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POST-TYPHOON MAWAR POPULATION COUNTS OF THE ENDANGERED YÅYAGUAK (MARIANA SWIFTLET) ON GUAM

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ABSTRACT

The yåyaguak (Mariana swiftlet, *Aerodramus bartschi*) is an endangered cave-roosting species native to Guam and southern Mariana Islands, Micronesia. The population on Guam has declined substantially over the last half century, likely due to the introduction of the brown treesnake (*Boiga irregularis*), but other factors have been proposed including habitat loss, pesticides, reduced food resources, and powerful storms. On May 24–25, 2023, Guam was hit by the category-4 Typhoon Mawar, which brought wide-spread destruction to the island. Approximately 6 weeks prior to the typhoon in April 2023, we conducted surveys of the three known colonies of yåyaguak at Mahlac, Maemong, and Fachi caves. This survey provided a baseline population estimate prior to Typhoon Mawar's landfall. In July 2023, we resurveyed the caves to estimate colony size and assess whether the cave colonies experienced significant declines in the immediate aftermath of the storm. In November 2023, we conducted our regularly scheduled biannual surveys which provided a longer-term assessment of potential impacts from the typhoon. Our counts indicated that in the immediate aftermath (~6 weeks) there was a 7–8% reduction in size of colonies compared to the April 2023 counts, but in November there were larger, 19–35% reductions in the cave colonies from pre-Mawar surveys. These results suggest that the long-term effects of the storm were more detrimental to the yåyaguak populations than the immediate impacts if these colony size reductions are a result of the storm. Continued monitoring of the yåyaguak cave colonies will allow for documenting the pace of recovery from the storm.

INTRODUCTION

The endangered yåyaguak (Mariana swiftlet, *Aerodramus bartschi*) is one of the last native bird species persisting in the wild on Guam (in CHamoru, Guåhan), with a distribution now restricted to southern Guam. Historically, yåyaguak were common throughout Guam (Jenkins 1983) and on other southern Mariana Islands (Steadman 1999), but today exist only on three islands: Guam, Aguijan, and Saipan (Chantler *et al.* 2020), plus an introduced population on O'ahu, Hawai'i (Wiles and Woodside 1999). A cave roosting and nesting species, they are only known to occur in three caves in southern Guam: Mahlac, Maemong, and Fachi. One of the key reasons for the plight of the species in Guam was the introduction of the brown treesnake (BTS, *Boiga irregularis*) in the 1940s as a result of cargo movement following World War II (Rodda *et al.* 1992). The BTS introduction led to the loss of most of Guam's avifauna (Jenkins 1983, Savidge 1987, Wiles *et al.* 2003), and studies have found high prevalence of snakes and evidence of swiftlet predation in occupied caves (Klug *et al.* 2021). However, although BTS are considered the main threats to yåyaguak on Guam, yåyaguak disappeared from Rota and Tinian Island, Commonwealth of the Northern Mariana Islands (CNMI) in the 1970s and they are declining on Aguijan Island (CNMI; Johnson *et al.* 2018), all islands without BTS. Therefore, other threats may be contributing to population declines on Guam beyond BTS, which could include pesticides, disease, cave disturbance, and typhoons (USFWS 1991).

Although tropical islands frequently experience typhoons or hurricanes, and island flora and fauna have certainly evolved to be resilient to storm damage, storms can devastate tropical island species both through direct mortality during the storm as well as longer-term starvation and displacement from habitat destruction (Askins and Ewert 1991, Wiley and Wunderle 1993). Yåyaguak on Guam are potentially very vulnerable to storms depending on where the storms make landfall, as all three known caves are located less than 1 km from each other within the Talofofo River watershed. Past typhoons that have struck Guam have adversely affected forest habitat, with at least one (Typhoon Yuri in 1992) possibly leading to a decrease in yåyaguak

numbers (DAWR 1991, 1992). However, linking changes in yáyaguak numbers as a result of large storms is difficult, and responses are likely to be different for each storm.

On May 24–25, 2023, the powerful category-4 Typhoon Mawar struck Guam, causing widespread damage (NOAA 2023). Much of the island's forests were severely damaged, with most leaves stripped of trees and substantial flooding across the island. Although the storm's eye ultimately crossed northern Guam, southern Guam forests were heavily impacted. In the Talofofo River watershed where the yáyaguak roost and nest, wind speeds were estimated to attain a category 2 level (mean wind speed of 154–177 kilometers per hour [kph], with gusts up to 224 kph) and rainfall of ~580 mm (NOAA 2023). Approximately 6 weeks before the storm landed on Guam, we had conducted comprehensive surveys of all three caves, detailed in Gorresen *et al.* (2024). We were not able to immediately return to Guam to resurvey the population because of closed roads, lack of electricity, and general travel restrictions. We returned to Guam on July 17–20, 2023, and resurveyed the caves approximately 6 weeks post-Mawar using the methods of Gorresen *et al.* (2024). In November 2023, we returned again to conduct surveys of yáyaguak approximately 6 months post-Mawar. These resurveys present two temporal assessments of the possible impacts of Mawar on yáyaguak populations—an assessment of the immediate impacts and another of the longer-term effects from the powerful typhoon.

METHODS

Mahlac, Maemong, and Fachi caves occur within the boundaries of the Naval Magazine Site, managed by the U.S. Navy, in the upper Talofofo River watershed, a region of low hills covered in limestone forest (Morton and Wiles 2002). The area averages 260 cm of rainfall per year (Lander and Guard 2003), broadly divided into a wet (July to December) and dry season (January to June). The caves are solution cavities in a limestone substrate with interior volumes large enough to have low-light areas where the yáyaguak roost and nest. Fachi cave can be partly flooded during periods of heavy rainfall (Morton and Amidon 1996). Breeding occurs year-round but at higher frequency in spring (Gorresen *et al.* 2024). Typically, birds will leave roosts and nests in the morning to forage for insects and return in the afternoon or evening to roost for the night. Although it is not known where the birds forage for insects, yáyaguak are most commonly seen in the Talofofo River valley (Jenkins 1983), and this is presumably where the birds do most of their foraging.

We surveyed Mahlac and Maemong caves post-typhoon from July 17–20 and November 6–16, 2023. The surveys were identical to those conducted by Gorresen *et al.* (2024) to ensure accurate replication of counts prior to the typhoon. The last counts from the Gorresen *et al.* (2024) surveys were April 3–20, 2023, approximately 6 weeks before the typhoon. Cameras were deployed within caves below roost sites to capture images of birds, nests, and roosting adults. The interior of Fachi cave was not accessible in July due to high water levels in the cave, but we placed cameras at both entrances to the cave to detect birds entering and exiting. Fachi cave was accessible in November 2023, and a roost-site count was conducted then.

Surveys of the Mahlac, Maemong, and Fachi caves used near-infrared (NIR) video surveillance cameras (Q1798-E; Axis Communications, Lund, Sweden) equipped with a CMOS (complementary metal oxide semiconductor) sensor composed of 2,592 x 1,944 pixels, a built-in NIR illuminator (peak wavelength of 850 nm), and a 12- to 48-mm varifocal lens. Recordings at 30 frames per second were made to memory cards, which yielded about 1 hour of video per gigabyte. Each NIR camera was powered by lithium-iron-phosphate (LiFePO4) batteries (Dakota Lithium, Seattle, Washington, USA) which provided about 48 hours of continuous recording. A single NIR camera at each of Mahlac and Maemong caves provided full coverage

of the roost and nest areas. For the cave entrance surveys of Fachi cave, we used thermal network video surveillance cameras (Q1922-E; Axis Communications) that have a 640 x 480-pixel image sensor sensitive to the “far” spectrum of infrared light (approximately 9,000–14,000 nm) and require no illumination. These weatherproof thermal cameras record digital video to memory cards at 30 frames per second and were fitted with a 19-mm lens. Thermal cameras were also powered with Dakota LiFePO4 (Dakota Lithium) batteries that provided about 70 hours of continuous recording.

We used the first full 24 hours of video recordings (starting at least 6 hours after camera set-up to avoid disturbance effects) to visualize diurnal and nocturnal bird activities and identify active nests. Video recordings were reviewed using open-source video processing software VirtualDub (version 1.10.4; virtualdub.org). Bird counts were made directly from high-resolution NIR imagery recorded at night between 20:00 and 05:00 hours when all birds were settled at the roost and within-cave flight activity was at its lowest. The identification and count of active nests at each colony was conducted using daytime imagery from after the initial emergence of birds (beginning about 45 minutes before sunrise) to 5 or 6 hours after sunrise, when most volant birds were away from the cave. Specifically, active nests were determined based either on the consistent presence of an adult at a nest for a minimum of 3 hours or direct observation of a nestling from the high-resolution NIR recordings. The proportion of non-nesting individuals in a colony was calculated as the difference between the total colony count and twice the associated active nest count (assuming one breeding pair per nest).

To test for significant differences between the post-Mawar counts and earlier counts (2019–2023), counts were log transformed, and a one-sample t-test was performed with the July and November 2023 post-Mawar counts as the comparison values to the average of counts from April 2019–April 2023. Statistical analysis was done in Program R, Version 4.2.1 (R Core Team 2023), using base package functions with statistical significance set at alpha = 0.05. Data from Gorresen *et al.* (2024) and this report can be found at Gorresen *et al.* (2023) and Paxton *et al.* (2024), respectively.

RESULTS

During our July 2023 survey, we counted 549 yáyaguak in Mahlac cave and 132 in Maemong cave (Figure). Fachi cave was flooded with almost the entire cave entrance below water (approximately 15 cm of the upper cave entrance was above water). Therefore, we could not make a direct count of birds in the roosting chamber. However, we placed thermal cameras at the entrance of Fachi and detected yáyaguak flying in and out of the cave, concluding the cave was still occupied. In November 2023, we counted 459 yáyaguak at Mahlac cave, 116 at Maemong cave, and 21 at Fachi cave (Table).

Our immediate post-Mawar counts were lower than the pre-Mawar counts by 41 individuals at Mahlac and 12 individuals at Maemong cave (Table). The July counts at Mahlac cave represented a 7% decline from April counts but were within the 95% confidence interval (CI) of the April 2019–April 2023 counts for Mahlac (524, 673) and not significantly different ($t = 1.76$, $P = 0.152$). For Maemong cave, the July 2023 post-Mawar colony estimate represented an 8% decline, was outside the 95% CI (137, 189) and was significantly lower than counts from the previous several years ($t = 3.65$, $P = 0.022$). The November 2023 post-Mawar counts were considerably lower than the July counts, with 131 fewer birds in Mahlac compared to the April 2023 counts, 28 fewer birds in Maemong cave, and 14 fewer birds in Fachi cave (Table). For the Mahlac cave colony, this is a 22% decline from the April 2023 count and significantly lower than the April 2019–April 2023 average ($t = 5.62$, $P = 0.005$). For the Maemong cave colony, the

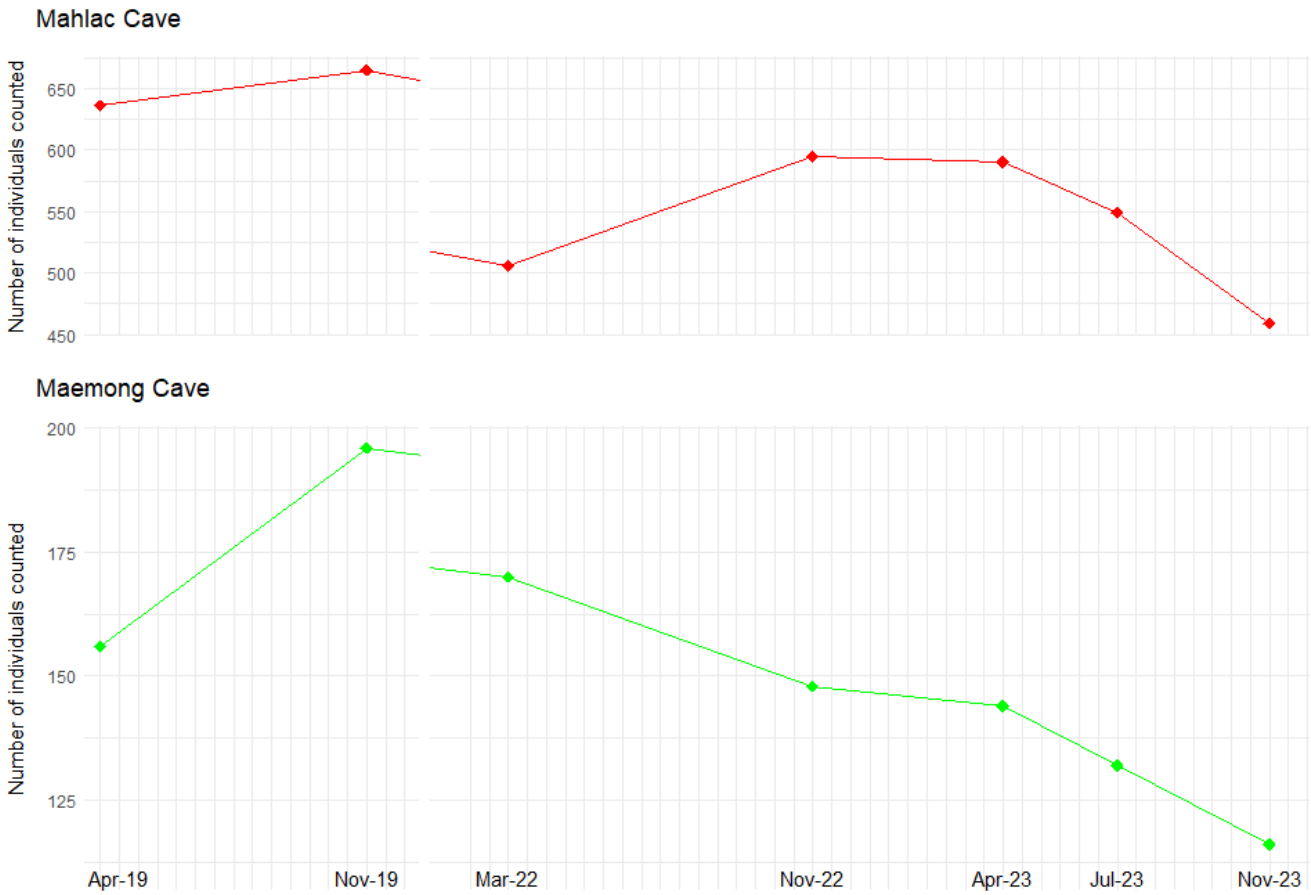

Figure. Colony roost-site estimates for yåyaguak at Mahlac (top) and Maemong (bottom) caves, Guam. Values from April 2019 to April 2023 are from Gorresen *et al.* (2024).

November counts indicated a 19% reduction in size from April 2023, which was significantly different than the April 2019–April 2023 average ($t = 5.97$, $P = 0.004$). For Fachi cave, the November 2023 count was 40% lower than the April 2023 count.

The number of yåyaguak active nests were a little lower in the July post-Mawar survey compared to the period before the storm, and the percentage of non-breeders was higher. However, we have documented high seasonal variation in these two metrics (Table) and have no mid-summer survey data to compare (Gorresen *et al.* 2024). For the November 2023 counts, the number of active nests and proportion of non-breeders were low, but these lower values were similar to past November counts (Table). Therefore, these low November 2023 numbers may be seasonally appropriate.

Table. Counts of yǻyaguak adults (colony size), active nests, and proportion of individuals not associated with nests for Mahlac, Maemong, and Fachi caves, Naval Magazine Site, Guam, from April 2019 through November 2023. Values from April 2019 to April 2023 are from Gorresen *et al.* (2024). The last column, Total, is the sum of adults and active nests, or the average of non-nesting proportion across caves. Asterisks for Fachi represent times when the cave could not be accessed because of flooding.

	Survey	Mahlac	Maemong	Fachi	Total
Colony size	Apr 2019	636	156	28	820
	Nov 2019	665	196	*	861
	Mar 2022	506	170	*	676
	Nov 2022	595	148	*	743
	Apr 2023	590	144	35	769
	Jul 2023	549	132	*	681
	Nov 2023	459	116	21	596
Active nests	Apr 2019	254	68	8	330
	Nov 2019	43	6	*	49
	Mar 2022	228	62	*	290
	Nov 2022	18	6	*	24
	Apr 2023	263	58	11	332
	Jul 2023	235	41	*	276
	Nov 2023	17	3	0	20
Non-nesting proportion	Apr 2019	20%	13%	43%	25%
	Nov 2019	87%	94%	*	91%
	Mar 2022	10%	27%	*	19%
	Nov 2022	94%	92%	*	93%
	Apr 2023	11%	19%	37%	22%
	Jul 2023	14%	35%	*	25%
	Nov 2023	93%	95%	100%	96%

DISCUSSION

Powerful tropical storms (e.g., typhoons, hurricanes, cyclones) can have devastating effects on island bird populations (Askins and Ewert 1991, Wiley and Wunderle 1993), and over time can shape the ecological communities, especially where storms land frequently (Lee *et al.* 2008). However, bird species are affected differentially depending on the food resources they depend upon, as well as other changes to their habitats. For example, surveys of birds following Hurricane Hugo on Saint John, U.S. Virgin Islands, found species dependent on fruit or nectar declined the most as the storm greatly reduced the availability of these foods (Askins and Ewert 1991). In Rota, response of bird populations to the strength and distance of storms from 1952–2005 was mixed (Ha *et al.* 2012). For åga (Mariana crow, *Corvus kubaryi*), Philippine collared-dove (*Streptopelia dusumieri*), and chuchurika (rufous fantail, *Rhipidura rufifrons*), there was evidence of a relationship between storms and population declines, but for Rota's other bird species there was no statistical relationship. Ha *et al.* (2012) concluded that typhoons may be contributing to long-term population declines when combined with the effects of habitat loss and invasive species. Often, the effects of a large storm can be more detrimental to a population in the months following the brief period of landfall when food resources have been reduced (Wiley and Wunderle 1993). Thus, the ecological impacts of any given storm may vary based on the actual damages of the storm, the long-term changes to habitat and food resources, and a species' particular resource needs.

We evaluated the impacts of the powerful, category-4 Typhoon Mawar passing over Guam on the population of yáyaguak both in the short-term (6 weeks) and longer-term (6 months). The work of Gorresen *et al.* (2024) provides a baseline of cave colony size estimates from 2019–2023 from which we can compare colony size estimates following Mawar. Our last pre-storm survey in April 2023 was about 6 weeks before Mawar's landfall, providing a snapshot of the population size just before the typhoon hit Guam. Our July 2023 visit, 6 weeks post-landfall, revealed downed trees and damaged infrastructure across the island. Most trees were still leafless, or just beginning to bud new leaves. We found a 7–8% reduction in the number of yáyaguak individuals from Mahlac and Maemong caves 6 weeks post-Mawar compared to the population counts 6 weeks pre-Mawar, which may be a result of direct mortality from the storm or its immediate aftermath. However, the July counts were either not significant or barely significantly different than the 2019–2023 average and could reflect ordinary fluctuations in population sizes. For example, from 2019–2023, we observed changes in subsequent counts to be as much as 13%, but with an averaged 5% change. The November 2023 counts showed much larger (19 and 35%) declines in the cave colonies than the July surveys, and a larger percent change than observed in previous years (Gorresen *et al.* 2024). This may indicate that longer-term effects of reduced food resources, reduced reproduction, and possible increased predation could all have contributed to significantly lower colony sizes in all three caves 6 months following Mawar. We can only speculate on how the storm may have directly affected yáyaguak, but heavy damage to forests and flooding could have disrupted arthropod prey leading to starvation of yáyaguak or failed nesting attempts. A lack of food resources in the forest for BTS could have driven higher numbers than normal into caves to prey on yáyaguak. The number of active nests were lower than 5 weeks earlier in April, but we have observed a strong seasonal effect on nests and percentage of adults associated with nesting (Gorresen *et al.* 2024), and the decrease may be partly due to both the storm and a seasonal shift away from the peak breeding period.

There is much we still do not know about the habitat and diet needs of the yáyaguak on Guam, and where the swiftlets forage when they leave the caves. The eye of Typhoon Mawar crossed northern Guam, but heavy damage to forests and substantial flooding was seen in southern Guam where yáyaguak occur. A more direct hit by Mawar on the Talofofo River valley may have resulted in greater wind damage and flooding and consequently even greater impacts to the yáyaguak. A deeper understanding of the geographic areas critical for the population's persistence would allow us to better link storm damages to population dynamics. The Talofofo River valley is largely undeveloped, providing multiple areas with intact forests where the birds may be foraging. The location of the caves in this largely undeveloped area, as well as restricted access that may have reduced disturbance, may be key reasons that the Naval Magazine Site caves are the last occupied yáyaguak caves. However, our analysis of counts from 2019–2023 indicated a decline in the Guam yáyaguak population size (Gorresen *et al.* 2024), and the storm appears to have accelerated the downward trend, at least in the short-term. Continued monitoring of the population would help us to understand the ability and speed at which this population can recover from the post-storm declines, or how storms may contribute to the longer-term decline in the Guam yáyaguak population.

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