Yellow-billed Magpie Population and Habitat Characteristics in Urban Sacramento, California

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ABSTRACT: The Yellow-billed Magpie (*Pica nuttalli*), a California endemic, declined substantially after the arrival of West Nile virus in the state in 2003 and has not recovered. The species primarily occupies oak woodlands and savannas, but some urban and suburban populations are sizable. Most research on the species' ecology has been focused within the Central Coast region, and urban and suburban populations have received little attention. We provide information on population size, reproductive success, and nesting and foraging habitat use at sites in the Sacramento region, California, that support sizable breeding populations. We identified seven study areas based on high numbers reported in eBird or observed by us during 2017-2020. Site populations estimated in 2020 based on direct counts were generally lower than those from nest counts. Counts of recently fledged young in family groups yielded estimated reproductive rates similar to those observed on the Central Coast before arrival of West Nile virus, suggesting that the virus is not disproportionately affecting nestling survival. Sacramento magpies nested in the upper canopy of a wide variety of large native and non-native trees. Foraging occurred mainly in areas of irrigated turf and unirrigated annual grassland that was mowed or grazed. Analysis showed a strong relationship between the sizes of populations and amounts of low herbaceous foraging habitat within 0.5 and 1.5 km of colony sites and suggested a minimum of 6 and 48 ha of low foraging habitat is needed at these distances, respectively, to support nesting colonies. Absence of nesting colonies in many urban Sacramento parks, cemeteries, and schools with irrigated turf may be a result of inadequate area of foraging habitat or lack of mowed or grazed grassland. Our results provide habitat conservation and management guidance for the species.

The Yellow-billed Magpie (*Pica nuttalli*) is a California-endemic species whose geographic range that is limited to the Central Valley and Central Coast regions of the state (Koenig and Reynolds 2020). Following the arrival of West Nile virus in California in the early 2003 (Reisen et al. 2004), extensive mortality was documented in magpies (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 West Nile virus, the magpie apparently has not developed immunity to the disease and has continued to decline (Pandolfino 2013, 2018, 2020) as West Nile virus persists (Snyder et al. 2020).

The most recent Yellow-billed Magpie population assessment conducted in 2008 identified a statewide population of 396,399 (95% confidence interval [CI]: 319,891 – 491,206; Crosbie et al. 2014). A recent evaluation of numbers reported on Christmas Bird Counts (CBCs) in the Central Valley has shown substantial subsequent decline through 2019 (Pandolfino 2020). The species is recognized as a Species of Conservation Concern by the U.S. Fish and Wildlife Service (2008) and is on the North American Bird Conservation Initiative's (2014) watch-list as a species with limited range or significant threats.

The Yellow-billed Magpie mostly occupies oak woodlands and savanna (Koenig and Reynolds 2020). The 2007-2008 statewide California study indicated that nearly all of the population occurred in lands characterized as rural (62%) and agricultural (37%), while only and only 1% (5,347 ±2,962-9,652 CI) occurred in urban areas (Crosbie et al. 2014). Population decline in many areas has been attributed historically to deliberate poisoning (Lyndell 1962) and more recently to urbanization, although the species has persisted in some urban areas (Koenig and Reynolds 2020). In particular, the continuation of relatively abundant (though unquantified) breeding populations in the Sacramento-Davis metropolitan region in Sacramento and Yolo counties has been considered anomalous (Koenig and Reynolds 2020).

Nearly all modern ecological research on the Yellow-billed Magpie has occurred at and near the Hastings Reservation, a University of California Natural Reserve in the Carmel Valley, Monterey County, in the Central Coast region of California (Verbeek 1972, 1973; Koenig and Reynolds 2020; Reynolds

1990; Bolen 1999; Bolen et al. 2000). This area supports coastal oak woodland, savanna, and grasslands. Other than the statewide or regional population surveys (Smallwood and Nakamoto 2009, Crosbie et al. 2014), ecological research on magpies in the Central Valley of California and in urban and suburban areas has been limited to characterization of a few winter roosting sites and population trends at those roosts (Crosbie 2006). Given the species' declining status, the continued growth of urban and suburban areas in California's Central Valley (Tietz et al. 2005), and uncertainty regarding the factors that allow persistence in these areas, more research is needed on population status and basic natural history of the Yellow-billed Magpie in urban and suburban areas (Koenig and Reynolds 2020, including foraging and nesting habitats).

The Yellow-billed Magpie exhibits several characteristics that facilitate ecological research. They are large, boldly colored, noisy, build large nests, feed in open areas, and are non-migratory. Several aspects of their natural history, however, inhibit study. Their occurrence in groups that are often widely dispersed can make it difficult to locate flocks to estimate population size. They place their spherical stick nests in tall inaccessible trees and other locations, which inhibits assessing reproductive success. Also, the tendency of fledged young to gather in multi-brood creches shortly after fledging and to rapidly resemble adults makes it difficult to assess pair productivity (i.e., number of young fledged per nesting pair) after fledging.

Efforts to assess Yellow-billed Magpie population sizes or trends have included generalized formulaic estimate (Rich et al. 2004), a short-term highly intensive sampling survey (Crosbie et al. 2014), and analyses based on the Breeding Bird Survey (Koenig et al. 2007) and Christmas Bird Count data (Airola et al. 2007, Crosbie et al. 2008, Pandolfino 2013, 2020). Its declining status has led to recommendations for additional population monitoring and studies of genetic diversity, population structure, and population viability (Koenig and Reynolds 2020).

We initiated this study to acquire information on the relative population size and habitat use by a Yellow-billed Magpie population in urban and suburban Sacramento. Study objectives were to evaluate the abundance of the species at important use sites in Sacramento; quantify nesting productivity; identify nest characteristics, locations, and tree species and sizes used for nest placement; identify use of various land covers for foraging; and evaluate the relationship between the amounts of foraging habitats and breeding colony sizes.

STUDY AREA

We studied Yellow-billed Magpies in and adjacent to seven parks and recreation areas in urban and suburban Sacramento, California (Figure 1). We use the term *urban* to refer to both urban areas (densely developed) and suburban areas (occupied mainly by residential housing). *Study areas,* defined as the general areas within which occupied *colony sites* occurred, were initially selected based on the reporting of larger numbers of magpies in eBird (ebird.org). Major study areas were within and adjacent to the following parks: Discovery Park and Del Paso Regional Park (which supported three separate colony sites: Horseman's Club (west of Watt Ave), Renfree Field and nearby areas, and Park Road East (including the Del Paso Park picnic area) within the City of Sacramento, and Ancil Hoffman Park, William B. Pond Park, and Oak Meadows Park within unincorporated areas of Sacramento County.

All park areas 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 at various sites included native valley oak *(Quercus lobata),* non-native London Plane *(Plantanus* x *acerifolia*), and many other species of native and non-native urban forest trees (see RESULTS). All sites were adjacent to or within 1 km of creeks or rivers, including Arcade Creek (Del Paso Regional Park sites), the Sacramento River and American River (Discovery Park), and American River (all other sites). Much of the lands surrounding park sites consisted of residential or commercial development (see RESULTS).

We also surveyed for breeding magpies during 2017-2019 in 14 park, cemetery, and school sites within the City of Sacramento and adjacent areas that supported extensive areas of irrigated turf.

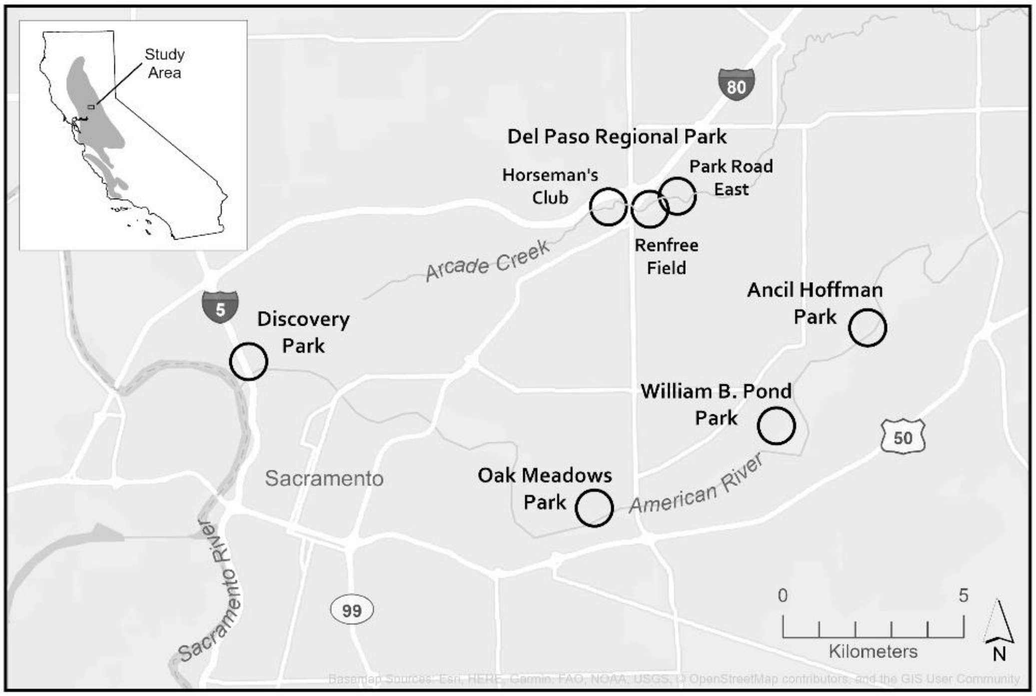

Figure 1. Yellow-billed Magpie study areas in the Sacramento region. Inset map shows magpie geographic range.

METHODS

Use of eBird to Identify Study areas

We used our knowledge and eBird to locate areas with larger numbers of Yellow-billed Magpies in the Sacramento region. We examined magpie numbers reported over January 2017- January 2020 at 50 eBird "hotspots" (ebird.org/hotspots), which are public-accessible areas identified and frequently visited by birders. We selected those hotspot sites where high counts exceed 30 for our field studies.

Population Estimates

We quantified number of breeding magpies at study sites mid-December 2019 through early April 2020 using two estimate methods. D. Airola conducted all surveys. During the pre-nesting period we directly counted magpies when they were flocked together and highly visible, with a minimum of four counts per site. We also counted the magpie's large, domed stick nests during one or several visits during 21 February – 28 March 2020, before deciduous foliage emerged and nest attendance reduced nest detectability.

Because some magpie nests, but generally not the domed portion, may persist for several years (Verbeek 1973, D Airola, pers. obs.), we identified nests as occupied in 2020 only if they were domed or if adults were seen building the nest or attending the nest (i.e., present within 10 m). Some nests likely were not detected at Ancil Hoffman Park because it was surveyed late in the season, after deciduous trees had leafed-out. Nests in evergreen trees, including coast redwoods (*Sequoia sempervirens*), also were more difficult to detect throughout the season, and may have been under-represented in our surveys. We multiplied the number of occupied nests by two to estimate the nesting population, as magpies are monogamous (Koenig and Reynolds 2020).

We compared the average and maximum numbers of magpies estimated from bird counts and nest counts at each colony sites to evaluate the similarity of estimates. We selected the highest number from either direct counts or nest counts as the population estimate to use in an analysis of habitat (see *Relationship between Foraging Habitat Availability and Colony Sizes)* below.

D. Airola also conducted repeated informal surveys during 2017-2020 at the 14 other Sacramento sites identified as having potential to support magpies, based on the presence of extensive areas of irrigated turf.

Nest Productivity

We could not directly observe nests, eggs, or chicks because of the nest heights and presence of foliage and the nest domes that obscured nest contents. Therefore, we determined productivity by counting the number of young in family groups that included recent fledglings. This assessment, conducted by D. Airola, was confined to the 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 2020, D. Airola, pers. obs.). We considered counts complete where we were able to locate both pair members and confidently detected all young in the group visually or aurally.

Nest Locations, Sites, and Characteristics

We characterized the general locations of nests as parks, golf courses, school grounds, urban residential areas (<1 dwelling unit per ha), and rural residential areas (<1 dwelling unit per ha). We identified the species of trees and other substrates used to support nests 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. We counted the larger sticks (>0.5 cm diameter) that comprised the exterior portion of nest 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 and estimated the number of "dabs" (bills-full) of mud used in nest construction by weighing a sample of 20 dabs and dividing the total mud mass by the average mass of dabs. We visually inspected and described the inner nest component.

Foraging Habitat Use

We classified and mapped ten land cover types within and near colony sites according to the definitions in Table 1. During mid-December through mid-April, we recorded numbers of magpies foraging within each of the various land covers at study areas. Observations were recorded once per date, to ensure independence. We used the chi-squared statistic (χ^2) to compare the use (number of foraging observations) of land covers with an expected random-use value, based on the relative availability of those cover types within 1.5 km of the centroid of colony nests at each study area. Cover types where magpie use significantly exceeded expected values based on availability were considered *selected.*

Table 1. Land cover types used to characterize foraging locations by Yellow-billed Magpies and describe lands surround 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 so that it was maintained at heights <15 cm throughout the winter and spring seasons
Unmanaged Annual Grassland	Unirrigated annual grasslands and fallow areas that were not mowed or grazed and generally ≥15 cm height
Golf Course	Irrigated golf course
Agriculture	Cultivated lands and managed orchards
Pavement	Asphalt 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 and other areas)
Woodland	Riparian and oak woodland >1 ha in size with >20% canopy cover
Barren	Unvegetated areas of former mining tailings and river floodplains
Water	Rivers and ponds

Relationship between Foraging Habitat Availability and Colony Sizes

We quantified the area of the 10 land covers within the three distance classes (0.5 km, 1.0 km, and 1.5 km) around the nest centroid point at each study area using Esri ArcGIS Pro 2.5.2 geographic information system (GIS) program. The distances were identified as hypothetical areas within which most magpie foraging may occur, based on observed foraging location. We then evaluated the relationship between the numbers of magpies at colony sites and the amounts of various land covers at the three distances. We used Microsoft excel to calculate correlation coefficients (r) between the area of various land cover types (and combinations of types) that could be used for foraging and the population estimates for each site. The land cover groups with the strongest correlations were then subjected to regression analysis to create a predictive equation that described the relationships between habitat amounts within various distances of colonies and their population sizes. This equation was used to estimate the minimum amount of habitat required to support a small magpie colony (i.e., 5 pairs).

We used Google Earth Pro (google.com/earth) to quantify the total area of irrigated turf and mowed or grazed annual grassland at the additional 15 urban parks, schools, and cemeteries where we surveyed and did not find magpies, to determine possible reasons for their absence.

RESULTS

Magpie Abundance at eBird Hotspot Sites

High counts at the 50 eBird hotspots during 2017-2019 were highly skewed toward lower numbers, with over half of sites supporting high counts of fewer than 10 magpies, and only 5 sites supporting high counts of more than 30 birds (Figure 2).

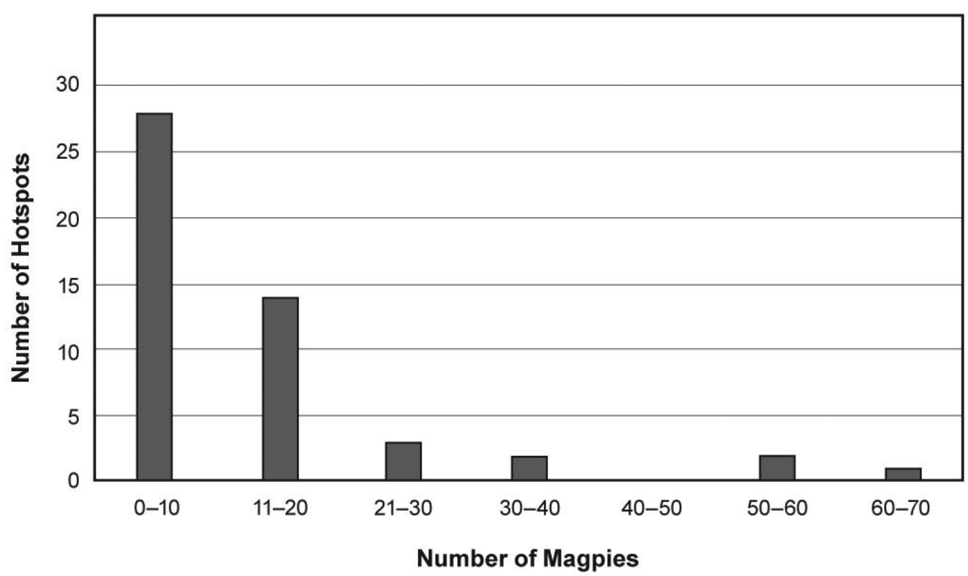

Figure 2. Number of eBird hotspot sites in Sacramento with 2017-2019 maximum abundances of Yellow-billed Magpies.

Population Estimates from Counts of Birds and Nests

Numbers of nesting magpies at the high-population sites we selected, based on the population estimate from counts of adults and nests, ranged from 10-174 individuals (Table 2). Magpie numbers determined from the number of nests observed was higher than the maximum number of birds observed during counts at four of the seven study sites. Total numbers across all sites estimated from the number of nests exceeded the total from high counts by 51% (384 versus 250; Table 2). The total population for the eight sites determined from the highest number from magpie or nest counts was 12% higher than the total from nest counts alone (430 versus 384).

We recorded no magpies during 2017-2020 at the 15 Sacramento park, school, and cemetery sites that supported irrigated turf but had no mowed or grazed annual grassland (Table 3).

Table 2. Yellow-billed Magpie counts of adults, nests, and population estimates from these counts at urban Sacramento study areas.

	Adult Counts				Nest Counts		Highest
Colony Location	No.	Ave. No.	S.D.	High Count	Nests	Estimated Population	Population Estimate[a]
Park Road East	10	20	9.6	40	43	86	86
Renfree Field	14	24	16.3	57	18	36	57
Horseman’s Club	4	3	2.6	5	5	10	10
Discovery Park	6	48	9.3	56	87	174	174
Oak Meadows 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]*Highest population estimate* is the highest number from either counts or the population estimated from numbers of nests.

Table 3. Surveyed sites in Sacramento with low herbaceous vegetation that did not support nestingYellow-billed Magpies during 2017-2020. Low herbaceous cover at all sites consisted of irrigated turf, with no mowed or grazed irrigated grassland.

Survey Site	Area (ha) of Low Herbaceous Cover
East Lawn Cemetery	8.7
Granite Regional Park	8.7
William Land Park	6.6
Christian Brothers High School	6.5
St John’s Catholic Cemetery	5.1
Reichmuth Park	4.5
Tretheway Oak Preserve	3.3
William Curtis Park	3.2
McKinley Park	2.9
East Portal Park	2.6
Wilhaggin Detention Basin	2.5
Glen Hall Park	1.2
Sierra School Park	0.7
Sutter’s Fort Park	0.8

Productivity of Successful Nests

We observed 28 family groups with recent fledglings at six of the study areas. These successful pairs contained an average of 2.8 young (±0.9 SD, range = 1-4). All except two family groups contained at least two young.

Nest Locations, Sites, and Characteristics

Of the 202 Yellow-billed Magpie nests we found, most (74%) were within parks. Rural residential and dense residential and areas supported 13% and 12% of nests, respectively. Only one study area, Park Road East, had adjacent rural residential lands. Only two nests were at schools, but only two of the seven studied colony sites had schools nearby. We found no nests within the golf courses at the two study sites where courses were present.

The vast majority of the nests we found (96%) were in trees, with the others in light standards at an abandoned baseball field (3%) and cell phone towers (1%). The 168 nests for which we identified tree species were within 16 different species, with nearly half each in native (52%) and non-native species (48%). A large majority of nests (89%) were in deciduous trees. Valley oak (*Quercus lobata*) was the predominant native tree used for nest placement (31%), with much less use of the native western sycamore (*Plantanus racemosa*, 9%), interior live oak (*Q. wislizenii*, 6%), Fremont cottonwood (*Populus fremontii, 4%*), and <1% of nests in Oregon ash (*Fraxinus latifolia*), white alder (*Alnus rhombifolia*), and blue oak (*Q. douglasii*).

The London plane (*Plantanus* x *acerifolia*) was the predominant non-native nest tree, supporting 35% of all tree nests. Most London Plane nests were in planted shade trees at Discovery Park, which supported the largest nesting population (Table 2). Forty-nine (83%) of the 59 nest trees identified to tree species at this site were planes. A few nests were found in a wide variety of other non-native trees, including coast redwood (3%), sweetgum (*Liquidambar* sp., 2%), and <2% in red oak (*Quercus rubra*), white mulberry (*Morus alba*), Modesto ash (*Fraxinus vetulina*), and Chinese elm (*Ulmus parvifolia*). We found no nests associated with either oak mistletoe (*Phoradendron villosum)* on native oaks or big-leaf mistletoe *(P. macrophyllum*), which occurred on several non-native species.

Nests were placed near the tops of large trees at each colony. The 102 measured nest trees averaged 80 cm dbh ($\pm$32 cm SD, range = 28-234 cm). The species with the largest trees used for nesting was Fremont cottonwood (dbh range = 81-234 cm; N = 5) and coast redwood (range = 81-117; N = 4). Most nest trees (83%) contained a single magpie nest; 13% supported two nests, while 3% had three nests and 2% had four nests. We did not measure nest heights, but most nests were estimated to be at 15-25 m height.

We found three nest that fell from trees. One nest at Park Road East in Del Paso Regional Park fell when its supporting valley oak toppled after a localized flooding event. A second nest fell from a London plane in in Discovery Park. One nest that fell from a coast redwood in the Oak Meadows Park study area was not collected or described.

Table 4. Composition and mass of two fallen Yellow-billed Magpie nests recovered at Sacramento colonies

	Outer Stick Layer		Central Mud Layer			
Nest No.	# Sticks	Mass (kg)	No. Mud Dabs	Mass (kg)	Inner Nest Mass (kg)	Total Nest Mass (kg)
1	920	5.7	302	1.9	0.6	8.2
2	661	4.1	221	1.4	0.7	6.2

The two described nests were constructed of sticks up to about 60 cm in length and 2 cm in diameter in the outer nest, weighing an average of 4.9 kg (Table 4). The central mud portion of the nest contained an average of 262 individually transported mud dabs, weighing an average of 1.7 kg. The inner nest 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 km. Total nest mass averaged 7.2 kg. No anthropogenic materials or horsehair were used in the nests.

Foraging Habitat Use

Over 80% of the 730 Yellow-billed Magpie foraging observations we recorded were in low herbaceous vegetation (irrigated turf and mowed or grazed grassland land cover types; Figure 3). Large (>2 ha) irrigated turf areas in parks were used in over half of foraging observations, while 30% of use occurred in mowed or grazed annual grassland. Turf and grazed or mowed grassland were used at levels significantly greater than expected based on their relative availabilities within 0.5 km of colony sites ($\chi^2_{1d.f.}$ = 1,418 and 692, respectively, p-values < 0.001). Unmowed and ungrazed grasslands, which were used in proportion to their availability (Figure 3), were used almost entirely in the early spring growing season when grass height was <15 cm. Foraging in residential and commercial areas occurred regularly, mainly on lawns and pavement. These cover types were used at levels below expected based on their availability (Figure 3). We only observed two instances of magpies using turf areas on golf courses at the two sites where courses were present (Ancil Hoffman and Horseman's Club). Foraging on turf areas, especially in the winter, occurred mainly in areas where fallen deciduous leaves were not regularly removed. There, magpies often flipped over leaves, presumably to locate invertebrates or seeds under them.

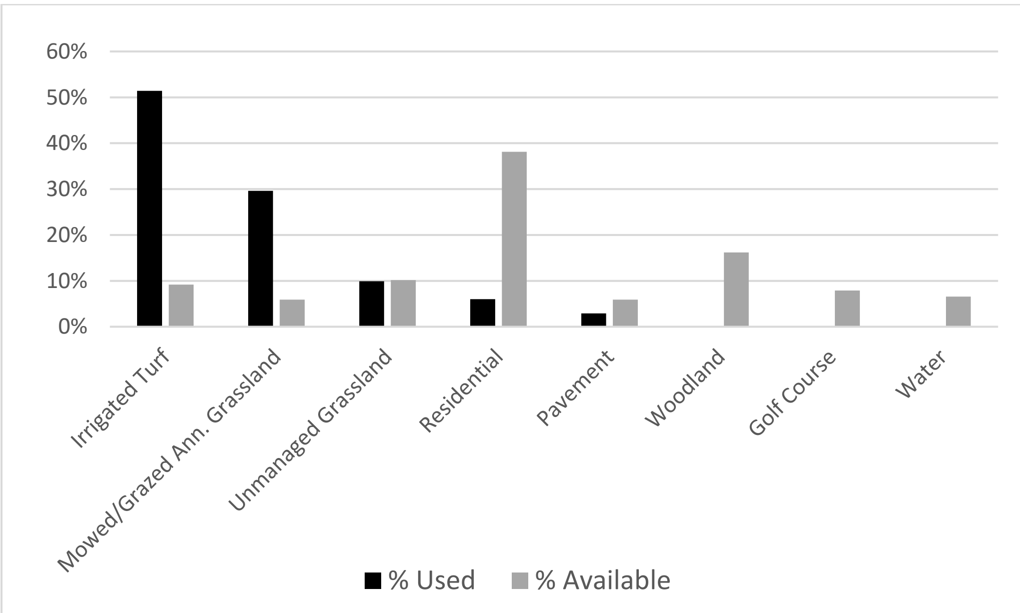

Figure 3. Proportions of various land cover types used for foraging by Yellow-billed Magpies and available within 0.5 km of nesting colonies at Sacramento study areas.

Relationship between Foraging Habitat and Colony Sizes

Correlation analysis showed several strong relationships between amounts of various land covers and numbers of breeding magpies. The two strongest land cover correlations were between populations and the combined area of low herbaceous land covers (irrigated turf and grazed-mowed grassland) within 0.5 km of colonies ($r = 0.80$) and within 1.5 km of colonies ($r = 0.73$) (Figure 4). The correlation of these variables within 1.0 km was weaker ($r = 0.34$). Regression analysis yielded predictive equations between population (y) and low herbaceous cover (x) of $y = 9.1x - 46.5$ within 0.5 km around colonies and y =

9.21x – 444.2 within 1.5 km of colonies. Solving this equation for five pairs of magpies (i.e., y = 10) identified the minimum amounts of selected foraging habitat required within these two distances. Thus, six ha are predicted to be required within 0.5 km and 48 ha are required within 1.5 km to support a five-pair colony.

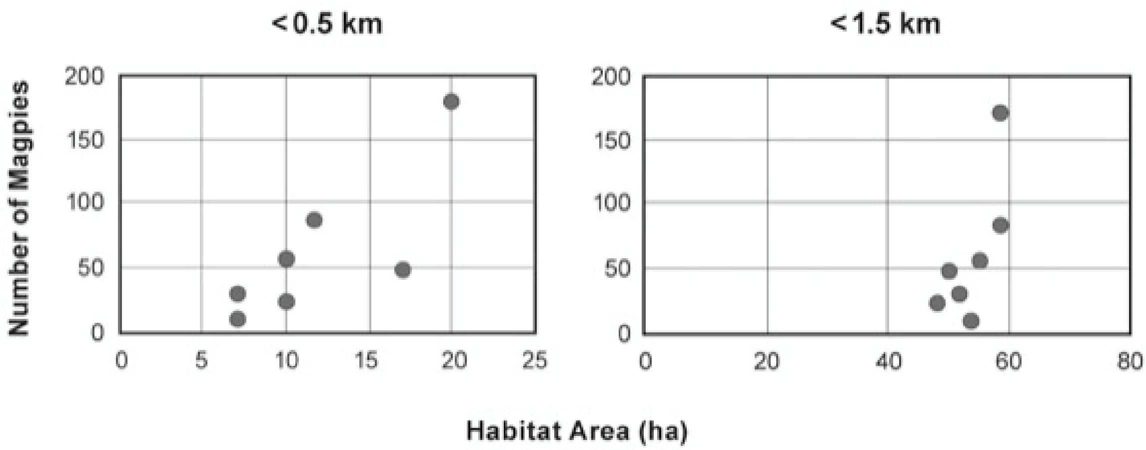

Figure 4. Relationship between Yellow-billed Magpie colony size and amount of low herbaceous cover (irrigated turf and mowed or grazed annual grassland) within 0.5 and 1.5 km of colony centroids

DISCUSSION

Population Status

Our 2020 estimated populations of 430 individuals for the seven Sacramento sites is 8% of the portion of the statewide population within urban habitats that was estimated in 2007-2008 by Crosbie et al. (2014). Since then, however, the statewide population has declined by an additional one-third due to West Nile virus infection (Pandolfino 2020). Considering that these sites represent only a portion of the Sacramento population and that many other Central Valley urban and urban areas support Yellow-billed Magpies, our number suggests that Crosbie et al. may have underestimated the true population within urban areas occupied by the species.

Absence of past data from surveys using consistent methods precludes a robust characterization of changes in the Sacramento region's population since arrival of West Nile virus. Available eBird data are largely limited to years after about 2006 (https://ebird.org/news/ebird-2018-year-in-review), which is about the time that West Nile virus arrival caused dramatic magpie declines (Airola et al. 2008, Crosbie et al. 2008). This leaves Christmas Bird Count data as the only consistent data source for assessing long-term population trends since pre-WNV times (Pandolfino 2020). The population in the surrounding region declined by 40% within two years of West Nile virus arrival (Airola et al. 2007), and cumulatively by >80% in the Central Valley through 2019 (Pandolfino 2020). Our 2020 population estimates, and especially the number of active nests, provides a baseline for monitoring future breeding populations of Yellow-billed Magpies at larger colonies in the Sacramento region.

Population Assessment Methods

The disparity between our colony population estimates based on maximum counts and number of occupied nests indicates the challenges inherent in surveying for Yellow-billed Magpies. Our observations confirm that magpies congregate more before the nesting season and are more dispersed during the nesting period. Their congregation complicates surveys, as the groups may move through large areas and thus may be difficult to detect when not in surveyed areas. Winter magpie congregations also have been reported to include birds from different nearby colonies (Koenig and Reynolds 2020), which complicates attribution of numbers observed to specific breeding colony sites.

Use of nest sites as a basis for determining populations appears to be more effective than direct counts, but this method also poses challenges. We observed nest-building from 15 January through 29 March. Early in the season, however, before domes are constructed on nests, it can be challenging to distinguish nests that are under construction from the previous years' nests (Verbeek 1973). Leafing-out of deciduous trees, which began in early April, obstructs visibility and can lead to incomplete nest counts.

Therefore, it appears that a relatively brief period from late January through late March is the optimum time for using active nests to estimate breeding populations.

Productivity of Successful Nests

Our productivity estimate provides a general measure of success but is not a true indication of population productivity (i.e., the number of young per nesting pair; Steenhof and Newton 2007) because it does not account for pairs whose nests failed completely. Lack of pre-West Nile virus productivity data in Sacramento precluded us from determining if the virus has affected reproduction there. Our productivity rate of 2.8 young per successful nest, however, is consistent with the characterization from Coast Range studies that most successful nests produce 2-3 fledglings (Koenig and Reynolds 2020).

It is possible that productivity at our study areas are exceptional rather than representative of the regional population. Their higher populations than elsewhere in Sacramento could be an indication of higher habitat value or lower West Nile virus infection rates. Records of dead magpies infected with West Nile virus near our study areas, however, were reported only in mid-June through mid-September (N= 27, https://www.fightthebite.net/media/west-nile-virus-activity/), after the nesting season, when mosquitos 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 causing the magpie decline.

Nest Locations, Sites, and Characteristics

Our study shows that larger parks with large trees, and irrigated turf and other low herbaceous vegetation, appear to be important in supporting larger Yellow-billed Magpie colonies in the Sacramento urban area. Although the literature mainly describes nesting trees as a few native species, including oaks and cottonwoods (Linsdale 1937, Koenig and Reynolds 2020), our data show that Yellow-billed Magpies in Sacramento are not highly selective in their use of trees species for nest placement. In urban Sacramento, they use a wide variety of trees, both native and non-native, as long as they are tall.

Our characterization of tree species used for nesting may be slightly biased toward deciduous trees due to reduce nest visibility in evergreens. The overwhelming use of deciduous trees, however, indicates that this effect was probably minimal. Despite the widespread presence of mistletoe at our study sites, mainly in native oaks, we did not observe magpies use mistletoe clumps as nest sites, in contrast to its use in 36% of nests examined in coastal oak woodlands (Koenig and Reynolds 2020). Although we did not formally assess tree size selection by urban magpies, it was obvious that large, tall trees were selectively used. Nest tree diameters in Sacramento averaged slightly lower (80 cm; see RESULTS) than those reported on the Central Coast (mean = 91 cm, SD = 42, N = 64). This difference approached statistical significance ($t = 1.91$, $df = 164$, $p = 0.058$) but is not considered biologically significant.

The composition of Yellow-billed Magpie nests in the Sacramento area is generally similar to that described previously (Linsdale 1937, Verbeek 1973). The Sacramento nests, however, had only about half as many sticks as the Central Coast nests, and the Sacramento nests weighted about one-third less than the Central Coast nests. These differences may 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 the small sample sizes involved, it is difficult to draw any conclusions, but our results add to the limited available data on nest characteristics.

Relationship between Population Size and Foraging Habitat Abundance

Irrigated turf and mowed and grazed annual grasslands that were selected for foraging by Sacramento urban magpies were similar in height to those areas used in more natural settings (Linsdale 1937, Koenig and Reynolds 2020). Therefore, periodic mowing or grazing of herbaceous areas in urban environments to <15 cm tall appears necessary to maintain their suitability for magpie foraging.

The need for at least 6 ha of low herbaceous foraging habitat needed to support a nesting colony of five pairs may be useful in identifying suitable areas for the species, planning for conservation and management, and perhaps in estimating species abundance. One factor that we could not examine that could influence magpie occurrence is the character of residential areas, especially lot sizes and associated amounts of available lawn turf. Lower density residential areas would be expected to support more magpie foraging.

Several results support the conclusion that the total area and presence of both irrigated turf and mowed or grazed annual grassland are important to nesting Yellow-billed Magpies. First, magpies selectively foraged in these two cover types. Second, the highest correlation between colony size and foraging habitat characteristics was between colony size and the combined abundance of irrigated turf and grazed or mowed grassland. Third, magpies were absent from many Sacramento urban parks, cemeteries, and schools with irrigated turf that supported <6 ha of low herbaceous vegetation and even from areas supporting up to 8.7 ha of irrigated turf that lacked mowed or grazed annual grassland.

The potential for a minimum amount of low herbaceous habitat to support a nesting colony is also demonstrated from the Tretheway Oak Preserve (formerly Natomas Oaks Park), a site where D. Airola conducted surveys in both 2006 and 2020. In 2006 when 6.5 ha of low herbaceous foraging habitat was present, 15 pairs nested. In 2020, following construction of an office park that reduced foraging habitat to 3.3 ha, the colony had disappeared. West Nile virus, however, also could have contributed to this decline.

Notwithstanding the relatively high correlation (r = 0.72) between population size and amounts of low herbaceous habitat within 1.5 km of nest colony centroids, we suggest this relationship deserves further scrutiny. The rapid predicted population increase over a relatively small change in habitat amount (i.e., between 48 and 58 ha at various study sites; Figure 4) raises some question about the relationship's biological significance. Also, the area encompassed within 1.5 km of colony nest centroids (708 ha) substantially exceeds the size of area occupied by nests at each colony (2-23 ha) and the home ranges reported from radio-tracked magpies in coastal California ($\bar{x}$ = 22.8 ha, ±30 ha SD)

Although we did not quantify human activity in park areas we surveyed, we recorded many instances of park users unintentionally disturbing foraging magpies. Thus, it is possible that certain levels of human activity and its associated disturbance makes the more populated parks unsuitable for magpies. High levels of use may explain the general lack of use of golf courses we observed, or it could be due to other factors (see next section).

Conservation Implications

Our information on population status and habitat use may help explain why certain urban areas support larger Yellow-billed Magpie populations, while others do not. It does not, however, address the central issue causing magpie population decline: the effects of West Nile virus infection on this non-resistant species (Airola et al. 2007, Crosbie et al. 2008, Pandolfino 2020). Nonetheless, our results provide useful information for conservation management of the large urban magpie population in the Sacramento region and perhaps other Central Valley urban areas, including for identifying potential areas that may support large populations. Characterizing the relationship between the amount of foraging habitat and nesting colony size also may inform conservation management for the species in urban areas, or in rural areas that are undergoing rapid urbanization (Teitz et al 2005).

Our detection of a relationship between magpie colony size and the amount of foraging habitat is surprising because the species' population is appears to be limited by West Nile virus infection (Pandolfino 2013, 2018, 2020) rather than habitat. Perhaps both factors operate simultaneously, with habitat setting the ultimate capacity of an area to support a colony of a given size and disease operating in a density-independent way to proportionally reduce the colony size below that capacity. Alternatively, areas where we found larger colonies may be areas with low mosquito populations and thus low West Nile virus infection, such that habitat determines the population sizes there. Mosquito populations are widely associated with areas of standing water (Collins and Resh 1989), which may be less abundant in the parklands where our colonies occurred than in residential areas that occupy much of the adjacent lands.

The high level of use of irrigated turf raises conservation issues. Restoration of these areas to more natural woodland conditions may be considered beneficial to most native plant and animal species but would appear to be detrimental to the Yellow-billed Magpie. Our data on foraging habitat use and relationships of populations sizes to habitat amounts suggests caution in converting turf to non-irrigated grasslands in areas with high magpie populations. Finally, the low level of use of turf on golf courses suggest that these areas may have limited value. Potential causes for magpie avoidance of these areas may include high levels of human disturbance, risk of injury from golf balls, and more intensive management, including frequent low mowing and pesticide use that may reduce prey abundance.

A key habitat characteristic that we did not examine is the relationship of colony size to mosquito populations or the amount of mosquito habitat nearby. We focused our studies on areas where magpies were abundant because site specific information is not available on where magpies have declined or been eliminated. Regardless of the immediate West Nile virus threat, ultimately, even if resistance develops or a treatment becomes feasible, information on habitat use and effects on population sizes should be useful for species conservation, especially in urban environments.

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