The Condor 110(3):421–427
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POPULATION TRENDS OF THE FOREST BIRD COMMUNITY ON THE PACIFIC ISLAND OF ROTA, MARIANA ISLANDS

ARJUN AMAR[1,5], FRED AMIDON[2], BEATRIZ ARROYO[3], JACOB A. ESSELSTYN[1,4], AND ANN P. MARSHALL[2]

[1]*Divison of Fish and Wildlife, Rota, Commonwealth of the Northern Mariana Islands, MP 96951*
[2]*U.S. Fish and Wildlife Service, Honolulu, Hawaii, HI 96850*
[3]*IREC (CSIC-UCLM-JCCM), Ronda de toledo s/n, 13071 Ciudad Real, Spain*
[4]*Natural History Museum, 1345 Jayhawk Blvd., Lawrence, KS 66045*

Abstract. The Pacific island of Rota is part of the Mariana archipelago, and is located approximately 60 km north of the island of Guam. Two Rota endemics, the Mariana Crow (*Corvus kubaryi*) and the Rota Bridled White-eye (*Zosterops rotensis*), have declined dramatically in the last 20 years. We examined trends in abundance of eight terrestrial bird species (six native, two exotic) on Rota between 1982 and 2004, and found that seven of them declined significantly, with five species showing declines >50%. Only Micronesian Starlings (*Aplonis opaca*) increased in abundance. Declines occurred in species abundant in both forested and open habitats, suggesting that the declines were unlikely to be simply the result of deforestation. While the introduction of the brown tree snake (*Boiga irregularis*) on Guam caused the collapse of that island's avifauna, we do not believe that Rota's declines are due to the establishment of a snake population. Other, as yet unidentified, agents are likely to be responsible. We suggest that future research into the causative agent(s) of decline focus on the comparatively common declining species, rather than studying small populations of endangered species.

Key words: Corvus kubaryi, *endangered species, Mariana Crow, Pacific Islands, population decline, Rota, tropical dry forest.*

Tendencias Poblacionales de la Comunidad Forestal de Aves en la Isla de Rota (Islas Marianas)

Resumen. La isla de Rota es parte del archipiélago de las Marianas en el Pacífico, y está situada aproximadamente a 60 km al norte de la isla de Guam. En Rota, dos especies endémicas de aves, *Corvus kubaryi* y *Zosterops rotensis*, han experimentado fuertes disminuciones poblacionales en los últimos 20 años. Examinamos las tendencias temporales de ocho especies de aves terrestres (seis nativas y dos exóticas) en Rota entre 1982 y 2004. La abundancia de siete de las ocho especies disminuyó significativamente durante el periodo de estudio; cinco de éstas tuvieron disminuciones de más del 50%. Sólo una especie, *Aplonis opaca*, aumentó su abundancia en el periodo estudiado. Entre las especies que disminuyeron había tanto especies forestales como especies típicas de hábitats abiertos, lo que sugiere que las disminuciones no son sólo el resultado de la deforestación. En Guam, la introducción de la serpiente *Boiga irregularis* causó el colapso de la avifauna insular. No obstante, no creemos que las disminuciones en Rota estén asociadas al establecimiento de una población de serpientes, sino a otros agentes, no identificados hasta la fecha. Sugerimos que los estudios para identificar los agentes causales de estas disminuciones se concentren en las especies en disminución más comunes, en vez de trabajar con poblaciones pequeñas de especies amenazadas.

INTRODUCTION

Micronesia is a biodiversity hotspot, with numerous endemic species, especially birds, on the region's many islands (Allison and Eldredge 1999). Unfortunately, island bird species are about 40 times more vulnerable to extinction than continental ones (Newton 1998). To identify when and where island avifaunal communities are experiencing problems, effective monitoring is needed to collect long-term data sufficient to document population trends. These findings can then be used to direct research aimed at identifying the causative agents of declines. The need to monitor and conserve the biota of oceanic islands cannot be overemphasized. Many insular avian communities were devastated upon initial human colonization (Cassels 1984, Olson and James 1984, Steadman 1999), and the arrival of Europeans has seen many more extinctions, leaving only remnants of the former avifauna (Diamond 1984).

Rota, one of the Mariana Islands, is an important Endemic Bird Area (EBA; Birdlife International 2003). It has a unique

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Manuscript received 5 February 2008; accepted 24 June 2008.

[5]Present address: RSPB–Scotland, Dunedin House, 25 Ravelston Terrace, Edinburgh, EH4 3TP, UK. E-mail: arjun.amar@rspb.org.uk

The Condor, Vol. 110, Number 3, pages 421–427. ISSN 0010-5422, electronic ISSN 1938-5129. © 2008 by The Cooper Ornithological Society. All rights reserved. Please direct all requests for permission to photocopy or reproduce article content through the University of California Press's Rights and Permissions website, http://www.ucpressjournals.com/reprintInfo.asp. DOI: 10.1525/cond.2008.8560

avifaunal assemblage, including two critically endangered species, the Mariana Crow (*Corvus kubaryi*) and the Rota Bridled White-eye (*Zosterops rotensis*). The Mariana Crow is also endemic to the island of Guam at the southern extremity of the island chain. Guam's crow population was extirpated by the introduced brown tree snake (*Boiga irregularis*; Wiles et al. 2003), but a very small population translocated from Rota presently exists there (Wiles et al. 2003). Between 1982 and 1998, Rota's Mariana Crow population declined by 83%. But, unlike the decline on Guam, this occurred in the absence of any known brown tree snake population (Plentovich et al. 2005). Likewise, the Rota Bridled White-eye declined by around 89% between 1982 and 1996 and is now restricted to a few small areas around the edge of the upper plateau region of the island (Fancy and Snetsinger 2001).

Suggested reasons for the decline of the Mariana Crow and Bridled White-eye on Rota include the impact of introduced predators such as rats (*Rattus* spp.), domestic cats (*Felis catus*), and Black Drongos (*Dicrurus macrocercus*), and habitat loss and degradation of the native tropical forest (Craig and Taisacan 1994, Fancy and Snetsinger 2001, Plentovich et al. 2005). For the Mariana Crow, human persecution is also suspected, due to conflicts over land development and habitat protection (U.S. Fish and Wildlife Service 2004, Plentovich et al. 2005).

Little is known about the population trends of Rota's other terrestrial bird species. Knowing their status would allow us to evaluate whether the declines of the two endemics are isolated cases or a reflection of widespread avifaunal declines on Rota. If declines were the predominant pattern among these species, we might predict a shared causal agent(s), whereas if only the two endemics were declining, this would suggest factors unique to these species.

Here, we examine the population trends of eight terrestrial bird species on Rota, using data from seven off-road point count surveys conducted between 1982 and 2004. We also update the population trend of the Mariana Crow by supplementing previously reported data with additional surveys from 1987, 1994, 2003, and 2004. We do not examine Bridled White-eye trends as the transects used in this study covered only a very small part of the species' current range. Furthermore, we test whether loss of forested habitat on Rota could sufficiently explain any observed declines, by examining whether declining species were those more closely associated with forested habitats. Finally, we discuss the evidence for other hypotheses, including whether the establishment of brown tree snakes could be responsible for declines.

METHODS

STUDY AREA

Rota (14°10′N, 145°12′E, 85 km^2, 491 m maximum elevation), a rugged island of raised limestone with only limited areas of volcanic origin, is part of the Mariana Archipelago, a chain of 15 small islands located approximately 1500 km east of the Philippine Islands (Fig. 1). The climate on Rota is tropical, with an average annual temperature of 26°C and annual precipitation of 2000–2600 mm (Kendrick 1997). The most recent estimates of forest cover, from the late 1970s and early 1980s (Falanruw et al. 1989), suggest that the island has approximately 60% forest cover. However, a large portion of the forest has been altered through human use and many forested areas are secondary growth (Engbring et al. 1986).

BIRD SURVEYS

We used data from point count stations located on transects that were distributed throughout the island, with the exception of the upper plateau, or "sabana," region (Fig. 1). Count stations were at 150 m intervals along transects, which varied in length from 1.35 km to 4.80 km (10–33 stations). Distances between stations were measured using either hip chains or global positioning system (GPS) units.

We attempted to complete counts within 4 hr after sunrise, and 97% ($n = 1463$) of surveys were conducted between 06:00 and 10:30. During each station count, the observer recorded the number of individuals of each bird species seen or heard over an 8 min period. Counts were abandoned if there was persistent rain or if the wind blew consistently at force four or above on the Beaufort scale. Sixteen observers were involved in the seven surveys, and seven of these observers conducted counts in two or more years, which reduced the potential biases of different observers in different surveys.

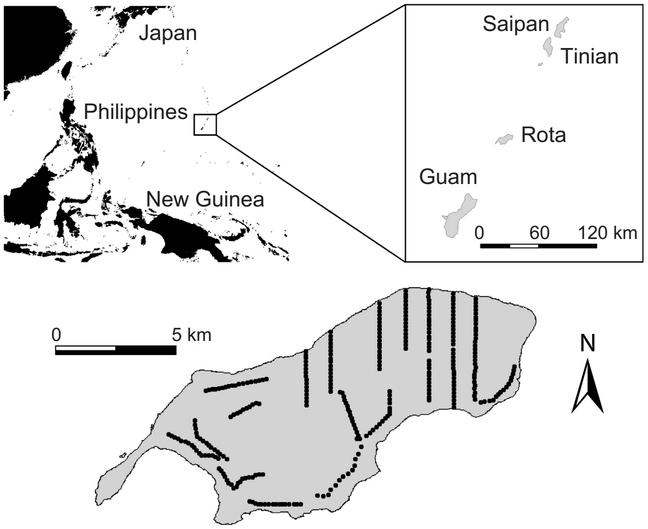

FIGURE 1. Map of Rota in relation to other islands within the Mariana island chain and in relation to the wider Pacific region, and showing the location of the point count stations along the transects used in our surveys to count terrestrial birds between 1982 and 2004.

TABLE 1. Details of point count transects and the number of point count stations surveyed along each transect in each year for six native and two exotic birds species on Rota, Mariana Islands, 1982–2004. "Transect number" reflects the numbers used in previous reports and surveys (Engbring et al. 1986; J. Engbring, U.S. Fish and Wildlife Service, unpubl. data; U.S. Fish and Wildlife Service, unpubl. data).

Transect number	Number of count stations surveyed						
	1982[a]	1987[a]	1994[a]	1995[b]	1998[b]	2003[b]	2004[a]
1	28			29	29	28	28
2	30			29	29	30	30
3	19			18	18	18	18
4	17	15		17	18	17	17
5	17	16		17	17	13	13
8	15	14	15	15	15	16	16
9	17	11		17	17	17	14
10	18			18	18	18	18
11	16			15	15	15	15
13	16		15	14	16	16	15
14	10			15	15	15	15
15				13	14	12	
16		10	10	10	10	10	
17				32	32	33	
18				17	17	18	
19				16	16	15	
20			20	20	19	18	
Total stations	203	66	60	311	315	309	199

[a] Surveys conducted in spring (March–May).

[b] Surveys conducted in autumn (October–November).

Surveys were conducted in the spring (March, April, and May) in 1982, 1987, 1994, and 2004, and in autumn (September, October, and November) in 1995, 1998, and 2003. In 1982, 11 transects were surveyed, with a further six added in 1995; however, only a subsample of the 17 transects were surveyed in 1987, 1994, and 2004 (Table 1).

HABITAT DATA

In 2003, we recorded the habitat type immediately surrounding all count stations. We subjectively classified habitat around each station into two types, forest or open, the latter of which was principally open fields, but also included other disturbed habitats such as agricultural crops, rock quarries, residential land, and golf courses.

SPECIES INFORMATION

Twenty-one bird species were recorded during the survey, but our analysis concentrated on the eight most common terrestrial species: Mariana Crow (*Corvus kubaryi*), Rufous Fantail (*Rhipidura rufifrons*), Mariana Fruit-Dove (*Ptilinopus roseicapilla*), Micronesian Starling (*Aplonis opaca*), Micronesian Honeyeater (*Myzomela rubratra*), Collared Kingfisher (*Halcyon chloris*), Black Drongo (*Dicrurus macrocercus*), and Philippine Turtle-Dove (*Streptopelia bitorquata*). The first six species listed are indigenous, with the first three endemic to the region. The Philippine Turtle-Dove was introduced to the Mariana Islands in the 1700s and the Black Drongo was introduced to Rota in the 1930s (Pratt et al. 1987).

STATISTICAL ANALYSES

We used generalized linear mixed models (GLMMs) fitted in SAS version 8 (SAS Institute 1999) to analyze the count data from each year. GLMMs were fitted with transect as a random effect, thereby controlling for the lack of independence of counts from the same transect in the different surveys, and also adjusting the analysis to account for the fact that each transect was not surveyed in all years. We used the total number of each species counted at stations along a transect as the response variable, with the log of the number of count stations surveyed fitted as an offset to account for the fact that the number of stations varied both among transects within a year, and also within transects among years. Thus, we modeled the number of birds recorded per count station. As our survey data were counts, models were fitted assuming a Poisson error structure corrected for overdispersion and a log-link function. Denominator degrees of freedom were estimated using Satterthwaite's formula (Littell et al. 1996).

To examine long-term trends in the data, we fitted separate models for each species, with year as a permanent continuous fixed effect. We also tested whether season (spring or fall) influenced abundance, and when it was significant at the 5% level, we retained it in subsequent models. We used the least squared means from each survey year derived from a GLMM with year specified as a categorical variable. Year was specified as a fixed effect in these models. Thus, means were generated after accounting for the fact that not all transects were surveyed in all years.

We also fitted two further models to examine whether trends in the data reflected a change in the number of stations where a species was present or a change in a species' abundance at occupied stations. Firstly, we analyzed the data according to the number of stations along a transect where a species was present and the total number of stations surveyed along the transect, fitted as the numerator and denominator, respectively, in a binomial analysis. This analysis used the same model structure as described previously but specified a binomial error structure and a logit-link function with no offset fitted. Secondly, to examine whether abundance at stations where a species was present had changed, we used the original model, but for the offset we used the log of the number of stations where the species was present on each transect. Occasionally, models failed to converge with transect as a random effect; when this occurred, we fitted transect as a fixed effect and used a generalized linear model (GLM).

To examine if habitat change (i.e., forest loss) alone could account for any observed declines, we assessed habitat-abundance relationships. We employed GLMs using the counts and habitat data for stations surveyed in 2003 only. We tested whether the abundance of each species varied according to habitat type (forest or open), fitted as a categorical fixed effect.

RESULTS

POPULATION TRENDS

All species except Micronesian Starlings showed significant declines in numbers counted per station between 1982 and 2004 (Table 2, Fig. 2). These declines varied from 34% for Collared Kingfishers and Black Drongos to 93% for Mariana Crows. All declining species except Collared Kingfishers showed long-term reductions in the proportion of stations at which they were recorded (Table 2). Declining species (except Black Drongos) also declined in abundance at the stations where they were present (Table 2). The Mariana Crow declined in range and numbers more than any other species. Only the Micronesian Starling showed an increasing population trend (Table 2).

HABITAT-ABUNDANCE RELATIONSHIPS

Of 309 stations surveyed in 2003, 102 were in open habitat and 207 were in forested habitat. Five of the seven declining species showed a significant difference in the number of individuals counted in each habitat type (Table 3). Rufous Fantails and Mariana Fruit-Doves were present in higher numbers in forested than open habitats, whereas Micronesian Honeyeaters, Black Drongos, and Collared Kingfishers had higher counts in open habitats.

DISCUSSION

Our analysis of population trends of Rota's terrestrial birds shows that the well-documented declines of the two endangered endemic species are not isolated cases. Rather, their declines appear to be symptomatic of widespread declines in many of the terrestrial bird species on Rota, although in this study the Mariana Crow did show the greatest decline. All but one study species showed a significant long-term decline since 1982. Although our analyses revealed long-term population declines, the greatest decline for many species appeared to occur between 1987 and 1994. Counts in 1987 were either higher than or similar to counts from 1982, whereas all declining species' counts were lower in 1994 than in 1987 or 1982. Many species continued to decline between 1994 and 2004, although some to a lesser extent, suggesting that whatever the causative agent of decline, it continues to operate. This pattern is consistent with the decline of the Rota Bridled White-eye (Fancy and Snetsinger 2001). Generally, declining species showed a reduction both in the number of stations where they were present, and a reduced abundance at these stations. This suggests that declines are linked with both a reduction in density in occupied areas and, ultimately, complete disappearance of species from certain areas.

TABLE 2. Results from generalized linear mixed models testing for long-term trends in the count data of eight terrestrial passerines on Rota, Mariana Islands, between 1982 and 2004. Results shown are: overall change in numbers counted; change in the proportion of stations where the species was recorded; and change in abundance at a station, given presence. An asterisk denotes models where season was significant; for these models, results are presented after controlling for the seasonal effect (i.e., a type III analysis), and percentage changes are presented for the spring season calculated from the modeled trends between 1982 and 2004. Species are ordered according to descending level of overall decline in numbers counted.

	df	F	P	Percent change
Total abundance				
Mariana Crow*	1, 64	58.8	< 0.001	–93%
Micronesian Honeyeater	1, 71	80.8	< 0.001	–72%
Mariana Fruit-Dove*	1, 65	71.3	< 0.001	–70%
Rufous Fantail	1, 66	108.6	< 0.001	–66%
Philippine Turtle-Dove	1, 64	17.9	< 0.001	–60%
Collared Kingfisher	1, 66	28.9	< 0.001	–34%
Black Drongo	1, 64	5.7	< 0.01	–34%
Micronesian Starling*	1, 63	15.5	< 0.002	+57%
Proportion of stations present				
Mariana Crow*	1, 79	110.8	< 0.001	–91%
Micronesian Honeyeater*	1, 79	97.2	< 0.001	–29%
Mariana Fruit-Dove*	1, 79	72.2	< 0.001	–26%
Rufous Fantail	1, 80	90.7	< 0.001	–43%
Philippine Turtle-Dove*	1, 79	14.6	< 0.001	–40%
Collared Kingfisher*	1, 79	3.2	0.07	–6%
Black Drongo*	1, 79	18.1	< 0.001	–20%
Micronesian Starling*	1, 79	48.3	< 0.001	+14%
Abundance given presence				
Mariana Crow	1, 57	65.9	< 0.001	–44%
Micronesian Honeyeater*[a]	1, 63	94.2	< 0.001	–67%
Mariana Fruit-Dove	1, 66	114.9	< 0.001	–22%
Rufous Fantail	1, 68	49.3	< 0.001	–43%
Philippine Turtle-Dove	1, 59	13.5	< 0.001	–24%
Collared Kingfisher	1, 67	22.9	< 0.001	–24%
Black Drongo	1, 68	0.2	0.64	–5%
Micronesian Starling*	1, 63	6.1	0.02	+5%

[a] Results given are from a generalized linear model with transect fitted as a fixed effect, because the mixed model failed to converge.

Buden (2000) examined changes in bird numbers between 1983 and 1994 on the Micronesian island of Pohnpei, and found that the encounter rates of many of the more common species of land birds had declined by at least 50%. His study included two of the same species analyzed here; Micronesian Honeyeaters declined on Pohnpei in upland and lowland areas by 74% and 68%, respectively. However, in contrast to our study, Micronesian Starlings on Pohnpei also declined in upland and lowland areas by 64% and 71%, respectively. In contrast, bird counts conducted between 1992 and 2004 on the island of Saipan (120 km north of Rota) reveal that no species (except the endangered Nightingale Reed-Warbler [*Acrocephalus luscinia*]) declined, and many increased (Commonwealth of the Northern Mariana Islands–Division of Fish and Wildlife,

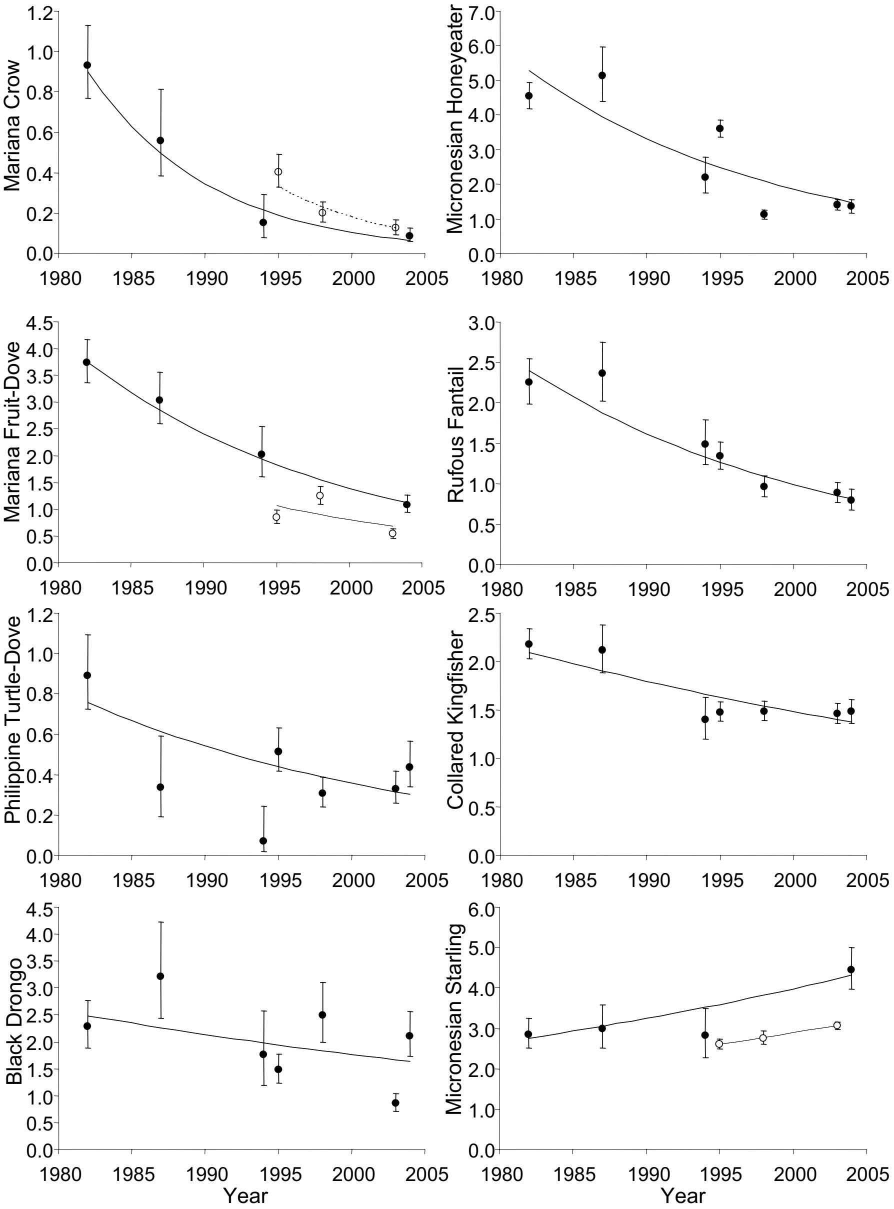

FIGURE 2. Graphical summary from eight generalized linear mixed models showing a declining population trend for all species except the Micronesian Starling on Rota, Mariana Islands, 1982–2004. Lines are drawn from the parameter estimates generated from the first model (Table 3), including year and, where significant, the effect of season in the model. Circles and error bars are the means ± SE calculated from the same models, but specifying year as a categorical effect. Solid lines and solid circles show the trend or means for spring surveys and dashed lines and unfilled circles show the data for autumn surveys, for species for which season was found to be significant. Note different *y* axis scales.

unpubl. data, 1992–2004). This suggests little support for the hypothesis that large-scale climatic changes, e.g., in rainfall or temperature, are responsible for the declines on Rota.

Numerous alternative hypotheses have been proposed for the cause of the Mariana Crow and Rota Bridled White-eye population declines (Craig and Taisacan 1994, Craig 1999, Fancy and Snetsinger 2001, U.S. Fish and Wildlife Service 2004, Plentovich et al. 2005). Declines of many species have been linked with destruction of preferred habitats, especially those of globally threatened bird species (Birdlife International 2004). Our analysis of habitat-abundance relationships suggests that loss of forest on Rota is unlikely to fully explain observed declines, since some declining species were found in higher abundance in open habitats. If simple loss of forest were the cause, we would expect species such as Micronesian Honeyeaters, Black Drongos, and Collared Kingfishers,

TABLE 3. Average number of individuals (mean ± SE) of eight terrestrial bird species counted per station located in forested or open habitats on Rota, Mariana Islands, in 2003. An asterisk identifies species whose abundance was significantly different between open and forested habitats. Test statistics are the results from a generalized linear model. Species are ordered according to descending level of overall decline in numbers counted.

Species	Forested	Open	$F_{1,307}$	P
Mariana Crow	0.14 ± 0.03	0.14 ± 0.04	0.0	0.83
Micronesian Honeyeater*	1.27 ± 0.08	2.01 ± 0.15	18.6	< 0.001
Mariana Fruit-Dove*	0.61 ± 0.06	0.40 ± 0.06	5.3	0.02
Rufous Fantail*	1.07 ± 0.07	0.49 ± 0.09	23.2	< 0.001
Philippine Turtle-Dove	0.37 ± 0.06	0.42 ± 0.07	0.4	0.54
Collared Kingfisher*	1.31 ± 0.07	1.74 ± 0.13	7.8	0.005
Black Drongo*	0.52 ± 0.08	2.31 ± 0.23	96.3	< 0.001
Micronesian Starling	3.01 ± 0.14	2.79 ± 0.20	0.8	0.38

which are associated with open habitats, to have increased in number.

We are unable to attribute the declines to an alteration of a specific food source (e.g., fruits, nectar, or insects), because the declining species belong to different trophic guilds. For example, Rufous Fantails are primarily arboreal insectivores, whereas Micronesian Honeyeaters are arboreal omnivores, and Mariana Fruit-Doves are herbivores (Fritts and Rodda 1998).

A further possibility, especially with respect to the timing of the declines, is the aerial spraying of the insecticide Malathion on Rota in 1988 and 1989 (Engbring 1989). Although roadside counts conducted shortly before and after the spraying did not show a change in avian abundance (Engbring 1989), the possibility exists that the effects may have been delayed. However, this hypothesis has difficulty explaining why Micronesian Starlings did not also show a decline. Interestingly, the Lāna'i 'Amakihi (*Hemignathus virens wilsoni*), a honeycreeper endemic to the Hawaiian island of Lāna'i, went extinct at the time that Malathion spraying occurred during the 1970s (Cox 1991).

To elucidate the possible cause of the declines on Rota, it may be beneficial to focus our attention on how the ecology of the Micronesian Starling, the one species in our study that did not decline, differs from the other species. One difference is the type of nest site used. Micronesian Starlings nest in cavities in trees and cliffs, as does the Collared Kingfisher (Jenkins 1983, Beckon 1986). Although the Collared Kingfisher declined, its overall decline was comparatively small (34%), and its probability of occurrence at a station did not change significantly (6% decline). Furthermore, its numbers appear to have remained very stable over the last 10 years. The nesting habits of these two species contrast with all other species in this study, which are open-cup nesters. Cavity-nesting birds often show higher nesting success than open-cup nesters and this is usually attributable to higher rates of predation experienced by open-cup nesters (Oniki 1979). Therefore, a plausible explanation for the observed declines is that the effect of nest predation has increased on Rota. If this were the case, we might also speculate that the predator involved is too large to enter the nest holes of Micronesian Starlings.

The avifauna on neighboring Guam collapsed following the introduction of the brown tree snake, with most species of land bird either extirpated or reduced to very low numbers (Savidge 1987, Wiles et al. 2003). However, there has never been a confirmed sighting of a live brown tree snake on Rota (N. Hawley, Commonwealth of the Northern Mariana Islands–Division of Fish and Wildlife, pers. comm.). There are other reasons why we believe that the declines on Rota are not snake-induced. First, there does not appear to have been any geographical pattern to the declines, unlike on Guam, where declines and localized extinctions spread from south to north, presumably as the snake population spread northward (Wiles et al. 2003). Second, the least affected species on Guam are the most affected on Rota. For example, the Mariana Crow showed one of the longest levels of persistence following snake establishment on Guam, whereas on Rota, the crow has suffered the greatest decline among the species considered here (–94%). Furthermore, brown tree snakes on Guam substantially reduced the Micronesian Starling population, whereas on Rota, this species has increased in abundance. Finally, although no data exist to look at population change, in 2003–2004, we observed a very high density of skinks (*Emoia* spp.) and we trapped a high number of rats (probably *Rattus tanezumi*; Morton et al. 1999) in forests on Rota; if snakes were well established on Rota, numbers of these prey species would be low.

Ectoparasites might cause declines. Observations of Mariana Crow juveniles suggest that they suffer badly from feather lice (unknown species), and observations of adult Mariana Crows with areas of feathers missing are consistent with feather mites being potentially detrimental ecotoparasites, at least in this species (AA, pers. obs.). Perhaps cavity-nesters are less prone to these parasites, e.g., by using nesting material high in volatile chemicals (Petit et al. 2002); further work on this issue is therefore warranted. The role of disease also cannot be ruled out.

Although this study shows that many avian species are declining on Rota, the two endangered endemics still remain the primary concern for bird conservation on the island. Ninety percent of the Rota Bridled White-eye population is confined to an area of only about 259 ha around the upper plateau of the island (Fancy and Snetsinger 2001). The Mariana Crow population has dropped approximately 27% from an estimated 117 pairs in the late 1990s (Plentovich et al. 2005), to around 85 pairs today.

The Mariana Crow and the Rota Bridled White-eye are particularly difficult species to study; therefore, the sample size for any study examining the cause of their declines will be small. However, we believe that the causative agents responsible for the declines of these endemics may also be affecting other species on Rota. This suggests the potential to study the limiting factors of other, more common species, such as the Rufous Fantail, rather than attempting to work directly with the now very rare crow or white-eye. Comparative research on the Micronesian Starling, which has not declined, and contrasting the findings from these species could therefore be illuminating in the search for causative factors of the avifaunal decline on Rota.

ACKNOWLEDGMENTS

We are grateful to all the people that took part in these surveys, including Celestino Aguon, Philip Ashman, John Engbring, Phil Glass, Dan Grout, Shelly Kremer, Jaan Lepson, Michael Lusk, John Morton, Sheldon Plentovich, Peter Pyle, Jim Reichel, Thomas Snetsinger, Estanislao Taisacan, Stan Villagomez, and Gary Wiles. We thank Shelly Kremer for organizing the data related to Saipan bird trends. We are particularly grateful to Dave Elston for his statistical advice and to Linzi Seivwright, Mick Marquiss, Gordon Rodda, Thalia Sachtleben, and Steven Fancy for their helpful comments on this manuscript.

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