (0.20, 95%-CRI: 0.18, 0.22). This difference was substantially different from zero (mean difference: -0.14, 95%-CRI: -0.16, -0.12).

The final model for the pre-pregnancy season (Table 7) contained a positive effect of mean grid cell elevation and a negative effect of the proportion of wet forest/grassland/shrub land cover. Estimated occupancy rates during the pre-pregnancy season (Table 9, Figure 9) increased during the Study Period, from 0.40 (95%-CRI: 0.32, 0.49) to 0.50 (95%-CRI: 0.39, 0.61). However, the trend estimates were not substantially different from zero, as evidenced by the 95%-CRI on the occupancy estimates (Table 7), the mean proportional trend estimate (0.08, 95%-CRI: -0.02, 0.19) and net proportional trend (1.26, 95%-CRI: 0.93, 1.66). The detection rate (Table 7, Figure 10) was estimated for the U1 microphone as 0.20 (95%-CRI: 0.18, 0.23) and for the U2 microphone as 0.28 (95%-CRI: 0.25, 0.31). The detection probability (Table 10, Figure 10) for the U1 microphone was lower than for the U2 microphone (mean difference: -0.07, 95%-CRI: -0.11, -0.04).

The final model for the pregnancy season (Table 8) contained a positive effect for elevation and negative effects for proportion of wet forest/grassland/shrub land cover and human population density within each grid cell. Estimated occupancy rates during the pregnancy season (Table 9, Figure 9) increased during the Study Period, from 0.31 (95%-CRI: 0.24, 0.38) to 0.46 (95%-CRI: 0.36, 0.57). The trend estimates were substantially different from zero, as evidenced by the 95%-CRI on the occupancy estimates (Table 8), the mean proportional trend (0.15, 95%-CRI: 0.04, 0.28), and the net proportional trend (1.53, 95%-CRI: 1.12, 2.04). The detection probability (Table 10, Figure 10) for the U1 microphone (0.32, 95%-CRI: 0.29, 0.36) was lower than for the U2 microphone (0.42, 95%-CRI: 0.38, 0.46) with a mean difference of -0.10 (95%-CRI: -0.14, -0.05).

Table 5. Correlated detection occupancy model estimates, standard error (SE), and credible intervals (CRI) for the Lactation season.

Parameter	Mean	SE	95%-CRI Lower Bound	95%-CRI Upper Bound
p[1]: U1 mic	0.44	0.02	0.40	0.48
p[2]: U2 mic	0.38	0.02	0.35	0.42
psivec[1]	0.61	0.06	0.50	0.74
psivec[2]	0.63	0.04	0.56	0.70
psivec[3]	0.64	0.04	0.56	0.71
psivec[4]	0.64	0.04	0.56	0.73
psivec[5]	0.65	0.05	0.55	0.74
beta0	2.37	0.94	0.92	4.54
beta: Elev	2.64	0.95	1.19	4.87
beta: PropWetClass	-4.14	1.61	-7.81	-1.55
gam	0.31	0.05	0.22	0.40
eps	0.17	0.03	0.11	0.23
meanPropTrend	0.01	0.03	-0.05	0.08
netPropTrend	1.07	0.14	0.82	1.36
theta0	0.06	0	0.05	0.07
theta1	0.90	0.01	0.88	0.92
pi	0.38	0.04	0.30	0.47

Table 6. Correlated detection occupancy model estimates, standard error (SE), and credible intervals (CRI) for the Post-Lactation season.

Parameter	Mean	SE	95%-CRI Lower Bound	95%-CRI Upper Bound
p[1]: U1 mic	0.20	0.01	0.18	0.22
p[2]: U2 mic	0.34	0.01	0.32	0.36
psivec[1]	0.75	0.06	0.63	0.87
psivec[2]	0.80	0.03	0.73	0.85
psivec[3]	0.81	0.03	0.74	0.87
psivec[4]	0.81	0.03	0.74	0.88
psivec[5]	0.81	0.03	0.74	0.88
beta0	1.15	0.34	0.52	1.86
gam	0.56	0.07	0.41	0.69
eps	0.13	0.03	0.08	0.18
meanPropTrend	0.02	0.03	-0.02	0.08
netPropTrend	1.09	0.11	0.91	1.32
theta0	0.04	0	0.04	0.05
theta1	0.95	0.01	0.94	0.96
pi	0.41	0.04	0.33	0.50

Table 7. Correlated detection occupancy model estimates, standard error (SE), and credible intervals (CRI) for the Pre-Pregnancy season.

Parameter	Mean	SE	95%-CRI Lower Bound	95%-CRI Upper Bound
p[1]: U1 mic	0.20	0.01	0.18	0.23
p[2]: U2 mic	0.28	0.02	0.25	0.31
psivec[1]	0.40	0.04	0.32	0.49
psivec[2]	0.45	0.04	0.38	0.53
psivec[3]	0.48	0.05	0.39	0.57
psivec[4]	0.50	0.06	0.39	0.61
beta0	0.57	0.44	-0.21	1.53
beta[1]: Elev	2.14	0.54	1.19	3.33
beta[2]: PropWet	-7.16	2.05	-11.73	-3.73
gam	0.20	0.04	0.13	0.28
eps	0.18	0.06	0.08	0.30
meanPropTrend	0.08	0.05	-0.02	0.19
netPropTrend	1.26	0.19	0.93	1.66
theta0	0.03	0	0.03	0.04
theta1	0.93	0.01	0.91	0.94
pi	0.28	0.05	0.18	0.39

Table 8. Correlated detection occupancy model estimates, standard error (SE), and credible intervals (CRI) for the Pregnancy season.

Parameter	Mean	SE	95%-CRI Lower Bound	95%-CRI Upper Bound
p[1]: U1 mic	0.32	0.02	0.29	0.36
p[2]: U2 mic	0.42	0.02	0.38	0.46
psivec[1]	0.31	0.04	0.24	0.38
psivec[2]	0.38	0.03	0.31	0.45
psivec[3]	0.43	0.04	0.34	0.52
psivec[4]	0.46	0.05	0.36	0.57
beta0	1.10	0.70	-0.17	2.56
beta[1]: Elev	2.47	0.68	1.29	3.93
beta[2]: PropWet	-18.22	6.40	-32.44	-7.92
beta[3]: PopSqMiClass	-1.94	0.87	-3.77	-0.35
gam	0.16	0.03	0.10	0.23
eps	0.14	0.05	0.06	0.24
meanPropTrend	0.15	0.06	0.04	0.28
netPropTrend	1.53	0.23	1.12	2.04
theta0	0.05	0.01	0.04	0.06
theta1	0.90	0.01	0.88	0.92
pi	0.37	0.06	0.26	0.48

Table 9. Estimated occupancy rates and credible intervals (CRI) by season and year.

Season	Year	Estimated Occupancy	95%-CRI Lower Bound	95%-CRI Upper Bound
Lactation	2017	0.61	0.50	0.74
	2018	0.63	0.56	0.70
	2019	0.64	0.56	0.71
	2020	0.64	0.56	0.73
	2021	0.65	0.55	0.74
Post-Lactation	2017	0.75	0.63	0.87
	2018	0.80	0.73	0.85
	2019	0.81	0.74	0.87
	2020	0.81	0.74	0.88
	2021	0.81	0.74	0.88
Pre-Pregnancy	2017	0.40	0.32	0.49
	2018	0.45	0.38	0.53
	2019	0.48	0.39	0.57
	2020	0.50	0.39	0.61
Pregnancy	2017	0.31	0.24	0.38
	2018	0.38	0.31	0.45
	2019	0.43	0.34	0.52
	2020	0.46	0.36	0.57

Table 10. Estimated detection rates and credible intervals (CRI) by season and microphone type.

Season	Mic Type	Estimated Occupancy	95%-CRI Lower Bound	95%-CRI Upper Bound
Lactation	U1	0.44	0.40	0.48
	U2	0.38	0.35	0.42
Post-Lactation	U1	0.20	0.18	0.22
	U2	0.34	0.32	0.36
Pre-Pregnancy	U1	0.32	0.29	0.36
	U2	0.42	0.38	0.46
Pregnancy	U1	0.20	0.18	0.23
	U2	0.28	0.25	0.31

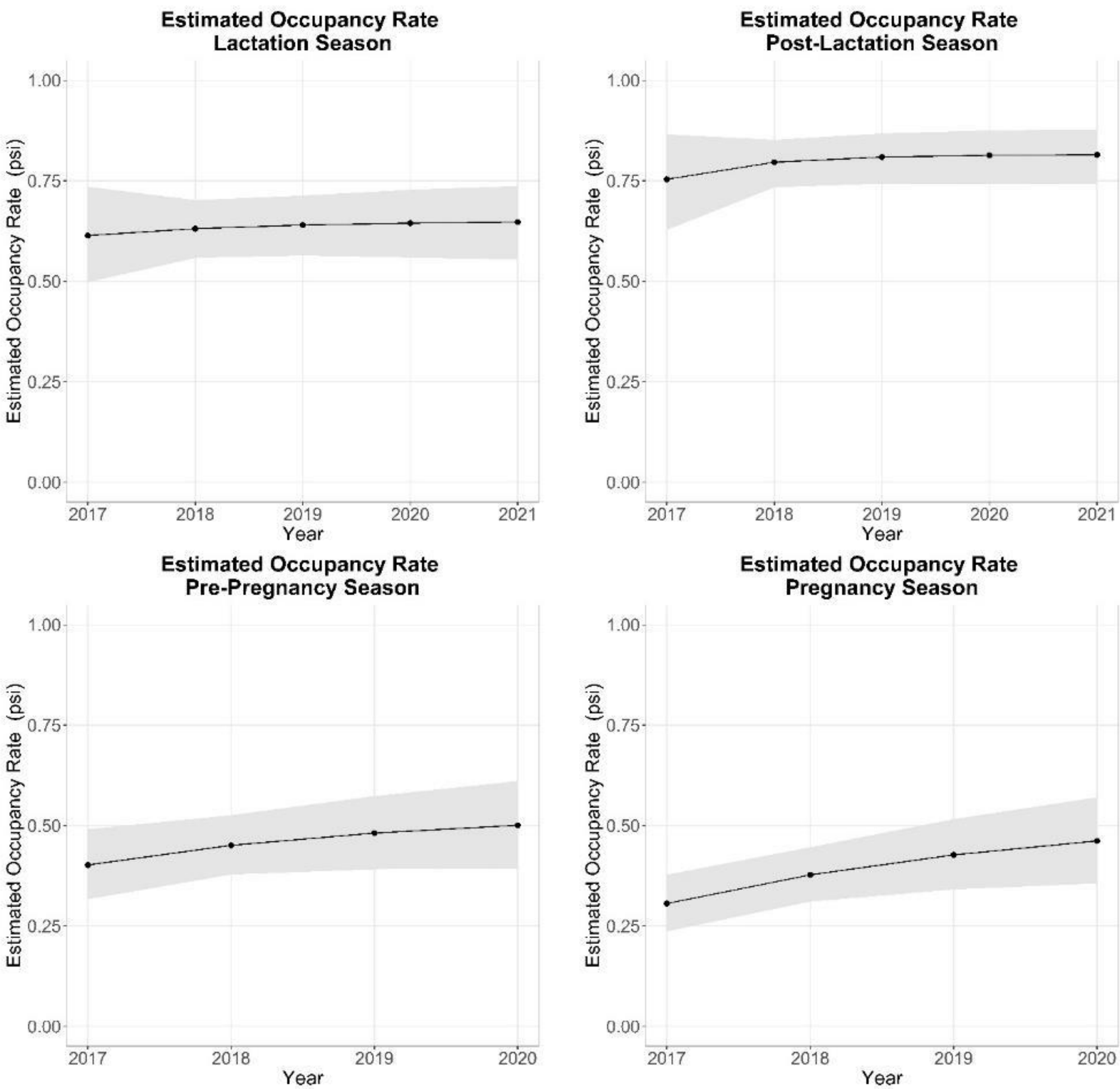


Figure 9. Occupancy estimates and 95% credible intervals by reproductive season and year.

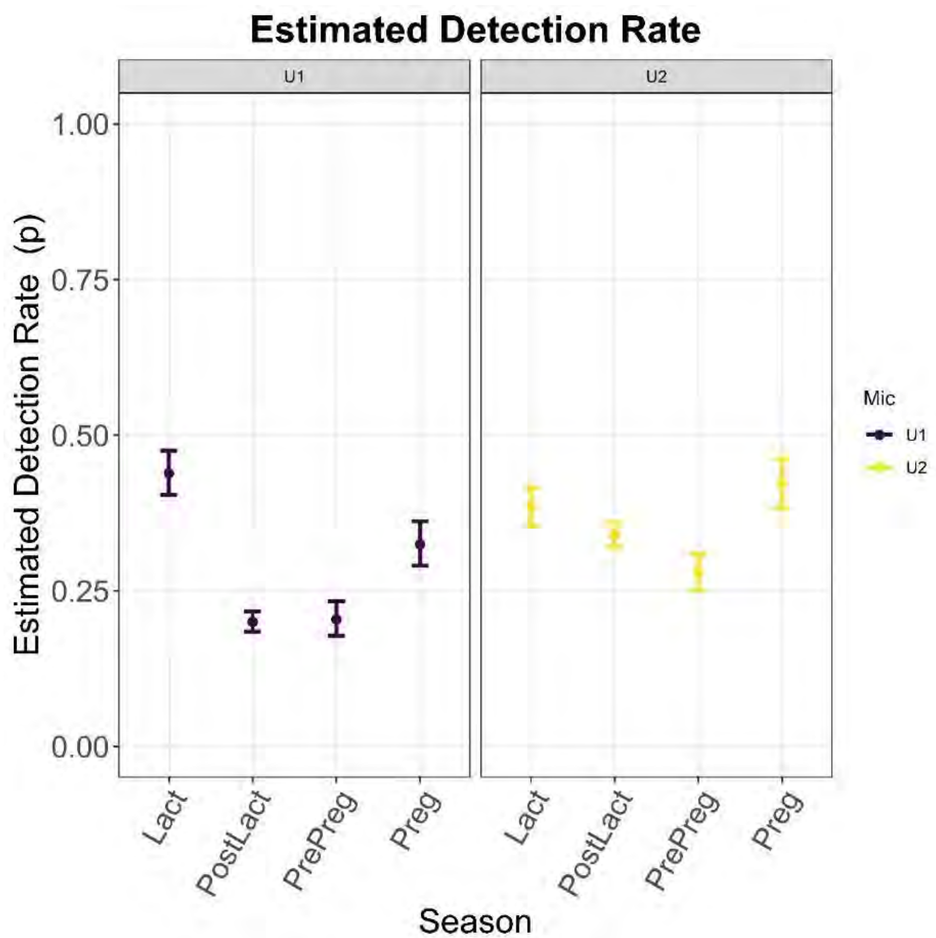


Figure 10. Detection probability estimates and 95% confidence bands by reproductive season and microphone type.

Heat maps of occupancy were developed from the final models for each season (Figure 11). With the exception of the post-lactation season, for which no site-level covariates were identified as important predictors, occupancy was modeled as a function of mean grid cell elevation and the proportion of the wet forest/grassland/shrub land cover type. Occupancy during the pregnancy season was additionally modeled as a function of human population density. Heat maps indicate areas with a high probability of being consistently occupied in a given season, and a comparison of maps provides indication of areas with a high probability of occupancy throughout the year.

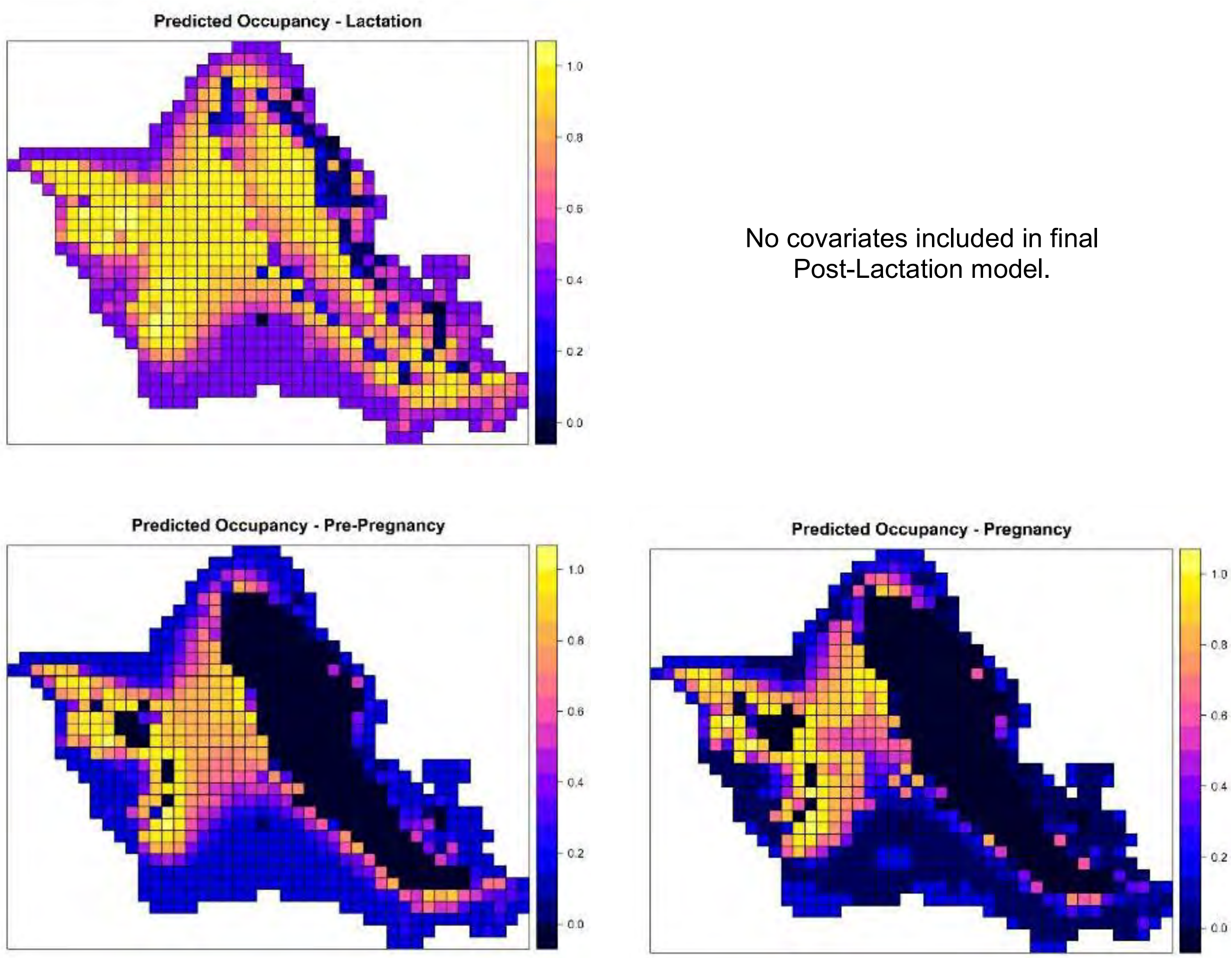


Figure 11. Predicted occupancy by season.

The relationship between elevation and the proportion of wet forest/grassland/shrub land cover was examined for the range of possible values by season (Figure 12). Occupancy rates during the lactation season were modeled as a function of the indicator of *any* wet forest/grassland/shrub in a grid cell, therefore estimates of occupancy differ for proportions of zero cover versus any non-zero cover. Preferred habitat in the lactation season is represented in green and includes areas above 100 m with no wet forest/grassland/shrub cover and areas above 300 m (984 ft) elevation with any wet forest/grassland/shrub cover. During the pre-pregnancy season, wetter areas (e.g., greater than 60% wet forest/grassland/shrub) are predicted to be occupied only at higher elevations, whereas during the pregnancy season, wetter areas are not predicted to be occupied, regardless of elevation. The post-lactation occupancy model did not include habitat covariates so we infer no preference by HAHOBA of specific elevations or land cover types during this reproductive season.

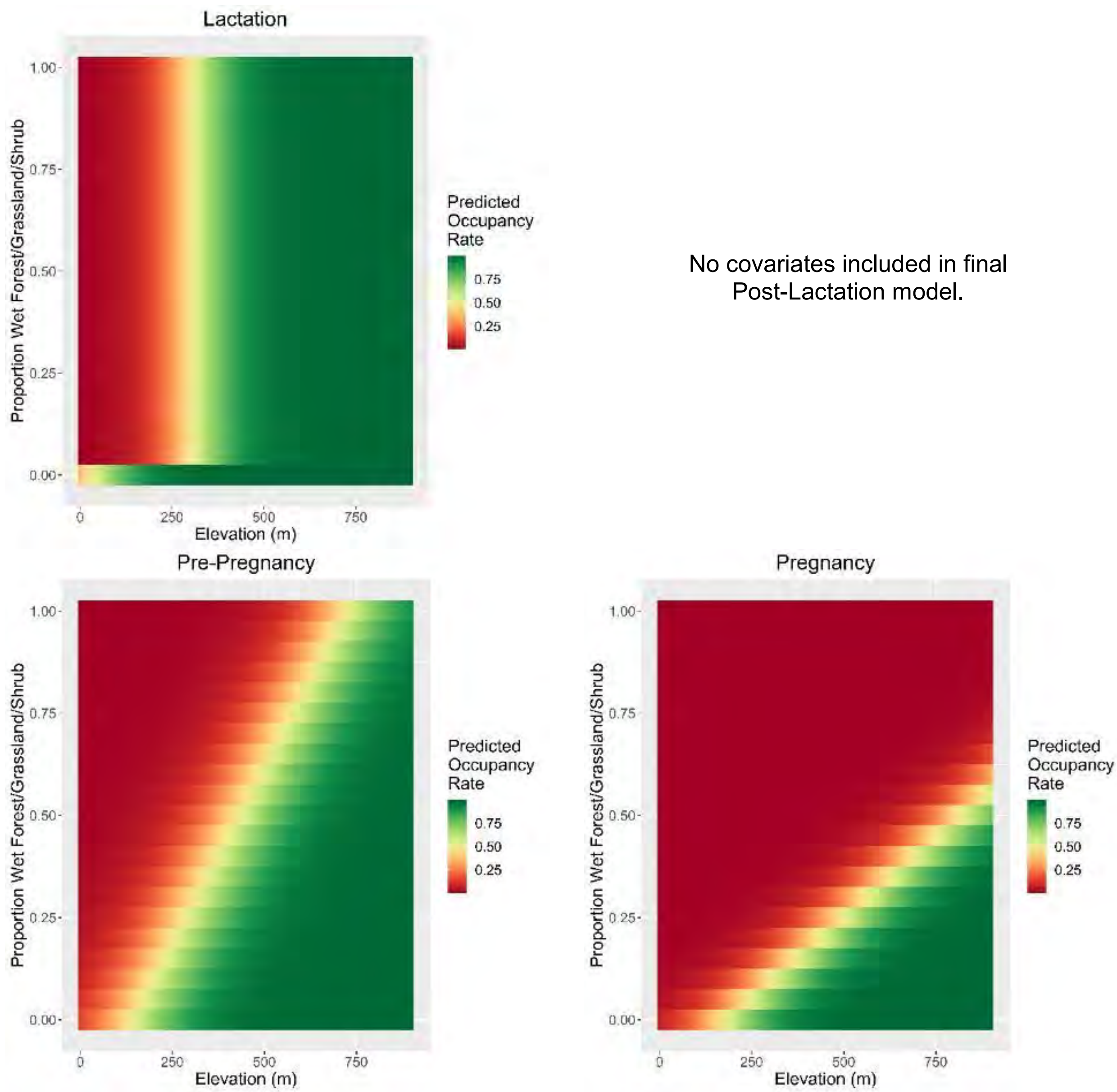


Figure 12. Predicted occupancy by season as a function of elevation (meters [m]) and the proportion of wet forest/grassland/shrub land cover. Note that the Lactation season model contains a classification variable for the proportion of wet forest/grassland/shrub land cover that takes a value of zero if no wet category land cover is present in a grid cell and a value of one if any wet category land cover is present in a grid cell.

Cyclical Changes in Occupancy

The proportion of operating detectors with any detections was calculated by Julian day and survey year (Figure 13) and the 5-day moving average of daily proportions was calculated by Julian day across survey years (Figure 14). See Appendix C for plots of detections by Julian day and survey year, which exhibit annual fluctuations in detections across years. Daily bat detection across sites was restricted to the smallest proportion of sites during the pre-pregnancy season (Figure 14). This was followed by a gradual increase in detections during the pregnancy season, then a rapid increase during the lactation season followed by a rapid decline during post-lactation (Figures 13 and 14). The peak period of detections during lactation and post-lactation also coincided with a more widespread distribution across Oahu, compared to the more restricted range (based on detections) observed during the pre-pregnancy season.

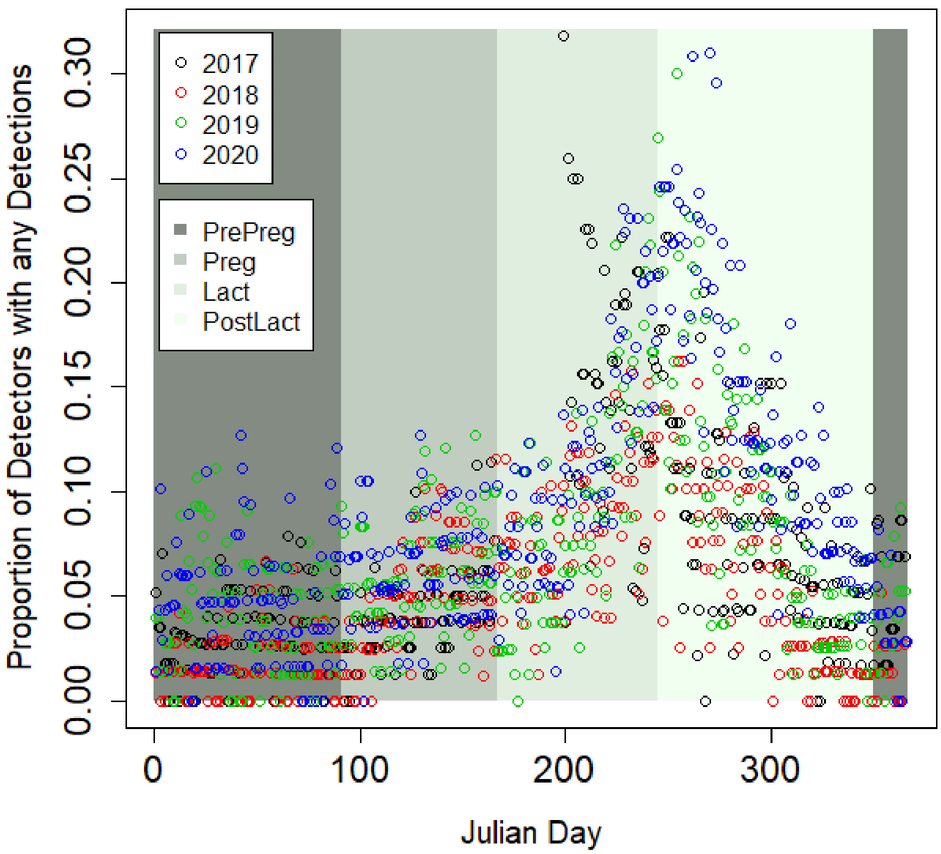


Figure 13. Proportions of detectors with detections by survey year and Julian day.

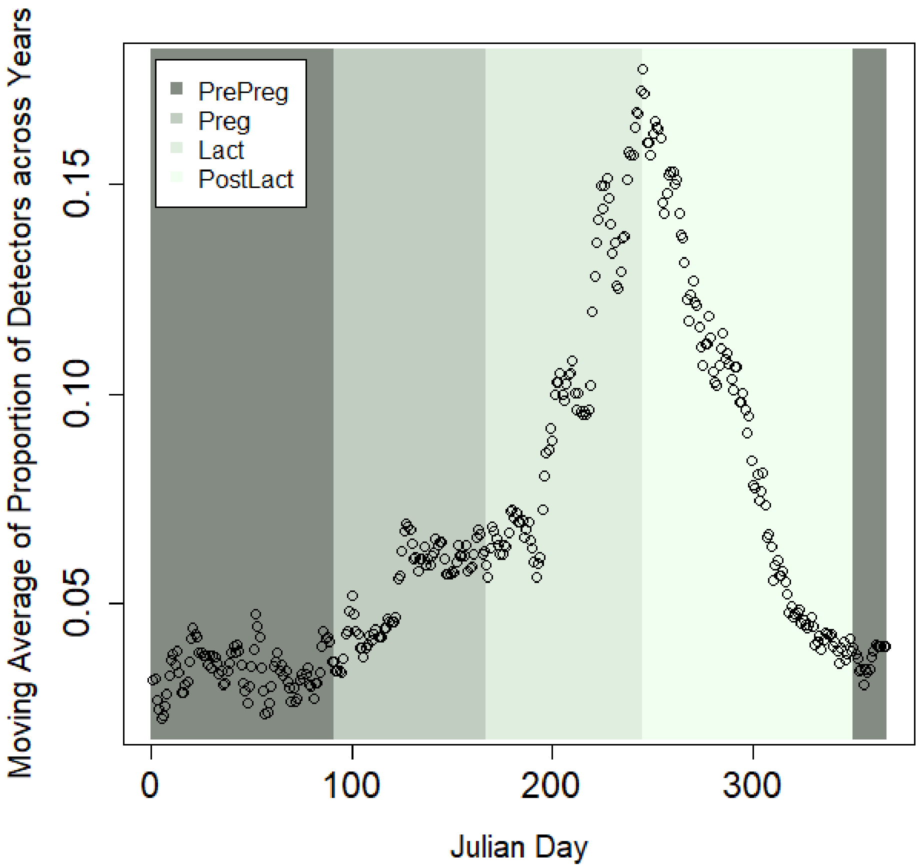


Figure 14. Five-day moving average of the proportion of detectors with detections across survey years by Julian day.

Power Analysis

The results of the power analysis (Table 11) indicate that the power to detect a 10% trend in occupancy over 10 years during the lactation season achieves power of 0.756 or more with as few as 20 sites, and exceeds 0.9 with 40 or more detectors. To detect a 15% annual trend over 10 years, monitoring as few as 20 detectors results in power exceeding 0.9.

Table 11. Power to detect trends in lactation season occupancy of 10% and 15% annually over 10 years.

	10 years	
Number of sites	**Power to detect a 10% annual trend**	**Power to detect a 15% annual trend**
20	0.756	0.932
40	0.916	1
60	0.976	1
80	0.996	1

DISCUSSION

For each of the seasons, occupancy across years was modeled from nightly detections in a sample of 86 selected grid cells. The dynamic occupancy model for correlated detections (Hines et al. 2014) was applied to account for correlation among detections recorded in subsequent nights. In addition to the inclusion of more data, the results reported here differ slightly from the results in previous reports due to changes in the covariate model selection process and changes in the occupancy model, as compared to preliminary reports from the prior years of the study. In this final analysis, a Bayesian modeling approach was used to model trend in occupancy independently by season, as defined above. The probability that a site is occupied in a given year depends on its occupancy state during the same season in the previous year, a practical consideration for a species that potentially occupies different spatial areas throughout the reproductive seasons.

As observed by Menard (2001) and Gorresen et al. (2013), occupancy rates varied by season, with the highest occupancy estimates observed in the lactation and post-lactation seasons and the lowest occupancy rates observed during the pre-pregnancy and pregnancy seasons. Bat occurrence (as indicated by the proportion of detectors with detections) expanded spatially over the pregnancy and lactation seasons, peaked near the beginning of the post-lactation season, and then contracted through the remainder of the post-lactation season to its most spatially restricted period during the pre-pregnancy season (Figures 13 and 14). Occupancy rates exhibited slight but significant increasing trends in both mean and net proportional trends during the pregnancy season (Table 8), while occupancy estimates during the other seasons had upward trajectories over the Study Period (Figure 9), but were not significant (Tables 5–7). This result may change with additional data and increased power to detect significant trends. Given the consistency in results across seasons and years, we infer that the HAHOBA occupancy rate for Oahu was stable to slightly increasing over the Study Period.

Relationships between habitat covariates and occupancy rates were examined by season. No habitat covariates were identified as significant predictors of site occupancy during the post-lactation season, a period when the HAHOBA population appears most dispersed across Oahu and occupancy rates are highest. The broader distribution and increased occupancy rates during this period could be indicative of the dispersal of young-of-the-year bats recently added to the population, versus a broader distribution of adult bats. Effects of elevation were positive for all seasons incorporating site-level covariates in the occupancy model (lactation, pre-pregnancy, and pregnancy), with the effects similar in magnitude among the three seasons (Tables 5, 7, and 8). The proportion of wet forest/grassland/shrub land cover was negatively associated with occupancy during the lactation season, and this negative effect was increasingly pronounced in the pre-pregnancy and pregnancy seasons. Mean monthly Oahu precipitation measured at weather stations between 1920 and 2012 ranged from 5.4 to 6.7 in (13.7 to 17.0 cm) per month from November through April, and from 3.1 to 4.6 in (7.9 to 11.7 cm) per month from May through October (Giambelluca et al. 2013), defining distinct wet and dry periods on Oahu. Predicted HAHOBA occupancy across Oahu (Figure 11) suggests that the drier mid-elevation areas are more consistently occupied throughout the year, while the leeward and more arid side of the island is preferred during the rainy season occurring principally during the pre-pregnancy season. Therefore, the HAHOBA distribution is most contracted during the wet period, when dry or mesic habitats appear to be preferred over wet habitats.

The U2 microphone yielded higher detection rates than the U1 microphone for every season except the lactation season, when the U1 microphone performed slightly better. The apparent higher detection rate for the U1 microphone during the lactation season is not readily explainable; however, accounting for this difference in the modeling approach is still important and ameliorates the concern that trends in occupancy may have resulted from the change in microphones.

Detection counts examined over time indicate some potential effects of external factors (Appendix C). Daily detections never exceeded 34 at Site-095 until late-summer of 2021 (Appendix C18), when daily detections numbered in the hundreds off and on for over a month. It was noted that invasive vegetation had been cut and removed at this site near the time of the spike in bat activity, suggesting that bat foraging habitat may have improved as a result of the vegetation treatment.

This study and modeling exercise examined main effects of site-level land cover covariates on occupancy rates and acoustic detector microphone models on detection rates independently by season to explore annual trends in occupancy and seasonal distribution of HAHOBA on Oahu. However, this 4-year data set of daily HAHOBA detections also provides a rich basis for additional modeling. Future work could include adding temporal covariates for detection modeling such as Julian date, month, and moon phase cycles. We did not account for environmental variables such as rainfall and temperature data because these data were not available at the site level. However, island-wide means of environmental covariates might provide useful information for modeling annual fluctuations in occupancy rates. Additionally, detection rates could be modeled as a function of habitat covariates to account for differences in echolocation activity in forested vs. non-forested sites (Gorresen et al. 2013). An occupancy model could be developed across all reproductive seasons with extinction and colonization parameters modeled as a function of season, year, and/or habitat covariates. A multistate occupancy analysis (Gorresen et al. 2018) to identify factors associated with high-use areas could provide additional information on habitat selection. Interactions and nonlinear relationships among covariates could also be examined.

A power analysis was conducted to assess the sample size of detectors needed to detect 10% or 15% annual trends in lactation-season occupancy rates over a 10-year period. We found that a sample of at least 30 sites was needed to detect a 10% increase in occupancy, and a sample of 20 detectors would be sufficient to detect a 15% increase in occupancy over 10 years. This prospective power analysis indicates that changes in occupancy could be detected with reasonable power for smaller samples of detectors than we have applied in this study. A fifth year of field data are being collected for a subsample of 40 of the 86 detectors reported on herein. This additional data will be used in an updated analysis to assess a 5-year trend in occupancy on Oahu, the minimum time span considered for assessing population stability in the USFWS' Recovery Plan for the Hawaiian Hoary Bat (USFWS 1998). We would suggest that these smaller samples would provide the best basis for inference if spatial balance and the probabilistic selection process used in this study were maintained so that the sampled population matches the target population as closely as possible.

REFERENCES

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A. and Rubin, D. B., 2013. Bayesian data analysis. CRC press.

Giambelluca, T. W., Q. Chen, A. G. Frazier, J. P. Price, Y. L. Chen, P. S. Chu, J. K. Eischeid, and D. M. Delparte, 2013: Online Rainfall Atlas of Hawai‘i. Bull. Amer. Meteor. Soc. 94, 313-316, doi: 10.1175/BAMS-D-11-00228.1. http://rainfall.geography.hawaii.edu/downloads.html

Gorresen, P. M., Brinck, K. W., DeLisle, M. A., Montoya-Aiona, K., Pinzari, C.A., Bonaccorso, F. J. 2018 Multi-state occupancy models of foraging habitat use by the Hawaiian hoary bat (*Lasiurus cinereus semotus*). PLoS ONE 13(10): e0205150. https://doi.org/10.1371/journal.pone.0205150 .

Gorresen, M. P., F. J. Bonaccorso, C. A. Pinzari, C. M. Todd, K. Montoya-Aiona, and K. Brinck. 2013. A Five-Year Study of Hawaiian Hoary Bat (*Lasiurus cinereus Semotus*) Occu Pancy on the Island of Hawai`I. Technical Report HCSU-041. Hawai`i Cooperative Studies Unit. 2 U.S. Geological Survey, Pacific Island Ecosystems Research Center, Kīlauea Field Station. July, 2013. Available online: https://hilo.hawaii.edu/hcsu/documents/TR41_Gorresen_Bat_occupancy.pdf

Hines, J. E., J. D. Nichols, and C. J. A. 2014. Multiseason Occupancy Models for Correlated Replicate Surveys. Methods in Ecology and Evolution 5: 583-591 pp. doi: 10.1111/2041-210X.12186. Available online: https://besjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/2041-210X.12186

LANDFIRE. 2017. Existing Vegetation Type Layer. Landscape Fire and Resource Management Planning Tools Project (LANDFIRE). Department of the Interior (DOI) US Geological Survey (USGS). Last modified February 2017. Available online: http://landfire.cr.usgs.gov/viewer/

MacKenzie, D. I. 2006. Modeling the Probability of Resource Use: The Effect of, and Dealing with, Detecting a Species Imperfectly. Journal of Wildlife Management 70(2): 367-374. doi: 10.2193/0022-541x(2006)70[367:mtporu]2.0.co;2.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Academic Press, Elsevier, Burlington, Massachusetts.

Menard, T. 2001. Activity Patterns of the Hawaiian Hoary Bat (*Lasiurus cinereus Semotus*) in Relation to Reproductive Time Periods. MSc Thesis. University of Hawaii. Available online: https://www.opeapea.org/paper-blog/2019/2/2/Activity%20patterns%20of%20the%20Hawaiian%20hoary%20bat%20(Lasiurus%20cinereus%20semotus)%20in%20relation%20to%20reproductive%20time%20periods.%20MSc%20Thesis,%20University%20of%20Hawaii.

Mitchell, T. J.; Beauchamp, J. J. 1988. Bayesian Variable Selection in Linear Regression. Journal of the American Statistical Association. 83(404):1023–1032.

National Geographic Society (National Geographic). 2020. World Maps. Digital topographic map. PDF topographic map quads. Accessed January 2020. Available online: http://www.natgeomaps.com/trail-maps/pdf-quads

Pinzari, C., K. Montoya-Aiona, D. Gross, and K. Courtot. 2021. Hawaiian Hoary Bat Acoustic Surveys on Marine Corps Base Hawaii, 2019-2021. DOI: 10.5066/P9L9HY6D. Report number: TR-100 University of Hawaii at Hilo. Available online: https://www.researchgate.net/publication/356223824_Hawaiian_hoary_bat_acoustic_surveys_on_Marine_Corps_Base_Hawaii_2019-2021

Plummer, M. 2019. rjags: Bayesian Graphical Models using MCMC. R package version 4-10. https://CRAN.R-project.org/package=rjags.

R Development Core Team. 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Information online: http://www.R-project.org/

Starcevich, L. A., J. Thompson, T. Rintz, E. Adamczyk, and D. Solick. 2019. Oahu Hawaiian Hoary Bat Occupancy and Distribution Study: Project Update and First-Year Analysis. Prepared for Hawaii Endangered Species Research Committee. Western Ecosystems Technology, Inc. Corvallis, OR.

Starcevich, L. A., J. Thompson, T. Rintz, E. Adamczyk, M. Martin, and D. Solick. 2020. Oahu Hawaiian Hoary Bat Occupancy and Distribution Study: Project Update and Second Year Analysis. Prepared for Hawaii Endangered Species Research Committee. Western Ecosystems Technology, Inc. Corvallis, OR.

Stevens, D. L., Jr. and A. R. Olsen. 2003. Variance Estimation for Spatially Balanced Samples of Environmental Resources. Environmetrics 14(6): 593-610 pp. doi: 10.1002/env.606. Available online: https://onlinelibrary.wiley.com/doi/abs/10.1002/env.606

Stevens, D. L., Jr. and A. R. Olsen. 2004. Spatially Balanced Sampling of Natural Resources. Journal of the American Statistical Association 99(465): 262-278. doi: 10.1198/016214504000000250.

Thompson, J., and L.A. Starcevich. 2021. Oahu Hawaiian Hoary Bat Occupancy and Distribution Study: Project Update and Third-Year Analysis. Prepared for Hawaii Endangered Species Research Committee. Western Ecosystems Technology, Inc. Corvallis, OR.

US Census Bureau. 2019. 2010 Census - Block Maps. Last update: March 14, 2019. Accessed July 2022. Available online: https://www.census.gov/geographies/reference-maps/2010/geo/_2010-census-block-maps.html

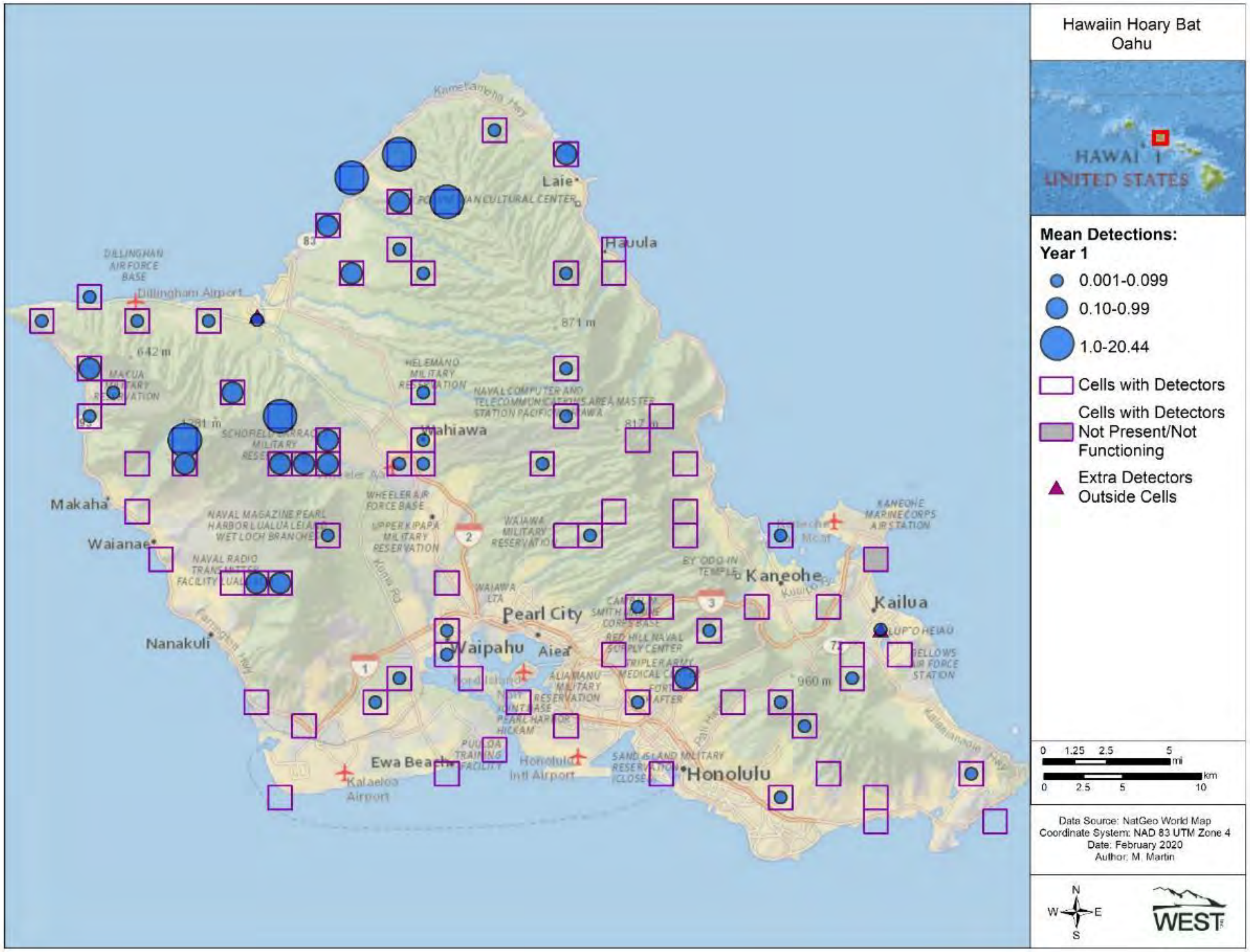
US Geological Survey (USGS). 2017. USGS National Elevation Dataset (NED). State of North Dakota, State Water Commission. Last updated February 27, 2019. Available online: https://catalog.data.gov/dataset/usgs-national-elevation-dataset-ned

US Fish and Wildlife Service (USFWS). 1998. Recovery Plan for the Hawaiian Hoary Bat. U.S. Fish and Wildlife Service, Portland, OR. 50 pp. Available online: https://ecos.fws.gov/docs/recovery_plans/1998/980511b.pdf

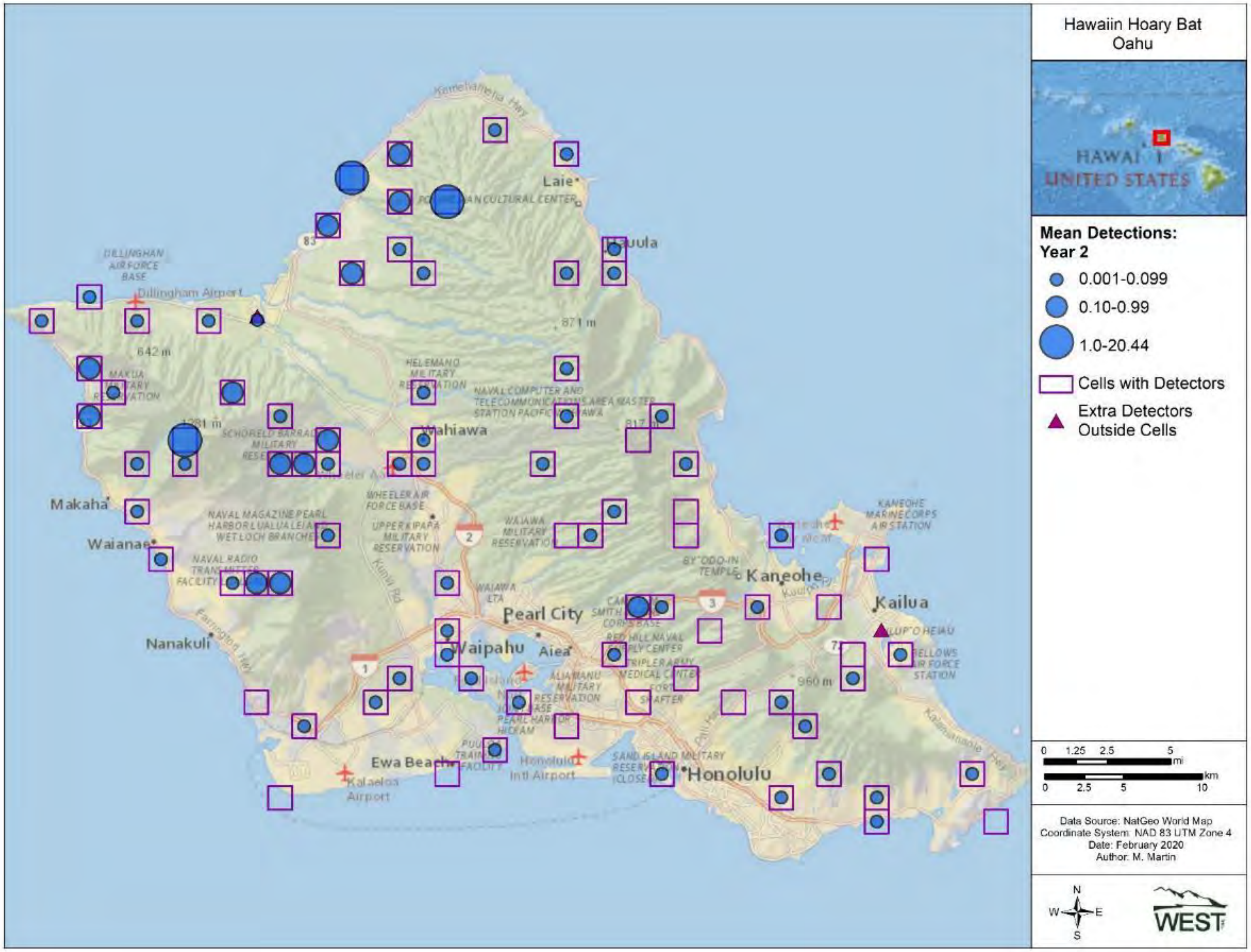
Wildlife Acoustics, Inc. 2019. Kaleidoscope Pro® Version 5.1.0. (Acoustic analysis computer software). Wildlife Acoustics, Maynard, Massachusetts. Information online: www.wildlifeacoustics.com

Wright, W. J., K. M. Irvine, and T. J. Rodhouse. 2016. A Goodness-of-Fit Test for Occupancy Models with Correlated within-Season Revisits. Ecology and Evolution 6(15): 5404-5415 pp. doi: 10.1002/ece3.2292. Available online: https://onlinelibrary.wiley.com/doi/full/10.1002/ece3.2292

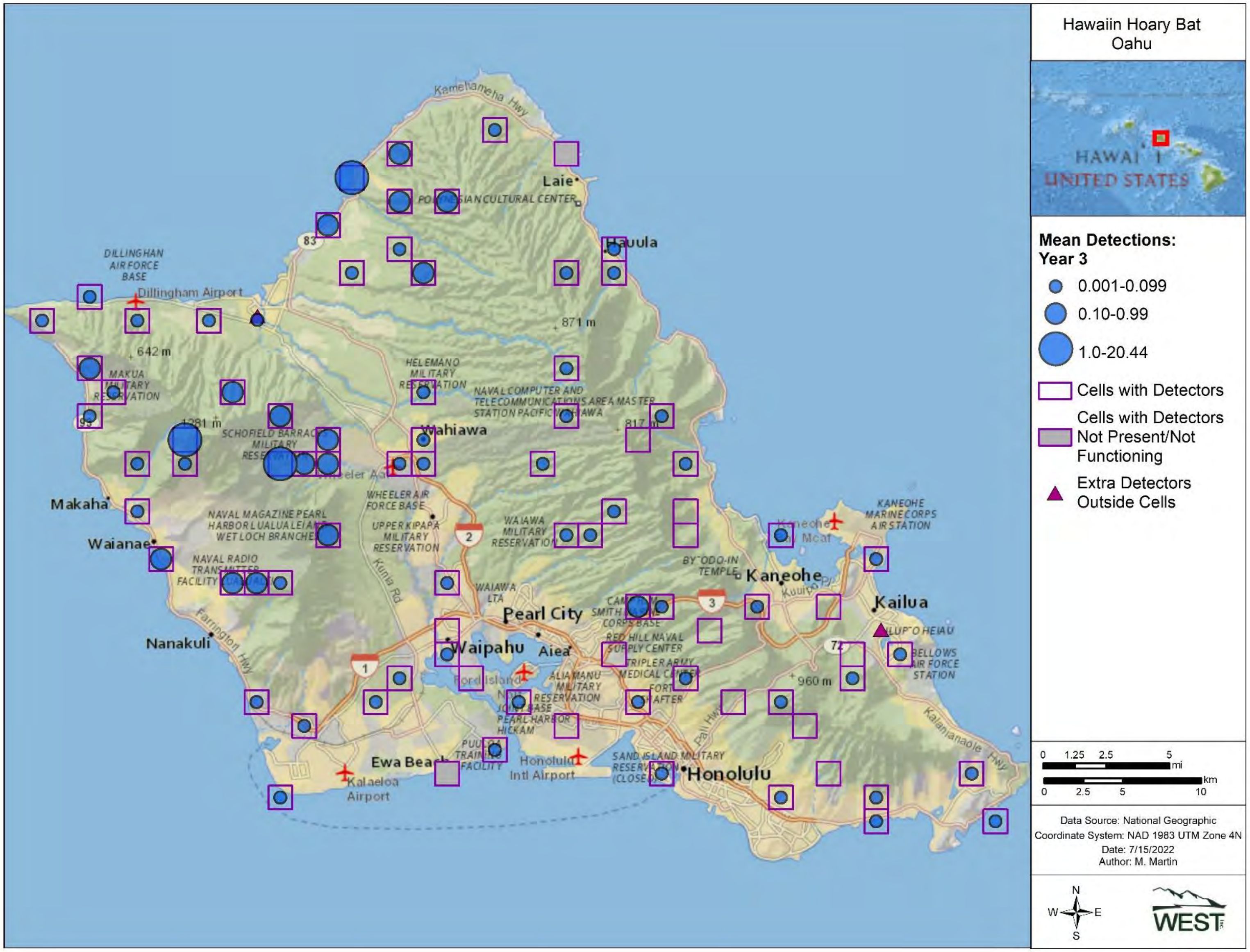
Appendix A. Mean Detections per Detector Night by Site, Season, and Year.



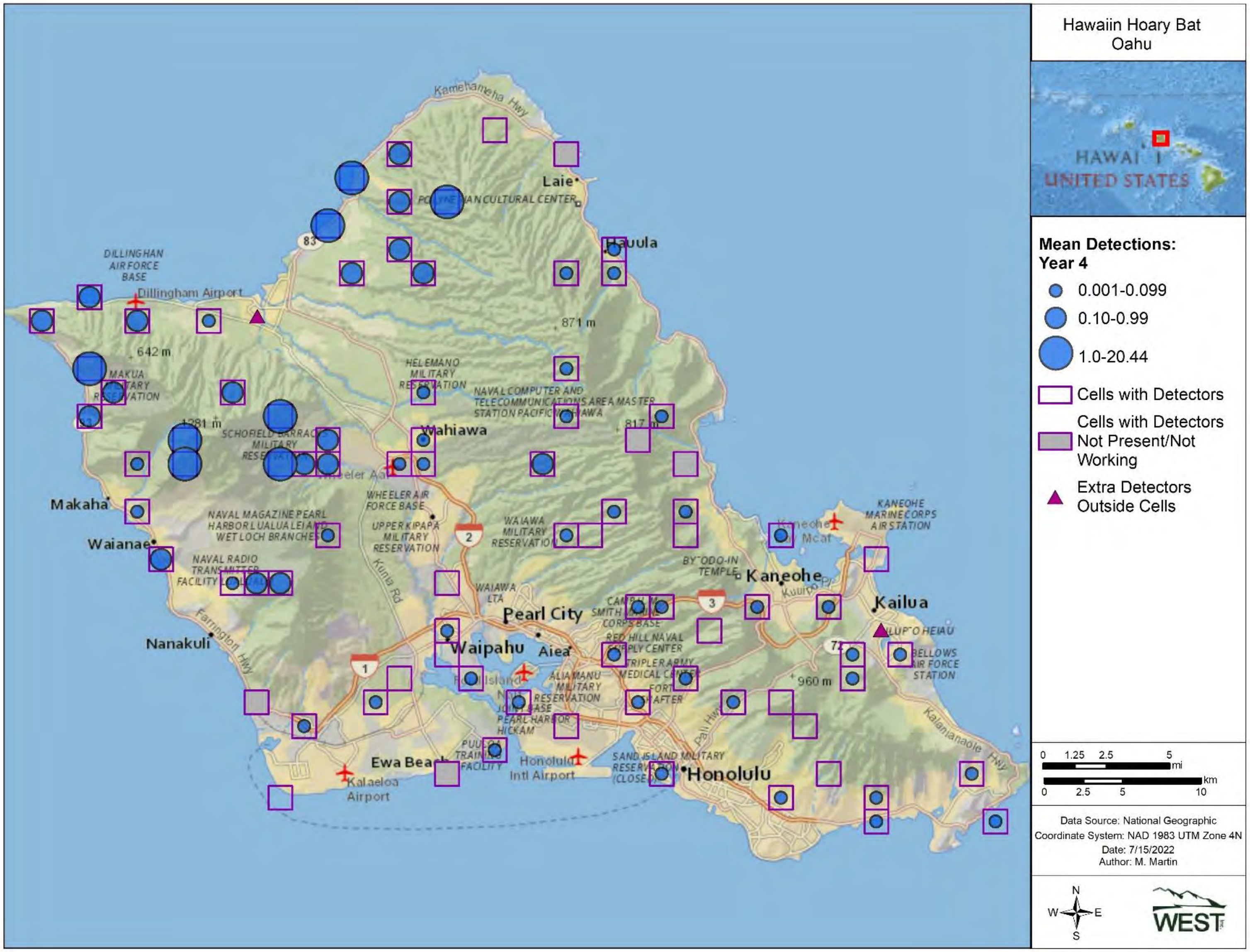
Appendix A1. Mean detections per detector night by site between June 2017 and June 2018.



Appendix A2. Mean detections per detector night by site between June 2018 and June 2019.

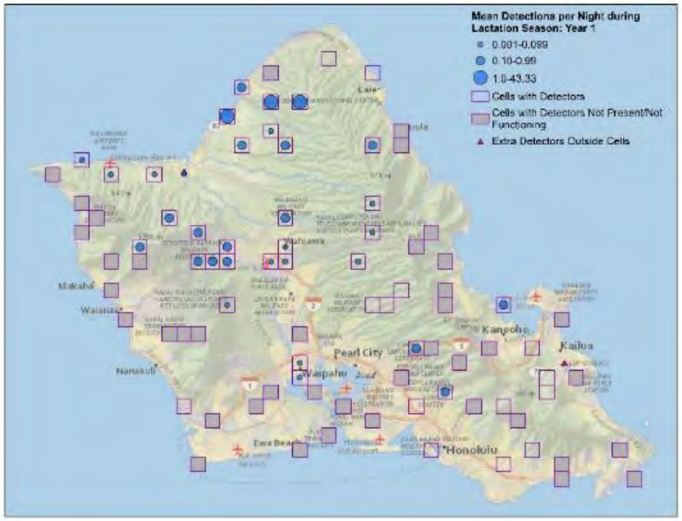


Appendix A3. Mean detections per detector night by site between June 2019 and August 2020.

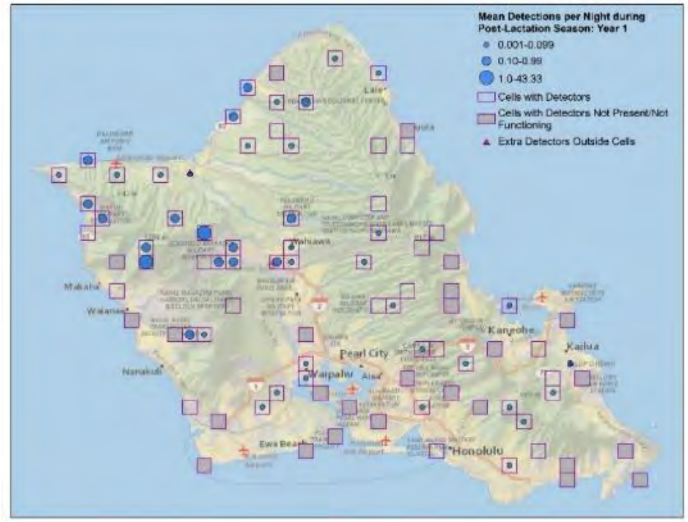


Appendix A4. Mean detections per detector night by site between August 2020 and October 2021.

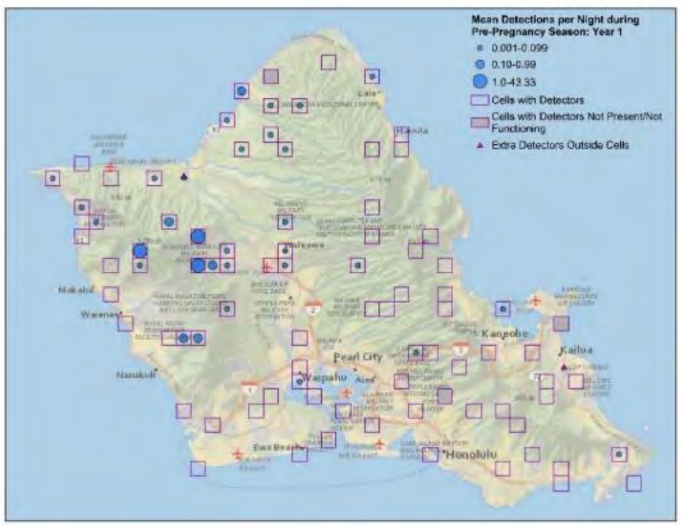
Lactation season (mid-June through August)



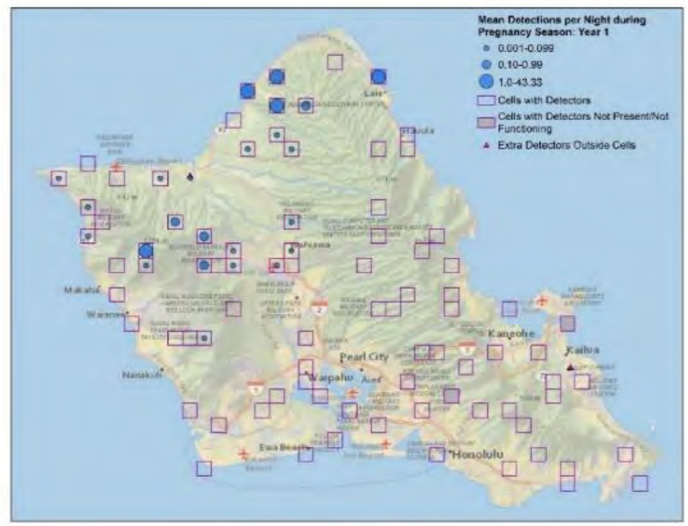
Post-Lactation season (September through mid-December)



Pre-Pregnancy season (mid-December through March)

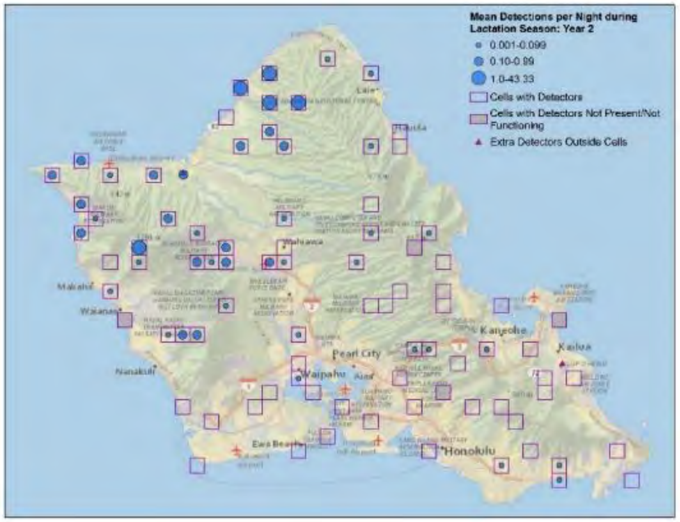


Pregnancy season (April through mid-June)

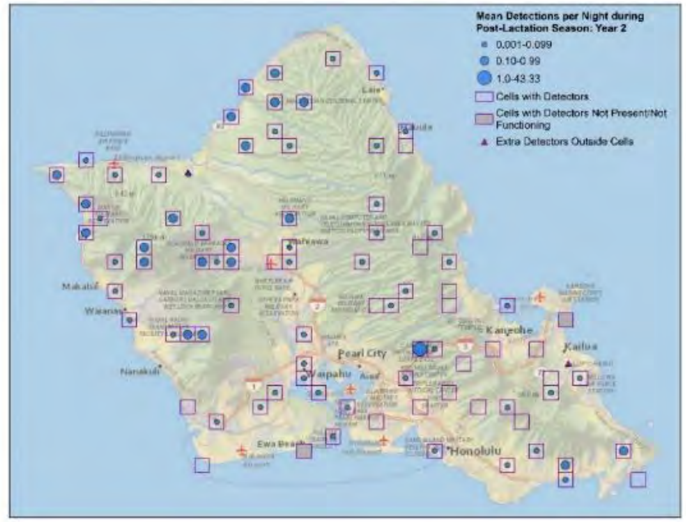


Appendix A5. Mean detections per night by site and season between June 2017 and June 2018.

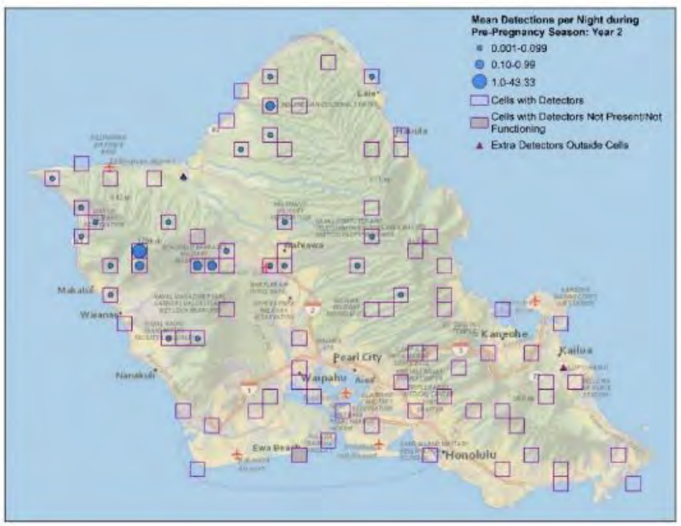
Lactation season (mid-June through August)



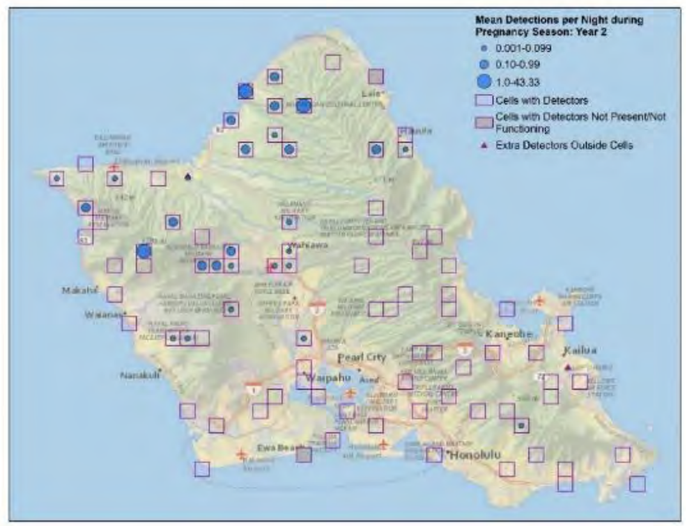
Post-Lactation season (September through mid-December)



Pre-Pregnancy season (mid-December through March)

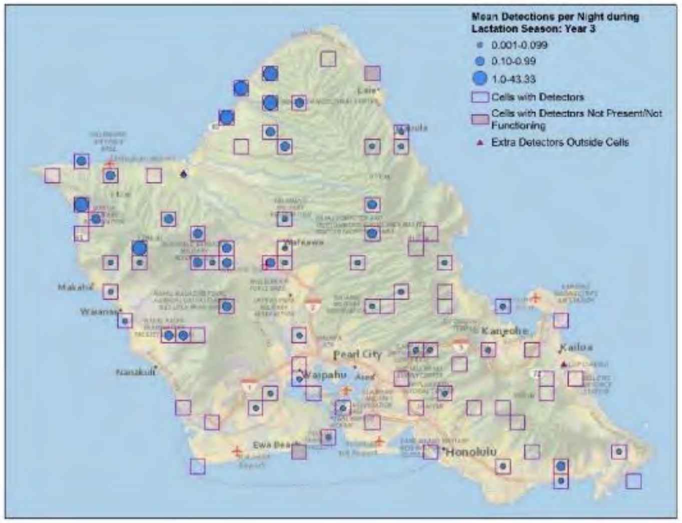


Pregnancy season (April through mid-June)

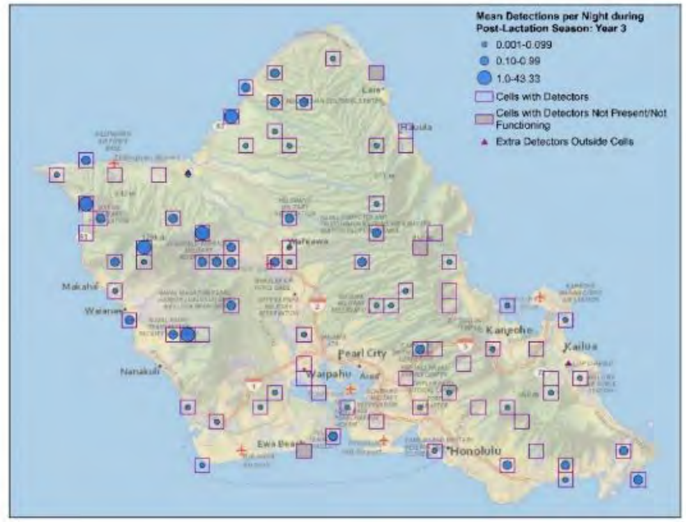


Appendix A6. Mean detections per night by site and season between June 2018 and June 2019.

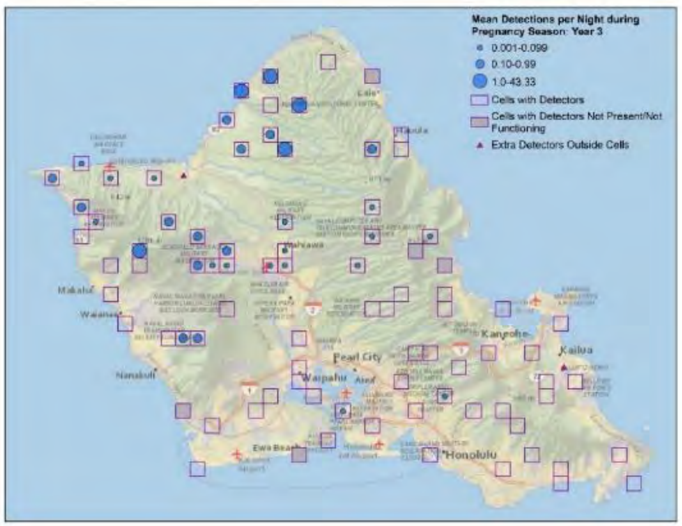
Lactation season (mid-June through August)



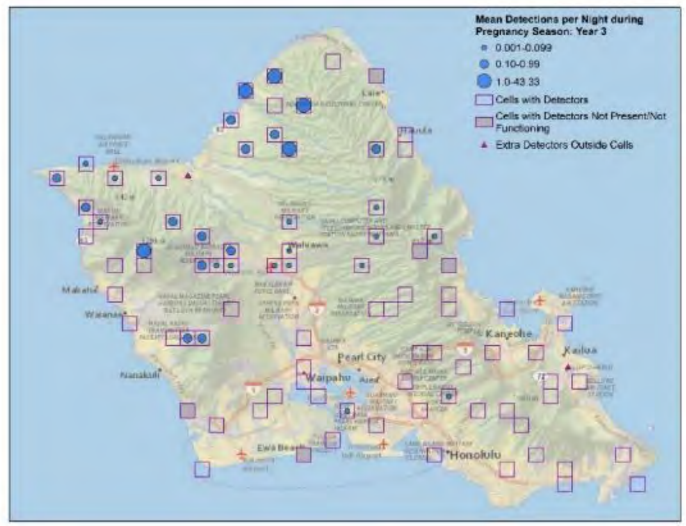
Post-Lactation season (September through mid-December)



Pre-Pregnancy season (mid-December through March)

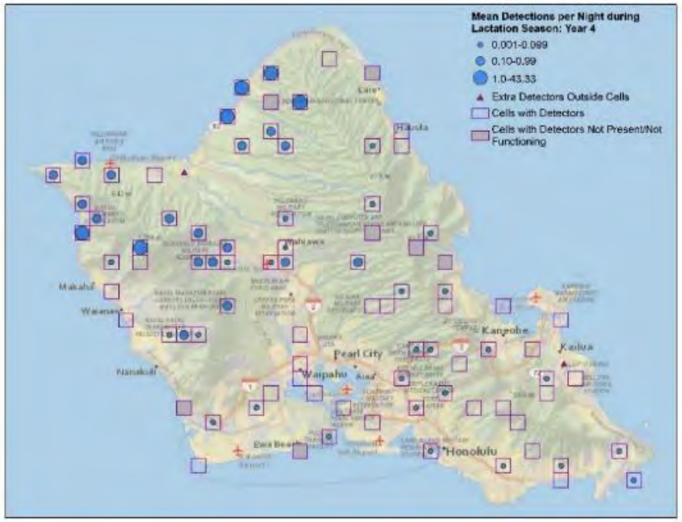


Pregnancy season (April through mid-June)

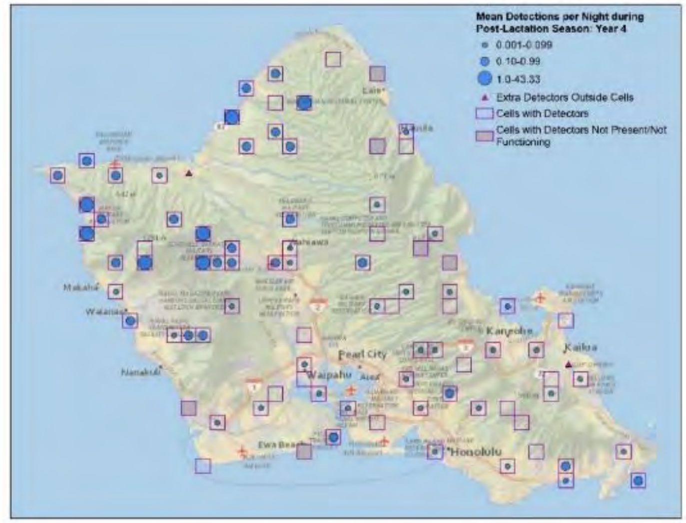


Appendix A7. Mean detections per night by site and season between June 2019 and August 2020.

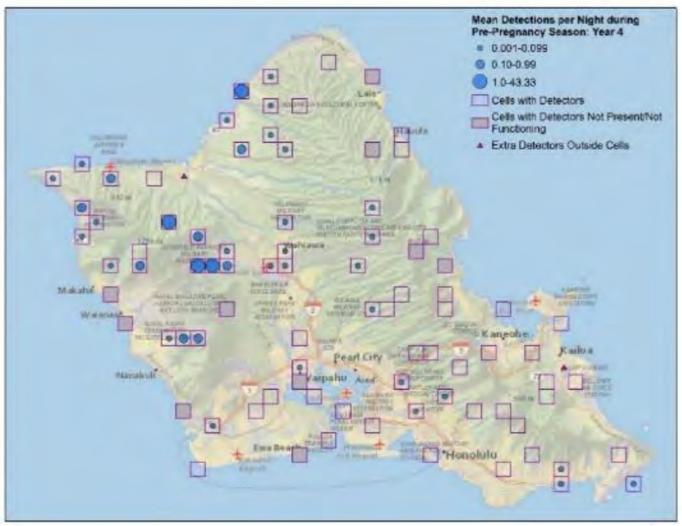
Lactation season (mid-June through August)



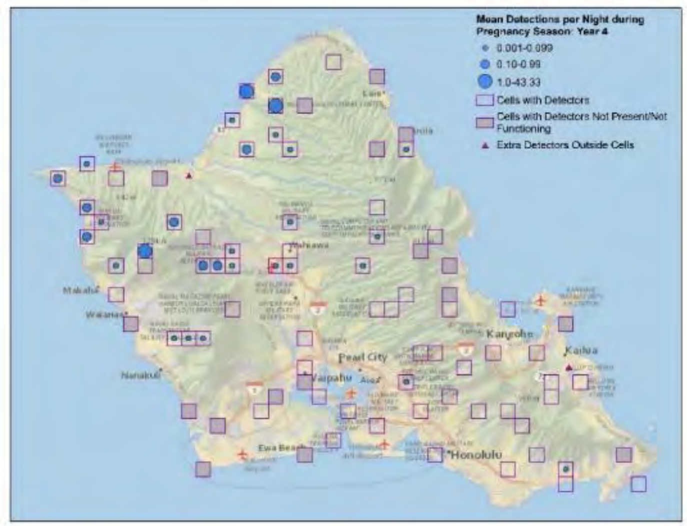
Post-Lactation season (September through mid-December)



Pre-Pregnancy season (mid-December through March)

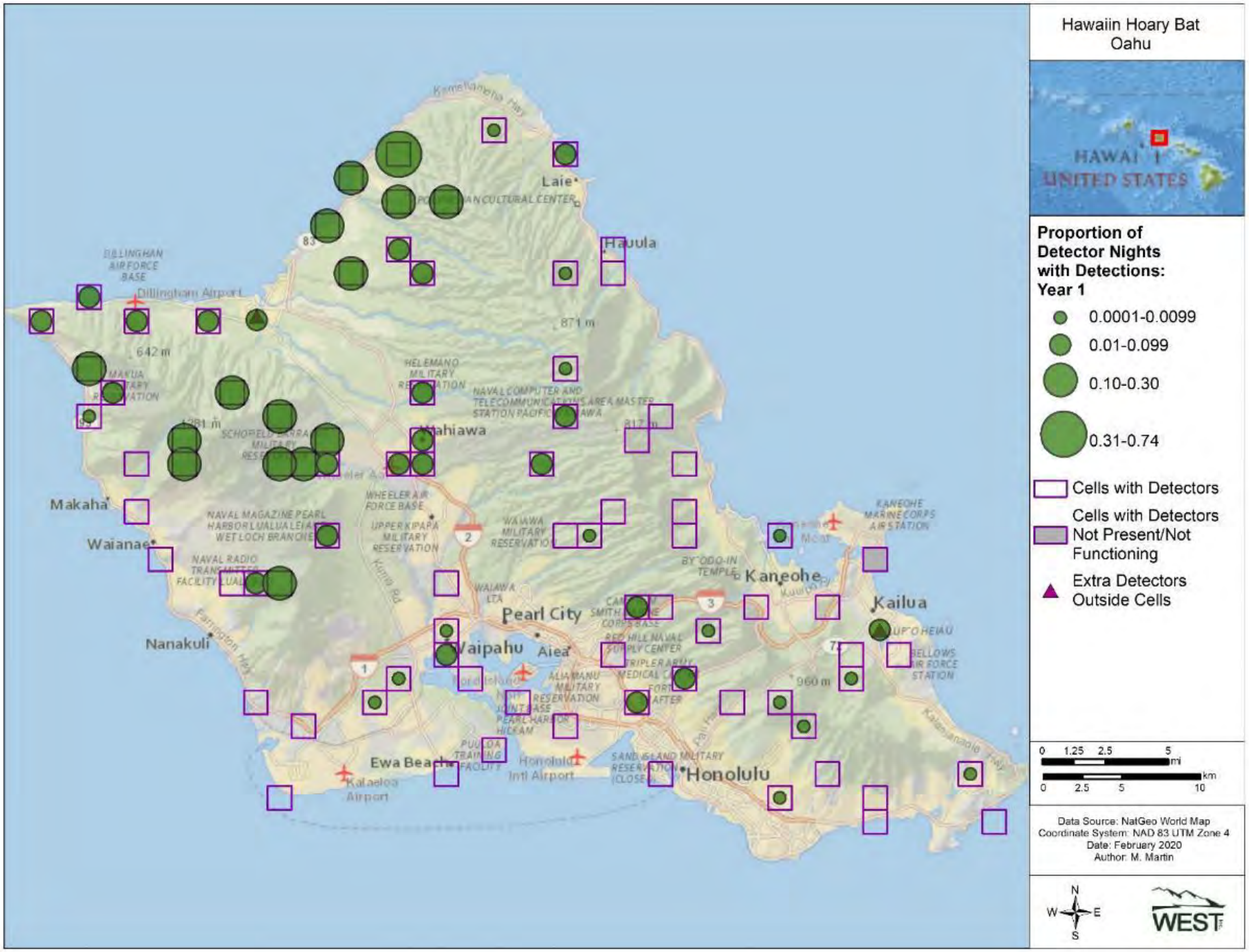


Pregnancy season (April through mid-June)

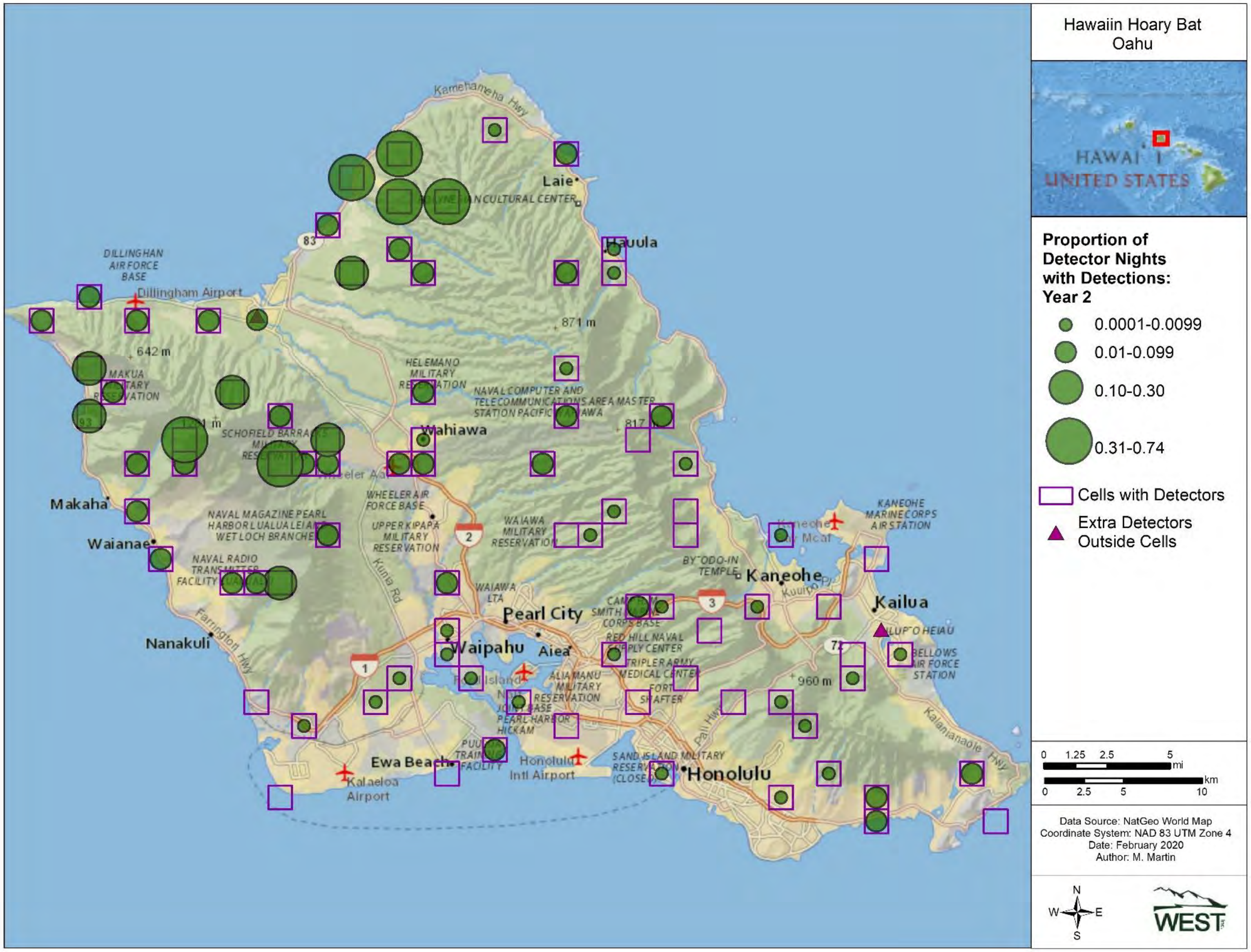


Appendix A8. Mean detections per night by site and season between August 2020 and October 2021.

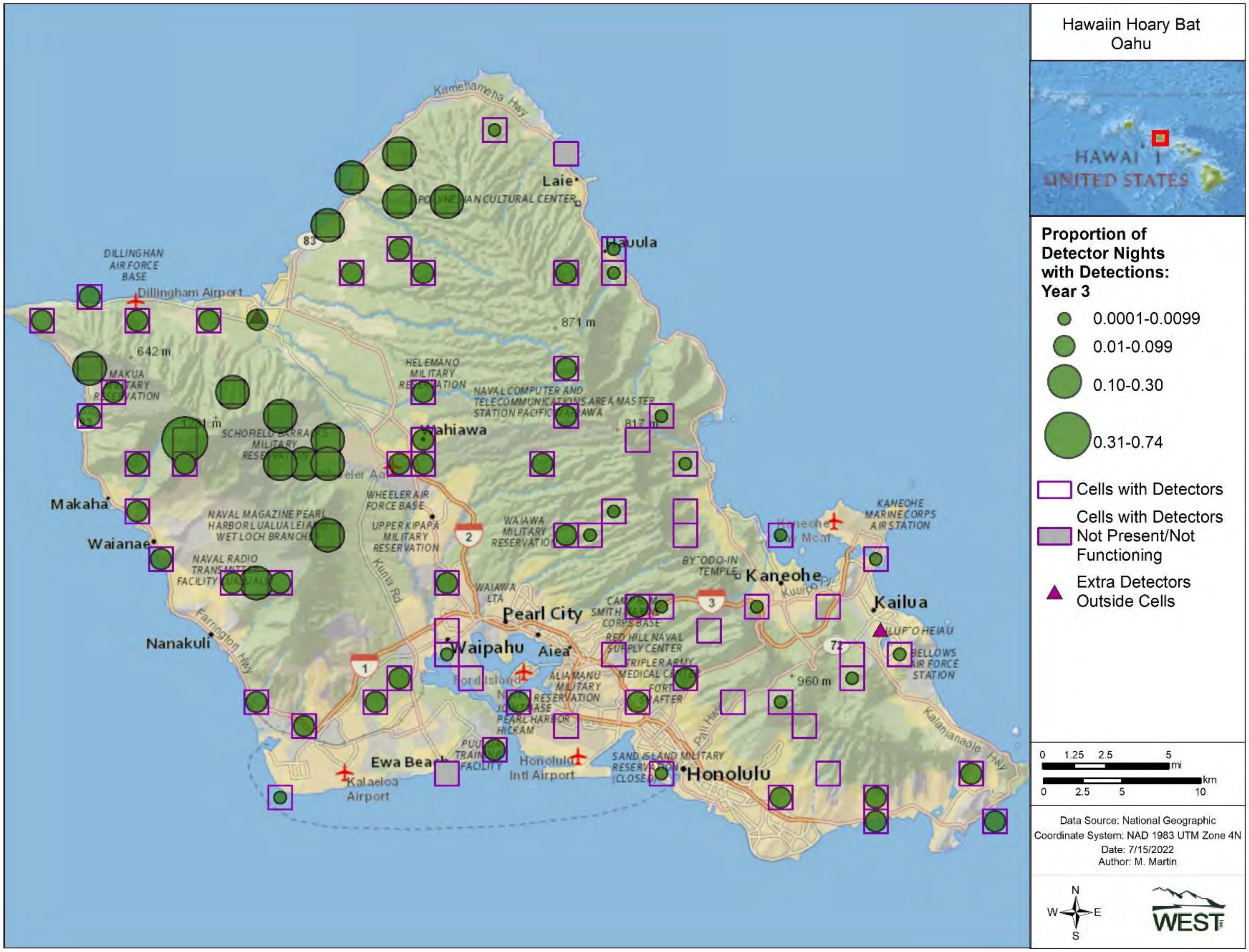
Appendix B. Proportion of Detector Nights with Detections by Site, Season, and Year.



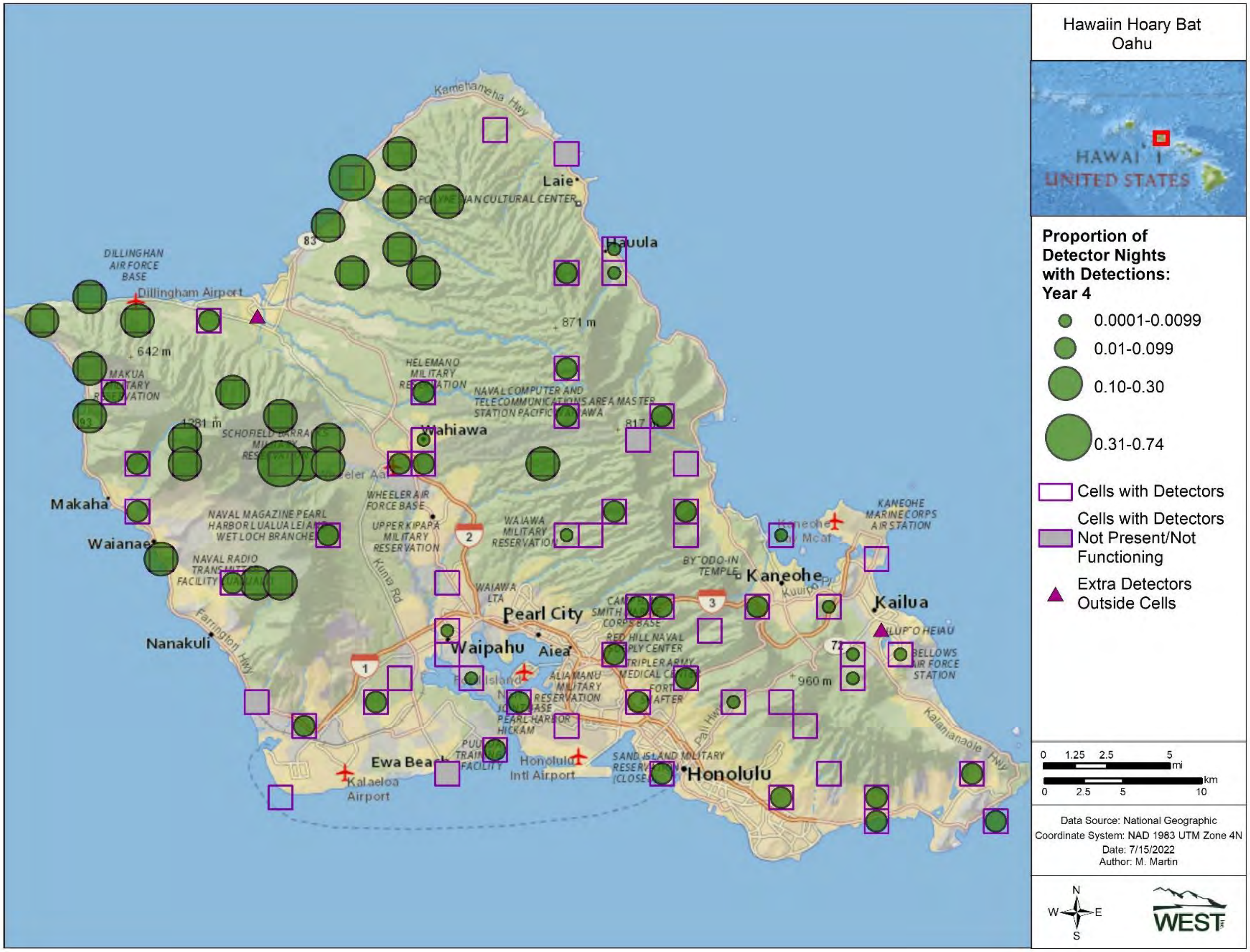
Appendix B1. Proportion of nights with detections by site between June 2017 and June 2018.



Appendix B2. Proportion of nights with detections by site between June 2018 and June 2019.

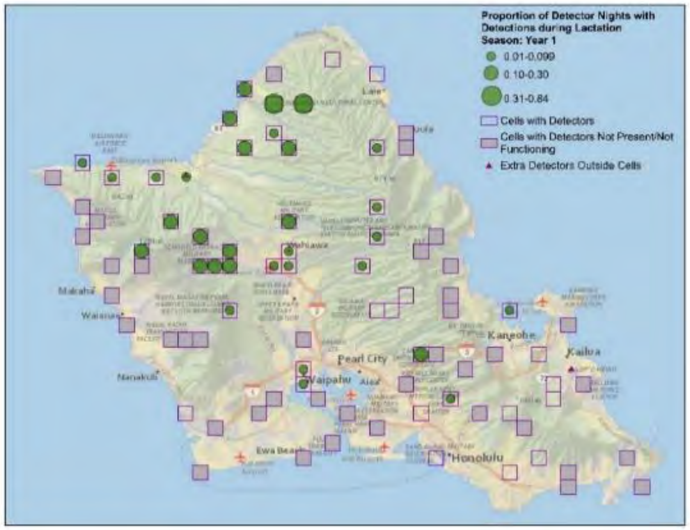


Appendix B3. Proportion of nights with detections by site between June 2019 and August 2020.

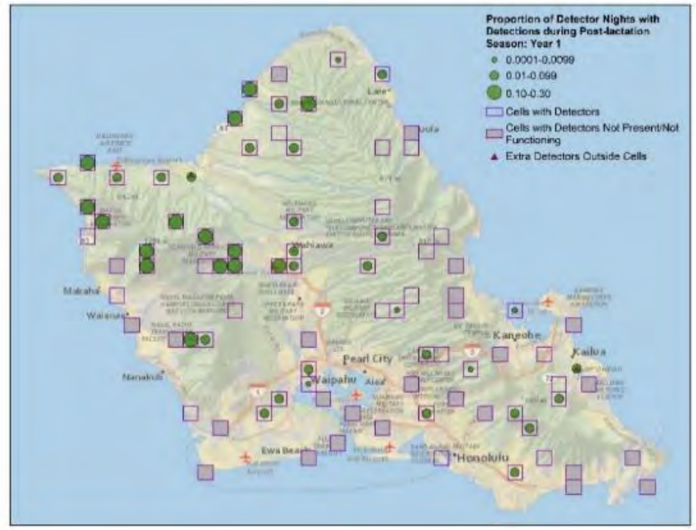


Appendix B4. Proportion of nights with detections by site between August 2020 and October 2021.

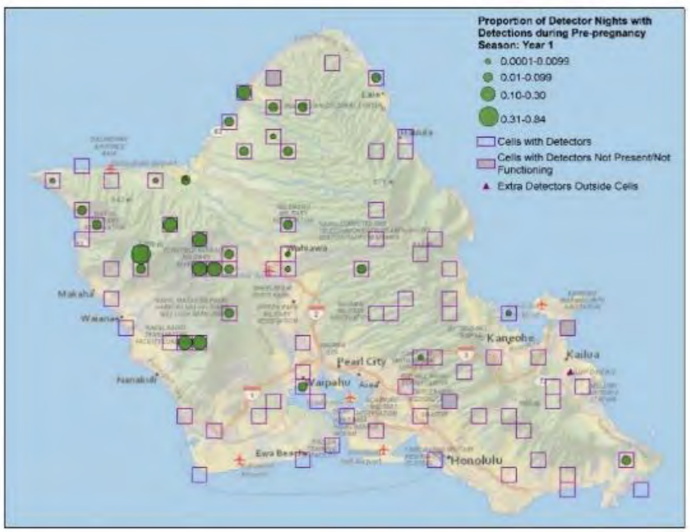
Lactation season (mid-June through August)



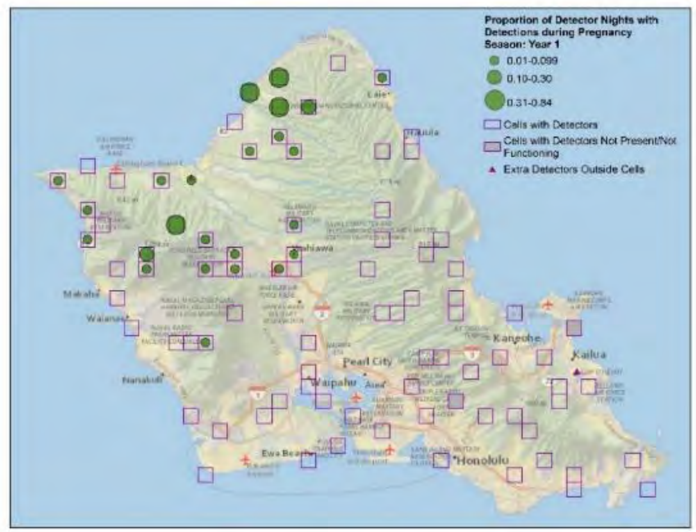
Post-Lactation season (September through mid-December)



Pre-Pregnancy season (mid-December through March)

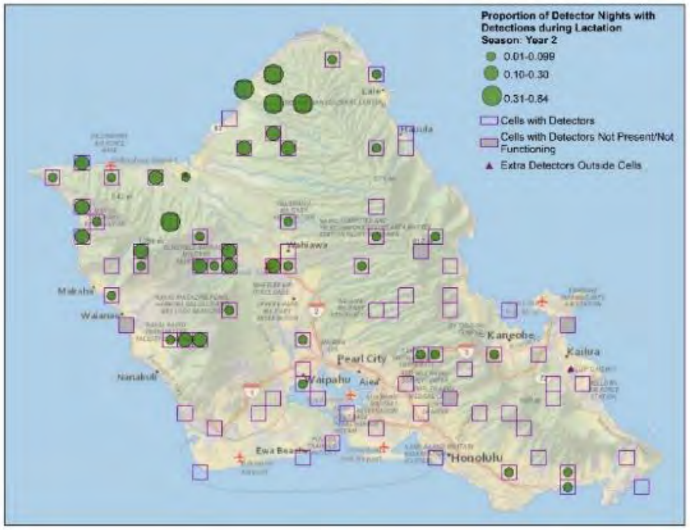


Pregnancy season (April through mid-June)



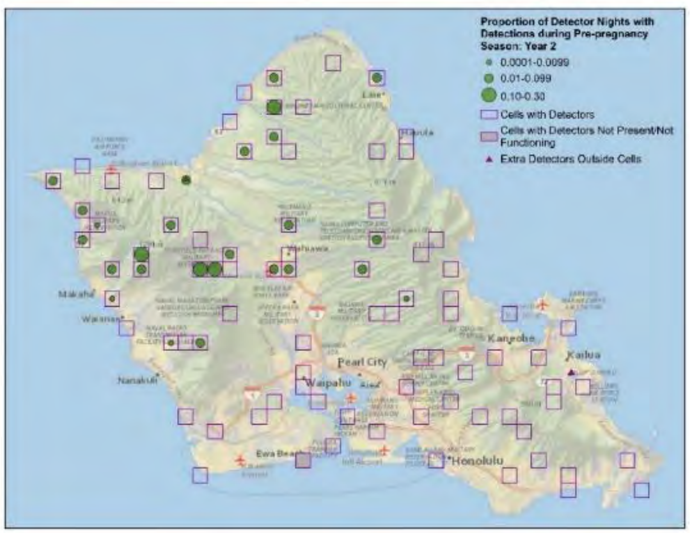
Appendix B5. Proportion of detector nights with detections by site and season between June 2017 and June 2018.

Lactation season (mid-June through August)

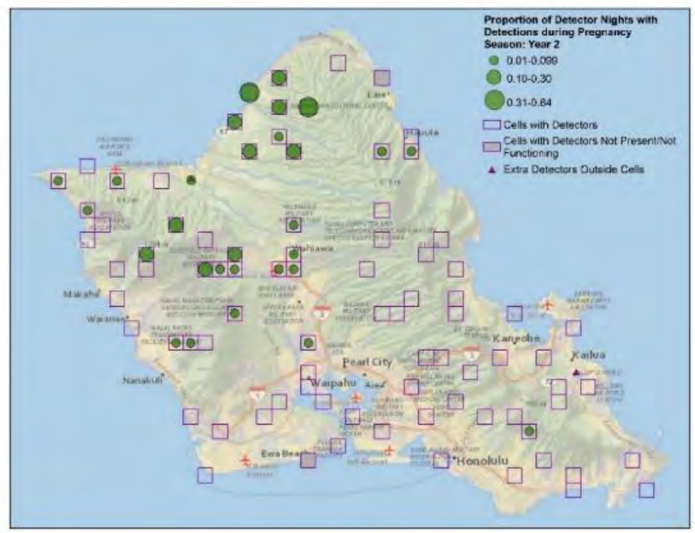


Post-Lactation season (September through mid-December)

Pre-Pregnancy season (mid-December through March)

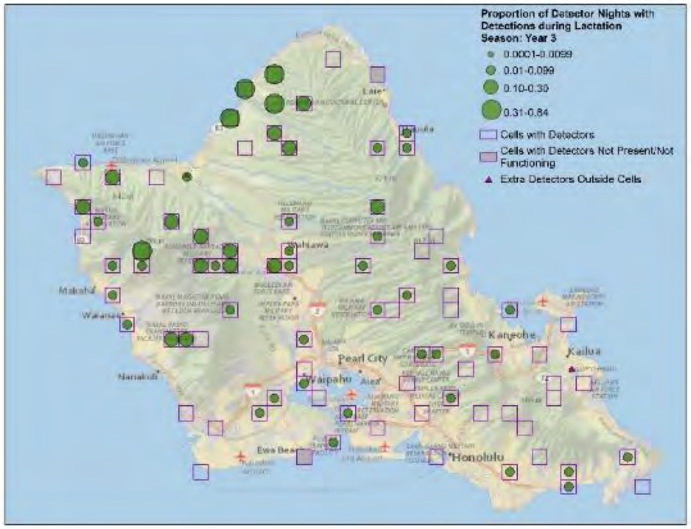


Pregnancy season (April through mid-June)

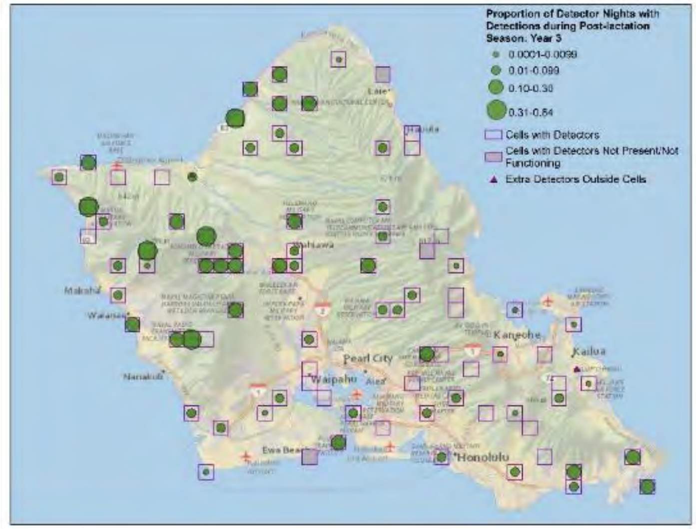


Appendix B6. Proportion of detector nights with detections by site and season between June 2018 and June 2019.

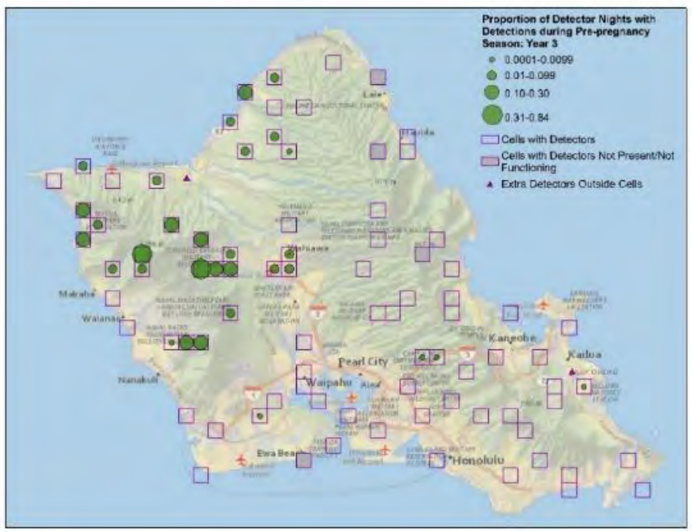
Lactation season (mid-June through August)



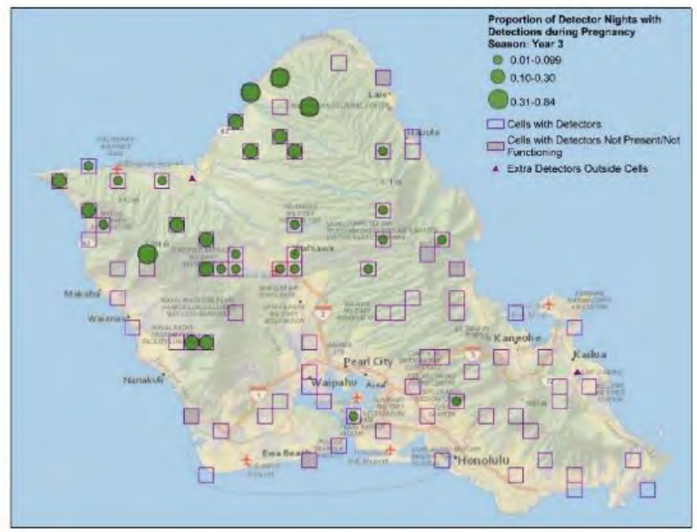
Post-Lactation season (September through mid-December)



Pre-Pregnancy season (mid-December through March)

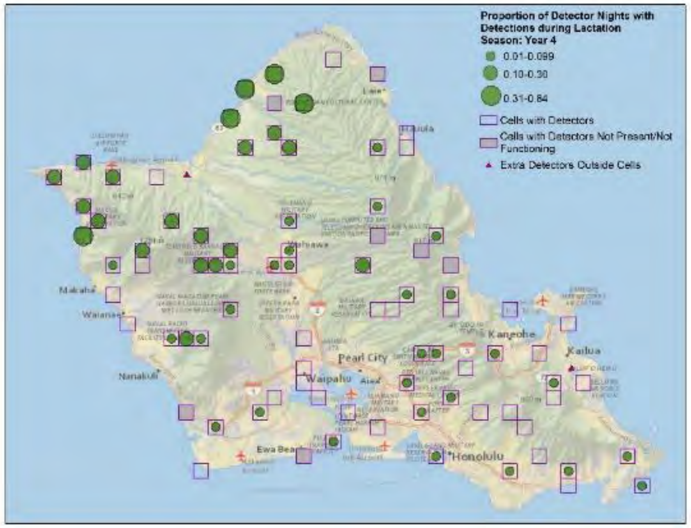


Pregnancy season (April through mid-June)

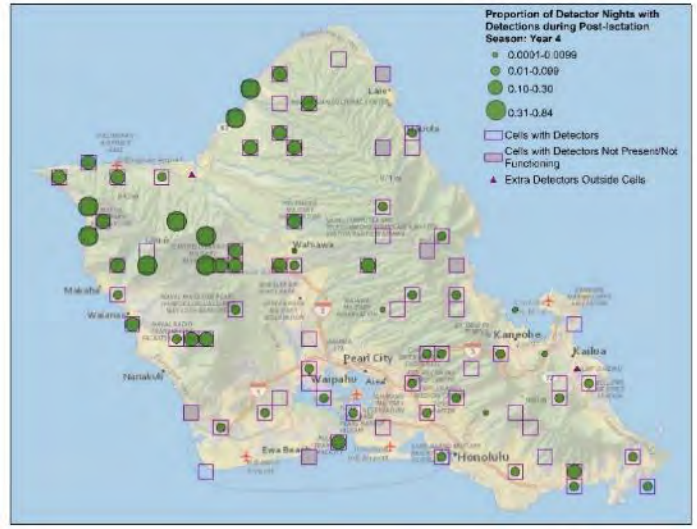


Appendix B7. Proportion of detector nights with detections by site and season between June 2019 and August 2020.

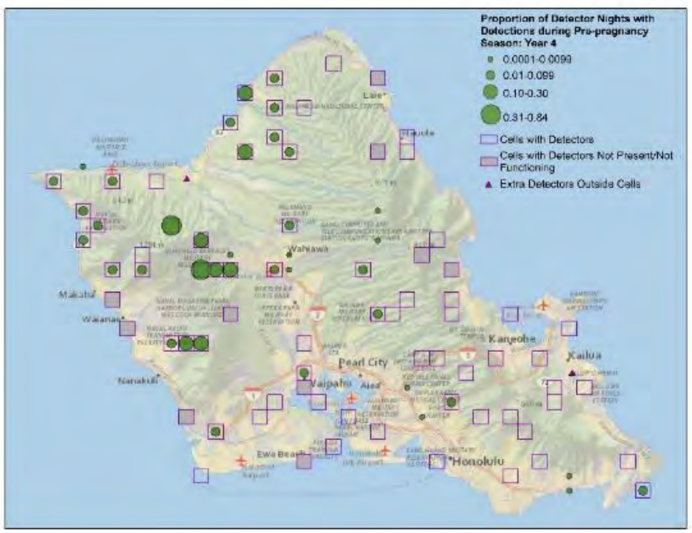
Lactation season (mid-June through August)



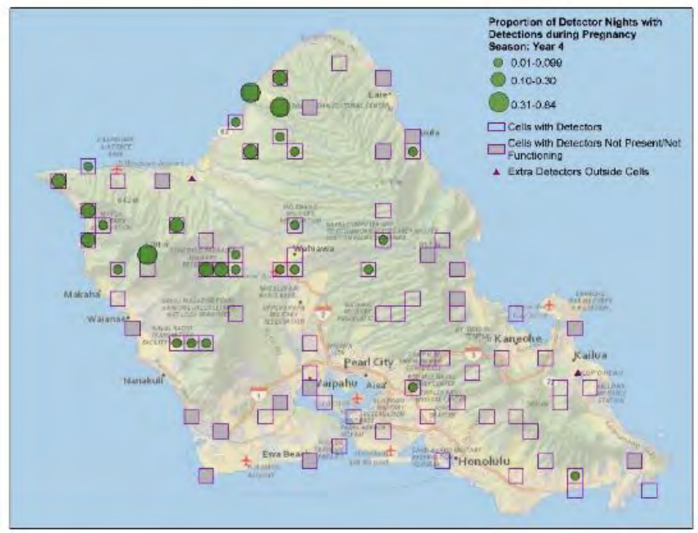
Post-Lactation season (September through mid-December)



Pre-Pregnancy season (mid-December through March)

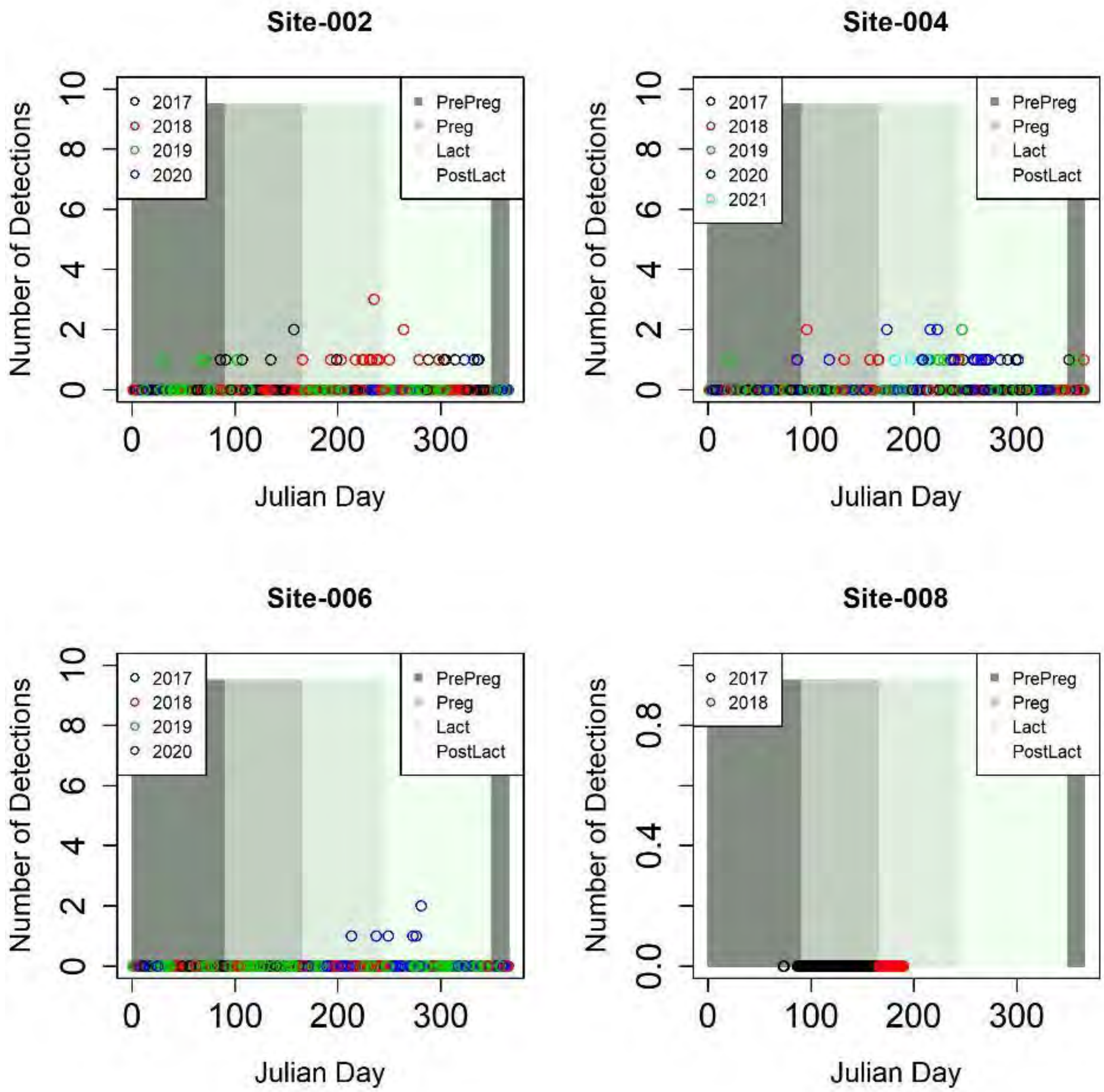


Pregnancy season (April through mid-June)

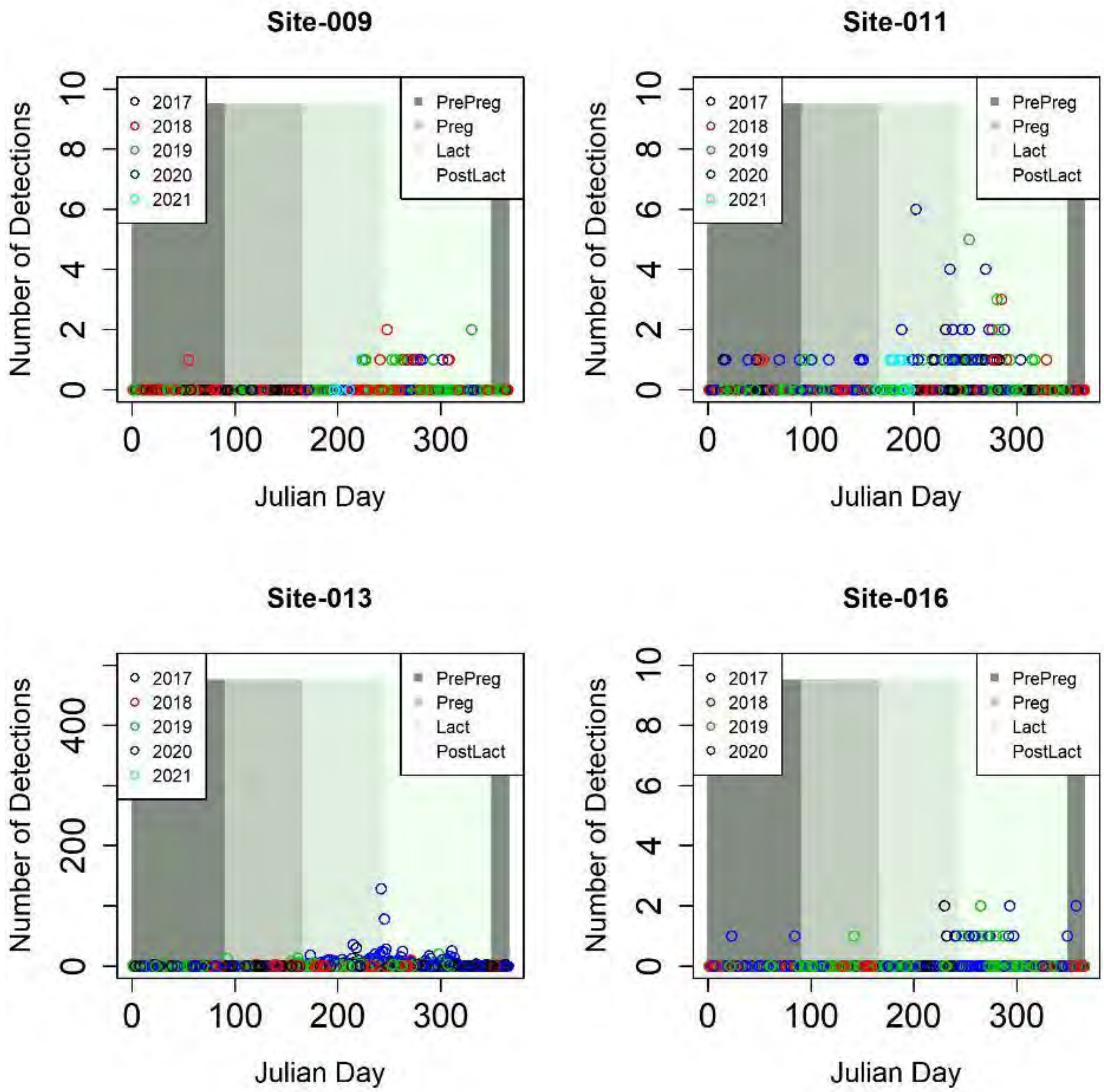


Appendix B8. Proportion of detector nights with detections by site and season between August 2020 and October 2021.

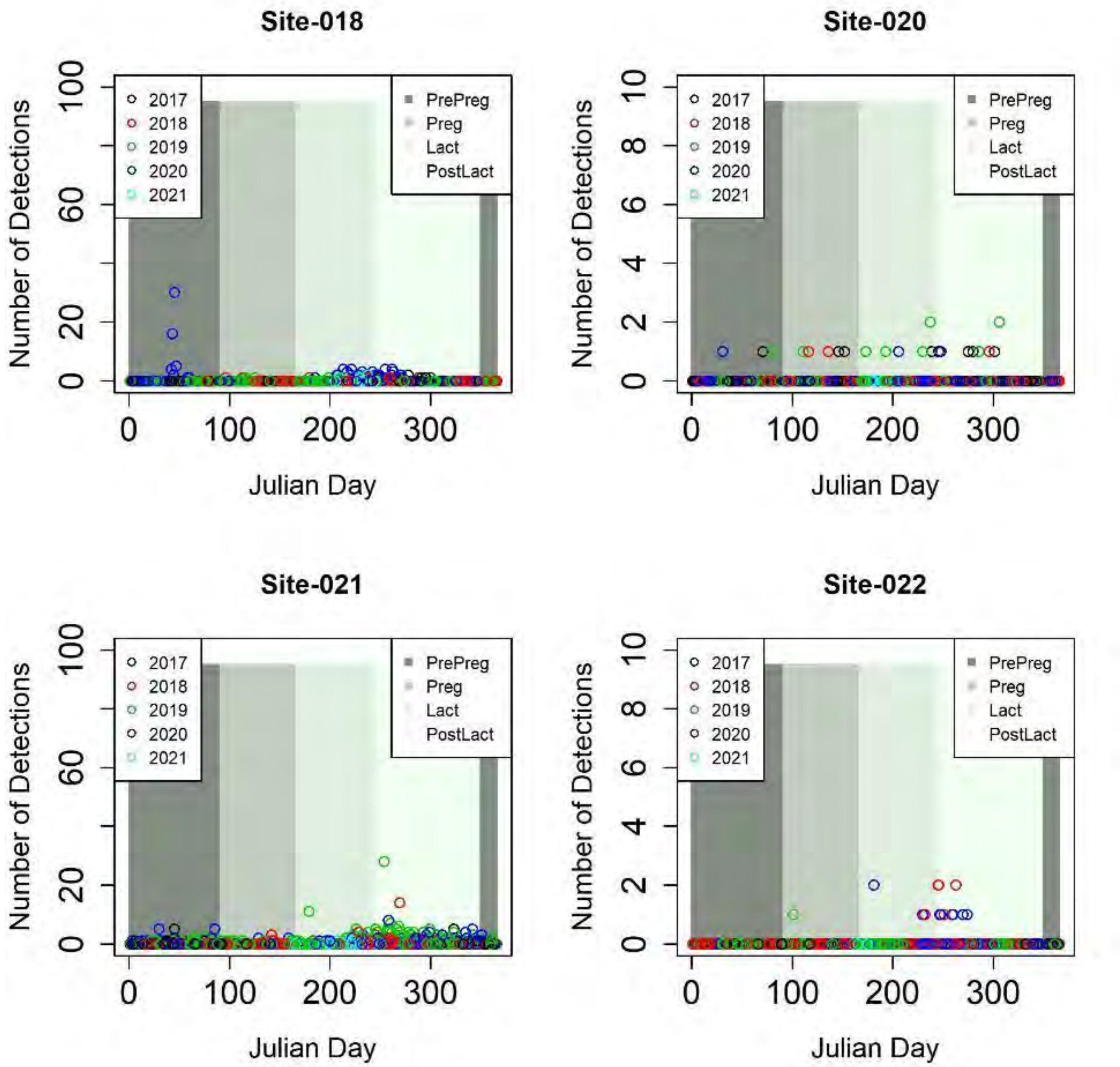
Appendix C. Hawaiian Hoary Bat Acoustic Detections by Julian Date and Detector.



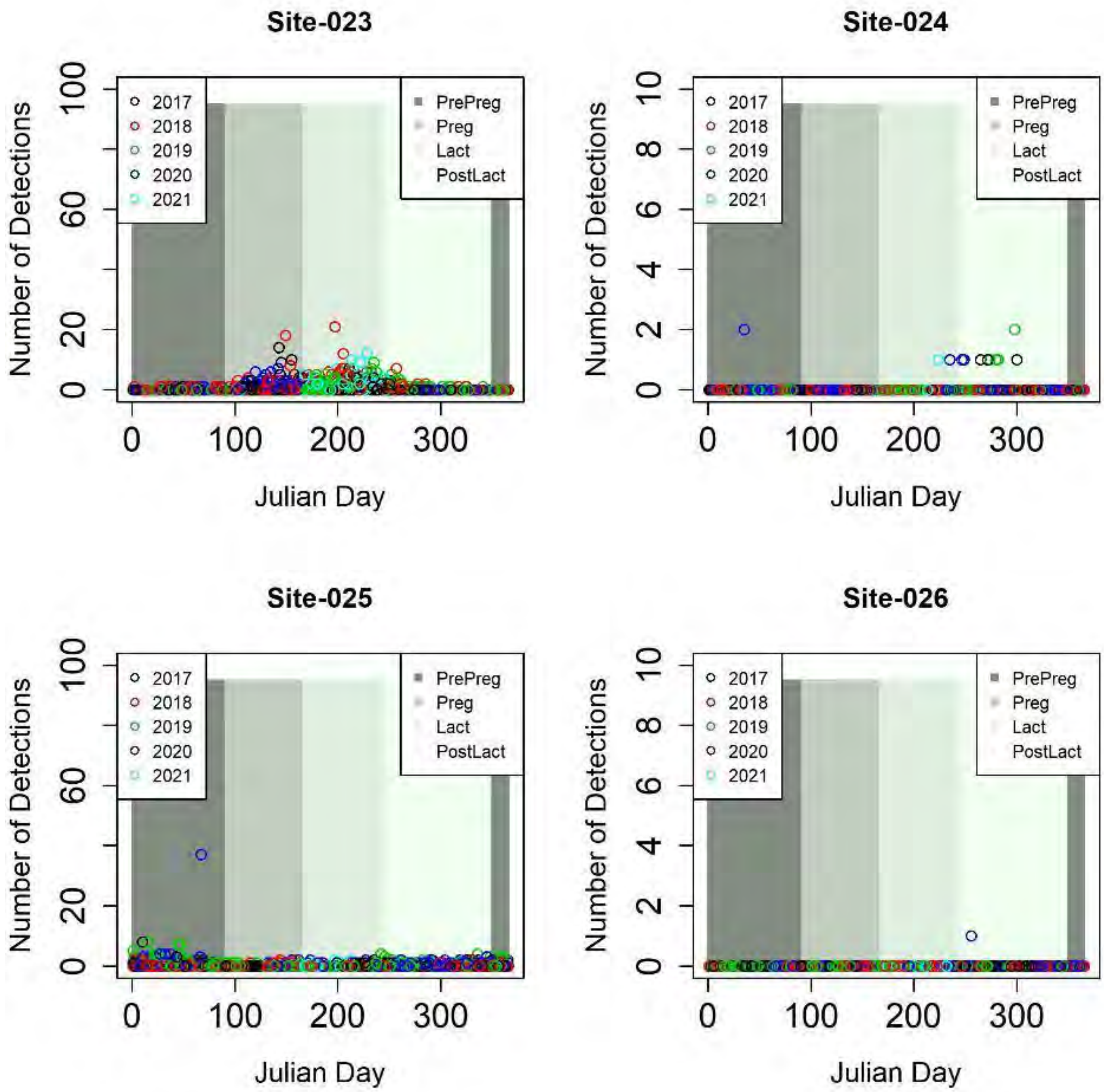
Appendix C1. Bat detections by Julian day and survey year for sites 002, 004, 006, and 008.



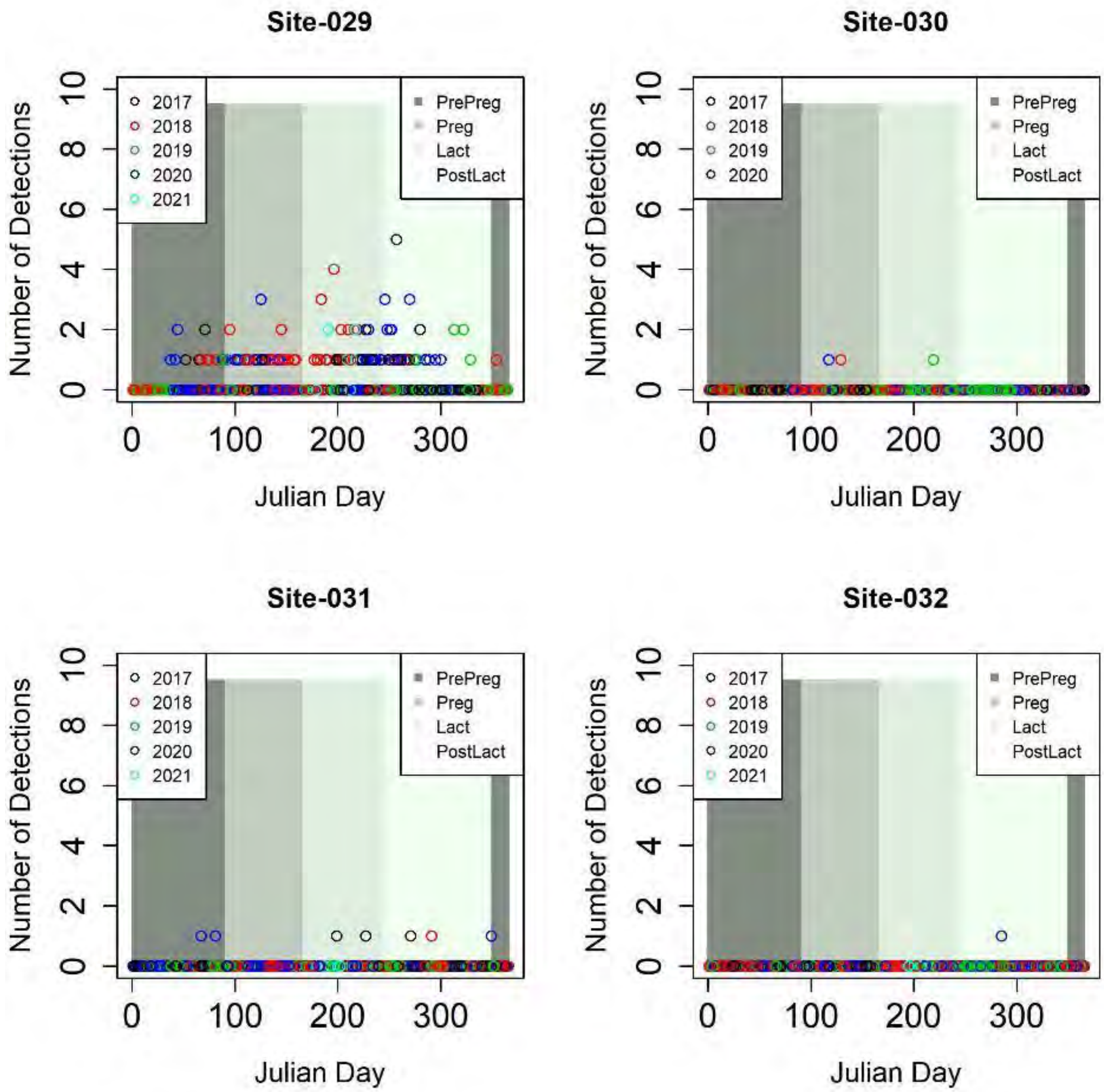
Appendix C2. Bat detections by Julian day and survey year for sites 009, 011, 013, and 016.



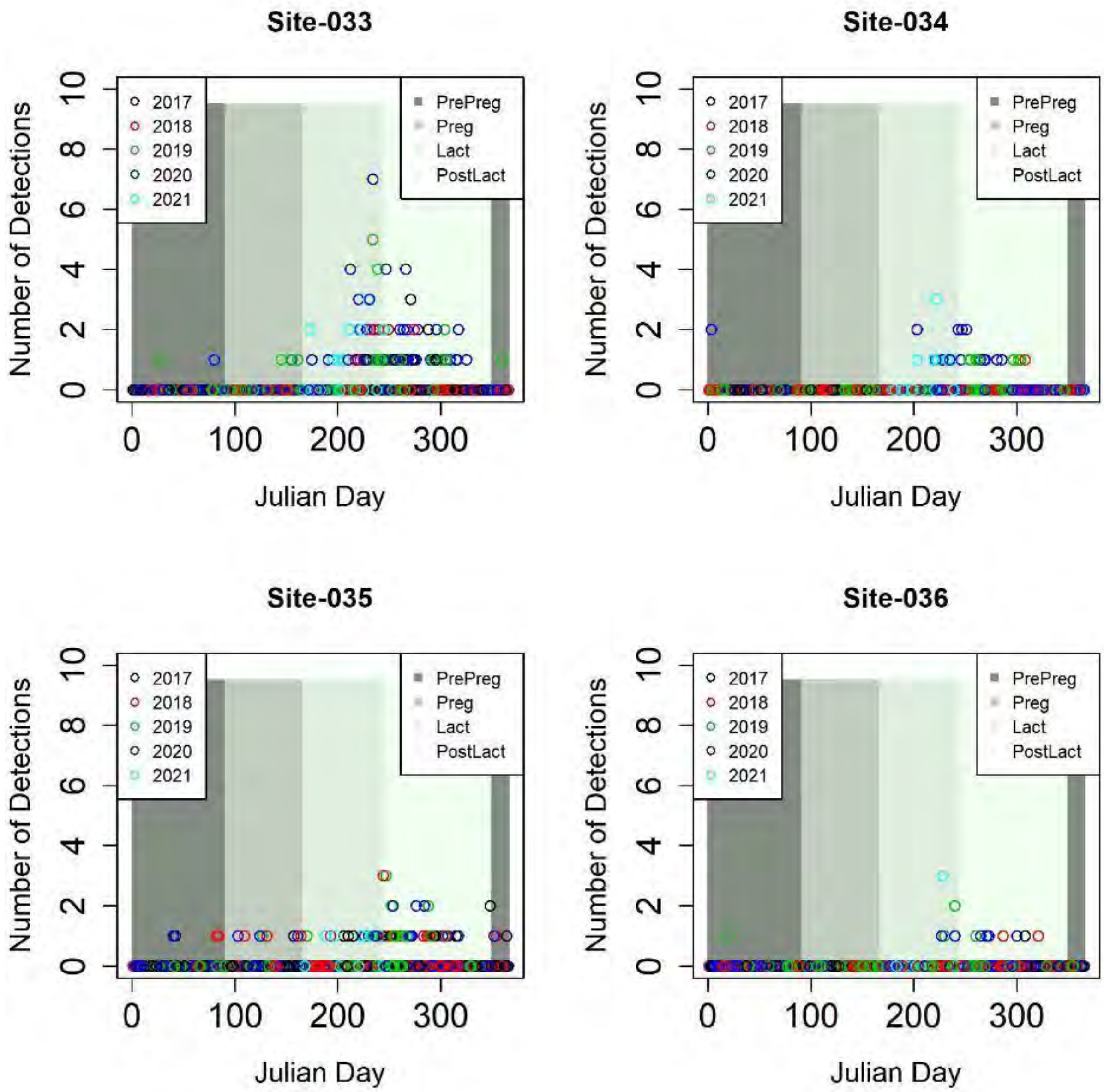
Appendix C3. Bat detections by Julian day and survey year for sites 018, 020, 021, and 022.



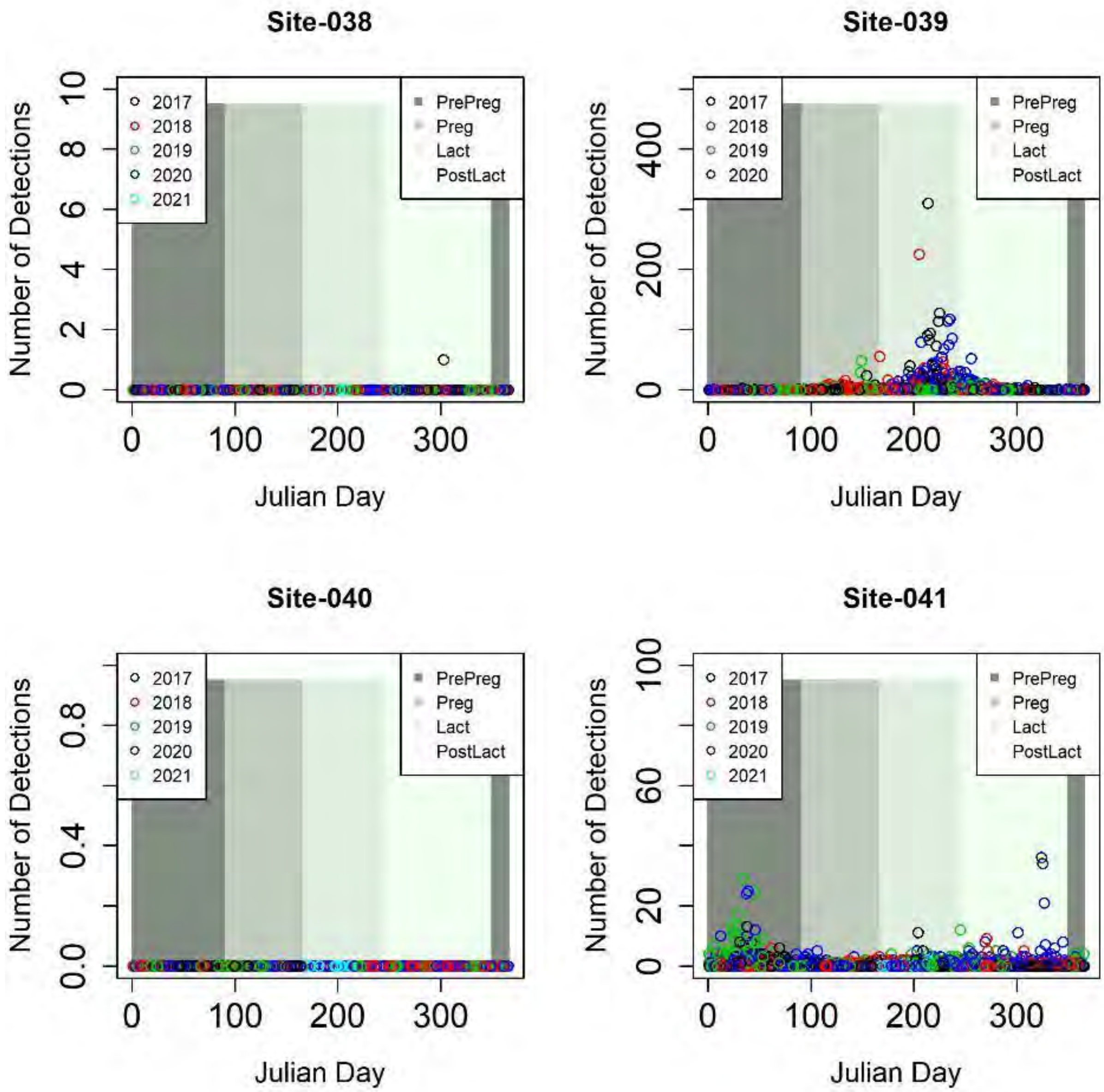
Appendix C4. Bat detections by Julian day and survey year for sites 023, 024, 025, and 026.



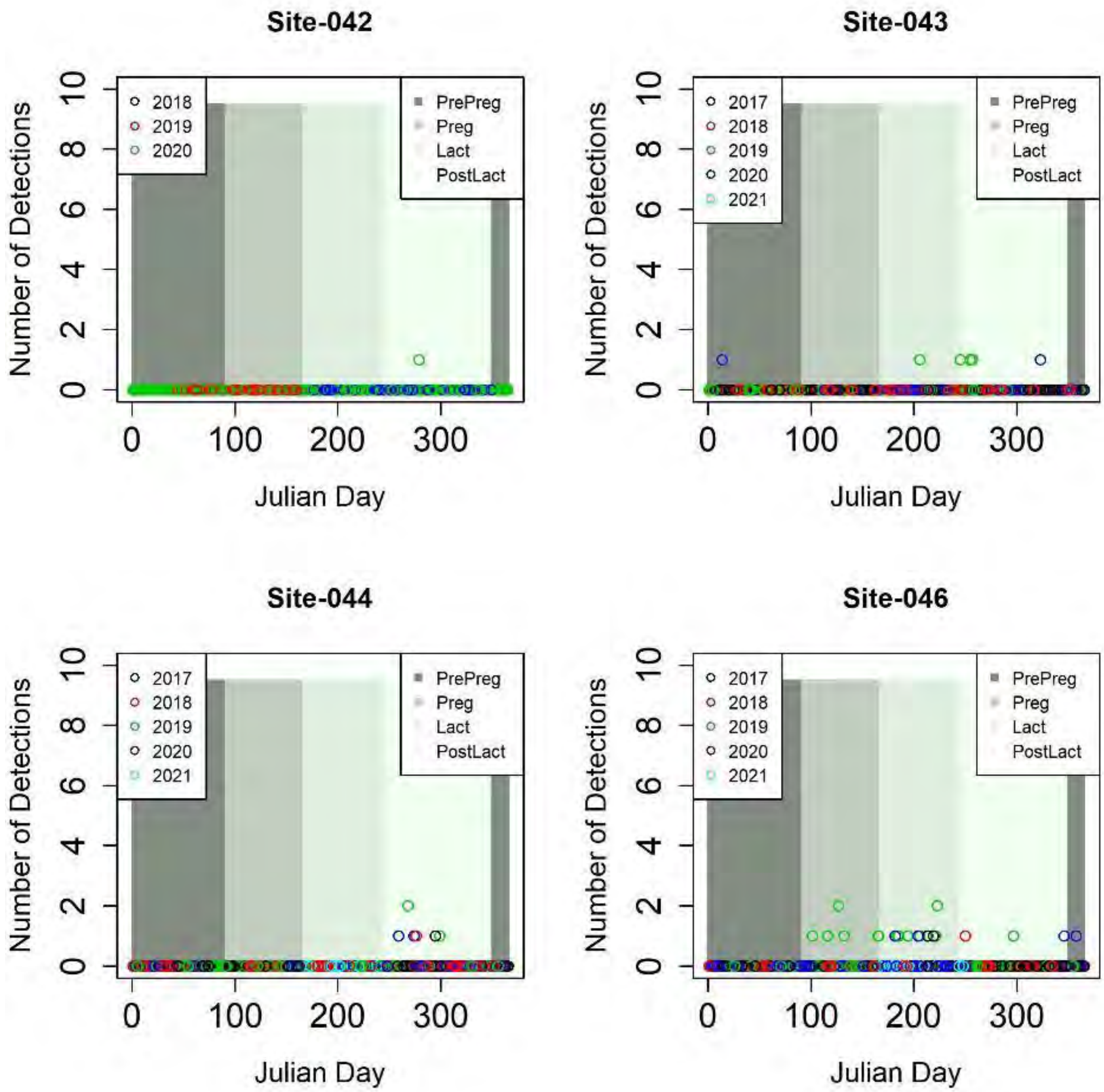
Appendix C5. Bat detections by Julian day and survey year for sites 029, 030, 031, and 032.



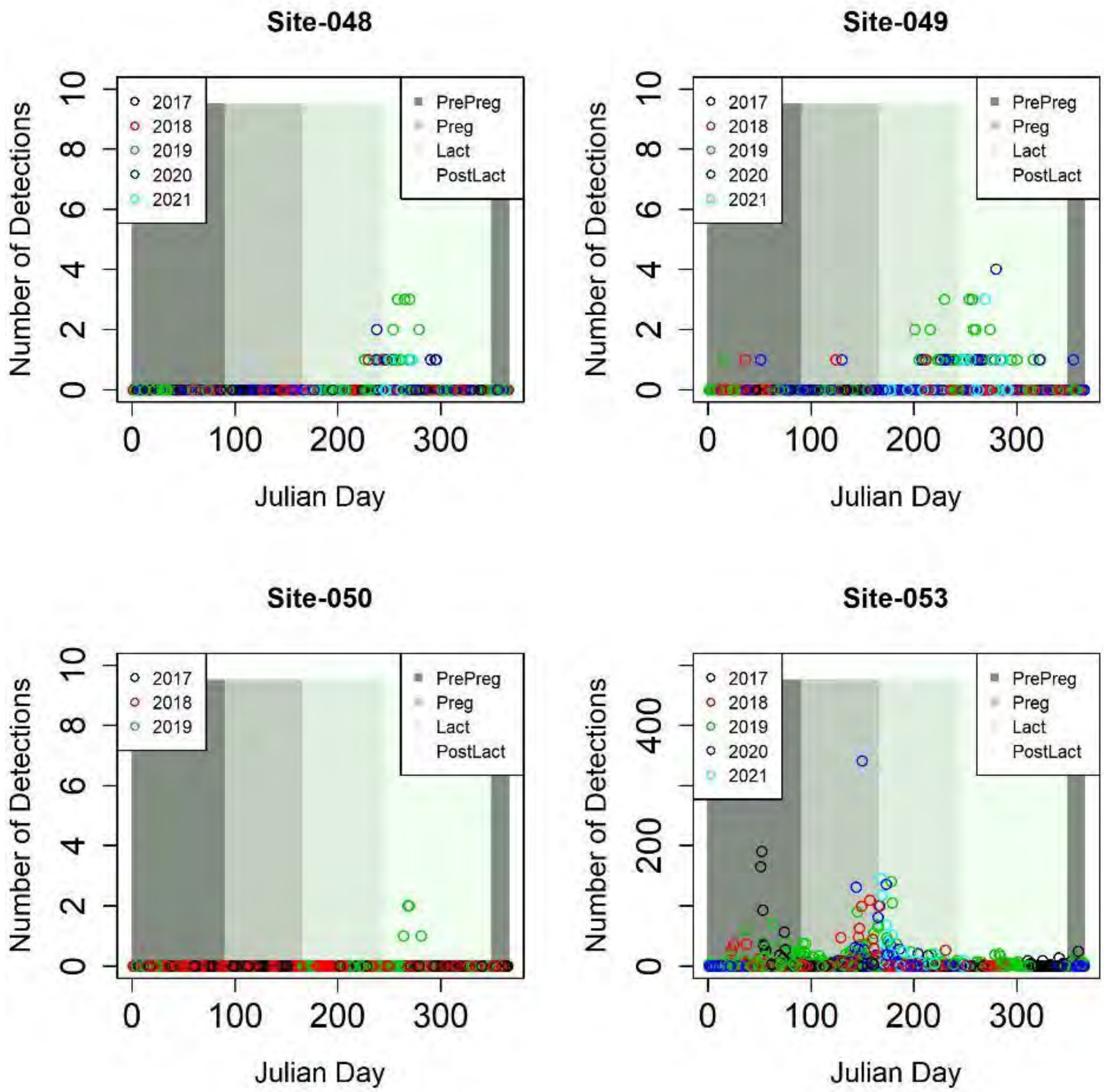
Appendix C6. Bat detections by Julian day and survey year for sites 033, 034, 035, and 036.



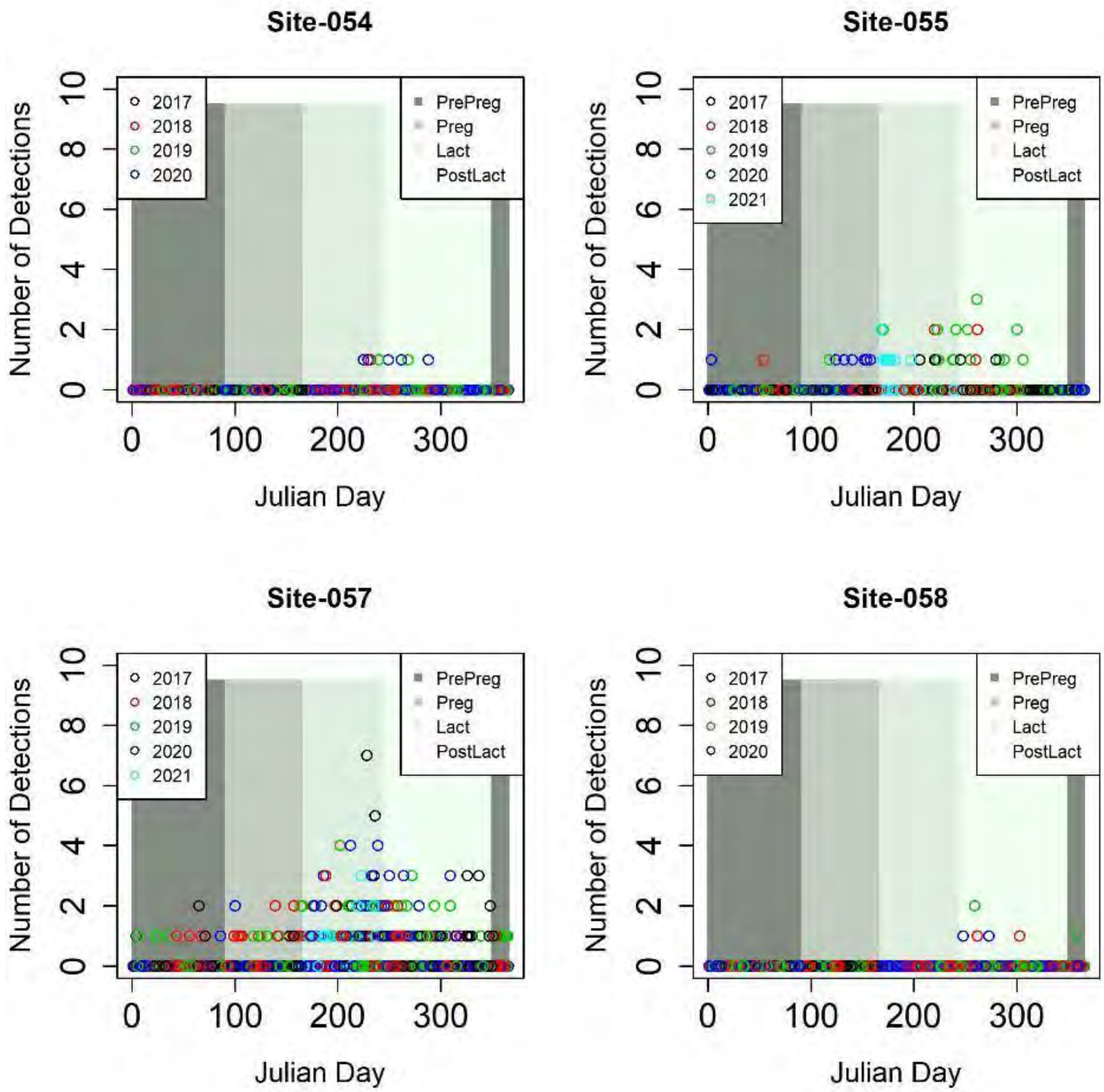
Appendix C7. Bat detections by Julian day and survey year for sites 038, 039, 040, and 041.



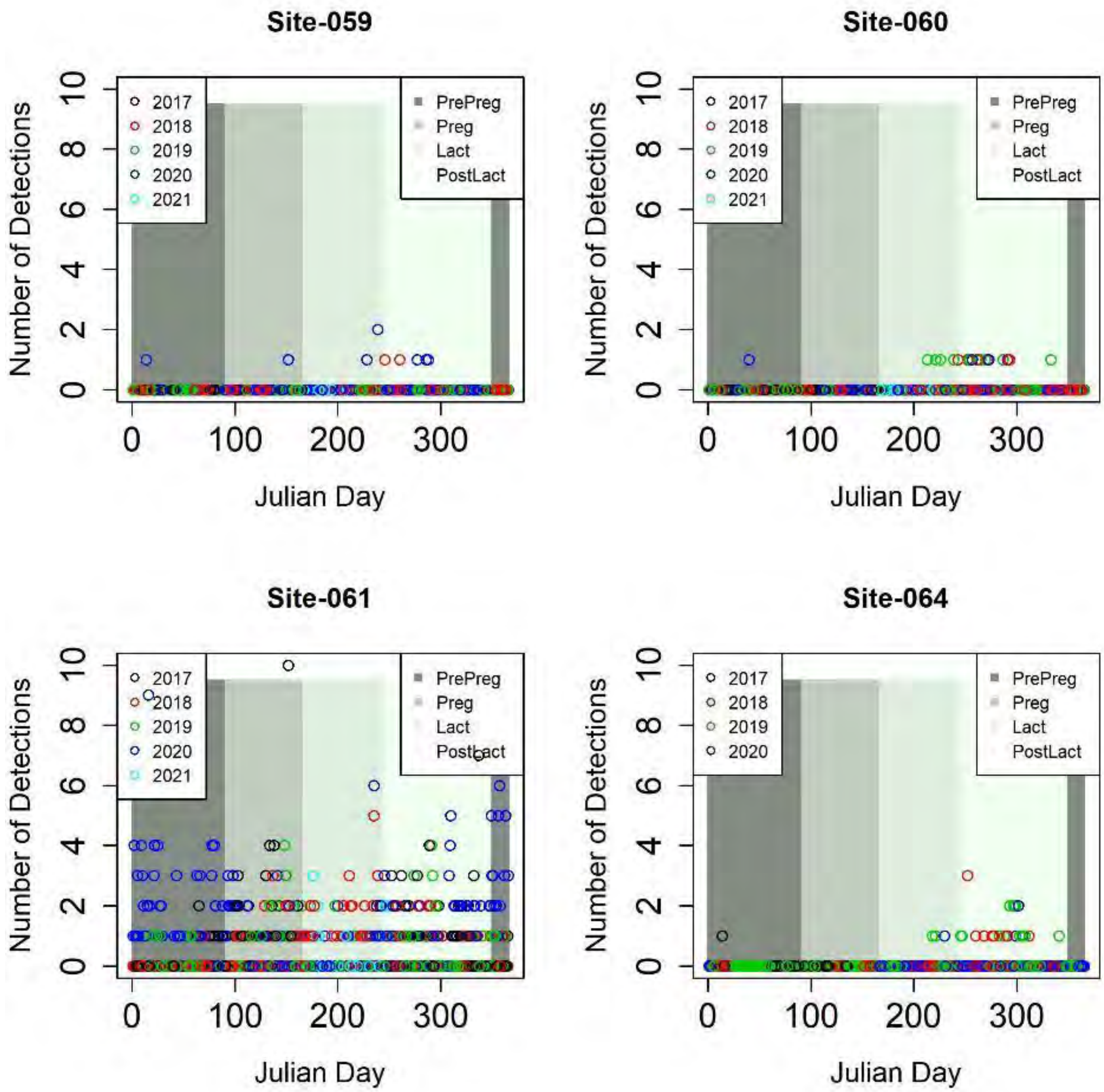
Appendix C8. Bat detections by Julian day and survey year for sites 042, 043, 044, and 046.



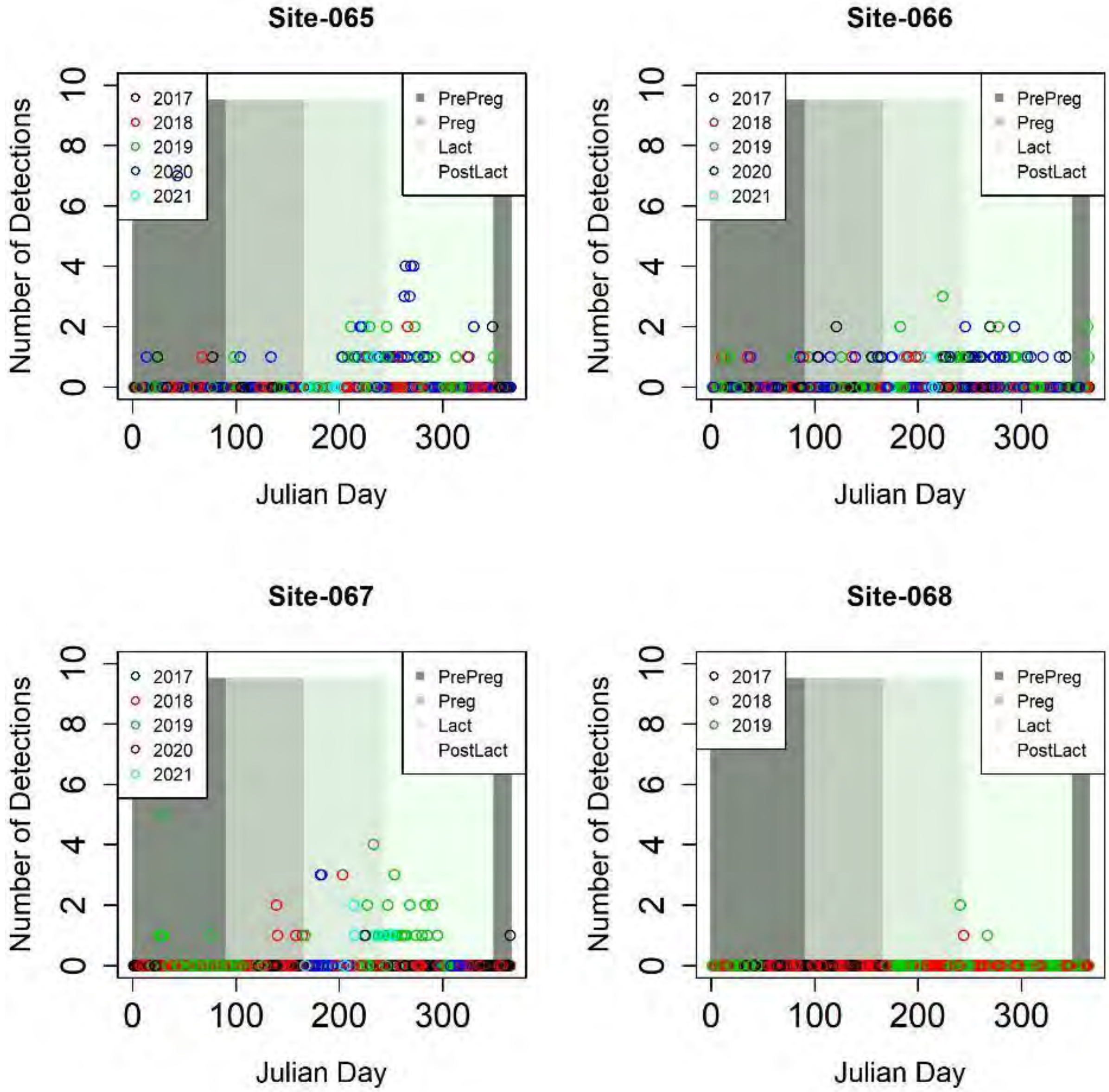
Appendix C9. Bat detections by Julian day and survey year for sites 048, 049, 050, and 053.



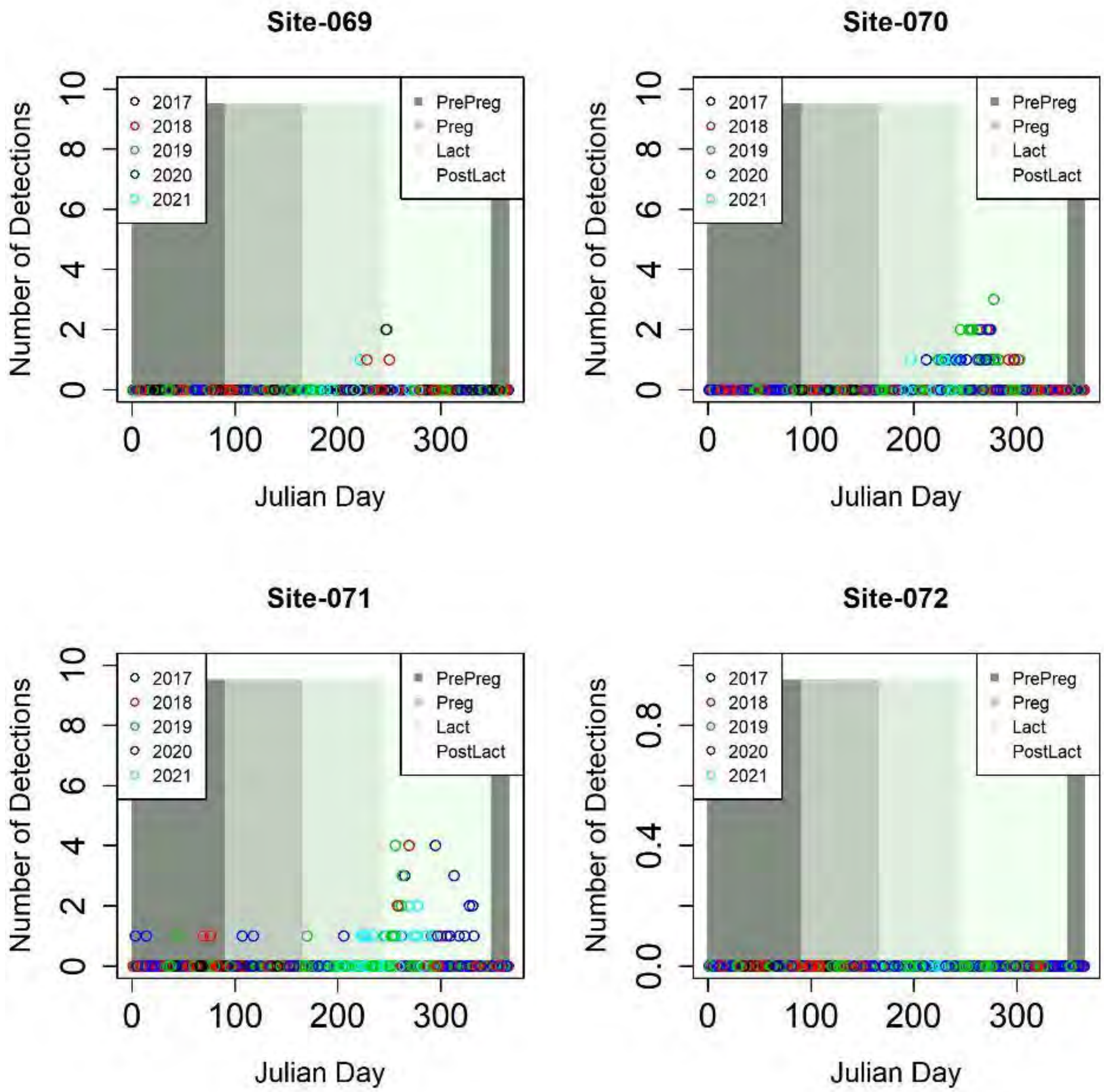
Appendix C10. Bat detections by Julian day and survey year for sites 054, 055, 057, and 058.



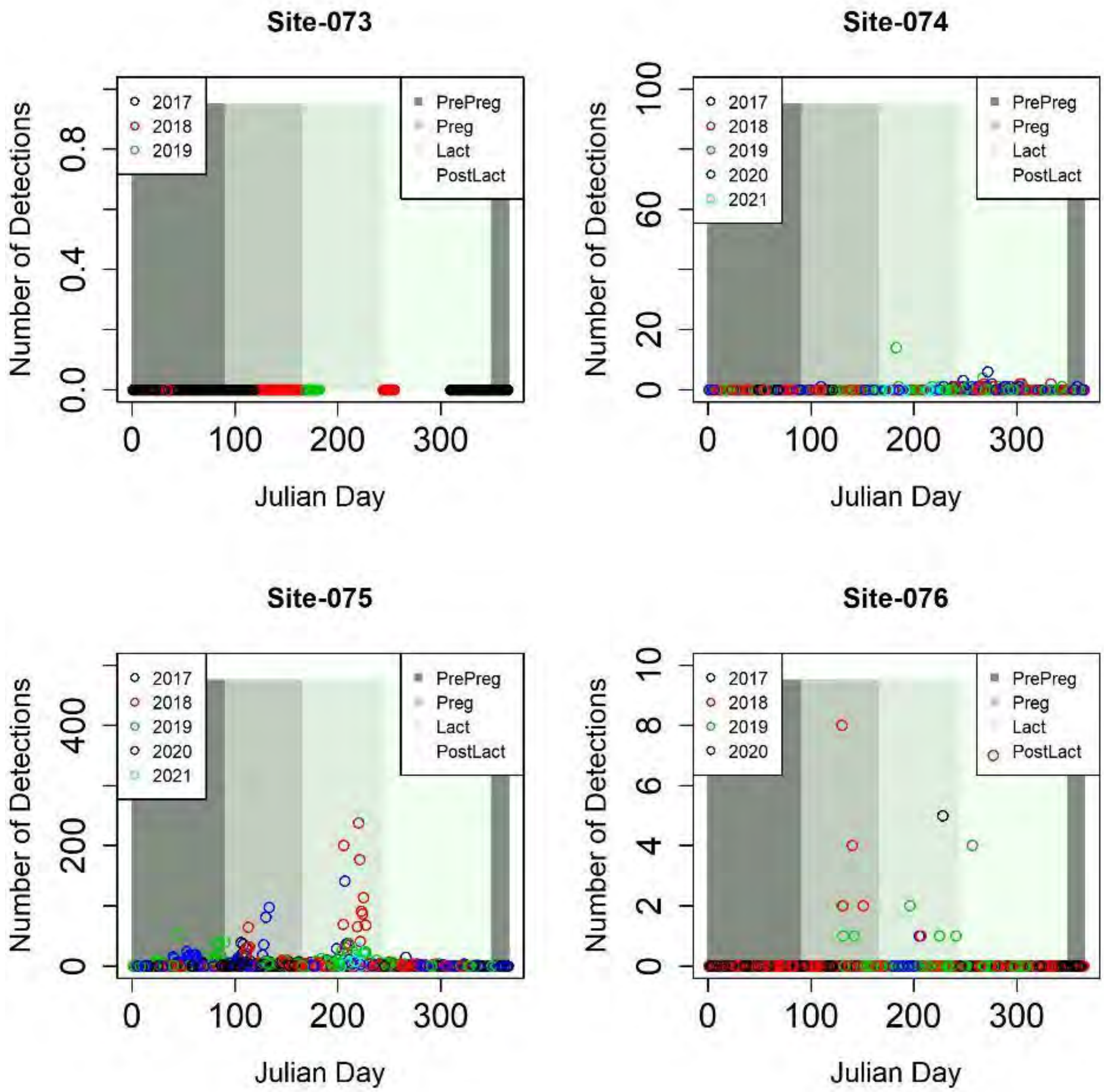
Appendix C11. Bat detections by Julian day and survey year for sites 059, 060, 061, and 064.



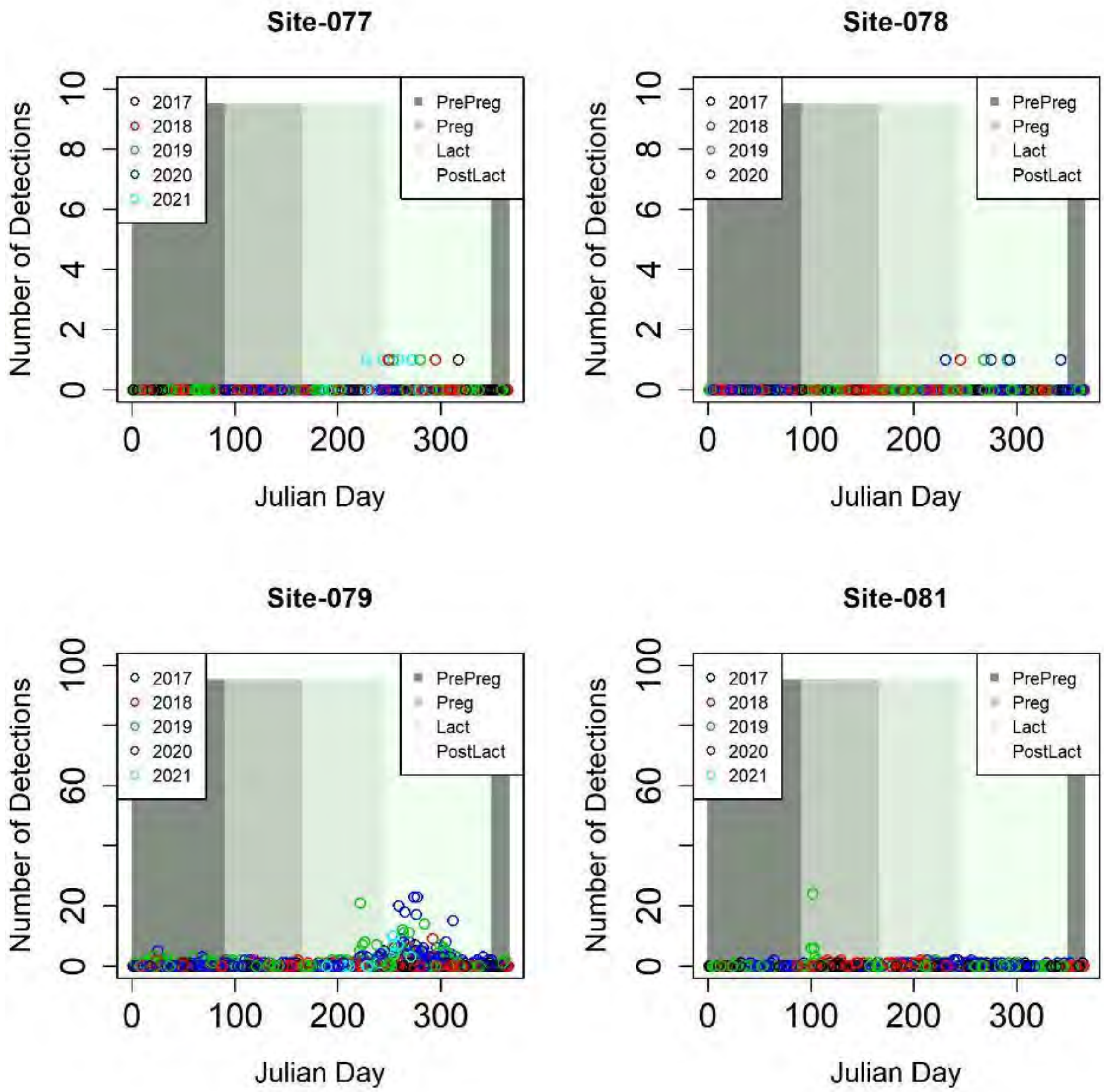
Appendix C12. Bat detections by Julian day and survey year for sites 065, 066, 067, and 068.



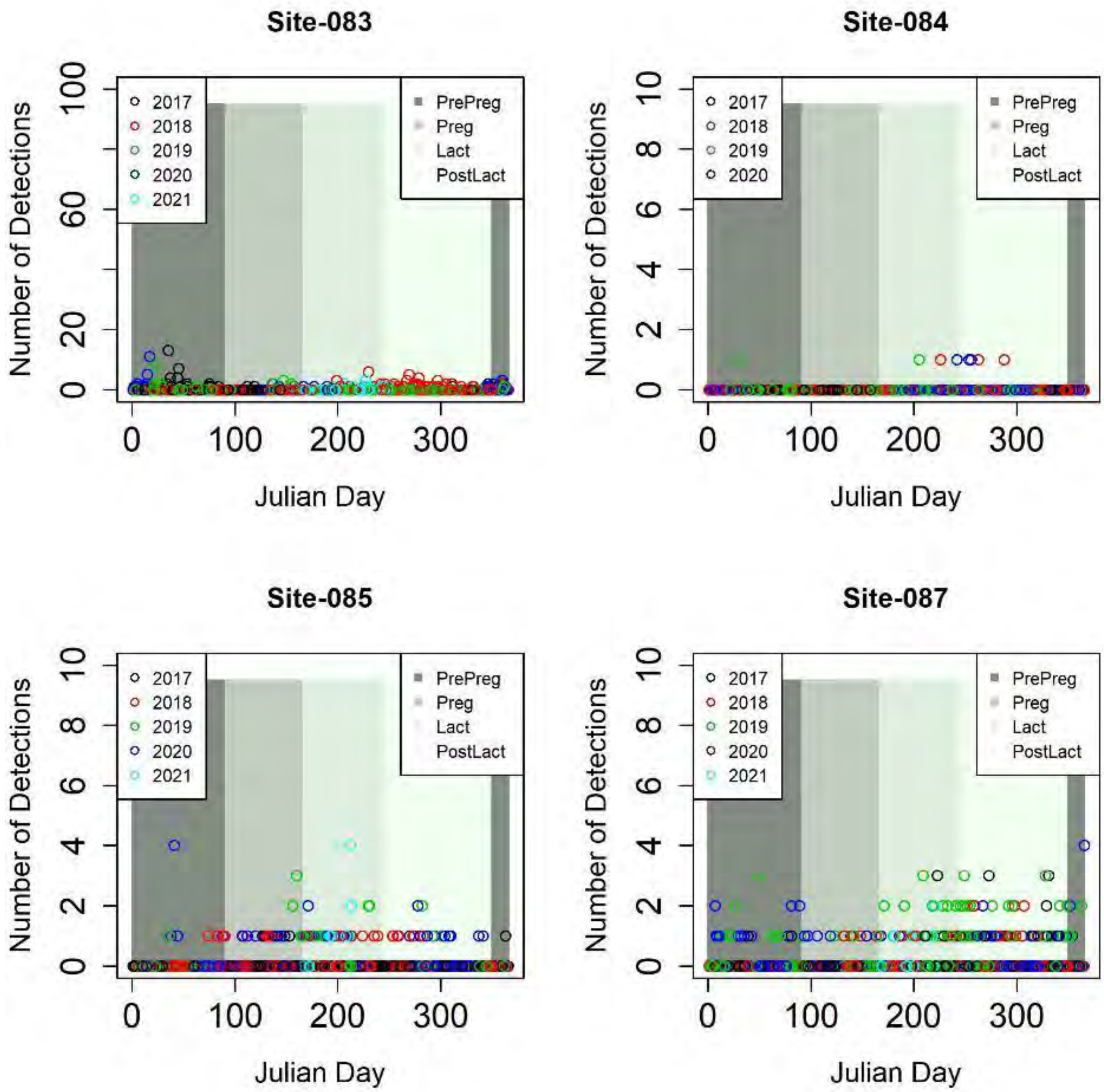
Appendix C13. Bat detections by Julian day and survey year for sites 069, 070, 071, and 072.



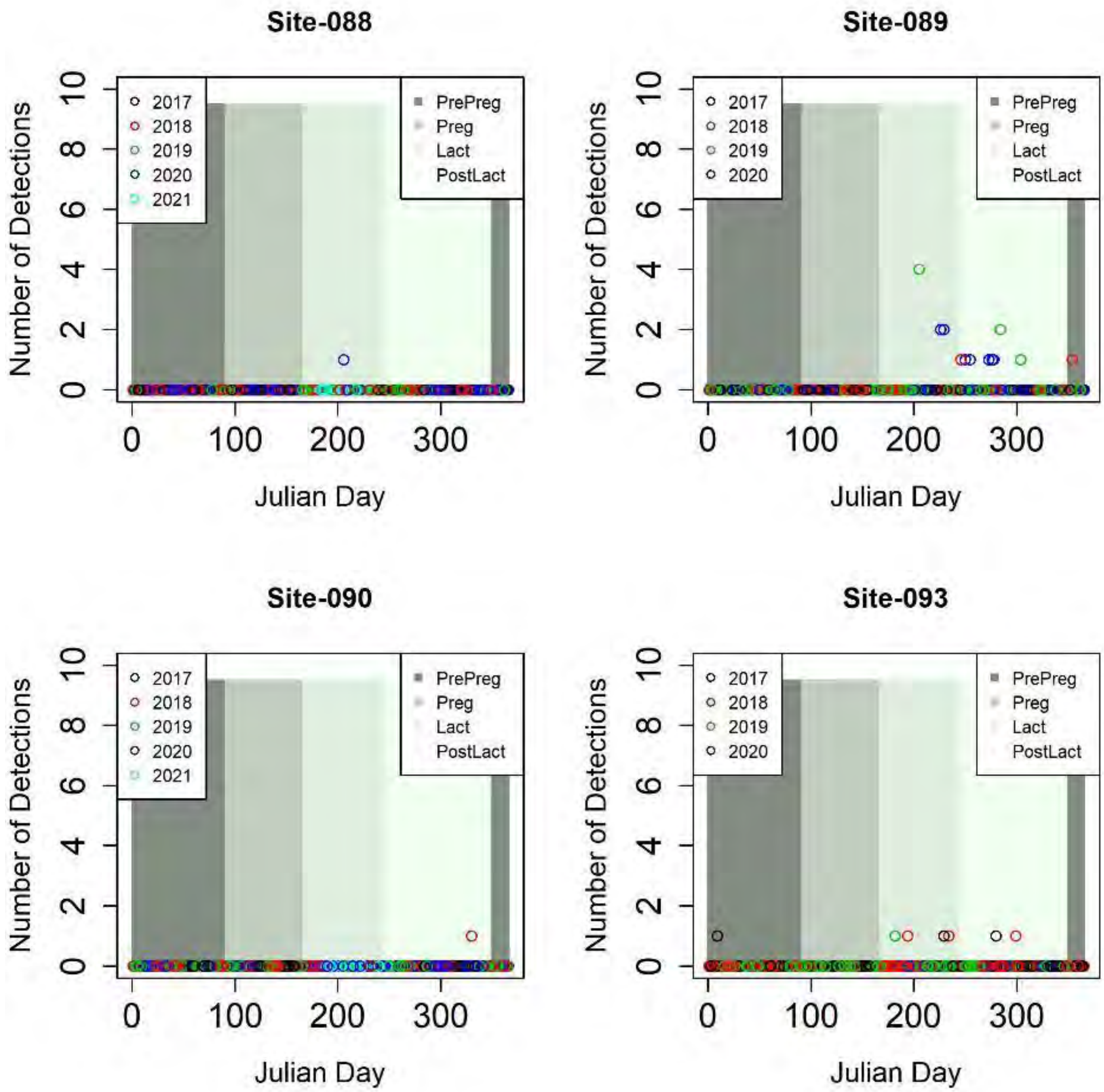
Appendix C14. Bat detections by Julian day and survey year for sites 073, 074, 075, and 076.



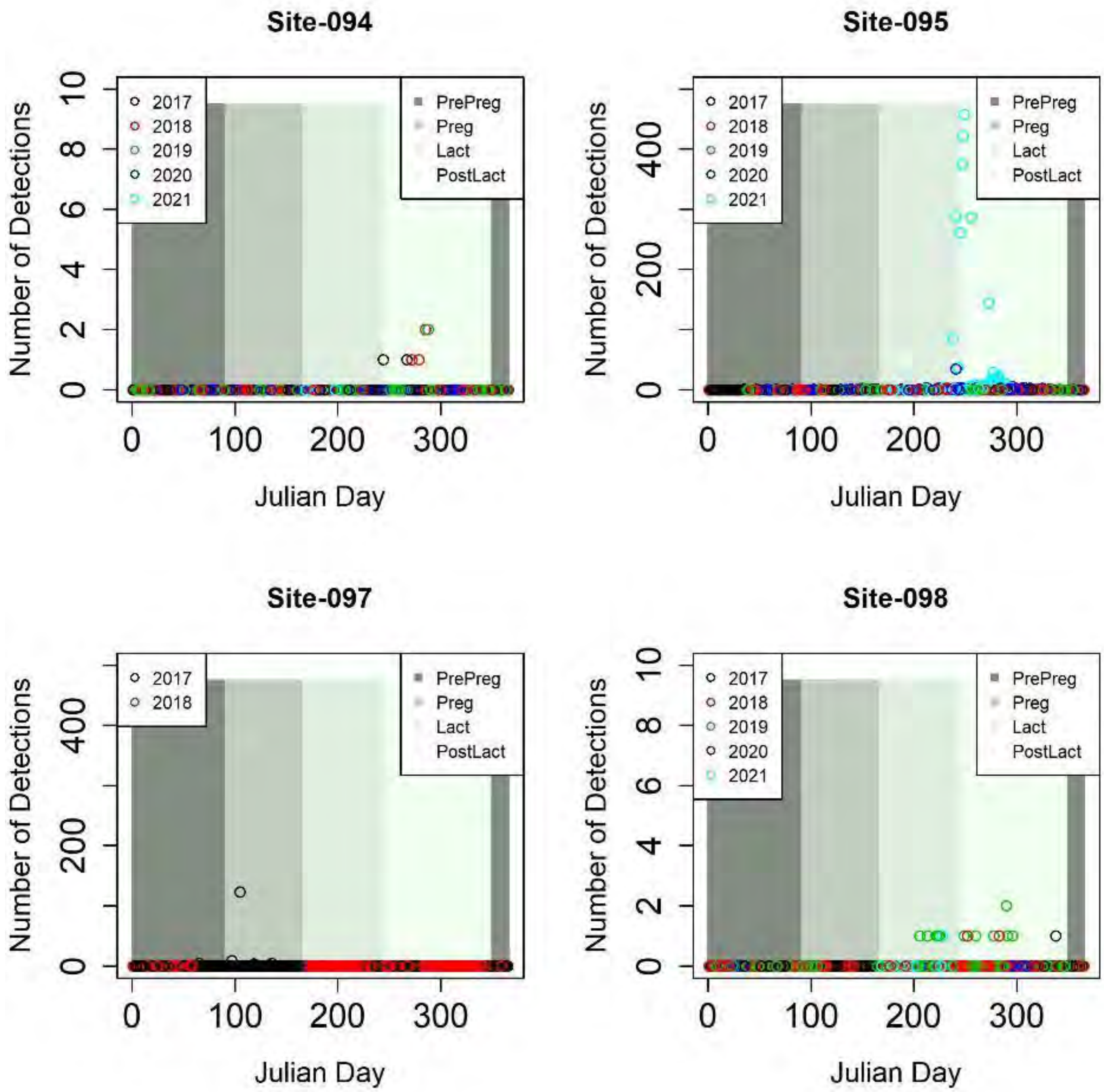
Appendix C15. Bat detections by Julian day and survey year for sites 077, 078, 079, and 081.



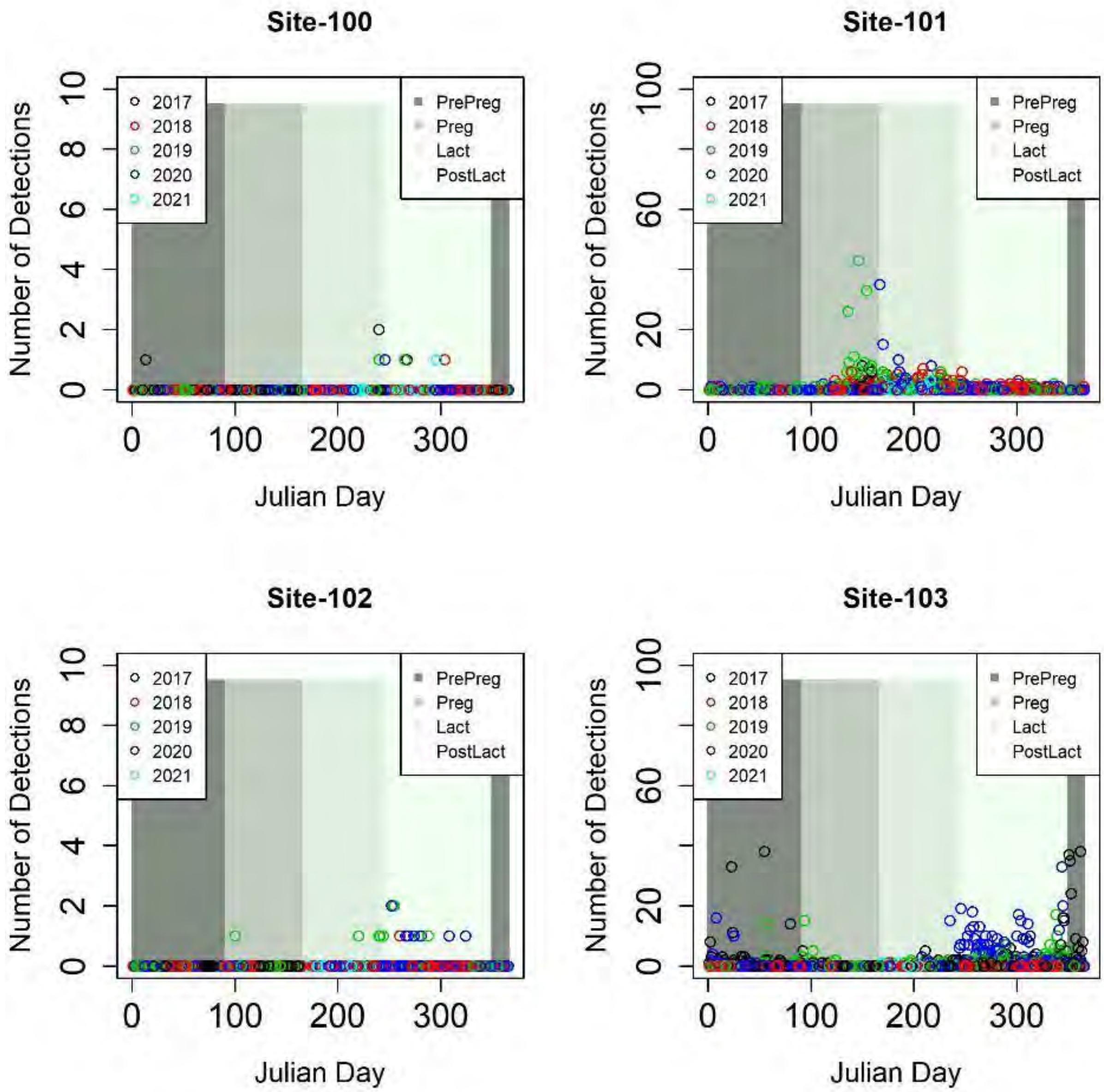
Appendix C16. Bat detections by Julian day and survey year for sites 083, 084, 085, and 087.



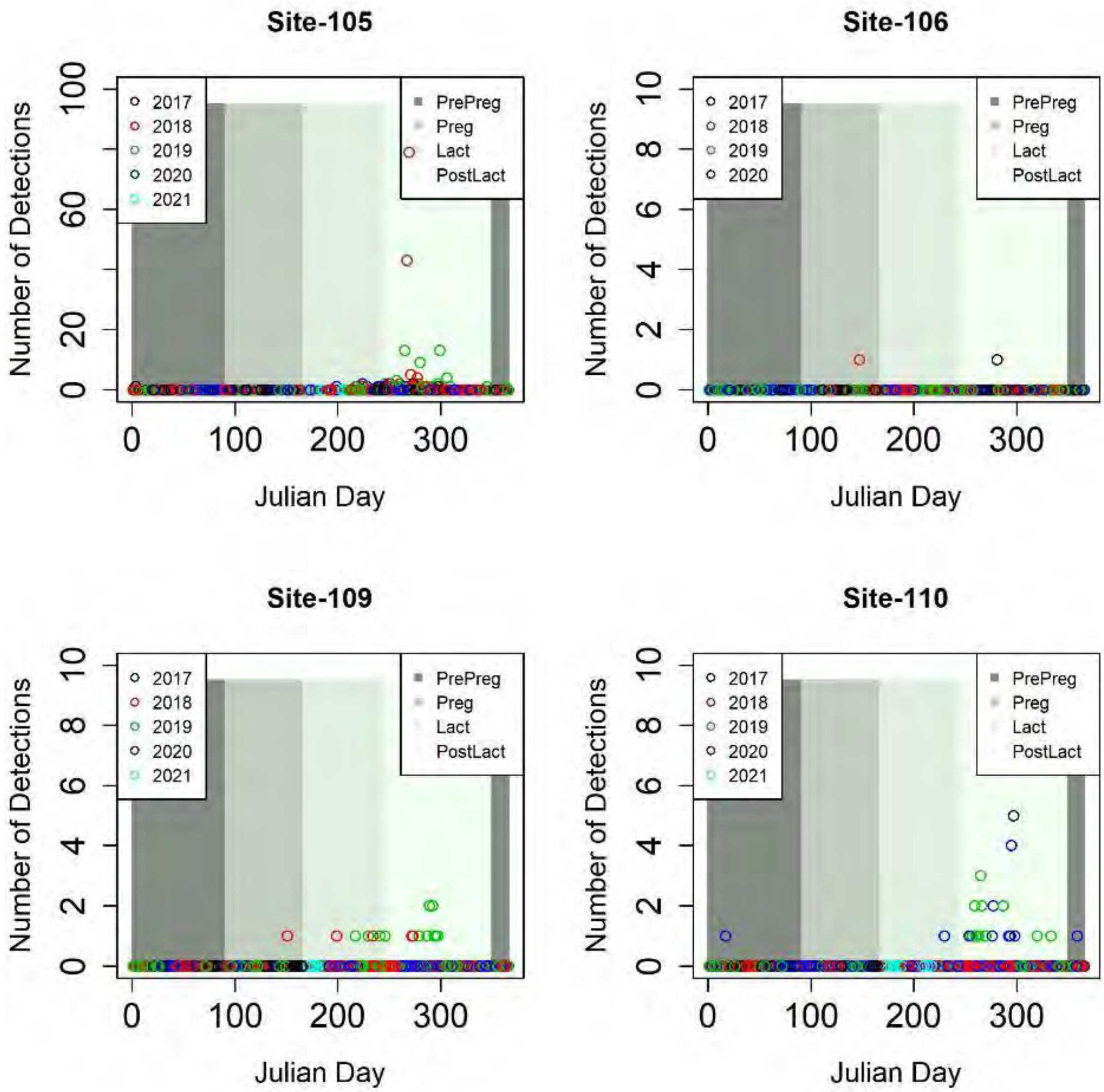
Appendix C17. Bat detections by Julian day and survey year for sites 088, 089, 090, and 093.



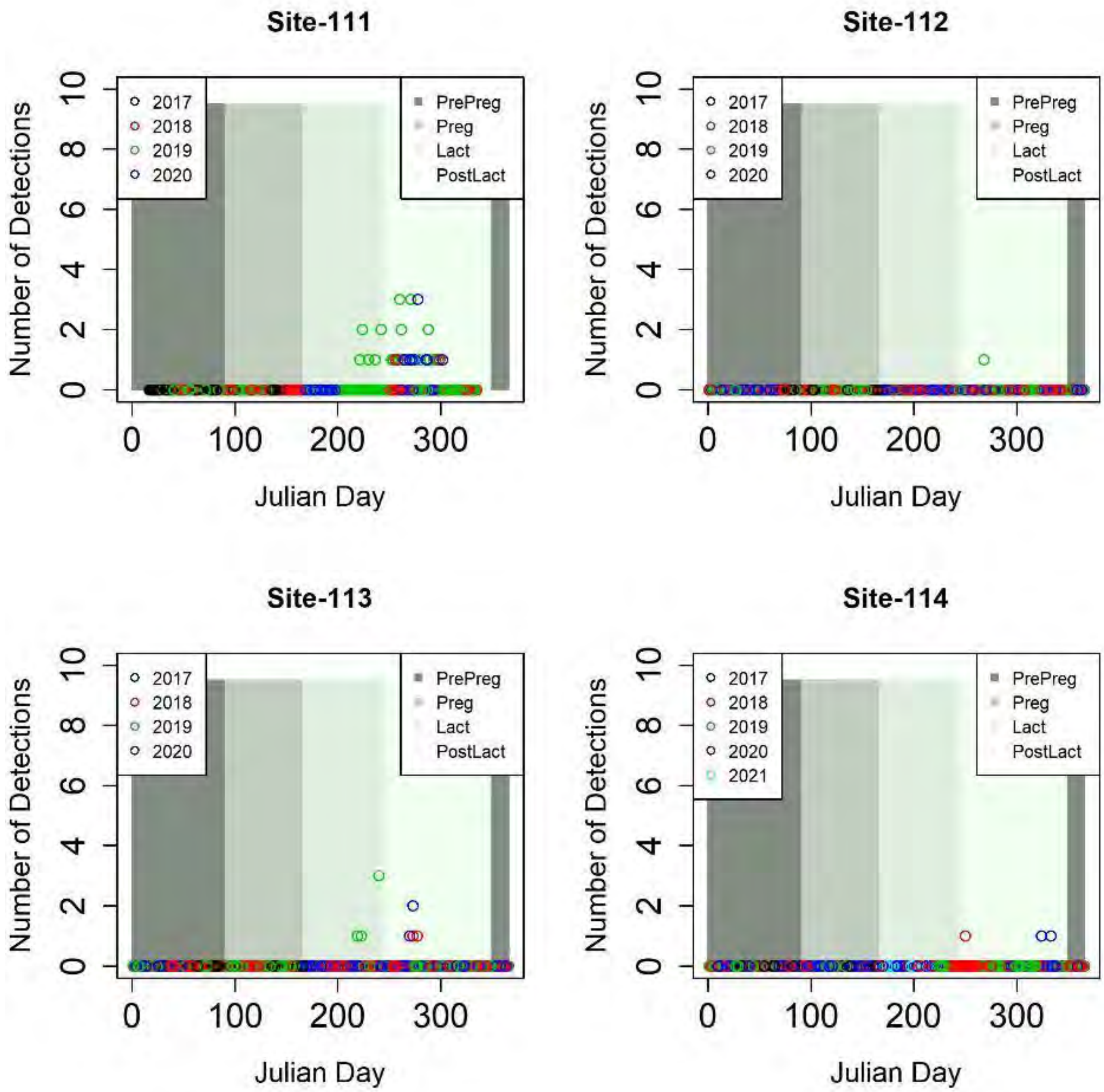
Appendix C18. Bat detections by Julian day and survey year for sites 094, 095, 097, and 098.



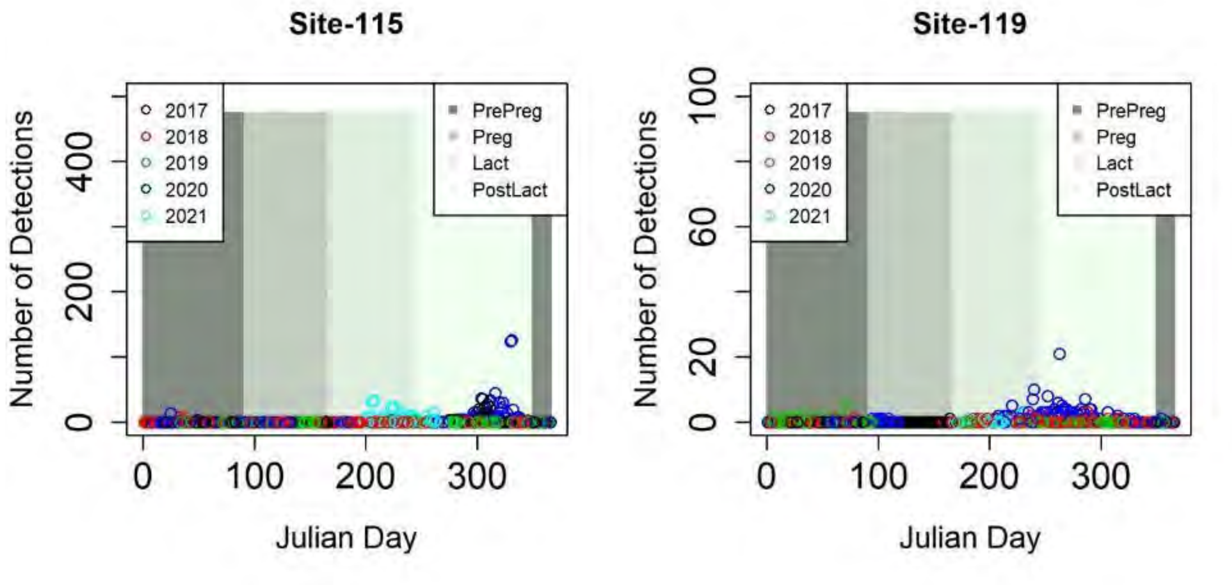
Appendix C19. Bat detections by Julian day and survey year for sites 100, 101, 102, and 103.



Appendix C20. Bat detections by Julian day and survey year for sites 105, 106, 109, and 110.



Appendix C21. Bat detections by Julian day and survey year for sites 111, 112, 113, and 114.



Appendix C22. Bat detections by Julian day and survey year for sites 115 and 119.

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