

ABUNDANCE AND DISTRIBUTION OF THE YELLOW-BILLED MAGPIE

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ABSTRACT: In 2007 and 2008, we evaluated the distribution of the Yellow-billed Magpie (*Pica nuttalli*) and estimated habitat-specific densities and abundances with point-transect surveys. We found possible contractions since the mid-20th century, with reductions from Fresno south to Bakersfield, in the Sacramento delta, and in southern portions of the Coast Ranges of central California. Over the species' entire range, its population density was 6.1 birds/km² and approximately 4.0×10^5 birds (percent coefficient of variation [%CV] 13.1%). Density was greatest in agricultural habitats (8.2 birds/km², 17.4% CV) and least in urban habitats (1.3 birds/km², 36.9% CV). Abundance was greatest in rural habitats (2.5×10^5 birds, 17.0% CV) and least in urban habitats (5.3×10^3 birds). Further monitoring of temporal trends in the abundance of this bird endemic to central California and studies of its population genetics, habitat usage, and demography are warranted.

The Yellow-billed Magpie (*Pica nuttalli*), on the National Audubon Society's "watch list" (<http://birds.audubon.org/species-by-program/watchlist>), is restricted to the Central Valley and sections of the Coast Ranges of central California (Reynolds 1995). In the two years following the establishment of West Nile virus throughout California in 2004, the species suffered high mortality. Of the 818 dead magpies tested for this virus by the California Department of Public Health Services' Dead Bird Surveillance Program in 2004 and 2005, 81% were found to be positive for it (Koenig et al. 2007). These data, and review of Christmas Bird Count (CBC) data from throughout the species' range, suggest a 42–49% decrease in abundance from 2004 to 2006 (Airola et al. 2007, Crosbie et al. 2008, Pandolfino 2013).

The only published estimate of the magpie's total population is 180,000, derived from 1990s Breeding Bird Survey (BBS) data (Rich et al. 2004). But low sample size, small portion of range sampled, inappropriate sampling methods/bias, and high variance in counts may degrade the estimate's accuracy. Historically, threats to the magpie have included direct persecution

[†]This work is dedicated to Dr. Scott Crosbie, who died 2 December 2012. Scott was a brilliant ecologist and fervent advocate for the conservation of wildlife (and the Yellow-billed Magpie in particular) and wildlife habitats. He was a kind, patient, and gentle teacher, as well as a treasured friend and colleague. A friend wrote this in Scott's honor: "There will be brilliantly feathered birds where you are going who will sing their lovely and welcoming songs and you'll call them by name."

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in agricultural habitats (Lynda 1962), habitat conversion, and accidental poisoning with Compound 1080 intended for the California ground squirrel (*Spermophilus beecheyi*) (Reynolds 1995). Concern over the species' viability in light of the recent mortality from West Nile virus prompted the need for rangewide information on its distribution and abundance. Here we report the results of rangewide point-transect surveys in 2007 and 2008.

METHODS

Study Area

Our study area was based on the range map generated by California Partners in Flight (www.prbo.org/calpif/htmldocs/mapdocs/oak/2002/ybmamap2002.html), which depicts both what is considered to be the "historical" (Grinnell and Miller 1944) and "current" (CWHR 1995) ranges of the magpie (Figure 1A). Using ArcView 3.2 and geographic information system (GIS) layers provided by the California Department of Fish and Game, we merged these two GIS layers to delimit our entire survey area prior to defining point transects randomly (Figure 1B).

We obtained GIS data on habitat types throughout the study area from a GIS layer (Multi-source Land Cover Data v02_2), resolution 100 m, available from the California Department of Forestry and Fire Protection Fire and Resource Assessment Program at <http://frap.cdf.ca.gov/data/frapgisdata/select.asp>. This layer depicts habitat types as defined by the California Wildlife Habitat Relationship (CWHR). To assess the magpie's density and abundance by coarse but specific categories, we combined these habitats into three broad types, "rural," "agricultural," and "urban." Rural habitats

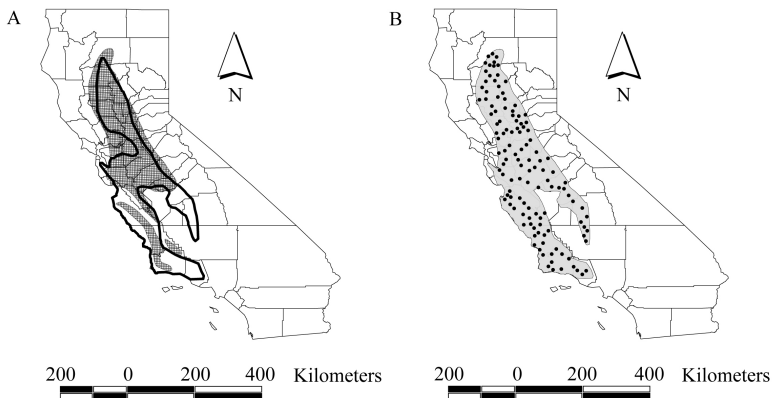


Figure 1. (A) Historical (thick outline), and current (gray shading) distributions of the Yellow-billed Magpie. See text and references in it for definitions of "historical" and "current." Adapted from maps created by the California Department of Fish and Game and California Interagency Task Group. (B) Gray shading, study area; dots, randomly located points upon transects (transect lines omitted for clarity) surveyed in 2007 and 2008.

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comprised the 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 comprised the layers deciduous orchard, evergreen orchard, vineyard, irrigated row and field crops, rice, irrigated hayfield, irrigated grain crops, dryland grain crops, and non-irrigated pasture. Urban habitat was the same as that defined by the CWHR.

This simplified habitat-classification scheme is not without limitation, as rural, agricultural, and urban habitats are not mutually exclusive with respect to land use. 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 that of agricultural areas designated as pasture. Similarly, some points within rural and agricultural habitats also had nearby housing development or ranchettes, but the human population density in such areas was clearly much lower than in urban areas. Nevertheless, because no prior information was available on habitat-specific magpie densities, our goal was to obtain baseline estimates of density by coarse habitat categories.

Point-Transect Surveys

We used ArcView GIS 3.2 to randomly establish 23 point transects (with a range of 4–8 points per transect and a total of 127 points) throughout the species' range (Figure 1B). Points were no closer than 5 km and were generally >10 km from their nearest neighbor. Points were stratified by habitat type, and the number of points per transect was determined by logistics (such that an observer could survey one transect per day within the time restrictions outlined below). Prior to starting surveys, we reviewed aerial photographs and visited each site to ensure points were in the correct habitat (rural, agricultural, or urban) and to obtain the landowner's permission for access where necessary. Transects were surveyed quarterly in both 2007 and 2008: once each in February, May, August, and November, corresponding with the winter (pre-breeding), spring (breeding), summer (fledging), and fall (post-fledging). After waiting for 1 minute after arriving at each point, a single observer (either Crosbie or Souza) counted for 6 minutes, recording the number of clusters of magpies (relatively tight flocks/groups), distance(s) from the point (measured with a laser rangefinder) and estimated the number of individuals within each cluster. A pilot study suggested that 6 minutes was generally sufficient for the observer to detect all magpies immediately at the point while limiting the amount of time available for any significant movement of birds within, into, or out of the area surveyed (see assumptions of point transects in Buckland et al. 2001). We recorded the time after sunrise and ambient weather including temperature (°C), estimating cloud cover to the nearest 10% and wind velocity on the Beaufort scale. Surveys were confined to the first 4 hours of local daylight and were not conducted in heavy rain or fog, or if wind velocity exceeded a value of 3 on the Beaufort scale, as prescribed for the BBS (Sauer et al. 2002). Points within transects were generally surveyed in a different order on each successive survey to reduce any potential bias of time of day on probability of detection at points within a transect.

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The differences between Grinnell and Miller's (1944) map of the Yellow-billed Magpie's range and that of the CWHR (1995) may reflect actual changes in the species' range and/or the data on which these maps were based. The most significant differences in the latter map include a decreased range in the San Joaquin Valley and Coast Ranges, an increased range in the Sacramento delta, and a slightly increased range in the northern Sacramento Valley. For our purposes we defined our study area as the combined coverage of both maps (gray polygon in Figure 1B).

The accuracy of density and abundance estimates depends on the accuracy of the estimated range (area of occupancy) of the species in question, including the areas of each habitat for which density may be calculated separately. Furthermore, because we suspect the magpie's range may have contracted recently, it was necessary to estimate the species' distribution during the study period and compare this with historical estimates of its distribution. To define the magpie's range for the estimate of density, we plotted the locations of all our detections whether during a survey or not (observations while we were traveling between points). We noted three main differences between the distribution of magpie sightings and the study area: we saw no magpies from Fresno County south to Kern County in the San Joaquin Valley, in Ventura County or eastern Santa Barbara County in the Coast Ranges, or in northwestern Contra Costa County in the delta. A search of records from these three regions in database of the BBS from 1966 to 2008 for magpie detections in these three regions turned up none, and a search at www.ebird.org yielded no more than one or two sightings in those regions over the same interval, suggesting a long-standing absence. Therefore, we assumed the species' distribution during our study period was consistent with the area defined in Figure 2, and we used this range for extrapolating abundance. This distribution resembles a compromise between those of the CWHR (1995) and Grinnell and Miller (1944), being broader in the Coast Ranges and more restricted in the San Joaquin Valley and delta. Adopting this range as the basis for our estimates necessitated removing three transects (19 points) from our analyses (each of the three regions excluded had one transect). The 21 remaining transects (108 points) were used for all analyses (Table 1).

Statistical Analyses

For the analysis of ungrouped data we used the program Distance 5.0 version 2 (Thomas et al. 2006) and the methods detailed in Buckland et al. (2001) and Buckland (2006). We fit all recommended combinations of key functions and series expansions to the observed distribution of bird distances: the uniform, half-normal, and hazard-rate key functions with cosine or polynomial series expansions (Buckland et al. 2001). For this analysis, we excluded observations at distances >270 m, at which the probability of detection was approximately 0.1 (see Buckland et al. 2001), although we noted magpies at distances up to ~600 m. This exclusion eliminated approximately 19% of our detections. In all analyses we used the method of size-biased cluster-size estimation, regressing $\ln(\text{cluster size})$ against the detection function to estimate mean cluster size at distance zero. For estimating variance in encounter rate, we used the transect as the independent, randomly selected unit of sampling.

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Figure 2. Clusters of Yellow-billed Magpies detected during point transects surveyed once per season (whether during formal surveys or incidentally) in 2007 and 2008. Total number of clusters detected, 416; total number of individuals detected, 1350 (many dots represent multiple sightings at the same or nearby locations). Gray shading represents the species' approximate core distribution during the study period.

In addition to using conventional distance sampling, in which the probability of detection is modeled as a function of a bird's distance alone, we also evaluated the inclusion of several covariates, using multiple-covariate distance-sampling (MCDS) methods (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 including covariates increases the precision of density and abundance estimates. The MCDS methods allow the entire data set to provide information about the shape of the detection function, while covariate-level data are allowed to affect

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Table 1 Survey Effort for the Yellow-billed Magpie in 2007 and 2008

Habitat	Land cover (km ²)	Number of transects	Number of points
Rural	46,806	11	60
Agricultural	19,759	5	23
Urban	4,215	5	25
Total	70,780	21	108

the scale—such methods may be preferred observations are too few to produce stratum-specific detection functions (Marques et al. 2007). We included both factor and nonfactor covariates that may have influenced the detection function. Nonfactor covariates included temperature, cloud cover, wind velocity, and minutes after sunrise (“time”), while factor covariates included observer, habitat type (used only when observations were stratified by season), and season (used only when observations were stratified by habitat type). We evaluated the models generated by Akaike’s information criterion (AIC), provided that goodness-of-fit tests [χ^2 , Cramér–von Mises (both uniform and cosine weighted) and Kolmogorov–Smirnov] all showed adequate fit and diagnostic plots (detection function and probability-density function) were biologically reasonable.

Because the number of detections in all strata of interest (seasons and habitat types) was insufficient for producing stratum-specific detection functions, we pooled the data for modeling the detection function. Upon selecting one detection-function model for the whole data set, we analyzed two separate stratifications of the data (Distance 5.0 will conduct only one stratification at a time): by season to examine changes in abundance over the study and by habitat type to examine habitat-specific densities and abundances. We estimated density over the magpie’s entire range by taking the mean of the weighted habitat-specific estimates.

To evaluate the temporal trend in magpie abundance through the study, we fit a least-squares linear regression to (log-transformed) seasonal abundance estimates with Systat 11.0. 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. Because we sampled at the same points over time, and because we used a pooled detection function for all analyses, we assumed the detection function remained constant over time and by habitat type. In other words, our density estimates were not independent, but estimating a temporal trend necessitated that we assume they were.

RESULTS

Modeling of the Detection Function

The number of detections of magpie clusters ranged from 12 to 31 per season and from 17 to 96 per habitat type. Estimated cluster size ranged from 1.39 to 3.92 per season and from 1.32 to 2.40 per habitat type. A half-normal key function provided the best fit with conventional distance

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sampling (AIC 2030.47), but the MCDS approach with the covariate of time improved the model slightly (AIC 2029.12). Because the AIC values were so similar (<2 points apart), as were goodness-of-fit statistics, we considered these models to be quite comparable. Nevertheless, we selected the hazard-rate MCDS model with the covariate of time for presentation on the basis of its minimizing the AIC score, a shoulder appreciably wider than that of the competing half-normal models, and a coefficient of variation in probability of detection (0.09–0.06) lower than that of the model based on conventional distance sampling (e.g., reducing variance in the detection function by accounting for time of day). The quandary of having two multiple models with similar scores was negated by examining the resulting density estimates, which were quite similar.

While all distances of detection were recorded where the birds were first observed, the detection-function histogram (Figure 3A) shows a spike at about 70 m, suggesting some evasive movement of magpies away from observers. Such evasive behavior was occasionally apparent during surveys, but we nevertheless conclude the model's fit was adequate, as judged by the probability-density function (Figure 3B; results of goodness-of-fit tests: $\chi^2 = 0.53$, Kolmogorov–Smirnov $P = 0.60$, Cramér–von Mises uniform and cosine weighted $P = 0.70$ and 0.60 , respectively). Detection-function plots for two levels of covariate time (Figure 4) show substantial difference in the scale of the detection function based on time of day, with probability of detection being appreciably greater earlier in the morning.

The variance (error) associated with habitat-specific estimates of density may be broken down into three components: the probability of detection, encounter rate, and cluster size. The component percentages of variance attributed to each of these three factors was generally consistent from season to season, averaging 4.0% due to the detection function, 23.6% to cluster size, and 72.4% to encounter rate.

Magpie Density and Abundance by Season

Estimated density (birds/km²), abundance, 95% confidence limits, and coefficients of variation by season are shown in Table 2. The estimates of density and abundance ranged from a high of 8.8 birds/km² (5.7×10^5 birds) in November 2007 to a low of 3.0 birds/km² (2.0×10^5 birds) in August 2008 (Table 2).

Magpie Density and Abundance by Habitat Type and Rangewide

Estimates of the magpie's density and abundance varied appreciably by habitat type: density was highest in agricultural habitat and lowest in urban, whereas abundance was greatest in rural habitat and lowest in urban (Table 2). Over the entire study, density, calculated as a mean of density estimates weighted by habitat type, was 6.1 birds/km² (95% CI = 5.0–7.6; percent coefficient of variation, 13.0%). Extrapolated, this density yields a total population of 4.0×10^5 birds (95% CI 3.2 – 4.9×10^5 birds).

Like that for the season-specific estimates, the variance (error) associated with the population density estimated by habitat may be broken down into the same three components: detection probability, encounter rate, and

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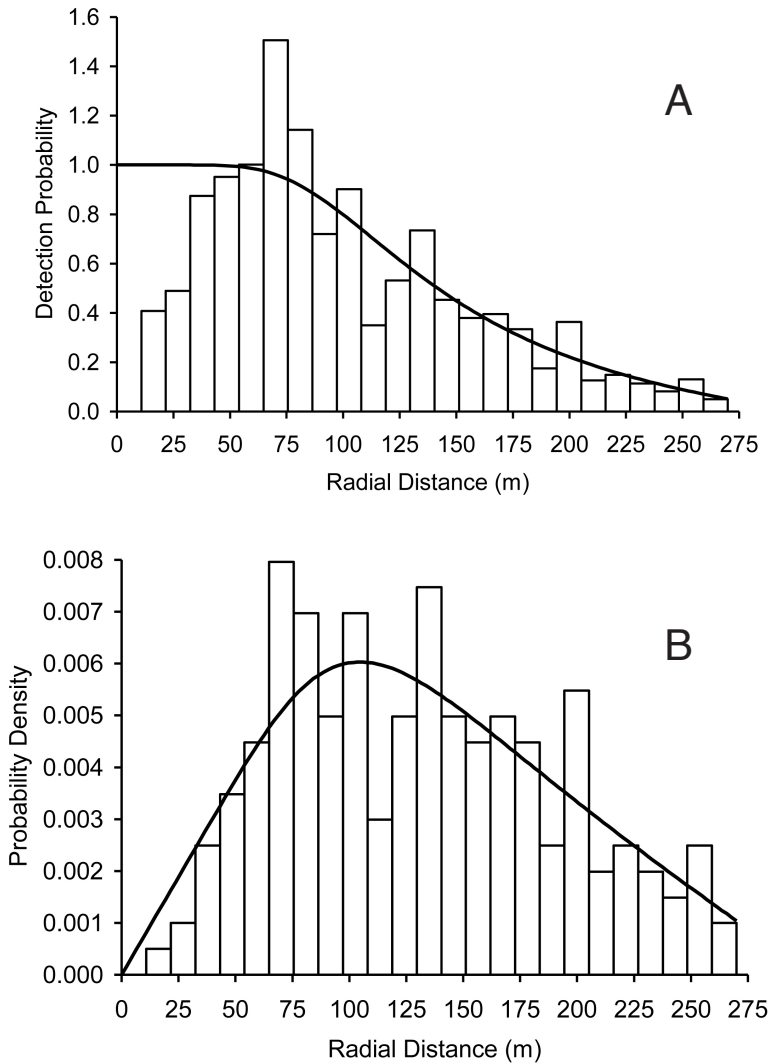


Figure 3. Histograms of distances of detection of the Yellow-billed Magpie during seasonal point-transect surveys, 2007–2008, with (A) fitted detection function and (B) probability-density function.

cluster size. Again, the component percentages of variance attributed to each of these three factors was generally consistent in all three habitats, averaging 10.2% due to the detection function, 16.3% to cluster size, and 73.5% to encounter rate.

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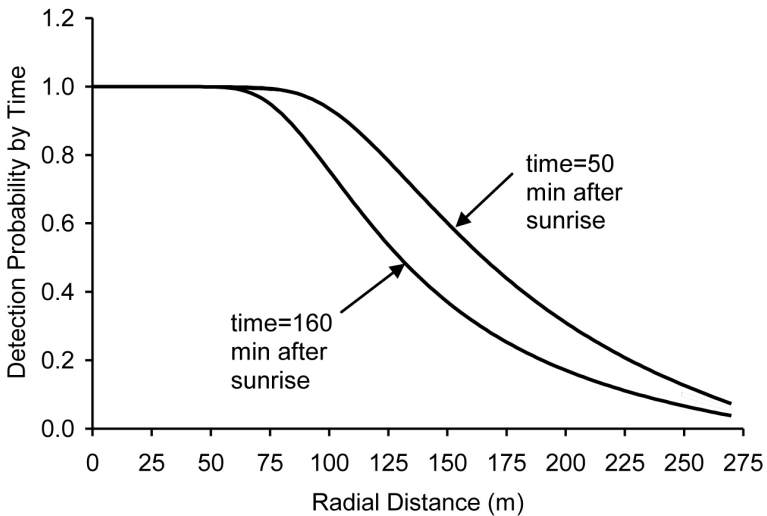


Figure 4. Two functions for detection of the Yellow-billed Magpie by distance, differing in number of minutes after sunrise, based on eight seasonal point transect surveys in 2007 and 2008.

DISCUSSION

The Yellow-billed Magpie is common but patchily distributed in the Central Valley and central Coast Ranges of California. During our 2007–2008 surveys we recorded it throughout the Sacramento and northern San Joaquin valleys and associated foothills, and in much of the central Coast Ranges (Figure 2). Lehman (1994) stated the species had been extirpated from Ventura and southern Santa Barbara counties, and we found no magpies in these areas. Since 1996, there have been eight reports from the south coast of Santa Barbara County, but at least some of these may represent escapees from captivity (P. E. Lehman pers. comm.). Furthermore, we found none in the core of the Sacramento Delta or from the Fresno area south to Bakersfield (Figure 2). Although our point transects were limited to two years of data and their coverage of the species' range was rather coarse, our data suggest contraction of the range in Fresno, Tulare and Kern counties, as the CWHR (1995) range map implies. Why the magpie remains extant, or in higher densities, in other areas also dominated by agriculture and development is perplexing. Range contraction in the southern San Joaquin Valley is likely due, in part, to the types and intensities of agricultural land use. Much of the former range in Fresno, Tulare, and Kern counties has been developed for intensive production of beef, dairy, vineyard, citrus, and row crops; these counties regularly rank at the top for agricultural productivity in California (California Department of Food and Agriculture; <http://www.cdffa.ca.gov/statistics/>) and currently may no longer be able to sustain the magpie. We caution, however, that our survey's coverage of the species'

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Table 2 Estimated Density and Abundance of the Yellow-billed Magpie from Point Transects Surveyed Eight Times 2007–2008

Stratum	Density (per km ²)			Abundance			%CV ^c
	Estimate	LCL ^a	UCL ^b	Estimate	LCL ^a	UCL ^b	
Season							
Winter 2007	6.8	4.4	10.6	437,620	281,390	680,580	28.0
Spring 2007	4.9	2.9	8.2	317,620	189,890	531,260	32.3
Summer 2007	5.2	2.4	11.5	336,480	152,600	741,920	50.0
Fall 2007	8.8	5.0	15.5	565,670	321,290	995,930	34.6
Winter 2008	4.2	2.7	6.5	268,630	171,600	420,530	26.3
Spring 2008	4.6	2.7	7.8	296,430	174,690	503,010	37.3
Summer 2008	3.0	1.5	6.0	195,450	98,849	386,460	40.0
Fall 2008	6.3	4.1	9.6	405,400	265,800	618,300	29.1
Habitat							
Rural	5.8	4.4	7.6	245,221	185,750	323,730	17.0
Agricultural	8.2	6.1	10.8	145,831	109,730	193,800	17.4
Urban	1.3	0.7	2.4	5,347	2,962	9,652	36.9

^aLower 95% confidence limit.

^bUpper 95% confidence limit.

^cPercent coefficient of variation.

range was coarse, so the layout of transects and points in the study area may not be suitable for a fine-grained assessment of range occupancy.

Estimates of magpie abundance by season varied considerably over the course of the study, but the confidence intervals for all monthly estimates overlapped (Table 2). While numerous studies corroborate the magpie's high susceptibility to West Nile virus (Ernest et al. 2010) and a decline in abundance in the first few years of exposure to it (see Airola et al. 2007, Koenig et al. 2007, Crosbie et al. 2008, Wheeler et al. 2009), our data limited to 2007 and 2008 do not provide evidence sufficient to indicate whether the decline continued.

The magpie's population density was highest in agricultural habitat and lowest in urban habitat but not significantly higher in agricultural than in rural (Table 2). Within agricultural habitats, 87% of the magpies detected were in nut orchards, pastures, and feedlots. Why these densities differ by habitat type is unknown (and not addressed with the methods of our study) but is likely due to differences in the supply of food, water, nest sites, and roost sites, resource competition, persecution or predation rates, density dependence, densities and feeding preferences of mosquitoes, rates of transmission of West Nile virus, diversity of mosquito hosts, and the mortality from the virus preceding our study.

Because of the recent mortality from West Nile virus, one might expect our estimates of the magpie's population to be considerably lower than the previous estimate of 180,000 (Rich et al. 2004). Yet even our smallest single-season estimate of 195,000 birds (summer 2008) exceeded it. 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 distances of

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detection constant for each species (among others), but these assumptions were not based upon recorded distance data from field surveys. For the magpie, detectability was assumed constant up to a distance of 400 m (T. Rich pers. comm.). Our results suggest that detectability remains constant for only 100 m at best (see Figure 3), so the assumption that it was constant for up to 400 m would result in severe underestimation of density and abundance. We stress the importance of estimating probabilities of detection and, where possible, avoiding tenuous assumptions about constant detectability without verification in the field. Unless the calculations are based on estimates of detectability validated with field data, estimated densities and extrapolated abundances may be substantially erroneous and mislead management.

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