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Terrestrial bird population trends on Aguiguan (Goat Island), Mariana Islands

FRED AMIDON, RICHARD J. CAMP, ANN P. MARSHALL, THANE K. PRATT, LAURA WILLIAMS, PAUL RADLEY and JUSTINE B. CRUZ

Summary

The island of Aguiguan is part of the Mariana archipelago and currently supports populations of four endemic species, including one endemic genus, *Cleptornis*. Bird population trends since 1982 were recently assessed on the neighbouring islands of Saipan, Tinian, and Rota indicating declines in some native species. Point-transect surveys were conducted in 2008 by the U.S. Fish and Wildlife Service to assess population densities and trends on Aguiguan. Densities for six of the nine native birds—White-throated Ground-dove *Gallicolumba xanthonura*, Collared Kingfisher *Todiramphus chloris*, Rufous Fantail *Rhipidura rufifrons*, Golden White-eye *Cleptornis marchei*, Bridled White-eye *Zosterops conspicillatus* and Micronesian Starling *Aplonis opaca*—and the non-native bird—Island Collared-dove *Streptopelia bitorquata*—were significantly greater in 2008 than in 1982. No differences in densities were detected among the surveys for Mariana Fruit-dove *Ptilinopus roseicapilla*, and Micronesian Myzomela *Myzomela rubratra*. Three federally and locally listed endangered birds—Nightingale Reed-warbler *Acrocephalus luscinius*, Mariana Swiftlet *Collocalia bartschi*, and Micronesian Megapode *Megapodius laperous*)—were either not detected during the point-transect counts, the surveys were not appropriate for the species, or the numbers of birds detected were too small to estimate densities. The factors behind the increasing trends for some species are unknown but may be related to increased forest cover on the island since 1982. With declining trends for some native species on neighbouring islands, the increasing and stable trends on Aguiguan is good news for forest bird populations in the region, as Aguiguan populations can help support conservation efforts on other islands in the archipelago.

Introduction

The island of Aguiguan, also known as Goat Island or Aguijan, is part of the Mariana archipelago, a chain of 15 islands located in the western Pacific (Figure 1). The archipelago was designated as an Endemic Bird Area by BirdLife International (Stattersfield *et al.* 1998) and is home to 31 resident land and wetland birds, 13 resident seabirds, and more than 100 migrant or vagrant birds (Reichel and Glass 1991, Wiles 2005). Of the 31 land and wetland birds, 10 are endemic to the Mariana archipelago, including one endemic genus, *Cleptornis*, which is represented by one species, the Golden White-eye *Cleptornis marchei* (Jenkins 1983, Engbring *et al.* 1986).

Currently four endemic species are found on Aguiguan, the Golden White-eye, Bridled White-eye *Zosterops conspicillatus*, Mariana Fruit-dove *Ptilinopus roseicapilla* and Mariana Swiftlet *Collocalia bartschi*. The Nightingale Reed-warbler *Acrocephalus luscinius*, which is listed by the IUCN as 'Critically Endangered' (BirdLife International 2014), once occurred on the island but is believed to be extirpated (Esselstyn *et al.* 2003, Marshall *et al.* 2008). The Golden White-eye is listed as 'Critically Endangered' by IUCN (BirdLife International 2014) and currently only occurs on Aguiguan and Saipan, but is known from the recent fossil record to have formerly occurred on

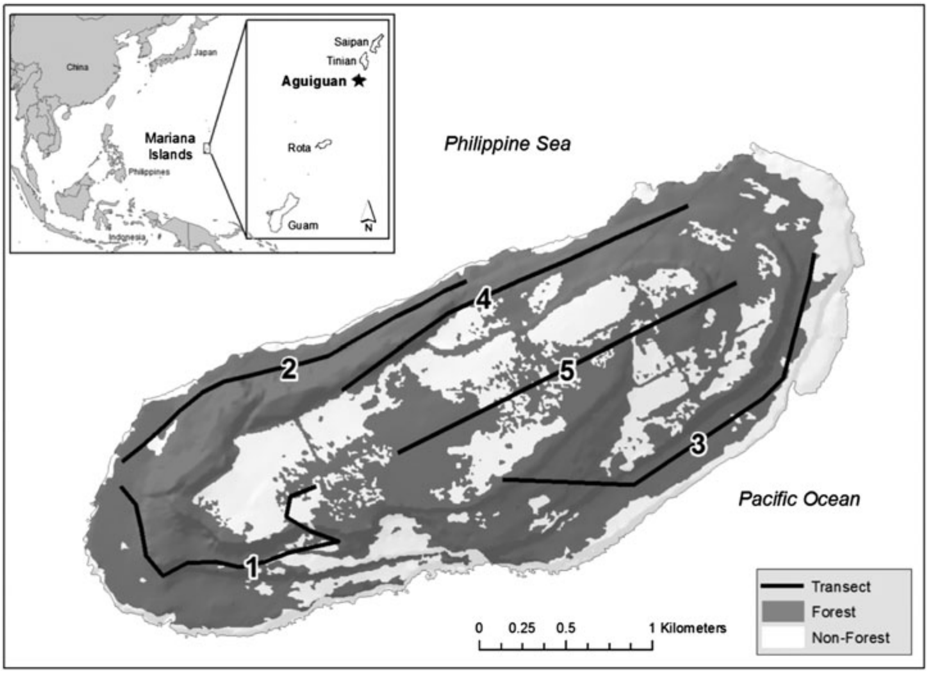

Figure 1. Island of Aguiguan showing the survey transects. Transects 1-4 were counted during 1982, 1995, 2000, 2002, and 2008 surveys, whereas transect 5 was established and counted during the 2008 survey. Map includes simulated shadows to highlight topography.

Tinian and Rota (Figure 1; Steadman 1999). The population on Saipan has experienced a significant population decline since 1982, presumably due to habitat loss (Camp *et al.* 2009). The Bridled White-eye, Mariana Fruit-Dove, and Mariana Swiftlet are all listed as 'Endangered' by IUCN (BirdLife International 2014). The Bridled White-eye is also found on Tinian and Saipan; a subspecies was extirpated from Guam in the 1980s presumably due to predation by the introduced brown tree snake *Boiga irregularis* (Savidge 1987, Wiles *et al.* 2003). The Mariana Fruit-Dove is also found on the neighbouring islands of Rota, Tinian, and Saipan but was extirpated from Guam in the 1980s, also likely due to the brown tree snake (Savidge 1987, Wiles *et al.* 2003). The Mariana Fruit-dove has also recently colonised the island of Sarigan, a volcanic island to the north of Saipan (RJC and PR pers. obs.). The Mariana Swiftlet is currently found on Saipan and Guam and once occurred on the islands of Rota and Tinian (Steadman 1999, Cruz *et al.* 2008).

Aguiguan also supports populations of six additional native terrestrial birds, the Micronesian Megapode *Megapodius laperous*, Yellow Bittern *Ixobrychus sinsensis*, White-throated Ground-Dove *Gallicolumba xanthonura*, Collared Kingfisher *Todiramphus chloris*, Micronesian Mzyomela *Myzomela rubratra*, and Micronesian Starling *Aplonis opaca*. The Micronesian Megapode is listed as 'Endangered' by IUCN (BirdLife International 2014) and it occurs on 12 islands in the Mariana archipelago and Palau (Baker 1951, Amidon *et al.* 2010). The White-throated Ground-dove is listed as 'Near Threatened' by IUCN while the remaining four species are listed as 'Least Concern' due to their wide ranges and large populations (BirdLife International 2014). Currently there is only one non-native bird on the island, the Island Collared-dove *Streptopelia bitorquata*.

Bird populations throughout the region, including Aguiguan, were first quantitatively assessed in 1982 by Engbring *et al.* (1986). Subsequent surveys have been conducted on all the islands and recent estimates of population trends and abundance have been completed for some of these islands (see Amar *et al.* 2008, Camp *et al.* 2009, 2012). Here we present, for the first time, results from 1995 and 2008 forest bird surveys of Aguiguan along with an assessment of population trends since 1982. Population trends are compared to results from recent surveys on the neighbouring islands of Rota, Tinian, and Saipan and the conservation implications are discussed.

Methods

Survey area

Aguiguan is a small, uninhabited island (7.09 km²; 14051`N, 145033`E) located 8 km south-west of the island of Tinian (Figure 1). It is composed of several concentric plateaus bounded by steep limestone scarps; the uppermost plateau averages about 150 m in elevation. The island rises abruptly from the ocean with sheer cliffs, and there are no beaches, bays, or harbours. The climate in the region is tropical with average monthly temperatures ranging from 24°C to 27°C and annual precipitation of 2,000 to 2,500 mm (Mueller-Dombois and Fosberg 1998). About half of the island was cleared for agriculture, primarily sugarcane, during the 1930s and 1940s and was subsequently abandoned after the Second World War (Butler 1994). Those fallow fields changed to *Pennisetum purpureum* in 1950 (Fosberg 1960), to a mix of *Lantana camara*, *Eupatorium* spp. and grasses in 1990 (Butler 1994), to *L. camara* and *Eupatorium* spp. being co-dominant in many fields in 1995 (G. Wiles pers. comm.) and to mainly *L. camara* in 2008 (Amidon 2009). In addition, some field areas were converted to secondary forests dominated by *Leucaena leucocephala* and *Acacia confusa* between the 1950s and 1990s (Amidon 2009). Currently, approximately 49% of the island is covered by native forest (344 ha) while the remainder is secondary forest (141 ha), coastal scrub (28 ha), bare ground (34 ha), and open fields of primarily *L. camara* (160 ha; Amidon 2009).

Aguiguan is uninhabited but supports a population of approximately 1,400 feral goats *Capra hircus* which were apparently introduced between 1820 and 1860 (Butler 1994, Esselstyn *et al.* 2003). The Polynesian rat *Rattus exulans* occurs on the island (Yackel Adams *et al.* 2010) but no populations of feral cats *Felis catus* or dogs *Canis lupus familiaris* are reported.

Abundance and population trends

An island-wide survey consisting of 66 stations on four transects (random-systematic placement) was conducted by the U.S. Fish and Wildlife Service (USFWS) on 2 and 3 June 1982 (Engbring *et al.* 1986; Figure 1). These four transects and 66 stations were resurveyed by Craig *et al.* (1993) in 1992 (21–22 May), USFWS in 1995 (31 May–3 June; survey by A. Marshall) and 2008 (25–27 June; surveys by S. Kremer and A. Marshall), and the Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife (DFW) in 2000 (31 March–8 April; Cruz *et al.* 2000) and 2002 (14–21 March; Esselstyn *et al.* 2003). An additional transect of 14 stations was sampled during the 2008 survey for a total of 80 stations. This transect was added to increase the numbers of bird detections and to sample the topmost plateau; placement of this transect on the plateau was random. Complete datasets were available for all surveys expect for the 1992 survey by Craig *et al.* (1993), which was not included in this analysis.

All surveys followed standard point-transect methods (see Buckland *et al.* 2001 for details). The USFWS surveys consisted of 8-minute counts, where horizontal distances to all birds heard and/or seen were estimated and recorded. The DFW counts lasted only five minutes. Sampling conditions recorded included cloud cover, rain, wind, noise level, detectability, and habitat type, all of which were later used as covariates in density calculations (see below). Counts commenced at sunrise, continued for up to four hours, and were conducted only under prescribed conditions. Stations were surveyed by two observers in 1982 and one observer in all subsequent surveys. Data from both counters were used to estimate 1982 densities, and the sampling effort was adjusted appropriately.

The raw data from the surveys were transcribed and compared to the electronic version on a line-by-line basis to correct transcription errors. All errors were corrected and rechecked for accuracy. After line-by-line proofing was completed, individual datasets were spot-checked for error rates. Ten percent of the survey-specific records were randomly selected and proofed to the raw data. If the error rate exceeded 1%, the whole dataset was proofed again using line-item procedures and a new set of random records checked via the spot-checking methods.

Population status was calculated as density (birds/ha) and abundance (mean of the density estimates weighted by habitat area). Density was calculated using the program DISTANCE, version 5.0, release 2 (Thomas *et al.* 2006) from species-specific global detection functions, where data were post-stratified by survey. Data were right-truncated to facilitate model fitting (Buckland *et al.* 2001). Candidate models included half-normal and hazard-rate detection functions with expansion series of order two (Buckland *et al.* 2001). Sampling covariates were modelled in the multiple-covariate engine of DISTANCE (Thomas *et al.* 2006, Marques *et al.* 2007). The model with the lowest second-order Akaike's information criterion corrected for small sample size (AICc) was used to select the detection function that best fitted the shape of the survey data (Burnham and Anderson 2002).The USFWS data were pooled, separately from the DFW surveys, to ascertain the best model of a species-specific global detection function for the 8-min counts (Burnham 1981, Buckland *et al.* 2001, Buckland 2006). Due to the limited detections for the 5-minute DFW counts, DFW survey data collected during 5-minute counts on the neighbouring islands were also used to develop the DFW count global detection function. Covariates (sampling conditions, habitat types, island, and survey year) were used to generate the global detection function when the best approximating model was improved by four or more AICc units. Detection function parameters used to derive population densities for each species on Aguiguan can be found by dataset in Appendix S1 in the online Supplementary Materials. Variances and confidence intervals were derived by 2.5 and 97.5 quartiles from bootstrap based methods (Buckland *et al.* 2001, Thomas *et al.* 2010). Survey-specific, density-by-station values were generated for population trend analyses (see *Population trends* below) from the global detection function. Area of habitat types came from Engbring *et al.* (1986) and Amidon (2009). Because the area of habitat types was not available for the 1995, 2000, and 2002 surveys, abundance was calculated only for the 2008 survey.

Changes in bird density among the annual estimates were assessed using repeated measures analysis of variance (ANOVA: PROC MIXED; SAS Institute Inc., Cary, NC). To stabilise error variance, density-by-station values were ln(density+1) transformed. Because the number of repeated measures was too small to fit a covariance model, the variance-covariance structure was assumed to be a compound symmetry, homogeneous-variance model (Littell *et al.* 1996). Degrees of freedom were adjusted using the Kenward-Roger adjustment statement, and a Tukey's adjustment was used to control experiment-wise alpha = 0.05 for multiple-comparison procedures.

Results

Thirteen terrestrial species were detected on the Aguiguan surveys from 1982 to 2008 (Table 1). Sufficient numbers of individuals were detected for eight native and one non-native species to calculate density and abundance estimates (Table 2). Micronesian Megapodes were detected during each of the surveys but at low numbers. Mariana Swiftlets were recorded during the 1982, 1995, and 2008 surveys but point-transect sampling is not an appropriate method for estimating densities for this species (see Discussion below). The Yellow Bittern was only recorded on-count during the 1982 survey but was observed off-count during the 2008 survey. The Nightingale Reed-warbler was only recorded on-count during the 1995 survey but was observed off-count during the 1982 survey. In 2008, the Bridled White-eye was the most abundant species, with over 50,000 birds on the island, and Collared Kingfisher, Island Collared-dove, and White-throated Ground-dove were the least abundant species, each with < 600 individuals (Table 2).

Densities of six native birds—White-throated Ground-dove, Rufous Fantail *Rhipidura rufifrons*, Golden White-eye, Bridled White-eye, Collared Kingfisher, and Micronesian Starling—and one

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Table 1. Summary of terrestrial birds detected from the five point-transect surveys on Aguiguan. In 1982, 66 stations were sampled on four transects (88 counts; several stations were counted more than once; effort not adjusted for indices below), and the same number of stations were counted in 1995, 2000 and 2002. In 2008, 80 stations were sampled along five transects. The numbers of birds detected (# Detect) and birds per station (BPS) are presented by survey. Speciesnot detected during a survey are noted with "—". In 2000 and 2002 only select species were recorded, thus other species are noted with "nr" for not reported. Nomenclature generally follows the AOU checklist and Reichel and Glass (1991). Density estimates were produced for birds in bold.

Species	Conservation		1982		1995		2000		2002		2008	
	Status[a]	Diet[b]	# Detect	BPS	# Detect	BPS	# Detect	BPS	# Detect	BPS	# Detect	BPS
Micronesian Megapode *Megapodius laperouse*	EN	O	14	0.16	19	0.29	12	0.18	15	0.23	15	0.19
Yellow Bittern *Ixobrychus sinensis*	LC	C	1	0.01	-	-	nr	nr	nr	nr	-	-
Island Collared-dove *Streptepelia bitorquata*	Alien	H	16	0.18	3	0.05	nr	nr	nr	nr	50	0.63
White-throated Ground-dove *Gallicolumba xanthonura*	NT	F	18	0.20	22	0.33	16	0.24	12	0.18	37	0.46
Mariana Fruit-dove *Ptilinopus roseicapilla*	EN	F	757	8.60	140	2.12	76	1.15	90	1.36	240	3.00
Mariana Swiftlet *Collocalia bartschi*	EN	I	157	1.78	8	0.12	nr	nr	nr	nr	27	0.34
Collared Kingfisher *Todiramphus chloris*	LC	C	154	1.75	89	1.35	57	0.86	32	0.48	101	1.26
Nightingale Reed-warbler *Acrocephalus luscinius*	CR	I	-	-	3	0.05	-	-	-	-	-	-
Micronesian Myzomela *Myzomela rubratra*	LC	O	745	8.47	188	2.85	124	1.88	121	1.83	174	2.18
Rufous Fantail *Rhipidura rufifrons*	LC	I	453	5.15	163	2.47	150	2.27	145	2.20	219	2.74
Golden White-eye *Cleptornis marchei*	CR	O	444	5.05	157	2.38	143	2.17	109	1.65	268	3.35
Bridled White-eye *Zosterops conspicillatus*	EN	O	823	9.35	311	4.71	217	3.29	179	2.71	758	9.48
Micronesian Starling *Aplonis opaca*	LC	O	207	2.35	75	1.14	74	1.12	39	0.59	167	2.09

[a]Conservation status based on IUCN categories (BirdLife International 2014), except Alien, which indicates non-native species: CR – Critically Endangered, EN – Endangered, LC – Least Concern, and NT – Near Threatened.

[b]Diet types based on Jenkins (1983) and Craig (1996): C – carnivorous, F – frugivorous, H – herbivorous, I – insectivorous, and O – omnivorous .

Table 2. Population density (birds/ha± SE, with 95% CI) and abundance estimates for native and alien land birds on Aguiguan. Abundance estimates (abundance equaled the mean of the density estimates weighted by habitat area with 95% CI) were only calculated in 2008. Species not recorded designated by 'nr'.

Species	Density 1982	Density 1995	Density 2000	Density 2002	Density 2008	Abundance 2008
Island Collared-dove	0.07 ± 0.18 (0.02–0.14)	0.08 ± 0.25 (0–0.16)	nr	nr	0.71 ± 1.69 (0.27–1.32)	451 (174–842)
White-throated Ground-dove	0.12 ± 0.05 (0.04–0.24)	0.82 ± 0.25 (0.40–1.37)	0.69 ± 0.29 (0.23–1.37)	0.38 ± 0.12 (0.17–0.61)	0.86 ± 0.25 (0.46–1.40)	548 (291–892)
Mariana Fruit-dove	1.12 ± 0.11 (0.94–1.41)	1.05 ± 0.13 (0.83–1.34)	0.71 ± 0.10 (0.50–0.90)	0.61 ± 0.10 (0.40–0.80)	1.34 ± 0.16 (1.08–1.72)	855 (687–1,093)
Collared Kingfisher	0.21 ± 0.04 (0.14–0.30)	0.82 ± 0.17 (0.54–1.22)	1.36 ± 2.29 (0.41–6.34)	0.65 ± 1.03 (0.17–3.24)	0.86 ± 0.18 (0.55–1.29)	546 (351–819)
Micronesian Myzomela	6.75 ± 1.57 (5.07–11.23)	8.60 ± 2.16 (6.08–14.42)	8.10 ± 1.68 (5.68–11.93)	7.90 ± 1.56 (5.70–11.79)	6.55 ± 1.75 (4.65–10.96)	4,171 (2,962–6,980)
Rufous Fantail	6.42 ± 0.86 (4.99–8.38)	17.88 ± 2.59 (13.76–23.44)	28.3 ± 4.47 (20.33–38.31)	27.99 ± 3.85 (21.12–36.29)	17.17 ± 2.47 (12.95–23.03)	10,939 (8,248–14,671)
Golden White-eye	10.94 ± 1.96 (7.53–15.08)	19.01 ± 3.82 (12.36–26.36)	22.24 ± 3.96 (15.26–30.85)	16.93 ± 2.75 (12.13–22.86)	24.33 ± 4.66 (16.30–34.97)	15,499 (10,383–22,277)
Bridled White-eye	17.98 ± 2.80 (13.65–24.55)	37.87 ± 7.12 (26.35–53.82)	24.27 ± 3.06 (18.59–30.52)	19.33 ± 2.00 (15.83–24.25)	78.82 ± 12.33 (59.50–107.12)	50,205 (37,902–68,235)
Micronesian Starling	1.58 ± 0.36 (1.08–2.42)	5.24 ± 1.28 (3.37–8.24)	11.3 ± 4.42 (5.16–20.8)	6.10 ± 2.48 (2.57–12.04)	10.05 ± 2.26 (6.24–14.97)	6,404 (3,976–9,535)

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non-native bird—Island Collared-dove—were significantly greater in 2008 than 1982 (Table 3, Figure 2, Appendix S2). Density estimates for the Rufous Fantail, Golden White-eye, and Micronesian Starling in 1995, 2000, and 2002 showed generally increasing trends for these species. White-throated Ground-dove densities appeared to decline in 2002 but the confidence intervals for that year overlapped with all other estimates indicating the apparent decline was not significant. Bridled White-eye densities showed an increase in 1995 and subsequent decline in 2000 and 2002 to levels that were similar to those recorded in 1982 indicating some fluctuation in trends for this species. Density estimates for the Island Collared-dove were not available for 2000 and 2002. However, density estimates for 1995 were similar to those reported in 1982 (Table 2), indicating that the increase in density may have been recent.

No differences in densities were detected between the 1982 and 2008 surveys for Mariana Fruit-dove and Micronesian Myzomela. Density estimates for the Mariana Fruit-dove from 2000 and 2002 indicate that it experienced a decline those years. Micronesian Myzomela density estimates were highly variable but showed stable trends throughout the entire survey period.

Discussion

Abundance and population trends

Despite increasing or stable population trends on Aguiguan, population trends for native forest birds on the neighboring islands of Saipan, Tinian, and Rota have been mixed (Amar *et al.* 2008, Camp *et al.* 2009, 2012). Of special concern is the Critically Endangered Golden White-eye on Saipan, which supports a third of the density estimated on Aguiguan (7 and 24 birds/ha, respectively) and has declined significantly since 1982 (Camp *et al.* 2009). In addition, Mariana Fruit-dove and Micronesian Mzyomela showed declines on Rota and Tinian while the Rufous Fantail declined on Rota and Saipan (Amar *et al.* 2008, Camp *et al.* 2009, 2012).Why these species have declined on the neighbouring islands is unknown, though Amar *et al.* (2008) and Camp *et al.* (2009, 2012) listed habitat loss, predation, food availability, pesticides, ectoparasites, and disease as potential factors. However, the declines on the neighboring islands may provide some insight into why native bird populations are stable or increasing on Aguiguan.

One feature which distinguishes Aguiguan from the neighbouring islands is that it does not support a population of the Malayan house rat *Rattus diardii*. Yackel Adams *et al.* (2010) reported that only the Polynesian rat occurred on Aguiguan while Wiewel *et al.* (2009) reported high densities of Malayan house rat on Rota, Tinian, and Saipan. The Polynesian rat was an early introduction to the Mariana archipelago (AD 1000–1200; Steadman 1999) and is generally considered to be less detrimental to avian populations than other introduced *Rattus* species (Atkinson 1985). It is possible that the differences in trends and densities between Aguiguan and the neighbouring islands may, in part, be related to rats.

Table 3. Repeated measures analysis of variance results to assess for differences in Aguiguan bird densities among years. All species showed significant among-year fixed effects at the alpha 0.05 level (see Appendix S2 in online Supplementary Materials). Change was defined as increasing (▲) or stable (▬), no species showed conclusive evidence of a declining trend.

Species	Num DF	Den DF	*F*-Value	Pr > *F*	Change
Island Collared-dove	2	168	16.56	<.0001	▲
White-throated Ground-dove	4	326	8.39	<.0001	▲
Mariana Fruit-dove	4	333	24.16	<.0001	▬
Collared Kingfisher	4	336	16.05	<.0001	▲
Micronesian Myzomela	4	337	3.17	0.0142	▬
Rufous Fantail	4	335	38.12	<.0001	▲
Golden White-eye	4	337	7.99	<.0001	▲
Bridled White-eye	4	340	26.74	<.0001	▲
Micronesian Starling	4	340	21.00	<.0001	▲

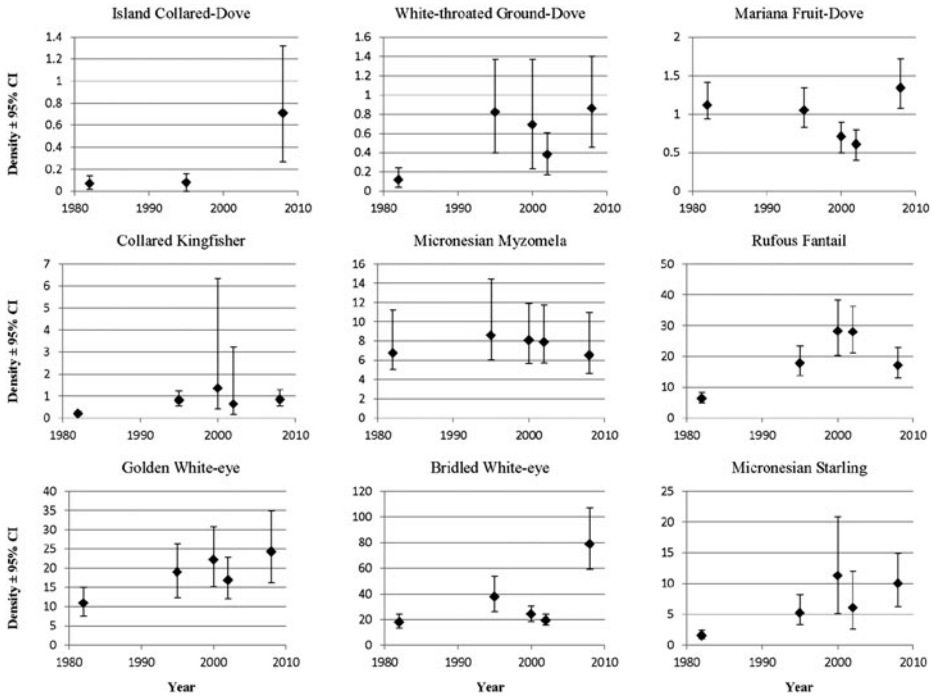

Figure 2. Density estimates (birds/ha and 95% CI) for nine native and alien birds on Aguiguan from point-transect surveys conducted in 1982, 1995, 2000, 2002, and 2008.

Another possible factor is the conversion of open fields to secondary forest and *L. camara* thickets on Aguiguan during the survey period. Amidon (2009) reported that the area of open field habitats declined by approximately 53% from the estimate provided by Engbring *et al.* (1986) for the 1982 surveys, while secondary forest and *L. leucocephala* both increased over that period by 14% and 6%, respectively, and native forest remained stable. The area covered by *L. camara* in 1982 was not reported in Enbgring *et al.* (1986), though they did report that the species was present on the island. However, notes written on the aerial photographs used by Engbring *et al.* to estimate land cover indicate that areas dominated by *L. camara* in 2008 were dominated by grass species in 1982.

The conversion of abandoned agricultural land to secondary forest and *L. camara* may provide additional foraging resources to omnivorous birds, and may partially explain increases in the densities of Golden White-eye and Bridled White-eyes. Golden White-eyes forage on the fruits and flowers of *L. camara*, while Bridled White-eyes forage on the fruits of *L. camara* and the flowers of *L. leucocephala* (Craig 1996). Increases in secondary forest may have also lead to increases in nesting habitat on Aguiguan for Bridled White-eyes, Golden White-eyes, and Rufous Fantails, which all nest in secondary forest on Saipan (Sachtleben 2005). Habitat-related increases in White-throated Ground-Dove, Collared Kingfisher, and Micronesian Starling are less certain as kingfishers are carnivorous and it is unknown whether ground-doves and starlings forage on *L. camara* or *L. leucocephala*. However, increased white-eye and fantail densities would also increase the potential availability of these species to kingfishers and starlings, which are known to depredate them (Craig 1996, Sachtleben 2005).

As noted in the Methods, we were unable to obtain the complete data set for the 1992 survey by Craig *et al.* (1993). In addition, the density estimates reported in Craig *et al.* (1993), like the density estimates by Engbring *et al.* (1986), are not directly compared to the estimates provided in this study due to advances in the analysis of point-transect data since the initial work by

Reynolds *et al.* (1980). The raw counts of detections reported in Craig *et al.*(1993) fall within the range of detections reported here indicating, at the very least, that the 1992 detections were comparable to the number of detections from the other surveys. However, more detailed assessments of trends using raw counts are not possible due to variation in detectability across the surveys.

Craig *et al.* (1993) noted that their average detection distances were consistently smaller than those from the 1982 surveys, likely altering their estimated detection functions for the 1982 and 1992 surveys. We assessed the average detection distances for the 1995 and 2008 surveys and observed that the average detection distances for those surveys were smaller than the 1982 survey estimates and similar to those reported in Craig *et al.* (1993). We accounted for this difference by pooling the data from the 1982, 1995, and 2008 surveys to estimate a global detection function for each species and post-stratifying by survey. Therefore, this difference in average detection distance does not affect the results of the analysis. However, the higher average detection distances for the 1982 compared to subsequent surveys is worth exploring as it could imply a problem with the data or a change in conditions on Aguiguan.

The 1982 survey of Agugiuan was completed after the survey of Rota, Tinian, and Saipan (Engbring *et al.* 1986). Therefore, we do not believe that there are any errors in the data related to observer experience or methodological issues. In addition, the 1982, 1995, and 2008 surveys all occurred during the months of May and June so seasonal differences are unlikely. Instead we believe that differences in average detection distances reflect changes in the habitat along the four transects sampled. As noted earlier, forested habitats on Aguiguan have increased since the 1982 survey with the conversion of open field areas to forested habitats. Detection distances in forested habitats are expected to be shorter than estimates in open field due to decreased visibility. In addition, a goat removal program was initiated on Aguiguan in 1989 and 1990 (Rice 1993) that led to a substantial reduction in goats, from 800–1,500 in 1987 to around 40 in 1990 (Reichel 1988, Rice 1991). Rice (1993) reported increased vegetation growth during and after the goat removal. Esselstyn *et al.* (2003) estimated that the goat population was around 1,400 individuals in 2002 indicating that goat numbers had rebounded after the control programme. However, the increased vegetation growth after the control program may have carried over into the 1992 and later bird surveys and reduced the overall visibility and detection distances along the survey transects. In addition, increased vegetation may attenuate bird vocalisations and reduce detection distances further. These factors may account for the lower average detection distances observed for surveys after 1982.

We did not assess population sizes and trends for three species of native birds—Micronesian Megapode, Yellow Bittern, and Nightingale Reed-warbler—because of the small numbers of detections for each species, which reflect their small population sizes. Density estimation relies on detecting a total of 80–100 individuals (Buckland *et al.* 2001), which was not achieved for any of these species despite pooling detections from different surveys. Aguiguan supports a small Micronesian Megapode population (Esselstyn *et al.* 2003), with similar numbers of birds detected during each of the surveys, including the 1992 Craig *et al.* (1993) survey (range 12–19 birds). Amidon *et al.* (2010) used play-back calls to increase Micronesian Megapode detections and estimated the Aguiguan population to be about 100 birds (61–206, 95% CI). Yellow Bittern occur in very low numbers on Aguiguan (Engbring *et al.* 1986). No birds were detected during the 2008 survey, although one was seen along a transect outside of the count period and one bittern was detected during the count period on the 1982 survey. During the 1982 survey on Aguiguan, four Nightingale Reed-warbler incidental sightings were recorded, but none occurred during the 8-min counts (Engbring *et al.* 1986). In 1995, three reed-warblers were detected at two stations during the counts. The reed-warbler has not been observed on Aguiguan since the 1995 survey and is likely extirpated from the island (Esselstyn *et al.* 2003, U.S. Fish and Wildlife Service 1998). Marshall *et al.* (2008) estimated that with the survey effort to date there was a 3% chance that a population of at most a few individuals persists on Aguiguan.

Point-transect methods are also not appropriate for assessing densities of the Mariana Swiftlet (Camp *et al.* 2009) because of the swiftlet's erratic flight behaviour, the difficulty in estimating horizontal distances to birds detected in flight, and violation of the no movement assumption of distance sampling (Buckland *et al.* 2001). The number of swiftlets detected in 1995 and 2008 was lower than that recorded for 1982 (Table 1). However, Cruz *et al.* (2008) reported that the Aguiguan swiftlet population was likely stable, based on counts at roosting caves between 1985 and 2002.

Conservation implications

With declining population trends for many of the endemic terrestrial birds on the neighbouring islands, increasing trends and high densities on Aguiguan are good news for native bird conservation in the region. Currently DFW, USFWS, and the members of the Association of Zoos and Aquariums are establishing "insurance" populations of endemic species on different islands in the region and in captivity to help ensure the long-term conservation of these species (Marianas Avian Conservation Working Group 2013). Aguiguan birds could assist these efforts by serving as source populations for translocations or restoration efforts on neighbouring islands. For example, Golden White-eyes on Aguiguan may be used as source population for translocations to other islands in their known range.

Though the outlook for birds on Aguiguan is good, maintenance of the island's forest and efforts to ensure additional alien species are not introduced will benefit Aguiguan's unique avian assemblage. Ecotourism has been proposed for Aguiguan (Eugenio 2013), which could increase traffic to the island and potentially promote the spread of invasive species to it. The presence of a large feral goat population and the invasive weed, *L. camara*, on Aguiguan may also pose a long-term threat to the remaining native forest on the island. We saw little evidence of tree recruitment in any of the native forest on Aguiguan in 2008, likely due to goat browsing, and similar observations were noted during previous surveys (Engbring *et al.* 1986, Cruz *et al.* 2000, Esselstyn *et al.* 2003). *Lantana camara* has become established within the native forest on Aguiguan in openings and heavily disturbed areas (Cruz *et al.* 2000, Esselstyn*et al.* 2003). Canopy removal and the resulting increase in light availability have been found to increase *L. camara* growth, germination, survival, and establishment in Australian forests (Duggin and Gentle 1998). Openings created in the canopy of the native forest from natural events, like tree mortality and typhoon damage, would therefore likely lead to the increased establishment of *L. camara* in Aguiguan's forests. This, combined with lack of recruitment in native trees, could lead to long-term alteration of native forest on the island.

Supplementary Material

The supplementary materials referred to in this article can be found at journals.cambridge.org/bci.

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FRED AMIDON*, ANN P. MARSHALL
U.S. Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, 300 AlaMoana Boulevard, Honolulu, HI, 96850, USA.

RICHARD J. CAMP
Hawai`i Cooperative Studies Unit, University of Hawai`i at Hilo,P.O. Box 44, Hawai`i National Park, HI, 96718, USA.

THANE K. PRATT
U.S. Geological Survey, Pacific Island Ecosystems Research Center.P.O. Box 44, Hawai`i National Park, HI, 96718, USA. Current address: P.O. Box 420, Volcano, HI, 96785, USA.

PAUL RADLEY
Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife, Department of Lands and Natural Resources,P.O. Box 10007, Saipan, MP, 96950, USA.

LAURA WILLIAMS
U.S. Navy, Naval Facilities Engineering Command Pacific, 258 Makalapa Drive, Suite 100, Pearl Harbor, HI, 96860, USA.

JUSTINE B. CRUZ
5 Osgood Avenue, New Britain, CT, 06053, USA.

**Author for correspondence; e-mail: fred_amidon@fws.gov*

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