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Burrow occupancy and nesting phenology of bank swallows along the Sacramento River

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The bank swallow (*Riparia riparia*), a threatened species in California, has been monitored along the Sacramento River since 1986. Annual counts of burrows and past data on the rate of burrow occupancy have been used to estimate the number of nesting pairs of bank swallows. However, the burrow occupancy figure in use (45 percent of burrows occupied) has not been updated for nearly 20 years. We conducted surveys of burrow occupancy at nine bank swallow colonies along the Sacramento River during and after the breeding season of 2010. We tracked changes in colony extent and number of burrows and made observations of burrow contents. Burrow counts increased through the latter half of June and then remained relatively constant through early August. Eggs and young were observed from the beginning of the study on April 26 through early July, but eggs were common only through June. Nests with eggs peaked in early May and again in the third week of June; nests with chicks were highest in late May and showed a lesser peak in early July. We observed wide variation in the proportion of burrows occupied before mid-June. Measurable occupancy was higher and relatively consistent after mid-June, including a post-breeding survey. Based on these results we recommend that (1) unconverted burrow counts should be used whenever possible as a rough abundance index to avoid introducing an additional variable (occupancy) and its associated uncertainty; (2) when an estimate of birds rather than burrows is essential, an approximate burrow occupancy value of 0.5 should be used to calculate nesting pairs from burrow counts; and, (3) in the future, burrow occupancy monitoring should be done regularly (e.g., every five years) and can take place in late July or early August, after juveniles have left the nest, to minimize disturbance of active nests.

Key words: Aves, bank swallow, breeding, California Central Valley, colonial nesting, disturbance, fossorial, monitoring, *Riparia riparia*, sand martin

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The bank swallow (*Riparia riparia*) is a neotropical migrant and is a state-listed threatened species in California. It is known commonly as the sand martin in Europe. Most of its population in California breeds along the Sacramento River, where remaining unconstrained river reaches meander through and erode banks in soils suitable for bank swallow burrows (Garrison 1999, Moffatt et al. 2005). Monitoring of the number of burrows along the river from Red Bluff to Colusa has been conducted nearly annually since 1986 by the California Department of Fish and Game (Department) or the U.S. Fish and Wildlife Service (FWS), and with assistance from the Department of Water Resources and other collaborators. The resulting long-term dataset provides a unique and valuable resource for population and viability assessment (Garcia et al. 2008, Girvetz 2010).

While burrow counts provide a useful index of population size, many burrows counted in the annual survey are incomplete or empty. Therefore, biologists multiply the burrow count by an estimate of burrow occupancy (proportion of counted burrows occupied by a nesting pair) to estimate number of nesting pairs in the Sacramento River bank swallow population (e.g., Garrison et al. 1987). The occupancy estimate in use (0.45, or 45 percent of burrows occupied), despite being a potentially important element of population size estimation, has not been updated in nearly twenty years (California Department of Fish and Game 1994). Consequently, the Department and the multi-partner Bank Swallow Technical Advisory Committee determined it to be a high priority to gather data on whether the rate of burrow occupancy by bank swallows has changed or is comparable to past estimates along the Sacramento River, and we report our findings here.

Study Area

We sampled burrow occupancy at nine colonies of bank swallow along the Sacramento River between river mile (RM) 165 and 222. These colonies fall within an area referred to as Reaches 2 and 3 in annual monitoring of burrows of the species, the most-frequently monitored reaches (RM 243-184 and RM 184-144). Colonies were denoted by their approximate river mile (U.S. Army Corps of Engineers 1991) and side (right or left bank, facing downstream).

Colonies often expanded and colony midpoints changed through time and, due to vagaries of estimating river mile based on a 1991 mapping that now is often off-channel, the colony number-names we assigned in April differed slightly from those given by the annual burrow monitoring survey conducted in early June (Silveira and Isola 2010). We provide a list of equivalent locations for the same colonies in Table 1.

This Study	Annual Burrow Monitoring, USFWS and DWR, June 8-9, 2010 (Silveira & Isola 2010)
165.1 L	164.9 L
167.1 L	167.2 L
170.2 L	170.1 L
182.5 L	182.5 L
189.6 R	189.6 R
195.0 R	194.9 R
210.4 L	210.3 L
211.1 R	211.1 R
221.2 R	221.2 R

Table 1.—Designations given (river mile and side) to the nine bank swallow colonies of this study, Sacramento River, California, USA, 2010, and those provided by Silveira and Isola

Methods

To allow comparison with previously published data, we generally followed the methods of Garrison et al. (1987; and unpublished materials). We prepared and vetted sampling design and protocols and conducted research during the spring and summer of 2010. We conducted six surveys at two-week intervals from late April through early July, and added a final post-breeding survey in early August. We surveyed a small, medium, and a large colony near each of three river access points (Butte City, Ord Bend, Woodson Bridge), for a total of nine colonies. These nine colonies were among 38 reported within Reaches 2 and 3 during 2010: 9 large, 12 medium, and 17 small (Silveira and Isola 2010). We used the colony size ranges given by Garrison et al. (1987; small [up to 130 burrows]; medium [131-375 burrows]; large [more than 375 burrows]). Over time, some of our colonies grew above the size category to which they were initially assigned, but the relative size rankings and our sampling procedures remained the same.

Each survey at a particular colony began with a burrow count, conducted from a boat by two experienced observers using standard annual burrow count methodology, which follows Garrison and co-workers (Bank Swallow Technical Advisory Committee 2010). We did not count burrows that were visibly shallow when viewed from the boat, appeared inactive, or were shaped more like those of another species (northern rough-winged swallow, belted kingfisher). Inactive burrows were craggy and eroded; active burrows were smooth and often showed recent swallow scratch marks. Most colony locations had been re-faced by bank erosion during the winter of 2009-2010, so most burrows we observed were new. We accepted and averaged burrow counts by two observers that were within 10 percent of one another; otherwise we re-counted the colony. Downstream and upstream ends of each colony were recorded with a handheld global-positioning unit.

We sampled occupancy of burrows within a colony in randomly-placed vertical transects of variable width. Transect width was extended outward in both directions from the transect center until 24 burrows were included. We examined 3, 5 or 6 transects in colonies designated as small, medium, or large, respectively (72, 120, or 144 burrows total). Actual sample sizes for calculation of the proportion of occupied burrows were reduced below the gross totals by "unknown" burrows that could not be categorized as to occupancy. Unknown burrows could not be classified because they were collapsed or too deep or curved to inspect. Unknown burrows averaged 7% of the gross sample, never exceeded 24% at any colony on any date, and 8 times out of 10 were less than 10% of the gross burrow sample.

Randomization of transect locations was challenging. We could not simply select random spatial locations along the colony because burrows were heterogeneously clumped even within colonies, and such a procedure would tend to oversample lower-density or even entirely empty areas. Therefore, we centered transects around burrows selected at random from among the total available burrows, so any burrow in the colony had an approximately equal chance of being sampled regardless of the density of burrows surrounding it. Random numbers that would result in transect overlap with an already-selected transect, or with an end of the colony, were rejected and another number drawn. Once random transect centers were selected, we counted upward from the downstream end of the colony to locate transect centers. We sampled occupancy in 24 burrows surrounding and including the central burrow of each transect.

We assessed burrow occupancy as did Garrison et al. (1987), by peering into burrows with a light and a small angled mirror on a stick. We mounted high-lux light-emitting diodes to 1-m bamboo sticks as our light probes. We used a close approximation of Garrison's original datasheets and coded burrow occupancy status as empty, partial (appearing deep from the boat and therefore included in the burrow count, but less than 10 cm deep), nest material, eggs, young, unknown-collapsed, unknown-not determinable, preyed upon, adult in burrow, or other. Burrows that terminated in another burrow were tallied as empty. Empty and partial burrows were considered unoccupied; remaining categories (excluding unknowns) were considered occupied. For a particular biweekly sample, the overall proportion of burrows occupied was calculated based on all determinable or "known" burrows examined—over 900 burrows on most dates—with standard error calculated as the standard error of a proportion with that sample size (Miller and Freund 1977:244).

To minimize disturbance, we sought to work quickly past any active burrows. If an adult or juveniles were in a burrow, we recorded this and moved immediately to another burrow without attempting to see whether the adult was incubating, or to count young. When juveniles near fledging were judged likely to be present we also worked as quietly as possible.

We made a final reconnaissance of the Sacramento River on 4 April 2011, from RM 243 to RM 144. The purpose of this pre-breeding survey was to assess persistence of burrows through the fall and winter, and to evaluate whether nest materials from a previous year could be mistaken for a current nest (i.e., an occupied burrow) in a subsequent breeding season.

We analyzed proportions of burrows occupied, arcsine square-root transformed to normalize the data, using repeated measures models (same colonies re-sampled on different dates) using PROC MIXED (SAS Institute, Inc., Cary, North Carolina). We used compound symmetry covariance structure (a simple model that treats correlations between pairs of repeated measurements as constant) and applied the recommended Kenward-Roger degrees-of-freedom correction (Littell et al. 2002).

Results

Swallows and their burrows were already present at colonies in late April when our surveys began. Burrow counts were stable until the latter part of May, when an apparent second wave of burrow construction began and continued through mid-June (Figure 1). Burrow numbers were high and relatively constant from late June through the August post-breeding sample.

Colony extent, as measured by bank length between the upstream and downstream burrows of the colony, also was variable through the season. Some colonies did not change while others grew dramatically in extent. For example, colony 221.2 R remained about 20 m in extent throughout the study, while colony 165.1 L expanded from approximately 240 m in April to over 1000 m in late June and July. Colony expansion or stasis appeared to be related to available habitat; for example, colony 165.1 L had plenty of room to expand but colony 221.2 R had little.

Distinct phases of burrow construction and occupancy reflected colony phenology over the season (Figure 2). Partial burrows (<10 cm deep) were most common during April-May, and were less common and relatively constant in frequency for the rest of the study. Burrows containing eggs peaked in early May and again in latter June. As expected from the species' two-week incubation period (Garrison 1999), burrows with young then peaked in latter May and showed a lesser peak in early July.

Detectable predation was low overall at about 2 percent of burrows, mostly at a single

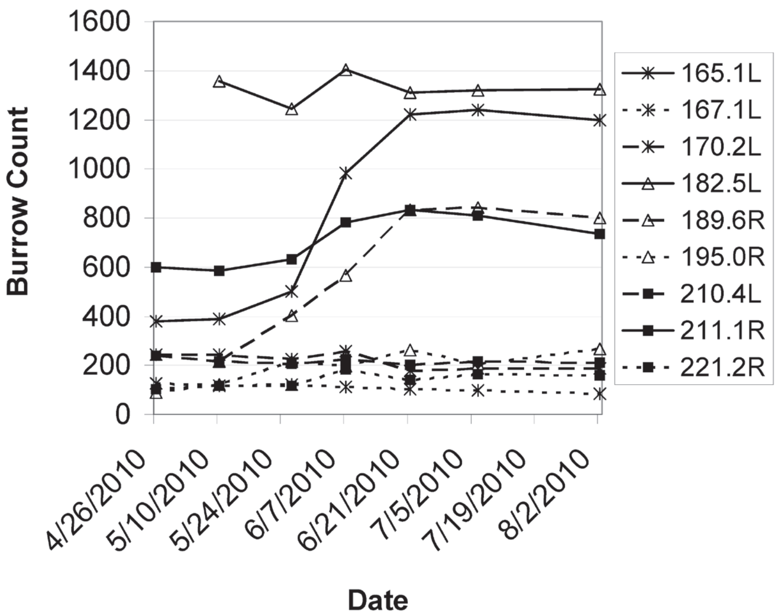

Figure 1.—Sizes of nine bank swallow colonies studied through the 2010 breeding season and post-breeding along the Sacramento River, California, USA (number of burrows, averaged counts of two observers). Colonies are named by river mile and side. Large colonies are indicated by solid lines, mid-sized colonies by dashed lines, and smaller colonies by dotted lines. Colonies in the same portion of the study area (northern, middle, or southern) share a common symbol shape. A full count was not completed for colony 182.5L on 26 April.

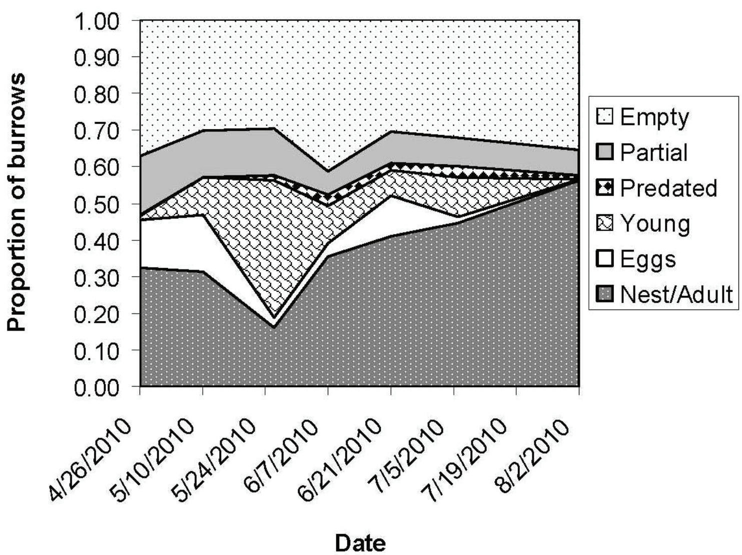

Figure 2.—Proportion of bank swallow burrows in each of six categories versus date for the 2010 breeding season and post-breeding along the Sacramento River, California, USA (cumulative *n* approximately 900 burrows on each sample date; burrows with unknown contents excluded from analysis). Other burrow status categories had negligible contribution, so proportions add to near 1.00. "Empty" and "Partial" are unoccupied burrows; remaining categories are considered occupied.

colony that was damaged substantially by raccoons. We consider this a minimum as some predation likely went undetected—for example, some predation by snakes probably leaves little evidence. Burrows observed to contain nest material or adults (predominantly the former) appeared more frequently later in the season (Figure 2); this occurs because once the young have departed only the nest remains.

Occupancy within the nine colonies varied considerably early in the season, but appeared to stabilize toward the end of June (Figure 3). Overall, occupancy was high and least variable in early July, when the proportion of burrows occupied was 0.60 (±0.02 *SE*, $n = 930$). Fresh nest material remained clearly observable in burrows during the post-season survey (early August) and there was not an appreciable amount of burrow collapse by that time. Post-season occupancy (0.58±0.02, $n = 951$) was similar to late-June (0.61±0.02, $n = 928$) and early-July occupancy.

In our repeated-measures analyses, no patterns were detectable in the complete data set due to high variability in burrow occupancy during earlier dates (Figure 3). When we restricted analysis to the last 3 sample dates, however, we found modestly significant differences among colony locations ($F_{2,6}=5.59$, $P=0.043$). During the late June, early July and the post-season August samples, the colonies around our central access point (RM 182.5 to 195) had a higher proportion of burrows occupied (0.63) than colonies to the south (0.52) or north (0.52). Even considering only the last three dates we did not detect differences in burrow occupancy among different sizes of colonies (P>0.05).

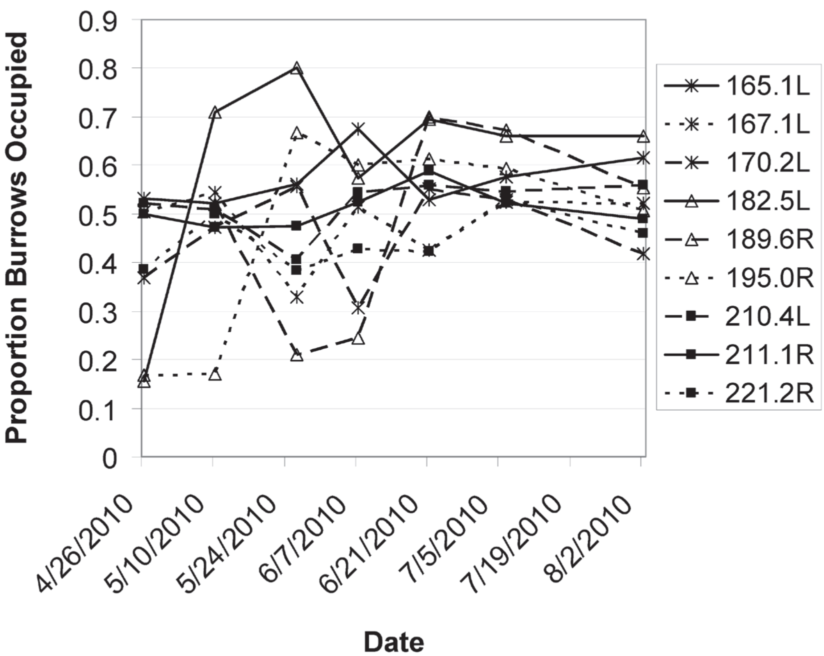

Figure 3.—Proportion of burrows occupied within bank swallow colonies, through the 2010 breeding season and post-breeding, along the Sacramento River, California, USA. Symbols as in Figure 1. Sampling of colony 182.5L on April 26 was not fully randomized over the entire colony. See Methods for details of sample sizes.

In our reconnaissance of Sacramento River banks on 4 April 2011, we found few burrows remaining from the 2010 breeding season. The Sacramento River experienced high flows during the winter of 2010-2011, cresting at about 90,000 cubic feet per second (cfs) at RM 184 (California Department of Water Resources 2011). Most of the banks that supported bank swallow colonies during 2010 had been re-faced by the resulting erosion. About 270 burrows persisted from the 2010 season compared to about 10,660 burrows during the June 2010 survey of this stretch (Silveira and Isola 2010). We examined the contents of about 30 of the persistent burrows, and no remnants of 2010-season nests were detected.

Discussion

The relatively high value of occupancy we found (0.6) does not alter worrisome prospects for the bank swallow. Garrison et al. (1987) reported similar occupancy more than two decades ago (55.9±2.7% *SE*, $n = 1330$). Recent burrow counts showed a one-third decline in burrows during 2010, relative to preceding years (Silveira and Isola 2010, Silveira et al. in preparation). Most of the Sacramento River's banks have been armored, making them uninhabitable by bank swallows, and proposals for additional armoring continue apace (Moffatt et al. 2005, Garcia et al. 2008, U.S. Army Corps of Engineers 2009). The bank swallow's prospects along the Sacramento River are unlikely to brighten until the rate of rock removal begins to exceed the rate of rock placement; however, although proposals exist, no intentional rock removal has yet occurred on the Sacramento River.

We urge caution in applying a rate of burrow occupancy. Many factors and sources of error may affect the number arrived at, notably including naturally occurring differences in occupancy between years, errors in estimation, double-clutching, mortality post-nesting and pre-reproduction, and predation. This uncertainty adds to uncertainty in any bank swallow population estimates derived by multiplying burrow count by occupancy. Therefore, we recommend that (1) whenever possible, the unconverted burrow counts should be used as the most straightforward index of bank swallow abundance and trends; and, (2) if an estimate of nesting pairs is essential, then investigaors use 0.5, or one-half, as the occupancy multiplier. This round number is both generally representative of various suggested values (0.559, 0.45, 0.60), and honestly reflects the uncertain state of our knowledge of the bank swallow population.

Annual burrow counts assume that few or no burrows remaining from the previous season would be counted as active in a current season. Our observations during two seasons support this, but we intend to continue pre-season checks for persistent burrows to test this assumption. During years of low river flows and reduced bank erosion there may be greater persistence of old burrows. We have observed a few persistent burrows being reused by bank swallows, and old burrows in active use are appropriate to count. Old burrows that are not being used should be distinguishable from active burrows due to full or partial collapse, craggy openings, occlusion by cobwebs or plants, or presence of bryophytes that would otherwise be scraped off by the passage of birds. During a rapid count of a sizeable colony, however, such fine details of particular burrows can be missed.

We observed considerable bank erosion and sloughing during our study. While we did not make measurements and sloughing was not constrained to this period, bank sloughing seemed especially pronounced around a higher flow period at the beginning of June 2010, when Sacramento River flows at RM 184 were 15 to 16 thousand cfs (Department of Water Resources 2011). Burrows were lost in many areas of sloughing, but bank swallows did not avoid areas of bank collapse. We observed many birds actively excavating in freshly exposed areas of bank. Some areas of bank collapsed repeatedly, and in some areas, such as at RM 189.6 R, burrows were repeatedly destroyed. Burrow numbers continued to increase at RM 189.6 R even after the early June high water event (Figure 1); we could only speculate whether they might ultimately have been higher in the absence of sloughing.

From our data on burrow numbers, eggs, and young there is evidence for a protracted "second wave" of nesting and reproduction in the colonies we examined. While we cannot preclude that there may have been some double-brooding, the late-May and June increase in burrow counts at some colonies exceeded the early-season numbers present (Figure 1), and occupancy did not decline (burrows were not being vacated; Figure 2). Therefore some or much of the "second wave" in burrows, egg-laying and young must have come from birds that either were not present or had not initiated burrow construction and breeding prior to mid-May. Weather conditions during spring and early summer 2010 were quite cool, and phenology of many species was delayed roughly two weeks (personal observations). Hence, it is possible some bank swallows delayed nesting due to environmental conditions. Another hypothesis is that there was a late wave of bank swallow arrivals from the wintering grounds. Based on his observations and review of the literature, Garrison (1999) reported that arrivals to the vicinity of colony sites progress over some weeks from older, experienced birds arriving first to first-year recruits arriving later. The spread of experienced early arrivers to first-year late arrivers is 5-6 weeks for purple martins (*Progne subis*) (Morton and Derrickson 1990). We cannot distinguish between these hypotheses for the "second wave" with our data, and a combination of the two is possible.

Our data also suggest a spatial difference in colony characteristics, with those from our "central" area around RM 184 showing higher burrow occupancy than colonies north or south. Other bank swallow researchers also are exploring spatial differences (R. Irwin, California Department of Water Resources, personal communication), and this topic deserves further study.

A significant concern for this threatened species is disturbance—including that caused by research—that might lead to mortality or reduced reproduction. To our knowledge, previous studies on the Sacramento River have not presented evidence of disturbance to bank swallows by research activities. We observed that adult bank swallows would usually exit burrows upon our approach (i.e., beaching of the motorboat), and that they appeared to return and resume normal behavior once we had moved away a distance of about 50 m. At one point we attached video cameras to poles or roots in the colony area and watched from a distance; in this case the birds flew in an apparently agitated manner around these newly-placed objects for a much longer period than if we had simply departed and left nothing behind. When we peered into a burrow with our light-sticks, occasionally there would be an adult in the burrow. Often this adult would then fly away.

Juveniles showed a progression of reactions to our inspection: very young chicks begged to be fed; young chicks capable of walking would retreat to the back of the burrow; juveniles that had fledged but were resting in burrows would generally depart with adults upon approach. Of most concern were juveniles very close to fledging, perhaps within a day or two. On one occasion we observed such a juvenile attempt to fly upon our approach. It eventually landed in the river—presumably resulting in mortality. This was the only study-related injury we observed, but we acknowledge there may be other adverse effects of research activities.

While bank swallows naturally endure bank collapse, predator attacks and considerable natural mortality of chicks (we observed numerous carcasses or moribund juveniles on the banks below colonies), researchers must go out of their way to avoid additional impacts. Research-related impacts might include nest abandonment by adults, or juveniles flying from the burrow before establishing good communication with their parents (Burtt and Tuttle 1983, Garrison 1999). Therefore, and despite the value of replicating this study in the manner that established an occupancy estimate two decades ago, we encourage continued attention to reducing disturbance.

Our observations suggest occupancy can be monitored successfully post-season to reduce impacts from disturbance. Nearly all 2010 burrows were destroyed by winter bank erosion before the 2011 breeding season, and no nest material was found in the approximately 30 remnant burrows we inspected during April 2011. At 50 percent occupancy or higher, we would have expected to see roughly 15 nests in 30 burrows if nests persisted, and it would be improbable that none of these burrows had contained a nest during 2010 (assuming independence, $[0.5]^{30}$=much less than a one in one million chance). We believe this indicates that nests did not persist to any substantial degree between the 2010 and 2011 breeding seasons, and that there is little risk of counting a previous-season nest as an occupied burrow in a subsequent year survey. Our future work will include further testing of this premise, particularly during dry years.

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