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## Surveys

# Current Land Bird Distribution and Trends in Population Abundance Between 1982 and 2012 on Rota, Mariana Islands

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## Abstract

The western Pacific island of Rota is the fourth largest human-inhabited island in the Mariana archipelago and designated an Endemic Bird Area. Between 1982 and 2012, 12 point-transect distance-sampling surveys were conducted to assess bird population status. Surveys did not consistently sample the entire island; thus, we used a ratio estimator to estimate bird abundances in strata not sampled during every survey. Trends in population size were reliably estimated for 11 of 13 bird species, and 7 species declined over the 30-y time series, including the island collared-dove *Streptopelia bitorquata*, white-throated ground-dove *Gallicolumba xanthonura*, Mariana fruit-dove *Ptilinopus roseicapilla*, collared kingfisher *Todiramphus chloris orii*, Micronesian myzomela *Myzomela rubratra*, black drongo *Dicrurus macrocercus*, and Mariana crow *Corvus kubaryi*. The endangered Mariana crow ( $\bar{x}$  = 81 birds, 95% CI 30–202) declined sharply to fewer than 200 individuals in 2012, down from 1,491 birds in 1982 (95% CI = 815–3,115). Trends increased for white tern *Gygis alba*, rufous fantail *Rhipidura rufifrons mariae*, and Micronesian starling *Aplonis opaca*. Numbers of the endangered Rota white-eye *Zosterops rotensis* declined from 1982 to the late 1990s but returned to 1980s levels by 2012, resulting in an overall stable trend. Trends for the yellow bittern *Ixobrychus sinensis* were inconclusive. Eurasian tree sparrow *Passer montanus* trends were not assessed; however, their numbers in 1982 and 2012 were similar. Occupancy models of the 2012 survey data revealed general patterns of land cover use and detectability among 12 species that could be reliably modeled. Occupancy was not assessed for the Eurasian tree sparrow because of insufficient detections. Based on the 2012 survey, bird distribution and abundance across Rota revealed three general patterns: 1) range restriction, including Mariana crow, Rota white-eye, and Eurasian tree sparrow; 2) widespread distribution, low abundance, including collared kingfisher, island collared-dove, white-throated ground-dove, Mariana fruit-dove, white tern, yellow bittern, black drongo, and Micronesian myzomela; and 3) widespread distribution, high abundance, including rufous fantail and Micronesian starling. The Mariana crow was dispersed around the periphery of the island in steep forested land-cover types. In contrast, the Rota white-eye was restricted to the high-elevation mesa. Only for the white-throated ground-dove was there a significant difference among cover types, with lower occupancy in open field than in forested areas. Vegetation was included in the best-fit occupancy models for yellow bittern, black drongo, Micronesian myzomela, and Micronesian starling, but vegetation type was not a significant variable nor included in the top models for the remaining five species: white tern, island collared-dove, Mariana fruit-dove, collared kingfisher, and rufous fantail. Given declining population trends, the Rota



bird-monitoring program could benefit from establishing threshold and alert limits and identifying alternative research and management actions. Continued monitoring and demographic sampling, in conjunction with ecological studies, are needed to understand why most bird species on Rota are declining, identify the causative agents, and assess effectiveness of conservation actions, especially for the Mariana crow.

**Keywords:** abundance; bird monitoring; Mariana Islands; occupancy; Rota; trend

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## Introduction

Island birds, especially in the Pacific, are among the world's most endangered species (King 1985). Between 13% and 14% of the world's avian species are considered threatened, with approximately 30% of these occurring in Oceania, where 34% of the world's extinct avian species once existed (International Union for the Conservation of Nature [IUCN] 2013). Accurate and timely population estimates and trend assessment are essential to the conservation and management of the remaining species.

The island of Rota, located in the Mariana Archipelago in the western Pacific, is designated as an Endemic Bird Area by BirdLife International (Stattersfield et al. 1998). Rota harbors a unique and imperiled assemblage of native land birds, many of which are endemic to either the Mariana Archipelago or Rota itself. Most of these species have international, national, or local conservation designations (Table 1), with six species protected under the U.S. Migratory Bird Treaty Act and two listed as Birds of Conservation Concern (U.S. Fish and Wildlife Service [USFWS] 2008, 2012). Rota has great conservation significance as the last home of the Mariana crow *Corvus kubaryi* and the only home of Rota white-eye *Zosterops rotensis*. Both species are protected under the U.S. Endangered Species Act (ESA 1973, as amended; USFWS 2005, 2007) and designated as critically endangered by the IUCN (2013). The island also harbors two endemic subspecies—the Rota populations of the collared kingfisher *Todiramphus chloris orii* and rufous fantail *Rhipidura rufifrons mariae*; the latter is a Species of Concern under the Commonwealth of the Northern Mariana Island's Comprehensive Wildlife Conservation Strategy (Berger et al. 2005). Throughout, taxonomic order follows Gill and Donsker (2015).

Twelve large-scale surveys of bird populations have been conducted on Rota between 1982 and 2012 using point-transect techniques. Estimates of population den-

sity for all endemic and nonendemic forest birds were calculated only for the 1982 survey (Engbring et al. 1986), though density estimates for the Mariana crow were estimated through the 1998 survey (Fancy et al. 1999; Plentovich et al. 2005). A 2008 analysis of all the forest bird data using detections per station as an index of relative abundance indicated large-scale declines in many of the forest bird species (Amar et al. 2008). However, these analyses used the single-visit point-transect distance-sampling data without accounting for detectability (i.e., the probability of detecting an object; Buckland et al. 2001), and estimates of population size were not calculated. Although changes in the number of birds counted across years are often assumed to be a close surrogate for changes in true abundance, detection probabilities can change across years, making such trend analysis questionable (Thompson et al. 1998; Anderson 2001). The point-transect distance-sampling method used in the 12 surveys provided the information needed to calculate detection probabilities and convert the indices to estimates of absolute population abundance (Buckland et al. 2001).

In this study, we used standard distance analysis (Thomas et al. 2010) of all previously collected land-bird survey data to estimate absolute population abundances and subsequently assess status and trends for each species. These assessments, which are analogous to recent estimates for bird populations on the neighboring islands of Aguiguan, Saipan, and Tinian (Camp et al. 2009, 2012; Amidon et al. 2014), were used to compare bird population patterns at the landscape level throughout the main islands of the archipelago, as required for monitoring the status of each species (USFWS 2005, 2007). Evaluating population trends of forest birds on Rota is also a priority under the Commonwealth of the Northern Mariana Island's Comprehensive Wildlife Conservation Strategy (Berger et al. 2005). We also utilized occupancy modeling of the 2012 survey data to evaluate bird distributions in relation to land cover characteristics





**Table 1.** List of resident native forest birds of Rota (Mariana Islands, 2012) that have conservation designations with their distributions, and designated conservation status.

Taxon	Distribution	Conservation designations <sup>a</sup>
White-throated ground-dove <i>Gallicolumba xanthonura</i>	Mariana endemic	MBTA; IUCN (NT); CNMI CWCS
Mariana fruit-dove <i>Ptilinopus roseicapilla</i>	Mariana endemic	MBTA; IUCN (EN); CNMI CWCS
Collared kingfisher <i>Todiramphus chloris orii</i>	Mariana endemic	MBTA
Micronesian myzomela <i>Myzomela rubratra</i>	Widespread in Micronesia	MBTA/BCC
Rufous fantail <i>Rhipidura rufifrons mariae</i>	Rota endemic	MBTA/BCC; CNMI CWCS
Mariana crow <i>Corvus kubaryi</i>	Guam and Rota endemic	MBTA; ESA (EN); IUCN (CR); CNMI CWCS
Rota white-eye <i>Zosterops rotensis</i>	Rota endemic	ESA (EN); IUCN (CR); CNMI CWCS

<sup>a</sup> Organizations and Legislation: MBTA = Migratory Bird Treaty Act; IUCN = International Union for Conservation of Nature; ESA = Endangered Species Act; BCC = Birds of Conservation Concern; CNMI CWCS = Commonwealth of the Northern Mariana Islands Comprehensive Wildlife Conservation Strategy. (Designations): NT = near threatened; EN = endangered; CR = critically endangered.

(MacKenzie et al. 2002, 2006) to help managers understand the relevance of land use practices and develop conservation strategies.

## Methods

### Study area

Rota (14°10'N, 145°12'E), at 85 km<sup>2</sup>, is the fourth largest of the 15 isles in the Mariana archipelago (Figure 1). The climate is tropical with little seasonal temperature variability (annual average = 28°C, range = 22–32°C; National Weather Service 2014); however, rainfall is seasonal, with a dry period from December to June and a wet period from July to November (annually 2,200–3,000 mm rainfall; National Weather Service 2014). An uplifted mesa (Sabana; 450 m elevation) dominates the western half of the island, which is surrounded by a plateau that ranges from sea level to the base of the mesa at approximately 200 m elevation. Most of the >2,500 humans inhabiting the island live in the villages of Songsong, on the Taipingot Peninsula that juts to the southwest of the island, or Sinapalo on the plateau (U.S. Census Bureau 2010). Agriculture and other human activities occur throughout the island in a patchwork of open fields and residential land-cover types, while the steep slopes around the mesa are dominated by native forests and secondary forests in former agricultural areas (Figure 2).

### Bird sampling

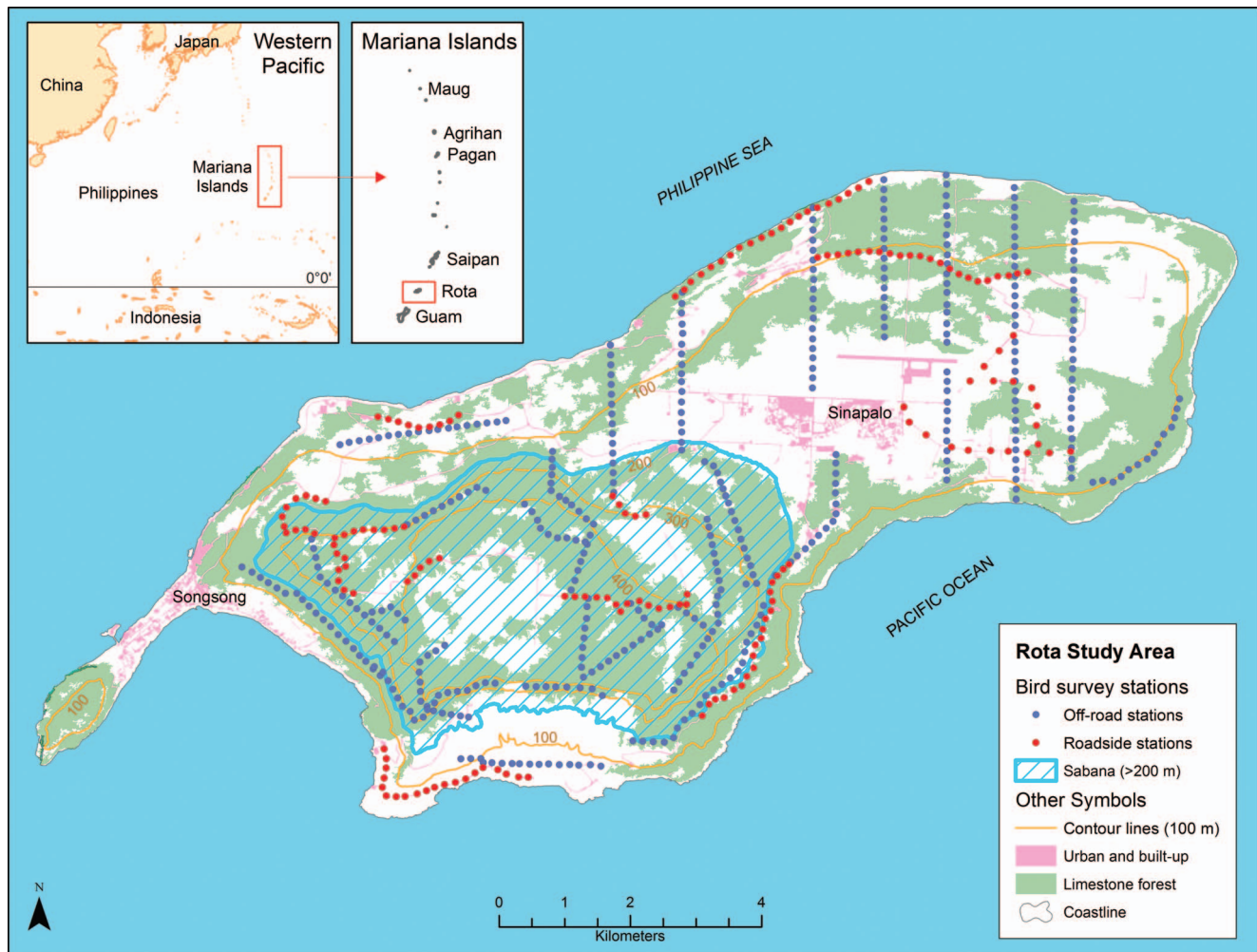
Avian surveys were conducted on Rota in 1982, 1987, 1988, 1989, 1994, 1995, 1998, 2003, 2004, 2006, and 2012. Surveys were conducted along roads (1988 and 1989), off-road (1982, 1987, 1994, 1995, 1998, 2003, 2004, and 2006) or both (2012). Sampling month varied among surveys (Table 2). In 1988, surveys were conducted in both August and December. All stations above 200 m elevation on the uplifted mesa were assigned to the Sabana region, while all stations below 200 m elevation were designated to the Plateau region, including those stations just below the 200-m elevation north, east, and south of the mesa (Figure 1). Surveys were conducted in the Sabana region (1987, 1994, and 2006), in the Plateau region excluding the Sabana (2004), or in both areas

(1982, 1995, 1998, 2003, and 2012). The 2004 Plateau survey was limited in scope compared with other Plateau surveys. Survey stations in 2012 were sampled repeatedly (median = 6 counts, max. = 12 counts), which was a sampling requirement necessary to conduct occupancy analyses.

All surveys followed standard point-transect sampling methods (also termed variable circular-plot sampling; see Buckland et al. 2001 for details), and analyses followed general procedures outlined in Buckland et al. (2001) and Thomas et al. (2010), and further detailed in Camp et al. (2009, 2012). Surveys were conducted on a varying number of transects and stations (Table 2; Figure 3). During 8-min counts, observers estimated and recorded the horizontal distances to birds heard or seen. Observers also recorded sampling conditions including cloud cover, detection type (heard, seen, or both), visibility (openness of understory), land cover type, rain, time of detection, and wind and gust strength (Table S1, *Supplemental Material*). Counts commenced at sunrise and continued until as late as 1330 hours, but most surveys were completed by 1130 hours. Counts were halted when rain, wind, or gusts exceeded prescribed levels (light rain, wind strength 3 on the Beaufort scale, or gust strength 5 on the Beaufort scale).

### Abundance

Detection functions were modeled using the Program Distance, version 6.0, release 2 (Thomas et al. 2010). This was done only for species with a sufficient number of detections (>100 detections over the 12 surveys; excluding red junglefowl *Gallus gallus*, Pacific golden-plover *Pluvialis fulva*, and brown noddies *Anous stolidus*; Buckland et al. 2001). Sampling effort by station was set to the number of counts per survey. Data were right-truncated at a distance where the species-specific probability of detecting a bird was approximately 10% to facilitate model fitting (Buckland et al. 2001). Candidate-detection function models were limited to half-normal and hazard-rate, with expansion series of order two (Buckland et al. 2001). Sampling conditions, along with observer and year, were modeled as covariates in the multiple-covariate engine of distance (Marques et al. 2007; Thomas et al. 2010). All covariates



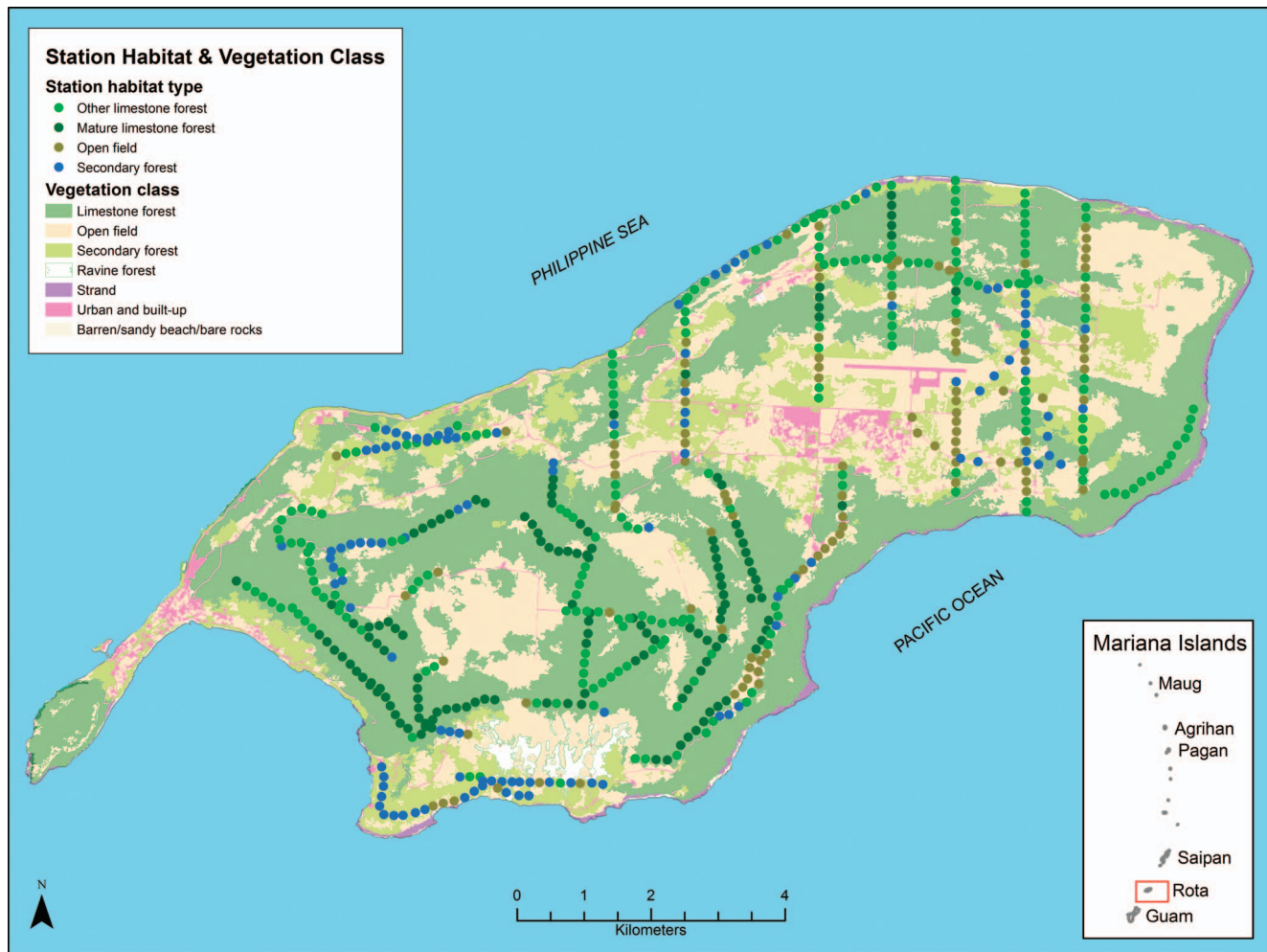
**Figure 1.** Off-road (blue dots) and roadside (red dots) avian sampling stations on Rota, Mariana Islands, between 1982 and 2012. The Sabana region is outlined in light blue with diagonal hash lines, while the Plateau is the remaining portion of the island below 200 m. Urban, built-up, and roads (pink); limestone forest (green); and contour lines (100 m; goldenrod) are provided.

were treated as factors, except that time of detection was treated as a continuous variable and year was treated as both a continuous and discrete factor. We also tested for a difference in detection probabilities above and below the 200-m contour, which is the elevation that roughly separates the Sabana area from the low-elevation Plateau. The model with the lowest second-order Akaike's information criterion (AIC), corrected for small sample size ( $AIC_c$ ), was used to select the detection function that best approximated the data (Burnham and Anderson 2002). Model selection results for each species are presented in Table S2 (*Supplemental Material*).

We tested for differences in detection probabilities and densities between roadside and off-road counts in the 2012 survey, the only year where both count types were conducted. We used  $AIC_c$  to determine whether the fit of the base model was improved by including a covariate for count type and a two-sample z-test for differences in densities by count type (Buckland et al. 2001). Preliminary analyses revealed that detection probabilities were different for white tern *Gygis alba*,

collared kingfisher *Todiramphus chloris orii*, Micronesian starling *Aplonis opaca*, and Eurasian tree sparrow *Passer montanus*, and that densities were different for all species except Eurasian tree sparrow. Thus, we did not directly compare estimates for the roadside-only surveys (August and December 1988, August 1989, and 2012 roadside counts) with the off-road surveys.

We used the best approximating species-specific global detection function model to estimate region-specific population densities using the poststratification procedure, and variances and confidence intervals were derived by bootstrap methods in distance from 999 iterations (Figure S1, *Supplemental Material*; Thomas et al. 2010). We estimated abundance by multiplying density by region area, where the area of the Sabana region was 2,537.2 ha and the area of the Plateau region was 5,973.4 ha. Rota white-eye occurred only in the Sabana region, but did not inhabit all cover types within that region. Therefore, the area of suitable land cover for Rota white-eye was set at 2,143.3 ha. For each bootstrap iteration, we summed region-specific abundances to create the



**Figure 2.** Land cover and vegetation characteristics at avian sampling stations on Rota, Mariana Islands, between 1982 and 2012. Vegetation types at sampling stations are other limestone forest (light green), mature limestone forest (dark green), open field (olive), and secondary forest (blue). Sampling stations are overlaid on the vegetation classes limestone forest (dark green); open field (tan); secondary forest (light green); ravine forest (white); strand (purple); urban, built-up, and roads (pink); and barren soils, sandy beach, and bare rocks (beige).

island-wide abundance, and we calculated the regional and island-wide population confidence intervals (95% CI) as the 2.5 and 97.5 percentiles.

Most Rota surveys were conducted in both the Plateau and Sabana regions. However, some surveys were restricted to just one region. If data were analyzed using conventional methods, the sampling frame would be defined by the spatial concurrency of the surveys that would restrict inference to either the Plateau or Sabana regions. Alternatively, samples from the surveyed region could be used to provide inference to the entire island-wide sampling frame (Thompson 2002). The former approach does not utilize all of the data, whereas the latter approach relies on assumptions that may not be realistic. Instead we used a linear regression estimator (Neter et al. 1996; Skalski et al. 2005) to predict abundance on the Plateau during the years it was not surveyed (1987, 1994, and 2006) based on abundances of the 5 y when both regions were surveyed (1982, 1995, 1998, 2003, and 2012). We did not estimate Sabana

abundance in 2004 because of logistical constraints (there was limited survey effort in that year). The regression estimates were fitted using a series of 999 bootstrap estimates (as described below in Trend Assessment), so the 95% credible intervals reported in Table S7, *Supplemental Material*, include uncertainty in the regression estimator. On average, the relative width of credible intervals using the regression estimator was 37% wider than intervals derived directly from the Distance estimates. We assessed the precision of the island-wide abundances over all surveys in terms of their percentage of the coefficient of variation (% CV): high precision <10%, moderate precision between 10% and 30%, and low precision >30%.

In 1988–1989 only roadside surveys (in both Plateau and Sabana) were conducted. Because bird distribution and behavior may be different along land-cover edges, such as roadsides (Peterjohn et al. 1995), we calculated separate abundance estimates for roadside and off-road transects using the 2012 survey. We then used the ratio



**Table 2.** Timing of avian surveys, number of transects and stations sampled, and number of counts conducted by survey on Rota, Mariana Islands. The range of counts conducted is provided. Surveys were conducted along roads (1988 and 1989), off-road (1982, 1987, 1994, 1995, 1998, 2003, 2004, and 2006), or both (2012). Data are presented for the 2012 off-road and roadside transect survey separately.

Survey	Survey months <sup>a</sup>	Transects sampled	Stations sampled	Counts conducted	Range of counts
1982	3–4	14	254	508	2
1987	4	7	76	182	2–3
1988	8	8	164	368	2–4
1988	12	8	164	460	2–6
1989	8	8	164	369	2–3
1994	5–6	12	161	299	1–4
1995	10–11	17	311	326	1–2
1998	10	17	314	314	1
2003	10–12	16	291	291	1
2004	4	3	47	47	1
2006	11	7	74	74	1
2012	4	37	568	1,108	1–8
2012 off-road		29	404	937	1–8
2012 roadside		8	164	171	1–2

<sup>a</sup> Numbers represent calendar months during which surveys were carried out (e.g., “3–4” represents “March–April”).

of these two abundances from 2012 to calculate adjusted abundance estimates for the roadside surveys in 1988–1989. For the endangered Mariana crow and Rota white-eye, the ratio estimator of abundance from roadside surveys to off-road surveys was highly variable, so for those species we did not use survey results in 1988–1989.

### Trend assessment

We assessed the long-term trend in population abundance for the 13 species by region strata and island-wide. We used a series of 999 bootstrap estimates generated in Program Distance by resampling within each survey area. For each bootstrap iteration, we estimated regression and ratio estimators as described above to produce adjusted, comparable estimates of abundance for the Plateau in 1987, 1994, and 2006. We used the same procedure to adjust the roadside-only surveys in 1988–1989 (except for the endangered species: Mariana crow and Rota white-eye). The Plateau survey in 2004 was not used for trends analysis. Abnormally low observations of the white tern may have resulted from detections not having been recorded in 1995 and not having been recorded consistently in 2006 (F.A. Amidon, personal communication); therefore, we did not use these 2 y to estimate the white tern trend.

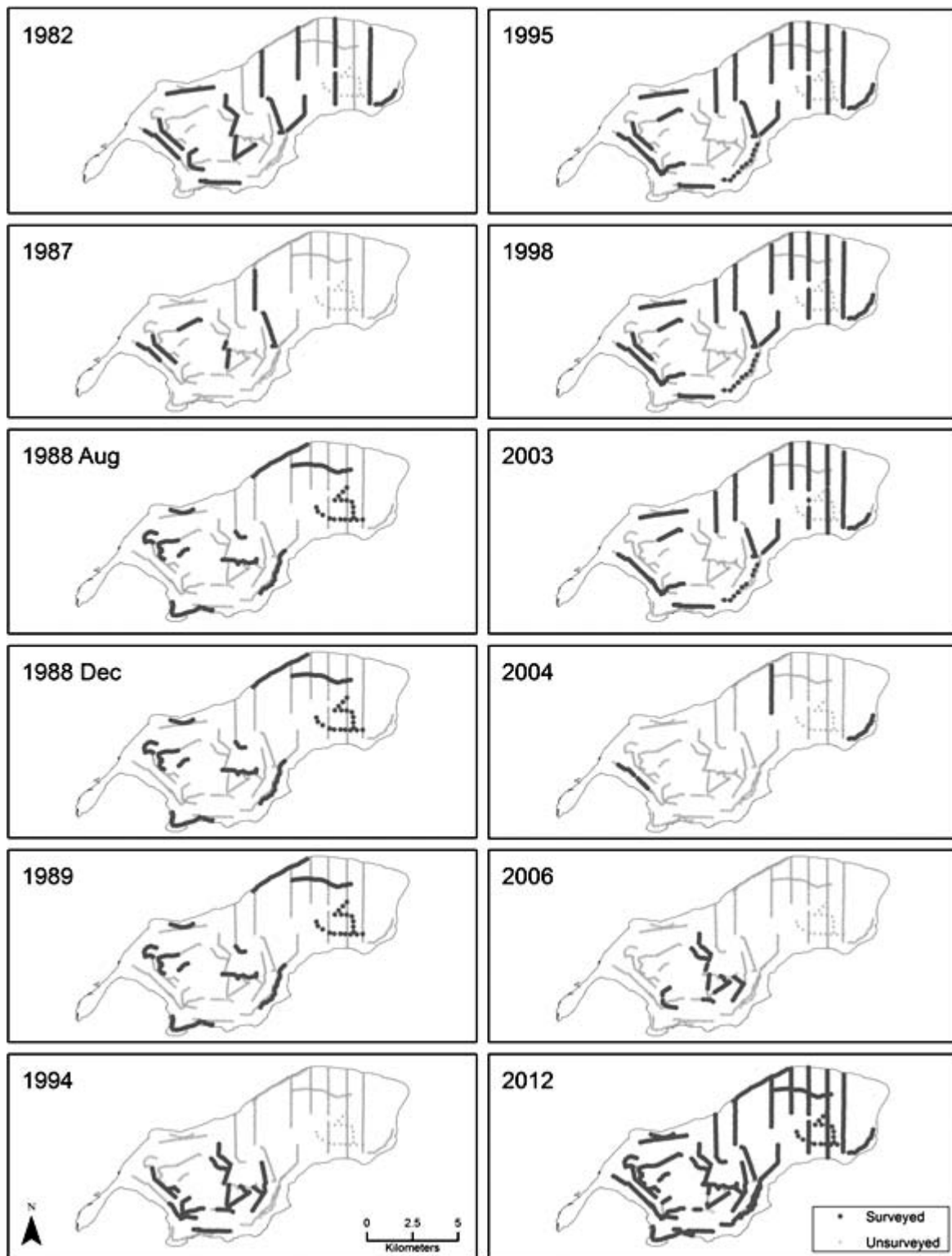
Using these adjustments, we created a series of 999 population estimates for both the Sabana and Plateau that incorporated the sampling and model-fit variation in the abundance estimates provided by Distance (Manly 2007). For each iteration, we added the Sabana and Plateau estimates together to produce 999 estimates of total abundance. For iterations in which the regression model predicted negative population size in the Plateau (<0.5% of simulation runs), we truncated estimates at zero before calculating the total.

We fitted a log-linear regression to each of the 999 estimates of population size. For years where estimated abundance was 0, we assigned a value of 0.5 before log-transformation. We used the August and December surveys in 1988 as replicate estimates for 1988 (i.e., the regression predictor variable was the year 1988 for both surveys). We predicted annual abundances with the regression model were saved along with regression intercepts and slopes; and means were calculated as the mean of all 999 entries, with 95% confidence intervals bounded by 2.5 and 97.5 percentiles. We performed all data manipulation, estimation, and summarization in Program R (R Core Team 2013).

We differentiated ecologically meaningful trends from negligible or statistically nonsignificant trends within an equivalency testing framework (Camp et al. 2008). We considered a rate of change of 25% over 25 y to be an ecologically meaningful level of change. This definition yielded a declining trend if the log-linear slope was less than  $-0.0119$ , an increasing trend if greater than  $+0.0093$ , and a negligible trend between these values. We described the strength of evidence for a trend based on the distribution of the bootstrap regression slopes as weak, moderate, strong, or very strong. Categories were assigned based on the percentage of bootstrap slopes in each category: weak if <50%; moderate if between 50% and 70%, strong between 70% and 90%, and very strong if  $\geq 90\%$ . We interpreted trends to be inconclusive when there was weak evidence among all three trend categories (i.e., decreasing, negligible, and increasing trends). We concluded that a population was stable given strong or very strong evidence of a negligible trend.

### Occupancy

*Land cover variables.* We incorporated both site and sampling covariates into occupancy modeling of the 2012



**Figure 3.** Distribution of stations surveyed during each of the 12 point-transect forest bird surveys on Rota, Mariana Islands, between 1982 and 2012. Each panel depicts the surveys done in a particular year and month.

survey data (summarized in Table S3, *Supplemental Material*). Site covariates included physical attributes of the survey station that remained constant during the period, including “vegetation” type, “visibility,” and

“elevation.” We derived vegetation cover type from land cover maps and high-resolution satellite imagery (Falanruw et al. 1989; Liu and Fischer 2006). Because a limited number of sites (133 stations) were sampled

repeatedly, we recategorized the original suite of land cover types into four vegetation classes: mature limestone forest, other limestone forest, secondary forest, and open field. Mature limestone forest was classified as native-dominated forest with trees averaging >30 cm diameter at breast height, as per Falanruw et al. (1989). Other limestone forest included all other native-dominated forests on the island, while secondary forest included all forest dominated by introduced species (e.g., *Cocos nucifera*, *Leucaena leucocephala*). Open fields consisted of large forest gaps, agricultural lands, and mowed urban areas. Visibility, a function of vegetation complexity and clutter (or its absence), was represented as an ordinal variable that ranged from 1 (very obstructed) to 5 (very open). Elevation at each count station was derived from digital elevation models and ranged from 13 to 411 m above sea level. Sampling covariates, including “observer” identity, “survey day,” “time” of day (relative to sunrise), “cloud” cover, “rain,” “wind strength,” and “gust strength,” varied temporally during the survey. Eight observers, denoted as factors A through H, participated in the survey. We represented survey day as a continuous variable that ranged from 1 through 12, while we treated cloud cover as a continuous measure ranging from 0 through 100 (in 10% increments). We coded rain, wind, and gust strength as factors, ranging from 0 to 4 for rain and wind, and 0 to 5 for gusts (Table S1).

*Assessing species detection and land cover associations.* We converted counts of birds at each survey station into a matrix of 1s and 0s denoting detection or nondetection, respectively, to produce an encounter history for each sampling event and site. We used detection or nondetection data as a binary response variable in models that quantified species occurrence at sampled sites to characterize the variability in detecting different species. We applied the single-season occupancy model described by MacKenzie et al. (2002, 2006) to determine the relationship of covariates to detection and occupancy processes. Models for each species were developed in Program R with extension package unmarked (Fiske and Chandler 2011). The “occu” function in unmarked was used to fit the single-season occupancy model.

In cases where a widespread species was recorded at all or nearly all stations, site covariates could not readily identify a significant relationship to occupancy. Therefore, we discriminated among areas of high and low “use” for each of these species by examining their respective counts for all sampled sites. We defined high-use as a case where the count at a site exceeded the median value during the entire survey. We coded high-use events as 1, while we coded periods with no detection or counts below the median (i.e., low-use) as 0. Eurasian tree sparrows were detected at only 3 of the 133 stations sampled repeatedly for occupancy estimation; therefore, we developed no occupancy models for this species.

The models consisted of two parameters describing the mechanisms underlying species occurrence. “Occupancy” (designated as  $\psi$ ) is the probability that the species is present at a given survey site (or, in the case of

a high-use threshold, is relatively abundant). “Detection probability” (designated as  $p$ ) is the likelihood that an observer is able to detect a species that is present (or, detect it at relatively high abundance). We modeled these parameters with a logit link to ensure that estimates would be constrained to a 0–1 interval.

Model notation included two forms for each parameter; for example,  $\psi(\bullet)$  represented occupancy as a constant over all sample sites on Rota, and  $\psi(\text{cov})$  denoted occupancy as a function of some covariate(s). Likewise, notations of  $p(\bullet)$  indicated detection probability parameters equal to the overall mean effect across sample sites, and  $p(\text{cov})$  denoted the association of the parameter to one or more covariates. We used a null model,  $\psi(\bullet)p(\bullet)$ , that included only the intercept for each parameter as the basis for comparisons with models with site and sampling covariates. We developed a preliminary set of models separately for each of the two parameters, wherein we modeled one parameter with covariates and treated the other as a constant, i.e.  $\psi(\text{cov})p(\bullet)$  and  $\psi(\bullet)p(\text{cov})$ . We combined covariates to produce 8 site covariate-only models and 51 sampling covariate-only models. Each set also included the null model  $\psi(\bullet)p(\bullet)$ . Occupancy models are denoted in the text and tables by use of an abbreviation of the species’ common name, followed by the model number (e.g., BLDR-58 for black drongo model 58).

Within each set, we used a comparison of AIC values to select the model that provided the best fit to the data. Models were ranked by differences between each candidate model and the model with the lowest value ( $\Delta\text{AIC}$ ); a difference of  $\leq 4$  AIC units indicated a similar fit on the grounds of parsimony (Burnham and Anderson 2002). Candidate models that ranked above the null model and had an AIC weight of  $\geq 0.10$  were included as candidates for the set of final models. Candidate models were not included if one or more of the models with covariates ranked below the null model. These steps limited the number of covariate combinations, and reduced problems associated with overfitting models and Type I errors (Burnham and Anderson 2002). However, the information-theoretic approach to model selection does not rely on model coefficient significance, and given the exploratory objective of modeling the occupancy of Rota bird species, the relatively liberal AIC criteria used in this study could result in models with covariates that have nonsignificant coefficient  $P$ -values. We present model selection results for each species in Table S4 (*Supplemental Material*).

To conduct goodness-of-fit tests, unmarked provides a generic parametric bootstrapping function, “parboot,” that simulates data from the fitted model and applies a user-defined function to return statistics such as the Pearson’s  $\chi^2$  (Fiske and Chandler 2011). We generated goodness-of-fit statistics from 999 parametric bootstraps, and models where a  $\chi^2 P > 0.05$  indicated an adequate model fit (MacKenzie and Bailey 2004). We present occupancy estimates, detection probabilities, and interpretive results for the top-ranked models with adequate fit. We parameterized categorical variables against a mean of no effect (similar to forcing a linear

regression to go through zero to interpret only the effect of the predictor variable) to produce separate coefficients for each factor level to permit a more direct interpretation of factor-level effects. We produced parameter estimates for the final models from linear combinations of covariate values using the “predict” function in the unmarked package. Estimates of model coefficients for each species are presented in Table S5, *Supplemental Material*. Parameter values of 1 indicate occupancy at all sample sites and complete detectability at each survey point count.

## Results

Thirty-one species were detected on the 12 forest bird surveys between 1982 and 2012 (Table 3). Most species were detected at only a few stations and in low numbers during individual surveys (Table S6, *Supplemental Material*). Generally the index of relative bird occurrence at off-road stations was lower than the index of occurrence at roadside stations, but the indices seldom varied by >10% (Table S6). When indices differed by >10% (range = 16–52%), the indices for off-road stations were lower, as observed for the collared kingfisher, Mariana fruit-dove, white tern, rufous fantail, black drongo, Micronesian myzomela, and Micronesian starling. Indices of relative abundance were usually <0.5 birds/station at off-road and roadside stations (Table S6). When the abundance indices differed, values for roadside stations were 1.3–3 times greater than those for off-road stations. The only exception was for the Rota white-eye, whose relative abundance index was 3 times greater at off-road stations compared with roadside stations. Four species—the Abbott’s booby *Papadula abbotti* (one individual of this Indian Ocean–breeding species was observed several times on Rota between 2007 and 2012; Pratt et al. 2009), red-footed booby *Sula sula*, brown booby *Sula leucogaster*, and Guam rail *Gallirallus owstoni*—were observed only at off-road stations, and the rock dove *Columba livia* was observed only at roadside stations.

There were sufficient numbers of detections to reliably model detection functions and estimate abundances for 13 species, allowing us to plot bird density per station from the 2012 survey. Maps of bird distribution and abundance across the island revealed three general patterns: 1) range restriction, including Mariana crow, Rota white-eye, and Eurasian tree sparrow; 2) widespread distribution, low abundance, including collared kingfisher, island collared-dove, white-throated ground-dove, Mariana fruit-dove, white tern, yellow bittern, black drongo, and Micronesian myzomela; and 3) widespread distribution, high abundance, including rufous fantail and Micronesian starling (Table 4; Figure 4).

## Species accounts

Here we describe the abundance and 30-y trend for 13 species; from the 2012 survey data, we describe the occupancy, detection probability, and distribution. We compared results for the Plateau and Sabana regions separately and for the island overall. We also evaluated the status and distribution of species in relationship to

site (e.g., land cover types [“vegetation”]) and sample (e.g., “cloud cover”) covariates.

**Yellow bittern.** The yellow bittern occurred throughout Rota and was uncommon in 1982, with between 236 and 1,638 birds (95% CI,  $\bar{x}$  = 744) and, although its abundances fluctuated widely, it was estimated at 514–2,132 individuals in 2012 (95% CI,  $\bar{x}$  = 1,100; Table S7, *Supplemental Material*). The island-wide bittern abundances over all surveys were estimated with low precision ( $\bar{x}$  = 47.0% CV; range = 37.5–59.8). There was moderate evidence that the bittern population was stable in the Plateau, with weak evidence for both declining and increasing trend. The trend in the Sabana region indicated very strong evidence of a decreasing population, with weak evidence of either a stable or increasing trend. The overall pattern for the island was inconclusive (Table 5; Figure 5).

In 2012, the yellow bittern was detected during 59 of the 666 total point counts and at 35 of the 133 stations sampled repeatedly for occupancy estimation. The null model (YEBI-0) produced an expected detection probability of between 0.17 and 0.32 (95% CI,  $\bar{x}$  = 0.24; Table S8, *Supplemental Material*), and the expected occupancy probability ranged from 0.25 to 0.49 (95% CI,  $\bar{x}$  = 0.36; Table S9, *Supplemental Material*). The three top-ranked models for the species had a cumulative weight of 0.91, although the best model had an AIC weight of only 0.39 (Table S4). All models included the sampling covariates “time” and “cloud,” which demonstrated that detection probability declined as a function of time of day (i.e., minutes since sunrise) and was lower in cloudless compared with cloudy conditions. All models also included the site covariate “vegetation,” although wide confidence intervals precluded any conclusions about differences in occupancy among vegetation types (Figure S2, *Supplemental Material*; Table S5). Model YEBI-59 included the covariate “elevation,” and although the variable was not significant, the association suggested that occupancy declines at higher elevations. Model YEBI-60 included the covariate “visibility”; however, none of the factor levels were significant.

**White tern.** The white tern was common throughout Rota in 1982, with an abundance between 2,805 and 10,115 birds (95% CI,  $\bar{x}$  = 6,056) that had increased by 2012 to 4,763–16,880 individuals (95% CI,  $\bar{x}$  = 9,744; Table S7). The island-wide white tern abundances over all surveys were estimated with low precision ( $\bar{x}$  = 32.4% CV; range = 30.3–34.7). White terns were not consistently recorded during the 1995 and 2006 surveys; thus, these surveys were dropped from the trend analyses. There was very strong evidence that the tern population increased in the Plateau and Sabana regions, with weak evidence of a stable trend in the Sabana. The overall pattern for the island showed very strong evidence of an increasing trend, with no evidence of either a stable or decreasing trend (Table 5; Figure 6).

In 2012, the white tern was detected during 204 of the 666 total point counts and at 95 of the 133 stations sampled repeatedly for occupancy estimation. The null model (WHTE-0) produced an expected detection probability of between 0.35 and 0.44 (95% CI,  $\bar{x}$  = 0.39;



**Table 3.** Species detected during 12 avian surveys on Rota, Mariana Islands, between 1982 and 2012. Species alpha-code (four-character abbreviation), common and scientific names are provided and listed in taxonomic order following Gill and Donsker (2015). For the 2012 bird detections, land cover types in which the species were detected were assigned to the following four vegetation classes: mature limestone forest (MLI), other limestone forest (LI), secondary forest (SF), and open field (OF); with “—” indicating species not observed in 2012.

Alpha-code	Species name	Scientific name	Land cover
REJU	red junglefowl	<i>Gallus gallus</i>	MLI, LI, SF, OF
RTTR	red-tailed tropicbird	<i>Phaethon rubricauda</i>	LI
WTTR	white-tailed tropicbird	<i>Phaethon lepturus</i>	LI
YEBI	yellow bittern	<i>Ixobrychus sinensis</i>	MLI, LI, SF, OF
INEG	intermediate egret	<i>Egretta intermedia</i>	—
PARH	Pacific reef-egret	<i>Egretta sacra</i>	LI
GRFR	great frigatebird	<i>Fregata minor</i>	—
ABBO	Abbott's booby	<i>Papasula abbotti</i>	LI
RFBO	red-footed booby	<i>Sula sula</i>	LI
BRBO	brown booby	<i>Sula leucogaster</i>	OF
GURA	Guam rail	<i>Gallirallus owstoni</i>	LI, OF
PAGP	Pacific golden-plover	<i>Pluvialis fulva</i>	LI, SF, OF
WHIM	whimbrel	<i>Numenius phaeopus</i>	—
WATA	wandering tattler	<i>Tringa incana</i>	—
RUTU	ruddy turnstone	<i>Arenaria interpres</i>	—
BRNO	brown noddy	<i>Anous stolidus</i>	MLI, LI, SF, OF
BLNO	black noddy	<i>Anous minutus</i>	MLI, LI, SF, OF
WHTE	white tern	<i>Gygis alba</i>	MLI, LI, SF, OF
RODO	rock dove	<i>Columba livia</i>	—
ISCD	island collared-dove	<i>Streptopelia bitorquata</i>	MLI, LI, SF, OF
WHGD	white-throated ground-dove	<i>Gallicolumba xanthonura</i>	MLI, LI, SF, OF
MAFD	Mariana fruit-dove	<i>Ptilinopus roseicapilla</i>	MLI, LI, SF, OF
COLK	collared kingfisher	<i>Todiramphus chloris orii</i>	MLI, LI, SF, OF
MIMY	Micronesian myzomela <sup>a</sup>	<i>Myzomela rubrata</i>	MLI, LI, SF, OF
BLDR	black drongo	<i>Dicrurus macrocercus</i>	MLI, LI, SF, OF
RUFA	rufous fantail	<i>Rhipidura rufifrons mariae</i>	MLI, LI, SF, OF
MACR	Mariana crow	<i>Corvus kubaryi</i>	MLI, LI, SF
BARS	barn swallow	<i>Hirundo rustica</i>	—
ROWE	Rota white-eye	<i>Zosterops rotensis</i>	MLI, LI, SF, OF
MIST	Micronesian starling	<i>Aplonis opaca</i>	MLI, LI, SF, OF
EUTS	Eurasian tree sparrow	<i>Passer montanus</i>	LI, SF, OF

<sup>a</sup> Also called Micronesian honeyeater.

Table S8), and the expected occupancy probability ranged from 0.68 to 0.86 (95% CI,  $\bar{x}$  = 0.78; Table S9). The top-ranked models for the species included three models with AIC weights between 0.12 and 0.23 and a cumulative weight of 0.50, indicating only modest support for the suite of predictor variables (Table S4). All models included the sampling covariate “observer” and indicated that survey participants’ abilities were related to the likelihood of detecting terns (Table S5). In addition, model WHTE-62 also included the covariate “gust strength,” which demonstrated a negative but marginal relationship to detection probability. Although the site covariate “visibility” was included in the best models, only visibility classes 1 and 2 were significant factor levels (classes 3 through 5 were not significant as

factors, possibly because there were fewer than 10 observations in each of these classes; Tables S3 and S5). The site covariate “elevation” was also included in model WHTE-70; however, it demonstrated a weakly positive but nonsignificant relationship to occupancy (Figure S2).

*Island collared-dove.* The island collared-dove was common throughout Rota in 1982, with between 3,627 and 5,879 birds (95% CI,  $\bar{x}$  = 4,691), but had declined by 2012 to 1,044–1,852 individuals (95% CI,  $\bar{x}$  = 1,434; Table S7). The island-wide collared-dove abundances over all surveys were estimated with moderate precision ( $\bar{x}$  = 18.2% CV; range = 12.2–27.5). There was very strong evidence that the collared-dove population in the Plateau region decreased, with no evidence of either a stable or increasing trend. The trend in the Sabana

**Table 4.** Population density estimates (birds/ha) for the 2012 avian survey on Rota, Mariana Islands, for the 13 species with sufficient number of detections to reliable model abundance. Estimates for range-restricted species are for occupied region only. Variance was calculated analytically and presented as the standard error along with the upper and lower 95% confidence interval (Lower 95% CI and Upper 95% CI, respectively).

Species	Density	SE	Lower 95% CI	Upper 95% CI
Yellow bittern <i>Ixobrychus sinensis</i>	0.123	0.007	0.110	0.138
White tern <i>Gygis alba</i>	1.238	0.031	1.178	1.300
Island collared-dove <i>Streptopelia bitorquata</i>	0.172	0.005	0.163	0.182
White-throated ground-dove <i>Gallicolumba xanthonura</i>	0.417	0.014	0.390	0.446
Mariana fruit-dove <i>Ptilinopus roseicapilla</i>	0.397	0.005	0.387	0.407
Collared kingfisher <i>Todiramphus chloris orii</i>	0.467	0.008	0.451	0.484
Micronesian myzomela <i>Myzomela rubrata</i>	1.738	0.020	1.699	1.778
Black drongo <i>Dicrurus macrocercus</i>	1.657	0.215	1.615	1.699
Rufous fantail <i>Rhipidura rufifrons mariae</i>	6.514	0.160	6.208	6.836
Mariana crow <sup>a</sup> <i>Corvus kubaryi</i>	0.010	0.000	0.010	0.011
Rota white-eye <sup>a</sup> <i>Zosterops rotensis</i>	4.505	0.138	4.242	4.784
Micronesian starling <i>Aplonis opaca</i>	14.043	0.153	13.747	14.346
Eurasian tree sparrow <sup>a</sup> <i>Passer montanus</i>	0.151	0.006	0.139	0.163

<sup>a</sup> Range-restricted species.

region was inconclusive, with <38% evidence in each of all three trend categories. The overall pattern for the island was driven by the Plateau region, with very strong evidence of a declining trend and no evidence of a stable or increasing trend (Table 5; Figure 7).

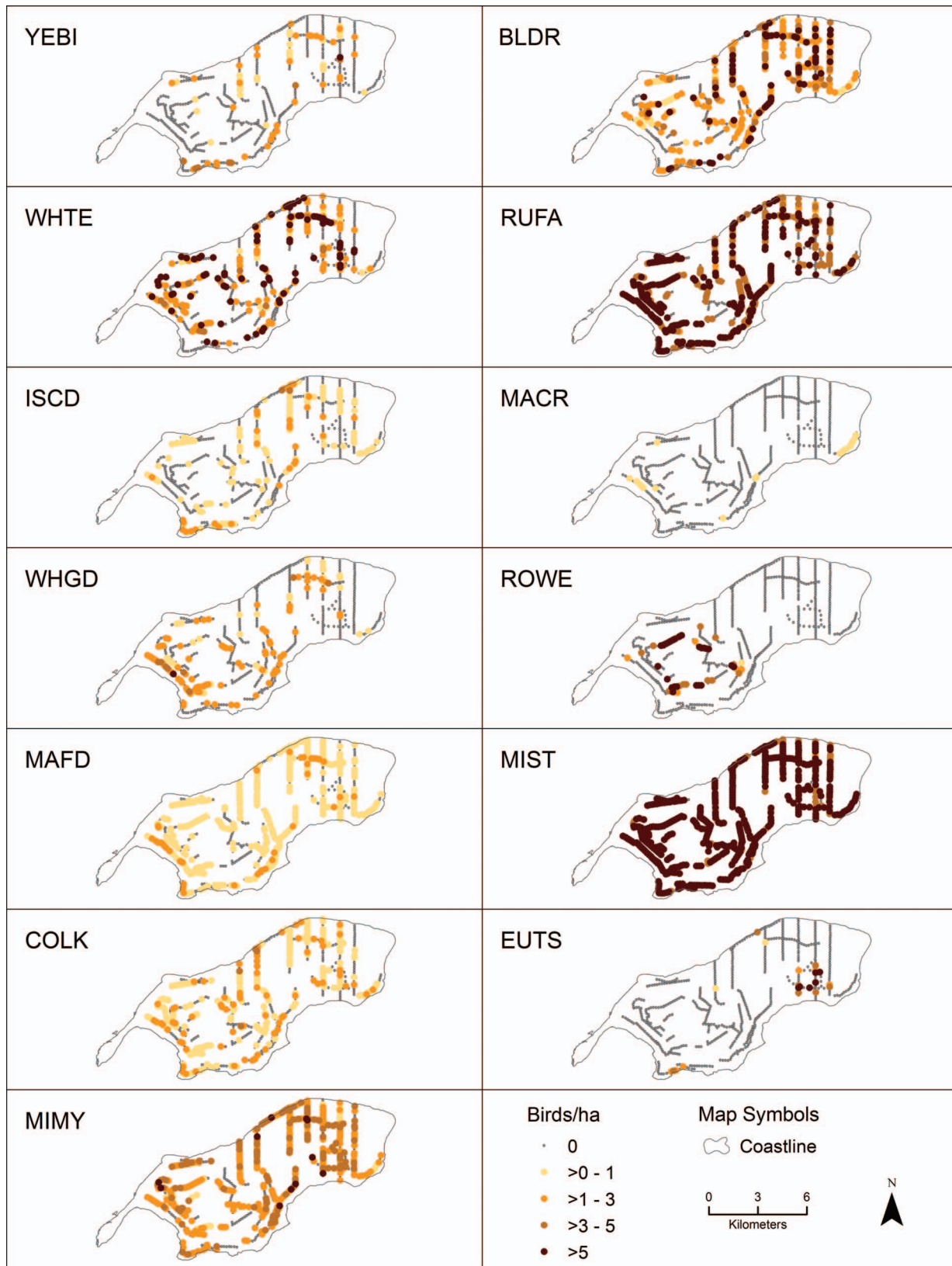
In 2012, the island collared-dove was detected during 127 of the 666 total point counts and at 76 of the 133 stations sampled repeatedly for occupancy estimation. The null model (ISCD-0) yielded an expected detection probability of between 0.21 and 0.32 (95% CI,  $\bar{x}$  = 0.26; Table S8), and the expected occupancy probability ranged from 0.59 to 0.85 (95% CI,  $\bar{x}$  = 0.74; Table S9). The top-ranked models for the species included two models that had a cumulative weight of 0.81 (Table S4). Both models included the sampling covariate “time” and indicated that the likelihood of detecting collared-doves declined markedly as a function of time of day (i.e., minutes since sunrise; Table S8). The second best model (ISCD-60) also included the sampling covariate “cloud,” but this variable was not significant, and only tentatively appears to demonstrate increased detectability with increasing cloud cover. Both models included the site covariate “elevation” as a marginally significant predictor variable and indicated that occupancy was greater at lower elevations (e.g., see model ISCD-58 [Figure S2; Table S5]).

**White-throated ground-dove.** The white-throated ground-dove occurred throughout Rota and was common in 1982, with between 5,792 and 9,619 birds (95% CI,  $\bar{x}$  = 7,622), but the species declined to very low abundances in the late 1990s and early 2000s before increasing sharply to 2,602–4,758 individuals by 2012 (95% CI,  $\bar{x}$  = 3,576; Table S7). The island-wide ground-dove abundances over all surveys were estimated with moderate precision ( $\bar{x}$  = 29.4% CV range = 12.8–69.8). There was very strong evidence that the ground-dove population decreased in the Plateau and Sabana

regions, and the overall pattern for the island showed very strong evidence of a decreasing trend, with no evidence of either a stable or increasing trend (Table 5; Figure 8).

In 2012, the white-throated ground-dove was detected during 140 of the 666 total point counts and at 65 of the 133 stations sampled repeatedly for occupancy estimation. The null model (WHGD-0) yielded an expected detection probability of between 0.34 and 0.46 (95% CI,  $\bar{x}$  = 0.40; Table S8), and the expected occupancy probability ranged from 0.44 to 0.63 (95% CI,  $\bar{x}$  = 0.54; Table S9). The top-ranked models for the species included two models that had a cumulative weight of 0.76 (Table S4). Both models included the sampling covariates “observer” and “gust strength” and indicated that the likelihood of detecting ground-doves depended on survey participants’ abilities and, to a lesser extent, on gust strength (Table S5). The sampling covariate “survey day” was also included in the second-best model (WHGD-59), but the variable was not significant and only weakly suggested a positive relationship to detection probability (Table S5). Both models included the site covariates “vegetation” and “elevation” and, in addition to a significant and positive relationship to elevation, the models tentatively demonstrated lower occupancy in open field relative to the forested vegetation types (Figure S2; Table S5).

**Mariana fruit-dove.** The Mariana fruit-dove occurred throughout Rota and was abundant in 1982, with between 9,734 and 12,283 birds (95% CI,  $\bar{x}$  = 10,901), but it declined through the 2000s before increasing sharply to 2,853–3,900 individuals by 2012 (95% CI,  $\bar{x}$  = 3,383; Table S7). The island-wide fruit-dove abundances over all surveys were estimated with high precision ( $\bar{x}$  = 9.2 % CV; range = 6.0–16.5). There was very strong evidence that the fruit-dove population declined in the Plateau and Sabana regions, and the overall pattern for the island was very strong



**Figure 4.** Relative abundance and distribution of species from the 2012 point-transect forest bird survey on Rota, Mariana Islands. Species Alpha-codes are YEBI = yellow bittern *Ixobrychus sinensis*, WHITE = white tern *Gygis alba*, ISCD = island collared-dove *Streptopelia bitorquata*, WHGD = white-throated ground-dove *Gallicolumba xanthonura*, MAFD = Mariana fruit-dove *Ptilinopus roseicapilla*, COLK = collared kingfisher *Todiramphus chloris orii*, MIMY = Micronesian myzomela *Myzomela rubratra*, BLDR = black drongo *Dicrurus macrocerus*, RUFA = rufous fantail *Rhipidura rufifrons mariae*, MACR = Mariana crow *Corvus kubaryi*, ROWE = Rota white-eye *Zosterops rotensis*, MIST = Micronesian starling *Aplonis opaca*, and EUTS = Eurasian tree sparrow *Passer montanus*.

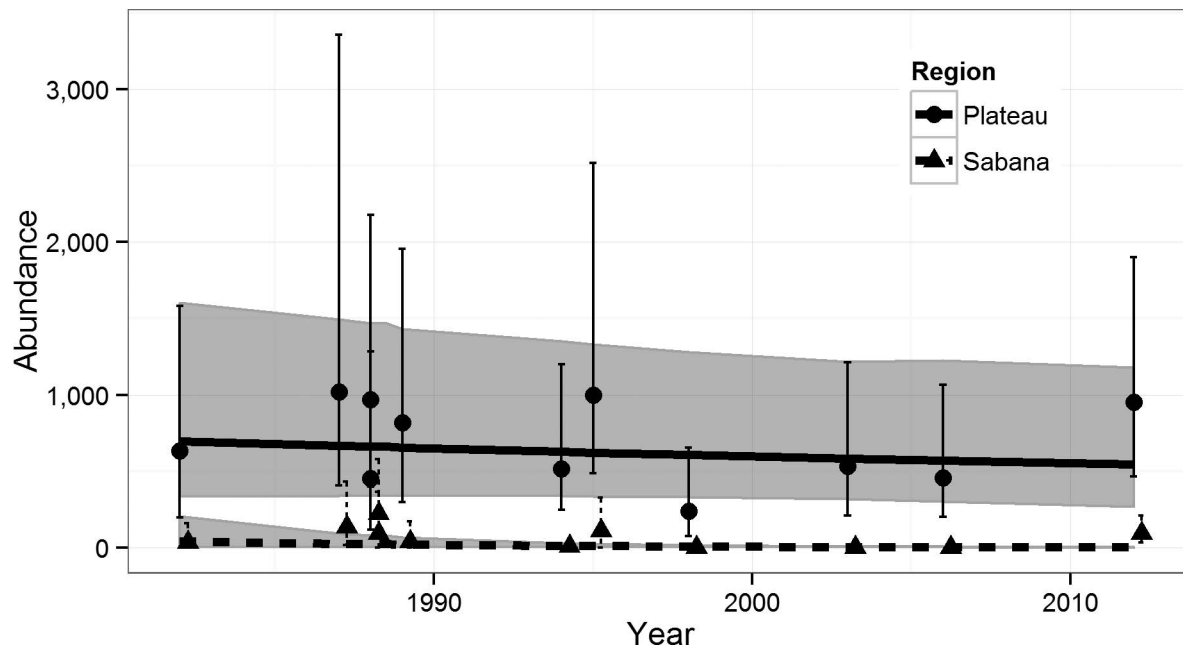
**Table 5.** Trends in abundance of land-bird species on Rota, Mariana Islands, between 1982 and 2012. Results of log-linear regression trends were assessed on the Plateau and Sabana regions and for the entire island (Total; Stratum). The ecological relevance of a trend was based on a 25% change in abundance over 25 y. The distribution of the bootstrap regression slopes was assigned trend categories of decreasing, stable, or increasing based on the percentage of bootstrap slopes in each category: weak if <50%, moderate if 50–70%, strong if 70–90%, and very strong if ≥90%. In cases where weak evidence was observed among all three trend categories, we interpreted the trend to be inconclusive. Interpretation of trend (increasing = ▲, stable = —, decreasing = ▼, and inconclusive = Inc), slope, 95% credible interval (95% CI), and percent evidence of each trend is also provided. The trend for Eurasian tree sparrow was not assessed. na = not applicable.

Species	Stratum	Trend	Slope	95% CI	Decreasing	Stable	Increasing
Yellow bittern	Plateau	—	−0.008	−0.029–0.015	36	59	6
<i>Ixobrychus sinensis</i>	Sabana	▼	−0.094	−0.164 to −0.012	97	2	1
	Total	Inc	−0.012	−0.033–0.010	49	48	3
White tern	Plateau	▲	0.025	0.015–0.035	0	0	100
<i>Gygis alba</i>	Sabana	▲	0.025	0.004–0.043	0	6	94
	Total	▲	0.026	0.018–0.035	0	0	100
Island collared-dove	Plateau	▼	−0.026	−0.035 to −0.018	100	0	0
<i>Streptopelia bitorquata</i>	Sabana	Inc	−0.006	−0.078–0.048	35	38	27
	Total	▼	−0.024	−0.034 to −0.017	100	0	0
White-throated ground-dove	Plateau	▼	−0.105	−0.213 to −0.057	100	0	0
<i>Gallicolumba xanthonura</i>	Sabana	▼	−0.162	−0.208 to −0.126	100	0	0
	Total	▼	−0.099	−0.171 to −0.064	100	0	0
Mariana fruit-dove	Plateau	▼	−0.044	−0.052 to −0.037	100	0	0
<i>Ptilinopus roseicapilla</i>	Sabana	▼	−0.075	−0.093 to −0.063	100	0	0
	Total	▼	−0.050	−0.056 to −0.043	100	0	0
Collared kingfisher	Plateau	▼	−0.015	−0.021 to −0.010	91	9	0
<i>Todiramphus chloris orii</i>	Sabana	▼	−0.032	−0.041 to −0.024	100	0	0
	Total	▼	−0.020	−0.025 to −0.015	100	0	0
Micronesian myzomela	Plateau	▼	−0.035	−0.039 to −0.030	100	0	0
<i>Myzomela rubratra</i>	Sabana	▼	−0.031	−0.038 to −0.024	100	0	0
	Total	▼	−0.034	−0.038 to −0.030	100	0	0
Black drongo	Plateau	▼	−0.018	−0.032 to −0.008	82	18	0
<i>Dicrurus macrocercus</i>	Sabana	—	−0.012	−0.031–0.004	49	51	0
	Total	▼	−0.017	−0.031 to −0.008	82	18	0
Rufous fantail	Plateau	—	0.005	−0.016–0.015	3	60	37
<i>Rhipidura rufifrons mariae</i>	Sabana	▲	0.038	0.028–0.050	0	0	100
	Total	▲	0.014	0–0.021	0	14	86
Mariana crow	Plateau	▼	−0.101	−0.122 to −0.084	100	0	0
<i>Corvus kubaryi</i>	Sabana	na	na	na	na	na	na
	Total	▼	−0.101	−0.122 to −0.084	100	0	0
Rota white-eye	Plateau	na	na	na	na	na	na
<i>Zosterops rotensis</i>	Sabana	—	0.005	−0.014–0.026	4	62	33
	Total	—	0.005	−0.014–0.026	4	62	33
Micronesian starling	Plateau	▲	0.026	0.016–0.033	0	1	99
<i>Aplonis opaca</i>	Sabana	▲	0.028	0.022–0.034	0	0	100
	Total	▲	0.026	0.019–0.033	0	0	100

evidence of a declining trend, with no evidence of a stable or increasing trend (Table 5; Figure 9).

In 2012, the Mariana fruit-dove was detected during 561 of the 666 total point counts and at all of the 133 stations sampled repeatedly for occupancy estimation. An initial null model yielded an expected detection

probability of between 0.81 and 0.87 (95% CI,  $\bar{x}$  = 0.84) and occupancy 1.00 (SE = 0.0003). However, because of the species' widespread occurrence, the models were run again defining "occupied" sites as "high occupancy" where the number of occurrences was greater than the median count of one bird, which included 319 of the 666

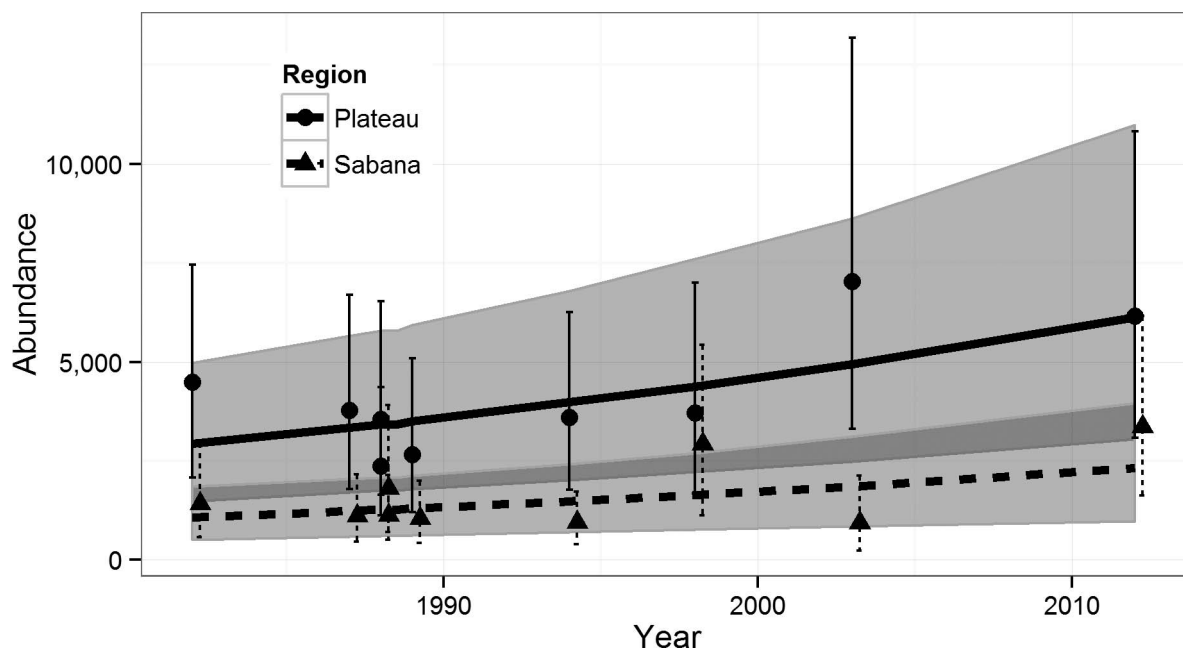


**Figure 5.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for yellow bittern *Ixobrychus sinensis* on Rota, Mariana Islands, between 1982 and 2012.

total station counts and 90 of the 133 stations. The null model (MAFD-0) for this modified data set produced an expected detection probability of between 0.51 and 0.59 (95% CI,  $\bar{x} = 0.55$ ; Table S8), and an expected occupancy probability range from 0.81 to 0.93 (95% CI,  $\bar{x} = 0.88$ ; Table S9). The revised detection probability reflects the lower likelihood of recording two or more fruit-doves during a station count. Model selection for the Mariana fruit-dove identified only a single best model (MAFD-44;

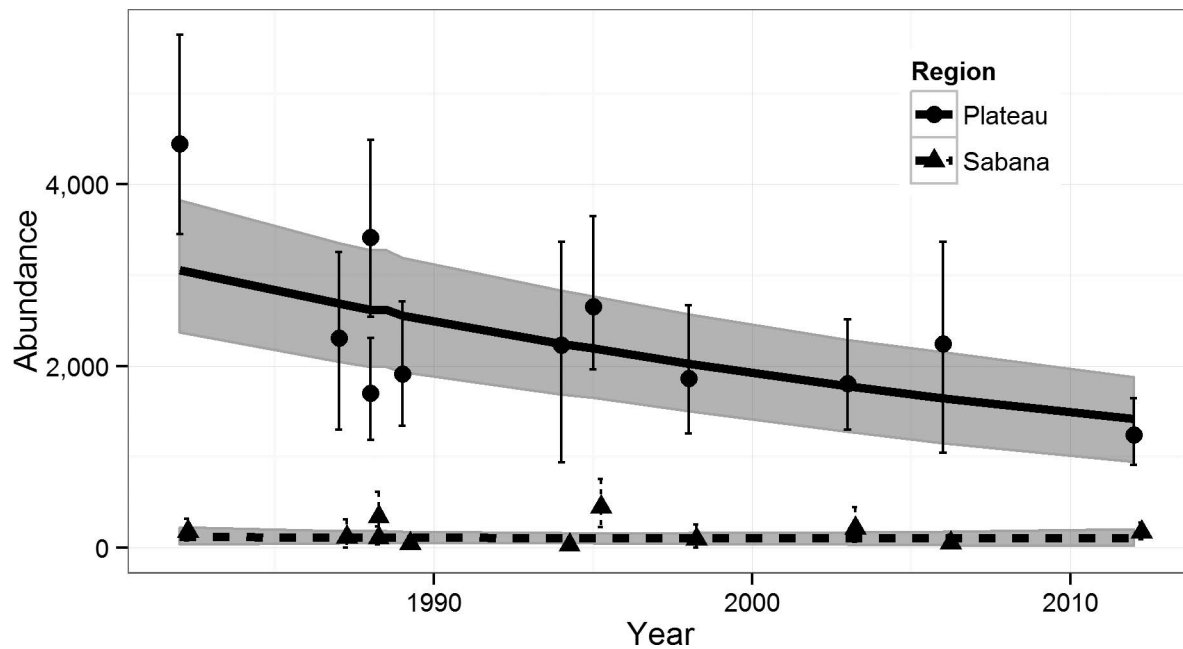
Table S4). This model included no site covariates but did include the sampling covariates "observer," "cloud cover," and "wind strength." These variables indicated that survey participants' (observer) abilities affected the likelihood of detecting fruit-doves and detection probability declined with increasing cloud cover and wind strength levels (Figure S2).

*Collared kingfisher.* The collared kingfisher occurred throughout Rota and was common in 1982, with



**Figure 6.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for white tern *Gygis alba* on Rota, Mariana Islands, between 1982 and 2012.



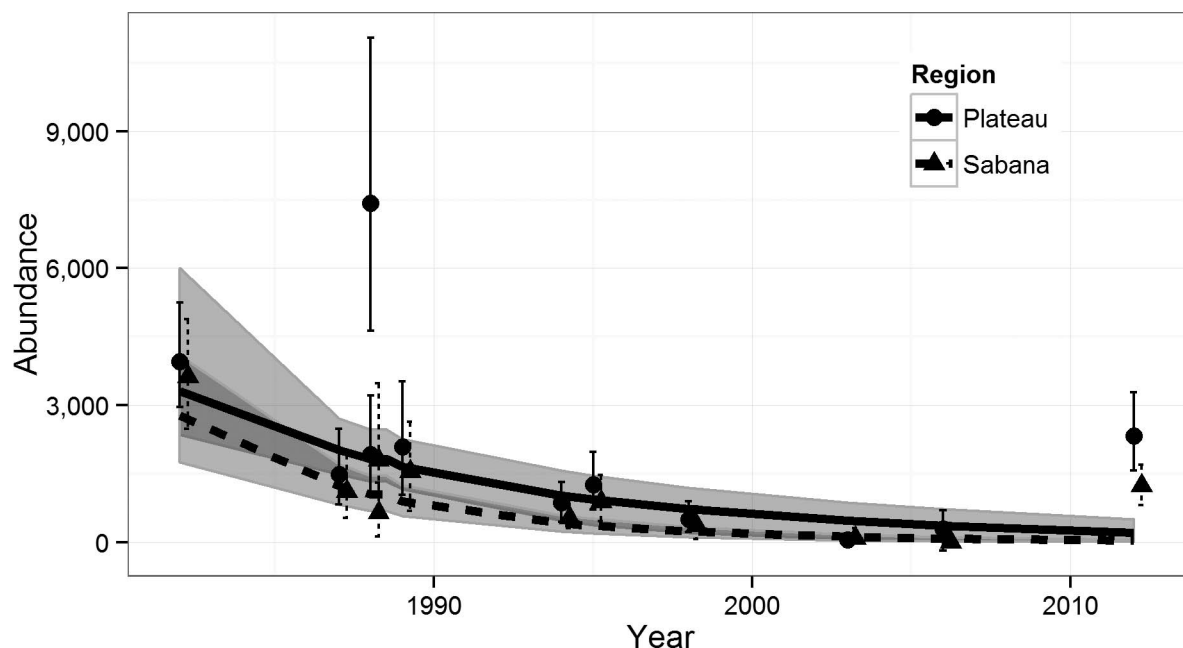


**Figure 7.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for island collared-dove *Streptopelia bitorquata* on Rota, Mariana Islands, between 1982 and 2012.

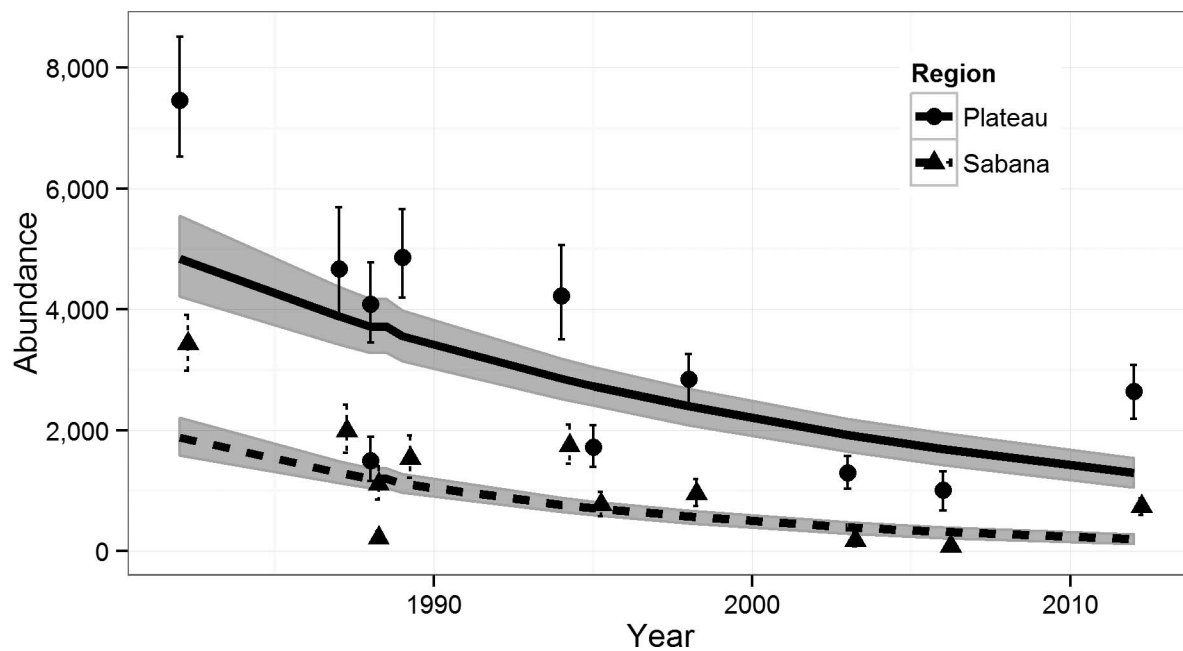
between 6,181 and 8,334 birds (95% CI,  $\bar{x} = 7,229$ ); it continued to be abundant until 2012, when the population was estimated at 3,281–4,607 individuals (95% CI,  $\bar{x} = 3,917$ ; Table S7). The island-wide kingfisher abundances over all surveys were estimated with high precision ( $\bar{x} = 8.5\%$  CV; range = 7.2–12.4). There was very strong evidence that the kingfisher declined in both the Plateau and Sabana regions, and the overall pattern for the island yielded very strong evidence of a declining

trend and no evidence of a stable or increasing trend (Table 5; Figure 10).

In 2012, the collared kingfisher was detected during 445 of the 666 total point counts and at 130 of the 133 stations sampled repeatedly for occupancy estimation. An initial null model yielded an expected detection probability of between 0.64 and 0.71 (95% CI,  $\bar{x} = 0.68$ ) and overall occupancy probability between 0.93 and 1.00 (95% CI,  $\bar{x} = 0.99$ ). However, because of the species'



**Figure 8.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for white-throated ground-dove *Gallicolumba xanthonura* on Rota, Mariana Islands, between 1982 and 2012.



**Figure 9.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for Mariana fruit-dove *Ptilinopus roseicapilla* on Rota, Mariana Islands, between 1982 and 2012.

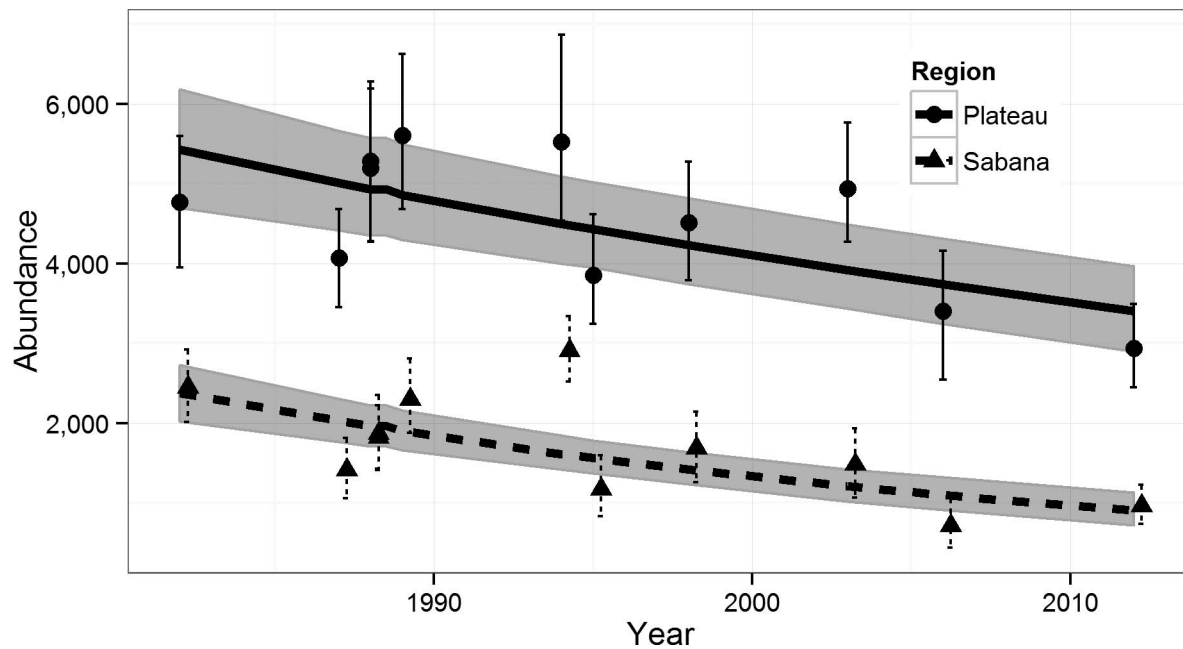
widespread occurrence, site covariates were not significantly related to occupancy (i.e., almost all sites were occupied). Therefore, the models were run again using “high occupancy” as sites with occurrences of two or more birds, which included 223 of the 666 total point counts and 66 of the 133 stations. The null model (COLK-0) for this modified data set produced an expected detection probability of between 0.34 and 0.43 (95% CI,  $\bar{x}$  = 0.38; Table S8) and an expected occupancy range from 0.77 to 0.94 (95% CI,  $\bar{x}$  = 0.88; Table S9). The revised detection probability reflects the lower likelihood of observing two or more birds during a single count at a station. Model selection for the kingfisher identified only a single best model with a total AIC weight of 0.88 (COLK-58; Table S4). This model included the site covariate “elevation,” which demonstrated declining occupancy (Figure S2) with increasing elevation and likely relates to the positive correlation of elevation with distance from the coast. The model also included the sampling covariates “observer,” “time,” and “gust strength,” and indicated that survey participants’ (observer) abilities were generally related to the likelihood of detecting collared kingfishers and detection probability declined with time of day (i.e., minutes since sunrise). Although included in the best-fit model COLK-58, “gust strength” was not significantly related to detection probability (Table S5).

**Micronesian myzomela.** The Micronesian myzomela occurred throughout Rota and was abundant in 1982, with between 38,276 and 63,191 birds (95% CI,  $\bar{x}$  = 49,962) and, although estimates fluctuated through the mid-1990s, they declined substantially from 1998 to 2012, when 12,399–21,270 individuals were estimated (95% CI,  $\bar{x}$  = 16,441; Table S7). The island-wide myzomela abundances over all surveys were estimated

with moderate precision ( $\bar{x}$  = 14.5% CV; range = 12.7–17.1). There was very strong evidence that the myzomela population declined in the Plateau and Sabana regions, and the overall pattern for the island showed very strong evidence of a declining trend, with no evidence of a stable or increasing trend (Table 5; Figure 11).

In 2012, the Micronesian myzomela was detected during 489 of the 666 total point counts and at 131 of the 133 stations sampled repeatedly for occupancy estimation. An initial null model yielded an expected detection probability of between 0.70 and 0.77 (95% CI,  $\bar{x}$  = 0.73) and occupancy equal to 1.00 (SE = 0.0002). However, because of the species’ widespread occurrence, the models were run again using a “high occupancy” threshold of sites with occurrences of two or more birds, which included 234 of the 666 total point counts and 66 of the 133 stations. The null model (MIMY-0) for this modified data set produced an expected detection probability of between 0.35 and 0.44 (95% CI,  $\bar{x}$  = 0.39; Table S8), and the expected occupancy ranged from 0.78 to 0.95 (95% CI,  $\bar{x}$  = 0.89 [Figure S2; Table S9]). The revised detection probability reflects the lower likelihood of observing two or more myzomela. The top-ranked models for the species included three models that had a cumulative weight of 1.00 (Table S4). All models included the sampling covariates “observer” and “time,” which indicated that survey participants’ (observer) abilities were related to the likelihood of detecting myzomela and detection probability declined with time of day (i.e., minutes since sunrise; Table S8). The two best models included the site covariate “elevation,” and although it was only marginally significant as a predictor variable, it demonstrated that the abundance of myzomela was generally greater at lower elevations (e.g., see model MIMY-59; Table S5). The site



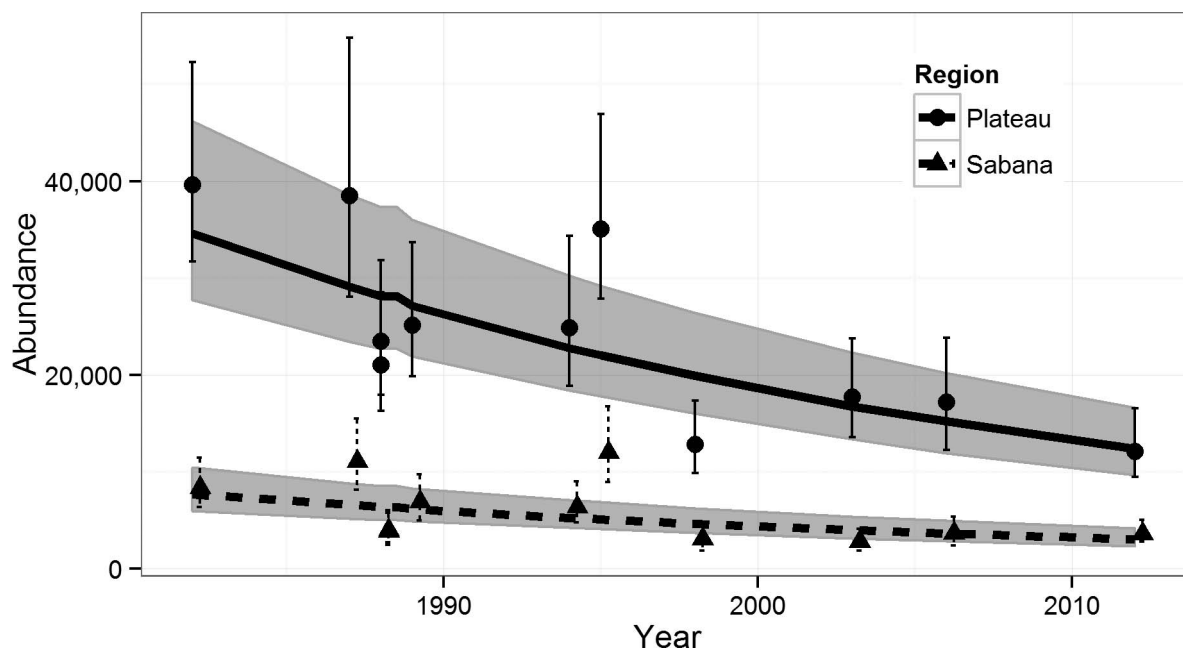


**Figure 10.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for collared kingfisher *Todiramphus chloris orii* on Rota, Mariana Islands, between 1982 and 2012.

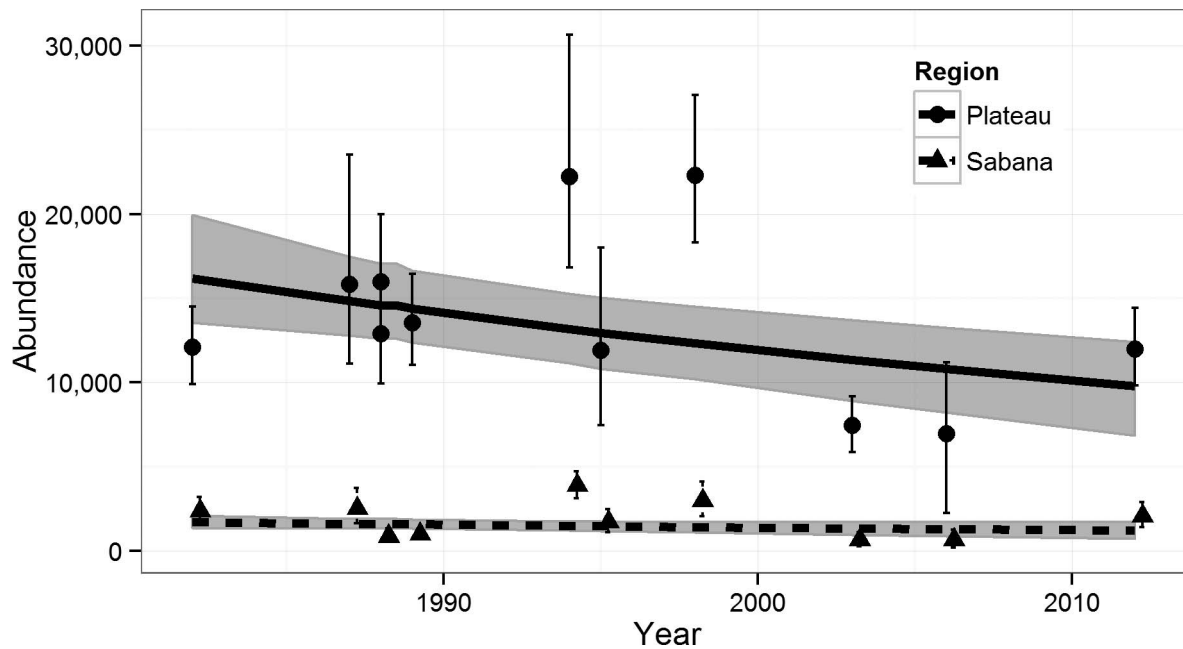
covariate “vegetation” was included in model MIMY-58, and although the models did not converge to produce a meaningful standard error for the factors secondary forest and open field, the species was ubiquitous in both of these vegetation types as well as mature limestone forest and other limestone forest.

*Black drongo.* The black drongo occurred abundantly throughout Rota in 1982, with between 12,011 and 17,295 birds (95% CI,  $\bar{x}$  = 14,505), and despite fluctuations

afterward, the population was estimated at 11,636–16,838 individuals in 2012 (95% CI,  $\bar{x}$  = 14,106; Table S7). The island-wide drongo populations over all surveys were estimated with moderate precision ( $\bar{x}$  = 14.3% CV; range = 9.0–33.0). In the Plateau region, there was strong evidence that the drongo population was decreasing, weak evidence of a stable population, and no evidence of a population increase. The trend in the Sabana region indicated moderate evidence of a stable population, with



**Figure 11.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for Micronesian myzomela *Myzomela rubratra* on Rota, Mariana Islands, between 1982 and 2012.



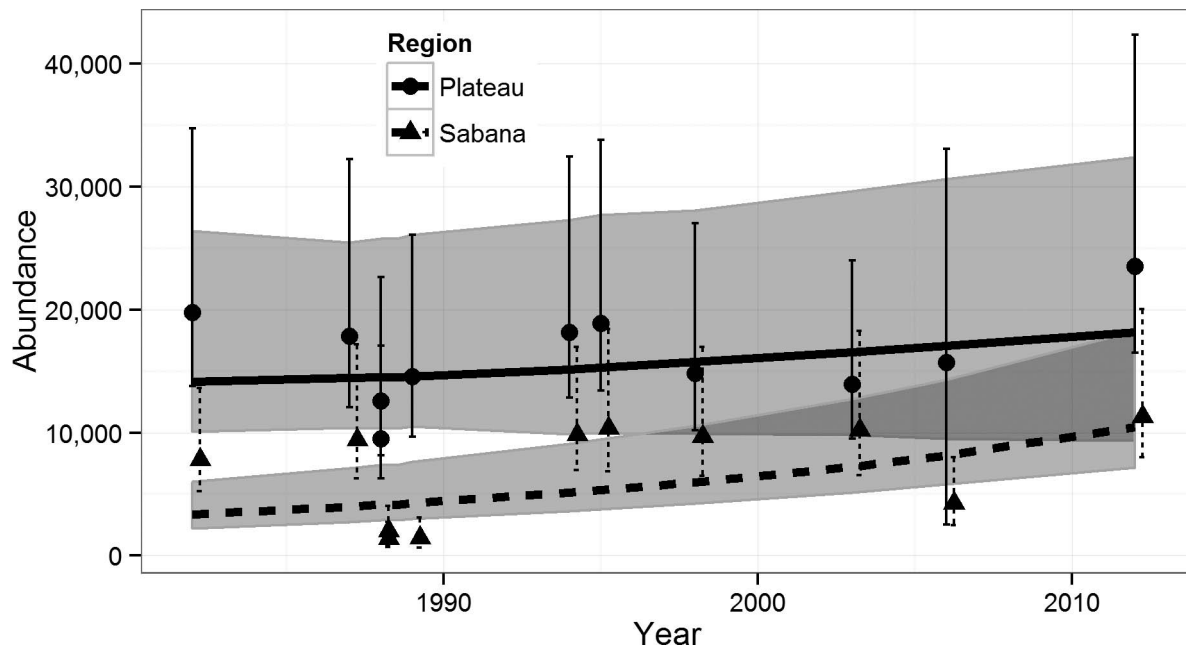
**Figure 12.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for black drongo *Dicrurus macrocercus* on Rota, Mariana Islands, between 1982 and 2012.

weak evidence of a decrease and no evidence of an increase. The overall pattern for the island was driven by the Plateau region with strong evidence of a declining trend (Table 5; Figure 12).

In 2012, the black drongo was detected during 313 of the 666 total point counts and at 107 of the 133 stations sampled repeatedly for occupancy estimation. The null model (BLDR-0) yielded an expected detection probability of between 0.53 and 0.61 (95% CI,  $\bar{x} = 0.57$ ; Table S8), and overall occupancy ranged between 0.74 and 0.88 (95% CI,  $\bar{x} = 0.82$ ; Table S9). The top-ranked models for the black drongo included three models that had a cumulative weight of 0.98 (Table S4). The models included the sampling covariates “time” and “cloud” and the site covariate “vegetation.” The site covariates “elevation” and “visibility” were also included in the second- and third-ranked models; however, elevation was not significant as a predictor variable (BLDR-59; Table S5). Although not significantly different from one another, mean probability of occupancy among vegetation types ranged from 0.68 to 0.83 to 0.92 for mature limestone forest, other limestone forest and secondary forest, respectively (BLDR-58). The models did not converge to produce a meaningful standard error for the factor open field, although black drongo occurred at all stations in this class. “Visibility” was a significant covariate (BLDR-60) and indicated that occupancy was greater at sites with increasing understory closure within the three forest types (Figure S2). The sampling covariates “time” and “cloud” showed that detection probability declined as a function of time of day (i.e., minutes since sunrise) and was lower in cloudless compared with cloudy conditions.

*Rufous fantail.* The rufous fantail was widespread and abundant on Rota in 1982, with between 19,128 and 48,415 birds (95% CI,  $\bar{x} = 29,931$ ), and the population increased to 24,587–61,688 individuals by 2012 (95% CI,  $\bar{x} = 38,092$ ; Table S7). The island-wide fantail abundances over all surveys were estimated with moderate precision ( $\bar{x} = 26.9\%$  CV; range = 24.4–41.5). There was moderate evidence that the fantail population in the Plateau region was stable, with weak evidence for either a declining or increasing trend. The trend in the Sabana region indicated very strong evidence of an increasing population, with no evidence of either a stable or decreasing trend. Driven by the Sabana region, the overall pattern for the island showed strong evidence of an increasing trend, weak evidence of a stable trend, and no evidence of a declining trend (Table 5; Figure 13).

In 2012, the rufous fantail was detected during 504 of the 666 total point counts and at 132 of the 133 stations sampled repeatedly for occupancy estimation. An initial null model yielded an expected occupancy probability of 1.0 (SE could not be generated) and a detection probability of between 0.72 and 0.79 (95% CI,  $\bar{x} = 0.76$ ). However, because of the species’ widespread occurrence, the models were run again using “high occupancy” as stations with at least two birds, which included 312 of the 666 total point counts and 81 of the 133 stations. The null model (RUFA-0) for this modified data set produced an expected detection probability of between 0.46 and 0.55 (95% CI,  $\bar{x} = 0.51$ ; Table S8) and the expected occupancy ranged from 0.85 to 0.96 (95% CI,  $\bar{x} = 0.93$ ; Table S9). The revised detection probability reflects the lower likelihood of observing two or more fantails. Only one model was selected as the best model (RUFA-42; Table S4), and it did not include any site



**Figure 13.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for rufous fantail *Rhipidura rufifrons mariae* on Rota, Mariana Islands, between 1982 and 2012.

covariates significantly associated with occupancy (Figure S2), but did include the sampling covariates “observer,” “time,” and “gust strength.” The model indicated that survey participants’ abilities were related to the likelihood of detecting fantails where detection probability declined with time of day (i.e., minutes since sunrise) and was negatively, albeit marginally, associated with gust strength (Tables S5 and S8).

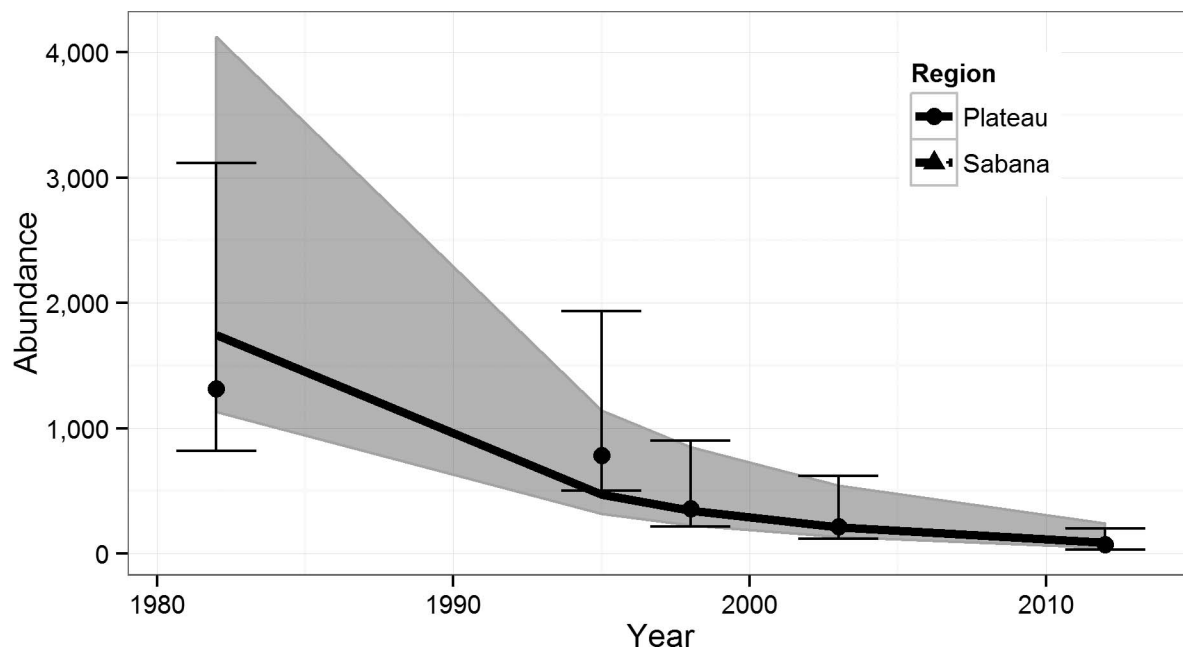
**Mariana crow.** Although the Mariana crow was found in both the Sabana and Plateau regions early in the time series, by 2012 the Mariana crow occurred only on the Plateau and was generally restricted to steep escarpments. Crows were uncommon in 1982, with between 815 and 3,115 birds (95% CI,  $\bar{x}$  = 1,491); they declined to between 30 and 202 individuals in 2012 (95% CI,  $\bar{x}$  = 81; Table S7). The island-wide crow abundances over all surveys were estimated with low precision ( $\bar{x}$  = 46.0% CV; range = 39.3–54.1). The 1988–1989 roadside surveys were not used for trend assessment because the ratio estimator of abundance between roadside and off-road surveys was highly variable. The overall pattern for the island showed very strong evidence of a declining trend, with no evidence of a stable or increasing trend (Table 5; Figure 14).

In 2012, the Mariana crow was detected during 27 of the 666 total point counts and at 18 of the 133 stations sampled repeatedly for occupancy estimation. The null model (MACR-0) produced an expected detection probability of between 0.12 and 0.34 (95% CI,  $\bar{x}$  = 0.21; Table S8), and the expected occupancy probability ranged from 0.11 to 0.32 (95% CI,  $\bar{x}$  = 0.20; Table S9). Model selection identified four models with AIC weights between 0.19 and 0.29, indicating only modest support for the suite of predictor variables. The weak association of predictor variables to detection probability and

occupancy was likely due to the species’ low abundance and the limited number of crow observations, rather than an actual lack of land cover preferences or sampling effects. The site covariate “vegetation” was present in all models, but because of high uncertainty in the estimates, no inference was possible about differences in occupancy among vegetation types (e.g., MACR-58; Table S5). The site covariate “elevation” and sampling covariate “time” were also present in the models. The relationship of occupancy and elevation was not significant (Figure S2) but was suggestive of higher occupancy at lower elevations in mature limestone forest, and distribution patterns support this conclusion. Likewise, the relationship between detection probability and time was not significant, but may indicate a weak but negative correlation with time of day (i.e., minutes since sunrise).

**Rota white-eye.** The Rota white-eye was not detected outside of the Sabana area during the 30-y time series. In 1982, the species was locally common at 8,741–18,487 birds (95% CI,  $\bar{x}$  = 14,963) and, although the population apparently declined through the 1990s, it increased by 2012 to between 5,620 and 20,961 individuals (95% CI,  $\bar{x}$  = 14,384; Table S7). The island-wide white-eye abundances over all surveys were estimated with moderate precision ( $\bar{x}$  = 29.6% CV; range = 16.6–50.7). The 1988–1989 roadside surveys were not used for trend assessment because the ratio estimator of abundance was highly variable. The Rota white-eye population declined from 1982 to the late 1990s but returned to 1980s levels by 2012, yielding moderate evidence of a stable trend and weak evidence for either decreasing or increasing trends (Table 5; Figure 15).

In 2012, the Rota white-eye was detected during 88 of the 666 total point counts and at 31 of the 133 stations sampled repeatedly for occupancy estimation. The null



**Figure 14.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for Mariana crow *Corvus kubaryi* on Rota, Mariana Islands, between 1982 and 2012.

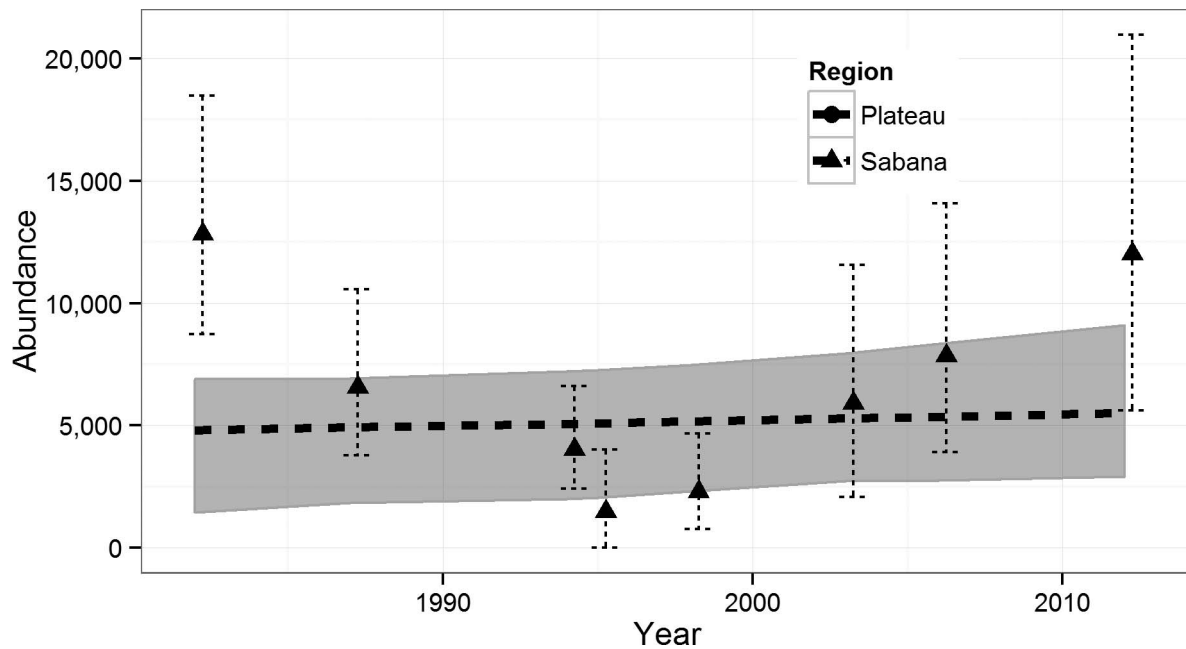
model (ROWE-0) produced an expected detection probability of between 0.48 and 0.65 (95% CI,  $\bar{x} = 0.57$ ; Table S8), and the expected occupancy ranged from 0.17 to 0.32 (95% CI,  $\bar{x} = 0.24$ ; Table S9). An initial model run identified four top-ranked models that included the site covariates “vegetation” and “elevation.” However, these models predicted full site occupancy at elevations above 200 m; this was an unrealistic result that indicated a linear relationship to elevation was not appropriate. Therefore, a quadratic term was used to characterize the relationship between occupancy and elevation. The resulting four top-ranked models did not demonstrate a sufficiently good fit to the data (i.e.,  $\chi^2 P < 0.05$ ), and an acceptable fit was only attained for the quadratic model ROWE-62Q that incorporated the site covariate “elevation” without any sampling covariates (Table S4). The expected occupancy for this model demonstrated a strong relationship to elevation and indicated that Rota white-eyes occurred primarily at elevations above 150 m, which was supported by its distribution pattern. Although the site covariate “vegetation” was included in the top-ranked models, wide confidence intervals precluded any conclusions about differences in occupancy among vegetation types (Figure S2; Table S9).

**Micronesian starling.** Micronesian starlings occurred abundantly throughout Rota in 1982, with between 30,595 and 41,682 birds (95% CI,  $\bar{x} = 36,128$ ), and they increased by 2012 to 101,174–127,228 individuals (95% CI,  $\bar{x} = 113,647$ ; Table S7). The island-wide starling abundances over all surveys were estimated with high precision ( $\bar{x} = 9.4\%$  CV; range = 5.8–23.2). There was very strong evidence that the starling population increased in the Plateau and Sabana regions, and the overall pattern for the island showed very strong

evidence of an increasing trend, with no evidence of a stable or decreasing trend (Table 5; Figure 16).

In 2012, the Micronesian starling was detected during 645 of the 666 total point counts and at all of the 133 stations sampled repeatedly for occupancy estimation. However, because of the species’ widespread occurrence, the models were run again using a “high occupancy” threshold of sites with more than the median count of four birds, which included 236 of the 666 total point counts and 65 of the 133 stations. The null model (MIST-0) for this modified data set produced an expected detection probability of between 0.45 and 0.54 (95% CI,  $\bar{x} = 0.50$ ; Table S8), and the expected occupancy ranged from between 0.62 and 0.79 (95% CI,  $\bar{x} = 0.71$ ; Table S9). The revised detection and occupancy probabilities reflect the lower likelihood of observing five or more starlings during a single count at a station. The best models included three, with a cumulative weight of 0.94 (Table S4). All models included the sampling covariate “observer” and indicated that survey participants’ abilities were related to the likelihood of detecting starlings (Table S8). In addition, the sampling covariate “cloud” was included in two models and, as a marginally significant variable, demonstrated that detection probability was weakly but negatively related to cloud cover (Table S8). The site covariate “elevation” was included in all the best models and exhibited a positive relationship with the occurrence of abundant starlings. The site covariate “vegetation” was included in the third-best model (MIST-59) but occupancy estimates among vegetation types were not significantly different (Figure S2; Table S9).

**Eurasian tree sparrow.** Based on our surveys, Eurasian tree sparrows occurred only on the Plateau and were generally restricted to the urban Sinapalo area and



**Figure 15.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for Rota white-eye *Zosterops rotensis* on Rota, Mariana Islands, between 1982 and 2012.

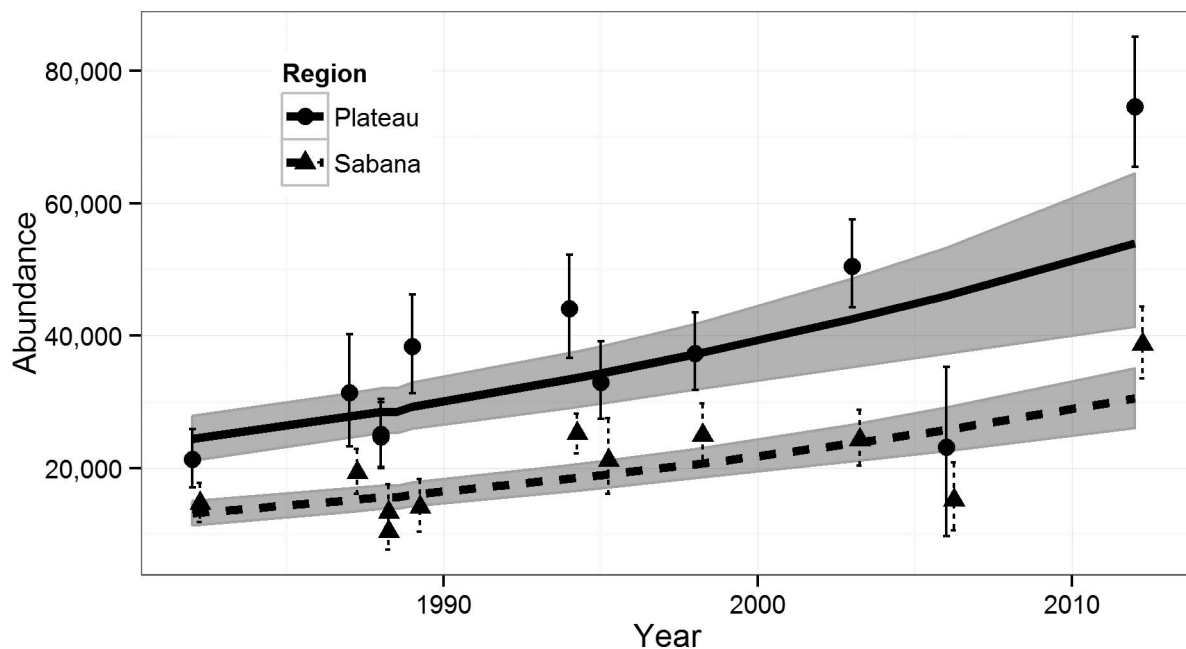
surrounding human-dominated land-cover types. They were locally uncommon in 1982, with between 29 and 1,846 birds (95% CI,  $\bar{x}$  = 719) and, although they increased in the 1990s, they subsequently declined and were locally uncommon at between 250 and 1,216 individuals in 2012 (95% CI,  $\bar{x}$  = 655; Table S7). The island-wide tree sparrow abundances over all surveys were estimated with low precision ( $\bar{x}$  = 52.1% CV; range = 23.5–81.3). The limited range and large fluctuations in

abundances precluded assessing trends in the Eurasian tree sparrow population. Occupancy was not assessed for the Eurasian tree sparrow.

## Discussion

### Population size and trends

Our study presents the first quantitative analysis of bird abundance on Rota since the original survey in 1982



**Figure 16.** Abundance (mean and 95% CI whisker lines) and trend (95% CI bands) estimates for Micronesian starling *Aplonis opaca* on Rota, Mariana Islands, between 1982 and 2012.



(Engbring et al. 1986). Similar to a qualitative assessment by Amar et al. (2008), we found that a majority of land birds (7 of 12 species) on Rota have declined since 1982, including island collared-dove, white-throated ground-dove, Mariana fruit-dove, collared kingfisher, Micronesian myzomela, black drongo, and Mariana crow. For these species, declines were usually observed for both the Plateau and Sabana regions, indicating that numbers have declined island-wide. Only the white tern, rufous fantail, and Micronesian starling increased over the 30 y between 1982 and 2012, whereas the Rota white-eye remained stable and the yellow bittern showed an inconclusive trend. Eurasian tree sparrow trends were not assessed; however, their numbers in 1982 and 2012 were similar. The Mariana crow has declined to precariously low numbers (upper 95% CI  $\leq 202$  individuals; Fancy et al. 1999; Plentovich et al. 2005; USFWS 2005). The Rota white-eye declined substantially during the first 18 y of the time series, but then recovered to approximately 1982 levels by 2012, when a population of approximately 14,400 birds was estimated. Both of these species remain a conservation concern (USFWS 2005, 2007, 2008; IUCN 2013).

Despite the decline of most Rota land birds since 1982, qualitative assessments of the current status of bird populations were similar to those reported by Reichel and Glass (1991). Over the 30-y period between 1982 and 2012, 8 of 10 native species and 2 of 3 nonnative species were common to abundant. Only the two endangered species (Mariana crow and Rota white-eye) and the nonnative Eurasian tree sparrow were rare or uncommon. The Mariana crow and Rota white-eye were restricted to lower elevation limestone escarpments and the upper elevation Sabana region, respectively. They were not certain to be found where they occurred, and, at most, only a few individuals were detected at any given location. Eurasian tree sparrow was detected only at forest stations on the Plateau, but the species is generally associated with urban, residential, and farm sites (Engbring et al. 1986:108), which were not extensively sampled during surveys. A small population of Eurasian tree sparrow is known to occur in Songsong, and several localized populations may exist around farm sites (Engbring et al. 1986). Where this nonnative bird occurred outside the Sinapalo, Songsong, and Palie, they were not certain to be found and only a few individuals were detected at any given location; these may represent local populations associated with agriculture.

Precise estimates are important for detecting changes in populations over time for conservation purposes such as evaluating threshold limits to both trigger and assess population responses to management actions. The level of precision of the abundance estimates for many species, including the Rota white-eye, was high ( $<10\%$  CV) or moderate ( $10\text{--}30\%$ ). The three species that occurred in low numbers—yellow bittern, Mariana crow, and Eurasian tree sparrow—all had large CVs ( $>40\%$ ). The numbers of common species ranged from tens-of to hundreds-of-thousands birds, with most species numbering several thousand individuals. The high level of precision of the abundant species lends confidence that

populations have declined, and high precision facilitates the application of threshold criteria (e.g., IUCN [2013] Red List criteria of 30% decline in density over 10 y or  $<2,500$  mature individuals). Discerning when a threshold criterion has been met is more difficult when population estimates include a wide confidence interval or when population trends are uncertain. Thus, for rare species, an evidentiary attitude to risk may not realistically reflect uncertainties in the data that a precautionary attitude may more accurately capture and may result in a more conservative status, prompting changes in management that could be crucial for remedial actions. Thus, for rare species, where uncertainty about population estimates and trends is typically high, prompt remedial action (the precautionary approach) is warranted because inaction while waiting for clearer evidence of population status and trends (the evidentiary approach) may increase the risk of extinction.

Trends were conclusive for all but 2 of the 32 trend analyses: island collared-dove on the Sabana region and the island-wide trend for yellow bittern. The 1982 and 2012 collared-dove population estimates on the Sabana were remarkably similar, but the widely fluctuating estimates on the Plateau obscured the overall trend. In contrast, although the yellow bittern regional trends were conclusive, the island-wide trend was inconclusive. Bittern abundances fluctuated substantially, with 2–5-fold differences on the Plateau and more than a magnitude difference on the Sabana. Nevertheless, combining the regional estimates added uncertainty to the island-wide trend, yielding an inconclusive result.

Our recalculated estimates of populations in 1982 were usually more than twice those of Engbring et al. (1986; their table 6:43). It is notable that estimates of yellow bittern, Mariana crow, Rota white-eye, and Eurasian tree sparrow numbers were similar, and our confidence intervals include those of Engbring et al. (1986). However, their mean estimates for widespread, common species fell below the lower 95% CI of our estimates. This is likely due to two factors: different algorithms used to estimate densities and additional survey data available to us. The multiple covariate distance sampling engine of distance differs from that used by Engbring et al. (1986) in that it incorporates hazard-rate models and covariates, which may in turn produce different estimates of population size (Ramsey and Scott 1979; Buckland et al. 2001, 2004). Additional data from subsequent surveys can improve the fit of detection functions to distance measures and produce differing abundance estimates (Buckland et al. 2001; Johnson et al. 2006), although the estimates are unbiased if critical assumptions are met (Buckland et al. 2001; Thomas et al. 2010).

The behaviors of the white tern and Rota white-eye challenged model assumptions. White terns were routinely observed in flight and during aerial courtship activities. Although we do not know whether terns (or other species) responded to the presence of observers, it was very difficult to detect terns when they were not moving. If the birds move closer to stations before being detected, abundances will be overestimated. Conversely, if terns move away from stations before being detected,

abundances will be underestimated. The consistency of tern movements is unknown; thus, it is not known whether tern abundance estimates were biased or not. The white-eye was sometimes detected in small flocks or family groups; thus, applying the individually based detection probability to the small groups will yield very large densities at stations where small flocks were recorded. Inflated density estimates may result in a slightly biased abundance estimate overall, but the trends assessment is useful because the process is consistent over time (Johnson et al. 2006).

### Occupancy

Occupancy analysis was applied to 12 species for which a sufficiently high rate of detections was available for modeling. Here we focus on differences in occupancy among vegetation types. Only the white-throated ground-dove had a significant relationship between occupancy and vegetation, in which the species was positively associated with the three forest land-cover types—mature limestone, other limestone, and secondary forest—and was negatively associated with the open-field cover type. The ground-dove uses a wide range of habitats, but Craig (1996) reported them in forested habitats more frequently than in disturbed habitats. Vegetation was included in the occupancy models of yellow bittern, Micronesian myzomela, black drongo, Mariana crow, Rota white-eye, and Micronesian starling. Although the variable was nonsignificant, some patterns can be discerned. The bittern and drongo were most positively associated with open fields, while the crow was most negatively associated with open fields. These patterns closely match what is known of each species' habitat preferences (Jenkins 1983). Associations for the remaining three species were less clear. Generally, myzomela was least associated with secondary forest and starling was least associated with mature limestone forest. The vegetation associations of the white-eye were all negative, with open field being least negatively associated. Our results contradict those of Engbring et al. (1986), Craig and Taisacan (1994), Amidon (2000), and Fancy and Snetsinger (2001), who all found that white-eye was recorded primarily in limestone forests or at stations in proximity to limestone forest. The difference in results may be due to differing sample sizes or it may be an artifact of whether land cover types were assigned at the station instead of at the bird's location (see below).

Two distinct distribution patterns emerged from the 2012 survey for the Mariana crow and Rota white-eye. Both species were sparsely distributed, with an estimated mean probability of occupancy of 0.20 and 0.24, respectively. Despite similarly low occupancy values, the probability of detecting these rare species differed substantially. These differences may be attributable in part to the territory sizes and densities typical of each species. The low detectability estimate for the Mariana crow implied wide-ranging movements within, and perhaps between, territories dispersed at low densities. In the late 1990s, Morton et al. (1999) estimated there to be 1 breeding pair per 22 ha of native forest, on average. The number of crow pairs recorded in 2008 was lower

(Zarones et al. 2015), and current research indicates that there may be 120–130 birds and only 35–45 pairs (R. Ha, University of Washington, personal communication), a number that is in agreement with our 2012 estimate. In addition to the large territory sizes and low numbers of crows likely resulting in their low detection probability, crow detectability may have declined over the past 30 y due to the decline of family groups and reduction in gregarious behaviors resulting from human persecution (J. Morton, U.S. Fish and Wildlife Service, personal communication). The moderately high detection probability for Rota white-eye indicated that they were readily detectable, albeit at a small number of sites. Mean white-eye abundance at these sites has been previously estimated to range from 2.0 to 9.8 birds/ha in low and high density areas, respectively (Amidon 2000). Craig (2002) found that the territory size of the bridled white-eye *Zosterops conspicillatus*, a congener species to the Rota white-eye, was relatively small with considerable overlap among individuals. Thus, detectability in Rota white-eye may be elevated because of interactions among birds if their home ranges also overlap. In addition, Rota white-eye form foraging flocks (Craig and Taisacan 1994) and may increase their rate of vocalization to maintain contact with flock mates (Powell 1985); both of these behaviors would increase the probability of detection.

Parameter prediction variability helped the assessment of model validity and can also be used to plan future surveys. For instance, despite its prevalence in species models, the site covariate “vegetation” generally demonstrated high CVs for model coefficients (i.e.,  $CV > 0.5$  as averaged for each vegetation factor across species models). This result suggests that more narrowly defined vegetation classifications may better characterize species–land-cover associations and improve predictive modeling. Most land cover types on Rota occur in small patches as a fragmented heterogeneous matrix. Consequently, land cover type was categorized based on the dominant vegetation type at each station, but birds were often detected in other adjacent vegetation types during a point count. Uncertainty in the identity of this covariate could be reduced by recording and modeling the vegetation type in which birds were detected instead of the dominant category at the station. It is likely that increasing the number of vegetation classes would require a concomitant increase in the number of sites sampled to ensure sufficient numbers of detections per class for reliable modeling. The number of stations sampled in future occupancy surveys should be based on the desired levels of coefficient of variation and expected occupancy probability for target species (both of which can be assessed with the Program GenPres, available at <http://www.mbr-pwrc.usgs.gov/software/presence.html>).

The precision of model coefficients also varied considerably by observer, indicating that a particular individual's ability to detect birds differed among species. It may also suggest that a nonrandom assignment of observers to survey transects contributed to dissimilar rates of bird detections (simply as a result of where observers concentrated their sampling relative to species distributions).



Estimates might also be improved by randomly assigning observers to transects on a daily basis to minimize observer familiarity and habituation to the same survey stations over time. Moreover, the average CV for parameter estimates ranged from 0.89 to 3.09 among observers, and this disparity indicates that additional training to standardize observer capabilities would improve survey results. In comparison, sampling covariates such as “cloud cover” and “time of day” had coefficient CVs of  $<0.5$  and indicated that these variables generally performed well for modeling purposes. Substantial differences in observer abilities are common in bird surveys (Diefenbach et al. 2003; Alldredge et al. 2007; Camp 2007) despite observers participating in training and calibration exercises conducted prior to each survey. Heterogeneity among observers originates from several sources, including observers’ experience, familiarity with Rota birds (e.g., many observers were brought in from off-island), hearing ability, and fatigue (Scott et al. 1981; Alldredge et al. 2007). The training and calibration exercises are intended to standardize observers’ abilities for both occupancy- and distance-sampling-based surveys, and these activities should continue until established abilities are met (Scott et al. 1981; Camp 2007).

### Threats

Several threats to forest birds may have contributed to bird population declines, although identifying a causal relationship between population declines and drivers is beyond the scope of these monitoring data. In 1982, Engbring et al. (1986) estimated 60% of Rota was native forest (5,082 ha) while secondary vegetation and *Leucaena* thickets comprised an additional 729 and 24 ha, respectively. Much of the forest at that time was “in an altered condition,” with the best forest restricted to slopes and cliffs along the rim of the Sabana mesa (Engbring et al. 1986:25). By 2005, the extent of native forest had been reduced by 11% to 4,511 ha, while secondary vegetation and *Leucaena* thickets had expanded to 742 ha and 133 ha, respectively (Liu and Fischer 2006). Forest conversion, development, and growing human population resulted in the expansion of nonforested land-use categories, thus reducing the total area of suitable land cover for native birds as well as the Mariana fruit bat *Pteropus mariannus mariannus*. Forest restoration will benefit native birds, especially the frugivorous doves and Mariana crow, which depend on intact forested land-cover types, and may increase resistance to damaging typhoons and resiliency afterward.

Rota lies in what is known as “typhoon alley,” where many tropical storms and typhoons pass over or near the island. For example, 102 tropical storms or typhoons have made direct landfall or passed within 200 km of Rota during the bird-monitoring time series and preceding 5 y ( $\bar{x}$  = 2.8 storms/y, SD = 2.1, range = 0–7; 1977–2012; JTWC Western North Pacific Best Track Data, accessed 13 May 2015; Available: [http://jtwccdn.appspot.com/NOOC/nmfc-ph/RSS/jtwc/best\\_tracks/wpindex.php](http://jtwccdn.appspot.com/NOOC/nmfc-ph/RSS/jtwc/best_tracks/wpindex.php); June 2015). These storms bring heavy rainfall and damaging winds that result in direct impacts, such as nest failure, increased bird mortality, and truncated

breeding seasons, as well as indirect impacts, such as forest destruction and defoliation (Fancy and Snetsinger 2001; Morton and Plentovich 2001; Plentovich et al. 2005). In addition to adversely affecting bird habitat and populations, minor storm events can reduce breeding synchronicity, and major events may increase breeding synchronicity (Morton et al. 1999). Thus, storm events can affect bird detectability, resulting in estimator variability.

On Rota, and elsewhere in the Pacific, declines in bird populations have been attributed to predation by introduced cats *Felis domesticus* and monitor lizards *Varanus indicus*; Amar et al. 2008), and predation and competition by rats *Rattus diardii*, *R. exulans*, and *R. norvegicus* (Atkinson 1985; Fancy and Snetsinger 2001; Wiewel et al. 2009). Harassment and occasional predation by the introduced black drongo has also been recognized as having adverse effects on small bird species (Maben 1982; Amidon 2000; Fancy and Snetsinger 2001; Amar et al. 2008), although declines we observed in drongos suggest that they had little or no effect on other species that declined during the same period. It is very unlikely that the brown tree snake *Boiga irregularis* has adversely impacted Rota birds because the first known record on the island occurred only as recently as 2014 (<https://www.fort.usgs.gov/node/2582>; June 2015) and population declines have not followed the same pattern of avian collapse observed on Guam (Savidge 1987; BirdLife International 2008). An assessment of the impacts of introduced predators has not been conducted on Rota. However, given the large assemblage and high densities of predators, such as rats (Wiewel et al. 2009), it is likely that predators have had adverse effects on Rota birds.

For the Mariana crow, human persecution has been a concern (Plentovich et al. 2005; Zarones et al. 2015). A recent survey by Sussman et al. (2015) revealed that residents harass crows by chasing them off their property and generally have little appreciation for crows or their survival. Sussman et al. (2015) made three recommendations that may help reduce human persecution of crows and other forest birds: 1) develop an education program; 2) revise current land-use regulations; and 3) implement a monetary compensation program for damage to crops or livestock. Persecution of other forest birds on Rota remains undocumented and unknown; however, it seems unlikely that persecution alone could have contributed greatly to the widespread population declines observed across most forest birds.

### Monitoring Implications

Understanding the dynamics of Rota bird species will require more frequent surveys, ideally with more even sampling effort among vegetation types. Identifying the causes behind the decline of many Rota species will require detailed ecological studies. Demographic studies will be needed to determine how bird populations are responding to changing biotic and abiotic factors such as land cover alteration and climate change and facilitate assessing population risk of extinction (Williams et al.



2002). Although causes of the mixed population patterns we observed are likely to be multifactorial and interacting, environmental stochasticity may be critically important in driving bird community assemblage and dynamics in the archipelago, as has been demonstrated analytically for long-studied systems of tropical trees and breeding birds (Kalyuzhny et al. 2014). Evaluating population dynamics with new analytical tools might provide important insights concerning the role of typhoons, for example, in destabilizing bird populations and communities in the Mariana Islands.

The time of year during which surveys were conducted varied across years and may have been carried out when birds were more or less detectable due to behavioral differences among seasons (Simon et al. 2002; Freifeld et al. 2004) or in response to typhoons (Morton and Plentovich 2001). Birds in the Mariana Islands tend to breed asynchronously (Craig 1996; Pyle et al. 2012), but seasonal effects on bird detectability were shown to be present in the Rota surveys. Year was included as a covariate in the final model for the collared kingfisher and Rota white-eye, and year was usually in the top 10 models for other species. For some species, wide differences in detection and abundance were seen between the August and December surveys of 1988. Standardizing the month when surveys are conducted will help to reduce the seasonal differences in bird detectability and produce annual estimates that are more directly comparable by accounting for the time since the last storm influenced bird breeding. Monthly sampling similar to Simon et al. (2002) and Freifeld et al. (2004) could be used to identify the month of peak bird detectability. The occupancy analyses we conducted on the 2012 survey also provides a quantitative metric of species' distribution that can be assessed through time. Criteria for assessing changes in occupancy would strengthen the Rota bird-monitoring program.

In general, additional surveys will increase the statistical power to detect a trend. This is particularly important for the rare and uncommon birds and those species with imprecise annual population estimates. Spatially consistent surveys conducted during the same month every year would maximize the ability to detect trends. Annual surveys would also allow for state-space trend assessment, a technique that partitions the error term into process and observation error components, yielding more accurate trend assessment (Camp et al., in press). Understanding the characteristics that distinguish declining populations from stable populations is critical for managers charged with protecting forest birds on Rota. A monitoring program similar to that developed for the National Park Service Inventory and Monitoring program (Camp et al. 2011) can help with this difficult and complex task if it is designed and implemented to that purpose.

## Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

**Data S1.** Microsoft Excel file containing data used in the analysis of abundance of birds detected during 12 surveys on Rota, Mariana Islands, 1982–2012.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S1> (5.4 MB XLSX).

**Data S2.** Microsoft Excel file containing data used in the analysis of occupancy of birds detected during the 2012 survey on Rota, Mariana Islands.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S2> (248 KB XLSX).

**Table S1.** Sampling conditions describing the weather, which were recorded while conducting avian point-transect surveys on Rota, Mariana Islands, between 1982 and 2012. **(Panel 1)** Cloud cover codes assigned to cloud cover estimates based on 10% categories. **(Panel 2)** Visibility codes describing openness of understory. **(Panel 3)** Description of land cover (vegetation) classes. **(Panel 4)** Rain codes describing intensity of rain. **(Panel 5)** Wind and gust strength codes based on the strength of wind or gust from the Beaufort scale.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S3> (17 KB DOX).

**Table S2.** Detection function models used to derive abundance estimates via avian point-transect distance-sampling surveys on Rota, Mariana Islands, between 1982 and 2012. Models were selected based on the lowest second-order Akaike's Information Criterion value ( $AIC_c$ ) after correcting for small sample size. Base models included half-normal (HN) and hazard-rate (HR) key detection functions with cosine (Cos), hermite polynomial (H-poly), and simple polynomial (S-poly) adjustment terms. Covariates were incorporated with the highest  $AIC_c$ -ranked base model, and included cloud cover, detection type (Det; auditory [A], visual [V], or both [B]), visibility, gust strength, observer, time of detection, rain, wind strength, and year. All covariates were treated as categorical variables, except time of detection was treated as a continuous variable, and year was treated as both a continuous and categorical variable. For each model the number of estimated parameters (# Par), change in  $AIC_c$  ( $\Delta AIC_c$ ),  $AIC_c$ , and estimate of the negative log-likelihood ( $-\text{LogL}$ ) are provided.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S4> (59 KB DOCX).

**Table S3.** Summary of the number of observations or range in values for the site and sampling covariates used in occupancy modeling of the 2012 avian survey on Rota, Mariana Islands.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S5> (15 KB DOCX).

**Table S4.** Occupancy model parameters of the 2012 avian survey on Rota, Mariana Islands. Column  $k$  is the number of model parameters; AIC lists the Akaike Information Criterion values used to rank models based on best fit to the data;  $\Delta AIC$  is the relative difference in AIC values from the model with the smallest value,  $w$  is the AIC model weight, and  $cw$  is the cumulative weight. Column  $\chi^2$  is the test statistic for model fit and  $P$  is the probability of observing a test statistic  $\geq \chi^2$  based upon 999 parametric bootstraps. These values are only presented for models for which  $\Delta AIC \leq 4$  and model

goodness-of-fit was adequate ( $P \geq 0.05$ ). These final models (highlighted in bold) are presented in the text and comprise the subset used for predicting expected occupancy and detection probabilities (Tables S7 and S8, *Supplemental Material*). The dot symbol in the site and sampling covariate columns denote a constant parameter (i.e., modeled as an intercept only). See Methods section for an explanation of covariates and Table S3 for covariate descriptions. Species name abbreviations are YEBI = yellow bittern *Ixobrychus sinensis*, WHITE = white tern *Gygis alba*, ISCD = island collared-dove *Streptopelia bitorquata*, WHGD = white-throated ground-dove *Gallicolumba xanthonura*, MAFD = Mariana fruit-dove *Ptilinopus roseicapilla*, COLK = collared kingfisher *Todiramphus chloris orii*, MIMY = Micronesian myzomela *Myzomela rubrata*, BLDR = black drongo *Dicrurus macrocercus*, RUFA = rufous fantail *Rhipidura rufifrons mariae*, MACR = Mariana crow *Corvus kubaryi*, and ROWE = Rota white-eye *Zosterops rotensis*. The covariates “vegetation,” “visibility,” “elevation,” and “observer” are abbreviated as “veg,” “vis,” “elev,” and “obs,” respectively. Occupancy was not assessed for the Eurasian tree sparrow *Passer montanus*.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S6> (39 KB DOCX).

**Table S5.** Occupancy models used to derive occupancy estimates of the 2012 avian surveys on Rota, Mariana Islands. Coefficients are only presented for the top-ranked models listed in Table S3. These final models are described in the text and comprise the set used for predicting expected occupancy and detection probabilities (Tables S7 and S8). See Methods section for an explanation of covariates and Table S3 for covariate descriptions. Species name abbreviations are YEBI = yellow bittern *Ixobrychus sinensis*, WHITE = white tern *Gygis alba*, ISCD = island collared-dove *Streptopelia bitorquata*, WHGD = white-throated ground-dove *Gallicolumba xanthonura*, MAFD = Mariana fruit-dove *Ptilinopus roseicapilla*, COLK = collared kingfisher *Todiramphus chloris orii*, MIMY = Micronesian myzomela *Myzomela rubrata*, BLDR = black drongo *Dicrurus macrocercus*, RUFA = rufous fantail *Rhipidura rufifrons mariae*, MACR = Mariana crow *Corvus kubaryi*, and ROWE = Rota white-eye *Zosterops rotensis*. The covariates “vegetation,” “visibility,” “elevation,” and “observer” are abbreviated as “veg,” “vis,” “elev,” and “obs,” respectively. The  $P$ -values for significant (0.05 level) covariates and factor levels are highlighted in bold. Occupancy was not assessed for the Eurasian tree sparrow *Passer montanus*.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S7> (69 KB DOCX).

**Table S6.** Indices of occurrence and abundance of birds detected during the 12 avian point-transect surveys on Rota, Mariana Islands, between 1982 and 2012. Relative occurrence was calculated as the number of stations or counts with one or more individuals divided by the total number of stations or counts  $\times 100\%$ . Relative abundance (BPS) was calculated as the total number of on-count detections divided by the number of stations or counts. On-count detections are records of bird detected during the 8-min count with distance estimates. The number of stations or counts conducted during each survey are

presented in Table 2 in the main text. Species name abbreviations are REJU = red junglefowl *Gallus gallus*, RTTR = red-tailed tropicbird *Phaethon rubricauda*, WTR = white-tailed tropicbird *Phaethon lepturus*, YEBI = yellow bittern *Ixobrychus sinensis*, INEG = intermediate egret *Egretta intermedia*, PARH = Pacific reef-egret *Egretta sacra*, GRFR = great frigatebird *Fregata minor*, ABBO = Abbott's booby *Papadula abbotti*, RFBO = red-footed booby *Sula sula*, BRBO = brown booby *Sula leucogaster*, GURA = Guam rail *Gallirallus owstoni*, PAGP = Pacific golden-plover *Pluvialis fulva*, WHIM = whimbrel *Numenius phaeopus*, WATA = wandering tattler *Tringa incana*, RUTU = ruddy turnstone *Arenaria interpres*, BRNO = brown noddy *Anous stolidus*, BLNO = black noddy *Anous minutus*, WHITE = white tern *Gygis alba*, RODO = rock dove *Columba livia*, ISCD = island collared-dove *Streptopelia bitorquata*, WHGD = white-throated ground-dove *Gallicolumba xanthonura*, MAFD = Mariana fruit-dove *Ptilinopus roseicapilla*, COLK = collared kingfisher *Todiramphus chloris orii*, MIMY = Micronesian myzomela *Myzomela rubrata*, BLDR = black drongo *Dicrurus macrocercus*, RUFA = rufous fantail *Rhipidura rufifrons mariae*, MACR = Mariana crow *Corvus kubaryi*, BARS = barn swallow *Hirundo rustica*, ROWE = Rota white-eye *Zosterops rotensis*, MIST = Micronesian starling *Aplonis opaca*, and EUTS = Eurasian tree sparrow *Passer montanus*.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S8> (54 KB DOCX).

**Table S7.** Abundance estimates for select bird species derived from avian point-transect distance-sampling surveys on Rota, Mariana Islands, between 1982 and 2012. Sampling was not consistent across regions (Plateau and Sabana) or surveys. In some years, Plateau estimates were predicted from Sabana surveys using a regression estimator of the correlation between the two areas. Surveys in 1988 and 1989 were based on roadside surveys adjusted using the ratio between simultaneous roadside and off-road surveys conducted in 2012. Estimates were based on 999 bootstrap estimates produced by Program Distance. Point estimate is the mean of the bootstrap samples, and the 95% CI is given by the 2.5 and 97.5 percentiles of the bootstrap population, rounded down for the lower CI and up for the upper CI. Strata in which species do not occur and for which no estimates were made are indicated with a hyphen.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S9> (32 KB DOCX).

**Table S8.** Occupancy model parameters used to estimate occupancy for select avian species of the 2012 avian point-transect survey on Rota, Mariana Islands. Predicted detection probability for final models given a range of input covariate values. For covariates treated as continuous variables, predictions are presented for minimum, mean, and maximum of observed values. The dot symbol in the covariate columns denotes a constant parameter (i.e., modeled as an intercept only). With the exception of the reference null model (e.g., BLDR-0), models for each species are ordered as ranked by AIC (see Table S4). See Methods section for an explanation of covariates and Table S3 for covariate descriptions. Species name abbreviations are YEBI = yellow bittern *Ixobrychus*



*sinensis*, WHITE = white tern *Gygis alba*, ISCD = island collared-dove *Streptopelia bitorquata*, WHGD = white-throated ground-dove *Gallicolumba xanthonura*, MAFD = Mariana fruit-dove *Ptilinopus roseicapilla*, COLK = collared kingfisher *Todiramphus chloris orii*, MIMY = Micronesian myzomela *Myzomela rubrata*, BLDR = black drongo *Dicrurus macrocercus*, RUFA = rufous fantail *Rhipidura rufifrons mariae*, MACR = Mariana crow *Corvus kubaryi*, ROWE = Rota white-eye (*Zosterops rotensis*, and Micronesian starling *Aplonis opaca*. The covariates “vegetation,” “visibility,” “elevation,” and “observer” are abbreviated as “veg,” “vis,” “elev,” and “obs,” respectively. Occupancy was not assessed for the Eurasian tree sparrow *Passer montanus*.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S10> (52 KB DOCX).

**Table S9.** Predicted occupancy probability estimates for the final models of select avian species of the 2012 avian point-transect survey on Rota, Mariana Islands. Predicted occupancy probability for final models given a range of input covariate values. For covariates treated as continuous variables, predictions are presented for minimum, mean, and maximum of observed values. Predictions for covariates with large coefficient standard errors (see Table S5) were not estimable and produced predicted 95% CIs that spanned 0.0 and 1.0; these predictions are indicated with a hyphen. The dot symbol in the covariate columns denotes a constant parameter (i.e., modeled as an intercept only). With the exception of the reference null model (e.g., BLDR-0), models for each species are ordered as ranked by AIC (see Table S4). See Methods section for an explanation of covariates and Table S3 for covariate descriptions. Species name abbreviations are YEBI = yellow bittern *Ixobrychus sinensis*, WHITE = white tern *Gygis alba*, ISCD = island collared-dove *Streptopelia bitorquata*, WHGD = white-throated ground-dove *Gallicolumba xanthonura*, MAFD = Mariana fruit-dove *Ptilinopus roseicapilla*, COLK = collared kingfisher *Todiramphus chloris orii*, MIMY = Micronesian myzomela *Myzomela rubrata*, BLDR = black drongo *Dicrurus macrocercus*, RUFA = rufous fantail *Rhipidura rufifrons mariae*, MACR = Mariana crow *Corvus kubaryi*, ROWE = Rota white-eye *Zosterops rotensis*, and Micronesian starling *Aplonis opaca*. The covariates “vegetation,” “visibility,” “elevation,” and “observer” are abbreviated as “veg,” “vis,” “elev,” and “obs,” respectively. Occupancy was not assessed for the Eurasian tree sparrow *Passer montanus*.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S11> (56 KB DOCX).

**Figure S1.** Species-specific detection function (line), and distance data (histogram) used to derive abundance estimates via avian point-transect distance-sampling surveys on Rota, Mariana Islands, between 1982 and 2012. Detections were pooled across the 12 avian surveys.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S12> (1512 KB DOCX).

**Figure S2.** Species-specific site and sample occupancy coefficients from the best-fit models of the 2012 survey, Rota, Mariana Islands.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S13> (6389 KB DOCX).

**Reference S1.** Berger GM, Gourley J, Schroer G. 2005. Comprehensive wildlife conservation strategy for the Commonwealth of the Northern Mariana Islands. Unpublished Report to the National Advisory Acceptance Team. Portland, Oregon: U.S. Fish and Wildlife Service.

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**Reference S10.** [USFWS] U.S. Fish and Wildlife Service. 2005. Draft revised recovery plan for the Aga or Mariana crow (*Corvus kubaryi*). Portland, Oregon: U.S. Fish and Wildlife Service.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S23> (2711 KB PDF).

**Reference S11.** [USFWS] U.S. Fish and Wildlife Service. 2007. Recovery plan for the Nosa luta or Rota bridled white-eye *Zosterops rotensis*. Portland, Oregon: U.S. Fish and Wildlife Service.

Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S24> (4257 KB PDF).

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Found at DOI: <http://dx.doi.org/10.3996/112014-JFWM-085.S25> (336 KB PDF).

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