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# Density and Abundance of Yellow-shouldered Parrots (*Amazona barbadensis rothchildi*) and Brown-throated Parakeets (*Aratinga pertinax xanthogenius*) on Bonaire, Netherland Antilles

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***Abstract.*** The national abundance estimate of 650 yellow-shouldered parrots ignored incomplete coverage of roosting sites and imperfect detection of roosting birds. Using a random-systematic survey design and combination of counting methods that accounted for incomplete coverage and imperfect detection, we estimated an average density of 0.34−0.38 parrots/hectare and added more than 1,000 individuals to the national abundance estimate (e.g., lower 95% CI of $\hat{N} = 0.22 \times 7{,}873 = 1{,}732$). In comparison, the estimated density of brown-throated parakeets was 1.3/hectare (95% CI = 0.85 to 1.98), meaning 10,215 individuals (95% CI = 6,700 to 15,576) in a survey region covering 7,873 hectares. Parakeets were highly abundant and widely distributed. Parrots also were widespread but much less abundant than parakeets, particularly in highly disturbed urban-agriculture areas. Although estimated density was high, the Bonaire parrot population is at high risk of extinction due to geographical isolation and the

negative effects of habitat destruction, poaching, and other human-induced disturbances on a small island with limited resources for successful reproduction and survival. In this report, we give recommendations to establish a long-term monitoring program for psittacids and other landbirds inside and outside the Washington-Slaagbai National Park.

## Introduction

Geographical isolation and small population size increase the risk of extinction of psittacids on islands (e.g., Beissinger et al. 2008). The island of Bonaire is outside the Caribbean hurricane belt, but prolonged dry periods, food limitation, poaching, predation, and habitat loss may be important factors driving the dynamics of psittacid populations that are closed to immigration and emigration. The yellow-shouldered parrot and brown-throated parakeet are well-established endemic subspecies, and thus long-term research and monitoring should be a priority for local organizations responsible for wildlife management and conservation.

Previous estimates of population size were based on incomplete roost-count data not adjusted for detection probability (e.g., Harms and Eberhard 2003, Williams 2004, Birdlife International 2008; also see www.stinapa.org/nee/lora.html). Unadjusted counts confound abundance and detection and do not provide valid estimates of population size or rate of change, unless detection probability is 1 or remains constant across time or space (Thompson et al. 1998; Williams et al. 2002; Buckland et al. 2001, 2004, 2008; Royle and Dorazio 2008; Nichols et al. 2009). Detection probability is rarely 1 or constant due to observer, species, and environment covariates. Moreover, it is unlikely that small and large roosts are equally detectable and have the same chance of being sampled to make valid inferences about population numbers. Not all parrots and parakeets use the same roosts yearly, and roosting behavior and roost-site occupancy may change seasonally, depending on food availability (e.g., highly patchy in dry periods and more evenly spaced in wet periods).

This survey was motivated by the lack of adequate count data for psittacids, which may serve as biological indicators of the health dry forests on Bonaire, and the need to design and establish a monitoring program to assess population status and trends to promote informed management decisions and actions. Wildlife managers often use density estimates to establish population objectives and evaluate the result of management actions (e.g., experiments with artificial and natural cavities to increase the number and productivity of breeding pairs). Distance sampling provides a well-tested and flexible theoretical framework for density estimation and modeling (Buckland et al. 2001, 2004, 2008; Buckland 2006; Alldredge et al. 2007*a*; Marques et al. 2007). We conducted point-transect distance sampling to estimate the densities of yellow-shouldered parrots and brown-throated parakeets on Bonaire in December 2009. Our main goal was to estimate their densities in the Washington-Slaagbai National Park and surrounding areas in Brasil, Karpata, Dos Pos, Rincón, and Fontein. However, because we were also interested in estimating densities at the level of sample units (points), the distance sampling method was extended by recording site-specific covariates (Hedley and Buckland 2004; Royle et al. 2004; Royle 2004*a*, *b*; Royle and Dorazio 2008).

## Study Area and Methods

The island of Bonaire lies between N12°18.981', W68°23.764' (Malmok) and N12°01.728', W68°15.281' (Pekelmeer), about 85 kilometers off the north-west coast of Venezuela. It is 35 kilometers long and 8−15 kilometers wide, covering about 288 square kilometers (28,800 hectares). The highest elevation is Seru Brandaris with 241 meters above sea level. Rainfall varies significantly between localities and years, falling mostly between October and December (De Freitas et al. 2005). The vegetation is xerophytic. Common plants include: *Pilosocereus lanuginosus*, *Subpilocereus repandus*, *Ritterocereus griseus*, *Opuntia* spp., *Melocactus* spp., *Crescentia cujete*, *Bourreria succulenta*, *Capparis odoratissima*, *Caesalpinia coriaria*, *Acacia tortuosa*, *Randia aculeata*, *Prosopis juliflora*, *Bursera simaruba*, and *Guaiacum officinale*.

The main survey area was within the boundaries of the Washington-Slaagbai National Park, covering about 54 square kilometers (5,400 hectares) at the northern side of Bonaire (Figure 1). However, we also surveyed areas outside the park with the idea of expanding future surveys throughout the island. The impact of introduced animals (goats, pigs, donkeys) on the vegetation and soils was evident everywhere from the salinas to the highest hills.

### Distance sampling

Conventional distance sampling is based on estimation of a detection function, $\hat{g}(r)$ in the case of point transects, which decreases with distance ($r$) and is needed to estimate probability of detection in the surveyed area ($\hat{P}a$; where $a = \pi r^2$). By definition, $g(r)$ is the conditional probability of detecting a single bird or cluster of birds, given radial distance ($r$) from a random point ($P[d|r]$). We extended conventional distance sampling by modeling detection as a function of distance ($r$) and other covariates (i.e., $g[r, \mathbf{z}]$; Buckland et al. 2004, Marques et al. 2007).

We surveyed 62 points ($k$) inside and outside the park. The survey region ($A$) covered 7,873 hectares (Figure 1). Points were located random-systematically using a 1-

square kilometer grid (100 hectares), along or near secondary and tertiary roads or trails (0-100 meters), and far from roads, trails, houses or any other development (over 200 meters). The minimum distance between points was 400−500 meters. Survey effort/point accounted for repeated visits ($v$) and the approximate proportion of the circle of radius $r$ ($\pi r^2$ or $[\pi - \psi/2]r^2$) that was considered potential habitat for psittacids (i.e., $v \times [1 - \psi/2\pi]$; Buckland et al. 2001). Two-observers surveyed all points, with an observer recording the data (FS) and the other measuring detection distances (FFRM). To meet the assumptions of distance sampling (e.g., $g[0] = 1$, detection at initial locations, accurate distance measurements) the observers remained side by side for 6 minutes, recording aural and visual detections, and measuring distances from points to birds detected singly or the geometric center of clusters (2 or more birds).

Six minutes provided an adequate snapshot to detect most calling birds visually in sparse or dense vegetation. An aural detection was one for which there was no visual contact with the calling bird. In that case, we measured the distance to the nearest location. Rangefinders were used to measure exact distances; but when this was not possible, we grouped detection distances into 10 categories (0–15, 16–30, 31–45, 46–60, 61–90, 91–120, 121–180, 181–240, 241–340, and 341–440 m; Rivera–Milán et al. 2003*a*, 2005). We recorded the angles and time periods of aural and visual detections (see below), and counted but did not include flying birds in density estimates, unless their initial locations were determined during or immediately after the 6-minute counts.

We surveyed points from sunrise to midmorning and from midafternoon to sunset to increase the chance of detecting birds given their availability within 440 meters from points. We truncated the distance data ($w$ = 160 meters) to reduce size-bias effect, remove outliers, and improve the fit of detection models. We evaluated the fit of detection models (uniform, half-normal, and hazard-rate key functions without adjustment and cosine or polynomial adjustment terms) to data with quantile–quantile plots and goodness-of-fit tests (Buckland et al. 2001, 2004). Model selection was based on minimization of Akaike's Information Criterion (AIC or $AIC_c$). Models with differences in AIC or $AIC_c$ values $\leq 2$ were considered equally supported by the data. We used nonparametric bootstrapping ($B = 999$ resamples) for robust estimation of standard errors (SE) and 95% confidence intervals (CI), and to account for model selection uncertainty through model averaging.

The half-normal and hazard-rate key functions without adjustment terms were used to account for factor (discrete) and nonfactor (continuous) covariates affecting detection (e.g., cluster size, time of day, point location [0 = on-road, 1 = off-road], form of detection [0 = aural, 1 = visual], time period [1 = 0–3 min, 2 = 3–6 min], disturbance [0 = none, 1 = low, 2 = medium, 3 = high], and vegetation cover [0 = open, 1 = 0–25%, 2 = 26–50%, 3 = 51–75%, 4 = 76–100%]). Time of day was treated as a factor covariate (e.g., 1 = 06:30 to 8:30 or 16:31 to 18:30, 2 = 08:31 to 10:30 or 15:30 to 16:30 hours) and as a nonfactor covariate (e.g., minutes after sunrise or minutes before sunset). We analyzed the data of parrots and parakeets using a common detection function (no species effect); with different detection functions (species effect) using post-stratification (observation layer); and using a detection function with a common shape and species as a covariate (scale parameter). For this analysis, we used program Distance 6.0 Release 2 (Thomas et al. 2009).

Based on the observed coefficient of variation (CV $\hat{D}$) and dispersion parameter ($\hat{b}$ = CV² × $n$), we calculated the number of points ($k$) that would need to be surveyed to have a desired coefficient of variation < 0.2 for the estimated density of yellow-shouldered parrots. For additional information about survey design and estimation methods, see Buckland et al. (2001, 2004, 2008), Marques et al. (2007), and Thomas et al. (2009).

**Removal-count sampling**

We recorded aural and visual detections in successive 1-minute intervals and used binomial-Poisson mixture models to estimate detection probability ($\hat{P}$), abundance ($\hat{\lambda}$), and density/point ($\hat{\lambda}/\pi w^2$; $w$ = 160 meters or 8.04 hectares/point). Birds were removed from counts after first detection (Royle 2004*a*). For example, detection history 0, 0, 0, 2, 0, 0 meaning no detections in the first 3 minutes, 2 birds detected for the first time in the 4rth minute, and no new detections in the last 2 minutes.

We considered successive 1-minute counts ($C_{ij}$) binomial random variables with index $N_i$ (abundance at point i) and detection probability $P_{ij}$ (j repeated counts at point i). That is, $g(C_i|N_i,P_{ij} = \Pi\ Bin(C_{ij}||P_{ij})$. The $N_i$ values were defined as random effects with point abundance distribution $f(N_i;\theta)$, and estimation and inference focused on parameter(s) θ. We assumed that $N_i$ followed a Poisson distribution with mean λ, and modeled abundance as a function of covariates (see below) to account for extra-Poisson variation in λ (over-dispersion) expressed as an additive normal random effect for log(λ). That is, $\log(\lambda_i) = \alpha + \sum\beta x_{ij}$. We used a linear logistic relationship to account for covariates affecting detection. That is, $\text{logit}(P_{ij}) = \alpha + \beta x_{ij}$.

We explored the effect of multiple covariates on parrot abundance (e.g., brown-throated parakeet [0 = not detected, 1 = detected], food abundance [0 = none, 1 = low 2 = low–medium, 3 = medium–high, 4 = high], habitat availability [0 = open, 1 = 0–25%, 2 = 26–50%, 3 = 51–75%, 4 = 76–100%], disturbance [0 = open, 1 = 0–25%, 2 = 26–50%, 3 = 51–75%, 4 = 76–100%], and habitat suitability index [food abundance + habitat availability – disturbance]). We indexed habitat type as dry forest (1, 0, 0), dry shrub (0, 1, 0), urban-agriculture (0, 0, 1), other (0, 0, 0) or more than 1 type (e.g., 1, 1, 0 for mixed dry forest and shrub without urban-agriculture). We expected a positive relationship between parrot density and food abundance and habitat availability (e.g., dry forest); and a negative relationship between density and disturbance (e.g., predators and other threats). Because psittacids use similar foraging resources, we also expected a positive relationship between parrot density and the presence or number (raw count) of parakeets at surveyed points. For this analysis, we used 'Royle Biometrics' option in program PRESENCE 2.2 (Royle 2004*b*, Bailey et al. 2007).

We conducted surveys in a manner that is compatible with multiple methods and analyses (e.g., Buckland et al. 2004, Hedley and Buckland 2004, Royle et al. 2004, Alldredge et al. 2007*b*, Kéry 2008, Webster et al. 2008). In this report, however, we concentrate on the use of distance sampling and removal-count sampling based on maximum likelihood estimation (for detailed information about models and estimators, see Buckland et al. 2001, 2004; Royle and Dorazio 2008). Other analyses will be presented in future reports and publications. We also surveyed a selected group of landbirds (e.g., pearly-eyed thrashers), but the main target was the psittacids, particularly the yellow-shouldered parrot, which is considered vulnerable (Birdlife International 2008).

## Results

### Distance sampling

We analyzed the distance data of yellow-shouldered parrots and brown-throated parakeets separated and combined to increase sample size and explore the effect of covariates on detection. The hazard-rate key function without adjustments or covariates fitted the data adequately (Kolmorov-Smirnov test, Cramer-von Mises family tests, and $\chi^2$ test; all $P$ values > 0.25; Figure 2*a*–*c*). Detection probability was about 1 up to 40 meters; but it dropped to about 0.5 between 40 and 60 meters; and was only about 0.1 at 160 meters from point centers (Figure 2*b*, *c*).

Based on sample size, model fit, and coefficient of variation of density estimates, we truncated the distance data at $w = 160$ meters. The hazard-rate key function without adjustments or covariates best fitted the data (Kolmorov-Smirnov test, Cramer-von Mises family tests, and $\chi^2$ test; all $P$ values > 0.25; Table 1, Figure 3*a*–*c*). Models with covariates did not receive strong support from the data (Table 1).

Density was 0.37 parrots/hectare (SE = 0.09, 95% CI = 0.22 to 0.6) and 1.3 parakeets/hectare (SE = 0.28, 95% CI = 0.85 to 1.98), and population size was 2,872 parrots (SE = 714, 95% CI = 1,757 to 4,694) and 10,215 parakeets (SE = 2,204, 95% CI = 6,700 to 15,576) in 7,873 hectares (Table 2). There was negative size-bias for parakeet cluster detection ($r = -0.18$, df = 106, $P$ value = 0.03) but not for parrot cluster detection ($r = 0.21$, df = 37, $P$ value = 0.9). Mean cluster size was 2.69 parrots (SE = 0.21, 95% CI = 2.3 to 3.15) and expected mean size of cluster was 2.22 parakeets (SE = 0.16, 95% CI =

1.93 to 2.55). Encounter rate was 0.32 for parrots (SE = 0.05, 95% CI = 0.23 to 0.43) and 0.87 for parakeets (SE = 0.08, 95% CI = 0.72 to 1.05). Detection probability and effective detection radius were 0.29 (SE = 0.05, 95% CI = 0.2 to 0.41) and 86 meters (SE = 8, 95% CI = 72 to 103) for parrots and 0.19 (SE = 0.03, 95% CI = 0.13 to 0.26) and 68 meters (SE = 6, 95% CI = 58 to 82) for parakeets.

With an observed coefficient of variation (CV $\hat{D}$) = 0.24 and a dispersion parameter ($\hat{b}$) = 4, we needed to survey about 300−400 points (*k*) to have a desired coefficient of variation < 0.2 (Figure 4). Parrot clusters were highly clumped during the nonbreeding period of the year. Parakeet clusters were also highly clumped ($\hat{b}$ = 5, CV $\hat{D}$ = 0.22).

### Removal-count sampling

There was a weak but positive correlation between the unadjusted point-count data of yellow-shouldered parrots and brown-throated parakeets (Figure 5*a*). Parrot density was positively influenced by habitat suitability and the presence of dry forest and shrubland; and it was negatively influenced by the presence of urban and agriculture areas with sparse vegetation due to grazing by goats and other domestic animals (Table 3, Figure 5*b*, *c*). Based on AIC values, the model with habitat suitability and time of day covariates received less support from the data than the model with habitat type and constant detection in 1-minute counts (Table 3). However, we provide parameter estimates of yellow-shouldered parrots generated from both removal-count sampling models for comparison with distance sampling models (see Tables 2 and 4).

Parrot density was 0.34/hectare (SE = 0.08, 95% CI = 0.22 to 0.53) and 0.38/hectare (SE = 0.08, 95% CI = 0.25 to 0.58) and population size was 2,647 (SE =

607, 95% CI = 1,697 to 4,131) and 2,981 (SE = 661, 95% CI = 1,938 to 4,583) in 7,873 hectares (Models 1 and 2 in Table 4). Detection probability within 160 meters ranged from 0.11 (SE = 0.02, 95% CI = 0.07 to 0.17) to 0.13 (SE = 0.03, 95% CI = 0.09 to 0.19). The naïve estimate of occupancy (number of points with parrots/total number of points) was 0.36. When we accounted for imperfect detection (false absence), occupancy ranged from 0.93 (SE = 0.22, 95% CI = 0.82 to 0.96) to 0.95 (SE = 0.21 , 95% CI = 0.86 to 0.99). That is, even if at low densities (Figure 5*c*), parrots were widespread and able to occupy highly disturbed habitats (e.g., urban-agriculture areas in Dos Pos and Fontein).

## Discussion

Based on roost-counts, the yellow-shouldered parrot population was considered to be about 650 individuals on Bonaire (Birdlife International 2008). These roost-counts, however, were not adjusted for differences in the detection probability of parrot singles and clusters, which is needed to estimate density (number/unit area), population size (number in a defined area), and rate of change over time (trend). Unadjusted counts confound abundance and detection ($N = C/P$) and do not provide a valid index of rate of change in population size ($E[C_2/C_1] = [N_2P_2]/[N_1P_1]$) unless detection is 1 or remains constant across samples (i.e., $N_2/N_1$ only if $P_1 = P_2$). In addition, it is unlikely that small and large roosts are equally detectable or available for sampling, and roosting behavior and roost-site occupancy may change seasonally (e.g., before and after reproduction) and annually (e.g., dry and wet years). Our survey data showed that roost-counts seriously underestimated the size of the parrot population on Bonaire.

Standardization of monitoring protocols and counting methods may reduce or eliminate some of the bias of roost-counts, but the assumption of perfect detection or constant proportionality is not likely to be met for parrots and parakeets. There was a sharp decline in the detection probability of both species beyond 40 meters from point centers. However, the effective radius of detection of parrots was somewhat larger than that of parakeets, because most parrot detections occurred while they were far away perching or feeding on cactus fruits (e.g., *Subpilocereus repandus* and *Ritterocereus griseus*). Parakeets also were perching or feeding on cactus fruits, but we detected many clusters near point centers in dense vegetation (e.g., *Prosopis juliflora*, *Randia aculeata*, *Capparis odoratissima*, *Caesalpinia coriaria*, and *Acacia tortuosa*).

The density and encounter rate of parakeets were about 3−4 times higher than those of parrots. Not surprisingly, parakeet density variation was mainly explained by factors related to detection probability (70%), and less importantly by factors related to encounter rate (20%) and cluster size (10%). Parrot density variation was explained by factors related to detection probability (49%) and encounter rate (41%), followed by cluster size (10%). Parakeets were highly abundant and widely distributed. Parrots also were widespread but much less abundant than parakeets, particularly in highly disturbed urban-agriculture areas. Parrot density was highest in areas with tall trees and columnar cacti mixed with shrubs, and lowest in urban-agriculture areas with sparse vegetation. However, parrots are highly adaptable and can aggregate in urban-agriculture areas where fruits are seasonally available (e.g., *Mangifera indica*, *Tamarindus indica*, and *Melicoccus bijigatus*; Williams 2004, Rivera−Milán et al. 2005).

It is encouraging that distance sampling and removal-count sampling gave similar density estimates for yellow-shouldered parrots. These methods use different theoretical frameworks (for an introduction, see Buckland et al. 2001, 2008; Royle 2004*a*; Royle et al. 2005; Marques et al. 2007; and for a review, see Nichols et al. 2009). We propose that this was the result of careful design and method application by experienced observers working as a team to maximize detection but not at the expense of meeting critical method assumptions. For example, we gave particular attention to accurate measurement of distances less than 120–180 meters from point centers. More importantly, we feel confident that all birds at or near points (0−15 meters) were detected by both observers (i.e., $g(0) = 1$). We minimized bias related to movement within the defined area of the point ($\pi w^2 = 8.04$ hectares) during the 6-minute count period by recording time, angle, and distance of first detection, and not including in density estimates any moving bird for which we could not determine initial location exactly or approximately using distance categories (0−15, 16−30, …, 341−440 meters). Truncation of data at 160 meters from points also helped with the accuracy of cluster size estimates. Moreover, by virtue of a random-systematic design (Thompson et al. 1998; Williams et al. 2002; Buckland et al. 2001, 2004), we consider the combination of on-road and off-road points representative of the density and abundance of psittacids over the entire survey region ($A = 7,873$ hectares).

In summary, the previous national population size estimate of 650 parrots ignored incomplete coverage of roosting sites and imperfect detection of roosting birds. Using a random-systematic design and combination of counting methods that accounted for incomplete coverage and imperfect detection, we added more than 1,000 parrots to the national estimate (e.g., lower 95% CI of $\hat{N} = 0.22 \times 7,873 = 1,732$). Improvements of naïve national abundance estimates have been reported for pigeons on Puerto Rico (Rivera−Milán et al. 2003*a*, *b*), parrots on Great Abaco and Great Inagua in the Bahamas

(Rivera−Milán et al. 2005) and Grand Cayman and Cayman Brac in the Caymans (F. F. Rivera−Milán, K. Godbeer, and M. Cottam, unpublished data), as well as for landbirds in Switzerland (Royle et al. 2007) and the United Kingdom (Newson et al. 2008).

The estimated density of yellow-shouldered parrots on Bonaire is comparable to that of Grand Cayman parrots (*Amazona leucocephala caymanensis*; $\hat{D}$ = 0.27, 95% CI = 0.20 to 0.35). Nevertheless, although both subspecies have high densities, their populations remain at high risk of extinction due to geographical isolation and the negative effects of habitat destruction, poaching, and other human-induced disturbances on small islands with limited resources for successful reproduction and survival.

## Recommendations

This survey was just a snapshot of the psittacid populations of Bonaire. In fact, this snapshot was taken during the rainy season, when parrots were not nesting, and were highly clumped in areas of food abundance. Surveys can be more effective ($n/K$) and precise (CV $\hat{D}$) when parrots have a more regular spatial distribution ($\hat{b}$). Here we give recommendations to establish a long-term monitoring program for psittacids and other landbirds inside and outside the Washington-Slaagbai National Park. The same survey scheme can be used for a selected group of landbirds (say, the 10 top priorities), although we are focusing on the yellow-shouldered parrot.

1) Increase the staff of STINAPA Natural Resources Unit to create additional 2-observer teams. Given the size of the island, 2 teams can greatly increase the effectiveness of survey effort.
2) In 2010, instead of sampling 300−400 points, which may not be feasible with the monetary and human resources available, we recommend sampling 150 points

immediately before and after reproduction to determine if surveys are more effective ($n/K > 0.4$) and precise (CV $\hat{D} < 0.2$) when parrots are more regularly spaced ($\hat{b} = 1-3$). These surveys can be used to monitor rate of change over time in a less expensive manner than having to estimate recruitment and survival separately. That is, $\hat{R}\text{t} = \hat{D}\text{t+1}/\hat{D}\text{t}$ or births − deaths in a closed population.

3) Randomization, replication, independence, and stratification are important elements of survey sampling design that should be helpful to optimize survey effort. We recommend stratifying Bonaire (north, central, south) and random-systematically allocating 50% of the points ($k = 75$) in the northern part (Washington-Slaagbai National Park, Brasil, Karpata, Dos Pos, Rincón), 30% of the points ($k = 45$) in the central part (Onima, Fontein, Bolivia, Seru Largu, Seru Grandi and surrounding areas), and 20% of the points ($k = 30$) in the southern part (Washikemba, Kralendijk, Flamingo Airport, Lima, Bakuna and surrounding areas).
4) All survey points should be georeferenced and included in a detailed GIS map of Bonaire. In 2010, a new survey region ($A$) should be defined to estimate density and abundance island-wide. A land cover map is needed to determine the total area of potential habitat, as well as the total area that has extremely low or no potential of being occupied at any time of the year (e.g., salt flats, low scrub, and bare soil areas in the southern end of the island). For the purpose of the survey, parrot habitat should include any area that can be potentially inhabited at any time of the year for nesting, roosting and/or feeding. For example, this should include

coastal areas with *Coccoloba uvifera* and other plants that provide food seasonally.

5) Integrate monitoring with long-term research and management efforts inside and outside the national park. For example, telemetry data can be collected to determine seasonal movements and estimate home range and demographic parameters during the breeding and nonbreeding periods of the year. Management experiments with artificial nest boxes and the creation and restoration of tree cavities can improve our understanding of population ecology (e.g., carrying capacity, growth rate, density dependence). Remote cameras can also be used for nest monitoring to estimate nest survival and productivity and identify avian and mammalian predators. These types of data are needed to assess population viability in the face of environmental random variation and human-induced disturbances (Lande et al. 2003, Rodríguez et al. 2004, Beissinger et al. 2008).
6) Rainfall and food abundance are key factors driving the dynamics of bird populations in dry ecosystems (e.g., Grant 2009). The same survey design and counting methods can be used to estimate the abundance, density, and occupancy of other landbirds. For example, occupancy models can be used to explore species interactions of parrots, parakeets, and pigeons, as well as those of thrashers, troupials, orioles, and mockingbirds during dry and wet years (MacKenzie et al. 2006; F. F. Rivera−Milán et al., unpublished data).

7) Because monetary and human resources are limited, research and monitoring efforts should target specific management objectives in an adaptive manner (Nichols and Williams 2006, Lindenmayer and Likens 2009).

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Table 1. Akaike's Information Criterion for detection models fitted to the combined point-transect survey data of yellow-shouldered parrots and brown-throated parakeets collected on Bonaire in December 2009. Data truncated at distance *w* = 160 meters.

| Key function + adjustment term (covariate) | AICc | ΔAICc |
|---|---|---|
| Hazard-rate without adjustment or covariate | 1,445.73 | 0.00 |
| Hazard-rate without adjustment (time period) | 1,448.34 | 2.60 |
| Hazard-rate without adjustment (time of day) | 1,448.36 | 2.62 |
| Hazard-rate without adjustment (species) | 1,448.37 | 2.64 |
| Hazard-rate without adjustment (vegetation cover) | 1,448.38 | 2.64 |
| Hazard-rate without adjustment (point location) | 1,448.38 | 2.64 |
| Hazard-rate without adjustment (cluster size) | 1,448.38 | 2.64 |
| Hazard-rate without adjustment (detection form) | 1,448.38 | 2.65 |
| Half-normal without adjustment (time period) | 1,451.92 | 6.19 |
| Half-normal without adjustment (detection form) | 1,456.08 | 10.35 |
| Half-normal without adjustment (species) | 1,456.78 | 11.04 |
| Half-normal without adjustment or covariate | 1,457.02 | 11.28 |
| Half-normal without adjustment (time of day) | 1,457.83 | 12.09 |
| Half-normal without adjustment (cluster size) | 1,458.33 | 12.60 |
| Half-normal without adjustment (vegetation cover) | 1,458.85 | 13.11 |
| Half-normal without adjustment (point location) | 1,458.98 | 13.25 |

Table 2. Parameter estimates ± SE of yellow-shouldered parrots and brown-throated parakeets based on point-transect survey data collected on Bonaire in December 2009.

| | Species | |
|---|---|---|
| Parameter estimate | Yellow-shouldered parrot | Brown-throated parakeet |
| Density ($\hat{D}$)[a] | 0.37 ± 0.09 | 1.30 ± 0.28 |
| Population size ($\hat{N}$)[b] | 2,872 ± 714 | 10,215 ± 2,204 |
| Cluster size ($\bar{s}$ or $\hat{E}[s]$) | 2.69 ± 0.21 | 2.22 ± 0.16 |
| Encounter rate ($n/K$)[c] | 0.31 ± 0.05 | 0.87 ± 0.08 |
| Detection probability ($\hat{P}a$)[d] | 0.29 ± 0.05 | 0.19 ± 0.03 |
| Effective detection radius ($\hat{p}$)[e] | 86 ± 8 | 69 ± 6 |

[a] Number of birds/hectare ($\hat{D}$) = $n\hat{h}(0)\bar{s}/2\pi k$; $n$ = number of singles or clusters; $\hat{h}(0)$ = slope of the estimated density function of radial distances ($\hat{f}[r]$), evaluated at $r = 0$; $k$ = number of points surveyed; $\bar{s}$ = mean cluster size in the absence of negative size bias for parrots. Expected mean size of clusters in the population in the presence of negative size bias for parakeets.

[b] Number of birds in the survey region ($A$) = 7,873 hectares (i.e., $\hat{N} = .\ \hat{D} \times A$).

[c] Number of single and cluster detections divided by survey effort.

[d] Probability of detection in a defined area ($\hat{P}a$) = $2/w^2 \int_0^w r\hat{g}(r)\,dr$.

[e] Effective detection radius ($\hat{p}$) = $w \times (\hat{P}a)^{0.5}$; $w$ = 160 meters.

Table 3. Akaike's Information Criterion for models fitted to the removal-count sampling data of yellow-shouldered parrots collected on Bonaire in December 2009.

| Parameter (covariate) | AIC | ΔAIC |
|---|---|---|
| $\hat{\lambda}$ (habitat type), $\hat{P}$ | 644.82 | 0.00 |
| $\hat{\lambda}$ (habitat suitability), $\hat{P}$ (time of day) | 649.56 | 4.74 |
| $\hat{\lambda}$ (disturbance), $\hat{P}$ | 658.29 | 13.47 |
| $\hat{\lambda}$ (point location), $\hat{P}$ | 664.58 | 19.76 |
| $\hat{\lambda}$ (habitat suitability), $\hat{P}$ | 665.71 | 20.89 |
| $\hat{\lambda}$ (urban-agriculture), $\hat{P}$ | 665.80 | 20.98 |
| $\hat{\lambda}$, $\hat{P}$ (time of day) | 667.07 | 22.25 |
| $\hat{\lambda}$ (habitat availability), $\hat{P}$ | 668.66 | 23.84 |
| $\hat{\lambda}$ (dry forest), $\hat{P}$ | 673.13 | 28.31 |
| $\hat{\lambda}$ (brown-throated parakeet), $\hat{P}$ | 679.67 | 34.85 |
| $\hat{\lambda}$ (food abundance), $\hat{P}$ | 688.04 | 43.22 |
| $\hat{\lambda}$, $\hat{P}$ | 689.66 | 44.84 |
| $\hat{\lambda}$ (dry shrub), $\hat{P}$ | 690.38 | 45.56 |
| $\hat{\lambda}$, $\hat{P}$ (point location) | 995.67 | 350.85 |
| $\hat{\lambda}$ (habitat), $\hat{P}$ (time of day) | 1,102.85 | 458.03 |

Table 4. Parameter estimates ± SE of yellow-shouldered parrots based on removal-count sampling data collected on Bonaire in December 2009.

| <u>Model</u><br>Parameter (covariate) | Point estimate ± SE |
|---|---|
| Model 1 | |
| $\hat{\lambda}$ (habitat type), $\hat{P}$ [a] | |
| Density ($\hat{D}$)[b] | 0.34 ± 0.08 |
| Population size ($\hat{N}$)[c] | 2,647 ± 607 |
| Detection probability ($\hat{P}$) | 0.13 ± 0.03 |
| Occupancy ($\hat{\Psi}$)[d] | 0.93 ± 0.22 |
| B̂0 [e] | −1.908 ± 0.228 |
| B̂1 | −19.989 ± 12.940 |
| B̂2 (dry forest) | 21.268 ± 12.940 |
| B̂3 (dry shrub) | 0.449 ± 0.346 |
| B̂4 (urban-agriculture) | −2.588 ± 0.705 |
| Model 2 | |
| $\hat{\lambda}$ (habitat suitability), $\hat{P}$ (time of day) | |
| Density ($\hat{D}$) | 0.38 ± 0.08 |
| Population size ($\hat{N}$) | 2,981 ± 661 |
| Detection probability ($\hat{P}$) | 0.11 ± 0.02 |

Table 4 (continued)

| | |
|---|---|
| Occupancy ($\hat{\Psi}$) | 0.95 ± 0.21 |
| $\hat{B}0$ | −0.258 ± 0.477 |
| $\hat{B}1$ | −0.263 ± 0.511 |
| $\hat{B}2$ (habitat suitability) | 0.399 ± 0.095 |
| $\hat{B}3$ (time of day)[f] | −2.588 ± 0.705 |

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[a] Abundance ($N_i$ or lambda/point) and detection probability based on binomial-Poisson mixture models.

[b] Number of birds/hectare.

[c] Number of birds in survey region ($A$) = 7,873 hectares. That is, $\hat{N} = . \hat{D} \times A$.

[d] Under the Poisson model, estimated occupancy ($\hat{\Psi}$) = $1 - \exp(-\hat{\lambda})$.

[e] Untransformed (beta) parameter estimates.

[f] 1 = 06:30 to 8:30 or 16:31 to 18:30, 2 = 08:31 to 10:30 or 15:30 to 16:30 hours.

Figure 1. Map showing 45 random-systematic points (*k*) at Washington-Slaagbai National Park, Brasil, and Karpata. Seventeen additional points were surveyed between Brasil, Karpata, Dos Pos, Rincón, and Fontein. Survey region (*A*) = 7,873 hectares.

Figure 2. Quantile−quantile plot showing the fit of the hazard-rate key function without series expansions to the distance data of yellow-shouldered parrots and brown-throated parakeets (A), and histograms of detection probability (B) and probability density function (C). Sample size (*n*) = 182 (65 parrot and 117 parakeet detections).

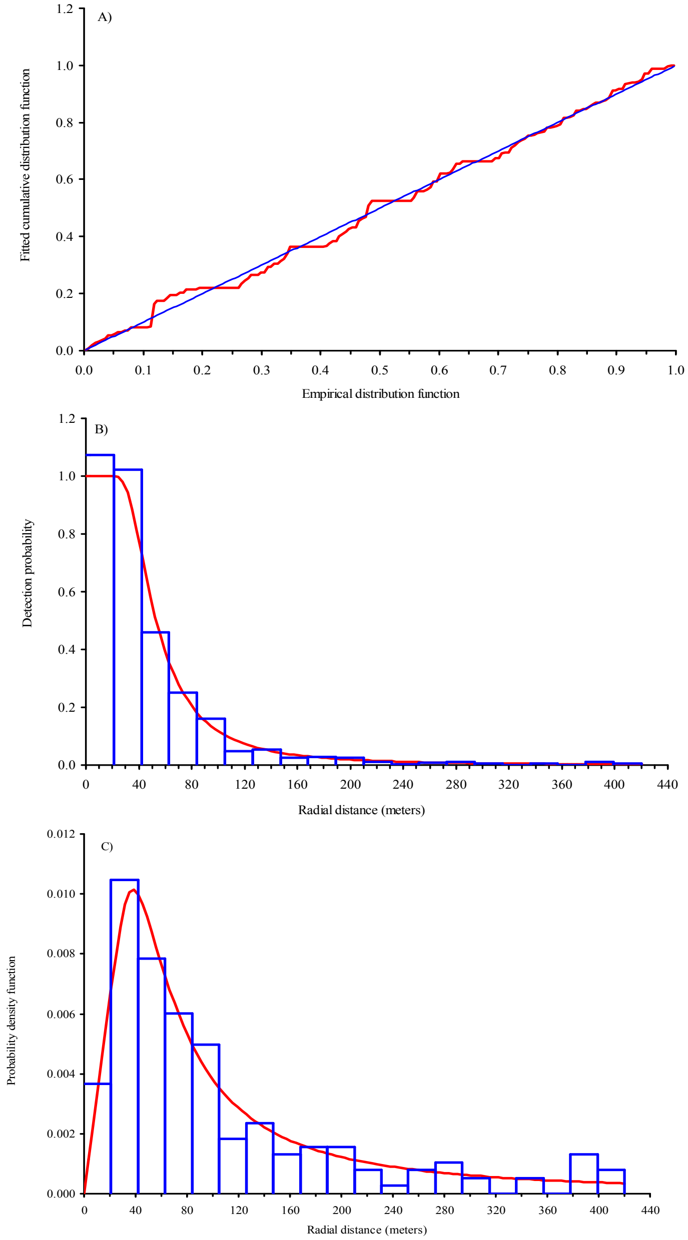

Figure 3. Quantile−quantile plot showing the fit of the hazard-rate key function without series expansions to the distance data of yellow-shouldered parrots and brown-throated parakeets (A), and histograms of detection probability (B) and probability density function (C). Sample size (*n*) = 147 (39 parrots and 108 parakeet detections).

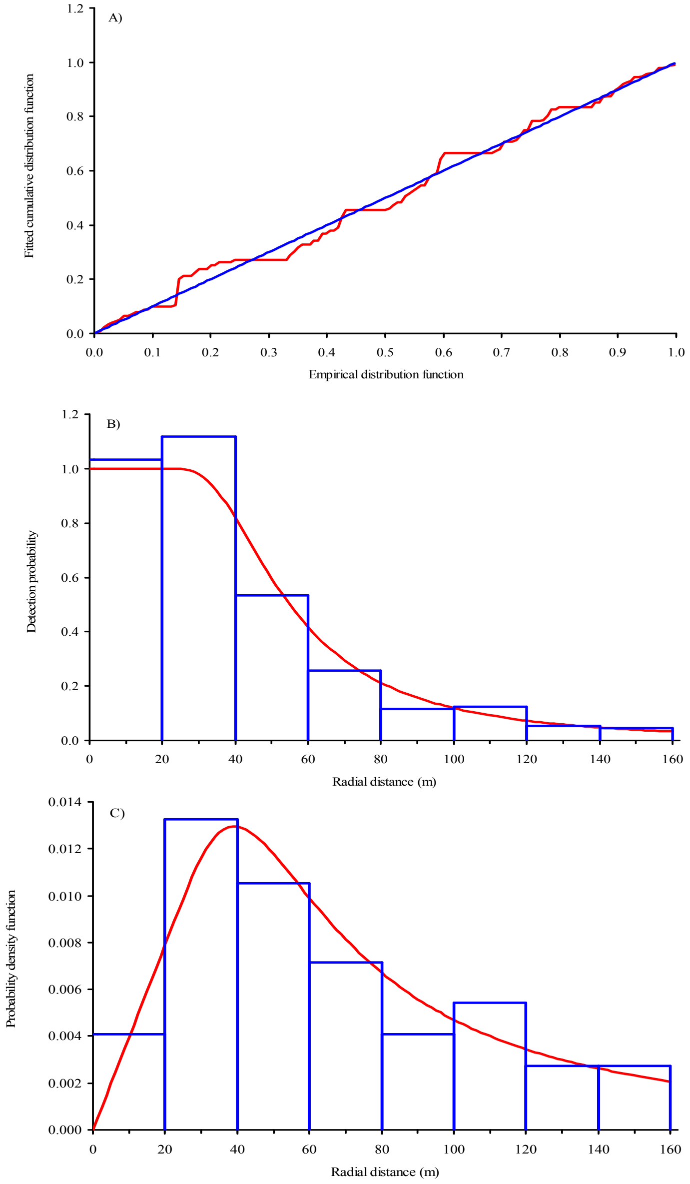

Figure 4. Number of points (*k*) that would need to be surveyed to have a coefficient of variation (CV $\hat{D}$) < 0.2 for estimated density of the yellow-shouldered parrot based on survey data collected at 62 points on Bonaire in December 2009. Dispersion parameter ($\hat{b}$) = 4, which suggests a highly clumped distribution during the nonbreeding period of the year. Observed CV = 0.24.

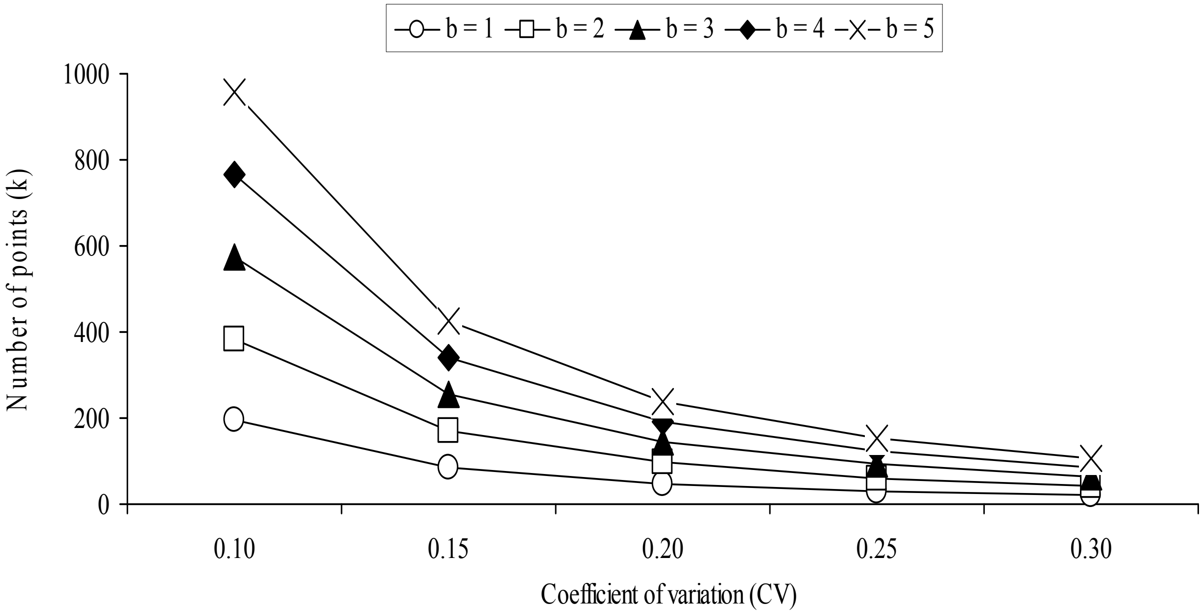

Figure 5. Correlation of unadjusted point-count data of yellow-shouldered parrots and brown-throated parakeets (A), and predicted density/point of yellow-shouldered parrots as a function of habitat suitability index (B) and habitat types (C); 1 = mixed dry forest and shrub, 2 = mostly dry forest, 3 = mostly dry shrub, and 4 = mixed urban (houses) and agriculture (cleared land with goats and other domestic animals).