Kahuku Wind Power
Habitat Conservation Plan
FY 2023 Annual Report

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Incidental Take License ITL-10/ BO#2010-F-0190

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Executive Summary

This report summarizes work performed by Kahuku Wind Power, LLC (KAH) at the Kahuku Wind Power Project (Project) during the State of Hawaiʻi fiscal year (FY) 2023 (July 1, 2022 – June 30, 2023) under the terms of the approved Habitat Conservation Plan (HCP). The HCP is dated May 27, 2010, and describes KAH's compliance obligations under KAH's state Incidental Take License (ITL) ITL-10 and federal Incidental Take Statement (ITS) Biological Opinion (BO) 2010-F-0190. The HCP covers eight species: seven are federally and state-listed as threatened and endangered and one is exclusively a state-listed endangered species. The Project was constructed in 2010 and has been operating since March 23, 2011.

Wildlife fatality monitoring at the Project continued in FY 2023 within the 35-meter radius circular search plots centered on the wind turbine generators (WTGs). Plots were searched by canine-handler teams once per week year-round. Bias correction trials were conducted quarterly to measure the probability that a carcass persists until the next search (carcass persistence) and the probability that an available carcass would be found (searcher efficiency). The results of these trials showed mean probabilities of persistence until the next search of 0.86 (bat surrogates) and 0.98 (medium-sized bird surrogates). Searcher efficiency was 0.96 for bat surrogates and 1.00 for medium bird surrogates.

Two ʻōpeʻapeʻa fatalities were found in FY 2023. A total of eight bat fatalities (including the two found in FY 2023) have been observed as direct take at the Project since beginning operations on March 23, 2011. The cumulative fatality estimate using the Evidence of Absence estimator at the upper 80 percent credibility level is 17 bats, and the total indirect take for this estimate is 3 adult equivalents. Combining these values, there is an approximately 80 percent chance that cumulative take of the ʻōpeʻapeʻa from the start of operations through FY 2023 was less than or equal to 20 adults. No fatalities of other covered or listed species have been observed at the Project.

During FY 2023, KAH monitored bat activity at the Project through four ground-based acoustic detectors located near Project WTGs. In FY 2023, two types of acoustic monitors were used simultaneously to collect data, the SM2BAT+ and the SM4BAT-FS, in an effort to compare detection rates between detectors as technology has improved/changed. Between June 1, 2022 and May 31, 2023, the ʻōpeʻapeʻa were detected on 50 out of 1,281 detector nights (3.9 percent of detector-nights) and 97 out of 1,458 detector nights (6.7 percent) using the SM2BAT+ with SMX-U1 microphone and the SM4BAT-FS with SMM-U2 microphone, respectively. Seasonal patterns of detection rate were similar over both types of monitors, and comparable with previous years; starting in FY 2024, only the SM4BAT-FS with SMM-U2 microphone will be used for acoustic montoring.

Baseline (Tier 1) mitigation obligations for the ʻōpeʻapeʻa were met prior to FY 2023. Higher Take (Tier 2) mitigation planning was initiated in FY 2020 and continued in FY 2023 with two separate rounds representing the third and fourth revisions of the Draft Mitigation Plan revisions presented to agencies. Mitigation obligations for baseline levels of take of waterbirds, seabirds, and the pueo were met prior to FY 2023.

KAH communicated actively with USFWS and DOFAW throughout FY 2023 with conference calls, submittal of quarterly reports, and e-mail communications related to the Project's HCP and associated mitigation. Communications included submittal of two additional revisions of the Tier 2 Mitigation Plan.

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1.0 Introduction

The Habitat Conservation Plan (HCP) for the Kahuku Wind Project (Project) was approved by the Hawai‘i Division of Forestry and Wildlife (DOFAW) in 2010. Kahuku Wind Power, LLC (KAH) received a federal Biological Opinion (BO 2010-F-0190) and associated Incidental Take Statement (ITS) from the U.S. Fish and Wildlife Service (USFWS), and a state Incidental Take License (ITL; ITL-10) from DOFAW in May and June of 2010, respectively. The ITS and ITL cover the incidental take of eight species: seven federal and state-listed threatened and endangered species, and one exclusively state-listed endangered species (collectively referred to as the Covered Species) over a 20-year permit term.

The Covered Species include:

- ‘Ōpe‘ape‘a (Hawaiian hoary bat; *Lasiurus cinereus semotus*);
- Ae‘o (Hawaiian stilt; *Himantopus mexicanus knudseni*);
- ‘Alae ke‘oke‘o (Hawaiian coot; *Fulica alai*);
- Koloa maoli (Hawaiian duck; *Anas wyvilliana*);
- ‘Alae ‘ula (Hawaiian gallinule; *Gallinula galeata sandvicensis*);
- ‘Ua‘u (Hawaiian petrel; *Pterodroma sandwichensis*);
- ‘A‘o (Newell’s shearwater; *Puffinus newelli*); and
- Pueo (Hawaiian short-eared owl; *Asio flammeus sandwichensis*); state-listed only.

The Project was constructed in 2010 and 2011 and commissioned for operation on March 23, 2011. Brookfield Renewable Partners, LP (Brookfield) acquired the Project’s LLC through acquisition of a controlling interest in TerraForm, LLC in 2017; the Project continues to be operated by KAH.

On behalf of KAH, Tetra Tech, Inc. (Tetra Tech) has prepared this progress report which describes work performed for the Project during the 2023 fiscal year for the State of Hawai’i (FY; July 1, 2022 – June 30, 2023) pursuant to the terms and obligations of the approved HCP, ITL, and ITS. Kahuku Wind submitted previous annual HCP progress reports for FY 2011 through FY 2022 to USFWS and DOFAW (Kahuku Wind 2011, Kahuku Wind 2012, Kahuku Wind 2013, Kahuku Wind 2014, Kahuku Wind 2015, Kahuku Wind 2016, Kahuku Wind 2017, Kahuku Wind 2018, Tetra Tech 2019, Tetra Tech 2020, Tetra Tech 2021, Tetra Tech 2022a).

2.0 Fatality Monitoring

In consultation with USFWS, DOFAW, and the Endangered Species Recovery Committee (ESRC), fatality search areas and search frequency have evolved over time from the start of operations in

2011 through the initiation of the current approach in April 2015. Below is a summary of how the fatality monitoring has evolved over time:

- In March 2011, the wildlife fatality monitoring effort involved twice weekly searches within a 64-meter radius circular monitoring plot centered on each wind turbine generator (WTG) in addition to searches every other week within a larger 96-meter radius plot.
- In September 2014, the 96-meter radius plot searches were suspended, but searches within the 64-meter radius plots continued twice weekly.
- In December 2014, plots were reduced in size to the current 35-meter radius (Figure 1). Search frequency was monthly from December 2014 through March 2015.
- In April 2015, the search frequency of the 35-meter radius plots was increased to occur weekly. This search area and frequency has continued to be used for monitoring through FY 2023.

Weekly searches of the 35-meter radius plots were completed throughout FY 2023 for a total of 52 weekly searches. The plots were searched by trained detector dogs and their handlers (canine search teams). To accommodate the detector dogs, starting in January 2021 and continuing through FY 2023, weekly searches primarily occurred over 2 consecutive days, with searches conducted at six of the 12 WTGs on each day. Occasionally, searches occurred on 1 day at all 12 WTGs. Fatality monitoring in FY 2023 achieved a mean search interval for WTGs of 6.98 days (Standard Deviation = 0.5 days). In FY 2023, all searches were conducted by canine teams, however, should conditions have prevented the use of dogs (e.g., weather, injury, availability of canine search team, etc.), plots would have been visually surveyed by Project staff.

One Covered Species, the ʻōpeʻapeʻa, was detected on two separate occasions during fatality searches in FY 2023 (see Section 7.1). Other species fatalities are reported in Section 7.2, and no fatalities of other Covered Species have been observed at the Project since the start of operations.

3.0 Carcass Persistence Trials

A 28-day carcass persistence trial was conducted in each quarter of FY 2023 for a total of four trials. These trials used carcasses of black rats (*Rattus rattus*) as surrogates for the ʻōpeʻapeʻa and wedge-tailed shearwaters (*Ardenna pacifica*) to represent medium-sized birds (surrogates for all avian Covered Species; see Section 1.0). In FY 2023, the mean probability that a bat surrogate carcass persisted until the next search was 0.86 (95 percent Confidence Interval [CI] = 0.75, 0.94; n=24) and for medium-sized bird carcasses was 0.98 (95 percent CI = 0.83, 1.00; n=8).

4.0 Searcher Efficiency Trials

Searcher efficiency trials occurred throughout the year to test wildlife carcass detection of canine search teams (no un-aided, human only searches occurred in FY 2023). A total of 67 searcher efficiency trials were administered to canine search teams over 22 trial days during FY 2023. Carcasses of black rats were used as surrogates for the ʻōpeʻapeʻa. Carcasses of wedge-tailed shearwaters were used as surrogates for avian Covered Species. Of the 52 bat surrogate trial carcasses placed, three were lost to scavenging for a total of 49 carcasses available to be found. Fifteen wedge-tailed shearwater carcasses were placed; all were available to be found. The overall searcher efficiency in FY 2023 for bat surrogates was 0.96 (95 percent CI = 0.86, 0.99; n = 49) and for medium-sized bird carcasses was 1.00 (95 percent CI = 0.85, 1.00; n = 15).

5.0 Vegetation Management

Search plots include searchable area out to 35 meters from the base of each WTG. Search plots are comprised of bare ground and vegetation that is mowed when it reaches 4 to 6 inches in height. The search plots accommodate a relatively flat search area that is easily maintained; however, a small portion of one search plot (WTG 3) has a slope that precludes vegetation management and is consequently not searched. Vegetation within the plots consists mainly of Bermuda grass (*Cynodon dactylon),* sensitive plant (*Mimosa pudica*), and Guinea grass (*Megathyrsus maximus*).

In FY 2023, all plots were mowed at regular intervals to maintain high visibility during fatality searches. Plots were checked weekly for vegetation conditions, and generally mowed two to three times per month during the wetter months of the year and at least once per month during the drier months. Mowing consistently occurred immediately following the weekly fatality searches at the WTGs where needed. Livestock are grazed within search plot bounds, keeping vegetation low and reducing the need for mechanical mowing.

During the spring of FY 2023, the thorn-bearing herb, sensitive plant, was noted as more abundant within the search areas at WTGs 3 – 7 than in previous years. Canine searchers were not significantly impacted by the increased spread of this herb. On-site biologists continue to maintain communication with the canine searchers to ensure there are no impacts to the searcher team. Additionally, the weedy common sand bur (*Cenchrus echinatus*) which bears sharp bur-like seed heads has not been observed at either WTG 12 or WTG 4 (where it has previously been noted to occur) since FY 2022.

6.0 Scavenger Trapping

In FY 2023, 75 Doc-250s and 15 Timms traps were in use during trapping efforts. Trap set and check frequency was conducted every other week. During FY 2023, a total of 203 target animals were captured and removed, including 161 mongooses (*Herpestes javanicus*), 29 rats (*Rattus* spp.), five mice (*Mus musculus*) and eight feral cats (*Felis catus*). Other miscellaneous non-native non-target captures during this timeframe included six species: common myna (*Acridotheres tristis*), chukar (*Alectoris chukar*), spotted dove (*Streptopelia chinensis*), African snail (*Lissachatina fulica*), cane toad (*Rhinella marina*), and one unidentified lizard.

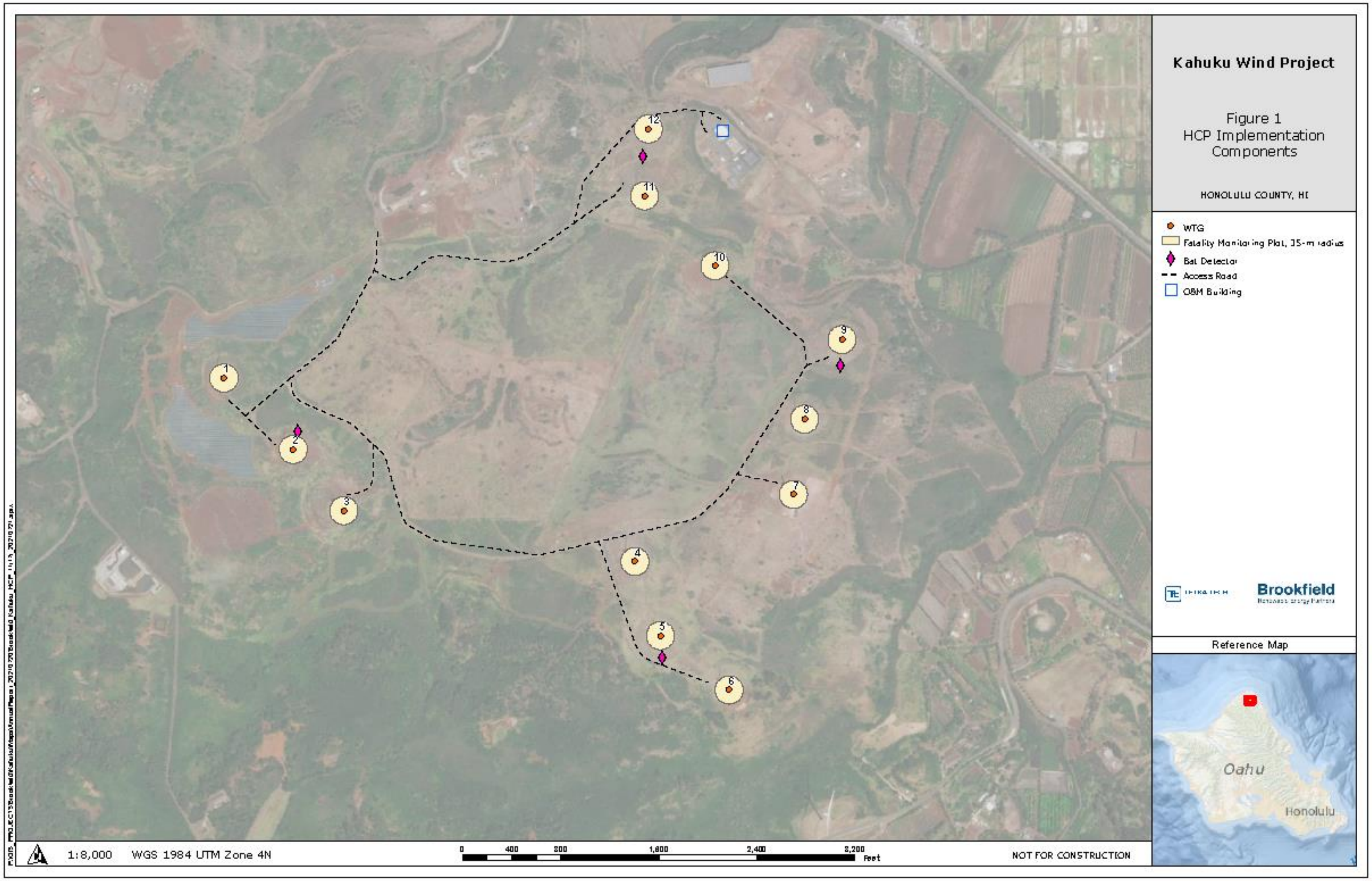

Figure 1. HCP Implementation Components

7.0 Documented Fatalities and Take Estimates

All downed wildlife observed during the fatality monitoring were handled and reported in accordance with the Downed Wildlife Protocol provided by USFWS and DOFAW (DOFAW and USFWS 2020). Two ʻōpeʻapeʻa (Covered Species) were detected as fatalities during FY 2023. No injured (live) downed wildlife were observed at the Project in FY 2023.

Various factors affect how the number of observed fatalities is scaled to estimate the unobserved fatalities. Unobserved fatalities are due to three primary factors:

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

Sections 3.0 and 4.0 describe methods that are used to estimate the effect of the first two factors. The search area for fatalities at the Project has evolved over time; therefore, the proportion of the carcass distribution searched has varied. However, no changes to the search area have been made since December 2014 (Section 2.0). Thus, the estimate of the proportion of the carcass distribution searched in FY 2023 remains the same as described in the FY 2018 annual report (Kahuku Wind 2018) and is presented in Appendix 1.

7.1 ʻŌpeʻapeʻa

7.1.1 Estimated Take

A total of eight ʻōpeʻapeʻa fatalities have been observed at the Project since operations began on March 23, 2011. The most recently documented ʻōpeʻapeʻa fatalities include two individuals of unknown sex, one detected on September 22, 2022 and one detected on March 16, 2023 during regular searches. The carcass observed in September was detected 25 meters from the base of WTG 7, and the carcass observed in March was detected 32 meters from the base of WTG 10; each carcass was collected and transferred to the Bishop Museum in July 2023, in coordination with USFWS under a new partnership established for genetic sexing. Genetic sexing results for these two bats are not yet available. All previous bat fatalities were transferred to USGS for genetic sexing under a program that is now discontinued.

All eight bats have been detected inside of search plots; no incidental bat fatality detections have occurred to date. Table 1 lists the observed ʻōpeʻapeʻa fatalities by fiscal year.

Table 1. Observed ʻŌpeʻapeʻa Fatalities at the Project through FY 2023

Fiscal Year	Observed Direct Take	Incidental Fatality Observations	Total
2011	0	0	0
2012	3	0	3
2013	0	0	0
2014	0	0	0
2015	1	0	1
2016	0	0	0
2017	0	0	0
2018	0	0	0
2019	0	0	0
2020	0	0	0
2021	1	0	1
2022	1	0	1
2023	2	0	2
Total	**8**	**0**	**8**

Cumulative take is estimated from three components: (1) observed direct take (ODT) during protocol (standardized) fatality monitoring, (2) unobserved direct take (UDT), and (3) indirect take. The Evidence of Absence software program (EoA; Dalthorp et al. 2017), an agency-approved analysis tool for analyzing direct take, uses results from bias correction trials and ODT to generate an upper credible limit (UCL) of direct take (i.e., ODT + UDT). USFWS and DOFAW have requested that estimates of direct take for KAH be reported at the 80 percent UCL. Direct take values from this analysis can be interpreted as: there is an 80 percent probability that actual direct take at the Project over the analysis period was less than or equal to the 80 percent UCL. Associated indirect take is estimated based on the sex and age characteristics of bat fatalities found at the Project, and the life history characteristics of (assumed to be representative of) the ʻōpeʻapeʻa, as described in the Project's approved HCP and current agency guidance (USFWS 2016).

The estimated direct take (ODT + UDT) for the eight ʻōpeʻapeʻa fatalities found between the start of operation (March 23, 2011) and end of FY 2023 (June 30, 2023) is less than or equal to 17 bats (80 percent UCL). Details of the estimated direct take parameters are in Appendix 1.

Indirect take is estimated to account for the potential loss of future individuals (offspring) that may occur as the result of the loss of an adult female through direct take during the breeding period when females may be pregnant or supporting dependent young. Indirect take for the Project is calculated using the USFWS (2016) guidance as follows:

- The average number of offspring (pups) per female that survive to weaning is assumed to be 1.8.
- The sex ratio of the ʻōpeʻapeʻa taken through UDT is assumed to be 50 percent female unless there is evidence (10 or more bats) to indicate a different sex ratio.
- The assessment of indirect take from the modeled UDT accounts for the fact that it is not known when the unobserved fatality may have occurred. The period from pregnancy to end of pup dependency for any individual ʻōpeʻapeʻa female 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 indirect take assessment uses a conversion of one juvenile bat as equal to 0.3 adults.

Based on the USFWS (2016) guidance, the estimate of cumulative indirect take as of the end of FY 2023 is calculated as:

- **Total Juvenile Take Calculated from Observed Female Take (April 1 – September 15)**
    - 3 (observed females) * 1.8 (pups per female) = 5.4 juveniles[1]
- **Total Juvenile Take Calculated from Observed Unknown Sex Take (April 1 – September 15)**
    - 1 (observed unknown sex) * 0.5 (assumed sex ratio) * 1.8 (pups per female) = 0.9 juveniles
- **Total juvenile Take Calculated from Unobserved Take**
    - 9 (unobserved direct take) * 0.5 (assumed sex ratio) * 0.25 (proportion of calendar year females could be pregnant or have dependent pups) * 1.8 (pups per female) = 2.0 juveniles
- **Total Calculated Juvenile Indirect Take** = 8.3 (5.4 + 0.9 + 2.0)
- **Total Adult Equivalent Indirect Take =** 0.3 (juvenile to adult conversion factor) * 8.3 = 2.5

Therefore, cumulative indirect take through FY 2023 is three adults (rounded up from 2.5).

The UCL for cumulative Project take of the ʻōpeʻapeʻa at the 80 percent credibility level is 20 adult bats (17 [estimated direct take] + 3 [estimated indirect take, measured in adult equivalents]). That is, there is an approximately 80 percent probability that actual take at the Project at the end of FY 2023 is less than or equal to 20 bats.

[1] DNA results have identified the sex of five of the eight bat fatalities detected at the Project, confirming that three of the fatalities were female (Pinzari and Bonaccorso 2022). Sex identification of one carcass did not yield a confirmed sex, and the sex of the remaining two bat fatalities will be incorporated once confirmed by genetic testing.

7.1.2 Projected Take

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

KAH projected take through the end of the permit term using the fatality monitoring data collected through FY 2023. The objective of this analysis was to evaluate the potential for the Project to exceed the permitted take limit at the 80 percent UCL prior to the end of the permit term (Appendix 2). For this analysis, the detection probability for future years is assumed to be constant at 0.59 (95 percent CI = 0.51, 0.66) which is the overall detection probability achieved in FY 2023. As future indirect take is unknown and will vary based on the timing of ODT, we assumed total indirect take for the Project over the permit term would be a maximum of four adult equivalents (14 juveniles based on assumed the ʻōpeʻapeʻa survival rates; USFWS 2016), or 17.4 percent of the permitted take. Currently, the proportion of total take that is attributable to indirect take is 12.8 percent (2.5 adult bat equivalents estimated from indirect take / 19.5 bats estimated combining the direct and indirect take) making the assumption of four adult equivalents conservative. Assuming four adult bat equivalents are attributed to the Project as indirect take, the permitted direct take under the Project's ITS and ITL would be 19 bats (i.e., 23 permitted take - 4 indirect take = 19 direct take).

Based on the analysis described above and presented in Appendix 2, there is a 10.2 percent chance that the 80 percent UCL of cumulative take will not be exceeded during the permit term (Appendix 2). The median number of years of operation without permit exceedance is estimated to be 17. It is important to note that the probability of permit exceedance at the Project may be overestimated, given that the proportion of risk in the model was not adjusted to reflect that the Low Wind Speed Curtailment (LWSC) regime (Section 10.0) initiated in April 2012. LWSC will remain in place for the remainder of the Project's permit term.

Brookfield has been in discussion with the agencies about turbine maintenance and component replacement including turbine blades and nacelles. The proposed maintenance and component replacement is anticipated to commence in FY 2024 and would result in a slightly larger rotor swept area (RSA). The installation of bat deterrents would occur in conjunction with turbine blade replacement as bat deterrents have proven effective at the neighboring Kawailoa Wind Project (Tetra Tech 2022b). Additionally, to compensate for the increase in RSA, KAH will increase the search area to maintain the current density weighted proportion (Appendix 1) in consultation with agencies. The updated search area will be a circular plot extending 45 meters out from the base of the WTGs. It will include all areas that are possible to clear and manage/maintain the vegetation. KAH will communicate with agencies on turbine-specific search plot details. KAH has committed to searching the 45-meter radius search plot for a minimum of four years, in consultation with USFWS.

The proposed equipment replacement is anticipated to reduce the risk of future ʻōpeʻapeʻa fatalities and the likelihood of permit exceedance due to the addition of the bat deterrents to the existing LWSC minimization measure.

7.2 Fatalities of Non-Covered Species

Eleven bird fatalities, representing ten species, were documented at WTGs at the Project site in FY 2023. Five of the species observed in FY 2023 are protected by the Migratory Bird Treaty Act (MBTA): great frigatebird (one fatality), white-tailed tropicbird (one fatality), Pacific golden-plover (one fatality), wedge-tailed shearwater (one fatality), and cattle egret (one fatality). For a complete list of fatalities detected in FY 2023, including Hawaiian and scientific names, see Appendix 3.

8.0 Wildlife Education and Observation Program

Wildlife Education and Observation Program trainings continue to be conducted on an as-needed basis to provide on-site personnel with the information to respond appropriately if they observe a Covered Species or encounter downed wildlife while on-site. Wildlife Education and Observation Program trainings were provided to 115 individuals over 13 dates in FY 2023.

9.0 Mitigation

The Project's mitigation requirements are described in Section 7.6 of the approved HCP.

9.1 ʻŌpeʻapeʻa

9.1.1 On-Site Acoustic Surveys

The HCP commits to acoustically monitoring for bat activity during years when systematic fatality monitoring is conducted. Acoustic monitoring has been conducted continuously at the Project since the start of operations in 2011. Over the course of this long-term monitoring effort, the the number of moniting locations and type of monitoring equipment has changed. Between FY 2014 and FY 2017, monitoring was conducted at 12 locations distributed across the Project. However, due to the low frequency in the number of nights with recorded bat activity, monitoring efforts were reduced to 7 locations beginning in FY 2018 (Kahuku Wind 2018), and then to 4 locations (WTGs 2, 5, 9, and 12; Figure 1) beginning in FY 2019. Anabat acoustic bat detectors (models SD1 and SD2) were deployed during the first 2 years of bat acoustic monitoring. In FY 2014 (July 2013) Anabat detectors were replaced with Song Meter SM2BAT+ ultrasonic recorders equipped with SM3-U1 microphones (Wildlife Acoustics, Maynard, MA, USA). In FY 2017, SM3-U1 microphones were replaced with SMX-U1 microphones. In FY 2023, the Song Meter SM2BAT+ acoustics recorders and SMX-U1 microphones were deployed alongside the newest models available, the Song Meter

SM4BAT-FS and SMM-U2 microphones, in order to understand how the more sensitive SMM-U2 microphones affected the detection of bat activity at the Project (Appendix 4).

The objective of monitoring is to better understand the annual and seasonal variations in bat activity at the Project. Analysis of variance (ANOVA) and Tukey's HSD were used to test for differences in detection rates between detectors and microphone models, and for differences in detection rates from FY 2014 through FY 2023. To test for a change in detection rates across all monitoring years, we used a linear mixed-effect model (LMM) with year, sampling effort (i.e., the number of monitoring locations) and detector/microphone model, as predictor variables, as well as interactions between these variables and included site location as a random effect. Data were normalized with an Ordered Quantile Normalization transformation using the 'bestNormalize' package in R (Peterson 2021). The distribution of residuals from the LMM were examined to check for violations of model assumptions. All tests were two-tailed, employed an alpha value of 0.05, and were conducted in R version 4.2.3 (R Core Team 2023).

As demonstrated over the past 10 sampling years, bat activity at the Project remains generally low. During FY 2023 across the 4 detector locations, the ʻōpeʻapeʻa were detected on 50 out of 1,281 detector nights sampled (3.9 percent) using the SM2BAT+ with SMX-U1 microphone, and 97 out of 1,458 detector-nights sampled (6.7 percent) using the SM4BAT-FS with SMM-U2 microphone (Table 2). There was no statistical difference in the annual detection rate between detector and microphone models (ANOVA: $F_{10,68} = 7.15$, $P < 0.001$; Tukey's HSD: $P > 0.999$), and as such we have used the SM4BAT-FS with SMM-U2 microphone data for the interannual variance analysis. The annual detection rate in FY 2023 (6.7 percent) was higher the annual detection rate in FY 2022 (2.1 percent) but not significantly different (Tukey's HSD: $P > 0.584$).

Among all monitoring years, annual detection rates were consistently low and represent less than 7.0 percent of detector nights sampled (Table 2). The observed annual detection rates in FY 2023 were significantly larger than all detection rates prior to FY 2022, excluding FY 2019 (Tukey's HSD: FY 2014 – FY 2023, $P < 0.001$; FY 2015 – FY 2023, $P < 0.001$; FY 2016 – FY 2023, $P < 0.001$; FY 2017 – FY 2023, $P < 0.001$; FY 2018 – FY 2023, $P < 0.002$; FY 2019 – FY 2023, $P > 0.055$; FY 2020 – FY 2023, $P < 0.001$; FY 2021 – FY 2023, $P < 0.006$). These observed differences in annual detection rates between years was similiar when compared with annual detections rates reported using the SM2BAT+ with SMX-U1 micrphone. Despite this increase in FY 2023, the annual detection rates across all monitoring years appear to be stable, with no significant increasing or decreasing trend, regardless of the variation in the sampling effort or detector and microphone model used (LMM; Year: $t_{12,75} = -1.55$, $P > 0.127$; Year*sampling effort: $t_{12,75} = -1.24$, $P > 0.221$; Year and detector/microphone model: $t_{12,75} = 1.89$, $P > 0.062$).

Table 2. Number of Detector-Nights Sampled and Proportion of Detector-Nights with Bat Detections Between FY 2014 and FY 2023

Dates	No. of Detector Nights Sampled	No. of Detector Nights with Detections	Proportion of Detector Nights with Detection(s)
FY 2014 (July 2013 - May 2014)[1]	3,146	31	0.010
FY 2015 (June 2014 - May 2015)[1]	3,113	12	0.004
FY 2016 (June 2015 - May 2016)[1]	3,030	28	0.009
FY 2017 (June 2016 - May 2017)[2]	3,093	15	0.005
FY 2018 (June 2017 - May 2018)[2]	1,458	10	0.007
FY 2019 (June 2018 - May 2019)[2]	1,046	12	0.011
FY 2020 (June 2019 - May 2020)[2]	1,413	6	0.004
FY 2021 (June 2020 - May 2021)[2]	1,283	9	0.007
FY 2022 (June 2021 - May 2022)[2]	1,076	23	0.021
FY 2023 (June 2022 - May 2022)	1,281[2]	50[2]	0.039[2]
	1,458[3]	97[3]	0.067[3]

1. SM2BAT+ with SM3-U1
2. SM2BAT+ with SMX-U1
3. SM4BAT-FS with SMM-U2

Number of monitoring sites: FY 2014 - 2017 (*n* = 12), FY 2018 (*n* = 7), FY 2021 - 2023 (*n* = 4)

In FY 2023, no activity was observed prior to July during the lactation reproductive period (mid-June to August)[2]. Detection rates peaked in September (32.5 percent of detector nights) during early post-lactation reproductive period, consisting of 39 detector nights with a detection. Following the peak in September, detection rates steadily declined in the months of October and November. Between December and March of the pre-pregnancy reproductive period only a single night with one detection occurred during the month of December. Activity was observed again in April and May of the pregnancy reproductive period with three and four detector nights with at a detection (Figure 2). The temporal patterns were similiar among the two detector and microphone models used. The overall pattern of the detection rates in FY 2023 were similar to the patterns of detection rates observed in previous years (Figure 3).

The Song Meter SM2BAT+ acoustics recorders and SMX-U1 microphones will be decomissioned in FY 2024 with the SM4BAT-FS and SMM-U2 microphones used exclusively.

[2] Corresponding reproductive periods defined by Gorresen et al. (2013).

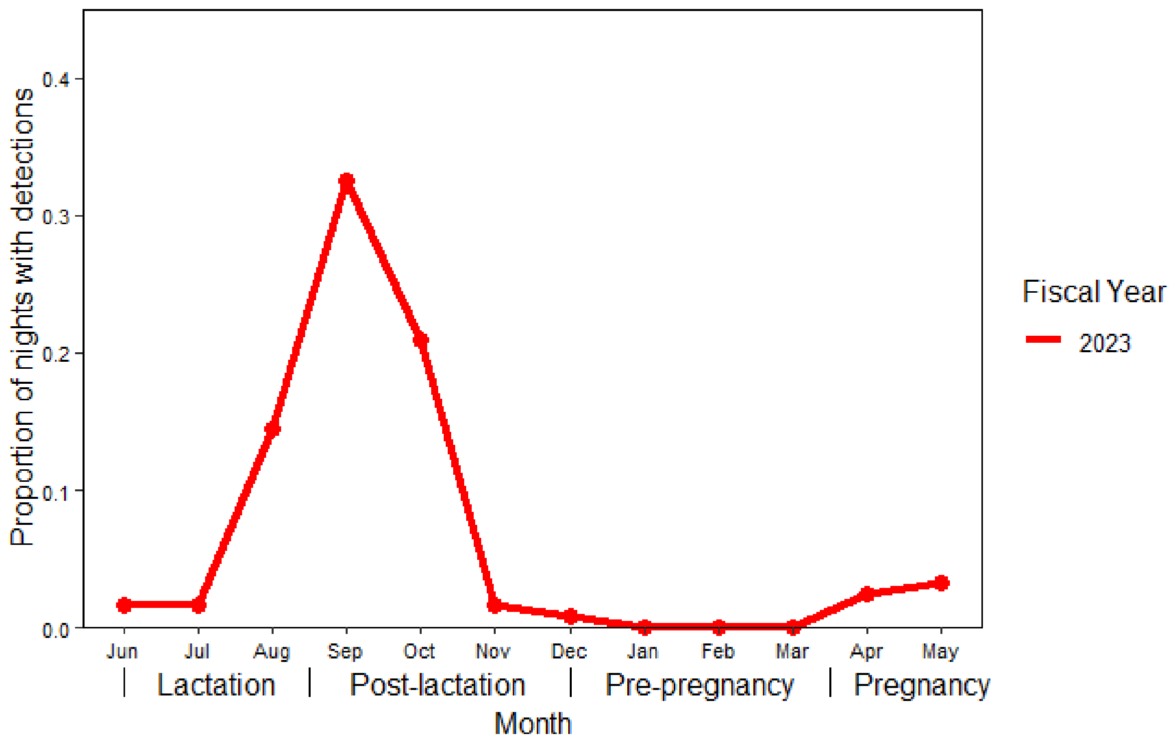

Figure 2. Monthly Bat Acoustic Activity at Kahuku for FY 2023 with Corresponding Reproductive Periods

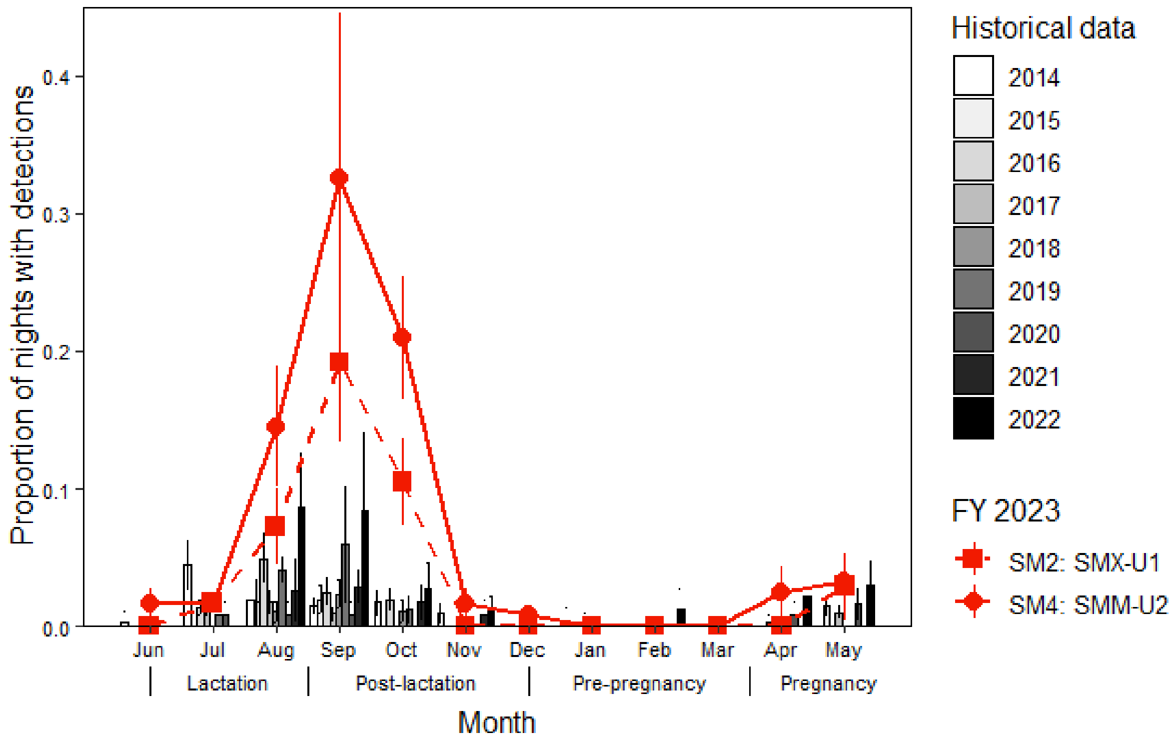

Figure 3. Monthly Bat Acoustic Activity at Kahuku for FY 2014 through FY 2023 with Corresponding Reproductive Period

9.1.2 Kahikinui Forest Reserve Mitigation

The Baseline (Tier 1) Mitigation obligation for the ʻōpeʻapeʻa is complete. Kahuku Wind paid the full obligation of $150,000 for Tier 1 bat mitigation conducted by DOFAW at the Kahikinui Forest Reserve on Maui in September 2011 (Kahuku Wind 2012). These funds were used for 2,500 meters of ungulate fencing around a 280-acre enclosed restoration area (Landon 2015).

9.1.3 Tier 2 Mitigation Planning

Mitigation planning for a Higher Take (Tier 2) was initiated in FY 2020. Based on input from USFWS and DOFAW, KAH is working with DOFAW Oʻahu to conduct management actions beneficial to bats at one of DOFAW's recent bat mitigation property acquisitions on Oʻahu, the Helemano Section of the ʻEwa Forest Reserve (Helemano Mitigation Area). Within this area, opportunities exist to perform habitat modification that are anticipated to achieve required benefits for bats. KAH has drafted a Tier 2 Mitigation Plan identifying habitat modification actions that are additive and complementary to the broad management goals and forest management activities identified and previously executed by DOFAW Oʻahu.

Due to the relatively low level of take identified in Tier 2 (8 bats) and the relatively short time left in the ITS and ITL terms, KAH is targeting a mitigation program that restores and enhances bat habitat quickly. KAH has presented USFWS and DOFAW with an original draft and three rounds of revisions of the Tier 2 Mitigation Plan as of the end of FY 2023, and consulted individually with members of the ESRC, from which suggested comments and approaches were incorporated by KAH (see Section 11.0). KAH is working through final approval with USFWS and DOFAW, including a presentation to the ESRC during FY 2024.

While anticipating finalization of the Mitigation Plan in 2023, KAH received agency permission in October 2022 to begin baseline monitoring for bat activity and insect sampling to measure insect diversity and biomass at the Helemano Mitigation Area. Baseline acoustic monitoring for bat activity began in March 2023 with the deployment of 12 SM4BAT-FS detector units each with an SMM-U2 microphone placed at and moved to randomly selected locations within the mitigation area monthly. Baseline insect sampling is set to commence in August 2023. In addition to and separate from the primary baseline acoustic monitoring effort, one acoustic monitor (SM2BAT+ with SMX-U1 microphone) was deployed at the site of a proposed water feature installation within the Helemano Mitigation Area to capture baseline activity at the location prior to mitigation actions.

9.2 Other Covered Species

Mitigation efforts for waterbirds were completed as of FY 2015 and no further reporting is required (Kahuku Wind 2016). All mitigation efforts for ʻaʻo and ʻuaʻu were completed as of FY 2017; no further reporting is required (Kahuku Wind 2017, Pacific Cooperative Studies Unit and DOFAW 2017). Mitigation efforts for the pueo were completed as of FY 2017 and no further reporting is required (Kahuku Wind 2017).

10.0 Adaptive Management

KAH has implemented adaptive management steps in accordance with the adaptive management framework in Section 8.3 of the approved HCP to understand and reduce the risk to the ʻōpeʻapeʻa. Adaptive management measures that have been and continue to be implemented include adjustments in vegetation management and scavenger control efforts to maintain a high probability of detecting Project-related wildlife fatalities and implementing a Project-wide LWSC regime.

LWSC of all turbines at wind speeds of up to 5 meters per second began April 27, 2012, and is currently implemented between sunset and sunrise from April through November. Curtailment is achieved by feathering blades to minimize rotation. The Project is operating under the LWSC regime described above, and KAH conducts regular checks to confirm the LWSC programming is operating as intended.

Five bat fatalities have been observed over approximately 11 years since the initiation of LWSC implementation at KAH, compared to three bat fatalities found across two calendar years prior to the initiation of LWSC.

11.0 Agency Meetings, Consultations, and Visits

KAH communicated actively with USFWS and DOFAW throughout FY 2023 through video teleconference, conference calls, quarterly reports, and e-mail communications related to the Project's HCP (Table 3). These communications included focused discussions of ʻōpeʻapeʻa Tier 2 mitigation planning and the development of the Mitigation Plan and equipment replacement at the Project.

Table 3. Summary of Agency Coordination and Communication in FY 2023

Date	Communication	Participants
August 25, 2022	E-mail communication with USFWS regarding required fatality reporting	Tetra Tech, USFWS
September 1, 2022	Submittal of Final HCP FY 2022 annual report	Submitted to DOFAW, USFWS by Tetra Tech
September 27, 2022	Meeting: Tier 2 Bat Mitigation Plan	KAH, Tetra Tech, USFWS, DOFAW
October 12, 2022	Annual HCP implementation review meeting (via teleconference)	KAH, Tetra Tech, USFWS, DOFAW
October 25, 2022	Helemano Mitigation Area cattle use discussion	KAH, Tetra Tech, DOFAW Oʻahu
October 27, 2022	Submittal of FY2023 Q1 report	Submitted to USFWS, DOFAW by Tetra Tech
November 23, 2022	Submission of Draft Tier 2 Bat Mitigation Plan, Revision #3	Submitted to USFWS, DOFAW by Tetra Tech
December 19, 2022	Kahuku Wind Project major maintenance/equipment replacement– agency discussion	KAH, Tetra Tech, USFWS, DOFAW
January 9, 2023	FY 2022 Annual ESRC review	KAH, Tetra Tech, ESRC
January 24, 2023	Helemano Mitigation Area water feature discussion	KAH, Tetra Tech, DOFAW Oʻahu
January 30, 2023	Submittal of FY 2023 Q2 report	Submitted to DOFAW, USFWS by Tetra Tech
March 9, 2023	Submission of Draft Tier 2 Bat Mitigation Plan, Revision #4	Submitted to USFWS, DOFAW by Tetra Tech
March 20, 2023	Helemano Mitigation Planning – onsite meeting	KAH, Tetra Tech, DOFAW Oʻahu
April 24, 2023	Submittal of FY 2023 Q3 report	Submitted to USFWS, DOFAW by Tetra Tech
April 24, 2023	Consultation regarding Tier 2 Bat Mitigation Plan	KAH, Tetra Tech, USGS (ESRC member-at-large)
April 24, 2023	Consultation regarding Tier 2 Bat Mitigation Plan	KAH, Tetra Tech, Loyal Merhoff (ESRC member-at-large)
May 11, 2023	Semi-annual HCP implementation review meeting (via teleconference)	KAH, Tetra Tech, USFWS, DOFAW

12.0 Expenditures

Total HCP-related expenditures for the Project in FY 2023 were $282,300 (Table 4).

Table 4. HCP-Related Expenditures at the Project in FY 2023

Category[1]	Amount
Permit compliance	$57,000
Fatality monitoring	$53,000
Acoustic monitoring for bats	$24,000
Scavenger control	$26,000
Vegetation management	$53,403
Equipment and supplies	$1,300
Tier 2 Bat Mitigation	$36,000
Tier 2 Bat Mitigation Baseline Monitoring	$57,000
Total Cost for FY 2023	**$282,300**
1. Staff labor costs are included in the overall costs for each category.	

13.0 Literature Cited

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Appendix 1. Dalthorp et al. (2017) Fatality Estimation for ʻŌpeʻapeʻa at the Project through FY 2023

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Modelling parameter		Modelling Period													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14 (current)
LWSC		N/A	N/A	Partial	5 m/s	5 m/s	5 m/s	5 m/s	5 m/s	5 m/s	5 m/s	5 m/s	5 m/s	5 m/s	5 m/s
Date Range of Modelling Period	Begin	1/1/2011	10/1/2011	4/1/2012	9/1/2013	8/1/2014	11/1/2014	4/1/2015	7/1/2016	7/1/2017	7/1/2018	7/1/2019	7/1/2020	7/1/2021	7/1/2022
	End	10/1/2011	3/31/2012	8/1/2012	7/31/2014	10/31/2014	3/31/2015	6/30/2016	6/30/2017	6/30/2018	7/1/2019	6/30/2020	6/30/2021	6/30/2022	6/30/2023
Period length (days)		273	182	122	333	91	150	456	364	364	364	364	364	364	364
Percent of Year		0.75	0.50	0.33	0.91	0.25	0.41	1.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Search Interval (days)		3.5	2.5	3.5	3.5	3.5	30.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Number of Searches in Modelling period		77	72	34	94	25	4	64	51	51	52	52	52	52	52
Observed fatalities (X)		1	0	2	0	1	0	0	0	0	0	0	1	1	2
K		0.7	0.7	0.7	0.7	0.7	0.7	1[1]	1[1]	1[1]	1[1]	1[1]	1[1]	1[1]	1[1]
DWP		1.0	1.0	1.0	1.0	1.0	1.0	0.7[2]	0.7[2]	0.7[2]	0.7[2]	0.7[2]	0.7[2]	0.7[2]	0.7[2]
ĝ	Ĝ	0.464	0.796	0.746	0.830	0.670	0.347	0.565	0.530	0.535	0.411	0.527	0.632	0.519	0.589
	95% LCI	0.262	0.675	0.611	0.647	0.460	0.166	0.486	0.465	0.464	0.326	0.434	0.549	0.421	0.521
	95% UCI	0.672	0.894	0.861	0.955	0.850	0.554	0.642	0.595	0.605	0.618	0.618	0.714	0.616	0.659
B	Ba	9.841	39.66	33.65	17.27	13.94	7.456	87.01	119.5	101.7	50.73	58.89	86.42	51.85	99.82
	Bb	11.38	10.18	11.43	3.528	6.853	14.05	67.09	105.8	88.60	72.82	52.93	50.40	48.05	70.31
M*[3]		4	3	7	6	7	8	8	9	9	9	9	11	13	17

1. Searches performed by canine teams which have a high probability of detecting a carcass during a subsequent search if initially missed.

2. Reduced search area (See FY 2018 Annual Report for detailed analysis).

3. Cumulative value representing estimate of total direct take from the start of operations through the identified monitoring period at the 80 percent UCL.

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Appendix 2. ʻŌpeʻapeʻa 20-Year Projected Take at the Project in FY 2023

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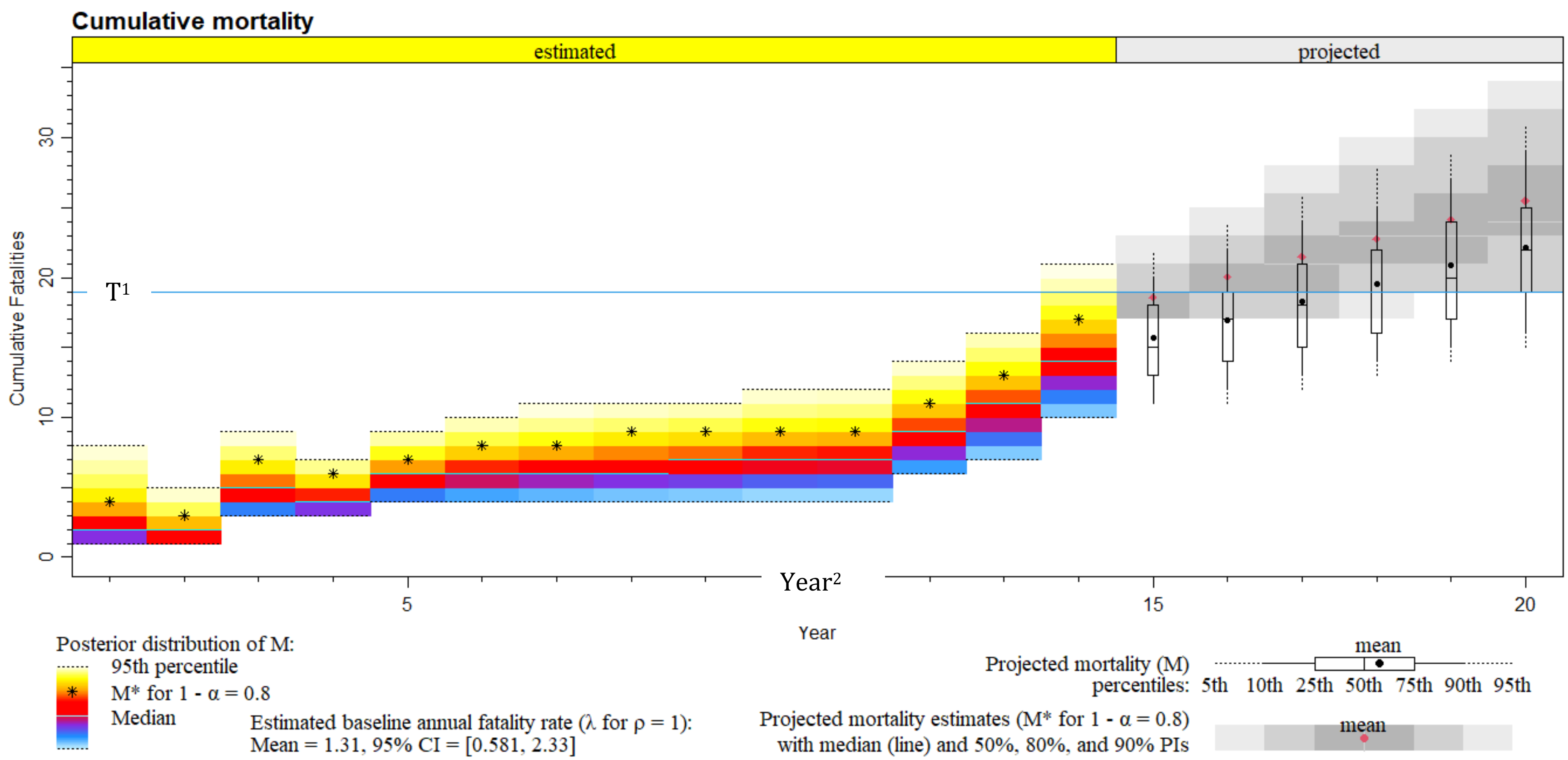

1. Permitted take for the ʻōpeʻapeʻa at the Project is 23; however, projected take as calculated using EoA only includes direct take. To account for indirect take in this analysis, an approximate take threshold (T) of 19 is shown, representing permitted bat take (23) minus 4 adult equivalents of indirect take (17.4 percent of the permitted limit). Currently, the proportion of total take that is attributable to indirect take is 12.8 percent.
2. The "years" 1 – 7 represent unique modelling periods rather than FY and cumulatively represent 5.5 years of operation. In contrast, starting with year 8, the years represent FYs. Therefore, the length of time displayed represents 19.5 years, or the actual time turbines are anticipated to be operational during the 20-year permit term.

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Appendix 3. Documented Fatalities at the Project during FY 2023

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Species	Date Documented	WTG	Distance to WTG (meters)	Bearing from WTG (degrees)	Search/ Incidental[3]
Fregata minor (great frigatebird) [2]	7/01/2022	11	110	280	Incidental
Geopelia striata (zebra dove)	8/07/2022	4	2	90	Incidental
Streptopelia chinensis (spotted dove)	9/06/2022	9	1	10	Incidental
Phaethon lepturus (white-tailed tropicbird) [2]	9/08/2022	12	44	310	Incidental
Lasiurus cinereus semotus (ʻōpeʻapeʻa/Hawaiian hoary bat,)[1]	9/22/2022	7	25	225	Search
Pluvialis fulva (Pacific golden-plover) [2]	11/23/2022	5	17	240	Search
Ardenna pacifica ('ua'u kani/wedge-tailed shearwater)[2]	11/25/2022	8	32	225	Search
Zosterops japonicus (warbling white-eye)	12/08/2022	7	34	275	Search
Phasianus colchicus (ring-necked pheasant)	12/21/2022	3	5	80	Search
Amandava amandava (red avadavat)	12/22/2022	7	5	50	Search
Lasiurus cinereus semotus (ʻōpeʻapeʻa /Hawaiian hoary bat,)[1]	3/16/2023	10	32	300	Search
Zosterops japonicus (warbling white-eye)	4/13/2023	5	19	208	Search
Bubulcus ibis (cattle egret) [2]	6/1/2023	11	30	205	Search

1. Federally and State endangered species.
2. Species protected under the MBTA.
3. Incidental equates being found outside of the searched area and/or outside of the regularly scheduled search time.

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Appendix 4. Implications of Acoustic Detector Upgrades for Long-Term Monitoring, Kahuku Wind Facility

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Implications of Detector Upgrades for Long-Term Monitoring

Kahuku Wind Facility

Prepared for
Brookfield Renewable Partners

Prepared by

TETRA TECH

Tetra Tech, Inc.

March 2023

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1.0 Introduction

Under the Kahuku Wind Project's (KAH) Habitat Conservation Plan (HCP), KAH has committed to performing acoustic monitoring of bat activity during years when systematic fatality monitoring is conducted. Under this commitment, bat acoustic monitoring has been conducted continuously at the facility since the start of operations in 2011. Given the 20-year timeline associated with the HCP and the long-term monitoring effort, advancements in acoustic monitoring technology are inevitable, and any potential change in monitoring technology requires careful consideration due to the potential for implications to the historical dataset. Anabat acoustic bat detectors (models SD1 and SD2) were deployed during the first two years of bat acoustic monitoring. In July 2013, Anabat acoustic bat detectors were replaced with Song Meter SM2BAT+ detectors which were equipped with higher sensitivity microphones, however, the increased sensitivity of the microphones used with the SM2BAT+ made prior datasets collected using the Anabat II detectors incomparable. Beginning in 2017, the SM2BAT+ units were equipped with SMX-U1 microphones and are currently the microphone model being used. There is a need to update the acoustic monitoring unit again as the SM2BAT+ units are old, frequently fail causing periods of data loss, and are no longer in production. Furthermore, the newer SM4BAT-FS model can be equipped with more advanced SMM-U2 microphones capable of recording bats at greater distances and providing a more accurate assessment of bat activity at KAH. Comparability of long-term monitoring data is important for tracking and interpreting trends over time. Therefore, it is important to evaluate the effects that changes in equipment will have on long-term monitoring data prior to upgrading. The objective of this study was to 1) compare differences in measures of bat activity between SMX-U1 (old model) and SMM-U2 (new model) microphones at KAH, 2) identify how the use of the SMM-U2 microphones at KAH may affect the tracking and interpretation of long-term bat activity, and 3) determine if adjusting KAH's historical data sets using a ratio estimator is appropriate.

2.0 Methods

We simultaneously deployed two models of bat detectors and microphones to record free-flying Hawaiian hoary bats (*Lasiurus semotus*) at the KAH between 13 December 2021 and 31 November 2022. Four Song Meter SM2BAT+ ultrasonic recorders equipped with one SMX-U1 high frequency microphone and four Song Meter SM4BAT-FS equipped with one SMM-U2 high frequency microphone (Wildlife Acoustics, Maynard, MA, USA) were deployed in tandem at four KAH wind turbine locations (2, 5, 9, and 12), approximately 50 meters from the base of the turbine (Figure 1). Microphones were positioned 3 meters above ground level and within approximately 1 meter of each other. Detectors were powered by 12-volt/36-amp-hour batteries connected to 10-watt/12-volt solar panels (ACOPOWER, Walnut, CA, USA) and programmed to record one hour before sunset to 1 hour after sunrise.

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Kahuku Wind Project

Figure 1
Project Layout

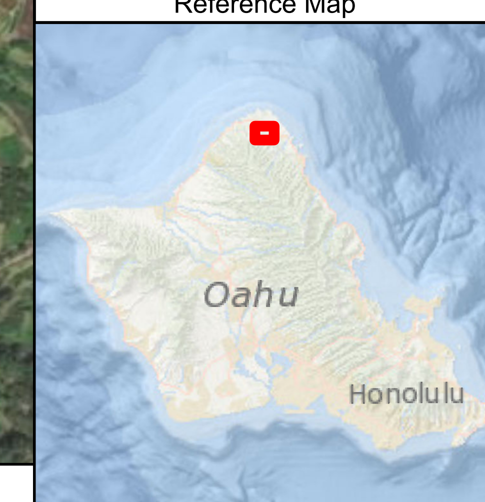
HONOLULU COUNTY, HI

- WTG
- Bat Detector

TETRA TECH

Brookfield
Renewable Energy Partners

Reference Map



1:8,000 WGS 1984 UTM Zone 4N

0 400 800 1,600 2,400 3,200 Feet

NOT FOR CONSTRUCTION

Tetra Tech processed acoustic recordings using Kaleidoscope PRO version 5.1.9 (Wildlife Acoustics, Inc., Maynard, Massachusetts) software incorporating the Bats of North America 5.1.0 AutoID classifier for Hawai'i. A single expert manually verified all recorded call files and removed all false-positive and negative identification errors prior to analysis. Positive detections required a minimum of two echolocation pulses within a single recording file. Over the course of this study, the SM2BAT+ units equipped with SMX-U1 microphones sampled a total of 1,191 detector nights[1] while the SM4BAT-FS units equipped with SMM-U2 microphones sampled a total of 1,372 detector nights. Therefore, we removed any sampling nights in which either SM2BAT+ and SM4 units were not simultaneously functional (*n* = 181) prior to the analysis.

3.0 Analysis

A t-test was used to test for differences in three activity metrics: the number of echolocation pulses, the number of call files[2] recorded, and the number of detector nights with detections between microphone models. A linear model (LM) with an interaction between microphone model and month was constructed to determine if there were differences in the proportion of detector nights with detections between SMX-U1 and SMM-U2 microphones during each sampling month. A Pearson's correlation test was used to test for correlations in activity metrics measure between the SMX-U1 and SMM-U2 microphones. Correlation tests were run on the number of echolocation pulses in each call file, the number of call files recorded each night and the number of detector nights with detections between SMX-U1 and SMM-U2 microphones. A ratio estimator was calculated for the number of detector nights with detections in the R package "survey" version 4.1.1 (Lumley 2020) using data from all detector locations and survey months for which simultaneously data was collected (*n* = 42). A LM was constructed to test the relationship between the predicted and observed data. All tests were two-tailed, employed an alpha value of 0.05, and were conducted in R version 4.1.2 (R Core Team 2022).

4.0 Results

Over the course of this study the SMM-U2 microphones detected a significantly greater number of echolocation pulses (*t*-test: $t_{1,200} = 2.980$, $P < 0.004$) and generated a significantly greater number of call files (*t*-test: $t_{1,200} = 3.395$, $P < 0.001$) than the SMX-U1 microphones (Figures 2 and 3; Table 1). However, the number of detector nights with detections was not significantly different between the SMX-U1 and SMM-U2 microphones (*t*-test: $t_{1,82} = 1.572$, $P > 0.119$; Figure 3 and Table 1). On average, the SMM-U2 microphones detected four times more echolocation pulses, generated five

[1] Detector night is defined as an individual sampling night in which the acoustic recorder remained active for more than 50 percent of the anticipated recording duration.
[2] Call file is defined as a file that includes as a sequence of echolocation pulses over a time span of milliseconds recorded from bats passing a microphone.

times more calls files and documented twice as many more detector nights with detection than the SMX-U1 microphones.

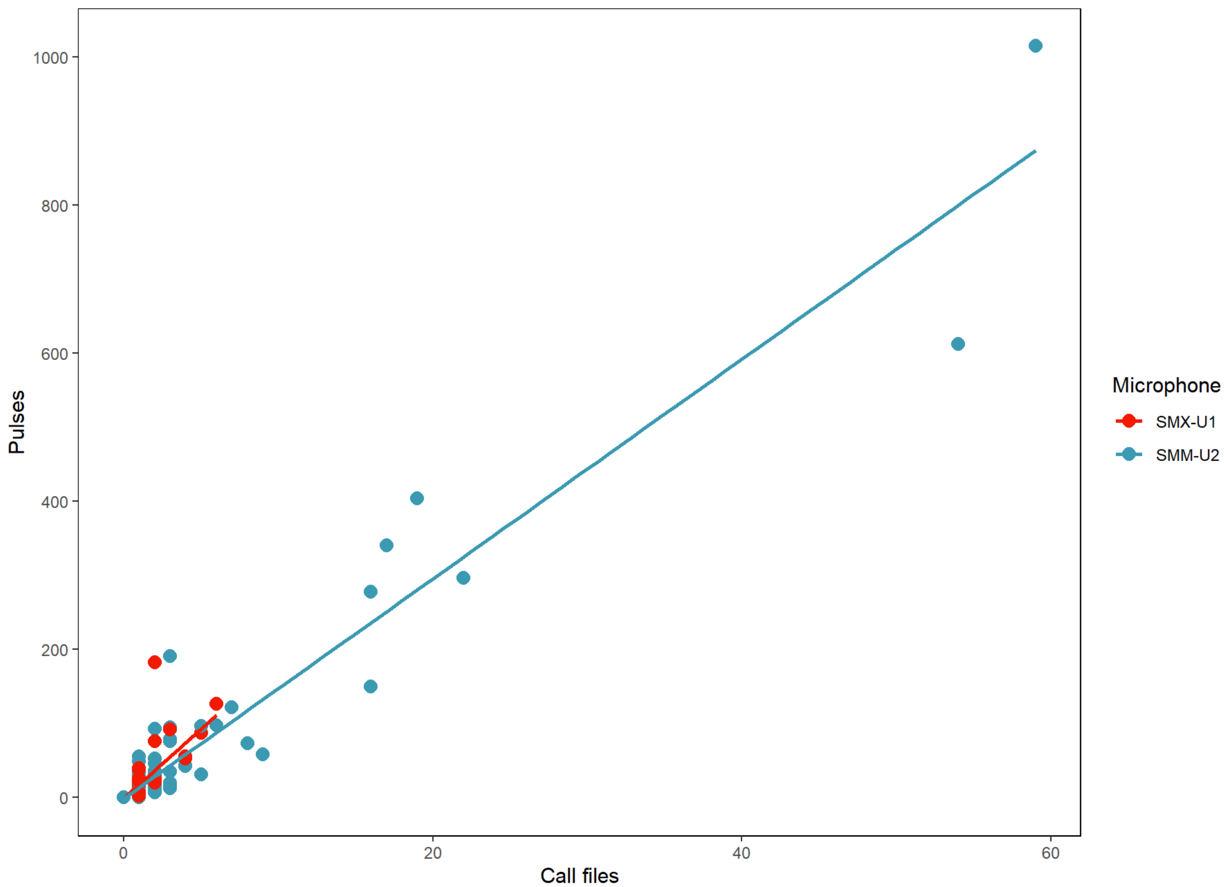


Figure 2. Number of Bat Echolocation Pulses Relative to the Number of Call Files Between 13 December 2021 and 31 November 2022

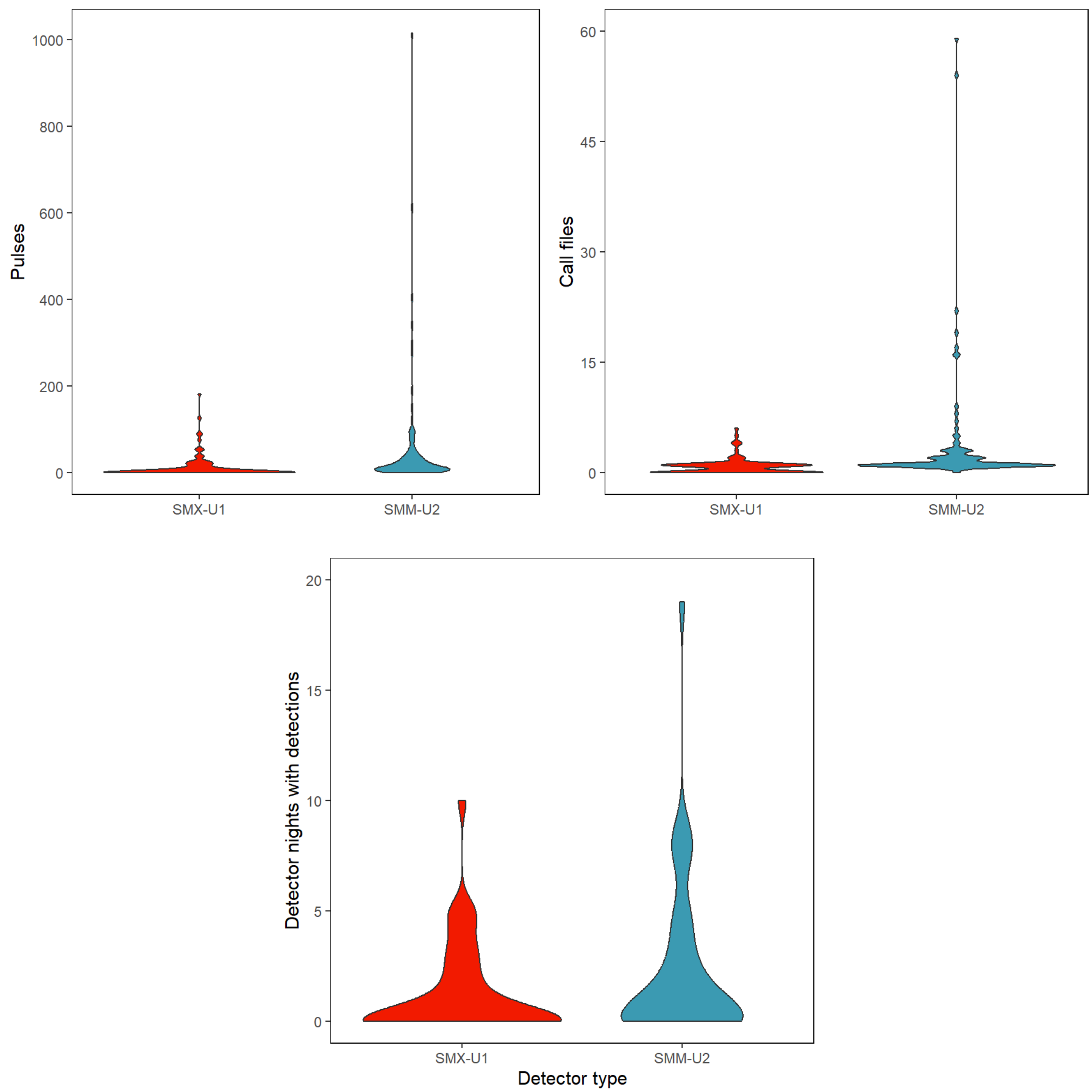


Figure 3. Violin Plot Demonstrating Differences in the Number of Detected Echolocation Pulses, Generated Call Files, and Documented Detector Nights with Detections

Table 1. Detected Echolocation Pulses, Generated Call Files, and Documented Detector Nights with Detections

Activity Metric	SMX-U1			SMM-U2			P-value
	Mean ± SE	Range	Total	Mean ± SE	Range	Total	
Pulses[1]	12.74 ± 2.71	0 - 182	1,287	52.59 ± 13.09	0 - 1,015	5,312	0.0032
Call files[1]	0.77 ± 0.11	0 - 6	78	3.66 ± 0.84	0 - 59	370	0.0008
Detector nights with detections	1.26 ± 0.33	0 - 10	53	2.31 ± 0.58	0 - 19	97	0.1199
1. P-value indicates significance at an alpha level of 0.05.							

The seasonal trend in the proportion of detector nights with detections (number of detector nights with detections/number of detector nights) was similar between SMX-U1 and SMM-U2 microphones (Figure 4). Between December and July, the proportion of detector nights with detections was low for both SMX-U1 (0.030) and SMM-U2 (0.039) microphones and the maximum number of detector nights with a detection (n = 3) for both SMX-U1 and SMM-U2 microphones occurred in the month of May (Figure 4, Table 2). For both microphone types, the proportion of detector nights with detections increased in the months of August, September, and October (Figure 3). During the period of low activity (December – July) the number of detector nights with detections was 33 percent greater on average among SMM-U2 microphones. During the period of highest activity (August – October) the number of detector nights with detections was 54 percent greater on average among SMM-U2 microphones. A comparison of the proportion of detector nights with detections between microphones for each sampling month indicated a significant difference only in the month of September (LM: $R^2 = 61.73$, $t_{23,61} = 2.255$, $P < 0.028$; Table 2). There was some variance in the proportion of detector nights with detections observed at each of the four monitoring locations; however, the overall seasonal trend was similar (Figure 5).

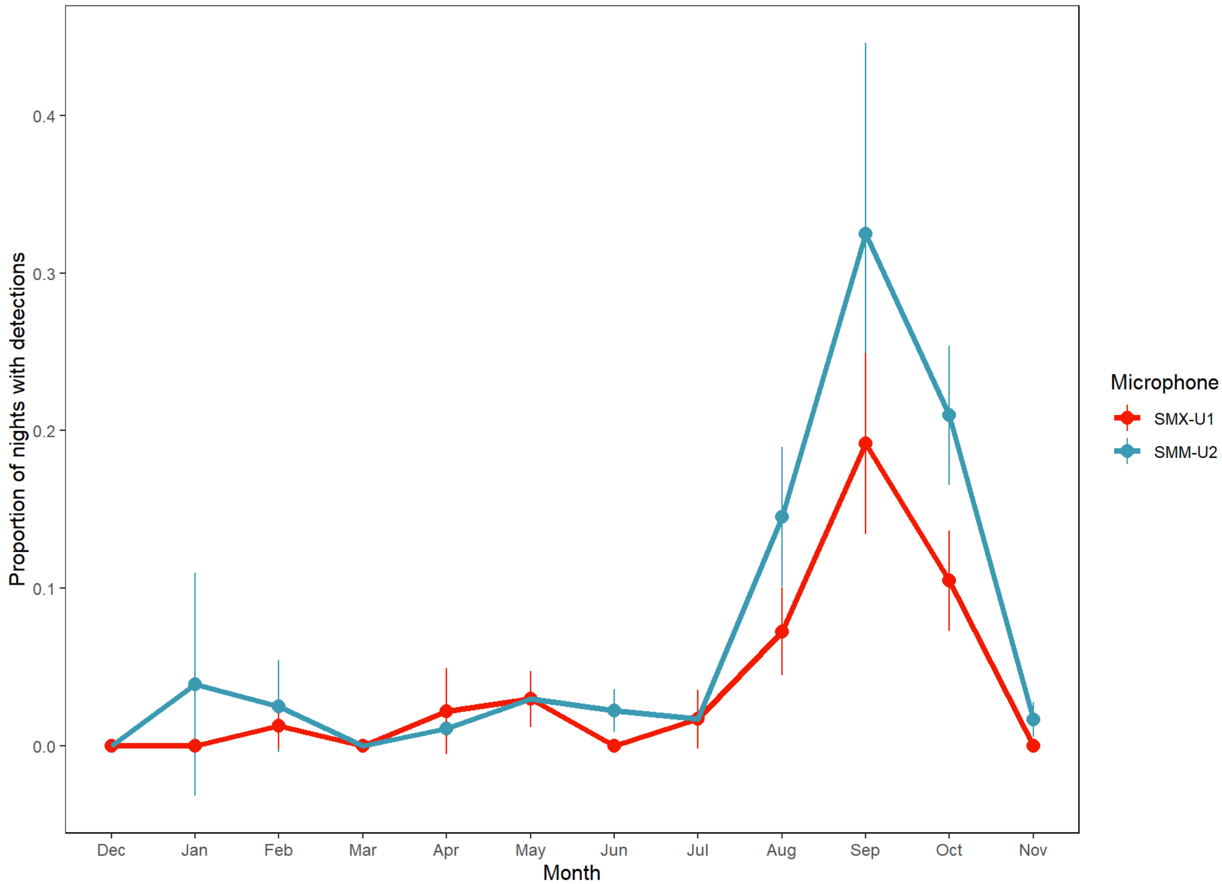


Figure 4. Monthly Comparison in the Proportion of Detector Nights with Detections

Table 2. Monthly Comparison for the Number of Detector Nights, Detector Nights with Detections, Proportion of Detector Nights with Detections, and Standard Error (*SE*)

Sampling Month	Detector Nights		Detector Nights with Detections		Proportion of Detector Nights with Detections		P-value
	SMX-U1	SMM-U2	SMX-U1	SMM-U2	SMX-U1 ± *SE*	SMM-U2 ± *SE*	
Dec	51	51	0	0	0.000	0.000	0.844
Jan	51	51	0	2	0.000	0.039 ± 0.071	0.421
Feb	80	80	1	2	0.013 ± 0.015	0.025 ± 0.029	0.714
Mar	121	121	0	0	0.000	0.000	0.832
Apr	91	91	2	1	0.022 ± 0.027	0.011 ± 0.10	0.448
May	101	101	3	3	0.030 ± 0.018	0.030 ± 0.018	0.832
Jun	90	90	0	2	0.000	0.022 ± 0.014	0.608
Jul	118	118	2	2	0.017 ± 0.019	0.017 ± 0.019	0.832

Sampling Month	Detector Nights		Detector Nights with Detections		Proportion of Detector Nights with Detections		P-value
	SMX-U1	SMM-U2	SMX-U1	SMM-U2	SMX-U1 ± *SE*	SMM-U2 ± *SE*	
Aug	124	124	9	18	0.073 ± 0.028	0.145 ± 0.044	0.190
Sep[1]	120	120	23	39	0.192 ± 0.057	0.325 ± 0.121	0.028
Oct	124	124	13	26	0.105 ± 0.032	0.210 ± 0.044	0.074
Nov	120	120	0	2	0.000	0.017 ± 0.011	0.641
Total	1191	1191	53	97	0.044 ± 0.004	0.081 ± 0.016	0.058

1. P-value indicates significance at an alpha level of 0.05.

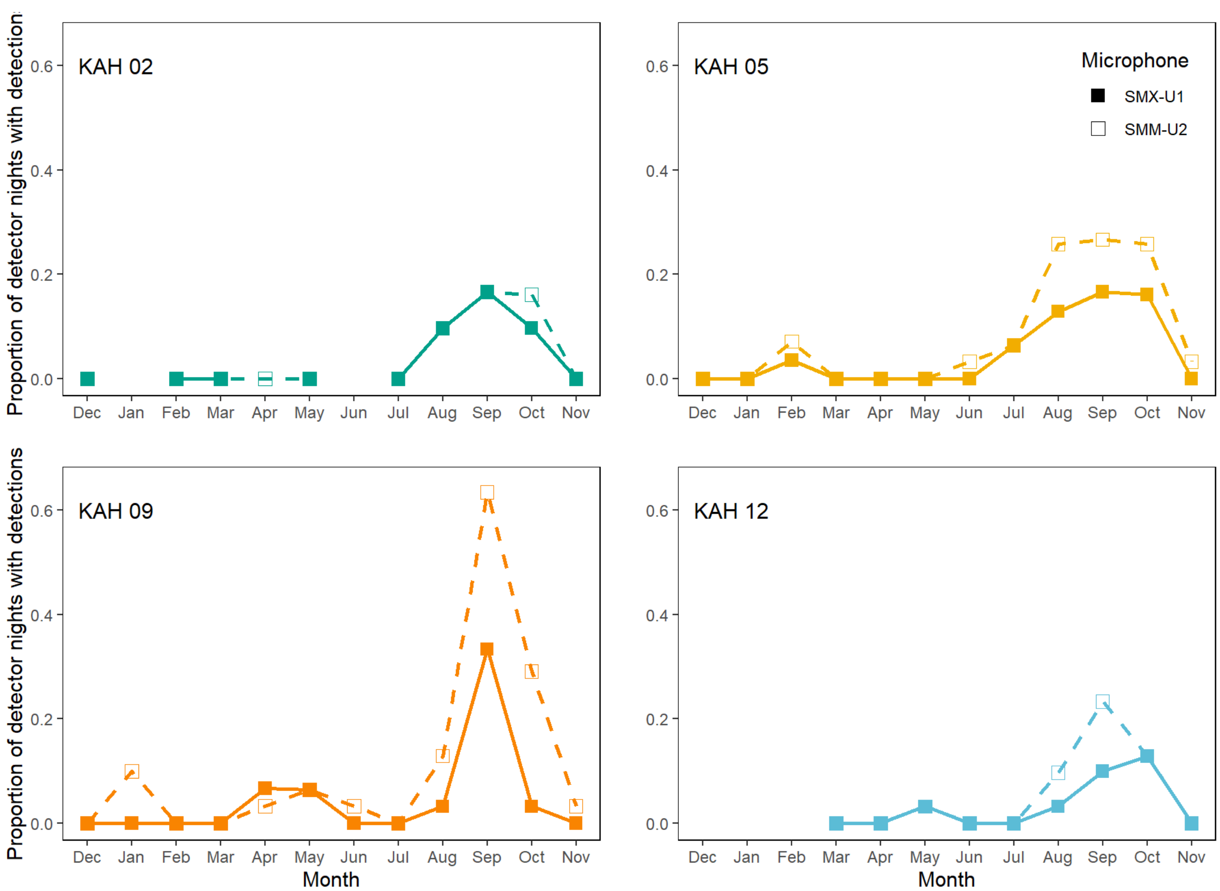


Figure 5. Monthly Comparison in the Proportion of Detector Nights with Detections SMX-U1 and SMM-U2 Microphones at Each of the Four Monitoring Locations[3]

[3] Months with missing data are from sampling nights without simultaneous operation of both microphones

A Pearson's correlation test demonstrated a low correlation between SMX-U1 and SMM-U2 microphones for the number of echolocation pulses detected (Pearson's correlation: $r = 0.571$, $P < 0.001$) and the number of call files generated (Pearson's correlation: $r = 0.562$, $P < 0.001$), but a strong correlation for the number of detector nights with detections (Pearson's correlation: $r = 0.900$, $P < 0.001$; Figure 6). Using the number of detector nights with detections resulted in a ratio estimation of 1.83 ± 0.00, which Tetra Tech then applied to the number of detector nights with detections from the SMX-U1 data. A linear regression of the predicted vs observed number of detector nights with detections (LM: $R^2 = 72\%$, $t_{1,40} = 7.14$, $P < 0.001$) had a slope of 0.834 (95 percent confidence interval: 0.591 – 1.078), an intercept of 0.767 (95 percent confidence interval: -0.718 – 2.245), and a residual standard error of 2.306 (Figure 7). Of the 42 predictions made using the ratio estimator, seven fell within the 95 percent confidence intervals of the regression line. Fifteen predictions fell outside of the 95 percent confidence intervals and either overestimated ($n = 10$) by a max of four or underestimated ($n = 5$) by a max of seven. The mean absolute error across all predictions was 1.77 (Figure 6). The remaining 20 resulted in a prediction of zero, as they were from detector nights in which the SMX-U1 did not record any bats. Across all sites and months, the ratio estimator predicted a total of 96 detector nights with detections, one less than observed from the SMM-U2 microphones (Table 2).

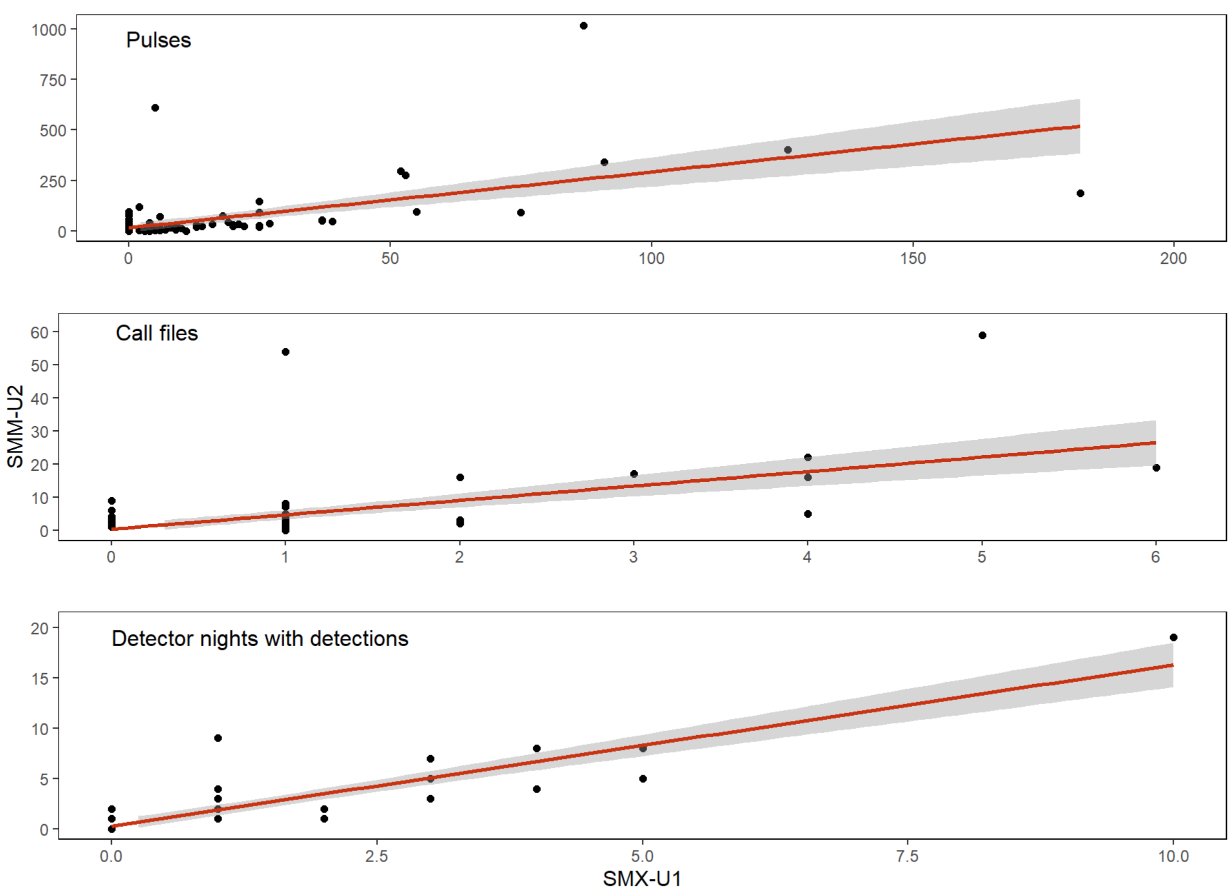


Figure 6. Correlation Plots for Number of Echolocation Pluses, Generated Call Files, and Detector Nights with Detections

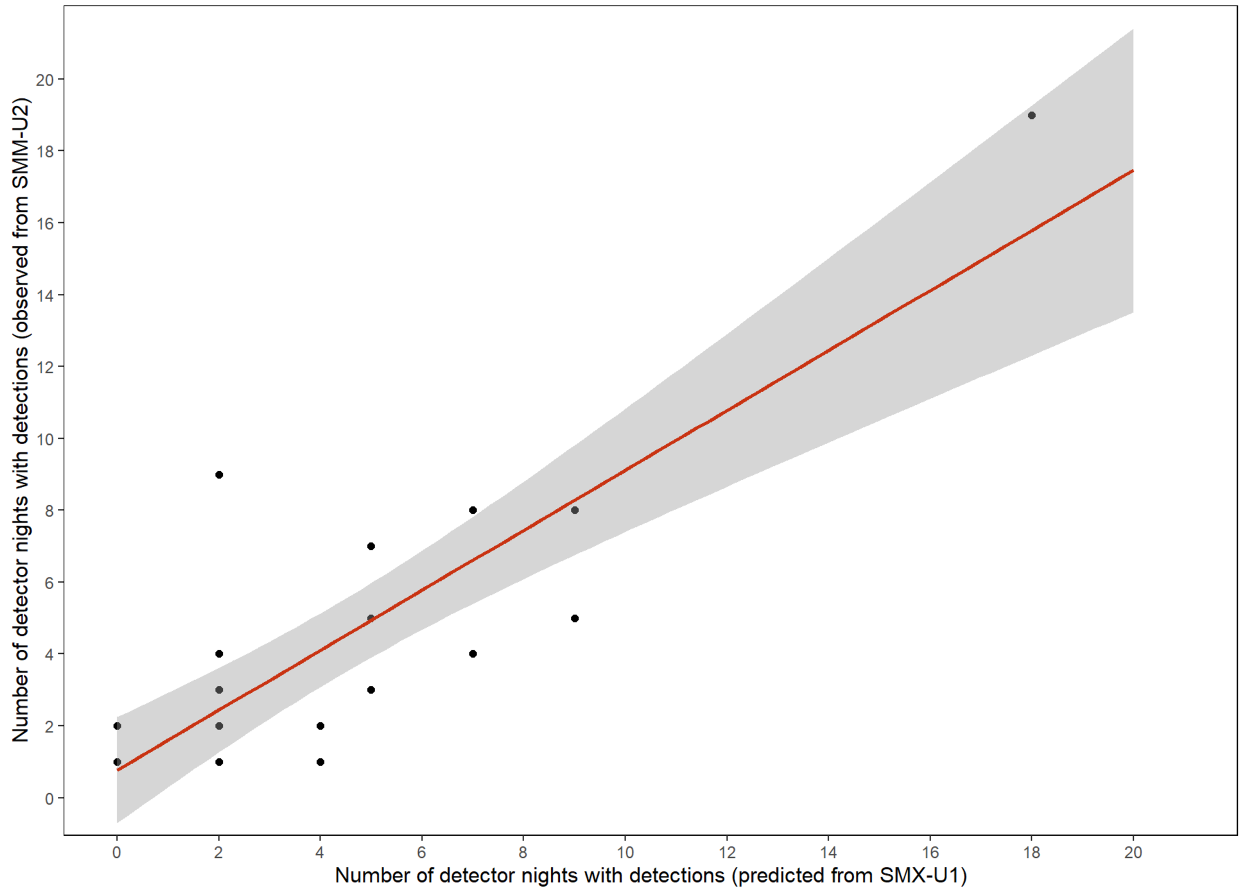


Figure 7. Linear Regression for the Predicted Versus Observed Number of Detector Nights with Detections

Calculating the proportion of detector nights with detections using the predicted values for the number of detector nights with detections and plotting them alongside the observed values for both SMX-U1 and SMM-U2 indicates a relatively close prediction during periods of higher activity (August – October). However, during periods of low activity (December – July) the predictions were less accurate (Figure 8).

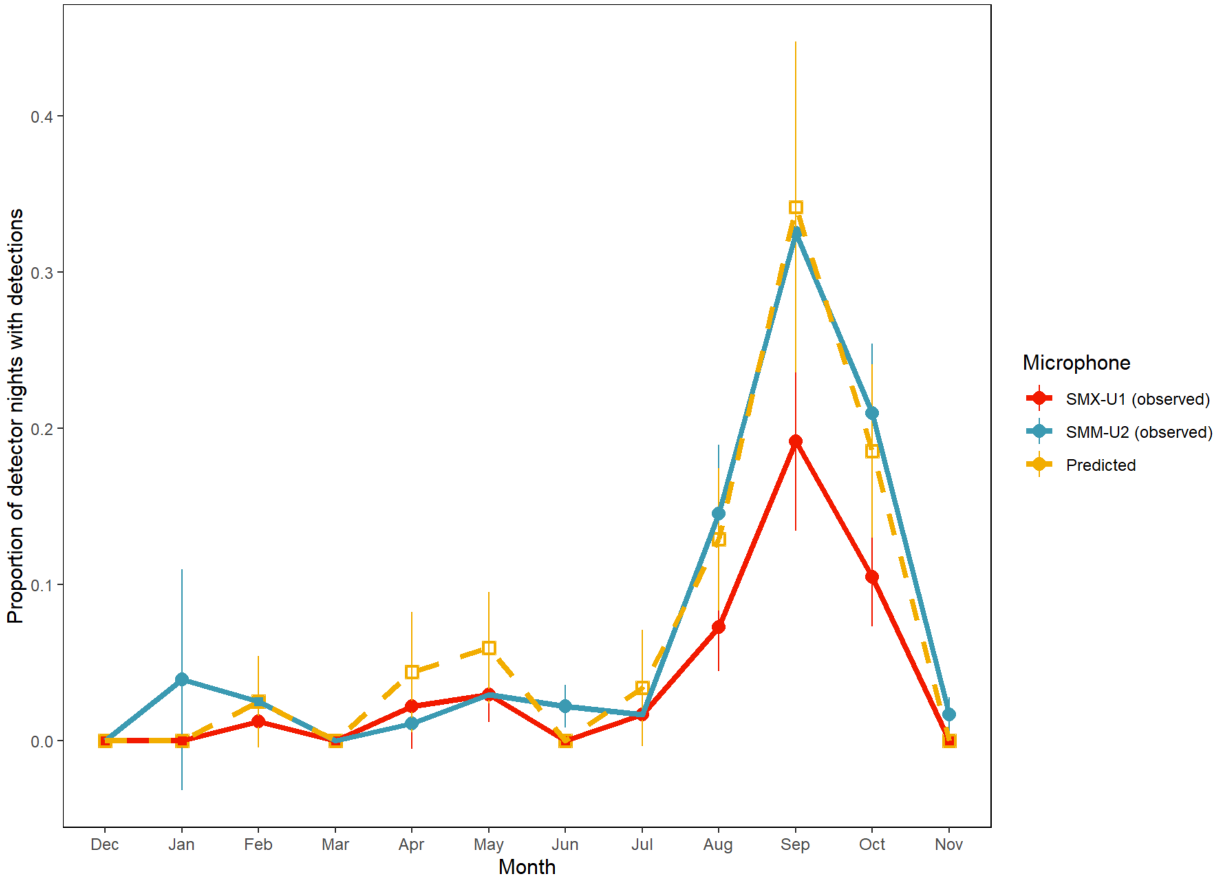


Figure 8. Monthly Comparison of the Proportion of Detector Nights with Detections and the Predicted Values from the Applied Ratio Estimator

5.0 Conclusion

The results of this study demonstrate the improvement in the detection capabilities of the newer SMM-U2 microphones compared to the older SMX-U1 microphones. On average, SMM-U2 microphones detected four times more pulses and generated five times more call files.

The metric of interest for assessing bat activity at KAH is the number of detector nights with detections. This metric which is then used to calculate the proportion of detector nights with detections, the primary metric for annual reporting on the current and historical trends in bat activity at KAH. Although not significantly different, SMM-U2 microphones had twice as many detector nights with detections compared to SMX-U1 microphones on average. The seasonal trend in the proportion of detector nights with detections was equally expressed by both microphone models, with a significant difference between microphone model occurring during the month of September, when activity was greatest. However, the lack of significance between the two microphone models during other months may be a result of small sample size (n = 4) and variance between monitoring locations (Figure 4). Therefore, results should be interpreted with caution.

Use of a ratio estimator to adjust historical data sets should be approached with caution. A ratio estimator performs best when the two factors being compared are highly linearly correlated (Sangngam 2014). Based on the weak correlation for the number of echolocation pulses and the number of call files between the two microphone models, the use of a ratio estimator on these two metrics may not be appropriate and is not advised. While we did find a strong correlation in the number of detector nights with detections between microphone models, the amount of usable data with which to calculate a ratio estimator was limited. Of the 42 samples, almost half (n = 20) had no detections for either of the microphone models and no more than 10 detector nights with detections per month were recorded by SMX-U1 microphones at any monitoring locations during this study (Figures 3 and 5). The ratio estimator performed well, when estimating the total number of detector nights with detections across all monitoring locations and months (i.e., the annually reported activity rate). However, when predicting monthly estimates for the number of detector nights with detections, only 32 percent of the predictions (n = 7) fell within the 95 percent confidence intervals and only 9 percent (n = 2) were 100 percent accurate. Furthermore, the residual standard error (2.31) and the mean absolute error (1.77) are relatively large compared to the 95 percent confidence intervals of the slope (0.591 – 1.078). For KAH's location, at which the historical bat activity is low and the reported annual average number of detector nights with detections between 2014 and 2022 is 16 (Kahuku Wind 2022), the error associated with using the ratio estimator from this study to predict bat activity is large and has the potential to alter the historical activity patterns observed at the site.

The results of this study are in line with Pinzari et al. (2019) which compared the SMX-US (old) and the SMX-U1 (new) microphone models for the SM2Bat+ and applied a regression estimator to correct data collected from the older SMX-US. Although their study was shorter in duration than the current study (only conducted at two sites over a six-week period), they recorded a greater amount of echolocation call data, enabling them to compare feeding buzzes in addition to the number of echolocation pulses and the number of call files. They concluded that that using a regression estimator to extrapolate and compare detections from SMX-US and SMX-U1 microphones was not advisable. Pinzari et al. (2019) did not include the number of detector nights with detections in their microphone comparison. It is possible that a more robust dataset may improve the accuracy of the ratio estimator or that other types of estimators (e.g., regression estimator) may be applied. However, any estimator should be location specific and the overall low activity at KAH, especially during the months December through July, make collecting an adequate dataset challenging.

6.0 References

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