YELLOW-BILLED MAGPIE POPULATION STATUS AND HABITAT CHARACTERISTICS IN URBAN SACRAMENTO, CALIFORNIA

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ABSTRACT: Most research on the ecology of the Yellow-billed Magpie (*Pica nuttalli*) has been focused in oak woodlands and savannas in California's Coast Ranges; urban and suburban populations, some of which are sizable, have received little attention. In 2020, we studied eight colonies in six parks around Sacramento and in 2021 expanded the survey to 43 sites, detecting 827 breeding magpies. Population estimates based on nest counts were generally higher than those from direct counts, and nest counts were more repeatable and efficient. Counts of recently fledged young in family groups yielded reproductive rates similar to those observed near the coast before arrival of West Nile virus in 2003, suggesting that the virus is not currently affecting nestlings' survival. Sacramento magpies nested in the upper canopy of a wide variety of large trees, both native and non-native. They foraged preferentially in low herbaceous habitat—irrigated turf and unirrigated annual grassland that was mowed or grazed. The presence of rivers and streams influenced occupancy strongly. Colony size was strongly related to the amount of low herbaceous foraging habitat within 0.5 km of colony sites with nearby flowing water. Our results suggest that at least 4 ha of low herbaceous foraging habitat is needed to support a small nesting colony. Retention of herbaceous habitat near large trees and flowing water, plus mowing or grazing to keep herbaceous growth low, should benefit urban Yellow-billed Magpies.

The Yellow-billed Magpie (*Pica nuttalli*) is a California endemic whose range is limited to the Central Valley and Central Coast regions (Koenig and Reynolds 2009). Following the arrival of West Nile virus in California in early 2003 (Reisen et al. 2004), mortality of Yellow-billed Magpies was extensive (Ernest et al. 2010), and the population declined substantially (Airola et. al. 2007, Koenig et al. 2007, Crosbie et al. 2008, Smallwood and Nakamoto 2009). Unlike other species affected by the West Nile virus, magpies apparently have not developed immunity to the disease, and population decline continues (Pandolfino 2013, 2018, 2020) as West Nile virus persists in the Sacramento region (Snyder et al. 2020). Because of its limited range, the species is also considered highly vulnerable to climate change (https://www.audubon.org/field-guide/bird/yellow-billed-magpie).

The most recent assessment of the Yellow-billed Magpie's population, based on surveys in 2007 and 2008, yielded an estimate of "396,399" (95% confidence interval [CI] 319,891–491,206; Crosbie et al. 2014). An evaluation of numbers reported on Christmas Bird Counts (CBCs) in the Central Valley has shown substantial subsequent decline through 2019 (Pandolfino 2020). The magpie is recognized as a species of conservation concern by the U.S. Fish and Wildlife Service (https://www.fws.gov/birds/management/managed-species/birds-of-conservation-concern.php) and is on the North American Bird Conservation Initiative's (2014) watch list as a species with limited range or significant threats.

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The Yellow-billed Magpie occupies primarily oak woodlands and savanna (Koenig and Reynolds 2009). The range-wide survey found that nearly all of the population occurred in lands characterized as rural (62%) or agricultural (37%), while only 1% (5347, 95% CI 2962–9652) occurred in urban areas (Crosbie et al. 2014). Population decline in many areas in the mid-1900s was attributed to deliberate poisoning (Lyndell 1962, Koenig and Reynolds 1987), more recently to urbanization, although the species has persisted in some urban areas (Koenig and Reynolds 2009). In particular, Koenig and Reynolds (2009) considered the persistence of rather large (though unquantified) breeding populations in the Sacramento–Davis metropolitan region in Sacramento and Yolo counties anomalous.

Nearly all recent ecological research on the Yellow-billed Magpie has taken place at or near the Hastings Reservation, a University of California Natural Reserve with oak woodland, oak savanna, and grasslands in the Carmel Valley, Monterey County, in the Central Coast region of California (Verbeek 1972, 1973, Reynolds 1990, Bolen 1999, Bolen et al. 2000, Koenig and Reynolds 2009). Other than the statewide or regional population surveys (Smallwood and Nakamoto 2009, Crosbie et al. 2014), research on magpies in the Central Valley and in urban and suburban areas has been limited to characterizing a few winter roosting sites and population trends at those roosts (Crosbie et al. 2006). Given the species' decline, the Central Valley's continuing urbanization (Teitz et al. 2005), and uncertainty regarding the factors that allow persistence in these areas, more research is needed on the Yellow-billed Magpie's population status and basic natural history in urban and suburban areas (Koenig and Reynolds 2009).

The Yellow-billed Magpie has several characteristics that facilitate ecological research: it is large, boldly colored, noisy, builds large nests, feeds in open areas, and is nonmigratory. Several aspects of its natural history, however, inhibit study. Magpies occur in groups that are often widely dispersed, which can make it difficult to locate flocks to estimate population sizes. They place their spherical stick nests mainly in tall, inaccessible trees, which inhibits assessing reproductive success. Also, the tendency of fledged young to gather in multi-brood creches shortly after fledging and the lack of a distinctive juvenile plumage make it difficult to assess a pair's productivity (Koenig and Reynolds 2009).

Efforts to assess the size and trend of Yellow-billed Magpie populations have included a generalized formulaic estimate (Rich et al. 2004), short-term highly intensive sampling (Crosbie et al. 2014), and analyses based on results of the Breeding Bird Survey (Koenig et al. 2007) and Christmas Bird Count (Airola et al. 2007, Crosbie et al. 2008, Pandolfino 2013, 2020). The species' decline has led to recommendations for additional population monitoring and studies of genetic diversity, population structure, and population viability (Koenig and Reynolds 2009).

We initiated this study to acquire information on the population size and habitat use of a Yellow-billed Magpie population in metropolitan Sacramento. Our objectives were to evaluate the abundance of the species at important sites in Sacramento, quantify nests' productivity, identify nest characteristics and foraging habitats, and evaluate the relationship between the extent of foraging habitats and the size of breeding colonies. We use the term *urban* to refer to areas of metropolitan Sacramento that are dominated not only by dense commercial and residential development but also areas of low-density residential housing that include smaller enclaves of parks and recreation areas, schools, and vacant land.

STUDY AREA

2020 Study Areas

In 2020, we used our knowledge of the regional avifauna and https://ebird.org to locate areas with high numbers of Yellow-billed Magpies in the Sacramento region. On the basis of numbers reported from January 2017 to January 2020 at 50 eBird "hotspots," areas accessible to the public and frequently visited by birders, we selected for study the five hotspots where high counts exceeded 30 magpies, each in or near a park or recreation area (Figure 1): Discovery Park and Del Paso Regional Park within the city of Sacramento, and Ancil Hoffman Park, William B. Pond Recreation Area, and Oak Meadow Park within unincorporated areas of Sacramento County. We recorded one colony within each park, except Del Paso Regional Park supported three, each >0.5 km from the others: Horsemen's Club (located west of Watt Avenue), Renfree Field and nearby park areas, and Park Road East (encompassing the eastern portion of Del Paso Regional Park and an adjacent rural residential area). In addition, we also counted nests at Phoenix Park in Sacramento County.

All colonies surveyed in 2020 supported large trees and extensive areas of managed turf or unirrigated annual grassland that was mostly mowed, but some was grazed or unmowed. Major canopy trees included the native valley oak (*Quercus lobata*) and non-native London plane (*Platanus ×acerifolia*), among many others, both native and non-native. All sites were adjacent to or within 0.5 km of creeks or rivers, including Arcade Creek (Del Paso Regional Park sites), the Sacramento and American rivers (Discovery Park), and American River (all other sites). Much of the land surrounding the colonies consisted of residential or commercial development.

2021 Study Areas

In 2021, we repeated surveys of the eight 2020 colony sites and initiated surveys of 35 other areas, selected after analysis of the previous year's results showed the importance of tall trees, low herbaceous vegetation, and water within 0.5 km of a colony (Figure 1, Table 1). The additional sites were centered mostly around urban parks with tall trees and irrigated turf, mowed levees, and other vacant areas supporting herbaceous vegetation that was maintained at a height <15 cm. The extent of such foraging habitat ranged from 1.5 to 20 ha.

METHODS

In 2020, we surveyed the eight colonies, quantified habitat use, and developed a model to predict the colonies' size on the basis of habitat conditions. In 2021, with results from the 35 additional sites, we refined the model and evaluated the extent of herbaceous vegetation as well as the influence of water bodies on the magpie's abundance.

Population Estimates

To control for potential differences among observers, D. Airola conducted all magpie and nest surveys. Beginning in mid-December 2019, before nesting, we counted magpies when they were flocked together and highly visible, with a minimum of four counts per site through early April 2020. We also counted the magpie's large, domed stick nests during one or more visits from 21 February to 28 March 2020, before deciduous foliage emerged and reduced the nests' detectability.

In 2021, during the nest-building period but before deciduous trees leafed out (15 February–22 March), D. Airola counted magpies and nests at the 8 previously surveyed sites (including Phoenix Park where we counted nests but not birds in 2020) and 35 new sites.

Magpie nests may persist for several years (Verbeek 1973, pers. obs.), but the domed portion generally degrades after the nesting season. Therefore, we identified nests as occupied only if they were domed or if adults were seen building the nest or attending within 10 m of the nest. Throughout the season, nests in dense-foliaged evergreen trees were more difficult to detect and may have been under-represented in our surveys. To estimate the nesting population, we multiplied the number of occupied nests by 2, as magpies are monogamous (Koenig and Reynolds 2009).

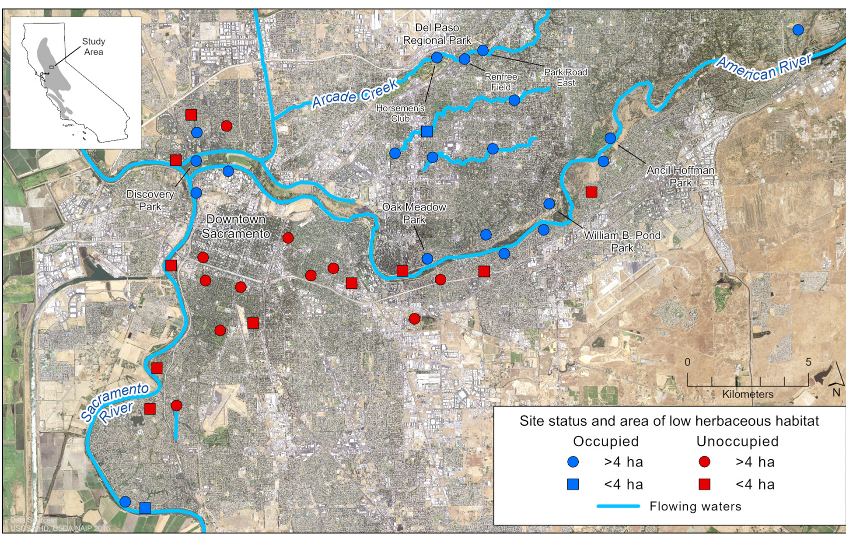

Figure 1. Sites in the Sacramento metropolitan area surveyed for Yellow-billed Magpies in 2020 and 2021, showing occupied and unoccupied sites in relation to sources of flowing water and extent of low herbaceous habitat for foraging. Inset map shows the species' geographic range (source: https://apps.wildlife.ca.gov/bios/?al=ds94).

Table 1 Critical Habitat Characteristics and Numbers of Yellow-billed Magpies Recorded at Sites Surveyed around Sacramento in 2020 and 2021

Water condition[a] and survey site	Survey years	Area of low herbaceous habitat (ha)	Population from nest counts[b]
Flowing			
Discovery Park	2020–21	20.0	173
William B. Pond Recreation Area	2020–21	17.1	30
Howe–Santa Ana Parks	2021	14.8	86
Hagan Community Park	2021	12.8	28
East Park Rd.	2020–21	11.8	86
Township Station 9	2021	11.2	26
El Camino HS–Del Paso Manor Park	2021	10.4	50
River Walk/Matsui Park	2021	9.9	58
Renfree Field	2020–21	9.8	39
Larchmont Park	2021	8.0	52
Oak Meadow Park	2020–21	7.5	19
Ancil Hoffman Park	2020–21	7.5	25
Mission North Park	2021	7.4	22
Horsemen's Club	2020–21	7.2	12
Garcia Bend Park	2021	6.0	12
Cottage Park and neighborhood	2021	4.8	46
Riviera East Park	2021	4.4	6
Seymour Park	2021	4.0	0
Miller Park	2021	3.9	0
Shore Park	2021	3.7	10
Tretheway Oak Preserve	2021	3.3	0
Creekside Park	2021	2.5	2
University Park	2021	1.5	0
Lake/pond			
Phoenix Park	2020–21	14.0	23
William Land Park	2021	10.4	0
Granite Park	2021	8.4	0
McKinley Park	2021	6.6	0
Southside Park	2021	5.4	0
Reichmuth Park	2021	4.5	0
No perennial water			
Sacramento City Cemetery	2021	22.1	0
East Lawn Cemetery	2021	12.2	0
Jefferson Elementary School	2021	2.7	0
Bannon Slough/S. Natomas Community Park	2021	7.8	14
Northgate Park	2021	7.1	0
Glenbrook Park	2021	5.9	0
Ashton Park/Estates Dr.	2021	5.2	8
St. Joseph's Catholic Cemetery	2021	5.2	0
East Portal Park/Kit Carson School	2021	4.8	0
William Curtis Park	2021	3.2	0
Taylor Park	2021	3.0	0
Bahnfleth Park	2021	2.6	0
Phoebe Hearst/St. Francis Schools	2021	2.5	0
Isador Cohen School	2021	2.0	0
Total			827

[a]Within 0.5 km of site.
[b]For sites surveyed in both 2020 and 2021, the number is the average of the two years.

We compared the average and maximum numbers of magpies estimated from bird counts and nest counts at each colony in 2020. That year, we selected the highest number from either direct counts or nest counts as the basis for a population estimate. After the surveys in 2021, we used population numbers derived from nest counts in both years in creating the habitat–population model. To assess evidence for short-term population changes, we compared estimates from the eight sites surveyed in both years.

Nesting Productivity

Because of the nests' heights, screening foliage, and domes, we could not observe eggs or chicks directly. Therefore, we quantified productivity in 2020 by counting the number of young in family groups that included recent fledglings. This assessment, conducted by D. Airola, was confined to 20–27 May when recent fledglings could be readily identified by their shorter tails and higher-pitched begging calls but before multi-family creches formed (Koenig and Reynolds 2009, D. Airola pers. obs.). We considered counts complete where we were able to locate both adults and were confident of having detected all young in the group visually or aurally.

Nest Locations, Sites, and Characteristics

We characterized the general location of each nest as a park, golf course, school ground, urban residential area (>2 dwelling units per ha), or rural residential area (≤2 dwelling units per ha with livestock present). We characterized water bodies within 0.5 km of each colony's centroid as flowing water (permanent streams or rivers) or lakes/ponds (still waters ≥0.1 ha in size).

For nests discovered in 2020, we identified the species of tree or other supporting substrate and measured the diameter at breast height (dbh) of a sample of those trees that we could access, mainly on public lands. We described the composition of two nests that fell to the ground during the early (pre-laying) nesting season in 2020. We counted the larger sticks (>0.5 cm diameter) constituting the exterior portion of these nests and estimated the total mass of sticks by weighing a sample of nest sticks and multiplying the average mass per stick by the number of sticks in each nest. We dried and weighed the central mud portion of the nests. We calculated the number of individual billfuls of mud ("dabs") used in nest construction by selecting and weighing a sample of 20 individual dabs, then dividing the total mass of mud by this average mass of an individual dab. We visually inspected and described the inner nest component.

Use of Foraging Habitat

We classified and mapped eight land-cover types within and near the colonies surveyed in 2020 according to the definitions in Table 2. From mid-December 2019 through mid-April 2020, we recorded the numbers of magpies foraging within each land-cover type within each study area. We used the chi-squared statistic (χ^2) to compare the use (i.e., number of magpies observed foraging within each cover types) to the number expected number if use of each cover type were proportional to its extent within 0.5 km of the centroid point of nests within each colony. Cover types where magpie

Table 2 Land-Cover Types Characterizing Locations of Foraging Yellow-billed Magpies around Colonies in the Sacramento Region

Land-cover type	Description
Irrigated turf	Irrigated lawns generally >0.25 ha in size, primarily in parks and schools
Mowed or grazed annual grassland	Unirrigated annual grassland mowed or grazed to a height <15 cm throughout the winter and spring
Unmanaged annual grassland	Unirrigated annual grasslands and fallow areas that were not mowed or grazed with vegetation generally ≥15 cm height
Golf course	Irrigated golf course
Pavement	Asphalt-covered areas generally >0.75 ha (most roads were included within the Residential land cover type)
Residential	Residential neighborhoods (including yards and roads) and adjacent commercial areas (office parks, etc.)
Woodland	Riparian and oak woodland >1 ha in size with >20% canopy cover
Water	Rivers and ponds

use significantly exceeded values ($p < 0.05$) expected from availability were considered *selected*, whereas those where magpie use was significantly less than the expected values were considered *avoided*.

Relationship between Types of Foraging Habitat and Colony Sizes

In 2020, we quantified the area of the eight land-cover types within three increments of distance (0.5 km, 1.0 km, and 1.5 km) around each colony's centroid with ArcGIS Pro 2.5.2 (ESRI, Redlands, CA). On the basis of locations of observed foraging, we hypothesized these distances as defining circles within which most foraging of the colony's magpies may occur.

We used Microsoft Excel to calculate correlation coefficients (r) between the area within the three distance classes of various land-cover types (and combinations of types) that could be used for foraging and the population estimates for each site surveyed in 2020. The land-cover groups with the strongest correlations to populations (irrigated turf and mowed and grazed annual grassland combined; see Results) were then analyzed by regression (https://www.graphpad.com/quickcalcs/linear2/) to predict the population at a site from the extents of these two cover types (collectively "low herbaceous habitat") across the three distance classes.

The results of the 2021 survey suggested a role of the availability and type of water in determining the magpie's occurrence and abundance. Therefore, we modeled the relationships among these water and habitat variables with linear multiple regression. The number of breeding Yellow-billed Magpies was our response variable, and the extent (hectares) of low herbaceous habitat and type of water source (flowing, standing, or none) within 0.5 km of the centroid of the colony's nests were included additively as the predictor variables. We followed this with a similar analysis restricted to the 23 sites with flowing water within 0.5 km in order to estimate the minimum amount of habitat required to support a small magpie colony (defined as 3 pairs because >90% of colonies consisted of >3 nesting pairs). For sites surveyed in both 2020 and 2021, we used the average population size in these models.

We modeled these relationships in R (R Core Team 2021) and considered results to be biologically meaningful at $\alpha = 0.05$.

RESULTS

Comparison of Population Estimates from Counts of Birds and Counts of Nests

In 2020, on the basis of counts of adults and nests, the number of nesting magpies at the seven colonies surveyed ranged from 10 to 174 individuals (Table 3). At four of the seven colonies the population according to nest counts was higher than the maximum number of birds observed during any count of that colony. For all sites combined, the total population estimated from the number of nests exceeded the total from high counts of birds by 51% (384 versus 250; Table 3).

Occupancy Determinants and Populations at 2021 Survey Sites

In 2021, we observed nesting magpies at 22 of the 43 sites surveyed (Table 1), including the seven colonies fully surveyed in 2020 plus Phoenix Park where we counted nests only. On the basis of nest counts (including averages of counts in both years at eight sites), the population at occupied sites ranged from 2 to 187 individuals (median = 26 individuals) and totaled 827 individuals. All sites included ≥0.5 ha of low herbaceous habitat (irrigated turf at most areas) and trees >15 m tall within 0.5 km of the colony's centroid (Table 1). Nineteen (83%) of the 23 sites with flowing water within 0.5 km supported nesting magpies, including all 17 sites with >4 ha of herbaceous habitat. In contrast, only one of six (17%) sites with natural ponds or vernal pools but no flowing water was occupied, and only two (14%) of 14 sites that lacked permanent water were occupied. The distribution of occurrence among sites with flowing water, standing water, and no water differed significantly from the values expected if occupancy of each category were proportional to its representation in the sample ($\chi^2_{4\text{d.f.}} = 20.66$, $p < 0.001$).

Table 3 Counts of Adults and Nests and Estimated Population of the Yellow-billed Magpie at Colonies in Urban Sacramento Surveyed in 2020

	Counts of adults				Counts of nests		
Colony location	*n*[a]	Mean	SD	High count	Nests	Estimated population	Highest population estimate[b]
Park Road East	10	20	9.6	40	43	86	86
Renfree Field	14	24	16.3	57	18	36	57
Horsemen's Club	4	3	2.6	5	5	10	10
Discovery Park	6	48	9.3	56	87	174	174
Oak Meadow Park	15	14	5.4	24	11	22	24
William B. Pond Park	11	17	14.9	49	13	26	49
Ancil Hoffman Park	5	13	5.0	19	15	30	30
Total	65	139		250	192	384	430

[a]Number of surveys.

[b]Highest number derived from either counts of adults or numbers of nests.

Changes in the populations estimated at the eight sites where we counted nests in 2020 and 2021 ranged from a 33% decline to a 40% increase. The overall population across these eight sites, however, remained essentially unchanged (404 in 2020 and 406 in 2021).

Productivity of Successful Nests

In 2020, we observed 28 family groups with recent fledglings at six colonies surveyed for reproduction. These successful pairs were accompanied by an average of 2.8 young (SD ±0.9, range 1–4). All family groups except two contained at least two young.

Nest Locations, Sites, and Characteristics

At the 22 colonies occupied in 2020 and 2021, we found 618 nests. Most (65%) were within parks. Dense residential and rural residential areas supported 25% and 7% of nests, respectively. Only two colonies, Park Road East and Ashton Park–Estates Drive, had areas grazed by livestock within 0.5 km of a colony. Only seven nests (1%) were at schools, but six (27%) of the 22 sites with nesting colonies had a school within 0.5 km. At the two study sites with a golf course within 0.5 km of a colony, we did not find any nests on the courses.

The vast majority (97.5%) of the nests we found were in trees, with the others in light standards at an abandoned baseball field (2.0%) or on cell-phone towers (0.5%). The 168 nests for which we identified the supporting tree in 2020 included 16 species, with nearly half each located in native (52%) and non-native species (48%). A large majority (89%) of these nests were in deciduous trees. Valley oak was the predominant native tree with nests (31%); fewer nests were in native western sycamore (*Platanus racemosa*, 9%), interior live oak (*Quercus wislizenii*, 6%), or Fremont cottonwood (*Populus fremontii*, 4%), and <1% each were in Oregon ash (*Fraxinus latifolia*), white alder (*Alnus rhombifolia*), and blue oak (*Q. douglasii*).

The London plane was the predominant non-native nest tree, supporting 35% of all tree nests. Most nests in London plane trees were at Discovery Park, site of the largest colony surveyed (Table 1). Forty-nine (83%) of the 59 nest trees identified to species at this site were London planes. A few nests were found in a wide variety of other trees not native to Sacramento, including coast redwood (*Sequoia sempervirens*, 3%), sweetgum (*Liquidambar styraciflua*, 2%), and <2% each in red oak (*Q. rubra*), white mulberry (*Morus alba*), Modesto ash (*Fraxinus velutina*), and Chinese elm (*Ulmus parvifolia*). We found 14 nests (2%) associated with oak mistletoe (*Phoradendron villosum*) or broadleaf mistletoe (*P. macrophyllum*). Most nests in mistletoe were in large Fremont cottonwoods along the Sacramento River.

Nests were placed near the tops of large trees at each colony. The 102 nest trees that we measured averaged 80 cm in dbh (SD ±32 cm, range 28–234 cm). The largest trees used for nesting were Fremont cottonwoods (dbh 81–234 cm; n = 5) and coast redwoods (dbh 81–117; n = 4). Most nest trees (83%) contained a single magpie nest; 13% supported two nests, 3% had three nests, and 2% had four nests. We did not measure nest heights but estimated most nests to be at 15–25 m above ground.

Of the three nests found fallen from trees, one, at Park Road East in Del Paso Regional Park, fell when its supporting valley oak toppled after a flood.

Table 4 Composition and Mass of Two Fallen Yellow-billed Magpie Nests Recovered at Sacramento Colonies

	Outer stick layer		Central mud layer			
Location	No. sticks	Mass (kg)	No. mud dabs	Mass (kg)	Inner nest mass (kg)	Total nest mass (kg)
Park Rd. East	920	5.7	302	1.9	0.6	8.2
Discovery Park	661	4.1	221	1.4	0.7	6.2

A second nest fell from a London plane in Discovery Park, and the third (not collected or described) fell from a coast redwood in a residential area near Oak Meadow Park. The outer part of the two nests analyzed was constructed of sticks up to about 60 cm in length and 2 cm in diameter, weighing an average of 4.9 kg (Table 4). The central mud portion of the nests weighed an average of 1.7 kg and contained an average of 262 individually transported mud dabs. The inner portion of the nests was composed of many smaller plant stems and fibers that became progressively finer from the exterior to the interior and weighed an average of 0.64 kg. The total mass of the two nests averaged 7.2 kg.

Foraging Habitat Use

Over 80% of the 730 observations of foraging Yellow-billed Magpies we recorded during 2020 were in low herbaceous vegetation (encompassing irrigated turf and mowed or grazed grassland; Figure 2). Over half were in large (>2 ha) expanses of irrigated turf areas in parks, while 30% were in mowed or grazed annual grassland. Turf and grazed or mowed grassland were used at levels significantly greater than expected from their relative availabilities within 0.5 km of the colony ($\chi^2_{1 d.f.} = 1418$ and 692, respectively, $p < 0.001$). Foraging on turf, especially in the winter, was mainly in areas where fallen deciduous leaves were not regularly removed. There, magpies often flipped over leaves, presumably to locate invertebrates or seeds. Unmowed and ungrazed grasslands, which were used in proportion to their availability ($\chi^2_{1 d.f.} = 0.05$, $p = 0.82$; Figure 2), were used almost entirely in the early spring growing season when the grass was <15 cm tall. Areas of residential or commercial development and pavement were strongly avoided for foraging, relative to their availability ($\chi^2_{1 d.f.} = 198$, $p < 0.001$ and $\chi^2_{1 d.f.} = 11$, $p < 0.001$, respectively; Figure 2). At the two sites with golf courses (Ancil Hoffman and Horsemen's Club), we observed only two instances of magpies using them. No foraging was observed in the other land-cover types.

Relationship between Foraging Habitat and Colony Size

Amounts of certain land-cover types were associated strongly with the numbers of breeding magpies. Among the colonies surveyed in 2020 (all of which had flowing water), the strongest correlation was with the extent of low herbaceous cover (irrigated turf and grazed-mowed grassland combined) within 0.5 km of the colony's centroid ($r = 0.83$). The relationship between population (y) and the area of low herbaceous cover (x) within 0.5 km was statistically significant ($F_{1, 5} = 11.1$, $p = 0.021$). The relationship was weaker and not statistically significant when the radius was increased to 1.0 km ($r =$

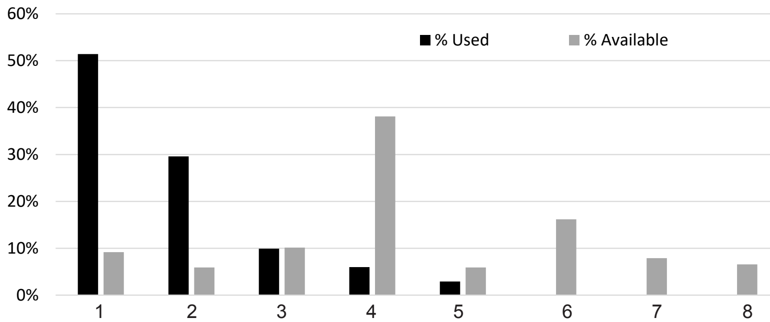

FIGURE 2. Proportions of land-cover types used by and available to foraging Yellow-billed Magpies in urban Sacramento, California, 2020, as measured within 0.5 km of nesting colonies. 1, irrigated turf; 2, mowed/grazed annual grassland; 3, unmanaged grassland; 4, residential; 5, pavement; 6, woodland; 7, golf course; 8, water.

0.34; $F_{1,5} = 0.52$, $p = 0.52$) and 1.5 km ($r = 0.69$; $F_{1,5} = 4.64$, $p = 0.084$). This result is consistent with our unquantified observations that during the nesting season most foraging was near the nest.

The multivariate model including the 2021 results from all 43 survey sites that predicts the number of breeding Yellow-billed Magpies from the extent of low herbaceous habitat and type of water within 0.5 km of a colony was biologically meaningful ($R^2 = 0.47$, $F_{3,39} = 13.36$, $p < 0.001$). The regression equation describing this relationship is $y = 4.07 + 3.63$(hectares low herbaceous cover) – 25.66(water type: none) – 27.92(water type: lake/pond), where the value of the water-type variables is 1 for present and 0 for absent. For instance, this model predicts that an expanse of low herbaceous habitat of 15 ha within 0.5 km of a lake or pond should support 31 magpies (i.e., 4.07 + [3.63 × 15] – 27.92) whereas 15 ha within 0.5 km of flowing water should support 58 magpies (4.07 + [3.63 × 15]). Thus the greatest numbers of magpies were found at sites with large expanses of low herbaceous habitat near flowing water (Figure 3). At sites with flowing water, there was a strong relationship between the amount of low herbaceous habitat within 0.5 km of a colony's centroid and size of the population ($R^2 = 0.60$, $F_{1,21} = 34.45$, $p < 0.001$; Figure 3). The regression equation describing this relationship is $y = 6.51x - 19.66$, implying that 3.3 ha of low herbaceous habitat is needed to support a single breeding pair of magpies, and 3.9 ha to support a minimal-sized colony of three pairs.

DISCUSSION

Population Status

Our 2021 estimated population of 827 Yellow-billed Magpies at the 22 identified nesting colonies in the metropolitan Sacramento area is approximately 23% of the 5300 individuals that Crosbie et al. (2014) estimated within urban habitats rangewide in 2007 and 2008. Since then, however, the population has declined by one-third because of West Nile virus infection (Pandolfino 2020). If this rate of decline also applied to urban populations, our 2021 estimate

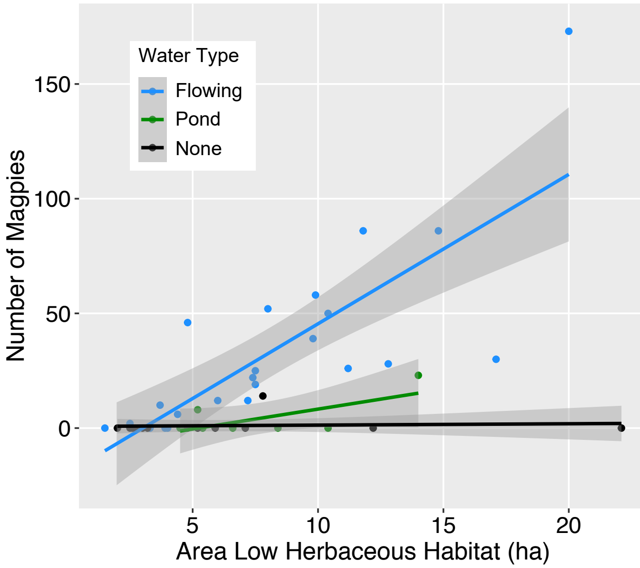

FIGURE 3. Relationship between the number of breeding Yellow-billed Magpies in a colony (estimated from counts of nests; see Methods) and extent of low herbaceous cover (irrigated turf and mowed or grazed annual grassland) and water source within 0.5 km of the colony's centroid in urban Sacramento, California, 2021. Results from 43 sites (Table 1) are colored by type of water source within 0.5 km, and solid lines depict least-squares regressions for each water type; gray shading reflects the 95% confidence interval on the regressions.

confirms the persistence of a relatively high population in the Sacramento region, as first noted over a decade ago by Koenig and Reynolds (2009).

Absence of past data from surveys using consistent methods precludes a robust characterization of changes in the Sacramento region's Yellow-billed Magpie population since arrival of West Nile virus. Observations recorded at eBird are largely limited to years after 2006 (https://ebird.org/news/ebird-2018-year-in-review), concurrent with the arrival of the West Nile virus (Reisen et al. 2004). This leaves Christmas Bird Count (CBC) data as the only consistent data source for assessing long-term population trends since the virus's arrival (Airola et al. 2007, Crosbie et al. 2008, Pandolfino 2020). On the basis CBC data from the three count circles closest to our study areas (Sacramento, Folsom, and Rio Cosumnes), within two years of the arrival of West Nile virus the magpie population (as quantified by birds/party-hour) had declined by about 40%, and by 2019 it had cumulatively declined by >80% in the local area and surrounding Central Valley (https://netapp.audubon.org/cbcobservation/, Airola et al. 2007, Pandolfino 2020).

The lack of a decline in the magpie population according to nest counts at the eight sites we surveyed in both 2020 and 2021 offers only modest encouragement regarding the effects of West Nile virus. Most of the regional population's decline took place soon after the virus's arrival; subsequently the population has fluctuated but not recovered (Pandolfino 2020). Our 2020 and 2021 population estimates (Table 1) provide a baseline for consistent and repeatable future monitoring.

Population Assessment Methods

The disparity between our population estimates based on maximum counts of birds and those based on counts of occupied nests indicates the challenges inherent in surveys for the Yellow-billed Magpie. Our observations and those of Birkhead et al. (1992) confirm that magpies congregate before the nesting season and are comparatively dispersed while nesting. Their congregating complicates surveys, as the groups may move over large areas and thus may be difficult to detect. Winter congregations may include birds from multiple nearby colonies (Koenig and Reynolds 2009), which complicates attribution of numbers observed to any specific colony.

Counts of nests as a basis for estimating populations appears to be more effective than direct counts of birds, but this method also poses challenges. We observed nest-building from 15 January through 29 March. Early in this period, however, before the dome is added to a nest, it can be challenging to distinguish nests that are under construction from nests left over from previous years (Verbeek 1973). Leafing out of deciduous trees, which begins in late March or early April, obstructs visibility and can lead to incomplete nest counts. Within this period, nests are easily visible from long distances because of their large size and placement at the tops of tall trees, allowing an efficient and accurate count of nesting birds. For these reasons, in the more extensive 2021 surveys, we relied on nest counts from late January though late March as the basis for estimating populations, and we recommend it generally. Notably, however, this technique does not count non-nesting birds, which may include some portion of the one-year-old and two-year-old cohorts (Verbeek 1973, Koenig and Reynolds 2009).

Productivity of Successful Nests

Our estimate of productivity provides a general indication of success but is not a true measure of the population's productivity (i.e., the number of young fledged per nesting pair; Steenhof and Newton 2007) because it does not account for pairs whose nests failed. Lack of data on productivity prior to the arrival of West Nile virus in Sacramento precluded us from determining if the virus has affected reproduction. Our productivity rate of 2.8 young per successful nest, however, is consistent with studies in the Coast Range that found most successful nests produced 2 or 3 fledglings (Koenig and Reynolds 2009).

It is possible that productivity at the colonies we studied was exceptional rather than representative of the regional population. That the populations at the seven colonies where we recorded productivity in 2020 were higher than elsewhere in Sacramento could be an indication of better habitat quality or lower rates of infection. Dead magpies infected with West Nile virus, however, were reported near our study areas only from mid-June through mid-September ($n = 27$, https://www.fightthebite.net/media/west-nile-virus-activity/), after the nesting season, when mosquitoes are more abundant (Elnaiem et al. 2008, Macedo et al. 2010). Thus our demonstration of apparently normal reproductive rates suggests that mortality from West Nile virus during summer and fall, not reduced reproduction, is preventing the Yellow-billed Magpie's population recovery.

Nest Locations, Sites, and Characteristics

We found that larger parks with large trees, and irrigated turf and other low herbaceous vegetation, appear to support larger Yellow-billed Magpie colonies. Although described as nesting primarily in a few species of native trees, i.e., oaks and cottonwoods (Linsdale 1937, Koenig and Reynolds 2009), in urban Sacramento Yellow-billed Magpies are not highly selective by species in their use of nest trees and use a wide variety of trees, both native and non-native.

Our characterization of tree species used for nesting may be slightly biased toward deciduous trees because of nests' reduced visibility in evergreens. The overwhelming use of deciduous trees, however, indicates that this effect was probably minimal. Despite the prevalence of mistletoe at our study sites, mainly in native oaks and cottonwoods, we observed little use of mistletoe clumps as nest sites (2% of nests), in contrast to its use in 36% of nests in coastal oak woodlands (Koenig and Reynolds 2009). Although we did not formally assess the height of the trees in which the magpies nested, nearly all nests were in large, tall trees. Nest trees' diameters in Sacramento averaged slightly smaller (80 cm, SD ±32) than reported in the Coast Range by Reynolds (1990; mean = 91 cm, SD ±42, n = 64).

The composition of the Yellow-billed Magpie nests that we examined from Sacramento is generally similar to that described previously (Linsdale 1937, Verbeek 1973). The Sacramento nests, however, had only about half as many sticks as those described from the Coast Range, and the Sacramento nests weighted about one-third less. These differences may simply reflect that the Sacramento nests were not fully completed, as they fell before egg-laying began, or that portions of the fallen nests remained in trees or were scattered during their falls. Given that we quantified only two nests, we cannot draw substantive conclusions from these comparisons, but our results nonetheless add to the limited information on the characteristics of Yellow-billed Magpie nests.

Importance of Flowing Water

Several factors may explain the magpie's occupying areas with low herbaceous vegetation within 0.5 km of rivers and streams at a rate substantially higher than of areas with ponds or lacking any permanent water source. Yellow-billed Magpies drink regularly (Linsdale 1937, Koenig and Reynolds 2009) and may prefer or require cleaner moving water rather than water in the more stagnant ponds of parks. Streams and rivers also provide more open areas for gathering mud for nests than do ponds, which were either lined with concrete (n = 3) or had emergent vegetation (n = 3) obstructing access to mud. Association with flowing water could also reflect that mosquito populations in these areas may be lower than in areas with still water (Collins and Resh 1989).

The several occupied sites that lacked moving water had alternative sources of water of higher quality than in park ponds. Phoenix Park, with vernal pools that were shallow and accessible but that dried during the nesting season in drier years, supported fewer magpies (20 and 26 each year) than the habitat model predicted from its extent of low herbaceous vegetation (14 ha). At Ashton Park/Estates Drive the magpies used a permanent source of clean water for livestock. Bannon Slough was the only other occupied site that lacked a source of flowing water nearby. The slough itself is a vestigial drainage that no longer transports water. Bannon Slough supported fewer nesting magpies (14) than predicted from its extent of low herbaceous habitat (7.8 ha). We suspected, but were unable to locate, an alternative water source that served this colony.

Relationship between Population Size and Extent of Foraging Habitat

The irrigated turf and mowed and grazed annual grasslands on which Yellow-billed Magpies foraged in urban Sacramento were similar in height to the vegetation in areas used in more natural settings (Linsdale 1937, Koenig and Reynolds 2009). The birds' abundance was also associated with the extent of these low herbaceous habitats. Our results strongly indicate that periodic mowing or grazing to keep this vegetation low (<15 cm tall) promotes the habitat's suitability for magpies. Furthermore, the need for at least 4 ha of low herbaceous foraging habitat to support a nesting colony of three pairs may be useful in identifying areas suitable for the species and in planning for conservation and management. One factor that we did not examine that could influence the magpie's occurrence is the variable character of residential areas, especially lot sizes and associated amounts of available lawn turf. Residential areas with larger lots would be expected to support more of the irrigated turf (i.e., lawn space) foraging Yellow-billed Magpies prefer and therefore higher populations.

Our results support the conclusion that the total area of both irrigated turf and mowed or grazed annual grassland is important to nesting Yellow-billed Magpies. First, magpies foraged in these two cover types selectively. Second, the strongest relationship between colony size and habitat characteristics was with the combined abundance of irrigated turf and grazed or mowed grassland. Third, magpies were absent from many urban parks, even near flowing water, with <4 ha of low herbaceous vegetation (Table 1). Explanations for the magpie's use of areas with shorter herbaceous vegetation height deserve further study, but may include greater availability or visibility of prey, increased efficiency of locomotion, or easier detection of predators. Anecdotally, the necessity of a minimum area of low herbaceous habitat to breeding magpies is also demonstrated at the Tretheway Oak Preserve (formerly Natomas Oaks Park), a site that D. Airola surveyed in 2006, 2020, and 2021. In 2006, 6.5 ha of low herbaceous foraging habitat was present, and 15 pairs of Yellow-billed Magpies nested there. By 2020 and 2021, however, following construction of an office park that reduced foraging habitat to 3.3 ha, the colony had disappeared. The advent of the West Nile virus may also have contributed to this decline.

Although we did not quantify human activity in the parks we surveyed, we observed many instances of park users unintentionally disturbing foraging magpies. Thus it is possible that a certain level of human activity and its associated disturbance makes the more popular parks unsuitable for magpies. For instance, high levels of human use may explain the general lack of Yellow-billed Magpies at golf courses, which were heavily used during the covid-19 pandemic, or it could be due to other factors (see next section).

One potential source of inaccuracy in our habitat–population model is the omission of all residential and commercial areas. We observed magpies foraging on residential lawns in some areas, particularly where lot sizes and areas dedicated to lawns were greater, such as at the College Park neighborhood site where lots averaged about 0.1 ha. As lot sizes increase, residential areas become more rural, offer more foraging habitat, and support more nesting magpies.

Conservation Implications

The results of our study on population status and habitat use provide a robust explanation for why certain urban areas support larger Yellow-billed Magpie populations than others. Our study does not, however, address the central issue of what is causing the broader decline in the magpie's population: the effects of West Nile virus infection on this nonresistant species (Airola et al. 2007, Crosbie et al. 2008, Pandolfino 2020). Nonetheless, our results provide novel and useful information for the conservation of this and other Yellow-billed Magpie populations in urban areas of the Central Valley, including the identification of areas that may support magpie populations in the event of population recovery. Characterizing the importance of rivers, streams, and other high-quality water sources and the relationship between the extent of foraging habitat and size of nesting colonies also can inform management for the species in urban areas or in rural areas that are undergoing rapid urbanization (Teitz et al. 2005).

The magpie's intensive use of irrigated turf raises conservation issues. Restoration of these areas to more natural woodland conditions may benefit most native plant and animal species but would appear to be detrimental to the Yellow-billed Magpie. Our results linking foraging habitat to population size suggests caution in converting areas of low herbaceous vegetation to other uses (i.e., development or wooded habitats). The magpie's light use of turf on golf courses suggests that these areas have limited value as habitat. Potential causes of the magpie's avoidance of golf courses may include high levels of human disturbance, risk of injury from golf balls, and more intensive management, including frequent low mowing and use of pesticides that may reduce prey abundance and be toxic to the birds.

Given the strong role of the West Nile virus in depressing Yellow-billed Magpie populations (Pandolfino 2013, 2018, 2020), our results are surprising in showing that water availability and habitat conditions appear to regulate Sacramento's urban magpie population. One interpretation of our results is that the virus operates in a density-independent fashion to reduce each colony by a similar proportion to a level below which it is ultimately regulated by habitat-related factors. Alternatively, although monitoring of both roosts and carcasses has documented the virus's effects on Sacramento's urban magpie population (https://www.fightthebite.net/media/west-nile-virus-activity/, Crosbie et al. 2006), it may be that areas where we found larger magpie populations (especially at sites with flowing water and no standing water) may have mosquito populations and infection rates (Collins and Resh 1989) lower than elsewhere within the magpie's range. If so, then these areas may serve as refugia from the virus where populations can be determined by habitat conditions. Regardless of the threat the West Nile virus poses to the Yellow-billed Magpie, our information on the species' habitat use in relation to population size can help guide its conservation, especially in urban environments.

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