Management and Conservation Article

Using California Gnatcatcher to Test Underlying Models in Habitat Conservation Plans

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ABSTRACT Habitat Conservation Plans are a widely used strategy to balance development and preservation of species of concern and have been used in southern California, USA, to protect the coastal California gnatcatcher (*Polioptila californica*). Few data exist on gnatcatcher abundance and distribution, and existing data have problems with issues of closure (i.e., sampling occurs in a short enough time period such that abundance or distribution are not changing), detectability, and proper attention to probability-based sampling schemes. Thus, a habitat model has been relied upon in reserve design. California gnatcatchers are the flagship and umbrella species of many plans and we provide the first estimates that incorporate probabilistic sampling and test predictions from the habitat model. Probability of occurrence was 26% ($\hat{SE} = 0.06$); however, occupancy varied by modeled habitat quality with slopes <40%, warm, and wet sagebrush habitat having higher occupancy probabilities. Interpreting abundance and occupancy probabilities by vegetation type was complicated by error detected in Geographic Information System vegetation metadata files. The slope (1.08, $\hat{SE} = 0.66$), temperature (0.79, $\hat{SE} = 0.70$), and precipitation (–2.62, $\hat{SE} = 1.21$) variables associated with habitat models were stronger influences on occupancy than was patch size (0.48, $\hat{SE} = 0.66$). Previous models weight patch size equal to slope and climate. Our work demonstrates that probabilistic sampling can be carried out on a large scale and the results provide better information for managers to make decisions about their reserves. (JOURNAL OF WILDLIFE MANAGEMENT 72(6):1322–1327; 2008)

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Habitat Conservation Plans (HCP) are widely used to balance management of species of concern and development (American Institute of Biological Sciences 1999). An HCP establishes a preserve system with a monitoring and adaptive management plan. Often, when HCPs are being developed little data exists concerning distribution of species of concern and habitat models are relied upon heavily to define the preserve system, which has partially led to criticism of such plans (Ball et al. 2005, Rahn et al. 2006). We tested the reliability of such a habitat model used in various stages of reserve planning in southern California, USA.

Arguably, coastal reserves plans are some of the highest profile HCPs and the coastal California gnatcatcher (*Polioptila californica californica*) has become the primary species of concern identified with 2 HCPs that encompass most of the open space remaining in coastal southern California (County of Orange 1996, San Diego 1998). The gnatcatcher was listed as a federally threatened subspecies in 1993 (U.S. Fish and Wildlife Service [USFWS] 1993*a*, *b*, *c*, *d*), and many of the conservation-related activities in this area are focused directly on this bird or the California sagebrush (*Artemesia californica*) vegetation it inhabits (Atwood and Bontrager 2001). The California gnatcatcher is the flagship and umbrella species in southern California representing coastal sage scrub communities.

Little information exists about gnatcatcher distribution and abundance and what information does exist has been compromised by issues of closure (i.e., occupancy and abundance are not changing during sampling [e.g., Atwood 1990, 1992; Erickson and Miner 1998; USFWS 1993*a*, *b*, *c*, *d*, 1996, 1999*a*, *b*]), detectability, and nonrandom sampling. With the lack of reliable gnatcatcher information and the need to design a conservation reserve network, habitat models were constructed and relied upon (California Department of Fish and Game 1993, Rolfe 2000). A habitat model used in the reserve design qualified areas as low-, medium-, high-, and very-high-quality habitat (Technology Associates International Corporation [TAIC] 2002) and the TAIC model suggests that occupancy probabilities increased with these categories. Data used in this model were not collected using probability-based sampling and the model did not consider detection error. The TAIC model utilized presence-only data, ignoring all visitation data where no gnatcatchers were observed, and at those presence-only points weighted equally the physical parameters of the environment. All data were pooled across years. In brief, the TAIC model incorporates biological hypotheses into a scoring system and rates each mapped location with sagebrush. The individual environmental variables (slope, patch size, annual precipitation, and average annual temp) and cut-off values used in the TAIC model resulted from consultation with gnatcatcher biologists.

We were able to perform a large-scale survey effort for gnatcatchers across the preserve system and used analytical methods to estimate occupancy (MacKenzie et al. 2002, 2006) and abundance (Farnsworth et al. 2002). We used these analytical methods to correct for detection probabilities and incorporated a probability-based sampling scheme to estimate these parameters within our sampling frame.

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Using these analytical methods we were able to provide, for the first time, quantitative occupancy probabilities to the qualitative categories (low-, medium-, high-, and very-high-quality habitat) produced by the TAIC model. We also were able to test whether the environmental variables from the TAIC model, either individually or in sum, helped to explain variation in occupancy.

Our objectives were to 1) obtain an estimate of percent area occupied and of number of pairs of California gnatcatchers across our sampling frame (i.e., preserve lands in Orange and San Diego counties), addressing past shortcomings by using a probability-based sampling scheme and methods incorporating detection probabilities, 2) evaluate the TAIC gnatcatcher habitat model by testing the model prediction that higher quality habitat has a higher percent of area occupied by gnatcatchers than does lower quality habitat, and 3) evaluate the underlying biological mechanisms incorporated into the TAIC habitat model.

STUDY AREA

Our study area consisted of all locations that could potentially be occupied by gnatcatchers in Orange and San Diego counties, California. We defined these locations as lands having California sagebrush or the sagebrush–chaparral ecotone as mapped by Jones and Stokes Associates, Inc. (1993) and San Diego Association of Governments (1995). Plant communities were mapped at various scales, ranging from 1:1,200 to 1:24,000, digitizing vector data. We were restricted to public and quasi-public lands (i.e., lands owned by city, county, state and federal agencies (except Department of Defense lands) as well as some private nongovernmental organizations. Ultimately we had access to 36,587 ha of the 122,094 ha of coastal scrub and 8,336 ha of the 19,586 ha scrub–chaparral ecotone. Statistical inference only applies to this 44,923-ha sampled population.

METHODS

We identified our sampling locations as the center points of a 600 × 600-m grid overlaid on the study area. We chose sampling points to be 600 m apart to avoid double-counting birds. We based this design feature on USFWS gnatcatcher spot-mapping records, which indicated that the longest axis across a territory was 295 m for birds studied at the San Diego National Wildlife Refuge, resulting in 1,282 possible sampling points (C. S. Winchell, USFWS, unpublished data). From preliminary simulations testing the power of various sampling strategies to estimate an occupancy rate of 0.5 ± 10%, 95% of the time with a detection probability of 0.5, we decided that 4 visits to 300 points would meet our goals. No data sets were available that were collected using probabilistic sampling to simulate various designs, so we based our design parameters on interviews with experienced gnatcatcher biologists. We did not know how many points could actually be visited in the time available and we also anticipated some points would be inaccessible for logistical reasons (e.g., avoiding cliffs, no access across private lands). Starting with a random point and moving in a randomly chosen direction we systematically chose points to survey in groups of 3 for logistical reasons. We visited 436 points (see Results) and assumed this to be a random, representative sample.

Surveyors completed our surveys during the 2002 breeding season. We visited points from 1 to 4 times over the 4 survey periods in 2002 (11 Apr–27 Apr, 28 Apr–14 May, 15 May–1 Jun, 2 Jun–17 Jun) and followed a protocol based on point counts and point-based distance sampling (Ralph et al. 1995, Buckland et al. 2001). At the start of each visit, a 2-minute period was spent in which we recorded temperature (° C), relative humidity (%), average wind speed (km/hr), and cloud cover, after which a bird-data collection period began, which consisted of a 10-minute period within which we recorded each detected gnatcatcher. We used a measuring tape to record the distance to each detected bird for observations <10 m from the point center and we used a digital laser range finder for those detections >10 m (±1 m). Observers also recorded exact time (min and sec) of detection. We used a compass to record the angle at which we detected each bird relative to magnetic north to aid in distinguishing between individual birds. During the survey we visually tracked birds to help control for double-counting, and we noted any points of confusion. If possible, we also noted age (ad or juv) and sex of the bird. Because of difficulties in identifying birds to sex, we focused on estimating percent area occupied and abundance as it related to pairs. We recorded juveniles but did not consider them when determining pairs. We defined a pair as 1 individual bird or 2 birds of different sex. We considered 2 birds of the same sex or 3 adult birds as 2 pairs. Rarely did we detect >1 bird or 2 birds of the same sex.

To ground-truth Geographic Information System (GIS) habitat maps on which we based our sampling frame, observers collected vegetation data to classify the vegetation community at each point during one visit. We used categories used in previous mapping exercises: coastal sagebrush, sagebrush–chaparral ecotone, or other (Jones and Stokes Associates, Inc. 1993, San Diego Association of Governments 1995). We classified plant communities using criteria set forth by Holland (1986).

To estimate occupancy we used the methodology of MacKenzie et al. (2002), which explicitly incorporates detection probability (p) with the estimation of the percent area occupied (ψ). We estimated number of gnatcatcher pairs using 4 methodologies, namely, removal methods, distance sampling, a naïve occupancy estimate (sensu MacKenzie et al. 2002), and the Royle and Nichols estimator (Buckland et al. 2001, Farnsworth et al. 2002, Royle and Nichols 2003). Because all these abundance estimators gave similar results we report only the removal-model estimates. Further details on these estimates can be found in Winchell and Doherty (2006). To employ the removal model of Farnsworth et al. (2002) we split each 10-minute visit into 3 consecutive 200-second periods and used the amount of time that elapsed until each gnatcatcher was first detected to estimate the number of gnatcatcher pairs for each visitation period. We used Program Mark (White and Burnham 1999) for both the occupancy and removal-method models. Assumptions for the occupancy and abundance estimator are similar: 1) closure such that occupancy or abundance does not change during the survey, 2) no unmodeled heterogeneity remains in parameters, 3) detection histories of locations or individuals are independent. For occupancy estimation we performed bootstrap goodness-of-fit tests and, if needed, adjusted our test statistics and variances using a variance inflation factor ($\hat{c}$; Burnham and Anderson 2002). For model selection we used Akaike's Information Criterion with a small sample size correction (AIC_c; Burnham and Anderson 2002). We report estimates with 95% confidence intervals.

We focused on testing the gnatcatcher habitat model (TAIC 2002). We were able to estimate occupancy for the overall qualitative habitat rankings from the TAIC model as well as for the underlying environmental variables used in the model. In the model gnatcatchers are thought to more likely occur on gentle slopes ($\leq$40% = 1, else = 0), in larger patches of sage scrub ($\geq$10 ha coastal or 20 ha interior = 1, else = 0), where annual precipitation is $\leq$33.65 cm and average January minimal temperature is $\geq$5° C. The TAIC (2002) model combined precipitation and temperature into a climate variable in which dry, warm locations were scored as a 2; dry and cold or wet and warm areas a 1; and wet, cold locations a 0. The TAIC model was based on the summed scores from these attributes and gave rise to the 4 categories (higher scores = higher quality and occupancy probabilities) listed above plus a zero category that indicated either no sagebrush habitat or sagebrush habitat, but outside of the above parameters (TAIC 2002, Winchell and Doherty 2006).

We contrasted the TAIC Model ($\psi_{group}p.$), which models occupancy (ψ) as a function of the 4 habitat groupings (low-, medium-, high-, and very-high-quality) and detection (p) as a constant, with models in which occupancy varied as a function of patch size ($\psi_{patch}p.$), slope ($\psi_{slope}p.$), precipitation ($\psi_{precip}p.$), temperature ($\psi_{temp}p.$), and climate ($\psi_{c\ \lim}p.$). Based on our observations of gnatcatchers in 2002 in small patches, we hypothesized no relationship between patch size and occupancy and designated this model as ($\psi_{slope+temp+precip}p.$). We constructed a model with occupancy varying as a function of patch size, slope, temperature, precipitation, and an interaction between temperature and precipitation ($\psi_{patch+slope+temp+precip+temp\times precip}p.$) to examine the underlying β estimates in concert. We constructed a model in which occupancy and detection were considered constant ($\psi.p.$). We also varied p in our modeling efforts. We ranked models using AIC_c and present overall model results, overall occupancy estimates, and β estimates associated with underlying variables.

RESULTS

We surveyed 436 points. Of these, we visited 208 4 times, 36 3 times, 50 twice, and 142 once. We dropped 24% and 3% of our points after one visit or attempt due to points being inaccessible or in nonhabitat, respectively. Therefore, we can only extrapolate our results to 73% (32,794 ha) of the original sampling frame (44,923 ha).

Table 1. Estimates of the number of gnatcatchers pairs in our sampled area of Orange and San Diego counties, California, USA, during spring 2002.

		95% CI	
Survey period[a]	No. of pairs	Lower	Upper
1	1,221	712	4,063
2	1,528	892	4,995
3	1,137	662	3,831
4	1,411	823	4,697
Arithmetic mean	1,324		
$\widehat{SE}$	178		

[a] Survey periods 1–4, respectively, were from 11 Apr to 27 Apr, 28 Apr to 14 May, 15 May to 1 Jun, and 2 Jun to 17 Jun.

We compared our field vegetation records to those predicted by the 2 previously mentioned mapping exercises because our sample frame was based on previous habitat-mapping exercises using different methodologies, scale, and degrees of ground-truthing (County of Orange 1996, San Diego Association of Governments 1995). We found an error rate of 27% with 3% of the points not being potential habitat. The error rate for our sample frame as a whole was constant across vegetation type, with error rates of 27% for the sagebrush category and 26% for sagebrush–chaparral ecotone category. However, error rates were not constant across the 2 counties. Orange County had a lower overall error rate of 20% compared to 34% in San Diego County. Error associated with nonhabitat was similar, with 4% for Orange County and 3% for San Diego County. However, San Diego County had a higher error rate for sagebrush (37%) than did Orange County (15%), but Orange County had a higher error rate for the sage–chaparral ecotone (37%) than did San Diego (14%).

At 2 sites we detected 4 birds at once, but we never detected >4 birds. We detected 4 separate juveniles at the end of our survey, but because we were interested in adult pairs we deleted these juvenile records from the analysis. Under our definition of pairs we assumed an equal sex ratio.

We derived a removal-method abundance estimate for each 2-week visit period and extrapolated this number of pairs to our 32,794-ha sampling frame. Average detection probability from this model was 0.20, ($\widehat{SE}$ = 0.13) and average density of gnatcatcher pairs over the 4 visitation periods was 0.041 pairs/ha ($\widehat{SE}$ = 0.006). The arithmetic average number of gnatcatcher pairs over the 4 visits was 1,324 (95% CI = 976–1,673; Table 1).

Our bootstrap goodness-of-fit test did not suggest any lack of fit in our data ($P > 0.99$) and, thus, we did not incorporate a variance inflation factor into our estimation and modeling. Models in which the site-level detection probability varied with time (p_t) exhibited little support and we do not present these models. From the most basic model where we considered detection and occupancy constant ($\psi.p.$), our overall estimate of detection probability was 0.21

Table 2. Occupancy results from testing the California gnatcatcher habitat model with data collected during 2002 in southern California, USA.

Model[a]	ΔAIC_c[b]	AIC_c wt[b]	Model likelihood	No. parameters	Deviance
$\psi_{slope+temp+precip}p.$	0.00	0.30	1.00	5	383.81
$\psi_{group}p.$	0.29	0.26	0.87	5	384.10
$\psi_{c\ \lim}p.$	0.80	0.20	0.67	4	386.66
$\psi_{patch+slope+temp+precip+temp\times precip}p.$	1.44	0.15	0.49	6	383.19
$\psi_{precip}p.$	5.31	0.07	0.07	3	393.20
$\psi_{temp}p.$	12.07	0.02	<0.01	3	399.97
$\psi_{slope}p.$	21.13	<0.01	<0.01	3	409.03
$\psi.p.$	26.29	<0.01	<0.01	2	416.21
$\psi_{patch}p.$	27.18	<0.01	<0.01	3	415.08

[a] We constructed models with occupancy rate ψ as a function of the 4 habitat-quality categories in the habitat model ($\psi_{group}p.$), as well as underlying variables used to create the 4 categories.

[b] ΔAIC_c is the standardized difference in Akaike's Information Criterion corrected for small sample size, and AIC_c wt is the Akaike wt associated with each model. Min. AIC = 393.95.

($\widehat{SE} = 0.05$; 95% CI = 0.13–0.33) and our overall estimate of occupancy probability was 0.26 ($\widehat{SE} = 0.06$; 95% CI = 0.16–0.40). However this model had a $\Delta AIC_c > 26$ (Table 2).

Quality categories of the TAIC (2002) California gnatcatcher habitat model performed well, in the sense that occupancy was ordered based on the categories and the model based on these categories ($\psi_{group}p.$) ranked among the highest (Table 2). Though this model was a qualitative model, we used our data to provide quantitative estimates of occupancy for these categories (Fig. 1). The very-high quality category had an occupancy rate of 0.48 ($\widehat{SE} = 0.12$) whereas the low-quality category had an essentially zero probability of being occupied (Fig. 1).

We also investigated the underlying variables and hypotheses upon which the habitat model was based. Our modeling suggests that the slope variable and variables associated with climate (i.e., temp and precipitation) are stronger influences on occupancy probabilities than is patch size (Table 2). The model using only patch size ($\psi_{patch}p.$) as a predictor ranked low ($\Delta AIC_c = 27.18$), whereas a model including all variables except patch size ranked first ($\psi_{slope+temp+precip}p.$; Table 2). We constructed a model that included the underlying variables in their binary states (patch, slope, temp, precipitation, temp $\times$ precipitation interaction) and examined the associated β parameter estimates (slope parameters; Table 3). These results also support the assertion that patch size is relatively unimportant for occupancy because the 95% confidence interval of the patch β estimate overlaps zero widely (–0.81 to 1.78; Table 3), especially as compared to the confidence intervals for the other β estimates (Table 3).

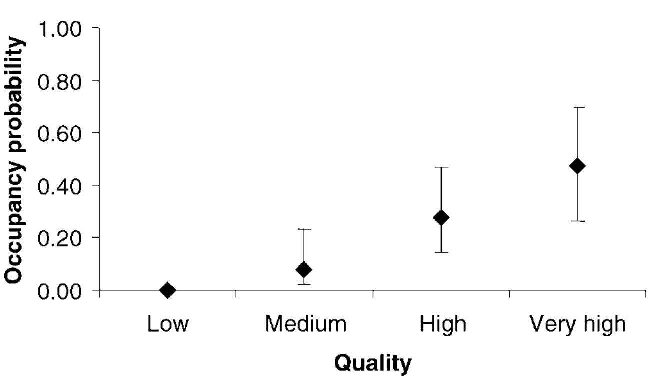

Figure 1. Percent area occupied for the habitat quality categories of the Technology Associates International Corporation California gnatcatcher habitat model. Data were collected in southern California, USA, during 2002. Error bars are the 95% confidence interval.

DISCUSSION

Our results supported the broad, qualified categories of the TAIC habitat model. We were also able to quantify occupancy probabilities associated with these categories, as well as investigate underlying covariates in the model. Our survey was contingent upon gnatcatcher-habitat mapping efforts because they defined our sampling frame. However, these mapping efforts have gone through differing levels of ground-truthing, and we detected error when we visited sites on the ground. The United States Geological Survey suggests an accuracy rate of $\geq$85% as acceptable for land-use and land-cover classifications interpreted by GIS (Avery and Berlin 1992). Our vegetation ground-truthing indicated the overall accuracy rate was 76% with Orange County's accuracy rate 80% and San Diego's 66%. Inadequate ground-truthing can have consequences for many activities based on these coverages, including prestratification in sampling designs, extrapolation of results, and identifying lands to be set aside in the interest of preserving gnatcatcher habitat. Thus, the design of monitoring programs and HCPs can benefit by updating GIS coverages.

Our estimated detection probabilities were lower than expected. We based the detection probability (0.5) used in planning the survey on interviews with biologists trained to survey for gnatcatchers. The difference in predicted versus observed detection probability may in part be attributable to a difference in survey technique; we employed a point-count methodology compared to the more time-intensive walking surveys commonly employed for disclosing impacts of development on gnatcatchers (USFWS 1997).

Our study is the first to incorporate detection probabilities into estimation procedures for the gnatcatcher. We calculated similar individual pair-detection probabilities using distance sampling from the removal model (0.20) as we did with the occupancy model (0.21). We would predict

Table 3. β estimates based on the California gnatcatcher occupancy model $\psi_{patch+slope+temp+precip+temp\times precip}p$. fit to data collected in southern California, USA, in 2002.

Variable	β estimate	$\widehat{SE}$	95% CI Lower	95% CI Upper
Patch	0.48	0.66	−0.81	1.78
Slope	1.08	0.56	−0.02	2.18
Temp	0.79	0.70	−0.58	2.15
Precipitation	−2.62	1.21	−4.99	−0.26
Temp × precipitation interaction	1.08	1.36	−1.60	3.75

slightly higher site-level detection probabilities given that >1 pair could be on a site, which should positively influence detection in the occupancy framework (Royle and Nichols 2003). However, we defined our survey sites such that rarely was >1 pair detected, and we would not expect these 2 levels of detection estimates to differ greatly. Our results suggest that future simulations to optimize sampling design for gnatcatcher monitoring efforts should be based on a detection probability of 0.20. For a future occupancy study, designed for an average detection probability of 0.20 and an occupancy probability of 0.26, an optimal occupancy design would repeatedly visit sites 8 times (MacKenzie et al. 2006).

We note that our estimates only apply to the portion of our sampling frame to which we had access. Any inference beyond our sampling frame is speculative, relying on biological inference rather than statistical sampling theory. Because most (68%) potential gnatcatcher habitat was not on accessible land, it may be tempting to apply our density estimates to inaccessible lands. Such an application of our density estimates would necessitate the assumption that the accessible lands and nonaccessible lands were indistinguishable, which is probably not the case. Much of the inaccessible land was located at lower elevations and on military bases, which may be quite different from accessible lands in terms of gnatcatcher occupancy and density (USFWS 2003).

Our occupancy modeling provides support for the habitat quality categories used in the San Diego Multiple Species Conservation Plan, an HCP, California gnatcatcher habitat model (Tables 2, 3; Fig. 1), though our results suggest variables associated with slope and climate (i.e., temp and precipitation) are stronger influences on occupancy than is patch size as defined in the TAIC (2002) model. Although patch size may be influential on demographic rates (e.g., survival, fecundity) it is not a good predictor of occupancy. Whereas this habitat model has only been qualitative, we can now attach quantitative estimates to the habitat categories, at least for one point in time.

We note that one assumption of the occupancy modeling approach we employed is closure, that is, that occupancy status (i.e., extinction and colonization) does not occur between sampling occasions. Because our sampling period extended over approximately 2 months, we cannot guarantee closure. If the closure assumption is not warranted, then our occupancy results should be interpreted as habitat use rather than occupancy (MacKenzie 2006).

Our survey design systematically spaced points across a large area, assumed to be random, and placed points in areas without regard to observer preference or bias. Visiting points spaced using a probability-based sampling plan was challenging at times due to logistical and access issues (Winchell and Doherty 2006), but it was possible and is critical to collecting a sample having integrity. We suggest incorporating randomization of sample points into HCP monitoring programs. Randomization is often avoided and viewed as impractical; we demonstrated it could be accomplished efficiently over a large landscape yielding results more appropriate for detecting true trends.

MANAGEMENT IMPLICATIONS

Patch size did not predict occupancy well, and therefore we recommend reserve designs not exclude coastal sage scrub patches ≤10 ha or ≤20 ha if interior. Distance between small patches may be more important, although we did not test it. Our estimates of detection probability are of particular use for land managers that hope to design monitoring programs aimed at detecting gnatcatcher population trends over time. For example, we recommend that a detection probability of 0.20 be used to calculate sample sizes and number of site visits needed for future study design. We advise against summing gnatcatcher observations that span several years (i.e., no closure) and that were collected using haphazard and judgment sampling (i.e., no probability-based sampling plan) to calculate an abundance estimate as has been done in the past (USFWS 1993*a*, *b*, *c*, *d*, 1996, 1999*a*, *b*).

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