



THE CHALLENGE OF ESTIMATING AND MONITORING THE POPULATION SIZE OF THE ENDANGERED PERUVIAN PLANTCUTTER (*PHYTOTOMA RAIMONDII*)

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Abstract · Population size is a major criterion in evaluating the conservation status of threatened species and for designing management strategies. Therefore, using a distance sampling approach, the number of adult individuals of the endangered Peruvian Plantcutter (*Phytotoma raimondii*) at the protected area Pómac Forest Historical Sanctuary was estimated in 2016 and contrasted with refined estimates from a survey conducted in 2011. Enough data to model the detection functions were obtained only for adult males because their vocalizations make them more conspicuous than other age classes and females. The estimated density of adult males within polygons of occupancy was 0.075 ind·ha⁻¹ (SE = 0.015) in 2011 and 0.057 (0.009) in 2016. Because the estimated number of individuals has remained stable between both sampling periods ($z = 1.05$, two-tailed $p = 0.30$), the count data were combined, resulting in an estimated density of 0.064 ind·ha⁻¹ (0.008) and a total subpopulation size of 188 adult males (95% CI = 144–237, CV = 0.13). By assuming plausible scenarios of sexual proportions from a male-biased population, in which 70% of adults are males to an even adult sex ratio, the total number of adults at this subpopulation can vary between 269 (95% CI 206–339) and 376 (288–474) individuals. The pooled data from both surveys were also used to estimate the sampling efforts required to achieve multiple levels of precision (CV = 0.10–0.20). In summary, this paper constitutes a baseline of the number of adult Peruvian Plantcutters at one of the last strongholds of the species, providing detailed information for replicability and improvement. The direct implications of the study results to the current knowledge and conservation status of this species are discussed.

Resumen · El reto de estimar y monitorear el tamaño poblacional de la amenazada Cortarrama Peruana (*Phytotoma raimondii*)

El tamaño poblacional es uno de los principales criterios para evaluar el estado de conservación de especies amenazadas y para el diseño de estrategias de manejo. Por esta razón, utilizando un enfoque sustentado en el muestreo por distancias, el número de individuos adultos de la amenazada Cortarrama Peruana (*Phytotoma raimondii*) dentro del área protegida Santuario Histórico Bosque de Pómac se estimó para el año 2016 y se contrastó con estimaciones refinadas de una evaluación realizada en el 2011. Solo se obtuvieron datos suficientes para modelar las funciones de detección para machos adultos debido a que sus vocalizaciones los hacen más conspicuos en comparación con las hembras y otras clases de edad. La densidad estimada para machos adultos dentro de polígonos de ocupación fue de 0.075 ind·ha⁻¹ (SE = 0.015) para el año 2011 y 0.057 (0.009) para el 2016. Debido a que el número de individuos estimados se mantuvo estable entre ambos períodos de muestreo ($z = 1.05$, bilateral $p = 0.30$), los datos fueron combinados, dando como resultado una densidad estimada de 0.064 ind·ha⁻¹ (0.008) y un total de 188 machos adultos (IC 95% = 144–237, CV = 0.13). Asumiendo escenarios plausibles de proporciones sexuales desde una población sesgada hacia machos en la que el 70% de adultos corresponden a este sexo hasta una proporción equitativa, el número total de adultos para esta subpoblación se estima que puede variar entre 269 (IC 95% = 206–339) y 376 (288–474) individuos. Los datos combinados también fueron usados para estimar el esfuerzo de muestreo necesario para alcanzar múltiples niveles de precisión (CV = 0.10–0.20). En resumen, este estudio constituye una línea base del número de individuos adultos para una de las mayores subpoblaciones remanentes de la Cortarrama Peruana, a la vez que proporciona información detallada para la replicación y perfeccionamiento. Las implicaciones directas del estudio para el conocimiento actual y el estado de conservación de esta especie son discutidas.

Key words: Conventional distance sampling · Herbivorous passerine · Imperfect detection · Model averaging · Multiple-covariate distance sampling · Population trend

Receipt 30 March 2018 · First decision 19 July 2018 · Acceptance 19 August 2018 · Online publication 26 August 2018

Communicated by Sandra Valderrama © The Neotropical Ornithological Society

INTRODUCTION

Population size is a major criterion for establishing the conservation status of any given species, and no less important is also monitoring its fluctuations and trends over time and space in order to prioritize objectively when and where conservation actions are urgently needed. However, many threatened species lack accurate estimates of their population sizes as well as long-term monitoring programs (e.g., Bolivian chinchilla rats: Bernal 2016, clouded leopards: Grassman et al. 2016; Hoffmann's pikas: Smith & Lissovsky 2016; Martial Eagles: BirdLife International 2017). In Peru, the endangered Peruvian Plantcutter (*Phytotoma raimondii*, Cotingidae) is one of these many examples, despite being one of the most well-studied birds in the region.

Peruvian Plantcutters are territorial and herbivorous —mainly folivorous— passerines, restricted to the seasonally dry forest and scrubland of northwestern Peru. The narrow specialization of this species on some plant resources explains its scattered distribution in small subpopulations over a large area (Atauchi et al. 2018). Today, these remaining subpopulations are rapidly disappearing because of habitat loss and fragmentation (Flanagan et al. 2009), mainly due to land conversion to agriculture, livestock overgrazing, and uncontrolled logging for timber and charcoal production (Kirwan & Green 2012).

The remaining total population of Peruvian Plantcutters is thought to consist of roughly 1000 to 2500 individuals (BirdLife International 2016), but other investigators believe that it may consist of fewer than 500 individuals (Romo et al. 2015). In any case, these numbers are merely speculative since no survey has been carried out in order to provide a reliable approximation of the population size. Likewise, no monitoring program has been undertaken at any of the subpopulations.

An initial attempt to obtain a reliable estimation of the number of Peruvian Plantcutters at one of its remaining subpopulations has been carried out in 2011 (Nolazco et al. 2014). The researchers estimated that 488 adults inhabited one of the last strongholds of the species in 2011, the Pómac Forest Historical Sanctuary (hereafter SHBP; Spanish acronym). However, they have been criticized for extrapolating their distance sampling approach to the entire extension of this site, disregarding that vast areas are unoccupied by the species, potentially leading to overestimation (Romo et al. 2015). Further, because they obtained sufficient data to model detection functions for adult males only, the total number of adults was estimated by assuming equal sex proportions. Given that adult sex ratios generally tend to be male-biased in birds (Breitwisch 1989, Donald 2007, Székely et al. 2014), alternative approaches should be considered as well.

The SHBP hosts one of the three major known subpopulations of Peruvian Plantcutters; the other two are located in Talara (4°35'7"S-81°14'35"W;

Piura department) and La Arenita (7°40'33"S-79°19'21"W; La Libertad department, close to the city of Paiján), respectively. These sites, along with some other minor subpopulations, need to be periodically assessed in order to obtain reliable estimates and trends of the population size (see Flanagan et al. 2009, Devenish et al. 2017). To contribute to this endeavor, the data from the 2011 survey conducted at the SHBP were reanalyzed in order to overcome the above-mentioned pitfalls, and a new survey was conducted to obtain new estimates for the year 2016. Unlike the former assessment, the new analyses were restricted to areas of occupancy within the SHBP, and more conservative estimates were presented on the basis of adult sex ratios typically found in birds rather than just assuming an even proportion (1F:1M). In addition, covariates other than distance were incorporated to account for potential heterogeneities in detection probabilities (Marques & Buckland 2003, Marques et al. 2007). Since the estimated number of birds has remained stable between surveys (see Results), the data were combined in order to obtain estimates with improved precision.

In summary, this study aims to provide wildlife managers with an adequate estimate of the subpopulation size and patterns of occupancy at the SHBP, and should also serve to establish a monitoring program for the species therein. For this reason, a comprehensive description of the methodological design and analyses performed is also included, as well as predictions of the sampling efforts required in further surveys to reach acceptable levels of precision ($CV \leq 0.20$; Buckland et al. 2004) under variable scenarios of clumped spatial distribution.

METHODS

Study area. The protected area SHBP (5887 ha) is one of the last strongholds of Peruvian Plantcutters and the only place where they are actively being protected. It is located in the lower Lercanlaech River watershed in northwest Peru, department of Lambayeque (06°28'25"S, 79°46'35"W, 80 m a.s.l.; Figure 1). The climate is hot, with a monthly average high temperature of 33.1°C (February, March) and low of 11.5°C (July, August). Rainfall is low and sporadic with an annual average of 108 mm but, in rare years, such as during the ENSO (El Niño–Southern Oscillation), may reach 1500 mm. Extreme droughts lasting several years are common between ENSO events. Vegetation is dominated by the trees algarrobo (*Prosopis pallida*, Fabaceae), sapote (*Colicodendron scabridum*), and the shrub vichayo (*Capparis avicennifolia*, both latter Capparaceae). Forest types are typical of the region, from closed canopies with sparse understories to shrub dominated areas with scattered trees and to areas of low vegetation with as little as 14% tree cover (SERNANP 2011).

Study species. Peruvian Plantcutters are generally found in strong spatial aggregations matching the dis-

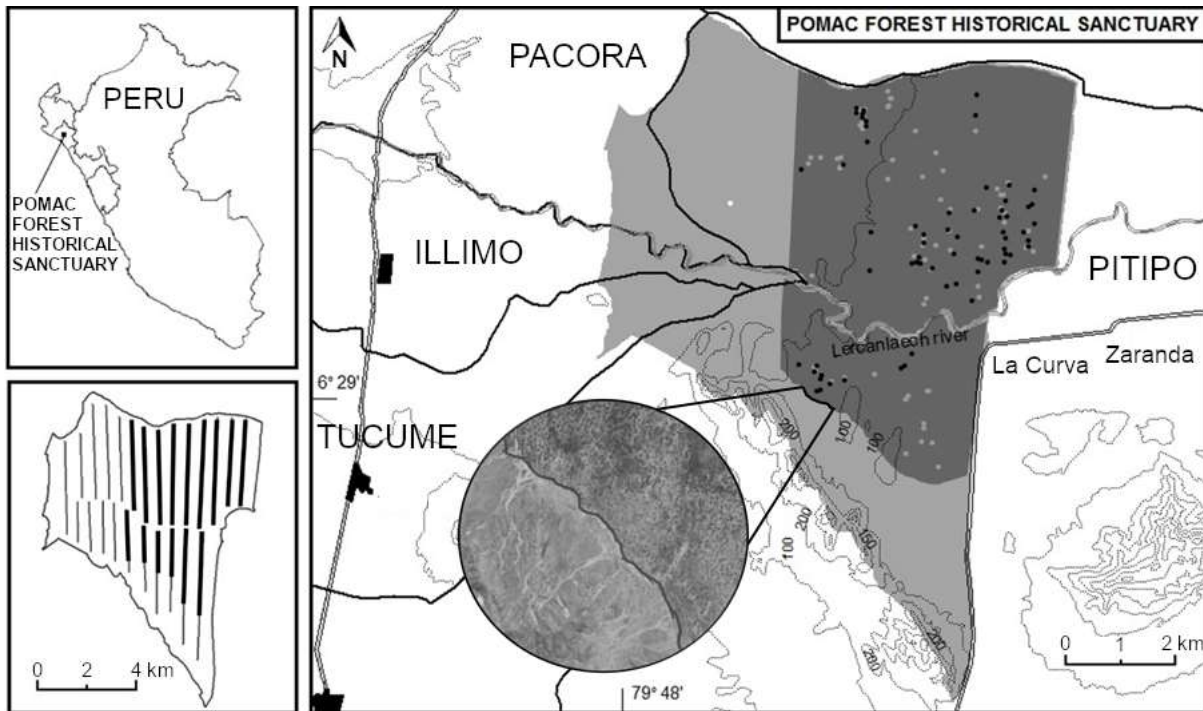


Figure 1. Map of the protected area Pómac Forest Historical Sanctuary (Lambayeque, Peru), distribution of line transects, and location of Peruvian Plantcutters (*Phytotoma raimondii*) detected from the transect line (light grey dots: 2011 survey; black dots: 2016 survey). Polygons of occupancy are based on detections and are shown in dark grey background (total = 2922 ha, ignoring one westernmost outlier during the 2011 survey and highlighted as a white dot). Transects within these polygons are represented by thickened lines, including some shortened after excluding southernmost areas known to be unoccupied by the species and characterized by an abrupt decline in vegetation cover (see magnification circle). Note that Peru map only shows departmental boundaries where Peruvian Plantcutters are currently known to be present; from top to bottom: Tumbes (vagrant?), Piura, Lambayeque, La Libertad, and Ancash.

tribution of selected plants used for both foraging and nest construction (Nolazco et al. 2014, Nolazco & Sánchez 2018). Socially monogamous, these birds form long-term pair bonds, breeding between December and May (Flanagan & Millen 2008, Rosina & Romo 2012, Nolazco & Roper 2014, Nolazco & Sánchez 2018), and occupy year-round territories generally defended by the males (Nolazco et al. 2014). The primary defense consists of patrolling the territory, vocalizing intensively from exposed perches, with physical confrontations only occurring during intrusions (author pers. observ.). In contrast, females usually remain less exposed and vocalize only occasionally, a similar behavior to that exhibited by young (unmated) birds, who either are still with their parents or have already dispersed but lack territories (Nolazco et al. 2014, Nolazco & Roper 2014). Apart from these behavioral differences, adult males also exhibit a more elaborated plumage than females and young males, characterized by two ornamental-like rufous patches, a large one that extends from the undertail coverts to the breast, and a small one on the forehead (see Nolazco & Roper 2013 for more details and photographs). These differences in behavior and plumage coloration can affect substantially the detectability probabilities among age and sex classes during distance-sampling surveys at the study site (Nolazco et al. 2014).

Sampling design. Initially, a systematic sampling design was performed replicating the one carried out between January and March 2011 (Nolazco et al. 2014). This design consists of a total of 25 parallel line transects of variable length (summed length ~ 84 km), spaced 500 m from one another throughout the whole SHBP and walked at a constant speed of 1.5 km/h (Figure 1). The new survey was conducted in this way between 06:00 and 13:00 h (UTC-5) at the end of December 2015 and at the beginning of January 2016 (hereafter named 2016 survey for simplicity; Figure 1). Line transects were chosen over point counts because the former are usually more efficient (Bollinger et al. 1988, Bibby et al. 2000, Wilson et al. 2000) and are easier to conduct in relatively open areas (Buckland 2006). Using 8x42 mm binoculars and a Callaway LR550 laser rangefinder (Nikon, Shinagawa, Tokyo, Japan), all Peruvian Plantcutters seen or heard from the transect line were recorded by a single observer (author). Data collected also included perpendicular distances from the transect line (Buckland et al. 1993, 2001), time of encounter indicated as minutes after midnight, sex and age class determined by plumage (Nolazco & Roper 2013), and a rough classification of vegetation cover into two categories, *dense* when vegetation tended to block the view of the surrounding landscape at eye height while *semi-dense* when not. In cases in which a bird

regularly vocalized from a same perch but was not being able to be sighted from the transect line, the exact position to calculate the *perpendicular distance*, and sex and age class were determined by approaching as close as possible to get visual confirmation.

Both surveys were undertaken during the breeding season to maintain sampling consistency, and thus avoid potential seasonal effects on detection probability variance (e.g., due to changes in birds' vocalization frequency or pronounced variations in vegetation cover). All material and sampling design that were applied here were intended to meet the basic assumptions for analyzing distance-sampling data (Buckland et al. 2001): (i) all animals located on the transect line are detected with certainty; (ii) animals are detected prior to any responsive movement; and (iii) measurements are accurate.

Once the distance data were fully collected, areas of occupancy were defined by the spatial range around the set of transects in which birds were detected during surveys. Although the spatio-temporal distribution of detections does not seem to remain constant, variation tended to occur within the same group of transects, leading to consistent areas of occupancy between surveys. Because birds were detected on the easternmost transects, the eastern limit of occupancy was defined by the delimiting contour of the protected area. The same was applied for the northern limit. To the west, the limits were defined as parallel lines to the left of the westernmost transects in which at least one bird was detected, setting the border at the greatest distance a bird was detected from the transect line across surveys. To the south, the limit was manually outlined by excluding southernmost arid areas with very sparse vegetation that are known to be unoccupied by the species. Lastly, the river area was excluded since no Peruvian Plantcutters were ever sighted or heard therein too, yielding to two final polygons of occupancy (see Figure 1).

Statistical analysis. Distance-sampling analyses were restricted only to transects within the polygons of occupancy (total area of occupancy = 2922 ha). This resulted in a total (summed) transect length of 49.77 km. Conventional distance-sampling (CDS; Buckland et al. 2001) using exact *perpendicular distance* as the sole explanatory variable and multiple-covariate distance-sampling (MCDS; Buckland et al. 2004, Marques et al. 2007), including additional covariates, were performed to model detection functions. For the present survey, *time of encounter* and *vegetation cover* were included as additional covariates. For the survey carried out in 2011 (Nolazco et al. 2014), the data were reanalyzed including *vegetation cover* as an additional covariate within the set of candidate models, but not *time of encounter* because this information was not available. In the previous analyses of the 2011 survey, the authors overlooked covariates other than distance by constraining the evaluation

period to the first hours after sunrise (06:00–10:00 hours) and assumed that the differences in vegetation cover were unlikely to affect detection probabilities (Nolazco et al. 2014). Another improvement involved using exact distance data into the analyses instead of binned distances into intervals, which may affect slightly the variance in abundance estimations.

Here, a brief explanation is presented on why and how the detection functions were used to estimate the probability of detection and therefore the abundance in a given area (following Buckland et al. 2001, 2004). For a defined strip transect sample, the density of objects per unit area can be calculated simply as $\hat{D} = n/2wL$, where n is the total number of detected objects, $2w$ is the strip width, and L is the total transect length for a given searched area $a = 2wL$. For the density (\hat{D}) to be accurate using this equation, perfect detection is required; a condition that is not satisfied for Peruvian Plantcutters because detection frequencies decreased with distance from the transect line (Nolazco et al. 2014). Therefore, the proportion of individuals detected (P_a) needs to be known in order to estimate the density accurately. P_a can be estimated (\hat{P}_a) from the data on *perpendicular distances* alone or by incorporating other covariates (e.g., *time* and *vegetation cover*) as follows:

$$\hat{P}_a = \frac{\int_0^w g(x)dx}{w}, \text{ or}$$

$$\hat{P}_a(z_i) = \frac{\int_0^w g(x, z_i)dx}{w} \text{ for multiple covariates}$$

The detection function denoted by $g(x)$ gives the probability of detection of an object at distance x from the transect line and a vector of covariates z_i can be incorporated if required (where $g(0)$ or $g(0, z_i) = 1$) (more details, including estimations of encounter rate variance, in Buckland et al. 2001, Marques & Buckland 2004, Marques et al. 2007). The density can then be estimated as follows:

$$\hat{D} = \frac{n}{2wL\hat{P}_a}, \text{ or}$$

$$\hat{D} = \frac{n}{2wL\hat{P}_a(z_i)} \text{ for multiple covariates}$$

In this case, the equations did not take into account any effect of cluster size (i.e., number of individuals) because most Peruvian Plantcutters detected from the transect line during the surveys corresponded to individuals (> 95%; mean cluster size ≈ 1).

The models included a parametric form known as 'key function' (uniform, half-normal, or hazard-rate in CDS with just the last two implemented for MCDS as the uniform function does not allow the inclusion of covariates) and additional adjustment terms in CDS models, if needed, for improving the fit through 'series expansions' (cosine, simple polynomial, or hermite polynomial). Adjustment terms were not

considered in the MCDS models because these typically add little to the detection functions once the additional covariates' effects have been included, and they can actually lead to problematic non-monotonically decreasing trends (e.g., Marques et al. 2007).

Models were first run for untruncated observations to explore data quality by using quantile-quantile (q-q) plots. No serious problems were found since the q-q plots showed a good fit of the data with no systematic departures near or far from the transect line and no systematic rounding of distances. Next, right truncation cutpoints (redefining w) were considered to exclude data that can produce heaping beyond a certain distance, thus avoiding difficulties for modelling implausible detection curves. Cutpoint selection was based on the models' fit and the precision among a range of truncation possibilities (excluding from 0–15% of detections). A good fit (p -values ≥ 0.10 for Chi-square, Kolmogorov-Smirnov and Cramer-von Mises goodness-of-fit tests) combined with a low coefficient of variation (CV) was used as the criteria for choosing final truncation cutpoints. Additionally, the fitting of models with the selected truncation values was evaluated graphically based on the shape criterion — the detection function should have a fitted 'shoulder' near the transect line —, and a monotonic downward trend of the detection function. Any models that did not meet these characteristics were discarded.

Model selection was based on the second-order Akaike Information Criterion for small sample sizes (AIC_c) (Burnham & Anderson 2002). Density estimations and inferred abundance for the searched area ($\hat{N}_a = a \times \hat{D}$) are presented as well as the extrapolated abundance for the entire protected area ($\hat{N}_A = A \times \hat{D}$, where A = total area of occupancy) along with a 95% log-normal CI (Buckland et al. 2001: 77). When more than one model was equally plausible ($\Delta AIC_c \leq 2$), model averaging was applied using equation 4.1 from Burnham & Anderson (2002) along with the 95% CIs as described by Turek & Fletcher (2012). To test the changes in density between surveys, we applied a z -test using the equation 3.102 in Buckland et al. (2001:85). Considering that there was not a significant difference in density estimations between the surveys (see Results), the data from 2011 and 2016 were combined to maximize the sample size and to estimate the number of Peruvian Plantcutters at the SHBP with higher precision. Within the set of candidate models for combined data, *survey* and *vegetation cover* were included as covariates other than *distance*.

Finally, to calculate the minimum effort required in terms of total transect length needed to estimate abundance with a higher precision level (CV = 0.10), equation 7.5 in Buckland et al. (2001:243) was applied. For expected scenarios of variable clumped spatial distribution ($b = 2$ – 3) and precision levels (CV = 0.10–0.20), equation 7.1 in Buckland et al. (2001:242) was used. Actual dispersion parameters

were estimated as $\hat{b} = n \times (CV[\hat{D}])^2$ (Burnham et al. 1980:35). The program Distance version 7.0 release 1 (Thomas et al. 2010) was used for the analyses, except for the model averaging that was performed using the RMark package (Laake 2013) in R environment v.3.1.1 (R Development Core Team 2014).

RESULTS

During the 2016 survey, 72 Peruvian Plantcutters were detected including 71 adults (66 males, 5 females) and one juvenile male. Similarly, 76 adults including 73 males and three females were detected in 2011. In general, females and young birds appear to be less vocal, and this was reflected in the detection patterns. In contrast, adult males were always easily located by their vocalizations; more than 80% of detections during both surveys corresponded to birds that were initially heard vocalizing on or near the top of shrubs and trees. There was no statistically significant difference in the encounter rates between both surveys within areas occupied by the species, 1.41 ind·km⁻¹ walked (95% CI = 1.35–1.47) for the year 2011 and 1.33 ind·km⁻¹ (1.29–1.36) for 2016. In relation to *vegetation cover*, over 80% of the detections occurred in *semi-dense* cover while the rest occurred in *dense* cover during both surveys, yet all corresponded to a scrubland structure (i.e., vegetation dominated by shrubs and sparse trees). This type of vegetation is predominant at the eastern site of the SHBP where Peruvian Plantcutters were detected (Figure 1).

In both count surveys, the distance data available only allowed to estimate the density of adult males within the total area of occupancy (2922 ha; Figure 1). For the 2011 data, after right truncation at 238 m (w), only six out of 73 adult males were discarded (greatest distance = 311 m) whereas for the 2016 survey only three of 66 individuals were excluded (greatest distance = 260 m) when data were truncated at 196 m. All selected models ($\Delta AIC_c \leq 2$) satisfied the shape criterion and chi-square goodness-of-fit tests showed no evidence of lack of fit (Table 1). For multiple-covariates models, the inclusion of covariates other than the *perpendicular distance*, namely the *time of encounter* and *vegetation cover*, did not improve the precision of the density estimator to the point of overcoming the penalty in AIC_c calculations (Table 1). Consequently, their effects on the detection probabilities can be considered negligible ('uninformative parameters', sensu Arnold 2010). Indeed, for the 2011 data, no models including the effect of *vegetation cover* fell within the set of plausible models being considered ($\Delta AIC_c > 3$).

Model averaging yielded an estimated subpopulation size of 220 adult males (95% CI = 145–315; CV = 0.20) for the entire SHBP in 2011, and 166 adult males (95% CI = 116–217; CV = 0.16) in 2016. Based on the levels of precision, the estimations were not significantly different between both count surveys ($z = 1.05$, two-tailed $p = 0.30$). Given this outcome, the

Table 1. Density (\hat{D}) and abundance (\hat{N}) estimates with 95% log-based confidence intervals for Peruvian Plantcutter (*Phytotoma raimondii*) adult males at the Pómac Forest Historical Sanctuary, 2011–2016. Summary of results for competitive models ($\Delta AIC_c \leq 2$) are shown for each survey and for data from both surveys combined (2011/2016), along with model averaged calculations. Models presented included either a uniform (Unif) or half-normal (Hnorm) key function, and some of them also a series expansion cosine (cos) or simple polynomial (pol). Additional covariates other than *perpendicular distance* (Distance), include two-level factors (*vegetation cover*: dense, semi-dense; *survey*: 2011, 2016) and a continuous variable (*time of encounter*: in minutes after midnight). k = total number of parameters in the model; w_i = Akaike weights; \hat{p}_σ = probability of detection; \hat{N}_G = inferred number of individuals for the searched area ($2wL$) after right truncation (2369 ha in 2011, 1851 ha in 2016, and 2180 ha for both surveys combined); \hat{N}_A = extrapolated number of individuals for the entire area of occupancy within the SHBP (2922 ha).

Survey	Covariate	Model (key+adj.)	k	ΔAIC_c	w_i	\hat{p}_σ	% CV	\hat{D}	\hat{N}_G	\hat{N}_A (95% CI)
2011	Distance	Unif + cos	2	0.00	0.29	0.41	15.04	0.069	164	201 (149, 271)
	Distance	Hnorm + cos	2	0.17	0.26	0.36	16.66	0.078	185	227 (162, 317)
	Distance	Hnorm + cos	3	0.58	0.21	0.32	17.83	0.088	209	257 (180, 365)
	Distance	Unif + cos	3	1.72	0.12	0.38	16.84	0.074	175	216 (155, 301)
	Distance	Hnorm	1	1.82	0.12	0.44	14.29	0.064	152	187 (141, 248)
	Model averaged						19.64	0.075	178	220 (145, 315)
2016	Distance	Unif + cos	1	0.00	0.25	0.57	14.61	0.056	104	165 (123, 220)
	Distance	Hnorm	1	0.63	0.18	0.56	16.06	0.056	103	164 (119, 226)
	Distance + cover	Hnorm	2	0.81	0.17	0.56	15.51	0.057	106	167 (123, 228)
	Distance + time	Hnorm	2	0.96	0.15	0.57	15.33	0.057	106	167 (123, 226)
	Distance + time + cover	Hnorm	3	1.10	0.14	0.55	15.64	0.058	107	171 (125, 233)
	Distance	Unif + pol	2	1.61	0.11	0.57	16.16	0.057	105	166 (120, 226)
	Model averaged						15.52	0.057	105	166 (116, 217)
2011/2016	Distance	Hnorm	1	0.00	0.23	0.53	10.85	0.063	137	183 (148, 227)
	Distance + survey	Hnorm	2	0.06	0.22	0.52	10.97	0.063	139	185 (149, 230)
	Distance	Hnorm + pol	2	0.89	0.14	0.48	10.99	0.068	148	199 (160, 246)
	Distance	Hnorm + cos	2	1.00	0.14	0.47	13.20	0.070	153	205 (158, 266)
	Distance	Unif + cos	1	1.78	0.09	0.58	9.33	0.057	124	166 (138, 199)
	Distance	Unif + cos	2	1.90	0.09	0.51	11.66	0.064	140	188 (149, 236)
	Distance + cover	Hnorm	2	1.90	0.09	0.53	10.95	0.063	138	184 (148, 228)
	Model averaged						12.63	0.064	140	188 (144, 237)

data from both surveys was combined and resulted in an acceptable level of precision (CV = 0.13) and an estimated subpopulation size of 188 adult males (95% CI = 144–237) after model averaging parameters from competitive models (Table 1, Figure 2). Combining the data leads to an increase in the sample size up to 129 observations ($w = 219$ m), and resulting in a higher level of precision.

Changes in the spatial aggregation patterns of individuals may occur, potentially affecting the required effort needed to achieve a desired level of precision in future surveys. This is highly plausible taking into account that from 2011 to 2016, variation in the aggregation patterns of individuals (see Figure 1) were translated into changes in the estimated dispersion parameters and precision ($\hat{b}_{2011} = 2.58$, $\hat{b}_{2016} = 1.61$; $CV_{2011} = 0.20$, $CV_{2016} = 0.16$). For instance, if the SHBP subpopulation becomes more clumped ($b = 3$), to obtain a desired precision threshold or lower ($CV \leq 0.15$), it is recommended to at least double the total transect length covered during individual surveys (Figure 3). In fact, doubling the effort after pooling the data from both surveys largely reduced the variance in encounter rates, and thus the dispersion

parameter ($\hat{b} = 1.07$), allowing to achieve a higher level of precision (CV = 0.13). Furthermore, to obtain even a higher level of precision (e.g., CV = 0.10) under scenarios of strong spatial aggregation or if both the number of individuals decreases and the encounter rate accordingly, the sampling effort may need to be increased further (Figure 3).

DISCUSSION

Neither a significant decline nor an increase in the Peruvian Plantcutter's numbers were found between the 2011 and 2016 surveys at the SHBP, so the overall count data was pooled to estimate abundance with higher precision (CV = 0.13). This resulted in an estimation of 188 adult males (95% CI = 144–237). Despite at no time being possible to model detection probabilities for other sex and age classes due to the apparent differences in detectability from transects (i.e., minimum sample sizes just achieved for the most conspicuous class, adult males), some plausible scenarios can be derived from the available results. For instance, assuming an even adult sex ratio (1F:1M), 376 (95% CI = 288–474) adults are currently

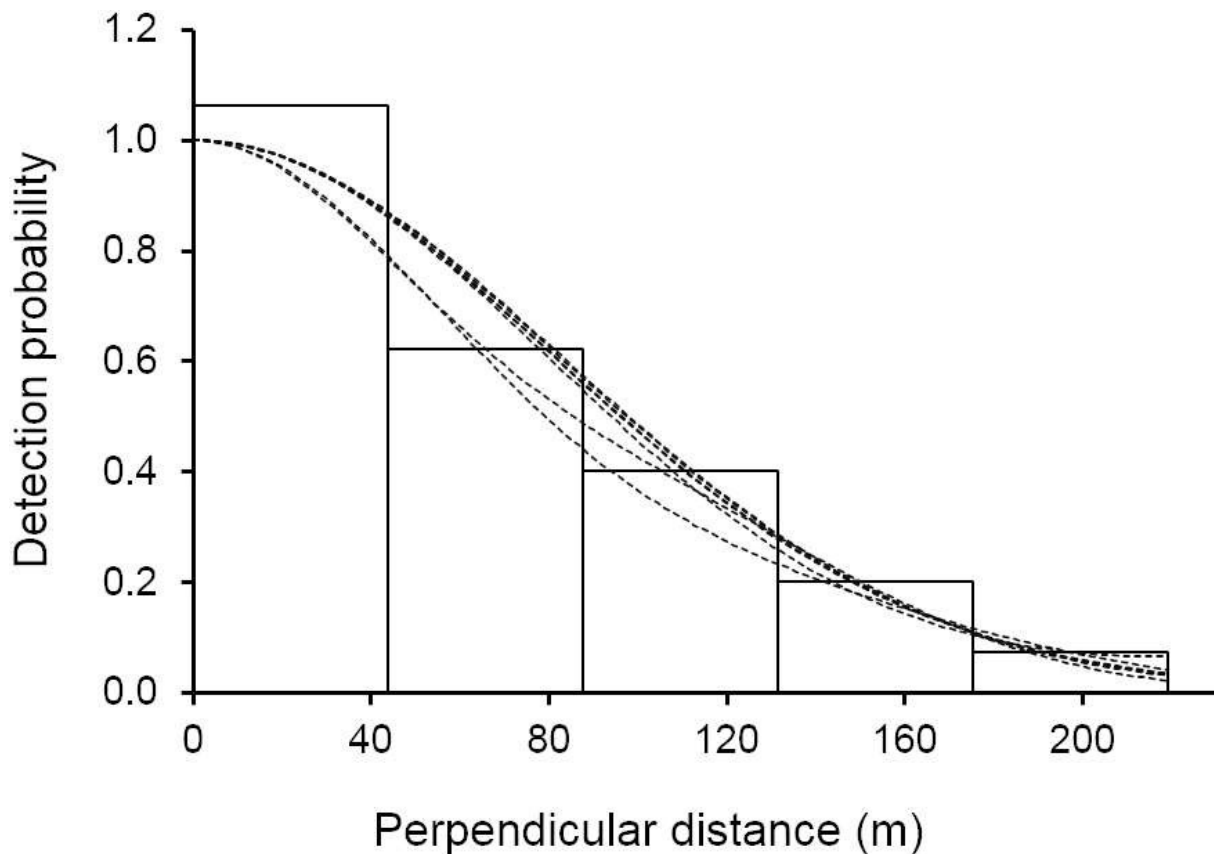


Figure 2. Fitted detection functions (dashed lines) for Peruvian Plantcutter (*Phytotoma raimondii*) adult males at the Pómac Forest Historical Sanctuary (Lambayeque, Peru) for the year 2016 using combined count data from surveys conducted in 2011 and 2016 (see Table 1 for models details). For multiple-covariate models, the average detection functions were plotted.

estimated to inhabit the SHBP. However, populations where males represent 60% to 70% of all adults (equivalent to male-biased adult sex ratios of c. 1:0.7 and 1:0.4, respectively) are common in birds (Donald 2007) and, if this is the case for Peruvian Plantcutters at the SHBP, the number of adults would be between 269 (95% CI = 206–339) and 313 (240–395) adult individuals.

The reliability of the estimates presented here relies largely on the research design, the same that can still be improved for future assessments. By covering the whole area of the SHBP with equally-spaced line transects, areas of occupancy were clearly identified and were also systematically sampled, thereby allowing to capture the spatial variation in encounter rates across the latter and reducing potential biases when inference-based densities are extrapolated (Strindberg et al. 2004, Fasham & Mustoe 2005, Thomas et al. 2010). Nonetheless, these surveys also allow identifying new challenges for future assessments. First, if this design is replicated the main aim should be focus on achieving high levels of precision ($CV \leq 0.15$) that ensure high sensitivity to detect more subtle changes in the subpopulation size over time. To ensure this, it may be necessary to perform complete repetitions of line transects within areas of occupancy, or establish new ones between the former. The later will result in considerable overlap

between sampling units, but this would not be a major issue since distance-sampling is robust to the violation of independence between samples (Buckland 2006, Buckland et al. 2008). Second, the sampling method applied allowed to estimate numbers of adult males with acceptable precision, but this is still a challenge for young males and females in general. Indeed, it seems that by vocalizing on the top of trees and shrubs, males become so conspicuous to the extent of overcoming the potential effects of vegetation cover in detection probabilities. In contrast, young birds and females are difficult to detect from the transect line even in relatively open vegetation. An alternative to this matter could be to obtain at least reliable estimations of adult sex ratios, and thus, more accurate approximations of the overall number of adults.

Taking into account the estimates obtained for adult Peruvian Plantcutters in this study, and that at least two other major subpopulations could be comparable in numbers to that of the SHBP (i.e., Talara, and La Arenita near Paján; BirdLife International 2016), it is extremely unlikely that less than 500 individuals will remain throughout its range as indicated in a recent publication by Romo et al. (2015). From the little information available, it seems that a more plausible and conservative scenario is what other researchers speculate (1000–2500 individuals,

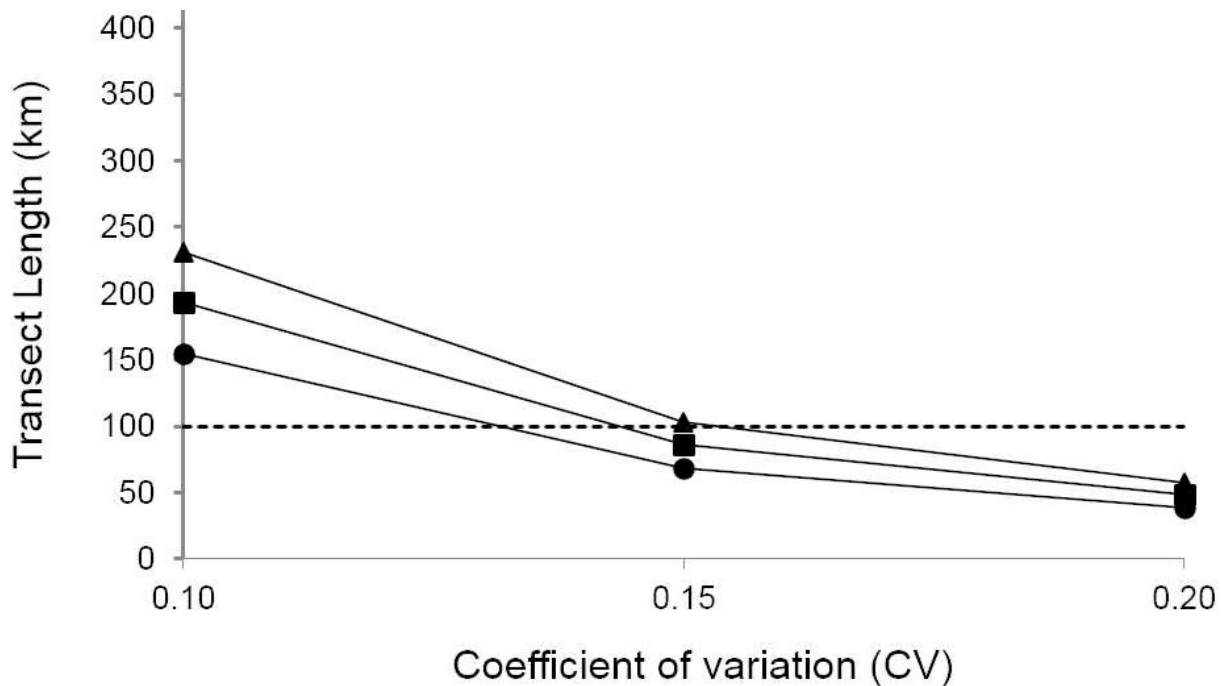


Figure 3. Estimated effort needed (total transect length) to achieve various levels of precision (CV = 0.10–0.20) for estimating the number of adult Peruvian Plantcutters (*Phytotoma raimondii*) at the Pómac Forest Historical Sanctuary (Lambayeque, Peru), including different scenarios of stronger clumped spatial distribution (circles: dispersion parameter [b] = 2; squares: b = 2.5; triangles: b = 3). Estimations are based on the distance data from adult males when observations from 2011 and 2016 surveys were combined. Accordingly, 129 individuals were detected in 49.77 km walked twice with a strip half-width of 219 m (w). The dashed line (~ 100 km) represents the actual effort applied therein.

670–1600 mature individuals; see BirdLife International 2016). This wide discrepancy between published sources arises because Romo et al. (2015) based their conclusion only on birds recorded during ‘casual counts’, without covering subpopulations in their full extent, and without accounting for imperfect detection, which would certainly lead to underestimation. For this reason, it is strongly recommended to keep the larger but more realistic rough estimate as the most plausible prediction until more information became available.

This study indicates that the numbers of adult Peruvian Plantcutters, even by considering only the estimates for the SHBP, are above the reference values for escalating the conservation status of the species in accordance with the IUCN criteria (see details in IUCN 2012). However, population size is just one out of the many criteria that this global authority uses for assessing and designating species’ conservation status. In fact, the Peruvian Plantcutter is classified as endangered not because of its population size, but rather due to having a highly restricted and severely fragmented range, in which a declining trend of its population is alleged to be occurring as a consequence of rapid loss of its remaining habitat (BirdLife International 2016). Conversely, the present study also indicates that there is no evidence that supports a decreasing trend at least for the SHBP subpopulation between 2011 and 2016. However, this may be one, if not the only, exception since the SHBP is the only place where the species is actively protected.

Almost in all other subpopulations throughout its range, the remaining habitat is under constant pressure from legal and illegal land-use activities (Flanagan et al. 2009, Romo et al. 2015). In view of this situation, it is necessary to conduct periodic assessments not only within the SHBP but also in other subpopulations, to provide useful information for reviewing the status of the species as well as to channel conservation efforts when and where required. In this endeavor, this paper can serve as a benchmark for the establishment of a monitoring program for Peruvian Plantcutters within the SHBP, as well as to encourage urgent assessments in other subpopulations of this threatened species.

ACKNOWLEDGMENTS

Thanks to Amalia M. Sánchez for assistance with field work, to the head of the SHBP (Antonio Gamonal) and park guards for allowing us to use their facilities, and to Frank F. Rivera-Milán, David Bradley, Brad Weber, and two anonymous reviewers for their valuable comments on earlier versions of the manuscript.

REFERENCES

- Arnold, TW (2010) Uninformative parameters and model selection using Akaike’s Information Criterion. *Journal of Wildlife Management* 74: 1175–1178.
- Atauchi, PJ, AT Peterson & J Flanagan (2018) Species distribution models for Peruvian Plantcutter improve with consid-

- eration of biotic interactions. *Journal of Avian Biology* 49, doi.org/10.1111/jav.01617.
- Bernal, N (2016) *Abrocoma boliviensis*. The IUCN Red List of Threatened Species 2016: e.T18A22182349. Available at <http://www.iucnredlist.org> [Accessed 22 January 2018].
- Bibby, CJ, ND Burgess, DA Hill & SH Mustoe (2000) *Bird census techniques*. 2nd ed. Academic Press, London, UK.
- BirdLife International (2016) *Phytotoma raimondii*. The IUCN Red List of Threatened Species 2016: e.T22700764A9379-5193. Available at <http://www.iucnredlist.org> [Accessed 9 November 2017].
- BirdLife International (2017) *Polemaetus bellicosus* (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2017: e.T22696116A112494400. Available at <http://www.iucnredlist.org> [Accessed 22 January 2018].
- Bollinger, EK, TA Gavin & DC Mcintyre (1988) Comparison of transects and circular plots for estimating Bobolink densities. *Journal of Wildlife Management* 52: 777–786.
- Breitwisch, R (1989) Mortality patterns, sex ratios and parental investment in monogamous birds. *Current Ornithology* 6: 1–50.
- Buckland, ST (2006) Point transect surveys for songbirds: robust methodologies. *The Auk* 123: 345–357.
- Buckland, ST, DR Anderson, KP Burnham & JL Laake (1993) *Distance sampling: estimating abundance of biological populations*. Chapman and Hall, London, UK.
- Buckland, ST, DR Anderson, KP Burnham, JL Laake, DL Borchers & L Thomas (2001) *Introduction to distance sampling: estimating abundance of biological populations*. Oxford Univ. Press, London, UK.
- Buckland, ST, DR Anderson, KP Burnham, JL Laake, DL Borchers & L Thomas (2004) *Advanced distance sampling: estimating abundance of biological populations*. Oxford Univ. Press, London, UK.
- Buckland, ST, SJ Marsden & RE Green (2008) Estimating bird abundance: making methods work. *Bird Conservation International* 18: 91–108.
- Burnham, KP & DR Anderson (2002) *Model selection and multi-model inference: a practical information-theoretic approach*. 2nd ed. Springer, New York, New York, USA.
- Burnham, KP, DR Anderson & JL Laake (1980) Estimation of density from line transect sampling of biological populations. *Wildlife Monographs* 72: 1–202.
- Devenish, C, GM Buchanan, GR Smith & SJ Marsden (2017) Extreme and complex variation in range-wide abundances across a threatened Neotropical bird community. *Diversity and Distributions* 23: 910–921.
- Donald, PF (2007) Adult sex ratios in wild bird populations. *Ibis* 149: 671–692.
- Fasham, M & S Mustoe (2005) General principles and methods for species. Pp 255–270 in Hill, D, M Fasham, G Tucker, M Shewry & P Shaw (eds). *Handbook of biodiversity methods: survey, evaluation, and monitoring*. Cambridge Univ. Press, Cambridge, UK.
- Flanagan, JNM & B Millen (2008) First nest and egg records of Peruvian Plantcutter *Phytotoma raimondii*, by O. D. Boggs. *Bulletin of the British Ornithologists' Club* 128: 271.
- Flanagan, JNM, G Engblom, I Franke, T Valqui & F Angulo (2009) Distribution of the Peruvian Plantcutter *Phytotoma raimondii* (Passeriformes: Cotingidae). *Revista Peruana de Biología* 16: 175–182.
- Grassman, L, A Lynan, S Mohamad, JW Duckworth, J Bora, D Wilcox, Y Ghimirey, A Reza & H Rahman (2016) *Neofelis nebulosa*. The IUCN Red List of Threatened Species 2016: e.T14519A97215090. Available at <http://www.iucnredlist.org> [Accessed 22 January 2018].
- IUCN (2012) *IUCN Red List categories and criteria: version 3.1*. IUCN, Gland, Switzerland.
- Kirwan, GM & G Green (2012) *Cotingas and manakins*. Princeton Univ. Press, Princeton, New Jersey, USA.
- Laake, JL (2013) RMark: An R interface for analysis of capture–recapture data with MARK. Alaska Fisheries Science Center, NOAA, and National Marine Fisheries Service, Washington, D.C., USA.
- Marques, FFC & ST Buckland (2003) Incorporating covariates into standard line transect analyses. *Biometrics* 59: 924–935.
- Marques, FFC & ST Buckland (2004) Covariate models for the detection function. Pp 31–47 in Buckland, ST, DR Anderson, KP Burnham, JL Laake, DL Borchers & L Thomas (eds). *Advanced distance sampling*. Oxford Univ. Press, London, UK.
- Marques, TA, L Thomas, SG Fancy & ST Buckland (2007) Improving estimates of bird density using multiple-covariate distance sampling. *The Auk* 124: 1229–1243.
- Nolazco, S & JJ Roper (2013) Descriptive note of reproduction in the Peruvian Plantcutter (*Phytotoma raimondii*) in the Bosque de Pómac Historical Sanctuary, Lambayeque, Peru. *Boletín Informativo UNOP* 8: 6–13.
- Nolazco, S & JJ Roper (2014) The challenge of estimating population trends in the endangered Peruvian Plantcutter (*Phytotoma raimondii*) and implications for conservation. *Ornitología Neotropical* 25: 125–134.
- Nolazco, S, AM Sánchez & JJ Roper (2014) Tamaño poblacional, distribución y ámbito de hogar de la Cortarrama Peruana (*Phytotoma raimondii*) en el Santuario Histórico Bosque de Pómac, Lambayeque, Perú [Population size, distribution and home range of the Peruvian Plantcutter (*Phytotoma raimondii*) in the Bosque de Pómac Historical Sanctuary, Lambayeque, Peru]. *Boletín Informativo UNOP* 2: 5–19.
- Nolazco, S & AM Sánchez (2018) Flexibility in resource selection for foraging and nest construction in Peruvian Plantcutters (*Phytotoma raimondii*). *The Wilson Journal of Ornithology* 130: 548–554.
- R Development Core Team (2014) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at <http://www.R-project.org/>.
- Romo, M, M Rosina, J Flanagan, L Pollack & I Franke (2015) Escasa presencia y grave amenaza para el “cortarramas peruano”, *Phytotoma raimondii* [Scarce occurrence and high threat of the Peruvian Plantcutter, *Phytotoma raimondii*]. *Revista Peruana de Biología* 22: 213–224.
- Rosina, M & M Romo (2012) Reproducción y alimentación de *Phytotoma raimondii*, Cortarrama Peruana en El Gramadal, Ancash [Reproduction and food habits and of *Phytotoma raimondii*, Peruvian Plantcutter in El Gramadal, Ancash]. *Revista Peruana de Biología* 19: 167–173.
- SERNANP (2011) *Santuario Histórico Bosque de Pómac: Plan Maestro 2011–2016 [Bosque de Pómac Historical Sanctuary: Master Plan 2011–2016]*. Servicio Nacional de Áreas Naturales Protegidas por el Estado, Lima, Perú.
- Smith, AT & A Lissovsky (2016) *Ochotona hoffmanni*. The IUCN Red List of Threatened Species 2016: e.T40800A45181807. Available at <http://www.iucnredlist.org> [Accessed 22 January 2018]
- Székely, T, A Liker, RP Freckleton, C Fichtel & PM Kappeler (2014) Sex-biased survival predicts adult sex ratio variation in wild birds. *Proceedings of the Royal Society B* 281: 1788.
- Thomas, L, ST Buckland, ER Rextad, JL Laake, S Strindberg, SL Hedley, JRB Bishop, TA Marques & KP Burnham (2010) Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47: 5–14.
- Turek, D & D Fletcher (2012) Model-averaged Wald confidence intervals. *Computational Statistics and Data Analysis* 56: 2809–2815.
- Wilson, RR, DJ Twedt & AB Elliott (2000) Comparison of line transects and point counts for monitoring spring migration in forested wetlands. *Journal of Field Ornithology* 71: 345–355.

