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Daily vocalization patterns of the Saipan Reed Warbler (*Acrocephalus hiwae*)

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ABSTRACT—We investigated how detectability and vocalization patterns of Saipan Reed Warblers (*Acrocephalus hiwae*) varied by time of day. We used long-duration sound recordings from 11 locations occupied by Saipan Reed Warblers to model the probability of detecting a vocalization in each hour of the day. We found that Saipan Reed Warblers sang during all daylight hours. We did not find evidence of a dawn chorus in this species. These results are useful for determining what time of day surveys of Saipan Reed Warblers should be conducted, which is particularly relevant because Saipan Reed Warblers are protected by local and U.S. Federal laws, which leads to frequent surveys for this species. *Received 12 February 2024. Accepted 28 June 2024.*

Key words: automated recording unit, diel vocalization, endangered species, tropical bird song, Mariana Islands.

Patrones de vocalizaciones diarias de carricero *Acrocephalus hiwae*

RESUMEN (Spanish)—Investigamos cómo la detectabilidad y los patrones de vocalización de carricero *Acrocephalus hiwae* variaban por hora del día. Usamos la larga duración de sonidos de grabaciones de 11 localidades con presencia de carricero *Acrocephalus hiwae* para modelar la probabilidad de detección de vocalizaciones en cada hora del día. Encontramos que el carricero *Acrocephalus hiwae* cantaba durante todas las horas del día. No encontramos evidencias de coros crepusculares en esta especie. Estos resultados son útiles para determinar a qué hora del día deben hacerse búsquedas del carricero *Acrocephalus hiwae*, lo que es particularmente relevante ya que el carricero *Acrocephalus hiwae* es protegido por leyes locales y federales en Estados Unidos de America, lo que lleva a frecuentes búsquedas de esta especie.

Palabras clave: canto de ave tropical, especies amenazadas, islas Mariana, unidades de grabación automáticas, vocalizaciones diarias.

The Mariana Islands are an archipelago of volcanic and uplifted limestone islands in the western Pacific Ocean ~2,300 km south-southeast of Japan, and 2,400 km east of the Philippines (Cloud et al. 1956). At least 2 of the Mariana Islands have extant populations of reed warblers in the genus *Acrocephalus*, a group of Old World reed warblers that includes many island endemic species (Winkler et al. 2020). Populations of at least 3 *Acrocephalus* species have been extirpated from 4 other islands in the chain (Saitoh et al. 2012). The extant populations on the islands of Saipan and Alamagan are considered by Saitoh et al. (2012) to belong to the same species, the Saipan Reed Warbler (*Acrocephalus hiwae*).

Besides its English name, the local common names for this bird are Ga'ga' karisu (Chamorro) and Malul ghariisu (Carolinian) (Northern Mariana Islands Administrative Code § 85-30.1-101 2016, Clements et al. 2023). The Saipan Reed Warbler populations on Saipan and Alamagan are listed as threatened or endangered under Commonwealth of the Northern Mariana Islands (CNMI) law and endangered under U.S. law under the name Nightingale Reed Warbler, *Acrocephalus luscinia* (Northern Mariana Islands Administrative Code § 85-30.1-101 2016; 50 CFR 17.11 2023).

The Saipan Reed Warbler is a high priority species for conservation and management activities by both local and federal organizations. The current global population of Saipan Reed Warblers is estimated to be 1,019–6,356 individuals, with ~75% residing on Saipan and 25% on Alamagan (Marshall et al. 2021). Surveys of the Saipan population found lower Saipan Reed Warbler density in 2007 than in 1982 (Camp et al. 2009), while the Alamagan population showed no significant difference in density between 2000 and 2010 (Marshall et al. 2021). Local agencies and their partners are currently preparing to translocate Saipan Reed Warblers to other islands in the Mariana archipelago to increase its range-wide resilience to anthropogenic threats and to meet the delisting requirements outlined in the recovery plan for this species (USFWS 1998, CNMI DFW 2014). Threats to the species

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include habitat conversion, brown tree snake (*Boiga irregularis*) and other invasive predators, and stochastic events such as typhoons (Marshall et al. 2021).

Surveys to determine Saipan Reed Warbler presence are regularly conducted by government agencies and consultancies to ensure development projects are in compliance with the U.S. Endangered Species Act and local laws. Building or development that results in mortality or disturbance of Saipan Reed Warblers, including habitat destruction (i.e., "take" as defined by the Endangered Species Act of 1973) may be offset by purchasing credits that fund habitat protection in the Saipan Upland Mitigation Bank, a forested area of ~330 ha on the northern part of Saipan (Northern Mariana Islands Public Law No. 10-84 1997). In addition to surveys for development, the CNMI Division of Fish and Wildlife (DFW) also conducts surveys to assess population status of Saipan Reed Warblers on Saipan and Alamagan. Recovery criteria for downlisting Saipan Reed Warblers include maintaining or increasing population numbers for 5 consecutive years on both Alamagan and Saipan (USFWS 1998). To delist the species, U.S. Fish and Wildlife Service (USFWS) requires that there be at least 8,000 individuals in the Mariana Islands, distributed in stable or increasing populations on at least 5 islands (USFWS 1998). Increasing the effectiveness of monitoring efforts is key to evaluating the recovery of this species, and to assessing the impact of conservation actions.

The USFWS recommends 10 repeat visits to survey for Saipan Reed Warbler occupancy (USFWS 2014). The survey windows recommended by USFWS are sunrise to "around 10:00 hours" and the 2 h before sunset (USFWS 2014). In practice, 95% of all surveys by the CNMI DFW at proposed development sites since 2005 have been conducted between 0707 and 1510 h (Supplemental Table S1).

For the CNMI DFW, the timing of surveys is based largely on the department work schedule, which starts daily at 0730 h and ends at 1630 h. However, private consultants may not necessarily follow the same schedule, and DFW surveys sometimes follow different schedules when logistical conditions necessitate it, including when conducting surveys on the remote island of Alamagan. On Alamagan and Saipan, in areas not targeted for development, DFW surveys for Saipan Reed Warblers have generally been conducted between dawn and 1100 h, using 5 min stationary point counts (or 8 min stationary point counts on Alamagan) along established transects. This is sometimes followed by a period of playback to increase the probability of detecting a bird when it is present (ER pers. obs.; Marshall et al. 2021).

Recommendations from USFWS allow the use of playback in addition to passive surveys for Saipan Reed Warblers (USFWS 2014), and playback is often used by CNMI DFW in addition to passive surveys. However, some biologists conducting surveys for Saipan Reed Warblers, including some private consultants, do not have permits to use playback. There is also some negative public perception about using playback to detect Saipan Reed Warblers. Because of this public perception, and the need for permits to conduct playback, there is an interest in using only passive surveys for Saipan Reed Warblers.

Tropical passerines show a variety of breeding patterns and behaviors that are uncommon in temperate regions, including asynchronous breeding, singing and territory defense by both males and females, and year-round territory defense (Stutchbury and Morton 2023). Tropical birds also differ in their daily singing patterns; some species of tropical birds have strong dawn choruses, but other species do not (Stutchbury and Morton 2023). Dawn and dusk choruses in birds are periods of increased vocal activity during a few hours before and after dawn and dusk (Stacier et al. 1996). Some species also use different song types at dawn compared to other times of day (Stacier et al. 1996), but for the purposes of detecting birds during surveys, the difference in singing rate is the most relevant feature of dawn and dusk choruses. Understanding the daily singing patterns of Saipan Reed Warblers is important when planning targeted surveys for this species because surveying at times when the birds are most vocal will increase the probability of detecting the species if it is present.

Automated recording units (ARUs) are compact audio recorders that can be deployed for extended time periods to increase the temporal and spatial extent of auditory bird surveys without increasing the costs associated with human observer hours in the field (Williams et al. 2018). Passive acoustic monitoring is widely used to study many taxa, including bats (Tuneu-Corral et al. 2020), whales (Baumgartner et al. 2019), invertebrates (Penone et al. 2013), and often as a substitute for point counts to monitor birds (Furnas and Callas 2015, Klingbeil and Willig 2015, Shonfeld and Bayne 2017, Darras et al. 2018).

The CNMI DFW and its partners plan to continue Saipan Reed Warbler surveys on Saipan and Alamagan both for development permitting and population monitoring. The CNMI DFW will also need to monitor any potential future translocated populations to meet recovery goals (CNMI DFW 2014). Using ARUs to monitor long-term resident and translocated bird populations in the remote and difficult to access islands north of Saipan in the Mariana archipelago will increase survey effort while minimizing the costs and logistical constraints associated with in-person surveys.

In this study, we used ARUs to investigate the daily vocalization patterns of Saipan Reed Warblers. The goal was to determine whether morning and evening survey times are appropriate for this species. This study provides novel information about the vocal behavior of Saipan Reed Warblers and fills a knowledge gap for designing targeted survey protocols for this species.

Methods

We analyzed the daily vocalization patterns of Saipan Reed Warblers using data collected on the island of Saipan. During 2021–2023, we deployed continuously recording ARUs on 15 known or suspected Saipan Reed Warbler territories in both the wet season and the dry season. We used random forests (Breiman 2001), which is a machine-learning regression method that can accommodate nonlinear relationships, to model observed vocalization patterns to understand the daily vocalization behavior for this species. Code and data to produce figures and results are available online (Gaul 2024).

Study species

Saipan Reed Warblers are territorial birds that inhabit wetlands and upland areas of tall grass and shrubs on the islands of Saipan and Alamagan. Saipan Reed Warbler plumage is sexually monomorphic, but males have a longer wing chord than do females (Radley et al. 2011, Craig 2021). Saipan Reed Warblers have been detected nesting in all months except November and December, although some seasonality in breeding activity is suspected (Craig 1992, Mosher and Fancy 2002).

Study area

We deployed ARUs on Saipan, the largest and most populous island in the CNMI, with a land area of ~124 km^2 (Cloud et al. 1956). Saipan is an uplifted island of limestone over a volcanic core (Cloud et al. 1956) and lies north of Guam in the tropical Pacific. The climate is generally warm and wet, with minimal seasonal temperature fluctuations; the mean daily temperature from 1991 to 2020 ranged from 26.1°C in February to 28.5°C in June (NOAA 2024). Precipitation fluctuates seasonally, with the wettest months between July and November (NOAA 2024). Saipan, like the rest of the Mariana Islands, is subject to periodic typhoons that can be severe enough to impact wildlife populations (Ha et al. 2012). Undeveloped areas on Saipan consist of mixed native and introduced vegetation including strand, wetland, savanna, limestone forest, and disturbed areas dominated by *Leucaena leucocephala* (tangantangan) and other introduced plants (Raulerson and Rinehart 2021). Saipan also contains developed areas including road edges with tall grass (over 1 m high) that, anecdotally, are common Saipan Reed Warbler habitats.

We placed ARUs primarily in conservation areas or on public land where human activity is relatively limited. While Saipan Reed Warblers also occur in more densely human-inhabited areas, we prioritized collecting sound recordings in areas that allowed us to minimize incidental recording of human activities and other anthropogenic sources of noise.

We deployed ARUs at 15 locations with suspected Saipan Reed Warbler occupancy. Occupancy was suspected if a Saipan Reed Warbler had been detected there over the previous calendar year by either DFW staff members or the authors. Locations for ARU deployment were selected opportunistically based on land access availability. Recorders were deployed at 1 location in August 2021, at 11 locations in July 2022, and at 11 locations between January and March 2023. Deployments in 2023 included 8 previously sampled locations and 3 new locations. We discarded 4 locations where Saipan Reed Warblers were never detected on ARU recordings.

Sound recordings

Sound recordings were collected using SWIFT bioacoustic automated recording units (Cornell Lab of Ornithology, Ithaca, New York, USA), which used a built-in PUI Audio brand omnidirectional microphone. ARUs recorded at a sampling rate of 48 kHz and saved recordings as uncompressed .WAV files. The microphone gain was set to 35 dB, with a signal to noise ratio of ∼58 dB reported by the manufacturers. The ARUs record sound comparable to what humans would detect in the same location (Klingbeil and Willig 2015, Roark and Gaul 2021).

ARUs were programmed to record continuously for 24 h per day during deployment. They were deployed at each site for a minimum of 48 h (often more). The total number of hours of recording from each deployment differed depending on how long the units were deployed. ARUs were deployed by strapping the units to trees at a height of ∼1.5 m (Darras et al. 2018). ARUs were always attached to trunks or branches that were less than 23 cm in diameter to avoid blocking the microphone from sampling sounds from the opposite side of the tree.

Audio data processing

Audio recordings were processed using a desk-based listening method, in which an observer listened to randomly selected 1 min segments from extended-duration recordings (Wimmer et al. 2013, Roark and Gaul 2021). A technician listened through headphones and viewed spectrograms of the recordings in Audacity (Audacity Team 2023) to determine whether a Saipan Reed Warbler vocalization was present or absent. Initially, observers inspected 10 min from each hour. After approximately 15 h of recordings had been processed this way, we subsampled these data to create a rarefied dataset with only 4 min of sampling per hour. We fit exploratory models using 10 min of sampling per hour and again using the rarefied dataset of 4 min of sampling per hour. The exploratory analyses gave similar results with both datasets. Therefore, we sampled 4 randomly selected minutes per hour from subsequent hours to reduce data processing time. Here, we present results using all minutes that were searched by an observer (10 min of sampling per hour for some hours, 4 min of sampling per hour for most hours).

For each selected minute of audio, the observer noted whether a Saipan Reed Warbler was detected vocalizing within the selected minute, or whether there was too much noise to determine whether a Saipan Reed Warbler vocalization was present. Decisions about noise were based on whether the observer felt that they would be able to detect a Saipan Reed Warbler vocalization if it were present by looking at the spectrogram and listening to the recording; this assessment by the observer was similar to the assessment that an in-person observer might make if they arrived at a location and decided that noise from nearby vehicles, rain, wind, or some other source prevented them from surveying. If there was too much noise to determine whether a vocalization was present, that minute was not used in subsequent analyses. A subset of minutes was searched for Saipan Reed Warbler sounds by 2 observers independently. The observers' data were compared, and the reliability of Saipan Reed Warbler detections was assessed using Krippendorf's alpha, which measures agreement between multiple observers after accounting for agreement by chance (Krippendorff 2013, Gamer et al. 2019).

Statistical analyses

We modeled the probability of detecting a Saipan Reed Warbler vocalization in each hour of the day using random forests, a machine-learning regression technique that can accommodate nonlinear relationships (Breiman 2001). The response variable was a dichotomous variable indicating whether a Saipan Reed Warbler vocalization was detected in the hour. The predictor variables were the time of day (in hours), which was the variable of interest, and 2 covariates accounting for sampling skill and effort (Johnston et al. 2018): the identity of the observer and the total number of minutes listened to from that hour (which was usually 4 min, but was sometimes fewer than 4 min if some minutes were discarded because of excessive noise, and was 10 min for some hours as described above). We assessed model predictive performance using 2 metrics: area under the receiver operating characteristic curve (AUC), which measures the ability of a model to discriminate between 2 classes (Fielding and Bell 1997); and Brier score, which measures model calibration as the mean squared error between predicted probabilities and binary observations (Brier 1950).

We fit random forests using the *randomForest* package in R 4.3.1 (Liaw and Wiener 2002, R Core Team 2023). We generated 100 bootstrap samples of the data to estimate bootstrap confidence intervals around model prediction performance metrics and pointwise bootstrap confidence intervals around model predictions (Hastie et al. 2009). For each bootstrap sample of the data, we fit models using 11-fold cross-validation (CV; Hastie et al. 2009). In each CV fold, data from one location were withheld as a test set and the random forest model was fit with data from the remaining 10 locations. Prediction performance was measured using predictions to the holdout data in each fold, and we reported mean prediction performance measured from all holdout folds across all bootstrap datasets.

To test whether time of day had a significant effect on the probability of detecting a Saipan Reed Warbler, we fit a model representing the null hypothesis, excluding time of day, so that the only predictor variables were the identity of the observer and the number of minutes searched. We then compared AUC and Brier score from the models with and without the time of day as a predictor variable. We fit models using data from all hours of the day, and also with data from only daylight hours.

To visualize the daily vocalization patterns of Saipan Reed Warblers, we generated model predictions to standardized data. The standardized predictions show the predicted probability of our most experienced observer (ER) detecting a Saipan Reed Warbler vocalization in each hour of the day if she listened to 4 randomly selected minutes of audio recording per hour. We graphed standardized predictions averaged over all the bootstrapped, cross-validated model replicates.

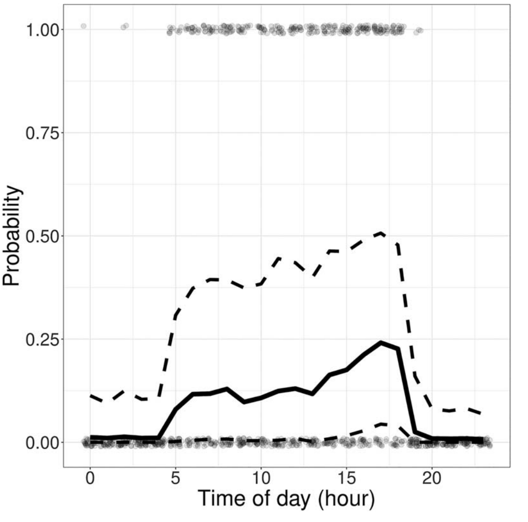

Figure 1. Probability of detecting a Saipan Reed Warbler vocalization by an experienced observer listening to 4 min of sound recordings randomly chosen from each hour. The solid line shows the model predictions from random forest models averaged over bootstrapped, cross-validated model replicates. Dashed lines show pointwise 95% bootstrap confidence intervals. Light gray dots show the observed detections (1) or non-detections (0) in 1 h sound recordings. Light gray dots have been jittered horizontally and vertically to aid visualization. Saipan Reed Warblers sang during all daylight hours.

Results

We detected Saipan Reed Warbler vocalizations on recordings from 11 locations. We collected 956 h of audio recordings (mean number of hours per location = 83, range = 42–159 h). We randomly sampled 3,844 min from those hours and subsequently removed 101 min, representing 29 unique hours, that had too much noise. Our final dataset consisted of 3,743 min of audio recording, randomly sampled from 927 h of recordings at 11 locations. Comparison of data from multiple observers showed that identifications of Saipan Reed Warbler sounds were reliable (Krippendorf's alpha = 0.735, $n = 215$ min searched by 2 observers).

Saipan Reed Warblers began singing around sunrise, continued singing throughout the day, and stopped singing around sunset (Fig. 1). The earliest detected Saipan Reed Warbler sound was just after midnight at 0016 h (ChST), and the latest detected Saipan Reed Warbler sound was at

1907 h, 15 min after sunset. Ninety-five percent of our detections occurred between 0545 and 1826 h. Saipan Reed Warbler vocalizations were detected in every hour from 0500 to 1900 h (Fig. 1).

Time of day was a significant predictor of the probability of detecting a Saipan Reed Warbler vocalization in the model that analyzed data from all hours of the day. Including time of day as a predictor variable significantly improved model prediction performance compared to a model with only nuisance covariates accounting for the identity of the observer and the sampling effort (model with time of day mean AUC = 0.735, 95% bootstrap CI [0.702, 0.764], mean Brier score = 0.184, 95% bootstrap CI [0.175, 0.194]; null model without time of day mean AUC = 0.508, 95% bootstrap CI [0.465, 0.553], mean Brier score = 0.227, 95% bootstrap CI [0.215, 0.239]).

For the model using data from only daylight hours, prediction performance was poor, and was not significantly improved by including time of day as a predictor variable (model with time of day mean AUC = 0.533, 95% bootstrap CI [0.495, 0.581]; null model without time of day mean AUC = 0.529, 95% bootstrap CI [0.460, 0.604]), although model calibration was slightly improved by the inclusion of time of day as a predictor variable (model with time of day mean Brier score = 0.280, 95% bootstrap CI [0.265, 0.296]; null model without time of day mean Brier score = 0.324, 95% bootstrap CI [0.302, 0.342]).

The mean predicted probability of detecting a Saipan Reed Warbler vocalization was highest in the afternoon around sunset, but confidence intervals around the predictions were wide (Fig. 1). The lower bound of the bootstrap 95% prediction interval remained close to zero at all times, except for the afternoon from about 1500 to 1900 h (Fig. 1).

Discussion

Saipan Reed Warblers sang throughout the day, but rarely at night. There was no evidence of a dawn chorus (Fig. 1). Model results show some evidence that, if a Saipan Reed Warbler is present at a site, the probability of detection may be highest in the evening before sunset (Fig. 1, confidence interval not overlapping zero), but the wide confidence interval indicated that this pattern was weak. The wide confidence intervals are likely due to the small number of locations we sampled, and the variability between locations. Our sample size of 11 locations was sufficient to demonstrate that Saipan Reed Warblers sing all day long, and vocal activity is not limited to mornings and evenings. A larger sample from more locations might be able to reveal if there are small but statistically significant differences in the probability of detecting a Saipan Reed Warbler vocalization at different times during daylight.

Marshall et al. (2021) found no significant difference in Saipan Reed Warbler detection probability between in-person surveys conducted in the morning and in the afternoon, which is consistent with our findings. Frequent nighttime singing and a dawn chorus were reported in a short review summary (del Hoyo et al. 2020). We did not find any evidence for either of those phenomena, though we did detect a small number of vocalizations between midnight and sunrise (Fig. 1).

Surveying locations in both the morning and the afternoon could help maximize probability of detection. At all locations, Saipan Reed Warblers were detected in both morning and afternoon during this study. However, Saipan Reed Warblers were not always detected during both morning and afternoon on the same day or even during the same multi-day ARU deployment period; recordings from 2 locations had only afternoon detections during one of the deployment periods, and another location had only morning detections during one of the deployment periods. This suggests that, at some locations and some times, Saipan Reed Warblers might not vocalize all day long. The variability in daily vocalization patterns across time within locations suggests that, whatever is causing the differences in vocal behavior, it is changing over the course of weeks or months within locations. It is possible that the variation in singing behaviors between locations and deployment periods is related to the breeding status of the birds. Flexible breeding schedules, with breeding possible all year long, are common in tropical birds (Stutchbury and Morton 2023) and have been documented in other species in the Mariana Islands (Jenkins 1983, Savidge et al. 2022). We did not attempt to determine the breeding status of birds in our study, so we do not have evidence linking singing behavior to breeding status. Seasonal variation in territorial behavior and nesting has been reported for this species (Craig 1992, Mosher and Fancy 2002). Singing has been reported in all months (eBird Basic Dataset 2023). Our study design did not permit us to assess seasonal differences in singing behavior, but a study of seasonal singing activity would be useful for informing targeted surveys and for understanding the biology of this species.

The recommended USFWS survey protocols for Saipan Reed Warblers already include a possible survey window in the 2 hours before sunset, in addition to a morning survey window (USFWS 2014). However, our data suggest that surveys need not be limited to only morning and evening survey periods; we suggest that observers targeting Saipan Reed Warblers may conduct surveys throughout the day. Additionally, we recommend that observers targeting Saipan Reed Warblers perform at least one site visit in the period before sunset, to maximize probability of detection if a Saipan Reed Warbler is present.

Surveys on Alamagan, which require logistically difficult and expensive expeditions, could also be conducted during any daylight hours, providing more flexibility and potentially greater sample sizes than would be possible if surveys are limited to mornings and before sunset. As an alternative to in-person surveys, ARUs have the potential to cut down costly person-hours in the field (Williams et al. 2018). Extended duration ARU deployment on Alamagan, for example, could increase survey effort without proportionally increasing costs associated with in-person expeditions. While automated detection algorithms would be a more efficient data processing tool, those methods often require substantial expertise. The method used in this study is an easily implementable, functional method for processing ARU recordings for Saipan Reed Warbler detections.

We noted some anecdotal differences between observers' confidence when identifying Saipan Reed Warbler sounds. For example, some observers felt comfortable identifying call notes, while others did not. We did not attempt to distinguish calls from songs, but rather treated all vocalizations from Saipan Reed Warblers in the same way. Additional work will be useful to explore patterns in the types of vocal behavior, including calls, long-duration songs, and short song snippets. Of particular interest is the difference in vocal behavior between the sexes. Craig (1992) suggested that females do not sing. More recent observations have noted that females may call regularly (A.W. Santos, CNMI DFW, pers. comm.). While we do not know of any well-documented cases of female song in Saipan Reed Warblers, female song is not unusual for sexually monomorphic tropical birds (Stutchbury and Morton 2023). It is possible that the lack of documented songs from females is due at least in part to the difficulty of visually determining the sex of Saipan Reed Warbler individuals, which have sexually monomorphic plumage. Genetic sexing, with accompanying behavioral observations, could helpfully distinguish male and female vocal behavior, which would improve our understanding of the differences in vocal behavior and detectability between sexes.

Singing activity in Saipan Reed Warblers was strongly limited to daylight hours in our study. Saipan Reed Warblers sang during all daylight hours, and we did not find any evidence for periods of higher or lower vocal activity within daylight hours. For a few locations, Saipan Reed Warblers were detected only during the morning or only during the afternoon, but this was not generalizable across locations, or across multiple seasons at a single location. Seasonal variations in Saipan Reed Warbler vocal activity are not well understood but addressing that knowledge gap would provide important information for timing targeted surveys for this species. For the purposes of targeted surveys, most detections of Saipan Reed Warblers are by sound. Because the probability of Saipan Reed Warblers vocalizing did not differ across daylight hours, we recommend that surveys for Saipan Reed Warblers can be conducted during any daylight hours. Increasing the times of day during which surveys may be conducted gives more flexibility to government agencies and consultancies conducting surveys.

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