PURPLE MARTIN POPULATION STATUS, NESTING HABITAT CHARACTERISTICS, AND MANAGEMENT IN SACRAMENTO, CALIFORNIA

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ABSTRACT: The Purple Martin (*Progne subis*) has been eliminated from most of California's Central Valley. The last known population nests in elevated roadways ("bridges") in the city of Sacramento. We reviewed bird records (1949–1990), conducted surveys to assess population size and trend (1991–2002), and evaluated management actions to protect and increase populations. Martins ceased nesting in buildings in Sacramento in the 1960s and 1970s as the European Starling (*Sturnus vulgaris*) population exploded, but adoption of vertical weep holes for nesting beneath bridges in the 1960s has allowed martins to persist. The known Sacramento population increased from four to seven colonies and from approximately 105 to 135 nesting pairs from 1992 to 2002. Martin colonies are located in longer (>85 m) bridge sections that provide at least 6 m of unobstructed airspace beneath the colonies. Management has included a pilot project to insert wire "nest guards" in weep holes to increase survival of young and protecting nesting colonies during construction activities near nests. Initial results indicate that nest guards reduce mortality of young falling from nests and do not result in increased competition for nest sites by starlings and other species. Exclusion of martins from nesting at a large colony to prevent disturbance from a construction project reduced nesting use of the site; such exclusion is not considered necessary to protect nesting birds. Martin recovery may require substantial management, including protecting and enhancing existing colonies, encouraging colonization of other elevated road sites, establishing martin use of artificial nest structures in unoccupied regions, and enlisting public adoption of management responsibility.

The Purple Martin (*Progne subis*) was once considered "fairly common" in California (Grinnell and Miller 1944) but recently has been considered rare to very uncommon in the state (Garrett and Dunn 1981, Zeiner et al. 1990, Williams 1998). The state of California identified the martin as a species of special concern because of a well-documented and drastic population decline and substantial reduction in the species' geographic range (Remsen 1978). A review of the status of the martin in California also confirmed that Sacramento remains the only location in the Central Valley where the species is known to breed (Williams 1998).

The major suggested cause of martin decline in California is competition for nest holes with the nonnative European Starling (*Sturnus vulgaris*) (Remsen 1978, Garrett and Dunn 1981, Williams 1998, 2002). Detrimental effects of starling and House Sparrow (*Passer domesticus*) competition are well documented elsewhere in the U.S. (Brown 1981, 1997) but not specifically in California. Williams (1998) has also suggested that loss of riparian habitat and snags that represented suitable nesting habitat may have contributed to martin decline in California. Pesticide effects have not been documented but cannot be dismissed.

In the eastern U.S., Purple Martins have relied on birdhouses and gourds as nesting sites for many years (Jackson and Tate 1974, Brown 1997). In the west, Purple Martins have only recently made substantial use of nest boxes in Oregon, Washington, and British Columbia (Copley et al. 1999, Fouts 1996, Horvath 1999). In California, martins formerly nested commonly in buildings but have seldom used nest boxes (Grinnell and Miller 1944, Garrett and Dunn 1981, Williams 1998). In the 1930s and 1940s, use of buildings in cities and towns in California was thought to have increased the state's martin population and range (Willett 1933, Grinnell and Miller 1944). Today, however, no urban areas except Sacramento are known to support nesting martins (Williams 1998).

As summarized by Williams (1998), Purple Martins were reported nesting in trees in Sacramento as early as 1853 (Baird 1858) and were documented nesting in buildings as early as 1924 (Bryant 1924). Nesting in buildings occurred mainly in holes formed by hemicylindrical roof tiles (i.e., Spanish tiles). No recent nests have been reported in buildings in Sacramento (B. and H. Kimball pers. comm.); all recent nesting has occurred in weep holes beneath bridges (including elevated freeways).

We initiated this study in 1991 and 1992 to evaluate the recent historical and current population status and nest site characteristics of the Purple Martin in Sacramento and to assess the effectiveness of management actions for the species. Grantham continued monitoring through 1997 at one site (see Study Area), and Airola reinitiated monitoring in 2002 to assess the population trend. This assessment also incorporates information collected at Sacramento colonies by Williams (1998).

The study's objectives were to:

- identify recent historical and current martin colonies in the Sacramento area.
- evaluate changes in local distribution and habitat use at martin colony locations.
- estimate current populations and recent trends at colonies.
- identify factors that may influence selection of colony sites.
- evaluate effectiveness of recent management actions to protect and enhance martin nesting habitat.
- identify threats to colonies and additional research and management needs.

STUDY AREA

We surveyed for Purple Martins at bridges and buildings in the Sacramento area where they had previously been observed nesting, as well as at other bridges with similar characteristics. All sites used by martins were in bridges built of steel and concrete box girders (Tonias 1995). All these bridges span urban areas and railroad tracks; none crosses water. The bridges support an enclosed chamber beneath the road surface. Weep holes on the underside of the chamber relieve air pressure during heating and cooling and drain condensation, but they do not drain water from the road surface.

The downtown area contains the greatest number of bridges in the region. We surveyed suitable bridge sections to locate colonies in 1991, 1992, and 2002. Colonies were defined as occupied sites separated by areas of unsuitable or unoccupied habitat that exceed the typical distances between nests within occupied sites.

We studied four occupied colony sites in detail in 1991 and 1992:

- I Street—Interstate 5 at I Street in Old Sacramento.
- 20th Street—U.S. Highway 50 between 19th and 21st streets.
- Broadway—the junction of State Route 99 and U.S. 50, above and adjacent to Broadway.
- 35th Street—U.S. 50 between 34th Street and Stockton Boulevard.

Grantham continued monitoring the 35th Street colony through 1997.

We studied three additional occupied colonies in 2002:

- Sutterville—Sutterville Road overpass of the Union Pacific Railroad (UPRR) yard.
- S Street—Capital City Freeway (Business Route 80) at S Street.
- Roseville Road—I-80 and the adjacent light rail parking-access ramp above Roseville Road and the UPRR tracks.

METHODS

Review of Recent Historical Records

Because available information on the early historical status of the Purple Martin is limited and has been summarized (Williams 1998), we confined the status review to the period since the mid-1900s, for which a substantial number of records were available. We reviewed approximately 970 martin records (1949–1990) from the Sacramento area that Betty and Harold Kimball compiled from their personal field notes, as well as records of other members of the Sacramento Audubon Society (unpubl. data). Other local records from California Department of Fish and Game files were provided by J. Estep and R. Schlorff (pers. comm.).

Many recent historical records noted locations of birds near known nesting colonies but did not confirm breeding activity. We considered breeding at a site to be *possible* if records noted that birds were present during the peak breeding season (mid-April through July) at a specific building or site, *probable* if birds were reported entering holes or carrying nesting material, and *confirmed* if adults were observed carrying food to a nest hole or feeding dependent young, if juveniles were observed within holes, or if recently fledged juveniles were reported near a known site.

We used 1965–1990 records only to document trends in colony locations and nesting habitats. We could not determine abundance and detailed occupation patterns because of limited information on nesting activity. Also, the reported incidental counts of martins are not reliable indicators of colony size (see Results). The first year of site occupation was especially difficult to establish because all potential sites were not surveyed systematically. Site abandonment dates are more reliable because once the sites were known, observers tended to visit them annually (B. and H. Kimball pers. comm.).

Surveys for Breeding Colonies

We surveyed previously reported martin colonies in 1991, 1992, and 2002. We also surveyed many other sites in Sacramento that could be nesting habitat; these included longer sections of elevated freeway, overpasses with weep holes, and buildings with Spanish tile roofs. We surveyed 25 potential nesting areas from April to July by searching for flying and perched birds. We conducted most surveys before 11:00 or after 17:00 because birds tended to be more active during these periods, especially on hot days (Airola unpubl. data).

Population Estimation at Colonies

Determining population sizes of nesting colonies in bridges is difficult because martins can be counted only as they enter or leave holes or when they are perched or foraging near the colonies. At any time, many birds in a colony cannot be counted because they are inside nest holes, foraging or perching away from colonies, or obstructed from observation by the overhead structure. Also, most chambers within bridges cannot be entered to observe nests. Accordingly, we used two primary approaches to evaluating population sizes: observation of nesting behaviors and hole use, and direct counts.

Evaluation of Nesting Behaviors and Hole Use. With the assistance of a group of trained volunteers, we estimated populations at colonies by observing nesting behavior and mapping bird use of individual weep holes throughout the nesting season. We developed and tested this method in 1991, but because effort and methods were inconsistent that year, we have not reported those results. We prepared maps of available weep holes for each colony site and assigned each hole a unique alphanumeric code. We visited each colony site repeatedly during the nesting season to count birds and map holes entered by martins. During the two years of most thorough surveys (1992 and 2002), we monitored each occupied colony for an average of 8 hours on an average of 13 days at 3- to 9-day intervals (Table 1). We documented more than 2000 individual hole entries by martins annually during 1992 and 2002.

We estimated numbers of nesting pairs on the basis of diagnostic nesting behavior and the frequency of hole use. Diagnostic behaviors that demonstrated nesting use of a weep hole by a pair included adults entering holes with food, adults carrying fecal sacs from holes, vocalizations of begging young, visible presence of young in nest holes, and presence of dead young beneath nest holes.

Diagnostic nesting behaviors were difficult to observe at some sites because of limited access and limited time to observe arrivals at and departures from holes (i.e., birds were often visible for only a few seconds). Accordingly, we also considered holes to be occupied by nesting pairs if adults made repeated visits to specific holes over the course of the nesting period. We considered holes entered two or more times on each of two or

Table 1 Survey Effort Assessing Purple Martin Breeding Populations in Sacramento during Two Years of Comprehensive Surveys

	1992		2002	
Colony	Days	Hours	Days	Hours
I Street	5	3.9	34	20.8
20th Street	17	5.3	12	6.7
Broadway	7	4.7	10	4.4
35th Street	20	15.0	13	12.0
Sutterville[a]	3	1.2	12	4.3
S Street[a]	3	1.3	10	5.0
Roseville Road[b]	0	0.0	4	6.1
Total		31.4		59.3

[a]Unoccupied in 1992.

[b]Not surveyed in 1992.

more days separated by more than one week during the nesting period to be occupied by a nesting pair. In general, the numbers of individual visits and days with visits recorded for most pairs considered to be nesting exceeded this minimum standard. In addition, we combined hole-use counts with less diagnostic behaviors (especially carrying nesting material) to indicate occupancy.

Estimation of populations by behavioral observation and hole mapping is affected by the amount of observation time. Levels of effort at three sites occupied in both 1992 and 2002 were comparable, but we spent substantially more time monitoring the I Street site in 2002 than in 1992 (Table 1). Low survey effort for the S Street and Sutterville sites in 2002 reflected the absence of the species from these sites that year. We have included population data collected by Williams (1998), who used methods generally consistent with ours.

Direct Counts. Because determining population sizes on the basis of nesting behaviors and hole use was so labor intensive, we evaluated the simpler method of directly counting numbers of individuals observed at colonies (direct counts). We evaluated the effectiveness of direct counting as a census technique or population index by comparing direct counts to numbers determined on the basis of behavioral observation and hole-use mapping. Direct counts were made during each visit by repeatedly counting the number of adults observed flying or perching near colonies or known to be in weep holes simultaneously, then recording the highest of these counts for each day. The proportion of the total population at each site observed during direct-count surveys was calculated by dividing the maximum number of birds observed during direct counts over the season by the number of nesting individuals determined to be at colonies on the basis of hole use and nesting behavior.

Habitat Characteristics at Nesting Colonies

Nesting sites and bridge sections not used for nesting were evaluated for a variety of characteristics, including

- length and width of the bridge section.
- height of holes from the ground or other flight obstructions.
- pedestrian activity, lighting, and other human uses (including construction activity).
- availability of nesting material and perch sites.
- relative levels of vehicular traffic beneath sites.
- distance to non-urban foraging areas.

Nestling Mortality

Discovery of dead nestlings below weep holes during population surveys prompted us to investigate the loss of nestlings from nest holes as a mortality source further. On the assumption that young more than 7 days old that were found beneath nest holes had fallen accidentally, we hypothesized the cause to be the lack of any physical barrier at the upper edge of the vertical nest hole. We systematically monitored mortality beneath nests at several colonies where vegetation or debris did not obscure our ability to locate fallen young. We conducted surveys for fallen nestlings every one to three days from mid-June to mid-July, the peak period of susceptibility, and left a sample of dead young in the field to assess losses due to scavenging by predators and pulverization by car tires. We determined ages of young from reference photographs (Rogillio 1992, Hill 1999).

Effectiveness of Nest Guards in Reducing Nestling and Fledgling Mortality

As a pilot project, Grantham devised wire nest guards and installed them in occupied and suitable weep holes at the 35th Street site from 1992 to 1996 (Figure 1). The guards, made of 0.5-inch hardware cloth (wire screen), were designed to provide an internal barrier (i.e., a "fence") to prevent young from falling from nests (see Kostka et al. 2003 for nest-guard design and installation). Effectiveness of nest guards in reducing nestling mortality was evaluated by comparing results of surveys for fallen young before and after installation (1992 and 2002).

Effects of Nest Guards on Roosting by Fledglings

Following fledging, Purple Martin young typically roost at night in the nest cavity for 1 to 12 days (Brown 1997). Because we observed recently fledged young experiencing difficulty reentering weep holes to roost in the evening (see Results), nest guards were also designed to provide a wire ladder to enhance the ability of recent fledglings to reenter holes to roost. We monitored the return of fledglings at the 35th Street site during the post-fledging period in 1992 and 1993 to assess their abilities to enter roost holes with and without nest guards.

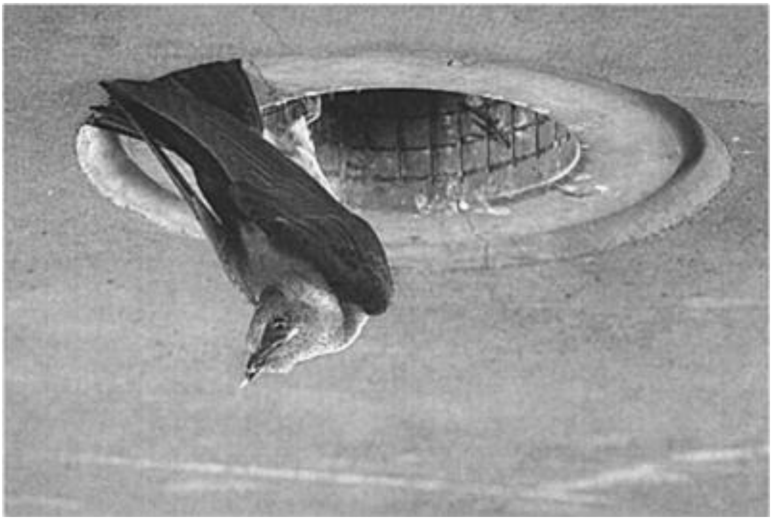

Figure 1. Female Purple Martin with food perching at a wire "nest guard" inserted into a weep hole beneath an elevated freeway in Sacramento, California.

Photo by Sacramento Bee/*Chris Crewell*

Competitor Use of Weep Holes with Nest Guards

Weep holes appear to represent the only nesting substrates in the Central Valley where starlings have not been able to displace martins. Because of the concern that the insertion of nest guards could make nest holes more accessible to starlings and other potential competitors, Airola evaluated use by competitors of holes with and without nest guards at the 35th Street site in 2002. Potential effects of wire sleeves on competitive interactions were analyzed by evaluating patterns of use by the species (i.e., use of holes with and without nest guards and changes in holes used over time by martins and competitors).

Locations of Holes Used by Martins and Starlings within Nest Colonies

In 2002, Airola initiated a study of hole-use locations by martins and starlings at the 35th Street colony. He mapped hole use by starlings during martin surveys at this site. Hole locations were characterized by their position (i.e., outermost, next to outermost, or interior) relative to the edge of the bridge. To assess for selection (non-random use) of nesting locations by each species at this colony, the number of holes used in each position was compared against an expected value, based on the proportional availability of holes in each category. Differences were tested for significance by the chi-square goodness-of-fit test (Sokal and Rohlf 1995).

RESULTS

Recent Historical Status

Martins were recorded during the breeding season at 16 sites in Sacramento from 1949 to 1990. Many identified sites supported suitable nesting habitat, but most records consisted of single or several isolated sightings, and breeding was not confirmed during most years (Figure 2). Sites regularly used by martins prior to 1991 were assigned to seven major groups for an assessment of breeding status over the 42-year period (Figure 2). Two groups, downtown buildings and the Capital City Freeway site between L and Q streets, are no longer used, while the other five sites have been used since 1991. Before 1964, all martin observations and nesting records were at buildings in downtown Sacramento. No confirmed nesting at or association with buildings was noted after 1974. Martins were first noted near bridges in 1964, and breeding in bridges (nest building) was first observed in 1967 (Figure 2).

Martin use was reported once historically at both the Sutterville (the site where bridge use was first documented in 1964) and Broadway colonies but then went unreported for extended periods (Figure 2, Table 2). These small colonies may have been overlooked or used intermittently during the intervening years. With the exception of the Capital City Freeway between L and Q streets, the three other freeway sites have been occupied regularly since they were first discovered (Figure 2, Table 2).

Number of Colonies and Population Status

Four bridges supported nesting colonies in 1991 and 1992 (Table 2). Fifteen bridges similar in design and character to occupied sites were not occupied. No martins were found during 1991 and 1992 surveys at nine buildings with tile roofs that the birds had occupied prior to 1972, nor were

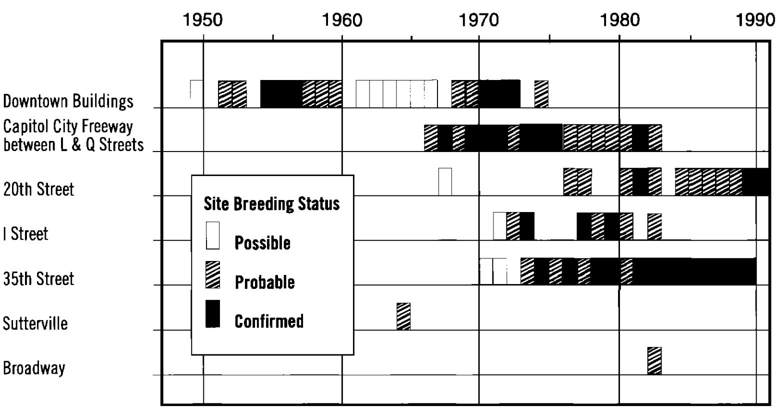

Figure 2. Known occupancy and breeding status of Purple Martin nesting areas in Sacramento, California, 1949–1990.

Table 2 Estimated Breeding Pairs of Purple Martins at Sacramento Colonies 1992–2002[a]

Colony	1992	1993	1994	1995	1996	1997	2002
I Street	23		25	21			37
20th Street	38	48	39	40			14
Broadway	14	10	4	3			8
35th Street	30	34	36	41	34	35	29
Sutterville	0[b]						4
S Street	0[b]						14
Roseville Road							29
Total	105		104	105			135

[a]Surveys conducted in 1992 by Airola and Grantham, 1993–95 by Williams (1998), except by Grantham at 35th Street, 1996–97 by Grantham, and in 2002 by Airola. Lack of a number indicates that no survey was conducted.

[b]Site was surveyed but no martins were found.

they found at other suitable buildings. Also, no martin use of buildings has been observed or reported in subsequent years. Starlings and House Sparrows were observed nesting at many of the former building nest sites.

We found seven active colonies in 2002, including the four sites active 1991–1995 (Table 2). Two other sites (S Street and Sutterville) that were not active in 1991 or 1992 were active in 2002. Roseville Road, which was not surveyed until 2002, was reported occupied as early as 1996 but was not monitored. Distances between nearest colonies averaged 2550 m and ranged from 600 to 9600 m.

We documented diagnostic nesting cues for 62% of pairs that we characterized as nesting in 1992 and for 70% of pairs in 2002; the balance of nesting pairs were so designated on the basis of hole use. In 1992, 105 pairs were estimated nesting at the four colonies (Table 2); three colonies each supported 23–38 pairs, and the Broadway colony supported 14 pairs. From 1993 to 1997, numbers remained stable at most monitored sites and for the population as a whole. They appear to have declined, however, at the Broadway site and increased slightly at the 35th Street site.

In 2002, after a 5-year gap in monitoring, numbers of recorded pairs had increased slightly at 35th Street and substantially at I Street. Numbers decreased substantially at 20th Street following blockage from 2000 to 2002 of 68% of nesting holes used in 1992; this blockage was undertaken to prevent disturbance during construction of a rail line near the colony (G. Moir and J. Mentzer pers. comm.). The two new colonies (Sutterville, not reported used since 1964, and S Street) together supported 18 nesting pairs, and the previously unsurveyed Roseville Road colony supported approximately 29 pairs (Table 2). In total, between 1992 and 2002 (the two years of most consistent and intensive surveys) the known population at all Sacramento colonies increased by 32% (from 105 to 135 pairs).

Despite concerns about overestimation of populations on the basis of counts of nest hole use alone (Williams 1998), we believe that our integrated approach to assessing numbers of nesting pairs produced reasonable estimates of actual nesting populations for most sites in 1992 and 2002. Moreover, the consistency in effort at most sites provides a reasonably reliable basis for evaluating population trends over this period. Similarity of population sizes at sites during different years (Table 2) suggests that numbers did not fluctuate substantially on an annual basis.

The highest population estimates generated by the direct-count method at three colonies in 1992 represented 12% (I Street), 26% (20th Street), and 28% (Broadway) of the populations estimated by nest-hole mapping at each site. Thus, the direct-count method clearly underestimated populations, and the proportion of the known breeding population counted by this method was inconsistent from site to site.

Habitat Conditions at Nesting and Non-Nesting Areas

Bridges hosting martin colonies had an abundance of weep holes apparently suitable as nest sites. There are more than 1800 holes within 100 m of the seven nesting colonies.

Habitat conditions at occupied sites varied substantially and were similar to those at many unoccupied sites (Airola unpubl. data). On the basis of qualitative evaluation, martins did not appear to select or reject sites because of the width of bridge sections, level of human use beneath sites, presence or absence of lighting, availability of nesting material, or distance to non-urban foraging areas.

Certain minimum conditions, however, were present at all colony sites. Occupied areas were always within a span of bridge at least 85 m long (mean 301 m, standard deviation 184 m). There was at least 6 m of vertical space beneath all occupied bridge sections (mean 8.3 m, standard deviation 1.5 m); martins were absent from all surveyed areas with less space. Martins abandoned one former breeding site (Capital City Freeway between L and Q streets; Figure 2) in the mid-1980s when flight space was reduced to less than 3 m by construction of a two-story parking lot. Also, all occupied sites had unobstructed flight access and low to moderate traffic levels.

Nestling Mortality and Effectiveness of Nest Guards

In 1992, prior to installation of nest guards, we found 32 nestlings that had fallen from nest holes (1.07 per nest) at 35th Street and 12 (0.32 per nest) at 20th Street; in 2002, also prior to nest guard installation, we found three fallen young (0.21 per nest) at S Street In 2002, seven years following installation of nest guards at 35th Street, 23 (79%) of 29 nesting pairs used weep holes with nest guards, and only one dead nestling was found (0.03 per nest). Most nestlings fell from nests 8–14 days after hatching. Scavenging rates of fallen young appeared to be low; all six dead nestlings that we left in place at various colonies were still on the ground during subsequent monitoring periods 7–17 days later. Even young that fell onto active roadways were visible for more than a week; consequently, fallen nestlings did not likely escape detection during surveys.

Fledglings' Use of Weep Holes with Nest Guards for Roosting

On evening returns to the 35th Street colony prior to installation of nest guards, we observed that many fledglings had difficulty reentering the vertical weep holes to roost. Young birds would misjudge the hole's location and not achieve sufficient vertical velocity to ascend through the hole. Fledglings showed extreme fatigue, which put them at risk of collision with passing vehicles. They eventually gave up and drifted off, apparently to roost outside holes. Some young began roosting in nest boxes that had been erected there. After nest guards were installed, fledglings regularly flew to holes, grasped the wire-mesh liner, and readily climbed into holes.

Competitor Use of Weep Holes with Nest Guards

Monitoring at 35th Street in 2002 showed that no potential nest-hole competitors regularly used holes with nest guards. We observed starlings, the most common competitors, entering 24 weep holes. Nesting behavior was confirmed at 10 holes, and we observed use on multiple days, which we considered to suggest nesting, at four other holes. Only two (8%) of the 24 holes that starlings entered had nest guards, and none of the sites where we observed either breeding behavior or multiple-day use had nest guards. Of the holes where we observed use by White-throated Swifts (*Aeronautes saxatalis*) (5 holes), House Sparrows (2), and Rough-winged Swallows (*Stelgidopteryx serripennis*) (1), none contained nest guards. Some of this difference in use probably reflects both site fidelity by martins and our purposeful installation of nest guards at active martin nest sites.

Use of Hole Locations within Colonies by Martins and Starlings

Starlings selected the outermost holes of the bridge at 35th Street more often than would be expected if selection were random; 13 of 24 (54%) holes used were the outermost holes at the bridge edge, while only 86 (19%) of 444 available holes at 35th Street were at the edge ($\chi^2 = 20.09$, $P < 0.001$, d.f. = 1). Starlings used the next-to-the-outermost holes in proportion to their availability (17% used versus 19% available) and used interior holes at lower than expected levels (7 of 268 interior holes, $\chi^2 = 10.36$, $P < 0.005$, d.f. = 1). Martins did not nest in the outermost holes at this site, but this use pattern did not differ significantly from that expected by chance ($\chi^2 = 2.3$, $P > 0.10$, d.f. = 1). Martins did use outer holes at other colonies.

DISCUSSION

Population Status and Long-Term Trends

The 1949–1990 records indicate that in Sacramento martins nested solely in buildings until they began colonizing bridges in the late 1960s. The effect on the martin population of loss of buildings as an available nesting substrate thus appears to have been offset at least partially by the adoption of bridges. Whether the abandonment of the colony at the Capital City Freeway between L and Q streets (coinciding with construction of a two-story parking lot beneath the freeway that restricted flight space) caused a population decline cannot be determined; individuals could have moved to new sites, or other established colonies may have grown independently.

Comparison of population sizes in 2002 with numbers in previous years shows the population in Sacramento to be stable or possibly increasing.

Most of the apparent increase, however, is attributable to the Roseville Road colony, which was not surveyed prior to 2002, making the determination of an increase uncertain. In the larger context, the Sacramento colonies are remarkable for being one of the largest concentrations of nesting martins in North America that do not rely on nest boxes (Williams 1998). Nonetheless, the Sacramento population is still small and restricted to seven sites that are widely separated from other nesting areas; consequently, it is vulnerable to disruption.

Reasons for Persistence of the Purple Martin in Sacramento

This study helps address the question of why Purple Martin colonies have persisted in the Central Valley only in elevated bridges in Sacramento and why martins have not been reported at bridges elsewhere in the Central Valley.

Nest sites are superabundant in girder and concrete-box bridges, while availability of natural nest sites in riparian habitats has declined with the degradation and loss of riparian and oak woodland habitats in the Central Valley (Katibah 1984). Reduced nest-site availability, however, appears insufficient to explain regional martin decline; martins have used many cavity types (including buildings) that are still readily available but unoccupied throughout a large portion of the species' former range.

Abandonment of colonies in tile roofs in Sacramento was complete by the mid-1970s. This decline, and the adoption of newly constructed elevated freeway bridges, coincided with the period when the starling population in lowland areas of California exploded (DeHaven 1973, Small 1974, Garrett and Dunn 1981, Robbins et al. 1986). This timing suggests that starlings may have excluded martins from tile roofs but could not exclude them from bridges. The abandonment of buildings also coincides with the loss of many colonies in natural habitats as starlings increased (Williams 1998).

The persistence of martins in Sacramento may reflect several interrelated factors. First, nest sites are superabundant in bridges. Second, the vertical weep holes (especially those in the interior portions of bridges) may not be optimal for use by starlings, although starlings regularly nest in weep holes in and near martin colonies in low to moderate numbers. Third, low food abundance in the highly urbanized area of nesting colonies may limit starling populations from reaching levels that would result in nest site competition.

Urban-nesting martins in Sacramento do not appear to be limited by food. Martins frequently foraged directly above urban colonies. During the period of peak food demand for young, martins regularly fed them dragonflies and damselflies (order Odonata), which were superabundant in the immediate vicinity of the nest colonies. The prevailing southerly winds ("Delta breeze") may carry odonates to the colonies from surrounding ricefields, where they reproduce abundantly, or the insects may disperse to urban areas on their own.

The lack of reports of martins at the many other steel and concrete box-girder bridges in the Central Valley and elsewhere in California indicates that use of these structures is rare. If such were not the case, we would expect birders in urban areas to have reported martins in many areas, as they have done in Sacramento. We did not find martins, for example, in an apparently ideal bridge in Stockton, 50 miles south of Sacramento; moreover, we have seen no martins in many larger bridges throughout the Central Valley that appear suitable.

Outside Sacramento, martins have been reported using elevated highway structures only at bridges on State Route 1 along the California coast (Williams 1998). Martins have also continued nesting in other areas, mostly within forests where lack of foraging opportunities has limited starling populations (Small 1974, Williams 1998).

The current pattern of use of elevated structures may be explained by the coincidence of the construction of suitable bridges with the invasion and subsequent population increase of European Starlings. Martins use bridges in Sacramento, where bridges were available before starling populations exploded, as well as in coastal regions, where starlings have not yet become abundant. Martins are not found where suitable bridges were built subsequent to starling establishment (e.g., Stockton, many Central Valley sites). In these areas, starlings presumably eliminated martin populations in buildings and natural habitats before bridges were available, and no local source population is available now to colonize the new habitat.

Monitoring Methods

Because Sacramento may support as much as a third of the known nesting Purple Martins in California, and because the species' status is so precarious elsewhere in the state (Williams 1998), the Sacramento population warrants consistent monitoring. Development of techniques to monitor martin populations and trends in inaccessible bridge sites, however, is problematic. Numbers observed vary with time of day, temperature, season, and time spent observing. In particular, the direct-count survey method is unreliable in assessing populations or trends; this method not only underestimated populations at bridge colonies but did so inconsistently between sites, despite substantial time spent at sites attempting to obtain the highest possible count. Such results cast doubt on other population estimates derived from direct counts (e.g., historical records in Williams 1998); however, it is likely that the degree of inaccuracy is greater at larger colonies, such as those in Sacramento, than at smaller ones.

Estimating martin populations by evaluating nesting behavior and hole use provides a basis for assessing population trends. However, the potential for inaccuracy stemming from variations in observation time, observer skill, and visibility cannot be fully avoided without access to nest chambers. Accordingly, the population sizes we report should be viewed only as estimates, although they were determined in a consistent manner and are therefore appropriate for assessing population trends.

Assumptions used in population estimation by mapping of hole use (i.e., the accuracy of using a certain number of visits to conclude nesting use) can be evaluated by more intensive study. Where access is possible, direct observation of potential nest sites with cameras or remote viewing equipment (e.g., Kostka et al. 2003) can be used both for monitoring and to test and refine assumptions used in interpreting population estimates derived from mapping hole use and evaluating behavioral cues.

Habitat Characteristics and Protection Needs

The lack of obvious difference between the characteristics of occupied bridge sites and a large number of unoccupied sites, as well as the abundance of unoccupied weep holes within occupied colonies, suggests that availability of nesting habitat is not limiting martin populations in Sacramento. The apparently suitable unoccupied habitat appears capable of supporting a population at least five times larger than currently exists.

Why martins have not occupied the available nesting habitat in Sacramento more fully, even within existing colonies, is perplexing. One possibility is that nestling mortality resulting from falling from weep holes has precluded or dampened any population increase. Moreover, the inability of many fledglings to roost in weep holes without nest guards may have reduced productivity, presumably because excluded young suffer from exposure, injury, predation, or starvation as a result of separation from their parents.

An alternative explanation for the lack of occupancy of apparently suitable habitat is that some important but subtle habitat characteristics may remain undetected. The importance of available perch sites adjacent to nest sites that facilitate nest defense from other pairs is one factor that may warrant further examination and is readily amenable to experimental manipulation.

A third possibility is that unknown factors affecting other California martins may also be affecting the Sacramento population. Starling competition, however, does not appear to be affecting martin populations at Sacramento bridge colonies. Potential population limitations that could be imposed on wintering grounds or migratory habitat remain unexplored, but recent population increases in response to adoption of nest boxes in Oregon, Washington, and British Columbia (Fouts 1996, Copely et al. 1999) suggest that factors on wintering and migratory areas are not significant long-term limiting factors.

Even though an abundance of apparently suitable unoccupied bridges exists in Sacramento, the martins there have strong fidelity to traditional colony sites. Consequently, maintaining the suitability of occupied sites is an important conservation priority. Land uses that reduce vertical airspace beneath colonies to less than 6 m pose the primary threat to current Sacramento martin colonies. Such uses include construction of two-story parking structures and storage buildings, which eliminated the colony in the Capital City Freeway between L and O streets (Figure 2). Construction of buildings and growth of landscape trees immediately adjacent to bridges has also restricted martin access to suitable habitat.

Existing uses protect four colony sites (I Street, Sutterville, 35th Street, and Roseville Road) from land-use changes. Portions of the I Street colony receive heavy pedestrian use, but martins appear unaffected. Sutterville and Roseville Road are in overpasses above railroads. Much of the 35th Street colony is over a Caltrans equipment yard. In contrast, 20th Street, Broadway, and S Street are at least partially above vacant land owned by Caltrans, which is actively soliciting lessees for these sites (L. Vieira pers. comm.). While martins have readily accepted highly urbanized sites and tolerate of many forms of human activity, protection of airspace and access to colonies in Caltrans leasing decisions is necessary to maintain the long-term occupancy of these existing colonies.

Treatment of Colonies during Construction Projects

The relocation of martins at 20th Street by installing plugs in nest holes from 2000 to 2002 apparently caused a substantial decline in this colony (Table 2). The effects on the entire Sacramento population cannot be determined with certainty, but such exclusion threatens the traditional use of colonies. Because colonies are so few, actions that exclude birds from a large number of occupied nest holes at any given colony, as was done at 20th Street, should be avoided. Since 1991, the area beneath the 20th Street colony has been used during the nesting season to stockpile topsoil and to store trucks and construction materials, but this activity does not appear have to disturbed the breeding birds (Airola pers. obs.). Given the Sacramento martins' past record of tolerance of substantial human activity beneath nest sites, we believe it is unwise to exclude birds from nest sites during construction projects, except where the nesting areas would be affected directly. Scheduling activities from September to mid-March, however, would ensure that disturbance of nesting Purple Martins is avoided.

Nestling Mortality and Effectiveness of Nest Guards

Lack of direct access to nest sites precluded the counting of young at fledgling age and hence the assessment of the nest guards' effectiveness in enhancing colony productivity. The installation of nest guards and their extensive use by martins at 35th Street has not resulted in an increase in the size of that colony, but population size at individual colonies is not a strong indicator of colony productivity because first-year breeders seldom return to their natal colonies (Miller et al. 2001). Many other factors could be influencing the sizes of individual colonies.

Nestling mortality due to falling from weep holes is high enough to be of concern as a factor inhibiting productivity. Reasons for the difference in nestling mortality rates between the two colonies studied (20th Street and 35th Street) are not readily apparent because the bridges are of nearly identical design. Pre- and post-installation data from the pilot study indicate that nest guards are effective in reducing nestling mortality and that martins readily accept nest guards and continue to reuse treated sites for many years after installation. The nest guards do not appear to foster increased competition with starlings or other species; hence, they have not demonstrated any negative consequences. Therefore, we are proceeding, with the help of volunteers, to install additional nest guards at other colonies (Kostka et al. 2003).

Use of Nest Boxes in Management

Managed nest boxes and gourds are the Purple Martin's primary nest sites in the eastern United States (Brown 1997) and the Pacific Northwest (Horvath 1999, S. Kostka pers. comm.). Grantham initiated a program to encourage martins to use nest boxes at the 35th Street site. While some fledged juveniles used boxes for roosting, in subsequent years no adults nested or roosted in boxes because they were taken over by House Sparrows. While encouraging martins at bridge sites to use nest boxes appears possible, we and other researchers and managers (Kostka et al. 2003) do not consider this a high priority. Developing a box-dependent population requires intensive human management, posing risks for the established colonies. Unless threats to bridge colonies (e.g., incompatible land uses, starling competition) increase substantially, we believe it is better to allow the existing colonies to breed in bridges, with provision of less intrusive management assistance (i.e., installing nest guards, protecting airspace, and avoiding exclusion during construction). A carefully managed program to attract martins to nest boxes, by playing taped dawn songs and mounting decoys (Kostka 2000), might play an important role in restoring martins to former areas of their range and increasing the total population. Success in such a program will depend on developing a dedicated group of professionals and volunteers to implement long-term management.

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