THE CONDOR
Ornithological Applications
AmericanOrnithology.org

Volume 118, 2016, pp. 329–337
DOI: 10.1650/CONDOR-15-67.1

RESEARCH ARTICLE

A comparison of point-count and area-search surveys for monitoring site occupancy of the Coastal California Gnatcatcher (*Polioptila californica californica*)

William B. Miller* **and Clark S. Winchell**

U.S. Fish and Wildlife Service, Carlsbad Fish and Wildlife Office, Carlsbad, California, USA
* Corresponding author: william_b_miller@fws.gov

Submitted April 22, 2015; Accepted February 4, 2016; Published April 6, 2016

ABSTRACT

Improving the efficiency of monitoring protocols prescribed by conservation plans can release typically limited funding for other management and conservation activities. We present an approach for optimizing protocols that considers the precision of parameter estimates, costs of implementation, and broader monitoring-program goals. In a case study of the Coastal California Gnatcatcher (*Polioptila californica californica*), we compared the efficiency of point-count surveys (with and without playbacks of vocalizations) and area-search surveys (with playbacks) for estimating site occupancy. Conducting an area-search survey of a 2.25 ha plot required an average of 19 min longer than conducting an 18-min point-count survey (15 min of silent observation followed by 3 min of playbacks) at the same location. However, the estimated detection probability (p) during a single visit was lower for point counts (0.41 ± 0.05) than for area searches (0.69 ± 0.05), while both methods generated similar occupancy (Ψ) estimates (0.34 ± 0.06). To obtain the specified level of precision for estimates of occupancy (i.e. with 10% coefficient of variation), the total survey effort (travel time + survey time) was projected to be 35% lower for area searches than for point counts because of differences in detection probability and, thus, in the required numbers of sites and visits per site. For point counts, detection probability increased from 0.35 ± 0.02 to 0.46 ± 0.03 visit^{-1} after playbacks were broadcast at the end of the count. Free use of playbacks is one of the factors that contributed to the higher detection probability of the area-search method, but playbacks may introduce a slight positive bias into occupancy estimates. Because there are tradeoffs in switching to area-search methods, the decision to switch protocols demands full consideration of monitoring-program goals and the costs and benefits of each survey approach.

Keywords: Coastal California Gnatcatcher, detectability, occupancy, optimization, playback recording, point count, walking survey

Comparación entre puntos de conteo y muestreos de área definida para el monitoreo de la ocupación de sitios por *Polioptila californica californica*

RESUMEN

El mejoramiento de la eficiencia de los protocolos de monitoreo prescritos por los planes de conservación podría liberar parte de la limitada financiación para su uso en otras actividades de conservación y manejo. Presentamos una aproximación para optimizar los protocolos que considera la precisión de los parámetros estimados, los costos de implementación y los objetivos más amplios del programa de monitoreo. En un estudio de caso en *Polioptila californica californica* contrastamos la eficiencia de los puntos de conteo (con y sin reproducción de vocalizaciones previamente grabadas) con la de los muestreos de área definida (con reproducción de vocalizaciones previamente grabadas) para la estimación de la ocupación de sitios. Hacer un muestreo de área definida de un cuadrante de 2.25 ha requirió un promedio de 19 minutos más que hacer conteos en puntos por 18 minutos (15 minutos de observación silenciosa seguidos de 3 minutos de reproducción de sonidos previamente grabados). Sin embargo, el estimado de la probabilidad de detección (p) durante una sola visita fue menor para los puntos de conteo (0.41 ± 0.05) que para los muestreos de área definida (0.69 ± 0.05) aunque ambos métodos generaron estimados de ocupación (Ψ) similares (0.34 ± 0.06). Para obtener el nivel requerido de precisión para los estimados de ocupación (i.e. 10% del coeficiente de variación) se estimó que el esfuerzo total de muestreo (tiempo de viaje + tiempo de muestreo) es 35% menor para los muestreos de área definida que para los puntos de conteo debido a diferencias en la probabilidad de detección y, por ende, en el número de sitios y el número de visitas por sitio requeridos. Para los puntos de conteo, la probabilidad de detección se incrementó de 0.35 ± 0.02 a 0.46 ± 0.03 por cada visita luego de la reproducción de sonidos previamente grabados al final del conteo. El uso libre de las vocalizaciones previamente grabadas es uno de los factores que contribuyen a la mayor probabilidad de detección en el método de muestreo de área definida, pero esta actividad puede introducir un ligero sesgo positivo en los estimados de ocupación. Debido a que cambiar a métodos de muestreo de área definida implica compromisos, la decisión de cambiar los protocolos de muestreo requiere considerar de forma completa los objetivos del programa de monitoreo así como los costos y beneficios de cada método.

Palabras clave: detectabilidad, grabación de sonidos previamente grabados, muestreo a pié, ocupación, optimización, *Polioptila californica californica*, puntos de conteo

INTRODUCTION

Habitat conservation plans have been developed to contribute to the survival of threatened and endangered species and, increasingly, to forestall or prevent the need to list other sensitive taxa (U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration [USFWS/NOAA] 1996). Conservation plans include biological goals that provide the broad guiding principles for operating the conservation program and associated management strategies. Monitoring is also an integral component of conservation-plan implementation (USFWS/NOAA 2000). Monitoring assists in refining biological goals, provides important information about range-wide population status, and provides information about the effectiveness of management actions. Monitoring programs often evolve over time, because time is needed to characterize natural variability in the populations of interest and to determine population state parameters and stressors that can be studied practically. Because more than one population state parameter can often be used for assessing attainment of conservation goals, part of refining a monitoring program involves selecting those population state parameters that are cost-effective to study and informative for directing management actions.

Within southern California, USA, the Coastal California Gnatcatcher (*Polioptila californica californica*; hereafter "gnatcatcher") is a flagship species that has been used to help guide the design of 11 multiple-species conservation plans formed in response to the California Natural Communities Conservation Planning Act (California Fish and Game Code §§ 2800 et seq.) and the federal Endangered Species Act (16 U.S.C. 1531 et seq). The goals of these plans are stated in general terms such as "maintaining net habitat values on a long term basis for target species" (R.J. Meade Consulting 1996) or "maintaining ecosystem functions and persistence of extant populations of covered species" (City of San Diego 1998). Each plan includes a commitment to monitor the gnatcatcher to track effectiveness of the conservation plan and, ideally, to inform management decisions. Although early gnatcatcher monitoring efforts within some of the plans were focused on tracking abundance and density (Hamilton 2004, Winchell and Doherty 2008), estimation of these parameters can require substantial effort and expense (Lancia et al. 1994, Pollock et al. 2002, Williams et al. 2002). Therefore, the need for abundance information to address conservation goals must be weighed against other monitoring and management mandates.

As plan managers have refined the monitoring programs, constrained budgets and competing priorities have led them to consider the relative expense, efficiency, and potential management application of information gathered by various monitoring methods (Preston and Kus 2015). In the case of the gnatcatcher, large-scale population fluctuations of $\geq$50% have been documented that are likely related to weather effects (Atwood and Bontrager 2001), so it can be difficult to discern an appropriate management response from abundance information. This has led the monitoring programs to consider site occupancy and associated variables, such as site-level colonization and extinction rates, as equally informative parameters to monitor (Leatherman Bioconsulting 2012, Winchell and Doherty 2014). Occupancy and abundance are different population state parameters; however, at intermediate occupancy rates, occupancy modeling can be used to study the relationship between site-specific covariates and site use. Therefore, occupancy may be equally informative and more cost-effective for guiding management decisions related to maintaining habitat quality for the gnatcatcher. Based on the decision of the monitoring programs to monitor site occupancy as an indicator of habitat quality, we present an approach to the optimization of monitoring methods using the gnatcatcher as a case study. We expect that our general approach could be applied elsewhere.

Our study is focused on contrasting the relative efficiency of point counts (Ralph et al. 1995) and plot-based area-search methods to monitor the gnatcatcher. To allow for the estimation of abundance and occupancy from point counts, Winchell and Doherty (2008, 2014) collected bird-detection distances for the estimation of abundance (Buckland et al. 2001) and compiled site-detection histories over repeated site visits for the estimation of site occupancy (MacKenzie et al. 2002, 2006). Because improving detectability can improve efficiency of surveys and monitoring programs (MacKenzie et al. 2006), Winchell and Doherty (2008, 2014) used playbacks of recorded gnatcatcher vocalizations during the point counts to boost individual detectability by prompting a territorial response from resident birds. To address the concern that use of playbacks could bias detection distances—and, thereby, density estimates—they divided the observation period into (1) an initial period, when silent observations were performed for the collection of distance data; and (2) a subsequent period, when playbacks were employed; the data from the two periods were then combined to estimate site occupancy. Using this approach, Winchell (2009) estimated site-level detection probability to be 0.45 $\pm$ 0.023 and recommended 6 site visits for monitoring site occupancy using point counts. Landscape-wide surveys designed to monitor the effectiveness of a conservation plan can be costly at this level of effort.

An alternative method that has been used to estimate gnatcatcher abundance is territory mapping, in which surveyors search prescribed areas for gnatcatchers while occasionally playing a recording of gnatcatcher vocalizations (Hamilton 2004). Results from territory-mapping surveys suggest that detection probabilities of gnatcatcher pairs using these methods could be reasonably high (e.g., 66–91% of presumed territories detected per survey), but efforts to correct for imperfect detection during these surveys have relied on assigning unmarked birds to presumed territories (Hamilton 2004).

We investigated gnatcatcher survey methods to evaluate whether site-level detection probabilities can be increased and efficiencies gained if one is solely interested in monitoring the rate of site occupancy within suitable gnatcatcher habitat within a habitat reserve. We contrasted point-count with area-search survey methods and used a cost–benefit approach to understand the trade-offs between time spent in the field and number of site visits required for optimal standard occupancy monitoring (MacKenzie et al. 2006). To investigate the effect of playbacks on site-level detection probability and precision of occupancy estimates, we studied how use of playbacks influenced these estimates during point-count surveys. Finally, because gnatcatcher detectability may be influenced by nesting behavior and habitat quality, we examined patterns in detectability over time and across modeled habitat suitability to investigate whether survey methods can be optimized in association with these variables.

METHODS

This study took advantage of an existing monitoring program for the gnatcatcher within San Diego County that uses point counts for data collection and includes public, quasi-public, military, and preserve lands within its sampling frame (Winchell and Doherty 2014). Potential sampling locations were identified as the points of intersection within a 600 $\times$ 600 m grid randomly overlaid on the study area. Points were spaced 600 m apart to avoid double-counting birds and to help ensure independence among points (C. S. Winchell personal observation). The San Diego County monitoring program uses a California Gnatcatcher Habitat Evaluation Model (Technology Associates International Corporation [TAIC] 2002, Winchell and Doherty 2008) to implement stratified random sampling among locations that are ranked according to 4 levels of habitat suitability: low, moderate, high, and very high. Because low and moderate suitability strata have extremely low occupancy rates (Winchell and Doherty 2014), our contrast of point-count and area-search methods used a randomly selected subset of locations within the "very high" and "high" habitat-quality strata where we had a reasonable likelihood of encountering gnatcatchers and where future statistical monitoring is feasible. Our investigation of the effectiveness of playback surveys used all the point locations surveyed by the San Diego monitoring program.

Point-count surveys were conducted by the San Diego County monitoring program's survey team at 355 randomly selected locations. Each point was visited one time each week from April 13 to May 24, 2009, with an objective of performing 6 surveys at each location. During each visit, the surveyor navigated to the point and implemented a 2-min "cool-down" period that was used to record the temperature (°C), relative humidity (%), average wind speed (km hr^{-1}), and cloud cover. Surveys were not conducted if average wind speed exceeded 20 km hr^{-1}, precipitation was greater than a drizzle, or ambient temperature was $<$4.5°C. Following the cool-down period, observers stood at the point location and used binoculars to search the vicinity for gnatcatchers over an 18-min observation period, divided into a 15-min period of silent observation, followed by a 3-min playback period during which a standardized digital recording of gnatcatcher vocalizations was broadcast. The playback recording was broadcast from an iPod attached to a speaker at 85–100 decibels at 1 foot from the speaker and included 2 rounds of 30 s of gnatcatcher mew calls followed by 60 s of silence. Observers recorded each auditory or visual detection of a gnatcatcher, the bird's sex and age, and the time, distance, and angle of the observation. All point-count data were truncated at 85 m to achieve a survey area similar in size to that of plots surveyed using area-search methods (i.e. 2.25 ha) and to ensure that estimates of occupancy were comparable.

Area-search surveys were conducted by a second survey team over a 12-days-longer, but overlapping, time interval (i.e. April 6–May 29, 2009) within 150 $\times$ 150 m plots that were overlaid and centered over 97 randomly selected point-count locations within the "very high" and "high" suitability strata (TAIC 2002), excluding military lands and areas that burned in 2007 wildfires. Our plot size was scaled to approximate the size of a single gnatcatcher pair's territory (Atwood et al. 1998, Atwood and Bontrager 2001) to minimize heterogeneity in detection probability arising from variability in the number of individuals within a plot (Royle and Nichols 2003). To address the assumption that all sites were closed to a change in gnatcatcher occupancy during the ~8 wk of surveys, we initiated surveys several weeks after territories were established and ignored observations of juveniles when determining site occupancy. Survey timing was coordinated between the 2 teams to avoid conducting both types of surveys at a location on the same day, because we were concerned that exposure to multiple surveyors and playbacks in a single day could harass birds and bias results. Area-search surveys were conducted once every 2 wk at each location, with an objective of completing 4 surveys location^{-1}.

Upon arriving at a field plot, area-search surveyors recorded the same environmental data and adhered to the same weather-based survey restrictions as point-count surveyors. Within each plot, the surveyor walked along a route of his or her choosing and surveyed for gnatcatchers with the aid of binoculars and the recording of gnatcatcher vocalizations. Surveyors broadcast playbacks at their discretion but were limited to a maximum of 6 playbacks survey^{-1} to minimize behavioral harassment, and were instructed not to use playbacks from the plot edge to minimize the potential of calling birds into the plot. Because there was considerable variability in topographic conditions and vegetation cover among plots that affected travel rates, we did not standardize area searches by time but capped search times at 1 hr and focused on traveling through the entire plot during the survey. To help standardize survey rates and minimize bias due to familiarity with a plot, we discussed and practiced area-search methods in the field with all surveyors together before data collection began; surveyors were instructed to follow similar routes during each survey. To aid with navigation and recording of data, each surveyor was given an aerial photo of each plot and carried with them a GPS device that displayed their position in relation to the plot center point and its boundary. During the survey, the observer recorded the number, sex, and age of any gnatcatchers that were detected and spot-mapped the location of each observation on the aerial photo. If a bird was initially observed outside of the plot but flew into the plot during the course of the survey, this was recorded as a positive detection. Surveys were concluded when the surveyor had covered the entire plot or an adult gnatcatcher was detected within the plot.

To evaluate the relative efficiency of point-count and area-search surveys, we needed estimates of the time required to travel to survey sites, time to conduct each survey, and detection probability per visit for each survey type. From these we could calculate the number of sites, number of visits per site, and total hours of travel and survey effort required to estimate occupancy with a specified level of precision for each survey type (MacKenzie et al. 2006). Members of the area-search team recorded travel time to visit survey points, which was considered a set cost per visit because the 2 surveys were conducted independently. Surveyors also recorded the duration of each area search, which was terminated during a given visit as soon as a gnatcatcher was detected. To correct for the methodological difference between survey methods that allowed area searches but not point counts to be terminated once a gnatcatcher was detected, we estimated the point-count effort needed per visit by calculating the time elapsed to the first detection of a gnatcatcher; if no gnatcatchers were detected during a point count, the standard duration of 18 min was used. Finally, because we performed 6 point-count surveys and 4 area-search surveys, we used the survey times associated with our first 4 point counts to contrast survey time requirements.

All survey data were analyzed using a single-season occupancy model (MacKenzie et al. 2006) in Program MARK (White and Burnham 1999) to estimate probabilities of detection (p) and occupancy (ψ). Because our comparison of survey methods relied on data collected at the same survey locations, we analyzed each dataset separately to address the lack of independence. To contrast estimates of p and ψ derived from point counts and area searches, we compiled separate detection histories for the 97 locations surveyed by both methods (6-visit histories for point counts, including playback detections; and 4-visit histories for area searches, which also employed playbacks). For both analyses, we modeled detection probability as a constant, as varying over time (i.e. survey week for point counts, biweekly for wandering transects), or as varying in relation to the 2 modeled habitat-suitability strata (TAIC 2002). Occupancy was modeled as a constant or as varying by habitat suitability. We used both additive and factorial models to combine model factors and used all possible combinations of factors to achieve a balanced model set (Doherty et al. 2012). To contrast point-count detection probabilities with and without use of playbacks, we again constructed 2 datasets that were analyzed separately but included all 355 points surveyed. The first dataset included 6-visit detection histories derived from the 15-min silent-observation period at each point; the second dataset used 6-visit detection histories derived from the entire 18-min period, including detections during the 3-min playback period. Because we were primarily interested in the effect of playback vocalizations, we modeled occupancy as a constant and we modeled detection probabilities as a constant or as varying over time (i.e. survey week).

To assess goodness-of-fit of our models, we replaced missing values in our datasets (i.e. missed site visits) with nondetections and performed the median $\hat{c}$ procedure in Program MARK. When this procedure suggested there was a lack of model fit to the data (i.e. $\hat{c} > 1$), we adjusted the estimates and models in our original dataset by the value of $\hat{c}$. For model selection, we used Akaike's

TABLE 1. Model rankings by survey method for the California Gnatcatcher in southern California, USA. Predictor variables for detection probabilities (p) and occupancy (ψ) were modeled to remain constant (.), vary by habitat quality strata (g), vary over time (t), and vary from combinations of these factors. For model selection, we used Akaike's Information Criterion corrected for small sample size (AIC$_c$; only models with ΔAIC$_c$ < 10 are listed; w_i = AIC$_c$ weight; k = number of parameters).

Survey method	Model	ΔAIC$_c$	w_i	Model likelihood	k
Point count	p(.),ψ;(.) [a]	0.00	0.43	1.00	2
	p(.),ψ(g)	0.93	0.27	0.63	3
	p(g),ψ(.)	1.60	0.19	0.45	3
	p(g),ψ(g)	2.80	0.11	0.25	4
	p(t),ψ(.)	9.84	0.00	0.01	7
Area search	p(g),ψ(.) [b]	0.00	0.27	1.00	3
	p(.),ψ(.)	0.43	0.22	0.81	2
	p(g),ψ(g)	0.76	0.19	0.68	4
	p(.),ψ(g)	0.96	0.17	0.62	3
	p(g+t),ψ(.)	3.97	0.04	0.14	6
	p(t),ψ(.)	4.21	0.03	0.12	5
	p(g+t),ψ(g)	4.86	0.02	0.09	7
	p(t),ψ(g)	4.88	0.02	0.09	6
	p(g*t),ψ(.)	5.45	0.02	0.07	9
	p(g*t),ψ(g)	6.46	0.01	0.04	10

[a] AIC$_c$ = 232.96.
[b] AIC$_c$ = 221.06.

Information Criterion corrected for small sample size (AIC$_c$). Models within 2 AIC$_c$ units of the best model were considered competitive, and model weights (w_i) were calculated to assess the relative likelihood of individual models within each candidate set (Burnham and Anderson 2002). Parameter estimates are presented as means ± SE with 95% confidence intervals (CI).

RESULTS

Point-Count vs. Area-Search Surveys

We conducted a total of 556 point-count surveys and 382 area-search surveys, at 48 sites modeled as having "very high" and 49 sites modeled as having "high" habitat suitability for the gnatcatcher. We conducted an average of 5.7 point counts location^{-1} (range: 1–6) and 3.9 area searches location^{-1} (range: 3–4). We detected gnatcatchers at 31 locations during point counts and 33 locations during area searches, but not all at the same sites by both methods. Gnatcatchers were detected in common at just 25 locations, with apparent site-occupancy differences recorded at 14 of the 97 locations. Point-count surveys detected gnatcatchers at 6 locations where area searches did not, and area searches detected gnatcatchers at 8 locations where point counts did not. We did not observe gnatcatchers beyond 85 m (i.e. our truncation distance) during point counts at any of the 8 locations where gnatcatchers were observed only during area-search surveys.

For point-count surveys, the model that estimated detection and occupancy probabilities as constants [p(.), ψ(.)] received the greatest support (w_i = 0.43) within the candidate set; this model was also competitive for area-search surveys (ΔAIC$_c$ = 0.43, w_i = 0.22; Table 1). These models indicated that detectability (p) was higher using the area-search method (0.69 ± 0.05, 95% CI: 0.59–0.78) than using the point-count method (0.41 ± 0.05, 95% CI: 0.31–0.51), but estimated occupancy rates (ψ) were similar between methods (point count: 0.34 ± 0.06, 95% CI: 0.23–0.47; area search: 0.34 ± 0.06, 95% CI: 0.24–0.46). Without data truncation, point-count detectability (p = 0.44 ± 0.05, 95% CI: 0.34–0.54) and occupancy (ψ = 0.36 ± 0.07, 95% CI: 0.24–0.50) estimates from the [p(.), ψ(.)] model (AIC$_c$ = 222.21, ΔAIC$_c$ = 0, w_i = 0.39) were a little higher than these estimates calculated with truncation.

For area searches, the 4 top models received almost equal support (w_i = 0.17–0.27). The most competitive model [p(g), ψ(.)] suggested that the probability of detecting a gnatcatcher during an area-search survey at a site, given that it was occupied, was greater in habitat of "very high" quality (0.75 ± 0.06, 95% CI: 0.63–0.85) than in habitat of "high" quality (0.59 ± 0.09, 95% CI: 0.42–0.75) and that occupancy did not differ between strata (0.35 ± 0.06, 95% CI: 0.25–0.46). There was some support (w_i = 0.19) for the model that also allowed occupancy to vary by stratum, but confidence intervals for these estimates were broadly overlapping ("very high": 0.41 ± 0.08, 95% CI: 0.27–0.57; "high": 0.28 ± 0.08, 95% CI: 0.16–0.45). There was virtually no support for models incorporating variability in detection probability over time for either survey (Table 1).

The average time to travel to a survey location was 41.75 ± 19.5 min (SD), to conduct a point count (to first gnatcatcher detection) was 16.50 ± 4.25 min, and to conduct an area search was 35.25 ± 14.0 min. The relatively small time savings from a standardized 18-min point count reflected the lack of gnatcatcher detections during most surveys and late gnatcatcher detections during others. Overall, the duration of area-search surveys was more variable than that of point counts, which was due to a combination of varying terrain among survey plots and the ability to terminate the survey once a gnatcatcher was detected. The average time that it took to travel to a survey location was greater than the average length of either survey.

Point Counts with and without Playbacks of Vocalizations

Across the larger sample of 355 locations visited as part of the San Diego County gnatcatcher monitoring program, we conducted a total of 1,835 point counts, achieving an average of 5.17 survey visits location^{-1} (range: 1–6). During these surveys, we recorded 317 gnatcatcher detections distributed among 121 locations. Of these detections, 29% ($n = 92$) were recorded during the final 3 min of the survey when playbacks were broadcast. Had the surveys concluded before the final 3 min, we would have detected gnatcatchers at 16 fewer locations.

Average detectability estimates for point-count surveys conducted without or with the aid of playbacks are provided by the model that estimated detection and occupancy probabilities as constant for each dataset [p(.), ψ(.)]. With this model, detection probability was estimated to be 0.35 ± 0.02 (95% CI: 0.30–0.40) without playbacks and 0.46 ± 0.03 (95% CI: 0.41–0.51) with playbacks; estimates of occupancy were 0.35 ± 0.03 (95% CI: 0.29–0.41) and 0.37 ± 0.03 (95% CI: 0.31–0.44), respectively. For point-count surveys with playbacks, the time-constant model ($AIC_c = 924.9$, $k = 2$) received far more support ($\Delta AIC_c = 0$, $w_i = 0.94$) than the alternative model considered [p(t), ψ(.)], which allowed detection probability to vary across weeks ($\Delta AIC_c = 5.44$, $w_i = 0.06$). For point-count surveys without playbacks, however, the model that allowed detection probability to vary during the season ($AIC_c = 1007.1$, $k = 7$) was better supported ($\Delta AIC_c = 0$, $w_i = 0.74$) than the time-constant model ($\Delta AIC_c = 2.12$, $w_i = 0.26$). However, there was broad overlap in estimates of detection probability during the 6-wk survey period, ranging from 0.26 ± 0.05 (95% CI: 0.18–0.36) during the third week to 0.48 ± 0.05 (95% CI: 0.37–0.58) during the final week of the survey window (April 20–May 3).

DISCUSSION

Area-search surveys that allowed use of a vocalization playback throughout the search were more efficient for documenting site occupancy by gnatcatchers than point-count surveys that employed the same playback but only at the end of the observation period. Although individual point counts required an average of 19 min less time to complete than individual area searches at the same sites, the increase in detection probability for area searches (0.69) vs. point counts (0.41) was appreciable enough to reduce both the number of sites and the number of visits per site required to achieve the same robust occupancy estimate. Thus, the efficiency of the shorter point-count survey time was far outweighed by the efficiency of performing a smaller total survey effort with the area-search method.

To illustrate using parameter values similar to those estimated here: When site occupancy is 0.34 and the detection probability is 0.41, the recommended optimal number of visits to a site is 4, using a standard survey design in which all sites are surveyed an equal number of times (from MacKenzie et al. 2006: equation 6.1). To achieve a 10% coefficient of variation for the occupancy estimate, the number of sites that should be sampled is 260 (from MacKenzie et al. 2006: equation 6.3). Based on the average time required to travel to a site and conduct a point count, this would result in a total recommended survey effort of 1,005 hr. Using the same occupancy rate and desired level of precision but a higher detection probability of 0.69, the optimal number of visits to a site would drop to 2, and the number of sites that should be sampled would be 253. Based on the time required to travel to a location and conduct an area search, this would result in a total recommended survey effort of 649 hr. These calculations suggest that the higher estimated detection probability associated with area searches could reduce the total survey time needed to obtain an occupancy estimate for the gnatcatcher at a specified level of precision by as much as 35%.

For comparison of occupancy estimates, we truncated our point-count data at 85 m to equate the search areas among methods, which slightly reduced the efficiency of the point counts. Selection of too short a truncation distance has potential to reduce detection probabilities by discarding potentially useful data. Our analysis of the untruncated data suggests that point-count detection probabilities could have been slightly better had we selected a larger survey area and/or a longer truncation distance, but the area-search method is still considerably more efficient for estimating site occupancy of the gnatcatcher.

Although it is not explored here, combining the higher detectability of the area-search method with a removal design, in which no further surveys of a site are conducted once the species is detected, can likely further increase efficiency (MacKenzie et al. 2006). Such a design is well suited to a circumstance when the primary focus of the survey is to confirm a species' presence, which is often the case with listed species. Combining the removal design with the area-search method may also be well suited for a situation such as ours, in which lengthy travel and navigation times to sites make it impractical to rotate surveyors among visits, and familiarity with a site has potential to result in higher detection probabilities during subsequent visits (MacKenzie et al. 2006).

Because funding for implementation of a conservation plan is always constrained, the potential cost savings from changing survey methods can be compelling, but the decision to do so should consider the tradeoffs involved. One potential criticism of the area-search method as it was implemented here is its focus on a single species, which can be inefficient if one is charged with monitoring multiple species. Because multiple species can be easily recorded during point counts, this method has the potential to be the more efficient one if the monitoring program's goals involve monitoring the abundance of other avian species. Given that the plot-based method could be adapted to monitor occupancy of several species simultaneously, the methodology that is most efficient for multispecies monitoring must be determined by assessing the total survey effort required to achieve all monitoring-program goals.

Another potential criticism of both the point-count and area-search methods applied here is the use of playbacks during the surveys, which may introduce heterogeneity in detection probability among visits (e.g., due to habituation, variations in detection of the playback associated with habitat, topography, wind, ambient noise, stage of the nesting cycle, specific location where playback is broadcast) and could positively bias occupancy estimates by drawing birds onto the plot. Our comparison of 15-min point counts with and without 3 min of additional playback time at the end of the count confounded the effect of the longer observation period with the effect of the playback but provided an indication of the benefit that is gained by broadcasting recorded vocalizations during surveys. Detection probabilities were indeed higher with the added playback period: 29% of all gnatcatcher detections were recorded during the 3-min playback period, which constituted only 16% of the observation period. However, the relatively small gain in detectability, from 0.35 without playback to 0.46 with playback, suggests that factors other than the free use of playbacks contributed to the larger gain in detectability (to 0.69) that was realized during area-search surveys.

Our analysis of the entire point-count dataset that excluded playback detections found some limited support for a model in which gnatcatcher detectability varied by week. The lack of a linear seasonal trend in detectability, however, suggests that it may be difficult to time surveys to coincide with seasonal periods when gnatcatchers are most detectable, at least during the time interval we studied, which was after the onset of breeding. Interestingly, support for time-varying models in detectability was not found when detections during the playback period were included in the point-count data, or during area searches, which also used playbacks. This suggests that use of playbacks during surveys may help overcome time-dependent behavioral shyness of gnatcatchers. To help control for potential heterogeneity in detection probability among plots that may arise from the area-search method, we recommend standardizing search times and the locations and number of times that playbacks can be employed.

Because measures of occupancy are scale dependent (i.e. a larger site is likely to have a higher probability of occupancy than a small site), the potential attraction of birds in response to playbacks and violations of the assumption of closure across multiple visits are both of great concern in terms of introducing positive bias. The estimate of occupancy increased only slightly, from 0.35 to 0.37, when comparing point counts without and with playbacks, respectively. This difference was well within the margin of error of these estimates, which suggests that bias arising from attraction to playbacks may be minimal.

The issue of population closure may be more problematic. To compare estimates of occupancy from point counts with those from area searches, we truncated our point-count observations at a radius of 85 m to approximate the size of our 150 $\times$ 150 m area-search plots. This circular survey area overlaps but covers a slightly different geographic area than the square survey plot. Although we obtained equivalent occupancy estimates from the 2 survey methods, we observed differences in the patterns of apparent site occupancies. The lack of correspondence among apparent site occupancies may be due to the slight differences in the survey areas, but may also indicate that our survey areas were smaller than the size of those gnatcatchers' territories or included only parts of them. Either scenario would result in a lack of closure (i.e. the species was not consistently present on a site and available for detection throughout the survey window) and would indicate that estimates from both methods better represent site "use" instead of occupancy.

Nevertheless, equivalency in the occupancy estimates suggests that, despite the possibility that the area-search method with playbacks being used throughout the plot has a higher possibility of attracting gnatcatchers from beyond the plot edge into the survey area, the attraction of birds during area searches was not more appreciable than when playbacks were used at the end of point counts. Interestingly, our examination of the untruncated point-count data did not reveal gnatcatcher detections beyond 85 m at any of the locations where area searches detected gnatcatchers and point counts did not. Overall, for both survey methods, it may be difficult to achieve closure when monitoring a territorial species in continuous habitat where a multitude of factors can affect territory size and location (Atwood et al. 1998, Preston et al. 1998). Using broadcast vocalizations for gnatcatcher surveys has potential to result in slightly positively biased estimates of occupancy. Thus, the decision about use of playbacks must jointly consider the cost savings of this approach and whether the bias introduced is likely to mask biologically meaningful trends in occupancy relevant to management decisions.

Based on the results of prior gnatcatcher monitoring in San Diego County, which indicated that site occupancy is influenced by habitat suitability (Winchell and Doherty 2008, Winchell 2009), we stratified sampling across 2 of the original 4 suitability strata ("high" and "very high") to see how this stratification might influence a recommended survey design. Our failure to find strong support for habitat-related differences in occupancy may, in part, have been due to our use of only 2 rather than all 4 strata; alternatively, the smaller sample size in our study may not have provided sufficient power to detect a difference. Our results did suggest, however, that habitat suitability influenced detection probability during area-search surveys. Because area-search surveys require the surveyor to travel throughout a plot while recording gnatcatcher detections whereas point-count surveys are largely passive, area-search methods may be more sensitive to differences between the strata in topography and the structure of vegetation. Although the difference between point estimates of detectability for the 2 strata does not prompt a change in the recommended number of site visits, it does alter the number of recommended sites that should be visited for estimation of the same occupancy rate with a desired coefficient of variation. Thus, an optimized monitoring program should be based on a range of anticipated values across the sampled strata for both detection probability and occupancy.

Conclusion

Constrained budgets generally present a considerable challenge for implementing monitoring programs and management actions prescribed by conservation plans. Because conservation dollars are limited and monitoring is expensive, improving the efficiency of protocols is important. Here, we present an approach to optimizing protocols that considers the precision of parameter estimates, costs of implementation, and consideration of broader monitoring-program goals. Application of this approach may be suitable for other programs that are overlaying sampling designs to collect data on both occupancy and abundance and that have a goal of monitoring habitat quality through occupancy, and for species that occur within discrete habitat strata, at low densities, and in nonclustered distributions.

ACKNOWLEDGMENTS

We thank the more than 30 people who were involved with this project and gave unselfishly of their time and talents. We also thank L. McAfee of the Nature Reserve of Orange County and K. Greer of the San Diego Association of Governments for their leadership and support of regional ecological monitoring, S. Wynn for input on the manuscript, and K. Preston, M. Pavelka, and P. Doherty for many thoughtful discussions.

Funding statement: This work was jointly funded by a grant from the Natural Communities Coalition and SANDAG Agreement no. 5000793 with funds provided via TRANSNET. None of the funders had any input into the content or required approval of the manuscript before submission or publication.

Ethics statement: The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

Author contributions: W.M. and C.W. conceived the study, developed the methods, collected data, and conducted the research. W.M. analyzed the data and wrote the paper. W.M. and C.W. contributed substantial materials, resources, or funding.

LITERATURE CITED

Atwood, J. L., and D. R. Bontrager (200l). California Gnatcatcher (*Polioptila californica*). In The Birds of North America 574 (A. Poole and F. Gill, Editors). Birds of North America, Philadelphia, PA, USA.

Atwood, J. L., S. H. Tsai, C. H. Reynolds, J. C. Luttrell, and M. R. Fugagli (1998). Factors affecting estimates of California Gnatcatcher territory size. Western Birds 29:269–279.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas (2001). Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, Oxford, UK.

Burnham, K. P., and D. R. Anderson (2002). Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, second edition. Springer, New York, NY, USA.

City of San Diego (1998). Final Multiple Species Conservation Program: MSCP Plan, August 1998. City of San Diego, San Diego, California, USA. http://www.sandiegocounty.gov/content/dam/sdc/pds/mscp/docs/SCMSCP/FinalMSCPProgramPlan.pdf

Doherty, P. F., G. C. White, and K. P. Burnham (2012). Comparison of model building and selection strategies. Journal of Ornithology 152 (Supplement 2):S317–S323.

Hamilton, R. A. (2004). Target Bird Monitoring Study, Nature Reserve of Orange County 2004. Report prepared for the Nature Reserve of Orange County, Irvine, California, USA. http://www.sdmmp.com/monitoring/animal_monitoring.aspx

Lancia, R. A., J. D. Nichols, and K. H. Pollock (1994). Estimating the number of animals in wildlife populations. In Research and Management Techniques for Wildlife and Habitats (T. A. Bookhout, Editor). The Wildlife Society, Bethesda, MD, USA. pp. 215–253.

Leatherman Bioconsulting (2012). Central and Coastal Reserve California Gnatcatcher Study 2011. Report prepared for the Nature Reserve of Orange County, Irvine, CA, USA. http://www.sdmmp.com/monitoring/animal_monitoring.aspx

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm (2002). Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines (2006). Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence. Elsevier, Amsterdam, The Netherlands.

Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey, and J. R. Sauer (2002). Large scale wildlife monitoring studies: Statistical methods for design and analysis. Environmetrics 13:105–119.

Preston, K., and B. Kus (2015). Coastal California Gnatcatcher proposed regional monitoring sampling design. Presentation to the Regional California Gnatcatcher Monitoring Workshop, July 17, 2014, Carlsbad, California, USA. http://sdmmp.com/Libraries/Regional_CAGN_Monitoring/CAGN_Regional_Monitoring_Sample_Design_Workshop_HO_071315.sflb.ashx

Preston, K. L., P. J. Mock, M. A. Grishaver, E. A. Bailey, and D. F. King (1998). California Gnatcatcher territorial behavior. Western Birds 29:242–257.

Ralph, C. J., J. R. Sauer, and S. Droege (Editors) (1995). Monitoring Bird Populations by Point Counts. USDA Forest Service General Technical Report PSW-GTR-149.

R.J. Meade Consulting (1996). Final Natural Community Conservation Plan & Habitat Conservation Plan: County of Orange Central & Coastal Subregion, Parts I & II: NCCP/HCP. Prepared for County of Orange Environmental Management Agency. Orange County, CA, USA. http://occonservation.wpengine.com/wp-content/uploads/2015/04/NCCP-Parts-I-II-Plan.pdf

Royle, J. A., and J. D. Nichols (2003). Estimating abundance from repeated presence–absence data or point counts. Ecology 84: 777–790.

Technology Associates International Corporation (2002). California Gnatcatcher habitat evaluation model for USFWS. Digital Data. U.S. Fish and Wildlife Service, Carlsbad, CA, USA.

U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration (1996). Habitat Conservation Planning and Incidental Take Permit Processing Handbook. http://www.fws.gov/endangered/esa-library/pdf/HCPBKTOC.PDF

U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration (2000). Addendum to the HCP Handbook (Executive Summary). http://nctc.fws.gov/resources/knowledge-resources/Pubs9/hcp_add_execsumm00.pdf

White, G. C., and K. P. Burnham (1999). Program MARK: Survival estimation from populations of marked animals. Bird Study 46 (Supplement):S120–S139.

Williams, B. K., J. D. Nichols, and M. J. Conroy (2002). Analysis and Management of Animal Populations. Academic Press, San Diego, CA, USA.

Winchell, C. S. (2009). Estimation of San Diego County California Gnatcatcher population size and recovery following the 2003 October wildfires. U.S. Fish and Wildlife Service, Carlsbad Fish and Wildlife Office, Carlsbad, CA, USA. http://sdmmp.com/reports_and_products/Monitoring_Reports/Animal%20Species/Calif%20Gnatcatcher/USFWS_CAGN%20Survey%20Report%20FINAL%2002NOV09.pdf

Winchell, C. S., and P. F. Doherty, Jr. (2008). Using California Gnatcatcher to test underlying models in habitat conservation plans. Journal of Wildlife Management 72:1322–1327.

Winchell, C. S., and P. F. Doherty, Jr. (2014). Effects of habitat quality and wildfire on occupancy dynamics of Coastal California Gnatcatcher (*Polioptila californica californica*). The Condor: Ornithological Applications 116:538–545.