

A review of the ecology and conservation biology of Sāli (Micronesian Starling, *Aplonis opaca guami*) on Guam*

ANDRE V. NGUYEN¹, MARTIN KASTNER², GARY J. WILES³, CHRISTOPHER WAGNER⁴, HENRY S. POLLOCK⁵, HALDRE S. ROGERS², LAURA DUENAS^{6,11}, EVAN C. FRICKE⁷, EVAN M. REHM⁸, ROBERT M. MCELDERRY⁹, SHANE R. SIERS¹⁰ AND EBEN H. PAXTON^{1,†}

¹ U.S. Geological Survey Pacific Island Ecosystems Research Center, Hawaii National Park, Hawaii, USA

² Department of Fish and Wildlife Conservation, Virginia Tech, Blacksburg, Virginia, USA

³ 521 Rogers St. SW, Olympia, Washington, USA

⁴ 3 Regency Square, Scarborough, Ontario, Canada

⁵ College of Forest Resources and Environmental Science, Michigan Technological University, Houghton, Michigan, USA

⁶ Guam Division of Aquatic and Wildlife Resources, Mangilao, Guam, USA

⁷ Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

⁸ US Forest Service, Northern Research Station, Morgantown West Virginia, USA

⁹ Research Corporation of the University of Guam, Mangilao, Guam, USA

¹⁰ U.S. Department of Agriculture, Wildlife Services, National Wildlife Research Center, Barrigada, Guam, USA

¹¹ Current address: U.S. Fish and Wildlife Service, Pacific Island Fish and Wildlife Office, Guam, USA

Abstract— The accidental introduction of the Brown Treesnake (BTS, *Boiga irregularis*) to Guam following World War II led to the extinction, extirpation, or severe decline of most of Guam’s native avifauna. One forest bird species that managed to persist is the cavity-nesting Sāli (Micronesian Starling, *Aplonis opaca guami*), a once-ubiquitous native omnivore whose current Guam distribution is restricted primarily to urbanized areas in the northern half of the island, with a second much smaller population on Cocos Island off southern Guam. Sāli on Guam breed year-round and are habitat generalists with large home ranges. Besides arthropods and small vertebrates, they consume fruit from a wide range of native and introduced plant species and are key seed dispersers within the local ecosystem. Sāli on Guam suffer extremely high post-fledging mortality due to predation by BTS and cats, leading to a population age structure strongly skewed towards adult birds. Other threats include habitat loss and degradation, extreme weather events, and sea level rise. Key management activities aimed at restoring this species include predator control, while non-native ungulate removal and vegetation management may be undertaken to support broader ecological recovery. This species account on Sāli provides a review of the literature on this species, synthesizing information on habitat use, life history, and demographics to provide a biological foundation for future recovery efforts.

* Citation: Nguyen, A.V., M. Kastner, G.J. Wiles, C. Wagner, H.S. Pollock, H.S. Rogers, L. Duenas, E.C. Fricke, E.M. Rehm, R.M. McElderry, S.R. Siers, and E.H. Paxton. 2023. A review of the ecology and conservation biology of Sāli (Micronesian Starling, *Aplonis opaca guami*) on Guam, *Micronesica* 2023-04, 18 pp. Published online 11 June 2024. <http://micronesica.org/volumes/2023> Open access; Creative Commons Attribution-NonCommercial-NoDerivs License.

† Corresponding author: epaxton@usgs.gov

Introduction

Guam (in Chamorro, Guåhan), the southernmost island of the Mariana archipelago, once supported a diverse avifauna composed of 25 resident bird species (Jenkins 1983, Wiles et al. 2003). However, the inadvertent introduction of the Brown Treesnake (BTS, *Boiga irregularis*) to Guam following World War II led to the rapid decline and eventual extirpation or extinction of most of the island's native forest avifauna (Savidge 1987, Wiles et al. 2003). The BTS is a relatively large colubrid snake species with a broad diet, and the snakes posed significant risk to the island's resident avifauna by colonizing virtually all habitats, including native and secondary forests, tangantangan (*Leucaena leucocephala*) thickets, urban areas, and savanna (Rodda et al. 1999, Rodda & Savidge 2007, Siers et al. 2017a). By virtue of its ubiquity, this novel apex predator created a landscape nearly devoid of native birds (Savidge 1987, Wiles et al. 2003). At present, few native birds survive in Guam's forests due to the continued presence of BTS (Rodda & Savidge 2007), although two species have persisted under unique circumstances: the cave-roosting Yáyaguak (Mariana Swiftlet, *Aerodramus bartschi*) and the urban-tolerant Sáli (Micronesian Starling, *Aplonis opaca guami*) (Wiles et al. 2003). Recent innovations in BTS control methodologies and, thus, the prospect of BTS removal or suppression from various parts of Guam (Dorr et al. 2016, Engeman et al. 2018, Siers et al. 2018, 2019a, 2019b, 2021), provide new opportunities for restoring Guam's native forest birds. Recent research has begun to identify which areas would most benefit from restoration of native birds (Thierry & Rogers 2020), which species are most appropriate for reintroduction (McElderry et al. 2021), and what level of BTS suppression is required for each species (McElderry et al. 2022).

This species account aims to compile all available information on habitat use, life history, and demographics of one of the remnant bird species on Guam, the Sáli. As the last remaining native seed-dispersing bird on the island, Sáli play an important ecological role, and their recovery across Guam may help in the restoration of the island's forest ecosystems (Pollock et al. 2020, Kastner et al. 2021). Given that Sáli still persist on Guam, albeit largely restricted to urban habitats, the species is considered one of the most promising candidates for range expansion into areas where BTS have been suppressed or eliminated (McElderry et al. 2021, 2022). Due to information gaps on the ecology of Sáli on Guam, or for added regional context, the account synthesizes data from other islands in the Mariana and Caroline archipelagos, and/or congeneric species, when relevant.

Taxonomy and Distribution

Sáli belong to the family Sturnidae, which is composed of 36 genera of starlings and mynas with native ranges throughout the Old World and introduced populations on all continents except Antarctica (Gill et al. 2023). The genus *Aplonis* includes 25 species distributed across the Indo-Pacific region (Lovette & Rubenstein 2007, Gill et al. 2023). *Aplonis opaca* occurs throughout the Mariana Islands except on the poorly vegetated, northernmost island of Uracas. Two subspecies exist in the Marianas, with *A. o. guami* found across the southern islands of Guam, Rota, Aguiguan, Tinian, and Saipan, and *A. o. aenea* known from Alamagan, Pagan, Agrihan, and Asuncion (Baker 1951). Populations on the five remaining Mariana Islands (Farallon de Medinilla, Anatahan, Sarigan, Guguan, and Maug) remain unassigned to subspecies. Five other subspecies of *A. opaca*, all from the Caroline Islands, are also recognized: *A. o. opaca* (Kosrae), *A. o. ponapensis* (Pohnpei), *A. o. anga* (Chuuk and various atolls), *A. o. kurodai* (Yap), and *A. o. orii* (Palau; Baker 1951, Gill et al. 2023).



Figure 1. Sâli, or Micronesian Starling (*Aplonis opaca guami*). Photo by Martin Kastner.

Appearance

Sâli are a medium-sized passerine (total length=23 cm; Pratt et al. 1987). On Guam, adult males are slightly heavier (\bar{x} =88.2 g, n=9) than adult females (\bar{x} =82.8 g, n=20), with an overall range of 75.0-108.0 g (n=30; Baker 1951, M. Kastner & H.S. Pollock, written communication, Virginia Tech and Colorado State University, 2023). Sâli on Saipan are a little lighter, averaging 84.8 g (n=13) for males and 80.8 g (n=4) for females, with an overall range of 72.1-93.2 g (Radley et al. 2011).

Adult plumage is uniformly black and is accentuated by a greenish iridescence on the contour feathers (except on the belly and vent), with this sheen more pronounced in males than females (Fig. 1; Seale 1901, Marshall 1949, Baker 1951, Drahos 1977, Jenkins 1983, Pyle et al. 2008, Radley et al. 2011). The feet and thick, slightly down curved bill are black. Males have marginally brighter yellow-orange irises than females (Drahos 1977). Fledglings have a soft-textured plumage, including dark brown upperparts and pale underparts with dense brown streaking, as well as dark brown eyes and a distinctive swollen bright-yellow gape. The fledgling plumage is retained only briefly (approximately 3-4 weeks) before being replaced by the juvenile plumage. Within the first month, the eyes also gradually lighten to a pale yellow, passing briefly through a bluish phase, and the yellow gape disappears. The plumage of juvenile birds is marginally paler than that of fledglings, and the streaking on the pale underparts is more prominent (M. Kastner, Virginia Tech, written communication, 2023). Juveniles retain their appearance for 8-9 months before they enter the subadult stage, which lasts approximately 2-3 months (M. Kastner, Virginia Tech, written communication, 2023). Subadults have a black bill, brighter yellow eyes, and undergo a protracted basic molt whereby the fresh, black adult feathers contrast with the retained, paler juvenile feathers, particularly on the breast and belly (Radley et al. 2011, Fig. S1 in Pollock et al. 2022). There are slight morphological differences within *A. o. guami*, such as the Guam form having a shorter wing and bill than the forms from Saipan and Tinian (Marshall 1949, Baker 1951).

Vocalizations

Vocalizations play an important role in intraspecific communication of most sturnids. Some starling and myna species are notorious for having complex vocalizations and for their capacity for mimicry (Feare & Craig 1999). Indeed, Sàli are highly vocal and noisy birds, and their songs and calls are a prominent feature of the chorus of birdsong on islands where they are present. This is particularly the case within their remnant range on Guam, where there are few other passerines on the landscape.

The song of *A. opaca* is a combination of simple clear, burry, and wheezy notes, with the number of notes being variable (range: 3-10) and lasting approximately 0.3-0.4 seconds each. The song is often performed by either member of a mated pair as it returns from foraging and approaches the nest location (C. Wagner, Colorado State University, written communication, 2023). Occasionally, the other member of a mated pair departs the nest location after the song has been performed and the singer enters the nest. Songs are also given away from the nest by solitary individuals or in chorus with other individuals (Jenkins 1983; C. Wagner, Colorado State University, written communication, 2023).

Alarm calls are a loud descending screech made by individuals in a pair or group as they swoop down at perceived threats (e.g., cats or humans approaching a nest; C. Wagner, Colorado State University, written communication, 2023). A less intense alarm call, a short metallic “tink”, can be made either by lone individuals or both members of a pair. Other vocalizations include contact calls, where individuals give a “too-wee” or “too-wee-urr” call, which is often replied with the same call by a nearby mate or a more distant individual. During preening, foraging, or while another Sàli is singing, individuals can make a high-pitched whistling call, often coinciding with other individuals moving closer to the calling bird. Individuals typically make single or multiple “hrraa” calls before taking flight. Birds in flight also utter a soft chipping sound, possibly a contact note (Jenkins 1983). Additionally, birds give a variety of low intensity gurgling sounds when in close proximity to their mate, which often elicits a similar call from the other pair member (C. Wagner, Colorado State University, written communication, 2023). Juveniles and subadults make variable calls that are distinct from adult calls (C. Wagner, Colorado State University, written communication, 2023). The congeneric *A. tabuensis* displays mimetic vocalizations (Craig & Feare 2000); further research into Sàli vocalizations is needed to determine whether it displays a similar range of vocal plasticity.

Historical Population Status

Sàli were once considered among the most numerous forest birds on Guam, described as ubiquitous across all habitat types (Coultas 1931, Bryan 1936, Stophlet 1946, Marshall 1949, Baker 1947, 1951, Tubb 1966, DAWR 1980, 1981, Drahos 2002). By 1971, Sàli had nearly disappeared from southern Guam, only rarely being observed in the ravine forests and savannas (Drahos 1977). Island-wide surveys in the late 1970s reported no other native forest birds inhabiting the southern half of Guam except for Sàli and Yáyaguak (Jenkins 1983).

By 1981, Sàli were restricted entirely to northern Guam, with the population’s size estimated at 16,776 individuals (Engbring & Ramsey 1984). Average Sàli density in the surveyed regions of northern Guam (as well as Cocos Island) was determined to be 1.78 birds/ha, with the highest densities found in mixed second-growth and native limestone forest (Engbring & Ramsey 1984). Ensuing annual bird surveys on Guam consistently showed persistent declines in Sàli abundance (DAWR 1982-1986, Wiles et al. 2003). In the early 1990s, the Guam Division of Aquatic and Wildlife Resources (DAWR) reported a remnant population of only 50-100 individuals inhabiting urbanized parts of Andersen Air Force Base (AAFB) and the adjacent village of Yigo, with only occasional sightings elsewhere on mainland Guam (Wiles et al. 1995). However, by 2018, the Guam population had increased to an estimated 1,435-1,475 birds, almost entirely concentrated around the

developed areas of AAFB (>90% of the total population), as well as in scattered small groups in other northern villages (Pollock et al. 2022).

Throughout this period, a second population of Sali has persisted in strand forest on Cocos Island (also known as *Islan Dano'* in Chamorro), a formerly snake-free, 33-ha island situated 2.5 km off Guam's southern coast (Wiles et al. 1995). This population was well surveyed only in 1981, when it was estimated at 198 birds (Engbring & Ramsey 1984), but numbers fell to as low as 20-25 birds following Typhoons Russ and Yuri in 1990-1991 (DAWR 1991, 1992). Abundance seemingly recovered after these storms, and the island has maintained unknown numbers of birds since then, but the population is now threatened by the discovery of BTS in 2020 (Barnhart et al. 2022, Siers et al. 2024).

Quantitative assessments of Sali populations on other islands in the Mariana archipelago provide context for the status of the population on Guam. The work of Engbring et al. (1986) established a baseline for the long-term monitoring of bird communities on the southern islands of the Commonwealth of the Northern Mariana Islands (CNMI). Island-wide surveys there have shown strong evidence of increasing trends across all surveyed islands since 1982 (Camp et al. 2009, 2012, 2015, Amidon et al. 2014). Sali density on Saipan increased by 242% between 1982 (0.47 birds/ha) and 2007 (1.62 birds/ha; Camp et al. 2009). Density estimates on Tinian showed a considerable increase from 1.86 birds/ha in 1982 to 4.17 birds/ha in 2013 (Camp et al. 2012, Spaulding et al. 2022). On Rota, Camp et al. (2015) estimated density at 14.0 birds/ha in 2012, a very large increase from the estimated 1.89 birds/ha reported in 1982. On Aguiuan, Amidon et al. (2014) reported a similar increase in density of Sali between 1982 (1.58 birds/ha) and 2008 (10.05 birds/ha). This comparison of density estimates dating back nearly three decades shows island-specific variability in changes in population density over time, but overall, Sali have remained widespread across their range in the southern CNMI, with broadly increasing population trends.

Sali reside on 8 of the 10 mainly volcanic Mariana Islands north of Saipan, with the species absent on Uracas and rarely present on Farallon de Medinilla (Lusk et al. 2000). Densities on the other islands vary by island and habitat, but generally range from estimates of about 0.5 to 3.0 birds/ha of land area (e.g., Cruz et al. 2000a, 2000b, Murray et al. 2018). Because of the islands' small sizes (i.e., from about 1-48 km²), population size per island is typically rather small, varying from several hundred to about 2,500 individuals, although Pagan reportedly held an estimated 9,500 birds in 2000 (Cruz et al. 2000b). Robust information on population trends is lacking for most of these islands.

Habitat Use

Sali are habitat generalists that formerly occupied all terrestrial habitats on Guam, from mature forest to early successional habitat, urbanized areas, abandoned farmland, and savanna (Bryan 1936, Downs 1946, Stophlet 1946, Baker 1947, Drahos 1977, Jenkins 1983, Engbring & Ramsey 1984, Engbring et al. 1986). Cavities in cliffs and caves previously served as important nesting and roosting sites (Marshall 1949, Baker 1951). Today, Sali are limited to nesting and roosting in urbanized areas of central and northern Guam, and among the derelict resort buildings and in strand forest on Cocos Island (Pollock et al. 2022). The largest portion of the Guam population is primarily confined to the housing and administrative areas of AAFB, but with foraging occurring extensively in nearby limestone and secondary forests (Pollock et al. 2022). On AAFB, Sali generally nest and roost in human-made structures, including artificial nest boxes, and in isolated ornamental trees (Pollock et al. 2019, 2022, Savidge et al. 2022).

Sali remain widespread across Rota, Aguiuan, Tinian, Saipan, and most of the more northern islands in the Mariana chain, despite substantial differences in vegetation types among islands due to distinct disturbance histories (including volcanic activity) and soil type. In 2004, avian surveys encompassing most of Rota showed Sali detections per count station were similar in both forested

and open habitats (Amar et al. 2008), although expanded surveys in 2012 indicated Sâli were least associated with mature limestone forest (Camp et al. 2015). On Saipan, Rehm et al. (2018b) quantified space use patterns of the extant avian frugivore community and concluded that habitat heterogeneity does not inhibit Sâli movement. Among the five frugivorous bird species, Sâli most frequently crossed from forest into degraded habitats such as areas of vines, unmowed grass, and developed sites (Rehm et al. 2018b).

Food Habits and Ecological Role

Sâli mainly forage in mid- and upper strata of the forest canopy (Marshall 1949, Baker 1951, Drahos 2002). The species also readily takes fruit from residential gardens and regularly forages on the ground (Engbring et al. 1986).

Sâli are dietary generalists, consuming a wide range of plant and animal matter (Seale 1901, Marshall 1949, Baker 1951, Drahos 1977, Jenkins 1983, Engbring & Ramsey 1984, Engbring et al. 1986, Craig 1996, Pollock et al. 2020, Kastner et al. 2021). However, their diet is largely fruit-based and, in the Marianas, includes the fruits of at least 22 tree species, 10 shrubs, and 5 vines, many of which (59%) are native to the archipelago (Pollock et al. 2020). Several early authors anecdotally mention the importance of papaya in the species' diet (Seale 1901, Kibler 1950, Baker 1951). Sâli are major seed dispersers of the culturally and economically valuable naturalized chili pepper *Capsicum frutescens*, whose local name Donne' Sâli translates to "Sâli pepper" (Egerer et al. 2018). Smaller amounts of protein-rich arthropods and small vertebrates are also eaten, and parents are often observed feeding arthropods to nestlings (M. Kastner, Virginia Tech, written communication, 2023). The species is a known nest predator and occasionally eats bird eggs and nestlings (Reichel & Glass 1990, Drahos 2002, Sachtleben 2005, Zarones et al. 2015). The composition of the fruit-based portion of the diet is similar across age classes and years (Pollock et al. 2020).

Sâli are important seed dispersers for many plant species in the Marianas (Pollock et al. 2020). Pollock et al. (2020) found that the vast majority (90%) of gut-passed seeds are native plants, although this is likely to vary by habitat type. On Guam, Sâli disperse at least 88% of the zoochorous species commonly found in limestone forest monitoring plots (Pollock et al. 2020). Kastner et al. (2021) compared the seedling communities at AAFB (Sâli present) and South Finegayan (Sâli absent) and found a much greater abundance and richness of seedlings (with a large proportion of native seedlings, including those of the federally protected species *Tabernaemontana rotensis*) at the site with Sâli. However, they also found seedlings of invasive trees (e.g., *Vitex parviflora*) and vines (e.g., *Coccinia grandis*) at the site where Sâli were present (Kastner et al. 2021). Therefore, a growing body of evidence has identified Sâli as an important contributor to seed dispersal and forest regeneration within its range (Egerer et al. 2018, Rehm et al. 2018b, Pollock et al. 2020, Kastner et al. 2021, Thierry et al. 2022). Nevertheless, the inclusion of invasive fleshy-fruited species in the Sâli's diet may be noteworthy from a habitat management perspective (Pollock et al. 2020, Kastner et al. 2021, Thierry et al. 2022).

Behavior

SPATIAL BEHAVIOR

Home range data are lacking for Guam. However, on Saipan, Sâli maintained the largest home ranges ($\bar{x} = 91.4 \pm 21.7$ [standard error] ha) of the island's five frugivorous bird species (Rehm et al. 2018a). Sâli regularly flew distances of 120 m and occasionally 500 m across various habitat types (Rehm et al. 2018b, 2019).

Sâli exhibit high roost fidelity on Guam and Saipan, but differ between islands in diurnal movement patterns. On AAFB, where BTS are present, radio-tagged Sâli make directed movements (often of several hundred meters or more) to forage in nearby forests during daylight hours and return

in the late afternoon to roost on base – often in the same tree (M. Kastner, Virginia Tech & H.S. Pollock, Michigan Technological University, written communication, 2023). In contrast, on Saipan, where BTS are absent, there is substantial overlap in roosting and foraging habitat, with birds generally selecting roost sites within their diurnal home ranges (Rehm et al. 2018a).

SOCIAL BEHAVIOR

Sâli are highly social and are regularly found in groups of varying size (2-50 individuals; Stophlet 1946, Stott 1947, Marshall 1949, Tubb 1966, Pratt et al. 1979, Jenkins 1983, Engbring & Ramsey 1984, Craig 1996, Drahos 2002, Pollock et al. 2022). Juveniles and subadults form loosely-organized flocks after the post-fledging period, sometimes mixed with adults (Marshall 1949, Jenkins 1983, Craig 1996). On AAFB, communal night roosts of juveniles and subadults have been documented, including with other species (i.e., Sâlen Taiwan [Black Drongo, *Dicrurus macrocercus*], Gâ'ga' Pâle' [Eurasian Tree Sparrow, *Passer montanus*], CHunge' [White Tern, *Gygis alba*], and Paluman Sinisa [Philippine Collared Dove, *Streptopelia dusumieri*]) (H.S. Pollock, Michigan Technological University, written communication, 2023).

TERRITORIAL BEHAVIOR AND INTERSPECIFIC AGGRESSION

Sâli aggressively defend nest sites against conspecifics (Suckow et al. 2022), as well as other native and non-native species (Drahos 2002). Nesting territories are actively defended by both sexes against intruders such as Åga (Mariana Crow, *Corvus kubaryi*), Sihek (Guam Kingfisher, *Todiramphus cinnamominus*), Sâlen Taiwan, Gâ'ga' Pâle', Utak (White-tailed Tropicbird, *Phaethon lepturus*), Hilitai (Mariana Monitor lizard, *Varanus tsukamotoi*), cats (*Felis catus*), dogs (*Canis familiaris*), and humans (Jenkins 1983, Drahos 2002, Savidge et al. 2022).

Other observations of interspecific aggression include Sâli being mobbed by Nosa' (white-eye spp., *Zosterops* spp.) and CHuchurikan Tini'an (Tinian Monarch, *Monarcha takatsukasae*) as potential nest defense behavior (Marshall 1949, Jenkins 1983), mutually antagonistic behavior between Sâli and Åga as they depredate each other's nests (Baker 1951, Beaty 1967, Zarones et al. 2015), and Sâlen Taiwan harassing Sâli outside of the drongos' territories and stealing their prey items (Maben 1982).

Breeding

PHENOLOGY

Sâli breed year-round on Guam and Saipan, but with higher nesting activity from March to September (Jenkins 1983, Craig 1996, Savidge et al. 2022).

NEST-SITE CHARACTERISTICS

Sâli are cavity-nesters that build their nests generally 2-15 m high in the holes of hollow tree trunks, cliffs, coconut palms, and human-made structures such as utility poles, crevices in buildings, and metal storm shutters (Seale 1901, Downs 1946, Marshall 1949, Kibler 1950, Baker 1951, Beaty 1967, Jenkins 1983, Engbring et al. 1986, Wiles et al. 1995, Drahos 2002, Savidge et al. 2022). Nests are constructed from Gâgu (*Casuarina equisetifolia*) branch tips; the leaves of Nunu (*Ficus* spp.), *Pandanus* spp., and other tree species; fine grasses; and other vegetative and woody material that are used to line the bottom of the cavity (Jenkins 1983, Drahos 2002, Savidge et al. 2022).

On Guam, nests have been recorded in Arbol del Fuego (*Delonix regia*), Lemmai (*Artocarpus altilis*), Panoa (*Guettarda speciosa*), Nunu, *Pandanus* spp., and Umumu (*Pisonia grandis*; Jenkins 1983, DAWR 1997, Drahos 2002). Sâli will also nest in holes in the bases of Galak (*Asplenium nidus*) previously excavated by Sihek (Drahos 2002). At present, the primary tree species used by nesting Sâli on AAFB is Niyok (*Cocos nucifera*), both within the crowns of living trees and cavities in standing dead trees, but the birds will also readily use nest boxes attached to power poles or cavities

in other anthropogenic structures (Savidge et al. 2022). On Cocos Island, Sāli build nests in cavities in buildings and in the trunks of large Gāgu trees (M. Kastner, Virginia Tech, written communication, 2023). Sāli exhibit high nest-site fidelity, with pairs repeatedly reusing the same nest sites (Jenkins 1983, Craig 1996, Savidge et al. 2022, Suckow et al. 2022).

INCUBATION, NESTLING AND FLEDGLING STAGES

Jenkins (1983) reported an incubation period of less than 24 days and nestling periods of 21-25 days, whereas Savidge et al. (2022), with much larger sample sizes, documented mean incubation and nestling periods of 13-16 days (\bar{x} =14.2 days) and 23.5–27.5 days (\bar{x} =25.1 days), respectively. Both sexes contribute to parental care and help rear the altricial young to independence (Jenkins 1983). Usually, one parent guards the nest while the other searches for food. Fledglings display limited movement during their first three weeks after leaving the nest, departing their natal territory at an average of 21.7 days (Pollock et al. 2019).

CLUTCH SIZE, NESTING ATTEMPTS AND NESTING SUCCESS

Modal clutch size is two eggs (range: 1-4; Hartert 1898, Seale 1901, Baker 1951, Savidge et al. 2022). Sāli readily re-nest following either successful or failed nesting attempts and can raise multiple successful broods per year (Jenkins 1983, Savidge et al. 2022). Savidge et al. (2022) reported re-nesting intervals of 25-226 days (\bar{x} =70 days), but one instance of a 5-day interval has also been recorded (Jenkins 1983). Therefore, adult pairs make about six nesting attempts per year on AAFB (M. Kastner, Virginia Tech, written communication, 2023), consistent with Jenkins' (1983) observation of five successful broods produced in seven months at one nest cavity. Nesting cycles are highly variable and are largely dependent on nest location and how successful the pairs were in previous nesting attempts (M. Kastner, Virginia Tech, written communication, 2023).

Comparison of nest success rates at artificial and naturally occurring nest sites on AAFB has demonstrated considerably higher success at nest boxes designed to be predator resistant (80% success) than at natural nests (52% success; Savidge et al. 2018). Nestling survival per successful nest was estimated at $93 \pm 0.04\%$ (SE) (Savidge et al. 2018).

Post-Fledging Survival

Post-fledging monitoring of Sāli on AAFB from April to December 2017 documented that 32 of the 43 (74.4%) tracked fledglings did not survive beyond 53 days, when the last fledgling death was recorded (overall monitoring lasted up to 6 months or more depending on the bird; Pollock et al. 2019). Fledgling mortality was higher during the first 5 days post-fledging (65.6%) than from days 5 to 8 days (12.5%) and days 9 to 53 (21.9%) post-fledging. Wagner et al. (2018), with a partially overlapping dataset, found that 66.7% of fledglings were depredated within 3 days of fledging. Pollock et al. (2019) implicated BTS in 56% of fledgling deaths, followed by feral cat predation (19%), exposure to the elements (13%), and unknown causes (13%), with snake predation generally occurring within 150 m of a fledgling's natal nest box. Some of the fledglings depredated by BTS were not successfully consumed by the snakes (Pollock et al. 2019). Although Sāli fledglings experience elevated BTS predation pressure throughout much of the urban environment, rates of snake predation are highest when natal nest sites are near forest edges (Engbring & Fritts 1988, Pollock et al. 2019), where fledglings may be exposed to incursions by forest-dwelling BTS (Campbell et al. 2008, Siers et al. 2014, 2016).

Rates of juvenile and adult Sāli survival are unavailable in the published literature. Adult survival on Guam appears to be relatively high compared to the younger age classes, and color-banded adult Sāli have been resighted more than five years after their initial capture (H.S. Rogers, Virginia Tech, written communication, 2023). Maximum longevity of Sāli is unknown.

Population Persistence Modeling

McElderry et al. (2022) simulated population growth under two scenarios using nest success rates from AAFB (Savidge et al. 2018). Sâli using natural nests experienced a 3% annual decline in numbers ($\lambda=0.97$), whereas those occupying nest boxes demonstrated annual growth of 10% ($\lambda=1.10$). Moreover, simulation models reported a high proportion of juvenile mortality, the consequences of which skewed the population age distribution to 5% fledglings, 14% juveniles, and 81% adults (McElderry et al. 2022). These modeled age-class metrics are similar to the age structure (1% fledglings, 8% juveniles, 91% adults) recorded on AAFB from September-October 2018 (Pollock et al. 2022) and include a much lower proportion of immature birds than the 51.4% reported by Jenkins (1983) largely from northern Guam during 1978-1979. Taken together, these results suggest that the elevated mortality rate experienced by younger age classes is currently skewing the population towards a high proportion of adult birds, and that management actions leading to a decrease in predation of young birds would allow greater recruitment into the population.

Threats

PREDATORS

Introduced predators pose the primary threat to Sâli on Guam. The strong negative effect of BTS predation led Sâli to decline from one of the most abundant bird species on the island to a small residual population on AAFB by the 1990s (Wiles et al. 1995, 2003). Although BTS have decreased in density since their peak irruption in the early 1990s (Rodda et al. 1999, Rodda & Savidge 2007), they continue to be the dominant avian predator throughout Guam (Wagner et al. 2018, Pollock et al. 2019, 2022). BTS are present in all terrestrial habitat types, with larger individuals in better body condition more prevalent in urbanized areas and savanna, where the richest prey sources (e.g., commensal mammals and birds) are currently most abundant on Guam (Savidge 1988, 1991, Siers 2015, Siers et al. 2017a, 2017b). In urbanized areas of AAFB, where the core Sâli population resides, snakes present a continuing concern for Sâli recovery by causing high fledgling mortality (Wagner et al. 2018, Pollock et al. 2019). Likewise, ongoing snake predation presumably limits Sâli expansion into other urban settings on the island (Pollock et al. 2022). BTS also represent the most immediate threat to the persistence of the small remnant Sâli population on Cocos Island (Barnhart et al. 2022, Siers et al. 2024).

Feral and domestic cats are among the deadliest predators of island birds worldwide (Medina et al. 2011). Cats are the second most important predator of Sâli on AAFB, accounting for 19% of all fledgling mortality (Pollock et al. 2019).

Rat predation has been implicated in the extirpation or declines of many island birds, particularly through their role as nest predators (Harper & Bunbury 2015). However, the role of rats as avian predators on Guam is poorly known. Baker (1951) and Brandt (1962) both implicated black rats (*Rattus rattus*) as potential predators of Sâli on Guam and Chuuk in the Caroline Islands, respectively. However, small mammal abundance has declined substantially on Guam since the arrival of BTS (Wiewel et al. 2009, Hanslowe et al. 2022), to the point that rodents are nearly undetectable in forested habitat (Siers et al. 2019b, 2019c). Existing evidence suggests that rats have little or no influence on Sâli nest loss and/or mortality at present (Savidge 1987, 1988, Pollock et al. 2019, Savidge et al. 2022), although sustained suppression of BTS populations could result in an irruption in rat numbers and, consequently, greater impacts on bird populations (Siers et al. 2019b).

Baker (1951) witnessed a monitor lizard climbing down a tree with a Sâli egg in its mouth as it was being mobbed by both parents. Other instances of predation by this species have not been reported (see Dryden 1965), suggesting monitor lizards may be only a minor predator of Sâli.

HABITAT LOSS AND DEGRADATION

Guam is the most urbanized island in Micronesia, with a human population that has increased almost twelve-fold in the last century (with an acceleration since WWII) to nearly 170,000 inhabitants in 2020. Much of the urban buildup has occurred on the island's northern limestone plateau, which was formerly largely forested, albeit with extensive land clearance and disturbance during wartime (Taboroši 2013, Spies et al. 2019). As a result, the extent of forest cover on Guam has greatly decreased, with native limestone forest and mixed introduced forest now accounting for 10% and 23% of the island's land cover, respectively (Amidon et al. 2017). Nevertheless, habitat loss through urban development or other disturbance is not considered a viable explanation for the declines of Guam's native forest birds, with most authors noting that these species disappeared rapidly from large tracts of intact habitat, and that many native bird species (including conspecific species to those lost from Guam) remain on nearby Mariana Islands with similar development histories (Jenkins 1983, Savidge 1984, 1987, Wiles et al. 1995, Liske-Clark 2015). Moreover, Sali readily use a variety of habitats including urban areas and early successional vegetation, which currently constitute much of Guam's land cover (Amidon et al. 2017).

Non-native ungulates such as Philippine Deer (*Rusa marianna*) and feral pigs (*Sus scrofa*) have degraded forest habitat through their browsing or rooting behavior, reducing vegetative diversity and forest complexity across most of Guam (Conry 1988, Wiles et al. 1995, 1999, Perry & Morton 1999, Wiles 2005, Gawel et al. 2018, Nafus et al. 2018). Over time, these impacts contribute to suppression of seedling recruitment and forest regeneration, likely resulting in poorer habitat quality for Sali.

SEVERE TYPHOONS AND CLIMATE CHANGE

The Mariana Islands occur in a region of the western Pacific Basin that hosts frequent tropical cyclone activity, with a historical archipelago-wide average of 2-8 storm events per year (USNOCC/JTWC 1991, Grecni et al. 2020). Climate change is projected to strengthen the future intensity of typhoons passing through the region, whereas frequency is expected to decline somewhat (Grecni et al. 2020). Extreme weather can negatively impact insular bird populations, especially those already small in size, through either direct mortality from heavy wind or rain, or delayed effects resulting from damaged habitat, such as starvation from fruit and insect loss, increased predation, or loss of nesting substrates (Wiley & Wunderle 1993, Plentovich et al. 2005, Askins & Ewert 2020).

One of the only examples of Sali being negatively affected by powerful storms followed the passages off southern Guam of Typhoon Russ in December 1990 and Typhoon Yuri in November 1991. High surf from both events either partially or fully overwashed Cocos Island and severely damaged the island's vegetation (DAWR 1991, 1992, Richmond & Jaffe 1991, McCoid 1996). Subsequent surveys and examination of Cocos Island Sali noted poor body condition and a depleted population (DAWR 1991, 1992). In response, DAWR biologists established supplementary feeding and water stations after both storms to support the Sali population and continued this activity until about nine months after Typhoon Yuri (DAWR 1991, 1992).

Although this demonstrates some vulnerability to Sali from severe typhoons, populations across the southern Mariana Islands have nevertheless shown increasing trends since the early 1980s (Camp et al. 2009, 2012, 2015, Amidon et al. 2014, Ha et al. 2018, Pollock et al. 2022), despite the occurrence of multiple major storms. These long-term trends suggest Sali populations in the Marianas are generally robust to the effects of severe weather, although this may change in the future if climate change produces typhoons of greater intensity.

Two other aspects of climate change, sea level rise and drought, are both projected to worsen in the Marianas in the future. Sea level rise, which is expected to increase by 0.3 to 1.3 m by 2100 (Wuebbles et al. 2017), is likely to produce minor effects for Guam's Sali, but could eliminate the population on Cocos Island under more extreme scenarios. Drought frequency could more than double by the end of the 21st century (Gingerich et al. 2019), resulting in a greater incidence of water

stress in ecosystems and thus possibly reducing available fruit, flower, and arthropod resources for Sâli.

Conservation and Management

Two key factors in combination have enabled Guam's population of Sâli to persist and partially recover in the presence of major predation by BTS. First, Sâli exhibit sufficient ecological flexibility to make use of nesting, roosting, and foraging sites in urban environments (Pollock et al. 2022, Savidge et al. 2022). Under the right circumstances, urbanized areas constitute a refuge for the species because BTS appear to generally avoid well-lit areas, while the presence of open spaces such as large, mowed lawns, roads, and parking lots can act as barriers to most snake movement (Campbell et al. 2008, Siers et al. 2014, 2016). Anthropogenic structures within urbanized areas also provide nest sites (e.g., cavities in buildings and power poles) that may be relatively safe from predation (Wiles et al. 2003, Savidge et al. 2022). Second, the core of the Sâli population, located on AAFB, has benefited from several decades of BTS suppression around the base's housing area, runways, cargo storage sites, and forest edges (Siers et al. 2017b, 2017c). Recent population growth on AAFB has allowed the species to expand off-base into other urban localities on the island, although it remains unclear whether these sites represent population sinks, or if any are now self-sustaining (Pollock et al. 2022).

Because Sâli are important dispersers of a wide variety of native seeds, management efforts focused on their recovery could play an important role in promoting forest regeneration and, more generally, rebuilding plant-animal interactions necessary for ecosystem function on Guam (Egerer et al. 2018, Rehm et al. 2018a, 2018b, 2019, Pollock et al. 2020, Kastner et al. 2021, Thierry et al. 2022). Their propensity to spread seeds beyond forest boundaries also suggests a potential role in catalyzing restoration of degraded habitat throughout their distribution on the island (Caves et al. 2013, Rogers et al. 2017, Rehm et al. 2018b, Thierry & Rogers 2020), although active control of invasive seed sources may be warranted to avoid their dispersal of undesirable plant species (Pollock et al. 2020, Kastner et al. 2021, Thierry et al. 2022). The restricted geographical range of Guam's remnant Sâli population entails that the ecological services the birds provide are currently lacking from most of the island (Thierry & Rogers 2020, Kastner et al. 2021). Therefore, natural range expansion or translocations of Sâli to BTS-suppressed areas may be a viable strategy for restoring seed dispersal to Guam's forests and surrounding habitats.

Expanding breeding populations of Sâli from the urban areas they currently inhabit into Guam's forests would require effective and sustained landscape-level BTS suppression. While management actions that address current high levels of post-fledgling mortality, such as additional BTS suppression and cat control (Pollock et al. 2019), would be beneficial in promoting additional recruitment into the current population, survival of Sâli in a forested environment would require BTS suppression to extraordinarily low levels (e.g., nightly contact rates ranging from 0.002 to 0.006) – levels that have yet to be demonstrated in BTS management (McElderry et al. 2022). Because all life stages of Sâli are vulnerable in a forested environment, BTS encounter probabilities would need to be near-zero to allow population-level survival (McElderry et al. 2022). Until sufficiently intense BTS suppression can be achieved in forested habitat, continuing and expanding the provisioning of predator-resistant nest boxes in urbanized areas is likely to have a positive population-level impacts by increasing nest site availability and nesting success, allowing greater numbers of birds to disperse into new habitats (Pollock et al. 2022, Savidge et al. 2022).

Nest boxes on AAFB have produced over 1,600 fledglings since the start of the program in 2015 (J.A. Savidge, Colorado State University, T.F. Seibert, Colorado State University, and H.S. Rogers, Virginia Tech, written communication, 2023). Early results indicate that nest boxes confer higher nest success relative to natural nest sites (Savidge et al. 2018), suggesting that Sâli populations can benefit from management. This would particularly be the case if strategies to increase fledgling

survival were implemented concurrently with nest box installation (Pollock et al. 2019, 2022). Theoretical modeling has identified potential priority areas where restoration of seed dispersal by Sâli may be of greatest benefit to local ecological function (Thierry & Rogers 2020). Effective predator control in those areas (Engeman et al. 2018, Siers et al. 2019a, 2019b, 2021) would constitute a major advance in conservation management on Guam by combining avian species recovery and restoration of ecological function at a landscape-level scale.

The Cocos Island population has persisted despite several decades of isolation from the Guam population and the severe impacts of successive typhoons. However, its fate remains far from secure. The presence of a breeding population of BTS on the islet (Barnhart et al. 2022) presents an existential threat to the population. The elimination of BTS and biosecurity measures to prevent additional incursions by BTS or other invasive predators are important to safeguard the immediate future of Cocos Island Sâli. The exchange of individuals with the Guam population, either through translocation or natural dispersal, may benefit the population from a genetic perspective. Ultimately, the long-term persistence of Sâli on Cocos Island depends on the severity of future typhoons, associated storm surges, and sea-level rise, all of which threaten the integrity of the habitat.

The Guam and Cocos Island Sâli populations remain unstudied from a genetic perspective. Specifically, the possibility of genetic issues as a result of recent population bottlenecks, such as inbreeding depression or loss of allelic diversity due to genetic drift, has yet to be investigated. A genomic assessment may be warranted should either population be considered as the source of individuals for translocation or as a recipient site (Neaves et al. 2023). Moreover, population genetics would be useful in understanding the dispersal rate of individuals between populations, and more broadly, resolving the subspecific status of populations across the region.

Acknowledgements

Funding was provided by the U.S. Geological Survey Pacific Island Ecosystems Research Center and U.S. Marine Corps Defense Policy Review Initiative under MIPR # M2002119MPDP154, administered by Marc A. Hall. We are deeply grateful for the work of past and present biologists who have contributed to our understanding of Sâli. The authors thank Julie Savidge and Tom Seibert for feedback on the manuscript and for their long-term commitment to Sâli conservation. Gordon Rodda and Julie Savidge provided constructive comments on the manuscript. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

- Amar, A., F. Amidon, B. Arroyo, J.A. Esselstyn & A.P. Marshall. 2008. Population trends of the forest bird community on the Pacific island of Rota, Mariana Islands. *Condor* 110: 421-427.
- Amidon, F., R.J. Camp, A.P. Marshall, T.K. Pratt, L. Williams, P. Radley & J.B. Cruz. 2014. Terrestrial bird population trends on Aguiguan (Goat Island), Mariana Islands. *Bird Conservation International* 24: 505–517.
- Amidon, F.A., M. Metevier & S.E. Miller. 2017. Vegetation mapping of the Mariana Islands: Commonwealth of the Northern Mariana Islands and Territory of Guam. Final Report: 94. Pacific Island Fish and Wildlife Office, U.S. Fish and Wildlife Service, Honolulu, Hawaii. 94 pp.
- Askins, R.A. & D.N. Ewert. 2020. Resistance and resilience of Virgin Islands bird populations following severe hurricanes. *Wilson Journal of Ornithology* 132: 898–910.
- Baker, R.H. 1947. Size of bird populations at Guam, Mariana Islands. *Condor* 49: 124-125.
- Baker, R.H. 1951. The avifauna of Micronesia, its origin, evolution, and distribution. University of Kansas Publications, Museum of Natural History 3: 1-359.
- Barnhart, P.D., Z. Quiogue, E.R. Fransch, D. Vice, C. Hopkins, A.A.Y. Adams, R.N. Reed & M.G. Nafus. 2022. *Boiga irregularis* (Brown Treesnake). *Herpetological Review* 53: 444-445.
- Beaty, J.J. 1967. Guam's remarkable birds. *South Pacific Bulletin* 21: 37-40.
- Brandt, J.H. 1962. Nests and eggs of the birds of the Truk Islands. *Condor* 64: 416-437.
- Bryan, E.H., Jr. 1936. Birds of Guam. *Guam Recorder* 13: 14-15, 24-25.
- Camp, R.J., T.K. Pratt, A.P. Marshall, F. Amidon & L.L. Williams. 2009. Recent status and trends of the land bird avifauna on Saipan, Mariana Islands, with emphasis on the endangered Nightingale Reed-warbler *Acrocephalus luscini*. *Bird Conservation International* 19: 323-337.
- Camp, R.J., F.A. Amidon, A.P. Marshall & T.K. Pratt. 2012. Bird populations on the island of Tinian: persistence despite wholesale loss of native forests. *Pacific Science* 66: 283-298.
- Camp, R.J., K.W. Brink, P.M. Gorreson, F.A. Amidon, P. Radley, S.P. Berkowitz & P.C. Banko. 2015. Current land bird distribution and trends in population abundance between 1982 and 2012 on Rota, Mariana Islands. *Journal of Fish and Wildlife Management* 6: 511-540.
- Campbell, S.R., S.P. Mackessy & J.A. Clarke. 2008. Microhabitat use by Brown Treesnakes (*Boiga irregularis*): effects of moonlight and prey. *Journal of Herpetology* 42: 246-251.
- Caves, E.M., S.B. Jennings, J. HilleRisLambers, J.J. Tewksbury & H.S. Rogers. 2013. Natural experiment demonstrates that bird loss leads to cessation of dispersal of native seeds from intact to degraded forests. *PLoS One* 8: e65618.
- Conry, P.J. 1988. Management of feral and exotic game species on Guam. *Transactions of the Western Section of The Wildlife Society* 24: 26-30.
- Coultas, W.F. 1931. Whitney South Sea Expedition Journals, Vol. W. Journal and letters, Vol. II, of William F. Coultas, November 1930 to December 1931. Unpublished, American Museum of Natural History, New York, New York.
https://data.library.amnh.org/archives/repositories/6/archival_objects/3494
- Craig, A. & C.J. Feare. 2020. Polynesian Starling (*Aplonis tabuensis*), version 1.0. In J. del Hoyo, A. Elliott, J. Sargatal, D.A. Christie, and E. de Juana, editors. *Birds of the world*. Cornell Lab of Ornithology, Ithaca, New York. <https://doi.org/10.2173/bow.polsta1.01>.
- Craig, R.J. 1996. Seasonal population surveys and natural history of a Micronesian bird community. *Wilson Bulletin* 108: 246-267.
- Cruz, J., L. Arriola, N. Johnson & G. Beauprez. 2000a. Wildlife and vegetation surveys, Agrihan, 2000. Technical Report #8, CNMI Division of Fish and Wildlife, Saipan, Commonwealth of the Northern Mariana Islands. 46 pp.
- Cruz, J., L. Arriola, N. Johnson & G. Beauprez. 2000b. Wildlife and vegetation surveys, Pagan, 2000. Technical Report #7, CNMI Division of Fish and Wildlife, Saipan, Commonwealth of the Northern Mariana Islands. 67 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1980. Survey and inventory of native land birds on Guam and Northern Mariana Islands. Job Progress Report Research Project Segment, October 1,

- 1979, to September 30, 1980. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 10 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1981. Survey and inventory of native land birds on Guam and Northern Mariana Islands. Job Progress Report Research Project Segment, October 1, 1980, to September 30, 1981. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 14 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1982. Survey and inventory of native land birds on Guam and Northern Mariana Islands. Job Progress Report Research Project Segment, October 1, 1981, to September 30, 1982. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 10 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1983. Survey and inventory of native land birds on Guam. Job Progress Report Research Project Segment, October 1, 1982, to September 30, 1983. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 10 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1984. Survey and inventory of native land birds on Guam. Job Progress Report Research Project Segment, October 1, 1983, to September 30, 1984. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 14 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1985. Survey and inventory of native land birds on Guam. Job Progress Report Research Project Segment, October 1, 1984, to September 30, 1985. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 12 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1986. Survey and inventory of native land birds on Guam. Job Progress Report Research Project Segment, October 1, 1985, to September 30, 1986. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 10 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1991. Survey and inventory of non-game birds. Job Progress Report Research Project Segment, October 1, 1990, to September 30, 1991. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 14 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1992. Survey and inventory of non-game birds. Job Progress Report Research Project Segment, October 1, 1991, to September 30, 1992. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 10 pp.
- DAWR (Division of Aquatic and Wildlife Resources). 1997. Survey and inventory of non-game birds. Job Progress Report Research Project Segment, October 1, 1996, to September 30, 1997. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam. 10 pp.
- Dorr, D.S., C.S. Clark & P. Savarie. 2016. Aerial application of acetaminophen-treated baits for control of Brown Treesnakes (RC-200925; NWRC study number: QA-1828). Environmental Security Technology Certification Program Final Report, Department of Defense, Alexandria, Virginia. <https://apps.dtic.mil/sti/citations/AD1030982>
- Downs, T. 1946. Birds on Tinian in the Marianas. *Transactions of the Kansas Academy of Science* 49: 87-106.
- Drahos, N. 1977. Population dynamics of Guam birds. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam.
- Drahos, N. 2002. The mysteries & histories of Guam's birds. Self-published, Aurora, New York.
- Dryden, G.L. 1965. The food and feeding habits of *Varanus indicus* on Guam. *Micronesica* 2: 73-76.
- Egerer, M.H., E.C. Fricke & H.S. Rogers. 2018. Seed dispersal as an ecosystem service: frugivore loss leads to decline of a socially valued plant, *Capsicum frutescens*. *Ecological Applications* 28: 655-667.
- Engbring, J. & T.H. Fritts. 1988. Demise of an insular avifauna: the Brown Tree Snake on Guam. *Transactions of the Western Section of the Wildlife Society* 24: 31-37.

- Engbring, J. & F.L. Ramsey. 1984. Distribution and abundance of the forest birds of Guam: results of a 1981 survey. U.S. Fish and Wildlife Service, Honolulu, Hawaii. 73 pp. <https://www.osti.gov/biblio/5935520>
- Engbring, J., F.L. Ramsey & V.J. Wildman. 1986. Micronesian forest bird survey, 1982: Saipan, Tinian, Aguijan, and Rota. U.S. Fish and Wildlife Service, Honolulu, Hawaii. 143 pp.
- Engeman, R.M., A.B. Shiels & C.S. Clark. 2018. Objectives and integrated approaches for the control of Brown Tree Snakes: an updated overview. *Journal of Environmental Management* 219: 115-124.
- Feare, C. & A. Craig. 1999. Starlings and mynas. Princeton University Press, Princeton, New Jersey.
- Gawel, A.M., H.S. Rogers, R.H. Miller & A.M. Kerr. 2018. Contrasting ecological roles of non-native ungulates in a novel ecosystem. *Royal Society Open Science* 5: 170151.
- Gill, F., D. Donsker & P. Rasmussen, editors. 2023. IOC world bird list (v13.2). doi:10.14344/IOC.ML.13.2. <https://www.worldbirdnames.org/new/>.
- Gingerich, S.B., A.G. Johnson, S.N. Rosa, M.D. Marineau, S.A. Wright, L.E. Hay, M.J. Widlansky, J.W. Jenson, C.I. Wong, J.L. Banner, V.W. Keener & M.L. Finucane. 2019. Water resources on Guam—potential impacts of and adaptive response to climate change. U.S. Geological Survey Scientific Investigations Report 2019–5095. 55 pp. <https://doi.org/10.3133/sir20195095>.
- Grejni, Z., W. Miles, R. King, A. Frazier & V. Keener. 2020. Climate change in Guam: indicators and considerations for key sectors. Report for the Pacific Islands Regional Climate Assessment, East-West Center, Honolulu, Hawaii. 60 pp. <https://www.eastwestcenter.org/publications/climate-change-in-guam-indicators-and-considerations-key-sectors>
- Ha, J., J.B. Cruz, S. Kremer, V.A. Camacho & P. Radley. 2018. Trends in avian roadside surveys over a 20-year period on Saipan, Commonwealth of the Northern Mariana Islands. *Pacific Science* 72: 81-93.
- Hanslowe, E.B., A.A. Yackel Adams, M.G. Nafus, D.A. Page, D.R. Bradke, F.T. Erickson & L.L. Bailey. 2022. Chew-cards can accurately index invasive rat densities in Mariana Island forests. *NeoBiota* 74: 29–56.
- Harper, G.A. & N. Bunbury. 2015. Invasive rats on tropical islands: their population biology and impacts on native species. *Global Ecology and Conservation* 3: 607-627.
- Hartert, E. 1898. On the birds of the Marianne Islands. *Novitates Zoologicae* 5: 51-69.
- Jenkins, J.M. 1983. The native forest birds of Guam. *Ornithological Monographs* 31: 1-61.
- Kastner, M., H.S. Pollock, J.A. Savidge, E.C. Fricke & H.S. Rogers. 2021. Functional robustness of seed dispersal by a remnant frugivore population on a defaunated tropical island. *Biotropica* 53: 359-366.
- Kibler, L.F. 1950. Notes on the birds of Guam. *Auk* 67: 400-403.
- Liske-Clark, J. 2015. Wildlife action plan for the Commonwealth of the Northern Mariana Islands, 2015-2025. CNMI Division of Fish and Wildlife, Saipan, Commonwealth of the Northern Mariana Islands. 292 pp.
- Lovette, I.J. & D.R. Rubenstein. 2007. A comprehensive molecular phylogeny of the starlings (Aves: Sturnidae) and mockingbirds (Aves: Mimidae): congruent mtDNA and nuclear trees for a cosmopolitan avian radiation. *Molecular Phylogenetics and Evolution* 44: 1031-1056.
- Lusk, M.R., P. Bruner & C. Kessler. 2000. The avifauna of Farallon de Medinilla, Mariana Islands. *Journal of Field Ornithology* 71: 22-33.
- Maben, A.F. 1982. The feeding ecology of the Black Drongo (*Dicrurus macrocercus*) on Guam. M.S. thesis, California State University, Long Beach, California. 97 pp. https://meridian.allenpress.com/jfwm/article-supplement/204068/pdf/112014-jfwm-085_s20/
- Marshall, J.T. 1949. The endemic avifauna of Saipan, Tinian, Guam and Palau. *Condor* 51: 200-221.
- McCoid, M.J. 1996. Effect of typhoons on the lizard community of a shelf atoll. *Atoll Research Bulletin* 439: 1-5.
- McElderry, R.M., E.H. Paxton, A.V. Nguyen & S.R. Siers. 2021. Distilling professional opinion to gauge vulnerability of Guam avifauna to Brown Treesnake predation. *Frontiers in Conservation Science* 2: 683964.

- McElderry, R.M., E.H. Paxton, A.V. Nguyen & S.R. Siers. 2022. Predation thresholds for reintroduction of native avifauna following suppression of invasive Brown Treesnakes on Guam. *Ecological Applications* 32: e2716.
- Medina, F.M., E. Bonnaud, E. Vidal, B.R. Tershy, E.S. Zavaleta, C.J. Donlan, B.S. Keitt, M. Le Corre, S.V. Horwath & M. Nogales. 2011. A global review of the impacts of invasive cats on island endangered vertebrates. *Global Change Biology* 17: 3503–3510.
- Murray, C., J. Liske-Clark, S. Mullin, R. Ulloa, D. Page & B. Eichelberger. 2018. Wildlife and vegetation surveys, Alamagan, 2017. Technical Report #17, CNMI Division of Fish and Wildlife, Saipan, Commonwealth of the Northern Mariana Islands. 69 pp.
- Nafus, M.G., J.A. Savidge, A.A. Yackel Adams, M.T. Christy & R.N. Reed. 2018. Passive restoration following ungulate removal in a highly disturbed tropical wet forest devoid of native seed dispersers. *Restoration Ecology* 26: 331-337.
- Neaves, L.E., R. Odgen & P.M. Hollingsworth. 2023. Genomics and conservation translocations. In M.J. Gaywood, J.G. Ewen, P.M. Hollingsworth & A. Moehrensclager, editors. *Conservation translocations*, pp. 271-302. Cambridge University Press, Cambridge, U.K.
- Perry, G. & J. Morton. 1999. Regeneration rates of the woody vegetation of Guam's Northwest Field following major disturbance: land use patterns, feral ungulates, and cascading effects of the Brown Treesnake. *Micronesica* 31: 125-142.
- Plentovich, S., J.M. Morton, J. Bart, R.J. Camp, M. Lusk, N. Johnson & E. VanderWerf. 2005. Population trends of Mariana Crow *Corvus kubaryi* on Rota, Commonwealth of the Northern Mariana Islands. *Bird Conservation International* 15: 211-224.
- Pollock, H.S., J.A. Savidge, M. Kastner, T. Seibert & T.M. Jones. 2019. Pervasive impacts of Brown Treesnakes drive low fledgling survival in endangered Micronesian Starlings (*Aplonis opaca*) on Guam. *Condor* 121: 1-11.
- Pollock, H.S., E.C. Fricke, E.M. Rehm, M. Kastner, N. Suckow, J.A. Savidge & H.S. Rogers. 2020. Sali (Micronesian Starling – *Aplonis opaca*) as a key seed dispersal agent across a tropical archipelago. *Journal of Tropical Ecology* 36: 56-64.
- Pollock, H.S., M. Kastner, G.J. Wiles, H. Thierry, L.B. Dueñas, E.H. Paxton, N.M. Suckow, J. Quitugua & H.S. Rogers. 2022. Recent recovery and expansion of Guam's locally endangered Sali (Micronesian Starling) *Aplonis opaca* population in the presence of the invasive Brown Treesnake. *Bird Conservation International* 32: 95–110.
- Pratt, H.D., P.L. Bruner & D.G. Berrett. 1979. America's unknown avifauna: the birds of the Mariana Islands. *American Birds* 33: 227-235.
- Pratt, H.D., P.L. Bruner & D.G. Berrett. 1987. *A field guide to the birds of Hawaii and the tropical Pacific*. Princeton University Press, Princeton, New Jersey.
- Pyle, P., P. Radley, J. Bradley & C. Carter. 2008. *Manual for ageing and sexing birds of Saipan, with notes on breeding seasonality*. Institute for Bird Populations, Point Reyes Station, California.
- Radley, P., A.L. Crary, J. Bradley, C. Carter & P. Pyle. 2011. Molt patterns, biometrics, and age and gender classification of landbirds on Saipan, Northern Mariana Islands. *Wilson Journal of Ornithology* 128: 588-594.
- Rehm, E.M., M.B. Balsat, N.P. Lemoine & J.A. Savidge. 2018a. Spatial dynamics of habitat use informs reintroduction efforts in the presence of an invasive predator. *Journal of Applied Ecology* 55: 1790-1798.
- Rehm, E.M., J. Chojnacki, H.S. Rogers & J.A. Savidge. 2018b. Differences among avian frugivores in seed dispersal to degraded habitats. *Restoration Ecology* 26: 760-766.
- Rehm, E., E. Fricke, J. Bender, J. Savidge & H. Rogers. 2019. Animal movement drives variation in seed dispersal distance in a plant–animal network. *Proceedings of the Royal Society B* 286: 20182007.
- Reichel, J.D. & P.O. Glass. 1990. Micronesian Starling predation on seabird eggs. *Emu* 90: 135-136.
- Richmond, B.M. & B.E. Jaffe. 1991. Typhoon Russ effects on the shoreline of Guam. U.S. Geological Survey Open-File Report 91-571.
- Rodda, G.H. & J.A. Savidge. 2007. Biology and impacts of Pacific Island species. 2. *Boiga irregularis*, the Brown Treesnake (Reptilia: Colubridae). *Pacific Science* 61: 307-324.

- Rodda, G.H., T.H. Fritts, M.J. McCoid & E.W. Campbell, III, 1999. An overview of the biology of the Brown Treesnake (*Boiga irregularis*), a costly introduced pest on Pacific Islands. In G.H. Rodda, Y. Sawai, D. Chiszar & H. Tanaka, editors. Problem snake management: the Habu and the Brown Treesnake, pp. 44-80. Cornell University Press, Ithaca, New York.
- Rogers, H.S., E.R. Buhle, J. HilleRisLambers, E.C. Fricke, R.H. Miller & J.J. Tewksbury. 2017. Effects of an invasive predator cascade to plants via mutualism disruption. *Nature Communications* 8: 14557.
- Sachtleben, T. 2005. Predation and nest success of forest birds in native and non-native habitat on Saipan, Mariana Islands. M.S. thesis, Colorado State University, Fort Collins, Colorado. 96 pp. <https://mountainscholar.org/items/67079893-0e19-433b-9747-18995904a140>.
- Savidge, J.A. 1984. Guam: paradise lost for wildlife. *Biological Conservation* 30: 305-317.
- Savidge, J.A. 1987. Extinction of an island forest avifauna by an introduced snake. *Ecology* 68: 660-668.
- Savidge, J.A. 1988. Food habitats of *Boiga irregularis*, an introduced predator on Guam. *Journal of Herpetology* 22: 275-282.
- Savidge, J.A. 1991. Population characteristics of the introduced Brown Tree Snake (*Boiga irregularis*) on Guam. *Biotropica* 23: 294-300.
- Savidge, J.A., M. Kastner & T.F. Seibert. 2018. Developing a predator-resistant nest box for Micronesian Starlings with application to endangered Guam Micronesian Kingfishers Final Report. Prepared for U.S. Department of Navy, NAVFAC Marianas, Santa Rita, Guam. 66 pp.
- Savidge, J.A., M. Kastner, H.S. Pollock, & T.F. Seibert. 2022. Nest-site selection and breeding biology of the locally endangered Micronesian Starling (*Aplonis opaca*) informs its recovery on Guam. *Avian Conservation and Ecology* 17(1): 18.
- Seale, A. 1901. Report of a mission to Guam. *Occasional Papers of the Bernice P. Bishop Museum* 1: 17-60.
- Siers, S.R. 2015. Microgeographic and ontogenetic variability in the ecology of invasive Brown Treesnakes on Guam, and effects of roads on their landscape-scale movements. Ph.D. dissertation, Colorado State University, Fort Collins, Colorado. 162 pp. <https://mountainscholar.org/items/1a34e890-c0d5-4fba-b2e4-e14d2bb03b6e>
- Siers, S.R., J.A. Savidge & R.N. Reed. 2014. Invasive Brown Treesnake movements at road edges indicate road-crossing avoidance. *Journal of Herpetology* 48: 500-505.
- Siers, S.R., R.N. Reed & J.A. Savidge. 2016. To cross or not to cross: modeling wildlife road crossings as a binary response variable with contextual predictors. *Ecosphere* 7: e01292.
- Siers, S.R., J.A. Savidge & R.N. Reed. 2017a. Quantile regression of microgeographic variation in population characteristics of an invasive vertebrate predator. *PLoS One* 12: e0177671.
- Siers, S.R., J.A. Savidge & R.N. Reed. 2017b. Ontogenetic and ecological variation in invasion risk of Brown Treesnakes (*Boiga irregularis*) on Guam. *Management of Biological Invasions* 8: 469-483.
- Siers, S.R., J.A. Savidge & E. Demeulenaere. 2017c. Restoration plan for the Habitat Management Unit, Navel Support Activity Andersen, Guam. 239 pp.
- Siers, S.R., B.S. Dorr, A.B. Shiels, F.M. Chlarson, L.G. Macaoay, R.M. Mundo, J.A.B. Rabon, R.M. Volsteadt, M.A. Hall, C.S. Clark, S.M. Mosher & P.J. Savarie. 2018. Assessment of Brown Treesnake activity and bait take following large-scale snake suppression in Guam. Final Report QA-2438, USDA APHIS Wildlife Services National Wildlife Research Center Hawaii Field Station, Hilo, Hawaii. 10 pp.
- Siers, S., W. Pitt, J. Eisemann, L. Clark, A.B. Shiels, C.S. Clark, R.J. Gosnell & M.C. Messaros. 2019. In situ evaluation of an automated aerial bait delivery system for landscape-scale control of invasive brown treesnakes on Guam. USDA National Wildlife Research Center - Staff Publications, Number 2252. 10 pp. https://digitalcommons.unl.edu/icwdm_usdanwrc/2252
- Siers, S.R., A.B. Shiels & P.D. Barnhart. 2019b. Invasive snake activity before and after automated aerial baiting. *Journal of Wildlife Management* 84: 256-267.
- Siers, S.R., A.B. Shiels, C.G. Payne, F.M. Chlarson, C.S. Clark & S.M. Mosher. 2019c. Photographic validation of target versus nontarget take of Brown Treesnake baits. *Wildlife Society Bulletin* 43: 752-759.

- Siers, S.R., S.M. Goetz, R.M. Volsteadt & M.G. Nafus. 2021. Evaluating lethal toxicant doses for the largest individuals of an invasive vertebrate predator with indeterminate growth. *Management of Biological Invasions* 12: 476-494.
- Siers, S.R., M.G. Nafus, J.E. Calaor, R.M. Volsteadt, M.S. Grassi, M. Volsteadt, A.F. Collins, P.D. Barnhart, L.T. Huse, A.A. Yackel Adams & D.L. Vice. 2024. Limitations of invasive snake control tools in the context of a new invasion on an island with abundant prey. *NeoBiota* 90: 1-33.
- Spaulding, R.L., R.J. Camp, P.C. Banko, N.C. Johnson & A.D. Anders. 2022. Status of forest birds on Tinian Island, Commonwealth of the Northern Mariana Islands, with an emphasis on the Tinian Monarch (*Monarcha takatsukasae*) (Passeriformes; Monarchidae). *Pacific Science* 76: 209-228.
- Spies, N.P., T. Mizerek, M.K. Reeves, F. Amidon & S.E. Miller. 2019. Developed systems in the Mariana Islands Archipelago. *Encyclopedia of the world's biomes*. Elsevier Publishing, Amsterdam, Netherlands.
- Suckow, N.M., H.S. Pollock, M.E. Hauber, M. Kastner, J.A. Savidge, K. Baker & H.S. Rogers. 2022. Nest defense, personality, and fitness of a locally endangered island passerine. *Ethology* 128: 499-507.
- Stophlet, J.J. 1946. Birds of Guam. *Auk* 63: 534-540.
- Stott, K., Jr. 1947. Notes on Saipan birds. *Auk* 64: 523-527.
- Taboroši, D. 2013. *Environments of Guam*. Bess Press, Honolulu, Hawaii.
- Thierry, H. & H. Rogers. 2020. Where to rewild? A conceptual framework to spatially optimize ecological function. *Proceedings of the Royal Society B* 287: 20193017.
- Thierry, H., E. Rose & H.S. Rogers. 2022. Landscape configuration and frugivore identity affect seed rain during restoration. *Oikos* 2022: e08323.
- Tubb, J.A. 1966. Notes on birds of Guam. *Natural History Bulletin of the Siam Society* 21: 135-138.
- USNOCC/JTWC. 1991. Tropical cyclones affecting Guam, 1671–1990. U.S. Naval Oceanography Command Center/Joint Typhoon Warning Center Technical Note 91-2, COMNAVMARIANAS, Guam. [www.weather.gov/media/gum/Tropical Cyclones Affecting Guam \(1671-1990\).pdf](http://www.weather.gov/media/gum/Tropical%20Cyclones%20Affecting%20Guam%20(1671-1990).pdf) 52.pp
- Wagner, C., C. Tappe, O. Jaramillo, M. Kastner, N. Van Ee, J.A. Savidge & H.S. Pollock. 2018. First reported predation of fledgling Micronesian Starlings (*Aplonis opaca*) by Brown Treesnakes (*Boiga irregularis*) on Guam. *Micronesica* 6: 1-7.
- Wiewel, A.S., A.A. Yackel Adams & G.H. Rodda. 2009. Distribution, density, and biomass of introduced small mammals in the southern Mariana Islands. *Pacific Science* 63: 205-222.
- Wiles, G.J. 2005. Decline of a population of wild seeded breadfruit (*Artocarpus mariannensis*) on Guam, Mariana Islands. *Pacific Science* 59: 509-522.
- Wiles, G.J., C.F. Aguon, G.W. Davis & D.J. Grout. 1995. The status and distribution of endangered animals and plants in northern Guam. *Micronesica* 28: 31-49.
- Wiles, G.J., D.W. Buden & D.J. Worthington. 1999. History of introduction, population status, and management of Philippine Deer (*Cervus mariannus*) on Micronesian islands. *Mammalia* 63: 193-215.
- Wiles, G.J., J. Bart, R.E. Beck, Jr. & C.F. Aguon. 2003. Impacts of the Brown Treesnake: patterns of decline and species persistence in Guam's avifauna. *Conservation Biology* 17: 1350-1360.
- Wiley, J.W. & J.M. Wunderle, Jr. 1993. The effects of hurricanes on birds, with special reference to Caribbean islands. *Bird Conservation International* 3: 319-349.
- Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart & T.K. Maycock, editors. 2017. *Climate science special report: fourth national climate assessment, Volume I*. U.S. Global Change Research Program, Washington, D.C.
- Zarones, L., A. Sussman, J.M. Morton, S. Plentovich, S. Faegre, C. Aguon, A. Amar & R.R. Ha. 2015. Population status and nest success of the critically endangered Mariana Crow *Corvus kubaryi* on Rota, Northern Mariana Islands. *Bird Conservation International* 25: 220-233.

Received 26 Feb. 2022, revised 25 Mar. 2024.