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ESTIMATING WESTERN SCRUB-JAY DENSITY IN CALIFORNIA BY MULTIPLE-COVARIATE DISTANCE SAMPLING

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Abstract. Using multiple-covariate distance sampling with seasonal point transects, we surveyed for the Western Scrub-Jay (*Aphelocoma californica californica* group) over a substantial portion of its range in California . Our goals were to produce seasonal and habitat-specific estimates of the scrub-jay's regional density and abundance in 2008 and to demonstrate how the concurrent collection and analysis of covariate data may be useful in improving estimates of bird density. Density and abundance estimates implied a significant 38% increase over 2008, from a low of 24 jays km^{-2} (2.3×10^6 jays) in February to a high of 78 jays km^{-2} (7.5×10^6 jays) in November. Density was greatest in agricultural habitats (98 jays km^{-2}) and least in rural habitats (38 jays km^{-2}). Averaged over the study, abundance was greatest in agricultural habitats (2.6×10^6 jays) and least in urban habitats (3.6×10^5 jays). Inclusion of covariates such as habitat type, observer, weather, and time of day often increased the precision of density estimates, and it significantly improved model results in one case. As detailed in this study, the techniques of multiple-covariate distance sampling may have application as effective and noninvasive methods for obtaining more precise estimates of bird density and monitoring the density and abundance of species across broad habitats.

Key words: *abundance,* Aphelocoma californica, *density, distance sampling, point transect, Western Scrub-Jay.*

Estimaciones de la Densidad de *Aphelocoma californica californica* en California con Muestreo por Distancia con Múltiples Covariables

Resumen. Utilizando muestreo por distancia con múltiples covariables y conteos estacionales en puntos a lo largo de transectas, censamos individuos de *Aphelocoma californica californica* en una parte importante de su área de distribución en California. Nuestros objetivos fueron producir estimados de densidad regional y de abundancia de *A. californica* específicos para cada estación y tipo de hábitat en 2008 y demostrar como la colecta simultanea y el análisis de datos de covariables pueden ser útiles para mejorar los estimados de densidad de estas aves. Los estimados de densidad y de abundancia indicaron un aumento significativo de un 38% durante 2008, desde 24 individuos km^{-2} (2.3×10^6 individuos) en febrero hasta 78 individuos km^{-2} (7.5×10^6 individuos) en noviembre. Promediando los datos de este estudio, la mayor abundancia fue registrada en hábitats agrícolas (98 individuos km^{-2}) y la menor en hábitats urbanos (3.6×10^5 individuos). Al incluir covariables como tipo de hábitat, observador, condiciones climáticas y hora del día generalmente aumentó la precisión de los estimados de densidad, y en un caso mejoró significativamente los resultados del modelo. Como se detalla en este estudio, estas técnicas de muestreo por distancia con múltiples covariables pueden ser aplicadas como una técnica efectiva y no invasiva para obtener estimados más precisos de la densidad de aves y para el monitoreo de la densidad y abundancia de especies a través de grandes extensiones de hábitat.

INTRODUCTION

The Western Scrub-Jay (*Aphelocoma californica*) is a common species in chaparral, oak and pine woodlands, and agricultural and urban landscapes of much of the western United States (Curry et al. 2002). Historically, no widespread threats to the scrub-jay have been documented, and its populations were considered "generally healthy and in little need of attention for conservation purposes" (Curry et al. 2002). However, since the introduction of West Nile virus (WNV) to the United States in 1999, high susceptibility to this disease has been observed in many species of birds, especially corvids. Because of the widespread distribution of the American Crow (*Corvus brachyrhynchos*), declines in its populations have been widely documented (Ward et al. 2006), and

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the species has been used as a nationwide WNV-surveillance tool (Centers for Disease Control and Prevention 2000). Recently, attention has turned toward other corvids with more restricted distributions or abundances such as the Yellow-billed Magpie (*Pica nuttalli*; see Crosbie et al. 2008 for discussion) and scrub-jay.

Abundance indices calculated from Audubon Society Christmas Bird Count (CBC) and U.S. Geological Survey Breeding Bird Survey (BBS) data show recent declines of the scrub-jay over a large geographic area. Airola et al. (2007) calculated a significant 46% decline in the number of scrub-jays detected per party-hour from 2005 to 2006 in CBC data from the lower Sacramento Valley, and Koenig et al. (2007) reported that 58% of BBS routes in California showed declines in scrub-jay detections from 2004 to 2005 (Koenig et al. 2007).

Recent declines have been attributed largely to WNV (see Curry et al. 2002). In a study of live birds in Kern County, California, Reisen et al. (2009) found the scrub-jay to have the highest seroprevalence of WNV (percentage of individuals testing positive for WNV antibodies in the blood; 40%) of over 80 wild bird species sampled. A review of 2004–2005 carcass data from the California Department of Public Health Services' Dead Bird Surveillance Program showed that among all corvids in California with adequate sample sizes, scrub-jay carcasses were WNV-positive at the second highest rate (70%; the greatest WNV prevalence was in the Yellow-billed Magpie; Crosbie et al. 2008). Furthermore, a comparative study of host competence for WNV among multiple avian and non-avian taxa (44 avian, 3 mammalian, 5 reptilian, and 1 amphibian species) indicated the scrub-jay had the highest index of host competence (a scale of infectiousness of the host; Kilpatrick et al. 2007).

The scrub-jay's population density varies widely by locality and habitat type (see Curry et al. 2002 for a synopsis), from as low as four scrub-jays km^{-2} in the central Baja California desert (George 1987) to as high as 179 scrub-jays km^{-2} on golf courses in Santa Clara County, California (Blair 1996). The only estimate of the scrub-jay's global abundance, 3 400 000 (Rich et al. 2004), is derived from 1990s Breeding Bird Survey data and considered "moderately accurate." There are, however, no estimates of the species' density or abundance since the establishment of WNV in its range. Furthermore, many estimates of bird density and abundance, including those of Rich et al. (2004), are based upon tenuous assumptions about bird detectability. Rather than estimating bird detectability directly from field data, many studies still rely upon assumptions of constant detectability under varying distances of detection, field conditions (habitat types or weather conditions), and/or by different observers. Such assumptions are usually difficult to meet and are best avoided (for a topical review see Thompson 2002).

Our goal in this study was to produce seasonal and habitat-specific estimates of the regional density and abundance of the scrub-jay in 2008 from opportunistically collected data from our companion study of the Yellow-billed Magpie in the Central Valley and central Coast Ranges of California (see Crosbie 2009). This study area comprises a large portion of the range of *Aphelocoma californica californica* and encompasses a region of the species' highest known densities based on past BBS data (Sauer et al. 2001). Yet it is only a fraction of the species' entire range, which extends from Washington, Wyoming, and Colorado south to Baja California, Texas, and mainland Mexico).

To derive estimates of density and abundance we used conventional and multiple-covariate distance-sampling techniques (see Buckland et al. 2001, 2004), a suite of field and statistical methods that are currently receiving wider application in field ornithology. In using such methods we also demonstrate how the concurrent collection and analysis of covariate data may be useful in improving estimates of bird density and eliminating the need for unsubstantiated assumptions about bird detectability.

METHODS

STUDY AREA

Our study area comprised the historical range of the Yellow-billed Magpie, for which we conducted seasonal point-transect studies in 2007 and 2008. Geographically, the study area included the Sacramento and northeastern San Joaquin valleys and associated foothills, the interior Sacramento/San Joaquin delta, and the central Coast Ranges from Alameda County south to Ventura County, California (Fig. 1).

We obtained geographic information system (GIS) data on habitat types throughout the study area from a 100-m-resolution GIS layer (Multi-source Land Cover Data version 02_2) available from the California Department of Forestry and Fire Protection's Fire and Resource Assessment Program (see Acknowledgments). This GIS layer depicts the study area's habitats as defined by the California Wildlife Habitat Relationship (CWHR; Zeiner et al. 1999), which we dissolved into three broad habitat types, "rural," "agricultural," and "urban," in order to broadly assess the scrub-jay's habitat-specific density and abundance. Rural habitats were composed of CWHR layers valley oak woodland, blue oak–foothill pine, coastal oak woodland, annual grassland, perennial grassland, valley foothill riparian, blue oak woodland, mixed chaparral, chamise–redshank chaparral, coastal scrub, freshwater emergent wetland, and eucalyptus. Agricultural habitats were composed of CWHR layers deciduous orchard, evergreen orchard, vineyard, irrigated row and field crops, rice, irrigated hayfield, irrigated grain crops, dryland grain crops, and non-irrigated pasture. We defined urban habitat as the urban CWHR layer. Further information on these CWHR habitat types may be found at the California Department of Fish and Game's Biogeographic Data Branch (see Acknowledgments).

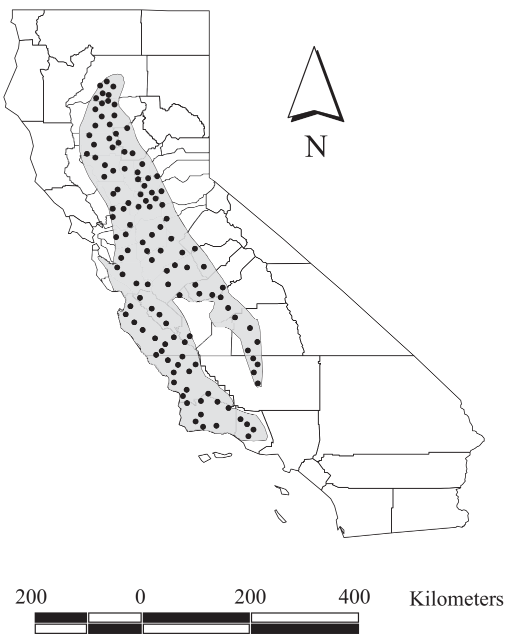

FIGURE 1. Study area (shaded) within California, including the Sacramento and northern San Joaquin valleys and associated foothills, the interior Sacramento/San Joaquin delta, and the central Coast Ranges. Dots depict the distribution of randomly located survey points upon transects (transect lines omitted for clarity) surveyed for the Western Scrub-Jay (*Aphelocoma californica*) in 2008.

Using the above simplified habitat-classification scheme is not without limitation, as rural, agricultural, and urban habitat types are not mutually exclusive in all land-use activities. For example, some points in rural CWHR habitats such as valley oak woodland and annual grassland clearly had light seasonal grazing, albeit at a level much lower than in agricultural areas designated as pasture. Similarly, some points within rural and agricultural habitats also had nearby housing development or ranchettes, but human population density in such areas was clearly much lower than in urban areas. Nevertheless, because little information was available on habitat-specific scrub-jay densities over such a broad geographic area, our goal was to obtain baseline estimates of scrub-jay density in broad habitat categories.

POINT-TRANSECT SURVEYS

Point and line transects are generally considered to be the most suitable methods for estimating the density and abundance of wild bird populations (Buckland et al. 2001, Norvell et al. 2003, Marques et al. 2007). Distance sampling allows for the estimation of density and abundance with empirical models of bird detectability based on a function of the birds' distance from the observer and, if desired, covariate information (Buckland et al. 2001, Buckland et al. 2004, Marques et al. 2007).

Using ArcView GIS 3.2, we randomly established 23 transects, with a mean of 5.5 points per transect ($n = 127$ points, range 4–8 points per transect), throughout the study area (Fig. 1). We established 69 points in rural habitat (which totaled 63 386 km^2), 30 points in agricultural habitat (which totaled 26 296 km^2), and 28 points in urban habitat (which totaled 6205 km^2).

Prior to starting surveys, we reviewed aerial photographs and visited the sites to ensure points were in the appropriate habitat type (rural, agricultural, or urban), and to obtain landowners' permission for access where necessary. We surveyed transects quarterly in 2008: once each during February, May, August, and November, corresponding with the winter (prebreeding), spring (breeding), summer (fledging) and fall (postfledging) seasons, respectively. After a 1-min wait, a single observer counted at each point for 6 min, during which he recorded the number of scrub-jay clusters (relatively tight flocks/groups of jays), measured distance(s) from the point (with a laser rangefinder), and estimated the cluster's size (number of individuals within each flock/group). During each survey, data were always collected by a single individual, and Crosbie and Souza were the only two observers. For all observations they recorded time after sunrise and ambient weather conditions including temperature (^{o}C), estimated cloud cover to nearest 10%, and estimated wind velocity on the Beaufort scale. Surveys took place in the first 4 hr of local daylight time and were not conducted in heavy rain or fog or if wind velocity equaled or exceeded 4 on the Beaufort scale, in accord with the methods of the Breeding Bird Survey (Sauer et al. 2001). Points within a transect were generally surveyed in a different order on each successive survey to reduce any potential bias of time of day on detection probability at points within a transect.

STATISTICAL ANALYSES

We used the program Distance 5.0 version 2 (Thomas et al. 2006) for two separate analyses of the data according to the methods detailed in Buckland et al. (2001). For the first analysis we stratified by season to obtain seasonal estimates of scrub-jay density and abundance. For the second analysis (using the same data), we stratified by habitat type to estimate mean habitat-specific densities and abundances over the study period. We truncated the data to eliminate the farthest 10–15% of observations, a routine process to facilitate model fitting and remove outliers (Buckland et al. 2001). When stratifying by season, we truncated data at 120–160 m (depending on season), and when stratifying by habitat type, we truncated data at 150 m for all three habitat types.

In addition to using the methods of conventional distance sampling (CDS), in which the detection probability is modeled as a function of bird distance alone, we also evaluated the effect of several covariates with multiple-covariate distance sampling (MCDS) (see Buckland et al. 2004, Marques et al. 2007). The MCDS methods can be used to evaluate the influence of covariates (in addition to bird distance) on the detection function and whether they yield increased precision of density and abundance estimates. We included both factor and nonfactor covariates that may influence the detection function. Nonfactor covariates included temperature, cloud cover, wind velocity, and minutes after sunrise (hereafter "time"); factor covariates included observer, habitat type (only used when results were stratified by season), and season (only used when results were stratified by habitat type). Model selection was based on minimization of Akaike's information criterion (AIC), provided that goodness-of-fit tests [χ^2, Cramér–von Mises (both uniform and cosine weighted), and Kolmogorov–Smirnov] showed adequate fit and diagnostic plots (histograms of detection function and probability-density function) were biologically reasonable.

To evaluate the temporal trend in abundance over the study period, we fit a least-squares linear regression to (log-transformed) seasonal abundance estimates with Systat 11.0 (Systat 2004). Examination of the residuals indicated a log transformation of seasonal abundance estimates was necessary to meet the distributional assumptions of normality and homogeneity of variance.

RESULTS

During our 2008 point transects, Western Scrub-Jays were detected over most of the study area, including the Sacramento and northeastern San Joaquin valleys and associated foothills, the delta, and the central Coast Ranges. The total number of clusters detected during point transects was 337, and the total number of individuals detected was 428 over the study period. We sampled throughout the study area once per season to estimate density and abundance during the winter (pre-breeding), spring (breeding), summer (fledging) and fall (post-fledging) of 2008.

SEASONAL CHANGES IN SCRUB-JAY DENSITY AND ABUNDANCE

After truncation, the number of scrub-jay clusters detected per season ranged from 58 to 92, and the mean observed cluster size ranged from 1.1 to 1.4 (Table 1). Sample sizes within each season were large enough for model results to be improved by the fitting of separate detection functions for each season over those from one pooled detection function (i.e., the sum of the AIC values for all four seasons' models was less than two points lower than the AIC of the best model based on a pooled detection function over the entire study period).

For the winter (February) 2008 data, the AIC values of the CDS and MCDS approaches were less than two points apart, so these models are considered equally adequate by AIC (CDS, AIC = 578.66 and $\chi^2 = 0.6$; MCDS, AIC = 578.95 and $\chi^2 = 0.4$). However, the MCDS model with temperature as a covariate yielded a slight reduction in the variance (coefficient of variation, CV) associated with the probability of detection [%CV($\hat{P}_a$)] and gave increased precision of density estimates by allowing the scale of the detection function to vary with ambient air temperature (Table 2). The MCDS detection function for winter 2008 shows that the probability of detecting scrub-jays was slightly greater with increasing ambient air temperature (Fig. 2A). The CDS and MCDS models gave very similar density estimates (23.9 and 24.4 birds km^{-2} for the CDS and MCDS results, respectively).

For the spring (May) 2008 data, the CDS and MCDS approaches resulted in AIC values that were less than two points apart (CDS, AIC = 548.72 and $\chi^2 = 0.7$; MCDS, AIC = 550.23 and $\chi^2 = 0.6$). Though considered equally adequate by AIC, the MCDS model with time of day as a covariate showed a slight reduction in the variance associated with the probability of detection [%CV($\hat{P}_a$)] and gave increased precision of the density estimate by allowing the scale of the detection function to vary with time of day. The MCDS detection-function histogram shows that the probability of scrub-jays being detected was slightly greater later in the morning (Fig. 2B). These CDS and MCDS models gave very similar density estimates (33.9 and 34.5 birds km^{-2}, respectively).

For the summer (August) 2008 data, the MCDS approach with habitat type as a covariate improved the model

TABLE 1. Number of detections of clusters of the Western Scrub-Jay before and after truncation, estimated cluster size and percent CV, mean observed cluster size and percent CV, and ranges of cluster size. A cluster is defined here as a relatively tight flock or group of scrub-jays. Data are from point transects surveyed seasonally in 2008.

Stratum (season or habitat type)	Truncation distance (m)	No. clusters before truncation	No. clusters after truncation	Estimated cluster size (%CV)	Mean observed cluster size (%CV)	Cluster size range
Winter	160	73	58	1.18 (4.60)	1.24 (6.66)	1–5
Spring	120	75	58	1.09 (3.51)	1.15 (4.15)	1–2
Summer	140	86	70	1.31 (5.32)	1.41 (6.51)	1–4
Fall	160	103	92	1.29 (3.69)	1.27 (4.40)	1–3
Total		337	278			
Rural	150	194	153	1.14 (2.98)	1.29 (3.92)	1–5
Agricultural	150	53	43	1.69 (7.33)	1.44 (8.42)	1–4
Urban	150	90	87	1.24 (3.02)	1.18 (3.79)	1–3
Total		337	283			

significantly over the CDS approach (MCDS, AIC = 675.01 and $\chi^2 = 0.7$; CDS, AIC = 687.74 and $\chi^2 = 1.0$), and substantially reduced the variance associated with the probability of detection [%CV($\hat{P}_a$)] by allowing the scale of the detection function to vary by habitat type (Table 2). The MCDS detection-function histogram shows that the probability of scrub-jays being detected was greatest in rural habitats and least in urban habitats (Fig. 2C).

For the November (fall), 2008 data, the CDS approach provided the best model fit (AIC = 919.19 and $\chi^2 = 0.9$). Inclusion of covariates with the MCDS approach did not improve the model for this season (Fig. 2D).

The variance (error) associated with estimated scrub-jay density may be broken down into three components, the detection probability, encounter rate, and cluster size. In this study, the component percentages of variance attributed to each of these three factors was generally consistent from season to season and averaged 52% due to the detection function, 44% due to cluster size, and 4% to encounter rate. Variance associated with the detection function was the largest source of error in this study, highlighting the reason we strive to attribute this error to known sources (covariates such as habitat type, temperature, time, etc.) to improve density estimates.

Point estimates of seasonal density and abundance increased consistently through the study, from a low of 24.4 birds km^{-2} (2.34×10^6 birds) in February 2008 to a high of 78.0 birds km^{-2} (7.48×10^6 birds) in November 2008 (Table 3). Log-transformed seasonal abundance estimates with a least-squares linear regression are shown in Fig. 3; the regression indicates a significant (38%; $r^2 = 0.99$; $F = 258.4$, $P = 0.004$) increase in abundance from winter (pre-breeding) to fall (post-breeding) 2008.

HABITAT-SPECIFIC DENSITY AND ABUNDANCE

After truncation, the number of scrub-jay detections per habitat type ranged from 43 to 153, and mean observed cluster size ranged from 1.2 to 1.4 (Table 1).

For the rural habitat, the AIC values by both the CDS and MCDS approaches were less than two points apart (CDS, AIC = 1529.28 and $\chi^2 = 0.9$; MCDS, AIC = 1529.80 and $\chi^2 = 0.8$) (Table 2). These models are considered equally adequate by AIC, but the MCDS model with percent cloud cover as a covariate showed a substantial reduction in the variance associated with the probability of detection [%CV($\hat{P}_a$)] (Table 2) and gave increased precision of density estimates by allowing the scale of the detection function to vary with percent cloud cover. The MCDS detection function histogram shows that the probability of scrub-jays being detected was slightly greater with increasing cloud cover (Fig. 4A). These CDS and MCDS models gave very simi-lar density estimates (38.5 and 37.7 birds km^{-2}, respectively).

For the agricultural habitat, the AIC values of the CDS and MCDS approaches were less than two points apart (CDS, AIC = 417.47 and $\chi^2 = 0.6$; MCDS, AIC = 418.87 and $\chi^2 = 0.3$). These models are considered equally adequate by AIC, but the MCDS model with percent cloud cover as a covariate showed a slight reduction in variance associated with the probability of detection [%CV($\hat{P}_a$)] (Table 2) and gave increased precision

TABLE 2. Pertinent statistics of models based on conventional distance sampling (CDS) and multiple-covariate distance sampling (MCDS) by stratum: fitted detection-function model, covariate type, Akaike's information criterion (AIC), number of model parameters (K), P-value from χ^2 goodness-of-fit test, estimated mean detection probability ($\hat{P}_a$), and percent coefficient of variation [%CV($\hat{P}_a$)]. Data are from point transects for the Western Scrub-Jay in 2008.

Stratum	Model	Covariate	AIC	K	P	$\hat{P}_a$	%CV($\hat{P}_a$)
Winter	CDS[a]	—	578.66	1	0.57	0.28	0.15
	MCDS[a]	Temperature	578.95	2	0.44	0.27	0.12
Spring	CDS[a]	—	548.72	1	0.71	0.32	0.16
	MCDS[a]	Time	550.23	2	0.57	0.32	0.11
Summer	CDS[b]	—	687.74	1	0.96	0.23	0.30
	MCDS[a]	Habitat type	675.01	3	0.75	0.24	0.13
Fall	CDS[b]	—	919.19	2	0.90	0.15	0.32
Rural	CDS[b]	—	529.28	2	0.86	0.24	0.26
	MCDS[c]	% Cloud cover	1529.80	3	0.79	0.24	0.07
Agricultural	CDS[c]	—	417.47	3	0.58	0.09	0.19
	MCDS[c]	% Cloud cover	418.87	4	0.30	0.09	0.15
Urban	CDS[b]	—	837.36	2	0.78	0.24	0.16
	MCDS[d]	Observer	839.25	4	0.72	0.24	0.13

[a]Half-normal key function.
[b]Hazard-rate key function.
[c]Half-normal key function with cosine series expansion.
[d]Hazard-rate key function with simple polynomial series expansion.

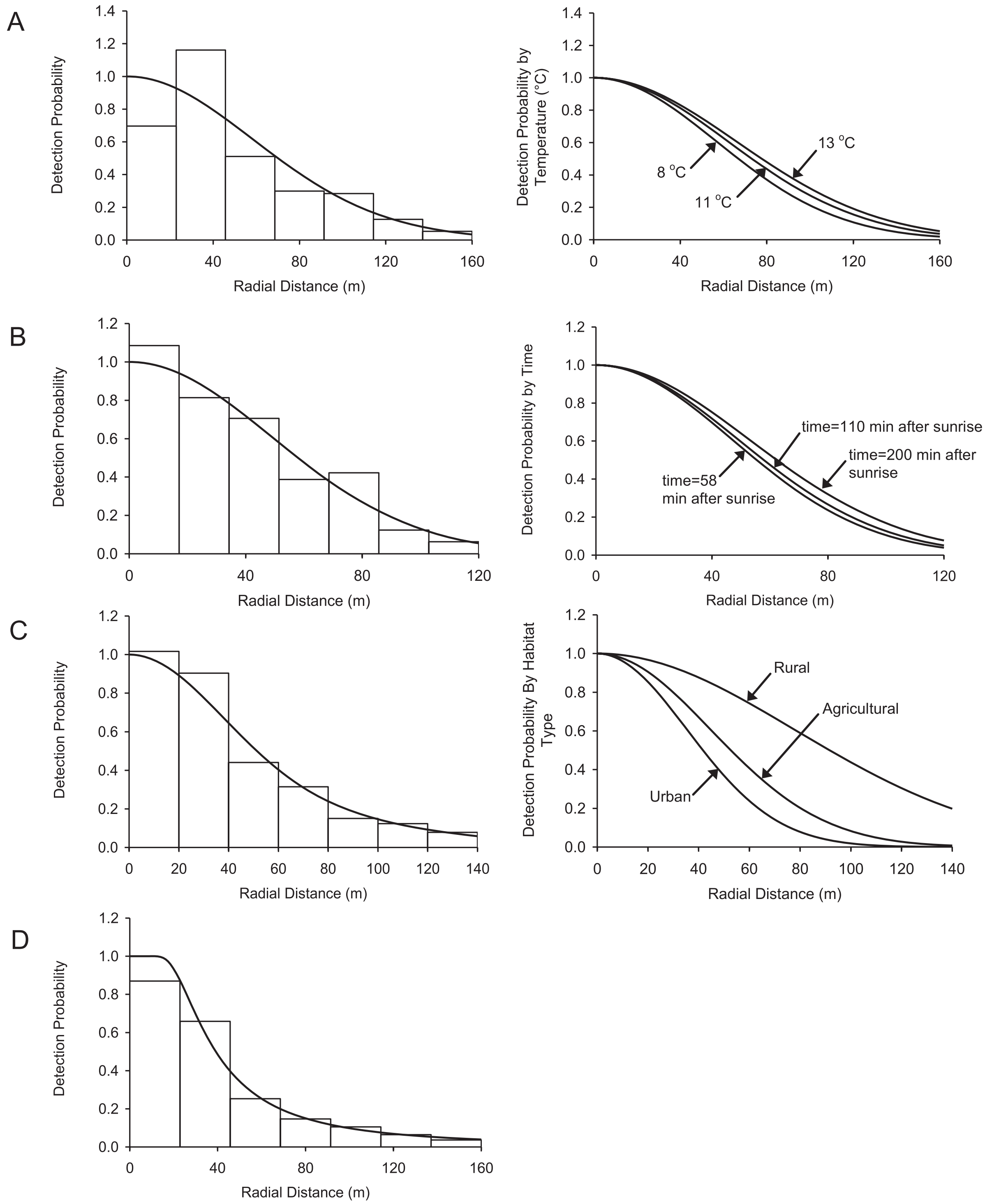

FIGURE 2. Histograms of distances of detection of the Western Scrub-Jay on point transects in 2008 with detection functions fitted by the season (A, winter; B, spring; C, summer; D, fall). Where inclusion of covariates improved the model's results, covariate histograms are shown on the right.

TABLE 3. Estimated Western Scrub-Jay (*Aphelocoma californica*) density, percent coefficient of variation (%CV), abundance, and 95% lower confidence limits (LCL) and upper confidence limits (UCL). Data are from point transects in 2008.

Stratum (season or habitat type)	Density			Abundance ($\times 10^6$)			
	km^{-2}	LCL	UCL	*n*	LCL	UCL	%CV
Winter	24.4	16.4	36.4	2.34	1.57	3.49	20.5
Spring	34.5	24.0	49.6	3.31	2.30	4.76	18.5
Summer	48.3	33.2	70.2	4.63	3.18	6.74	19.2
Fall	78.0	40.1	151.8	7.48	3.85	14.55	34.6
Rural	37.7	29.7	47.7	2.39	1.89	3.02	12.0
Agricultural	98.0	59.5	161.5	2.58	1.56	4.25	25.7
Urban	57.5	41.1	80.4	0.36	0.25	0.50	17.1

of density estimates by allowing the scale of the detection function to vary with percent cloud cover, as in rural habitats. The histogram for the MCDS detection function shows that the probability of scrub-jays being detected was slightly greater with increasing cloud cover (Fig. 4B). The CDS and MCDS models gave very similar density estimates (98.3 and 98.0 birds km^{-2}, respectively).

For the urban habitat, the AIC values of the CDS and MCDS approaches were less than two points apart (CDS, AIC = 837.36 and $\chi^2 = 0.8$; MCDS, AIC = 839.25 and $\chi^2 = 0.7$). Again, these models are considered equally adequate by AIC, but the MCDS model with observer as a covariate showed a slight reduction in the variance associated with the probability of detection [%CV($\hat{P}_a$)] and gave increased precision of density estimates by allowing the scale of the detection function to vary by observer, with observer SPC having a greater probability of detecting jays than did observer LES (Fig. 4C).

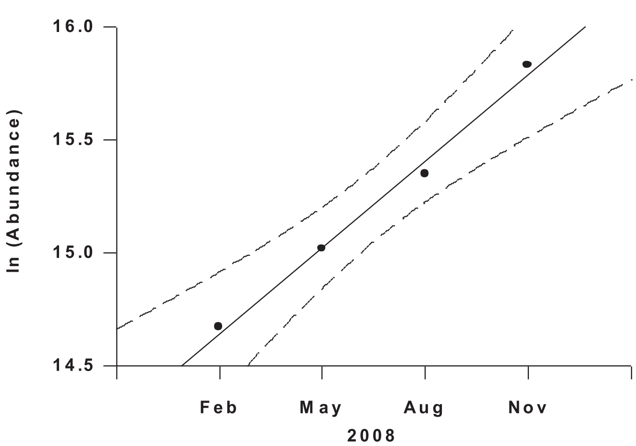

FIGURE 3. Log-transformed estimates of abundance of the Western Scrub-Jay by season (month) of 2008. Regression line indicates trend over the study period and associated 95% confidence bands (dashed lines).

Regardless, these CDS and MCDS models gave very similar density estimates (56.5 and 57.5 birds km^{-2}, respectively).

Over the study period, mean population density, weighted by the area of each habitat type, was 55.5 jays km^{-2}. Estimated mean density varied greatly by habitat type, being significantly higher in agricultural habitats than in rural habitats (Table 3).

The variance (error) associated with estimated density may be broken down into three components: the detection probability, encounter rate, and cluster size. In this study, the component percentages of variance attributed to each of these three factors was generally consistent among habitat types and averaged 47% due to the detection function, 48% due to cluster size, and 5% due to encounter rate.

DISCUSSION

The goal of this study was to provide seasonal and habitat-specific estimates of density and abundance of the Western Scrub-Jay over a substantial portion of its range in California. Furthermore, we demonstrated that the use of multiple-covariate distance-sampling techniques may result in more precise estimates of bird density, provide valuable information about the influence of covariates on detection probabilities, and eliminate the need for tenuous assumptions about constant detectability.

There are several prior estimates of scrub-jay densities in various habitat types. In general, scrub-jays prosper in human-altered landscapes and, in Santa Clara County, California, Blair (1996; who estimated detectability from his field data) estimated the following densities, in jays km^{-2}: 179 in golf courses, 84 in residential areas, 83 in open spaces, 70 in office parks, 45 in business districts, and 28 in preserves. Similarly, in modeling landscape and habitat associations, Stralberg and Williams (2002) found that scrub-jays respond positively to development and negatively to an increasing proportion of oak woodland. In chaparral in southern California, Yeaton (1974) found a density of 136 jays km^{-2}, intermediate between Blair's (1996) density estimates for golf courses and residential areas.

In general, we found that scrub-jay density was higher in developed (agricultural and urban) areas than in rural areas, consistent with the findings of Blair (1996) and Stralberg and Williams (2002). While we know of no prior estimates of scrub-jay density in agricultural habitats, our estimate (98.0 km^{-2}) is similar to what Blair (1996) found for residential and open-space areas (84 and 83 jays km^{-2}, respectively). At 57.5 jays km^{-2}, our urban density estimate is within the range of Blair's (1996) estimates for urban areas (84 jays km^{-2} in residential areas, 70 jays km^{-2} in office parks, and 45 jays km^{-2} in business districts); all of these urban habitats (residential, office parks, and business districts) were represented in our urban stratum.

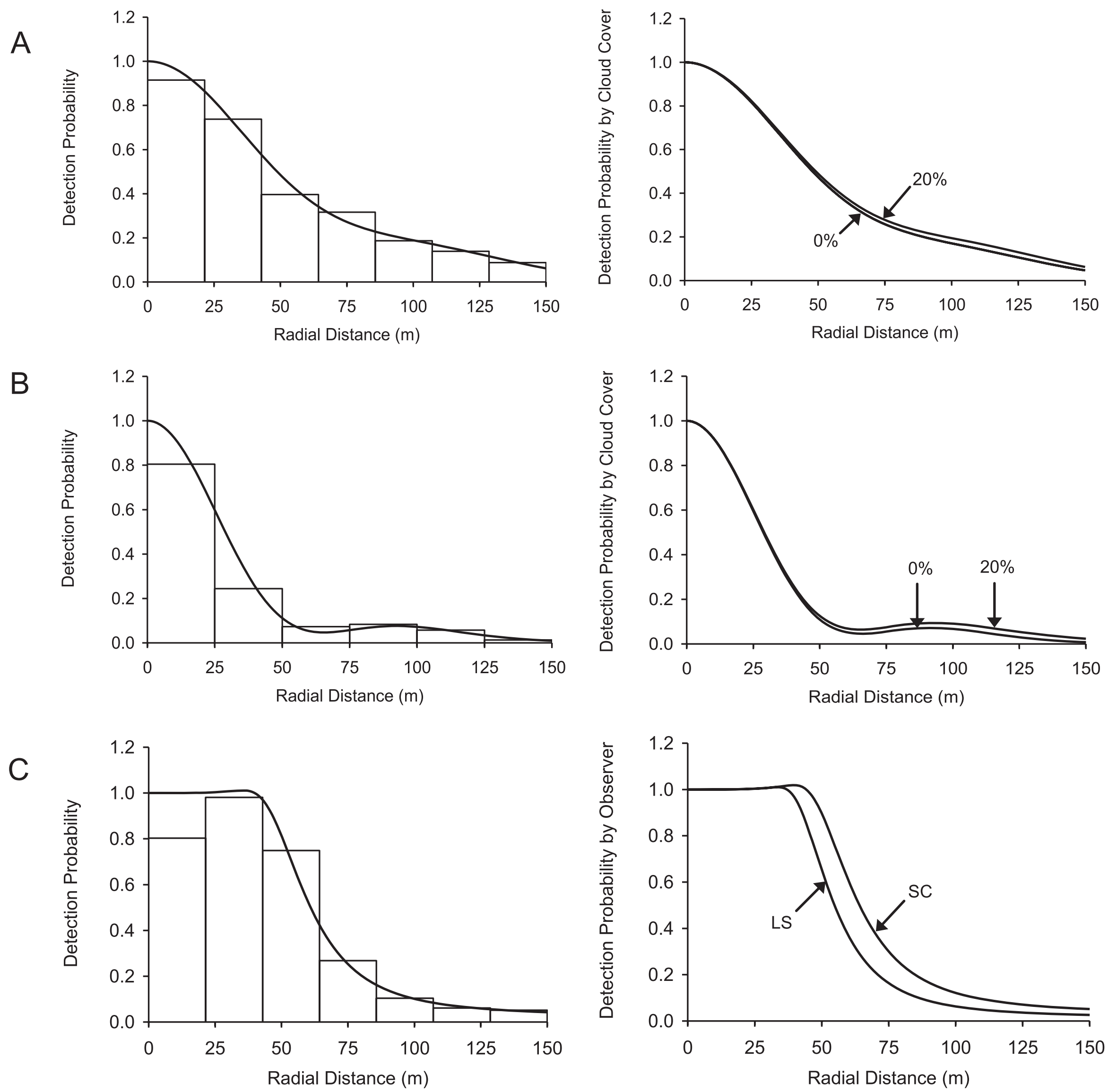

FIGURE 4. Histograms of distances of detection of the Western Scrub-Jay on point transects in 2008 with detection functions fitted by habitat type (A, rural; B, agricultural; C, urban). Covariate histograms are shown on the right.

Our estimates of scrub-jay density and abundance increased significantly by 38% from February (winter/pre-breeding) to November (fall/post-breeding) 2008, and this level of post-recruitment increase is very similar to that reported in prior work on the scrub-jay in California. Carmen (1988), who studied nesting scrub-jays at a reserve within our study area, found the species' annual productivity to be 0.84 independent young per pair, equivalent to an overall 42% increase in abundance over the breeding season.

Because our study area was only a fraction of the species' range (<10%), one might expect the abundance estimates generated from our study area to be considerably lower than the global abundance of 2.7×10^6 estimated by Rich et al. (2004). However, at 2.34×10^6, our smallest estimate (February 2008) is within the range of the global estimate of Rich et al. (2004). We believe that this inconsistency is partly explained by the methods and associated assumptions used by Rich et al. (2004), who derived their estimate from 1990s BBS data. Their methods included the assumption of constant detection distances for each species (among others), but these assumptions were not based upon recorded distance data from field surveys. For the scrub-jay, an assumed constant detection distance of 200 m was used (T. Rich, pers. comm.). Results from our survey suggest that the detection function remains constant for only approximately 25 m and can vary by habitat type (see Figs. 2 and 4), indicating an assumed constant detection distance of 200 m would result in severely underestimated values of scrub-jay density and abundance. We stress the importance of estimating detection probabilities and, where possible, avoiding tenuous assumptions about constant detectability without field verification. Without the use of validated estimates of detectability from field data, estimated abundances may be substantially erroneous and misleading for management. We also caution the use of one standard model of detectability for a given species, geographic area, or time period. In our study, the shape and/or scale of detection functions for the scrub-jay varied dramatically by habitat type, and, in some cases, to a lesser extent by observer, weather conditions, and time of day. The assumption that one detection function, and/or constant detection radius, are applicable to any given geographic area or habitat type does likely not hold true.

When modeling detection functions, we found the inclusion of covariates to be useful in several cases, and they are likely to yield more precise estimates of bird density (and more information) when data are sufficient. In particular, we found the inclusion of habitat type to improve model results significantly over a common (pooled) single detection function for all habitat types by allowing the scale of the detection function to vary by habitat type, providing a separate estimate of bird density for each habitat type. Using observer as a covariate produced similar results, highlighting the fact that observers may vary in their ability to detect a given species. Not accounting for observer bias may necessitate the adoption of unreasonable assumptions and result in less precise estimates of bird density. Given these findings, we recommend that multiple-covariate distance sampling receive greater consideration in the planning of future studies. Nevertheless, where conventional and multiple-covariate methods resulted in equally adequate models (i.e., less than two AIC points apart), they yielded very similar density estimates, suggesting conventional methods themselves are indeed robust to minor or moderate violations of assumptions, as suggested by Buckland et al. (2001).

The results of this study may have application to listed or imperiled species, such as the Island Scrub-Jay (*A. insularis*) or Florida Scrub-Jay (*A. coerulescens*). We found that point transects by the methods detailed in Buckland et al. (2001 and 2004), and Marques et al. (2007) were useful and cost-effective for monitoring scrub-jay abundance and habitat-specific densities. Desirable results are likely to be obtained if a power analysis is used to guide sampling efforts before data collection. We highly recommend recording covariate data in the field and testing the inclusion of covariates such as habitat type, observer, cloud cover, temperature, and time of day, especially when sufficient data are collected under a wide range of conditions. The results of this study support the utility of point transects and multiple-covariate distance-sampling methods in conservation biology and wildlife management and, in conjunction with the monitoring of demographic measures such as survivorship, fecundity, and dispersal, their use will enhance our understanding of population biology and the successes or failures of management techniques.

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