SPATIAL AND TEMPORAL PATTERNS OF THE BANK SWALLOW ON THE SACRAMENTO RIVER

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in

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by

Dawn Garcia

Summer 2009

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ABSTRACT

SPATIAL AND TEMPORAL PATTERNS OF THE BANK SWALLOW

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The Bank Swallow (*Riparia riparia*) in California was listed as a State threatened species in 1989 due to declining populations and continued habitat loss from bank armoring. As part of their Bank Swallow Recovery Plan, the California Department of Fish and Game implemented annual surveys on the Sacramento River to evaluate yearly trends of the Bank Swallow. I evaluated nine years of spatial and temporal trends in colony dynamics and incorporated local physical data possibly affecting colony parameters. I subset colonies based on size and years of persistence, and statistically analyzed differences in colony parameters. From 1998-2008, the Sacramento River population remained relatively stable but showed no increase since its decline from 1987 estimates. Colony numbers and total number of burrows were similarly distributed across the 100-mile study area, with a tendency for larger colonies to be located in the upstream reach and more colonies located in the downstream reach. Larger colonies persisted the longest (8-10 years). Colonies that were active 1-2 years and small and medium-sized colonies were most common. Erosion activity was associated with colonies that persisted longest. Riparian vegetation was the dominant overstory associated with all colonies. My study begins to elucidate some of the Bank Swallow colony trends and physical factors that may be associated with persistent colonies. It serves as a baseline for future research and comparative analysis. It contributes information necessary to inform the management of the species population dynamics as habitat loss continues by flood and erosion control projects on the Sacramento River.

CHAPTER I

INTRODUCTION

Species distribution and range, the patterns of how species occur temporally and spatially around the globe and the driving forces that create those patterns, are a major focus of disciplines including biogeography, population biology, macroecology, and landscape ecology. Early investigations emphasized the inventory of species (e.g., Wallace and Darwin) and knowledge for economic purposes (e.g., range limitations on commercially valuable plants). More recent interest in comparative and quantitative range dynamics is directed toward conservation of local and global biodiversity (Lawton, 1993; Brown *et al*., 1996).

Fundamental to the discipline of biogeography is determining the pattern of species range and associative range size and frequency distributions. Generally, frequency patterns indicate that the majority of species have small to moderate range sizes and high abundances; few species have large ranges and low abundances (Brown *et al*., 1996; Gaston, 1996). The term low abundance may refer to local abundance and/or those identified as habitat specialists. These specialists may be locally abundant where the required resource is available. Abundance patterns across their range may be patchy, with some areas entirely devoid of the species, and others densely occupied (MacArthur, 1972; Lawton, 1993).

The Bank Swallow (*Riparia riparia*) is an example of a species with a wide-ranging distribution, breeding throughout Europe, Asia and North America, and wintering in Africa and South America (Turner and Rose, 1989). Looking through field guide maps, one might assume the Bank Swallow is abundant across its North American range. However, range maps and descriptions are often general and result in a misleading and imprecise perception of swallow abundance (Brown *et al*., 1996). In contrast, relative abundance maps developed for the Bank Swallow in the United States, based on 30 years of Breeding Bird Survey (BBS) data, show a somewhat patchy localized distribution illustrated as small polygons of increasing color and correlated to population abundance (Price *et al*., 1995).

Another common species-range pattern is that species tend to be more abundant at the core of their range and less abundant as they extend outward toward their range boundaries. Range margins typically document a species at its extreme boundaries where conditions are not optimum for the species (Lawton, 1993). Range limits and occupancy throughout the range are driven by numerous factors including dispersal and establishment abilities, competition and predation, climate, and limitations in habitat resources (MacArthur, 1972; Lawton, 1993; Brown *et al.*, 1996; Gaston, 1996). Knowledge of the dynamics that occur at range boundaries can be a valuable contribution to management and conservation of that species (Lawton, 1993).

The Bank Swallow in California illustrates a species at the limits of its breeding range boundaries on the North American continent. Range maps show this swallow is limited at least by the geographical location of California on the southwestern border of the continent (Turner and Rose, 1989; Garrison, 1999). Once more abundant on coastal bluffs and river courses with appropriate nesting habitat throughout California, the majority of the Bank Swallow population now occurs along the Sacramento River in the Central Valley. The human practices of changing landcover, managed flows, and bank armoring have impacted the California population of Bank Swallows.

Decline of California and Sacramento River bank swallow populations

Appendix A summarizes the timeline of events regarding the California population of Bank Swallows. Remsen (1978) documented the extirpation of the Bank Swallow from southern California and the declining Bank Swallow population in the Sacramento Valley. Subsequently, it was listed as a second priority species of concern (Laymon *et al.*, 1988). Species in this category are in decline but populations are substantial enough that there is not immediate threat of extirpation (Remsen, 1978). Remsen noted the reach between Red Bluff and Tehama (approximately 15 river miles) on the Sacramento River as one of the remaining known Bank Swallow breeding areas where five colonies with an estimated 442 birds were documented (1978). On the Sacramento River, population declines may have begun prior to the 1960s, resulting from effects of early bank protection projects and construction of the Shasta Dam (Stillwater Sciences, 2007). Managed water releases from the dam moderated high flows and potentially reduced the amount of erodable bank required for Bank Swallow nesting habitat. However, habitat loss primarily due to armoring of riverbanks was noted to be the principal cause of decline for the Sacramento River population of Bank Swallow (Remsen, 1978; Laymon *et al.*, 1988; Schlorff, 1992, 1997; Hight, 2000; Garrison, 1998; Garcia *et al.*, 2008).

Statewide surveys and recovery plan

The decline of the California's Bank Swallow population and ongoing bank revetment projects instigated two significant regional and statewide studies. In 1986, Garrison *et al*. (1987) conducted an intensive study of Bank Swallow colonies concentrating their efforts along the Sacramento River from Red Bluff in Tehama County, downstream 160 miles to the confluence of the Feather River in Sutter County. They located 60 colonies ranging from 12 to 1,784 breeding pairs, and estimated a total breeding population of 16,149 pairs in this study area (Garrison *et al.*, 1987). This estimate was later revised to 13,170 pairs based on an adjusted burrow occupancy rate (CDFG, 1992). After review of proposed bank revetment projects on the Sacramento River, Garrison *et al.* (1987) concluded that over 50% of this population could be vulnerable and that a state status of “threatened” could be warranted. Subsequently, a statewide survey conducted by Laymon *et al.* (1988), documented a total of 111 bank swallow colonies throughout California: 71% of these colonies were found on the Sacramento River and its Feather River tributary (66 and 18, respectively). The species was listed as threatened in 1989 (CDFG, 2000). Varying degrees of surveying and research continued along the Sacramento and Feather Rivers since the preliminary efforts in 1986. This year was also the initiation of annual surveys focused on a 100-mile reach of the Sacramento River where most colonies were documented. A Recovery Plan for the Bank Swallow completed in 1992, documented the decline of the Sacramento River population by 39%, to a low of 7,525 pairs (CDFG, 1992). The Bank Swallow Recovery Plan goal was to maintain a self-sustaining wild population with objectives to ensure 1) no further decline in range or abundance, and 2) sufficient habitat availability for the species to survive as a member of California’s native avifauna (CDFG, 1992). Concepts of the plan included impact avoidance, habitat preserves, and a series of set-back levees to allow the river to meander, thereby creating and maintaining nesting habitat. Two status reviews submitted to CDFG in 1995 (Schlorff) and 2000 (Hight) recommended the threatened classification of Bank Swallow be retained.

Need for research investigation

Annual Bank Swallow surveys initiated on the Sacramento River in 1986 provided a rich dataset for analysis of colony dynamics. The survey data had been used to monitor population trends in the study area from year to year and in comparison to initial pair and colony estimates, but no comprehensive examination of colony size, persistence, and distribution of these categories had been conducted. More public awareness and conservation concern for this species made my thesis investigation crucial and timely to understand spatial and temporal trends in Bank Swallow population dynamics and use of river habitat. I also included quality assurance and quality control of a portion of the dataset which is essential to ensure integrity in future research using the dataset.

Objectives

To contribute to the conservation of a California threatened species, I examined the Sacramento River population of Bank Swallows nesting near the southwestern limits of its range, which has contracted due to habitat degradation and loss from direct and indirect impacts. The intent for my research investigation was to elucidate Sacramento River colony trends for the past 10 years (due to potential colony location inaccuracies; I examined only the most recent nine years of surveys for this analysis). I hoped to illuminate colony distributions by examining Bank Swallow use of two distinctly different geomorphic reaches of the Sacramento River and determining the range of colony persistence across the survey area. In addition, I wanted to evaluate potential population patterns as they relate to physical characteristics along the river. Specifically, I attempted to answer the following questions:

1. How do colonies vary in size and distribution throughout the study area during the survey period?

2. How many years are colonies active and how does their persistence vary throughout the study area?

3. What is the relationship between colony size and colony persistence?

4. Do mean winter flows affect the number or size of colonies that are present the following breeding season?

5. Do river processes such as erosion and morphology such as sinuosity have an effect on colony persistence?

6. What is the bank overstory vegetation cover where bank swallows occur?

CHAPTER II

BACKGROUND: NATURAL HISTORY OF THE BANK SWALLOW

The Bank Swallow is one of the most colonial and wide-ranging neotropical migratory passerines in the world (Turner and Rose 1989; Garrison, 1999). In Europe and Africa, the Bank Swallow is known as the Sand Martin. Both common and scientific names describe the nesting habitat of these colonial swallows, which typically excavate nest burrows in vertical banks along river systems (Figure 1, top photo) and other large water bodies (Remsen, 1978; Garrison, 1999). Their nesting colonies are ephemeral, as the swallows have evolved to exploit erodable cliffs and banks created by the dynamics of floods and waves. They also commonly nest in the walls of sand and gravel pits and mounds (Petersen, 1955; Windsor and Emlen, 1975), freshly eroded road cuts (Petersen, 1955; Garrison, 1999), and rarely in sawdust piles at timber mills (Gross, 1942).

The ephemeral nature of Bank Swallow nesting habitat, dependent on erosional forces (including manual material removal in active quarries), has resulted in low to moderate levels of nest site fidelity (Freer, 1979; Petersen and Mueller, 1979; Holmes *et al.*, 1987; Garrison, 1989, 1999). They are a highly social swallow, with some colonies consisting of over 3,000 nesting pairs (CDFG, unpubl. data files). Because of their migratory behavior, high degree of coloniality, and relatively low degree of site fidelity, colony dynamics such as regional phylopatry, dispersal, and survivorship may be difficult to determine in

Figure 1. Examples of natural river banks and Bank Swallow colonies on the Sacramento River. The top photo shows a freshly eroded bank. Note the vertical surface and lack of significant vegetation growth. The bottom photo shows a degraded bank for Bank Swallow nesting. Although burrows are present, they are confined to a limited area. Note the toe of the bank is sloped with significant vegetation growth allowing for predator access to the burrows. Both banks occur under grassland overstory. Photo credit D. Garcia 2008

this transient species. Factors affecting these life history traits, such as weather conditions and loss of habitat, if identified, may be difficult to isolate as causal factors of annual variations in population size.

Influences on bank swallow populations

Several factors have been identified to contribute to population dynamics of the Bank Swallow. Site suitability is known to influence the return rate of birds. Sand banks that were mechanically refreshed on an annual basis had a higher return rate of adult birds in subsequent years than those banks that were not refreshed (Freer, 1979). Burrowing surfaces that are not eroded (Figure 1, bottom photo) in as little as two to three years build up parasite loads and allow for increased predator entry; both factors are known to reduce productivity (Garrison, 1999). Natural predators which may take a significant toll on individual colonies include birds, snakes, and mammals (Hoogland and Sherman 1976; Plummer, 1977; Windsor and Emlen 1975; Blem, 1979; Schlorff, 1992; Garrison, 1991, 1999). Episodic flooding events during the nesting season and slumping of burrow faces have resulted in drowned nestlings or birds buried alive (Garrison, 1999; Stillwater Sciences, 2007). Drought conditions or variations in precipitation events on wintering or breeding grounds that reduce insect activity are documented to affect Bank Swallow survivorship and productivity (Mead, 1979; Garrison, 1999; Cowley and Siriwardena, 2005).

Human influences can have direct and indirect impacts on Bank Swallow dynamics. Changes in landscape cover, such as conversion from riparian habitats to agriculture, alter river processes (Larsen *et al.*, 2006) and remove habitats such as freshwater wetlands and meadows where swallows forage aerially for insects. Freshwater marshes are known to be high in insect abundance and biomass (Mitsch and Gosselink, 1993). The mosaic of agricultural and native landscapes influences where swallows forage and subsequently choose to nest. In their research on the Sacramento River, Moffatt *et al*. (2005) found that bank swallow colonies located nearer to grasslands, where presumably insect prey populations are more abundant, had less of probability of going locally extinct. The combination of foraging habitat loss with human activity and development are suspected causes of Bank Swallow population declines along the coast of California where suitable cliffs are still intact (Remsen, 1978; Laymon *et al*., 1988). Therefore, land use practices, such as agriculture and development, may influence the nesting behavior of swallows.

Direct human impacts on Bank Swallows include destruction of colonies during the breeding season. For example, releases of water on managed river systems during the nesting season can have the same result as episodic events, drowning nestlings or burying birds alive when banks slump (Schlorff, 1995; Garrison, 1999). Similar results occur as material is excavated from colonies located in active quarries and during installation of bank protection projects (Beyer, 1938; Garrison, 1991; Schlorff, 1995). Further, river bank protection projects permanently reduce nesting banks by removing available or potential future habitat. Rocking practices on the Sacramento River in California for various reasons demonstrate this point (Figure 2). In 2006, a levee maintenance project armored almost one mile of river bank and levee on property purchased as a State Wildlife Area (Figure 2, bottom photo; Garcia *et al*., 2008). The project destroyed prime nesting habitat with an estimated 11,000 Bank Swallow burrows in all nine survey years (this research). In 2007, a second project, designed to protect federal and State listed fish and irrigation to private non-profit, State and federal wildlife and habitat conservation lands, included rocking of 1,500 lineal feet (457 meters) at the toe of the bank along USFWS refuge land. This bank supported at least 10 years of

Figure 2. Example of two armored banks on the Sacramento River. The upper photo is private (and likely unpermitted) rubble, installed by landowner to protect property. The bottom photo is and example of almost 0.8 miles of permitted rock installed in 2007 on the riverbank with additional rock placed upslope on the levee. Bank Swallows were active on this previously erodible bank for most of the survey period. Photo credit D. Garcia 2007

consistent use by an estimated 790 pairs of Bank Swallows from 1998-2007. Though rock placed along the toe of a slope is less stable and therefore less permanent than fully armored banks, it continues to remove swallow nesting habitat as it halts the meander and erosion process.

Annual bank swallow surveys on the Sacramento River: Study area

Annual Bank Swallow surveys were initiated on the Sacramento River in 1986 to monitor the status of the Bank Swallow population and have continued through 2008. The Sacramento River is a highly managed system. It is controlled primarily by the Shasta Dam, a flood control structure and water supply impoundment, constructed in 1945 as part of the federal Central Valley Project (Carle, 2004). Southward from the Shasta Dam, natural flow is manipulated by 1) a series of dams, inputs and diversions, 2) setback levees for flood control, irrigation and municipal uses, and 3) more recently fish and wildlife habitat management. Generally, management has moderated the natural hydrograph so high and low flows are less frequent and less extreme. Bankfull flows and mean winter flows have been reduced in magnitude (Buer *et al.*, 1989; Larsen *et al.*, 2006; Snowden, 2002; Stillwater Sciences, 2007).

Although degraded from its natural condition, the Sacramento River is the most diverse riparian ecosystem in all of California (Golet *et al.*, 2003) and is invaluable to wildlife. Figure 3 shows the essential 100-mile reach for Bank Swallows between Red Bluff (River Mile [RM] 243) and Colusa (RM 143), where more than 50% of the California nesting population occurs (Laymon *et al.*, 1988; Schlorff, 1997; Garcia *et al.*, 2008). This 100-mile reach is the most meandering portion of the river. A consequence of the river's dynamic movement, erosion, and deposition is the creation of suitable habitat for nesting Bank

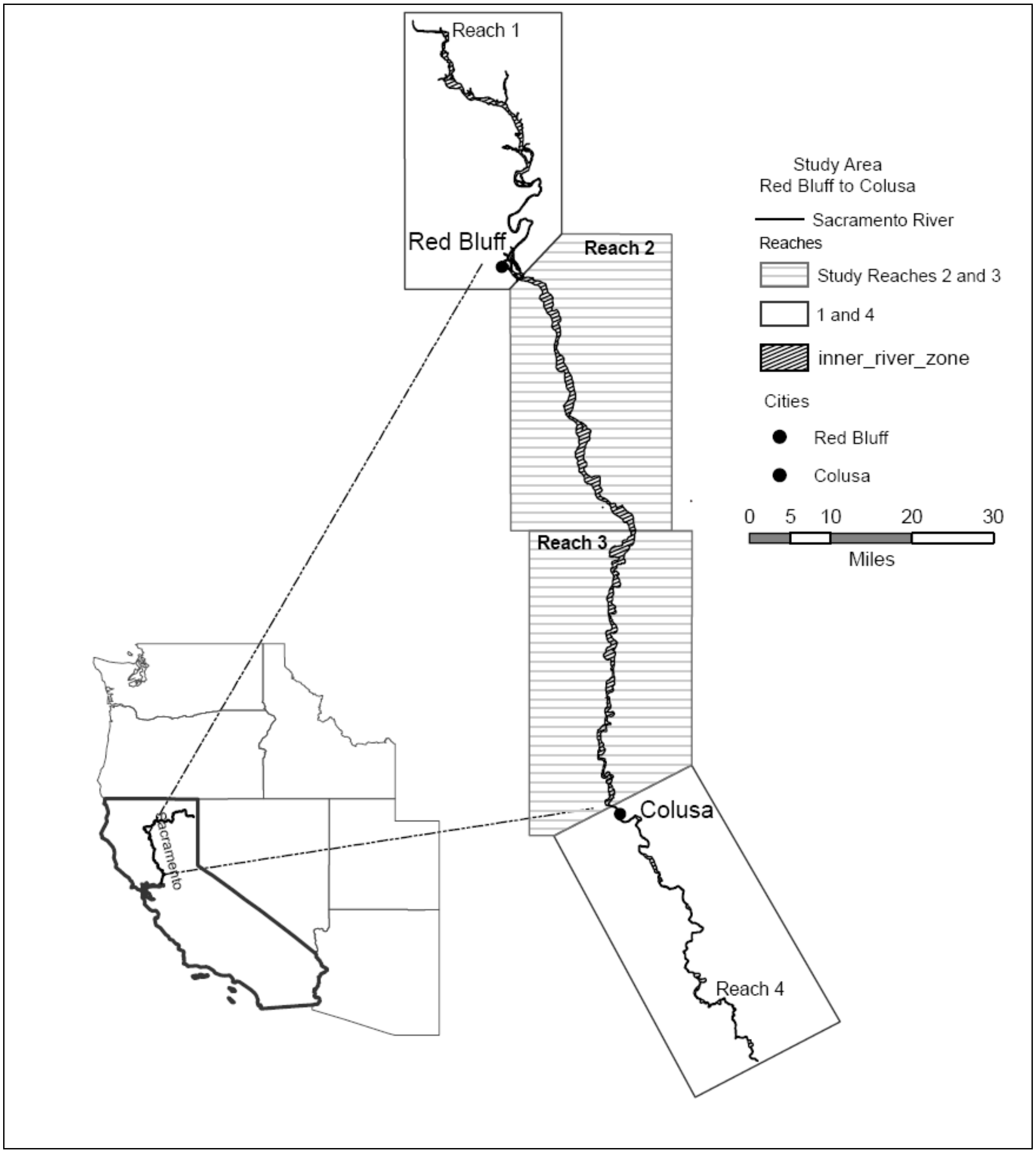

Figure 3. Bank Swallow study area on the Sacramento River, in Northern California. The two main study reaches, Reach 2 and 3, lie between Red Bluff (river mile 243) and Colusa (river mile 144). Each study reach is approximately 50 river miles long

Source data: CDWR (California Department of Water Resources). 2004. The distributable Sacramento River GIS data (DVD). Red Bluff, CA; California State University, Chico Geography Department. 2006, Fall. *CHICOCA and CA_outline class files*. California State University, Chico.

Swallows. This 100-mile reach was also the focus of the Sacramento River Project, established in 1988 by State agencies, the U.S. Fish and Wildlife Service (USFWS), and The Nature Conservancy to restore the riparian ecosystem (Osugi, 1989; USFWS, 1987, 2005). The project included purchasing flood-prone lands for revegetation and restoration of natural river processes (Golet *et al.*, 2003; USFWS, 2005). Further, an advisory council created by Senate Bill 1086 designated this reach as a Conservation Area (Sacramento River Area Conservation Forum, 2003). Within the Conservation Area is an “inner river zone,” that is the focal area for preservation and reestablishment of a continuous riparian ecosystem (Sacramento River Area Conservation Forum, 2003). This zone combines the 100-year meanderbelt with 50 subsequent years of projected erosion activity. A limited meander is allowed within the inner river zone allowing the river’s natural riparian ecosystem dynamics to occur but taking into consideration land uses (e.g., agriculture, buildings, flood control structures, etc.) that might need protection from erosion. However, public and private landowners along the inner river zone participate strictly on a voluntary basis and because of its erosive qualities, the 100-mile reach between Red Bluff and Colusa also has had extensive bank protection (riprap) installed to protect against property loss. Although the majority of the riprap was installed pre-SB 1086, the U.S. Army Corps of Engineers (ACOE) and California Department of Water Resources (CDWR) have armored an estimated 48% of erodable banks and levees along the study reach from Red Bluff to Colusa, as of 2002 (Garcia *et al.*, 2008). An additional mile of rock was installed in 2006 and 2007 on two different banks that supported colony activity for a considerable portion of the survey years. Further, approximately 16 miles (80,000 lineal feet, 24,384 meters) of riprap is slated to be installed for new and repair erosion projects, with a portion being constructed within the inner river zone (United States Army Corps of Engineers, 2007). Figure 3 shows the 100-mile study area that is the focus of this thesis.

For the purposes of this thesis, I discuss the 100-mile stretch of the Sacramento River as two distinct reaches, Reach 2 and Reach 3 which are existing designations based on different physical characteristics that include geology, soils, hydrology, channel sinuosity, and land use (Sacramento River Area Conservation Forum, 2003; Golet *et al.*, 2003; Stillwater Sciences, 2007). Channel planform varies in each of the two reaches as subsets of active meandering sections and relatively inactive straight sections. Soils and erosional processes that occur in the different channel sections influence the formation of Bank Swallow nesting habitat.

Reach 2

Reach 2, the upstream section, includes RM 244-194 from Red Bluff to Chico Landing (50 river miles, Figure 3, Table 1). While volcanic deposits and slowly eroding hardened sedimentary deposits (geologic control) are present, Reach 2 has a high proportion of loamy alluvial soils (Columbia and Vina series), that provide a valuable agricultural resource (Sacramento River Area Conservation Forum, 2003). Six major tributaries are identified in this reach (Figure 4) and they connect the main stem Sacramento River with riparian systems in upland watersheds. Reach 2 is a meandering section with high cutbanks and eight geomorphic subdivisions identified by channel shape (e.g., strait, anabranching) and sinuosity (Sacramento River Area Conservation Forum, 2003). Landuse within the inner river zone based on 1999 aerial photography consisted of 30% agriculture, 35% riparian vegetation, 18% upland vegetation, 4% water surface (excluding the mainstem), 11% miscellaneous (which includes “barren wasteland” e.g., gravel bars) and 2% urban

Table 1. Physical and cultural properties of Reach 2 and 3 within the Inner River Zone. Land use is based on 1999 aerial photography and published in the Sacramento River Area Conservation Forum (2003). Active and inactive Bank Swallow habitat mapping was based on 1989 surveys by USFWS (Sacramento River Area Conservation Forum 2003). In *1994 CDWR mapped and combined both active and inactive habitat in Reach 2 only (Sacramento River Area Conservation Forum 2003). Active habitat included banks with burrows and inactive sites included banks that appeared suitable, i.e., had vertical surfaces, suitable height, and soil erodability. Riprap information was derived by a CDWR GIS draft shapefile through 2004 plus an additional mile of new riprap installed in 2006 and 2008 (pers. obs). It does not likely include all the rock in each Reach

Properties	Reach 2	Reach 3
River Miles	50, RM 243-193	49, RM 193-144
City End Points	Red Bluff-Chico Landing	Chico Landing-Colusa
Geology	Geologic control, loamy alluvial soils	Finer silts and sands, less gravels
Tributary Input	6 major	1 major
Geomorphology	Meandering, high cut banks	Widely meandering, natural levees, lower gradient
Bank Swallow habitat -active	0.98 miles, *5.39 miles	8.97 miles
Bank Swallow habitat-inactive	4.98 miles, *5.39 miles	2.01 miles
Riprap	Approximately 24 miles	Approximately 23 miles
Ownership	Private – 59% Public – 41%	Private – 67% Public – 33%
Landuse (1999)	53% agriculture 20% riparian veg 20% upland 4% urban 6% miscellaneous	16% agriculture 48% riparian veg 11% upland 11% urban 13% miscellaneous

(Sacramento River Area Conservation Forum, 2003; Table 1). Throughout the estimated historical riparian zone within 10-mile increments from RM 190-250, the amount of riparian vegetation has been reduced to less than 1000 acres where previously it ranged from approximately 6,000 to nearly 30,000 acres (Stillwater Sciences, 2007). In 1989, the USFWS mapped active and inactive Bank Swallow habitat within this reach and estimated 0.98 miles

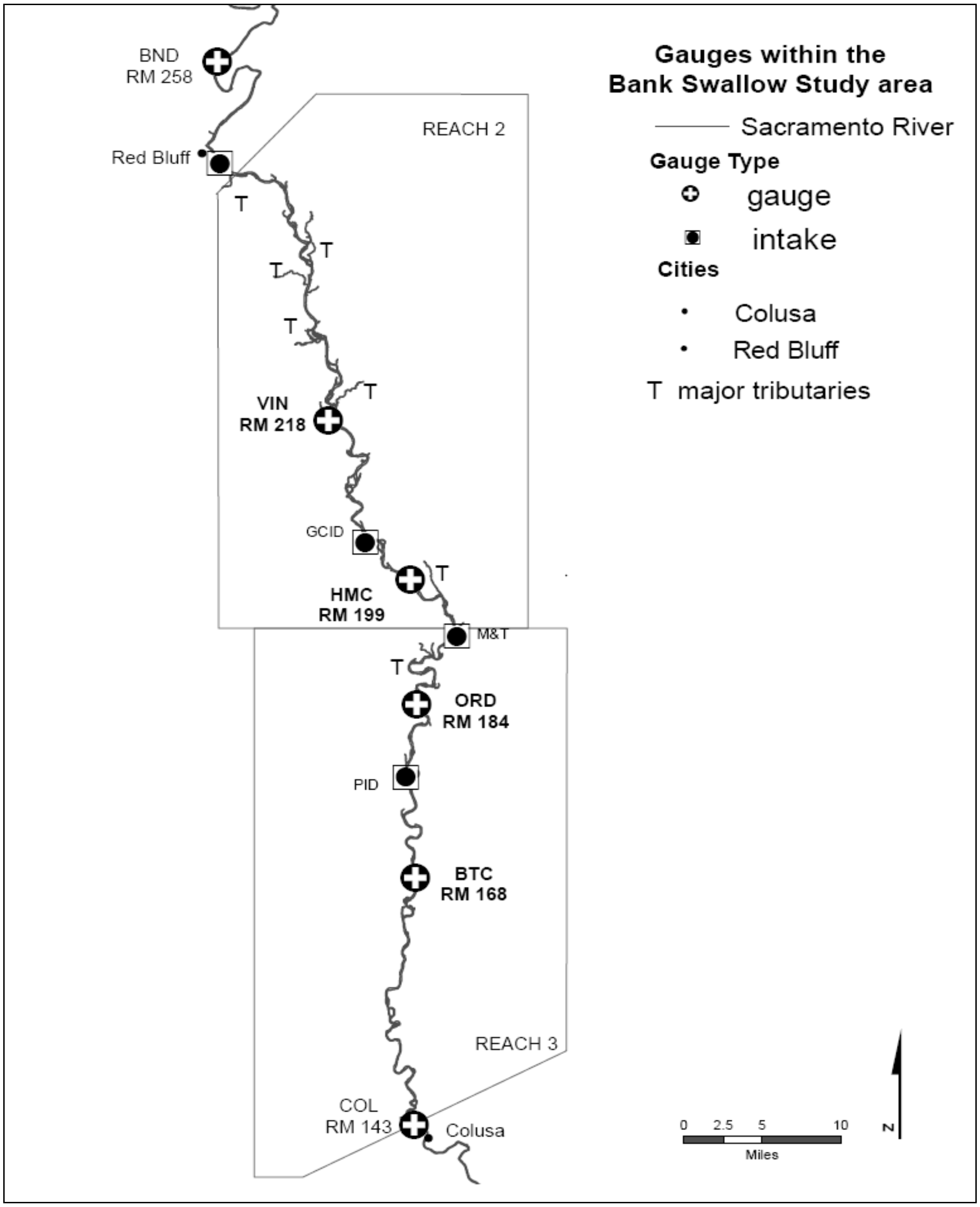

Figure 4. Gauges within the Bank Swallow study area. Four flow gauges used to assess winter flows within the 100 river mile Bank Swallow Study area (Reach 2 and 3) were VIN (RM 218), HMC (RM 184), ORD (RM 168) and BTC (RM 168). Major tributaries (inputs) and irrigation intakes (outputs) are also shown.

Map data sources: Gauges: CDWR (California Department of Water Resources). 2008. California data exchange center. http://cdecwatercagov/ (accessed June 2008); Sacramento River Area Conservation Forum (SRACF). 2003. Sacramento River Conservation Handbook. http://wwwsacramentoriverorg/ SRCAF/indexphp?id=handbook (accessed December 2007). Reaches and River Features: CDWR (California Department of Water Resources). 2004. The distributable Sacramento River GIS data. Red Bluff, CA of active habitat and 4.98 miles of inactive habitat (Table 1). CDWR mapped habitat in 1994 and estimated 5.39 miles of combined active and suitable nesting habitat (Table 1). Active habitat consisted of banks with burrows and inactive habitat appeared suitable, i.e., it had appropriate bank height, soil erodability, and slope (Sacramento River Area Conservation Forum, 2003).

Reach 3

Reach 3, downstream of Reach 2, runs from Chico Landing to Colusa (RM 194- 143, 49 river miles; Figure 3; Table 1). Tributary input is not significant in this reach (Figure 4). This portion of the river has a lower gradient compared to Reach 2 and is widely meandering, with well-developed natural levees downstream (Golet *et al.*, 2003). Natural overflow basins originally occurred in this reach, but these are now impacted by flow modifications of the Sacramento River Flood Control project which begins below Chico Landing. Water once flowing into the overflow basins is now rerouted via a system of levees and weirs for more efficient drainage into the Sacramento-San Joaquin Delta, where the Sacramento River outlets (Sacramento River Area Conservation Forum, 2003). The alluvial soils (Columbia and Gianella series) are finer and banks are composed of silts and sands, with less gravel than upstream in Reach 2. Landuse within the inner river zone based on 1999 aerial photography, consisted of 16% agriculture, 48% riparian vegetation, 11% upland vegetation, 2% water surface (not including the mainstem), 13% miscellaneous (which includes “barren wasteland” e.g., gravel bars), and 11% urban (Sacramento River Area Conservation Forum, 2003; Table 1). Throughout the estimated historical riparian zone within 10-mile increments from RM 140-200, the amount of riparian vegetation has been reduced to less than 1000 acres where previously it ranged from approximately 9,000 to nearly 30,000 acres (Stillwater

Sciences, 2007). In 1989, the USFWS mapped active and inactive Bank Swallow habitat within this reach and estimated 2.01 miles of active habitat and 8.97 miles of inactive habitat (Table 1). Active habitat consisted of banks with burrows and inactive habitat had no burrows but appeared suitable, i.e., it had appropriate bank height, soil erodability, and slope (Sacramento River Area Conservation Forum, 2003).

Additional survey reaches

Bank Swallow survey reports also incorporated information from two areas on the Sacramento River that had not been surveyed annually: Redding to Red Bluff (Reach 1, RM 244-292) and Colusa to the confluence with the Feather River at Verona (Reach 4, RM 144-80; Figure 3). The Redding to Red Bluff reach, upstream of Reach 2, mostly contains geologically unusable nesting habitat in the upper and middle portions. The Colusa to Verona reach, downstream of Reach 3 has extensive riprap, resulting in limited nesting habitat. From earlier surveys, it was estimated that Bank Swallows on these reaches comprise approximately 5% of the total population on Sacramento River and therefore were not routinely surveyed as part of the focal study area (Garcia *et al.*, 2008).

Survey methods

Since 1987, annual surveys have been conducted on the Sacramento River by CDFG in partner with the USFWS Sacramento National Wildlife Refuge Complex beginning in 1999. No surveys were completed in the years 1993-1995 due to lack of logistical support, and 2006 when boat problems occurred (pers. comm. R. Schlorff, 2008). Biologists documented the location and number of colonies and number of active burrows per colony in early June by boat, using methods as described by Schlorff (1997). Using the most updated ACOE Sacramento River aerial atlases, colony locations were identified by RM and right (R) or left

(L) bank facing downstream. Locations were determined to 0.1 mile accuracy using the atlas and area landmarks. Starting in 1999, colony locations were recorded with GPS units and therefore were more accurately mapped than the previous estimates. In 2007 and 2008, USFWS and DWR began digitizing both upstream and downstream ends of each colony. This measurement of colony length introduced a new dimension to colony habitat parameters.

To determine the number of nesting pairs in a colony, burrows that appeared active were counted by two experienced counters. The two results of the count were averaged and rounded to the nearest 10 and then reduced to reflect and estimated 45% burrow occupancy rate (Humphrey and Garrison 1987; Laymon *et al.*, 1988; Schlorff, 1997; Garrison, unpubl. data; CDFG, unpubl. data). In 2008, details of the survey protocols were being drafted to provide consistency in data collection so that other agencies could assist with surveys (Bank Swallow Working Group, unpubl.).

Survey results and model implications

Annual surveys indicate the number of nesting pairs had declined from 13,170 in 1986 on the Sacramento River in 1986 to 9,060 pairs in 2008 (Garcia *et al.*, 2008; CDFG, unpubl. data). The number of colonies has also declined from 72 in 1986 to 51 colonies in 2008 (CDFG, unpubl. data). More specifically, in the study reach from Red Bluff to Colusa the number of nesting pairs was estimated at 10,850 pairs in 1986 and had declined to 7,780 pairs in 2008 (CDFG, unpubl. data). In summary, though the Sacramento River Bank Swallow nesting populations had fluctuated, there was a general decline and nesting pairs have not increased to the 13,170 pairs estimated during the first surveys in 1986 and 1987. These numbers were almost 10 times below the estimated number for a stable population based on a Population Viability Analysis (PVA) conducted for the species (Buechner, 1992; Grivetz, 2007). Applying principles of population ecology, a PVA is a model developed to identify threats to a species and evaluate the likelihood of its persistence for a specific time in the future (Akçakaya *et al.*, 1999). Input parameters depend on availability of data for that species, but can include inherent biological parameters and environmental changes. Buechner's (1992) model input parameters included (1986/87) key demographic characters (e.g., survival and fecundity) and migratory factors based on other research from long term datasets. Results of the PVA showed a substantial (> 20%) chance of the Sacramento River Bank Swallow population declining to 1,000 breeding pairs or less and a 33% chance of disappearing entirely (Buechner, 1992). Further, the model results suggested that 100,000 breeding pairs of swallows would be necessary to ensure a less than 50% chance of the population falling below 5,000 breeding pairs within 50 years. Sufficient Bank Swallow habitat was assumed to allow for population growth and the model did not include habitat degradation or loss. Because rocking practices had been identified as the primary impact of the Sacramento River population, the outlook for the swallows would be even riskier then the modeled results (Buechner, 1992).

Recent Sacramento River bank swallow research

Research has continued beyond the annual surveys and first PVA. Moffatt *et al.* (2005) determined that large increases of water discharge to the Sacramento River in early spring (pre-nesting season), moderate amounts of grassland restoration, or direct restoration of nesting habitat by removal of 10% of existing riprap, could increase colonization probabilities. They based their results on analysis of 13 years of the annual survey data (selected between 1986 and 2003), proximate land cover to swallow colonies, and changes in maximum river discharge (Moffatt *et al.*, 2005).

Stillwater Sciences (2007) proposed updates to Garrison's Habitat Suitability Index (HSI) (1989) by incorporating river flows and proximate land use, as addressed by Moffatt *et al.* (2005). Garrison's HSI (1989) was developed to evaluate Bank Swallow nesting habitat in a variety of habitats including riverine. It was comprised of four variables; soil texture and slope, height and length of bank (Garrison, 1989). An example of an ideal HSI model for a riverine system such as along the banks of the Sacramento River would be a 25-meter long bank at two meters tall, an 80 degree slope, and composed of sandy loam soils for burrowing (Garrison, 1989).

A second PVA was conducted using nine years of Bank Swallow data from the 100-mile study reach and between survey years 1986-2001 (Girvetz, 2007). Demographic and spatial parameters including two environmental Sacramento River conditions were input into the analysis, 1) current conditions (with riprap through 2005) and, 2) restored conditions without riprap and where banks were identified and defined as suitable habitat based on slope and elevation (Girvetz, 2007). Results corroborated with the Buchner PVA (2002) and showed that there was a 21% chance of the population declining to below 2000 individuals in the next 50 years. Moreover, results suggested that the population viability of Sacramento River Bank Swallows had been reduced by approximately 50% due to habitat loss caused by riprap (Girvetz, 2007).

Most currently Garcia *et al.* (2008) documented the population and conservation status of the Bank Swallow since 1997 and discussed a variety of conservation and mitigation strategies recommended by published research as mentioned above.

In early 2007, the Bank Swallow Working Group (BSWG) was formed to address measures necessary to increase Bank Swallow populations on the Sacramento River. The group, composed of State and federal agencies and conservation organizations, is a forum for communication regarding bank protection projects and required mitigation, habitat protection and conservation measures, and research needs for the species. Priority research needs included creating a quality controlled and quality assured (QA/QC) dataset of the legacy survey data 1986-2008, a population trend analysis using the quality assured data since 1986, and field studies regarding habitat and reproductive parameters to assist in identification of critical Bank Swallow habitat and provide updated occupancy rate information (Bank Swallow Working Group, unpubl.).

The goals and objectives of my thesis investigation contribute directly to research needs outlined by the BSWG. I provide a quality assured dataset that will benefit future research. It reveals 10 years of population trends that can be used in comparative analysis studies. My examination of persistence trends is novel for the Sacramento River and identifies areas that are vital to the Bank Swallow. These locations can be the basis of field testing to aide in identification of the associated physical factors that create critical habitat.

CHAPTER III

METHODS

Statistical analysis

All data were analyzed using JMP Statistical Software (SAS Inc.), Versions 5.1 and 8.0 and ArcGIS Desktop (Environmental Systems Research Institute 2008) Versions 9.2 and 9.3. Specific analyses of research questions are discussed below. Data were natural log transformed when assumptions of normality were not met. Appendix B summarizes the questions, analysis and data set used in my thesis research.

Review and quality control of datasets

Three types of bank swallow data were provided to me and are the basis for this research: Geographic Information Systems (GIS) shapefiles, photocopies of raw field data, and unpublished annual survey report summaries. Draft GIS files included survey data from 1986-2003 (missing survey years 1993-1995) from CDFG, 2004 survey data (CDWR), 2005 and 2007 survey data (USFWS) and 2008 survey data (CDWR). No surveys were conducted in 2006 due to boat engine failure. I conducted quality assurance and quality control (QA/QC) by comparing the datasets to one another, correcting obvious inconsistencies, and met with biologists who collected the survey data to resolve more difficult discrepancies. Twenty percent of the corrected data was randomly selected and separately assessed by two thesis advisors.

In order to spatially analyze the bank swallow data, I created a GIS shapefile from the corrected and merged GIS layers. Shapefiles contain spatial features (points, lines or polygons) that are dynamically linked to descriptive attributes in a relational database. The coordinate system and projection (NAD 1983 UTM Zone 10N, projection Transverse Mercator) were unchanged from the original files. I used only data from 1999 through 2008 (excluding 2006 when no surveys were conducted) because these colony locations were collected by GPS, making their locations more accurate than the pre-GPS years, 1986-1998. GPS locations marked the downstream end of each active colony. The 2007 data file also included a point at the upstream end of the colony (USFWS, unpubl. data files) and the 2008 data included lines; both reflect attempts to delineate the length of the entire colony consisting of old burrows from previous years and fresh burrows (CDWR, unpubl. data files). All files had various and common attributes subsequently used in my analysis. These included colony location in UTM coordinates and right (R) or left (L) river bank, and river mile (RM) label recorded to one tenth of a mile, the defined distance that identifies a colony (Garrison *et al.*, 1987; Laymon *et al.*, 1989; Schlorff, 1997). Other colony attributes included the number of active burrows estimated at each colony rounded to the nearest 10, and the survey year. The shapefile I created as a result of the merge, included 380 records spanning nine years of Bank Swallow monitoring data from 1999-2005, 2007-2008 on the Sacramento River from Red Bluff to Colusa (100 river miles [RM]) as collected by CDFG, USFWS, and CDWR. Metadata for the shapefile is included in Appendix D.

Bank swallow colonies and colony subsets: Persistence and size categories

Colonies were defined as a group of nesting Bank Swallows with any number of active burrows separated from another by 0.1 miles (~161m), as in previous studies (Garrison *et al.*, 1987; Laymon *et al.*, 1989; Schlorff, 1997; Stillwater Sciences, 2007; Garcia *et al.*, 2008). I used GIS software and overlaid all colony locations (points) for the survey period over a 2004 aerial photograph (USDA-FSA Aerial Photography Field Office. National Agriculture Imagery Program (NAIP), 2004) of the study area. I uniquely identified colonies by their location on the river as labeled by RM labels and bank side (R or L) as recorded by the agencies during annual Bank Swallow surveys. For example, if an active Bank Swallow colony in 2007 was identified at RM 182, on the right bank, I called that colony 182R, 2007.

To determine if a colony persisted in an area for more than one year, I identified colonies within 0.1 of a mile from each other on the same bank side and examined the year and location labels. To do this, I applied a 0.1 mile (161 meter) buffer around each colony. Colony points with similar location labels (RM and bank side), that were present in different years and had overlapping buffer rings, were considered to be colonies or areas with persistence for more than one year (Figure 5). The colony extent features from the 2007/2008 files routinely encompassed several points from previous years. This supported my identification method of using the 0.1 mile buffer rings for colony persistence.

I subset colonies into four persistence categories to aide in determination of how many years colonies persisted in a particular area across the entire survey period from 1999-2008. I named these categories Consistently Active Areas (CAA), Frequently Active Areas (FAA), Occasionally Active Areas (OAA), and areas that were active on a Casual (C) basis. I considered a colony with activity in an area at least 80% of the survey period (8 years) as a CAA as in Figure 5. Areas with colony activity at least 50% of the survey period (5 -7 years) were assigned to the FAA category. Areas with activity for at least 30% of the survey period (3-4 years) were designated as an OAA. Finally, colony activity documented in an area for

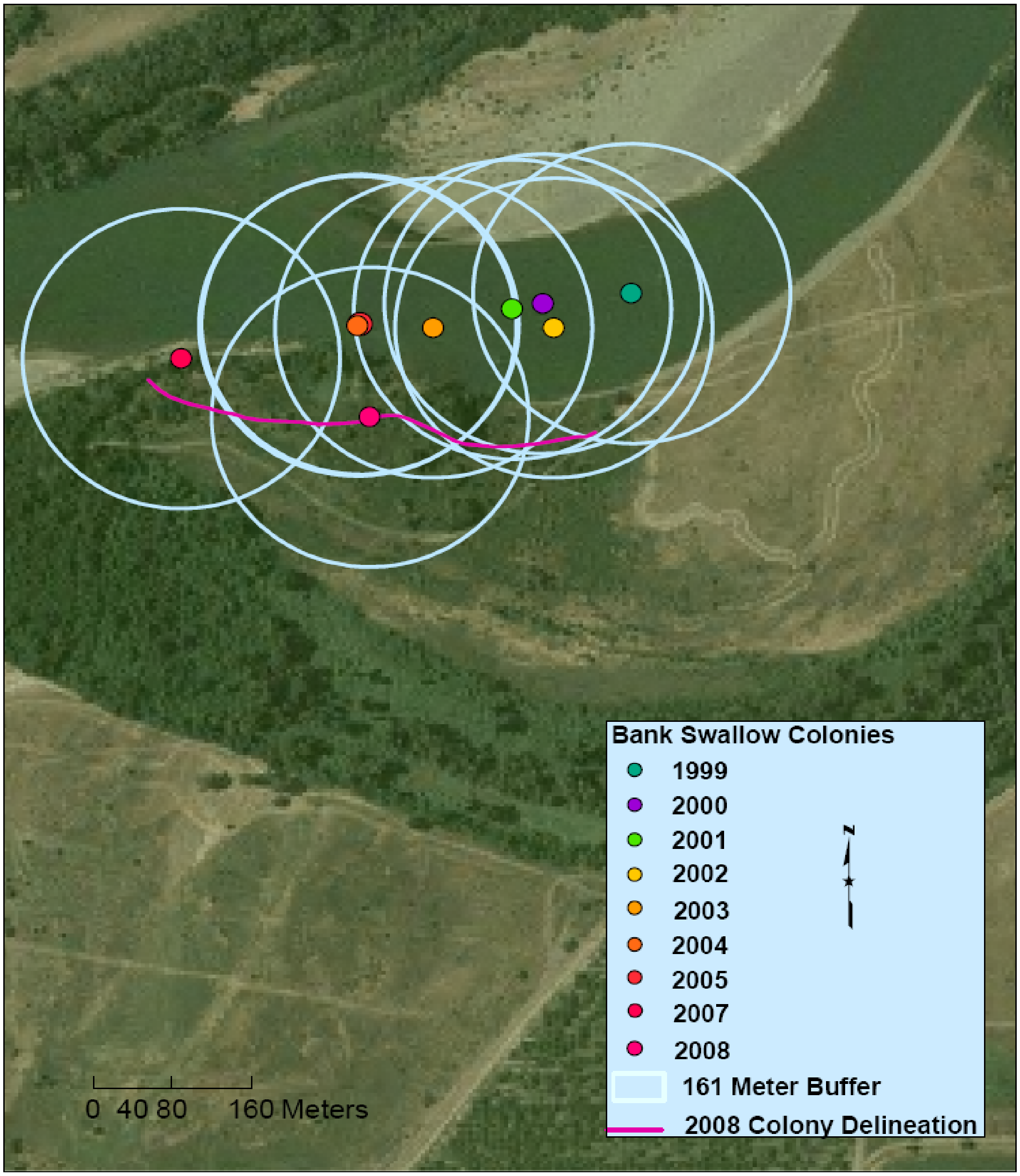

Figure 5. Example of a Bank Swallow colony, RM 182.3L, which was active for nine years, represented by different colored points for each year. I designated this area as a Consistently Active Area (CAA), an area with Bank Swallow activity for 8 to 10 years, using a variety of resources: a 2004 aerial photo of the study area, a 161-meter (0.1 mile) radius buffer, and 2008 colony length digitized lines (pink line)

Source: Photo from USDA-FSA Aerial Photography Field Office. National Agriculture Imagery Program (NAIP). 2004. Remote sensing image of a portion of the Sacramento River, CA, ALAMEDA, CA. USDA-FSA National Agriculture Imagery Program: Salt Lake City, UT.

only 1- 2 years of the survey period, were assigned to a C category. I further assigned two rules to the categories: 1) colonies that had activity in 2005 and 2007 were assumed to be active in 2006 (when no surveys were conducted), and 2) colony activity did not have to occur in sequential years. For example, a colony active at RM 171.2R in years 1999, 2003, 2004, 2005, 2007, 2008 was considered to have seven years of activity and classified as an FAA.

I conducted a two-way Analysis of Variance (ANOVA) to test the difference in the mean number of burrows (on transformed data) in the four persistence categories and in the two river reaches (see below) that comprised the study area (Figure 3). I ran a Tukey HSD (Tukey) analysis to determine pairwise differences within groups.

To evaluate variations within and between colonies of different sizes, I assigned colonies to four size categories defined by burrow number. I used the categories of Garrison et al. (1987), classifying colonies as small (5-130 burrows), medium (131-375 burrows), large (376-1000 burrows). I added an extra-large category to capture colonies with more than 1,000 burrows. I conducted a contingency table analysis tested with a Chi-square statistic to assess differences in the annual contribution of size categories (S, M, L, and XL) between years.

Sacramento River variables: Reaches, flow data, erosion, sinuosity and bank overstory vegetation

The study area is discussed as two reaches, Reach 2 and 3 (Figure 3). As described previously, these reach sections have physical differences that may affect Bank Swallow nesting habitat. I subdivided the colony survey data by reach over all survey years. I ran a two-way ANOVA to determine if there were differences in mean burrow numbers between years and reaches, and tested potential interaction effects of year and reach on colony size. I also ran two nonparametric Wilcoxon signed rank tests for matched pairs testing the median difference in number of colonies between Reach 2 and 3, and to test if the mean colony size (burrow/colony) differed between Reaches 2 and 3 in all survey years. For the latter, I took the mean colony size by dividing raw (untransformed) total number of burrows by number of colonies for each reach and in each survey year.

To determine if changes in colony parameters (number of colonies and burrows) occurred between and within years relative to changes in flow rates, specifically mean winter flow and peak flows, I obtained corrected mean daily flow and maximum monthly flow data in cubic feet per second (cfs) for water years 1998 through 2008 from the CDWR Water Data Library (CWDR, 2009). A water year runs from October in a given year through September the following year (CDWR, 2009). To calculate mean winter flow, I averaged the mean monthly flow for each of the high flow months; December, January, February, March and April for each survey year, and at four specific gauges within the study area (Figure 4). I used flow data for gauging stations at Vina (VIN, RM 218), Hamilton City (HMC, RM 199), Ord Ferry (ORD 184) and Butte City (BTC, RM 168), to represent the flow changes along the 100 mile-study reach. Corrected data were not available for the VIN and HMC gauges in 2008 so I used the raw real-time data from California Data Exchange Center (CDWR, 2008). To evaluate maximum peak flows, I selected the month with the maximum flow during each water year; in each year this was between December and April. High flow months are likely to generate the majority of erosional events that establish bank surface conditions necessary for burrowing upon arrival of Bank Swallows in late March/early April (Garrison, 1999). Similarly, maximum peak flows could cause widespread or local erosion (Buer, 1989; Larsen *et al.*, 2006; Sacramento River Conservation Area Forum Handbook, 2003; Stillwater Sciences, 2007). I performed four correlations using all survey years: 1) number of colonies by mean winter flow, 2) number of colonies at associated gauges by max peak flow 3) total number of burrows by mean winter flow and, 4) total number of burrows at associated gauges by max peak flow. I used the flow data from gauges upstream of the colonies for the analysis. For example, at the BTC gauge at RM 168, all Bank Swallow colonies below RM 168 to the end of the study area (RM 144) were associated with the flow data recorded at BTC (Figure 4). One exception was made; all colonies between Red Bluff (RM 244) and the VIN gauge (RM 218) were associated with the VIN gauge flow data, which is 24.5 river miles downstream from the most upstream documented colony at RM242.5L. I disregarded using the upstream gauge at Bend (BND, RM 258; Figure 4) for the Bank Swallow colonies between Red Bluff and Vina because there were no corrected data for the BND gauge. Using the raw data may have introduced more inaccuracies to this method of Bank Swallow association with flow; upon comparison of the raw data to the corrected data for the mean winter flow values at other gauges, differences varied over 4,000 cfs. Specifically, in 1999 at gauge BTC, the calculated mean winter flows were 24, 648 cfs using the corrected data and 19,938 cfs using the raw data; or about of 20% less than the corrected flow value. In total, 97 colonies (26% of all colonies) were located between the BND and VIN gauges in all survey years. The BND gauge is approximately 16 river miles above the most upstream colony located at RM242.5L.

I also examined colony persistence and size categories with the mean winter flow and maximum peak flow data from each survey year. I conducted one-way ANOVAs to examine whether there was a significant difference in winter flow rates and peak flow by persistence category and size categories. I used a Tukey test to reveal where the differences might occur.

Sinuosity

I obtained a draft sinuosity GIS shapefile (E. Larsen, UC Davis) calculated for the Sacramento River in years 1997 and 2007. Sinuosity is a unitless measurement of channel curvature and ranges from 0 in straight reaches to just over 3 at the most extreme bends on the Sacramento River (pers. comm. E. Larsen, 2008). Meandering channels such as the Sacramento River shift between straight and curving stretches and tend to have a moderate to high Sinuosity Index value between 1.5 - 4.0 (Gorden *et al.*, 2004). The draft shapefile was comprised of two lines digitized down the center of the river channel representing years 1997 and 2007. Each channel line was composed of hundreds of line segments with associated values representing the local sinuosity at that portion of the river (Figure 6). I examined sinuosity with persistence categories only (not size category) because persistence categories consisted of different colony sizes overlapping the same general area (within 0.1 miles of each other). From each persistence category (CAA, FAA, OAA, and C) I randomly selected 10 colonies for a total of 40 colonies (39% of the total) included in the analysis. I overlaid the sinuosity lines for 2007 and 1997 on the selected colonies to determine line segments and values associated with the colonies in both years (Figure 6). If more than one segment was associated with the colonies, I took the mean of those segments. The maximum number of line segments that I used in my calculations was three; the majority consisted of one line segment corresponding to one sinuosity value. I took the difference of the 2007 sinuosity values and the 1997 values and ran a one-way ANOVA with persistence category to see if potential sinuosity differences might occur between each category. I also conducted a paired

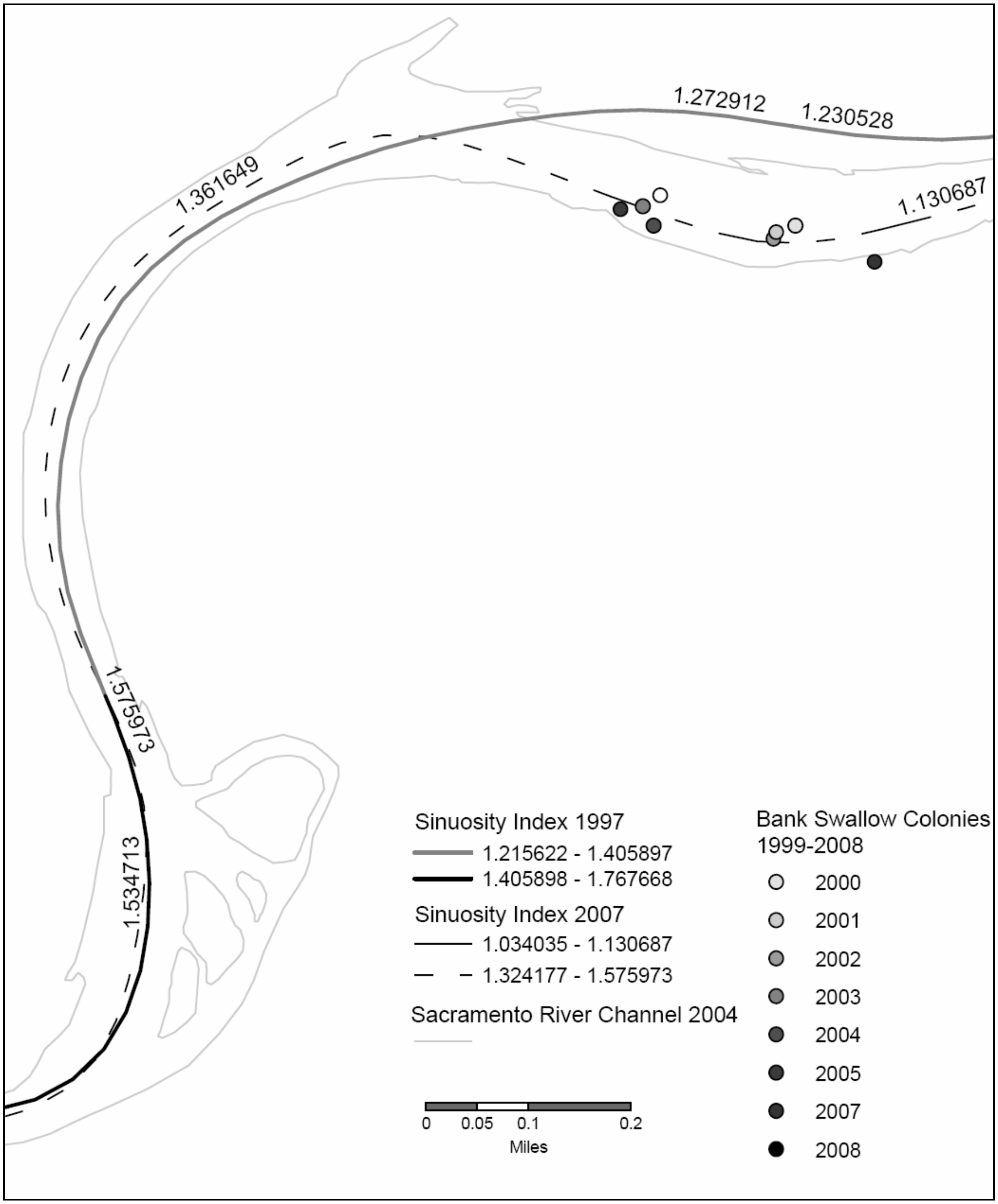

Figure 6. Sinuosity Index (SI) values show for 1997 and 2007 on a selected portion of the Sacramento River. The solid lines represent various SI values in 1997 and the patterned lines represent SI values in 2007. The fine gray line represents the 2004 river line. Bank Swallow colonies are represented in different years by different colored dots. Where swallows were present, I subtracted the 1997 from the 2007 SI index to calculate a difference in sinuosity (how the curviness of the channel changed), over 10 years

T- test to determine mean differences in sinuosity between years 1997 and 2007 for the areas where colonies occurred.

Erosion sites

I examined a draft GIS shapefile of 15 erosion sites in the study area mapped in years ranging from 1999 - 2007 by CDWR. I selected erosion sites that were consistently mapped over the same time range, which included 11 sites mapped for four years from 2000-2004. I used ArcGIS to measure the distance in feet from the 2000 erosion line to the 2004 erosion line, in the area where swallow colonies were documented. If colonies were spread out along the bank and the erosion lines were of unequal distances across that area, I took a measurement at the widest and narrowest areas and averaged those distances. I noted the persistence category if Bank Swallows occurred at an erosion site. I calculated the average eroded distance from 2000-2004 for each persistence category and qualitatively compared differences in erosion distance by persistence category. Colony sizes were not examined with erosion due the variety of sizes comprising each persistence category at the erosion sites.

Vegetation analysis

To examine whether vegetation surrounding the Bank Swallow colonies assigned to different persistence categories might vary, I created a 300-foot (91.5 meter) radius buffer around each colony. I dissolved buffers around colonies that were included in the categories CAA, FAA, and OAA, which resulted in a large polygon around the individual colonies in each category. I used these buffers to clip vegetation shapefile created and classified by DWR. Although vegetation was classified in different years (1999, 2003, and 2004) the main categories were not likely to change markedly between years along the 100-mile study area. However, some changes could occur. For example, a mature orchard might be replaced with young new trees or a different crop. To ensure quality control of how the vegetation was classified for each vegetation category, I selected and examined a random subset of polygons overlaid on the 2004 aerial photograph used for the study area. For example, I selected the categories classified as “Barren and Wasteland” which the GIS highlighted over the aerial photo. Zooming to these features I determined that the majority of the barren class within my persistence categories was gravel bars. Similarly, “native vegetation” was mostly grassland, with smaller areas of grassland and scattered scrub. A few polygons in this category appeared to be slightly denser scrub. I renamed the native vegetation classification to “herbaceous with scattered scrub.” I only included overstory vegetation and not the open water or gravel bars categories or roads (an insignificant contribution), and ended up with four categories: 1) riparian forest, 2) herbaceous/scrub, 3) deciduous orchards (trees), and 4) hay and grain crops. Lastly, I summed the area (acres) of each vegetation classification group and calculated the percentage of the total for each class in each Bank Swallow persistence category. As with erosion and sinuosity features, I did not compare vegetation with colony size categories.

CHAPTER IV

RESULTS

Bank swallow colonies

A total of 380 colonies and 154,640 estimated burrows comprised the Bank Swallow dataset for all nine survey years (1999-2005, 2007-2008). The total numbers of burrows and colonies varied between survey years (Table 2). The estimated total number of Bank Swallow burrows per year ranged from a low of 13,900 in 2005 to a high of 19,170 in 2001. However, there was no significant difference in mean number of burrows between years (F=0.6997, p = 0.6919; Table 3). The average colony size (i.e., number of burrows per colony) across all survey years was 408 burrows (SD=468) and colony size ranged between 10 and 3640 burrows. Although colonies were highly variable in size, the majority (63%, N=242) consisted of 10 to 340 burrows (Figure 7).

The number of colonies and colony size (mean burrow number) per year ranged from a low of 34 with a mean burrow number =533, (SD=614) in 2000 to 49 colonies in 2008 with a mean burrow number of 353, (SD=423, Table 2). A low number of colonies and high number of burrows within a survey year indicated an increase in mean colony size (regression analysis, R^2 = 0.7021, Figure 8).

Variations in colony size

Within the four colony size categories (S, M, L, XL) over all survey years, 127 colonies (33.4%) were in the small category, 121 (31.7%) were in the medium category,

Table 2. Bank Swallow Colony data for each survey year, 1999-2008, documented in the 100 river-mile study reach, Red Bluff to Colusa. R2/R3 indicates Reach 2 (R2) and Reach 3 (R3) annual number of burrows and colonies and combines to create the totals. Min and Max burrows are the number of minimum and maximum burrows estimated at a single colony in each survey year

Survey Year	Number of Colonies (total)	R2/R3 colonies	Number of Burrows (total)	R2/R3 burrows	Mean burrows (total)	SD Burrows (total)	Median Burrows (total)	Min Burrows (total)	Max Burrows (total)
1999	47	23/24	16590	8370/8220	353	374	190	10	1540
2000	34	15/19	18130	8870/9260	533	614	280	20	2770
2001	38	16/22	19170	7440/11730	504	541	260	10	1800
2002	44	15/29	16160	7780/8380	367	435	175	30	1720
2003	48	19/29	18260	8170/10090	380	357	240	10	1640
2004	43	17/26	17040	7480/9560	396	392	270	20	1570
2005	39	20/19	13990	7280/6710	368	394	260	20	1840
2007	38	16/22	17640	8400/9240	464	672	240	10	3640
2008	49	21/28	17660	9110/8550	353	423	255	10	1920

Table 3. Two-way ANOVA table testing the difference in burrow numbers as a dependent variable of year and reach, and the interaction of both. Significant at $p < 0.05$

Source of Variation	*DF*	*SS*	*F*	*p*
Year	8	7.8007146	0.6997	0.6919
Reach	1	2.2561911	1.6189	0.2041
Reach x Survey Year	8	9.7046354	0.8705	0.5416
Error	362	504.48851		
Total	379	526.44422		

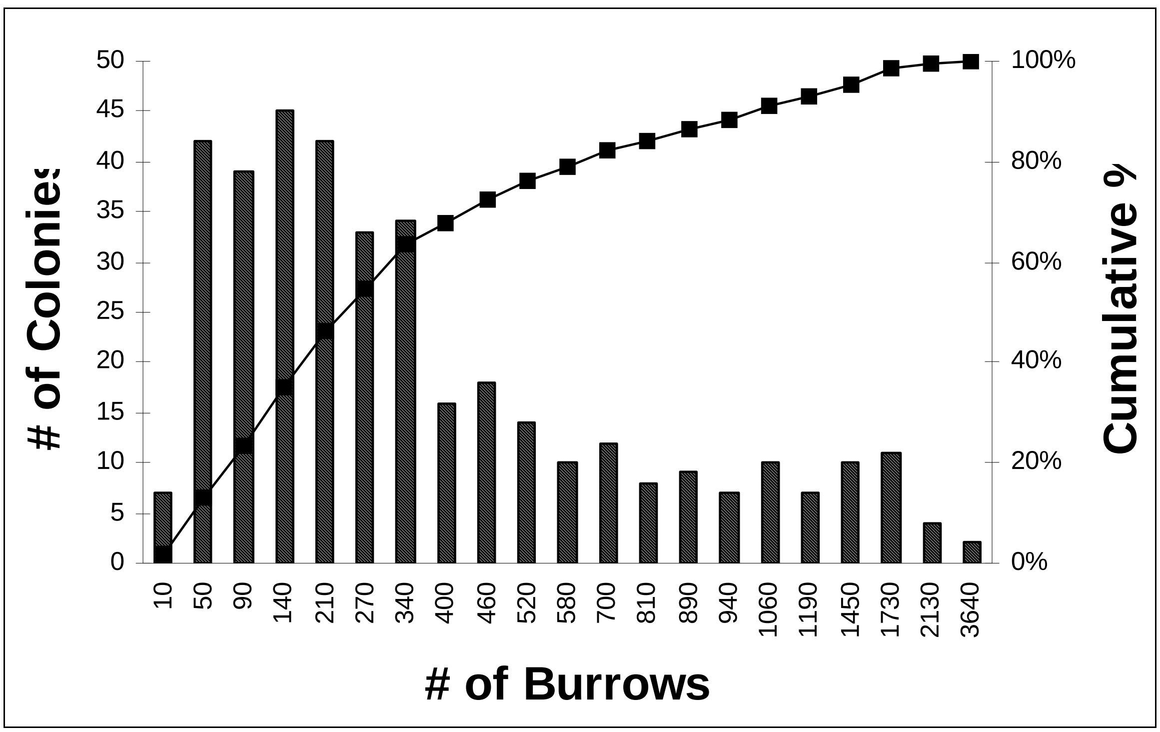

Figure 7. Distribution of Bank Swallow colonies by number of burrows for the 100-mile study reach (Reach 2 and Reach 3). The cumulative percent line on the second Y- axis shows that about 60% of the colonies are comprised of 340 or fewer burrows

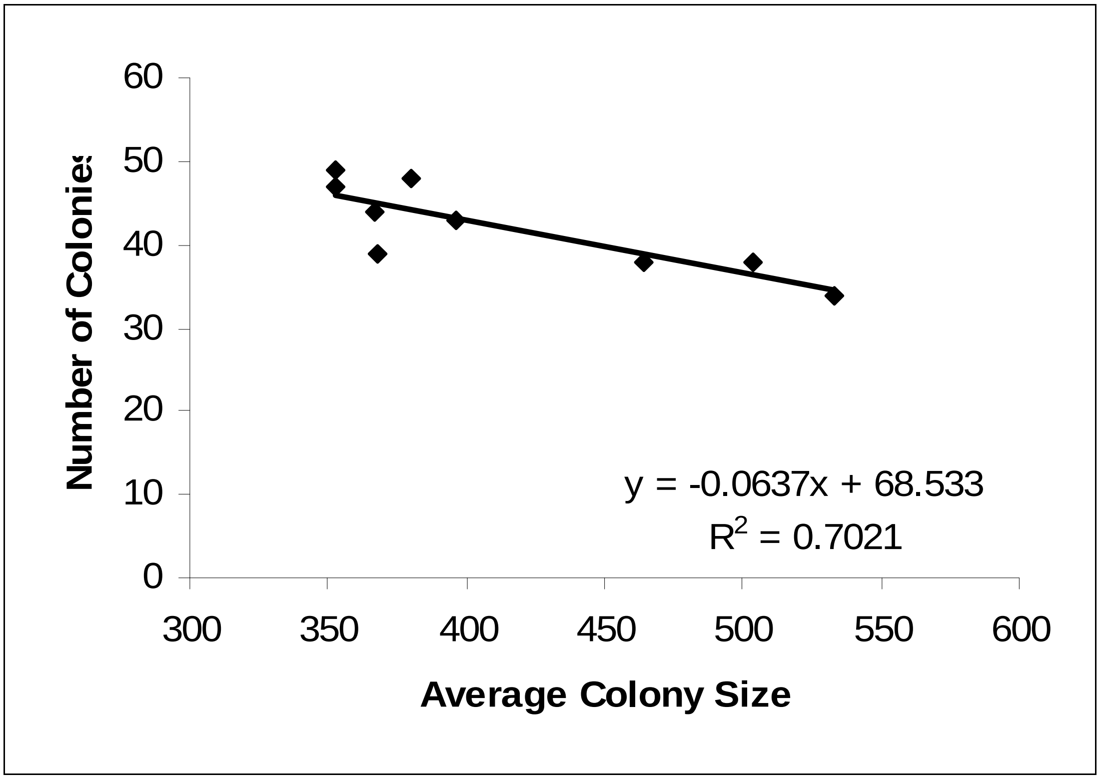

Figure 8. Regressing average colony size (burrows divided by colonies) with number of colonies shows and inverse relationship (R^2 = 0.7021). When fewer colonies occurred, the average colony size was larger

95 (24.9%) were in the large category and 37 (10%) were in the extra large category (Table 4). Figure 9 graphically depicts the variation in the number of colonies for each survey year. Colony size categories did not differ significantly between years (Contingency analysis, χ^2 = 19.659, p= 0.7160, Table 5). The distribution of burrows by colony size category further illustrates the relationship between number of colonies and mean colony size. For example of 38 total colonies in 2001, seven colonies (18%) in the extra-large category supported 10,500 or 55% of the total 19,170 burrows (Tables 2 and 4). Conversely, of 47 total colonies in 1999, only three extra-large colonies (6%) accounted for 22% (3,990) of the total 18,260 estimated burrows (Tables 2 and 4).

Table 4. Bank Swallow colony sizes subset into four size categories, based on number of burrows in each colony; small (*S*=10-130 burrows), medium (*M*=131-375 burrows), large (L=376-1000 burrows) and extra large (XL>1000 burrows) in each survey year. Data include the number of colonies (#C) and burrows (#B) and percentage of colonies (%C) and burrows (%B) contributing to each size category. Total numbers of colonies and burrow size category are summed below each column. Total percentages of colony and burrow number in each size category across all years are also calculated. For example, the total number of small colonies (*n*= 127) accounted for 33% of the total number of colonies (*n*=380). Data is inclusive of the 100 -mile study reach (Reach 2 and Reach 3)

Size	Small Colonies				Medium Colonies				Large Colonies				Extra Large Colonies			
Year	# C	% C	# B	% B	# C	% C	#B	% B	# C	% C	#B	% B	# C	% C	#B	% B
1999	18	38	1080	7	13	28	3090	19	13	28	8430	51	3	6	3990	24
2000	7	21	600	3	11	32	2500	14	11	32	6240	34	5	15	8790	48
2001	12	32	830	4	11	29	2660	14	8	21	5180	27	7	18	10500	55
2002	19	43	1340	8	10	23	2160	13	11	25	6640	41	4	9	6020	37
2003	12	25	4280	24	19	40	990	6	15	31	9740	54	2	4	2990	17
2004	15	35	1070	6	13	30	3520	21	10	23	6340	37	5	12	6110	36
2005	14	36	1200	9	14	36	3620	26	9	23	5760	41	2	5	3410	21
2007	13	34	900	5	13	34	3060	17	6	16	3660	21	6	16	10020	57
2008	17	35	960	5	17	35	4290	24	12	24	6290	36	3	6	6120	35
Total #	127	33	12260	8	121	32	25890	17	95	25	58280	38	37	10	57950	37

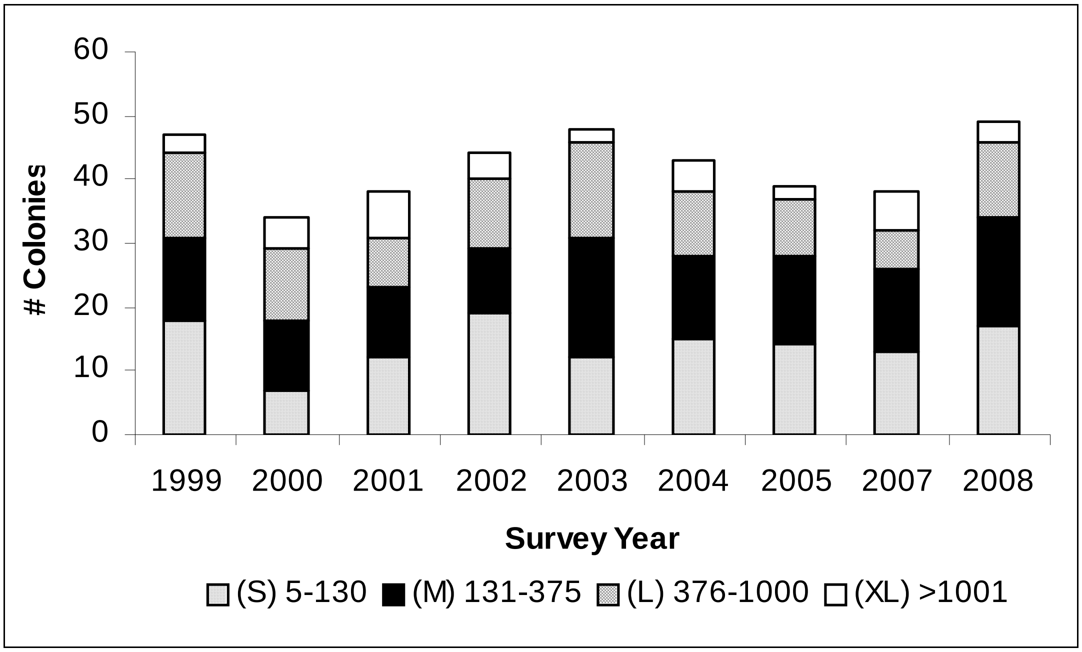

Figure 9. Contribution of Bank Swallow colony sizes subset into four size categories, based on number of burrows, small (S), medium (M), large (L) and extra large (XL) in each survey year for the 100-mile study reach (Reach 2 and Reach 3)

Colony variations in river reaches

In six of the nine monitoring years, there were more Bank Swallow burrows in Reach 3 (*n* = 81,745) than in Reach 2 (*n* = 72,900, Figure 10). There were also more colonies in Reach 3 (*n* = 219) than in Reach 2 (*n* = 162) except for in 2005 (Figure 10). Results of a Wilcoxon signed rank test suggested that the greater number of colonies in Reach 3 was significant (df = 8, T = -21.00, p = 0.0117). Results of a two-way ANOVA showed that the number of burrows in each reach did not differ significantly between reaches (F = 1.6189, p = 0.2041; Table 3), and the total burrow number did not vary between reaches between years (F = 0.8705, p = 0.5416; Table 3). However, the colonies were larger in Reach 2 (mean = 450, *SD* = 450) than in Reach 3 (mean = 373, *SD* = 447) in all years but 2001 (Figure 11). This results from a cumulative higher percentage of Large and X-large colonies, in Reach 2

Table 5. Contingency table and cell chi-square values showing the number of different colony size categories; Small, Medium, Large, and X-large, in each survey year for the 100 -mile study reach (Reach 2 and Reach 3) did not differ significantly. Colony counts observed, colony counts expected, and the cell chi-square value are recorded for each year in each size category column

Survey Year	Small (10-130 burrows)	Medium (131-375 burrows)	Large (376-1000 Burrows)	X-large (> 1000 burrows)	Totals Counts (%)
1999	18 15.7079 0.3345	13 14.7184 0.2006	13 11.75 0.1330	3 4.82368 0.6895	47 (12.37)
2000	7 11.3632 1.6753	11 10.6474 0.0117	11 8.5 0.7353	5 3.48947 0.6539	34 (8.95)
2001	12 12.7 0.0386	10 11.9 0.3034	8 9.5 0.2368	8 3.9 4.3103	38 (10.00)
2002	19 14.7053 1.2543	10 13.7789 1.0364	11 11 0.0000	4 4.51579 0.0589	44 (11.58)
2003	12 16.0421 1.0185	18 15.0316 0.5862	15 12 0.7500	3 4.92632 0.7532	48 (12.63)
2004	15 14.3711 0.0275	13 13.4658 0.0161	10 10.75 0.0523	5 4.41316 0.0780	43 (11.32)
2005	14 13.0342 0.0716	14 12.2132 0.2614	9 9.75 0.0577	2 4.00263 1.0020	39 (10.26)
2007	13 12.7 0.0071	13 11.9 0.1017	6 9.5 1.2895	6 3.9 1.1308	38 (10.00)
2008	17 16.3763 0.0238	17 15.3447 0.1786	12 12.25 0.0051	3 5.02895 0.8186	49 (12.89)
Total count (%)	127 (33.42)	119 (31.32)	95 (25.00)	39 (10.26)	380

(n = 67, 41%) than in Reach 3 (n = 72, 33%, Table 6). The mean colony size in each year was statistically significantly greater in Reach 2 than in Reach 3 (T = 19.5000, p = 0.0195, Table 7).

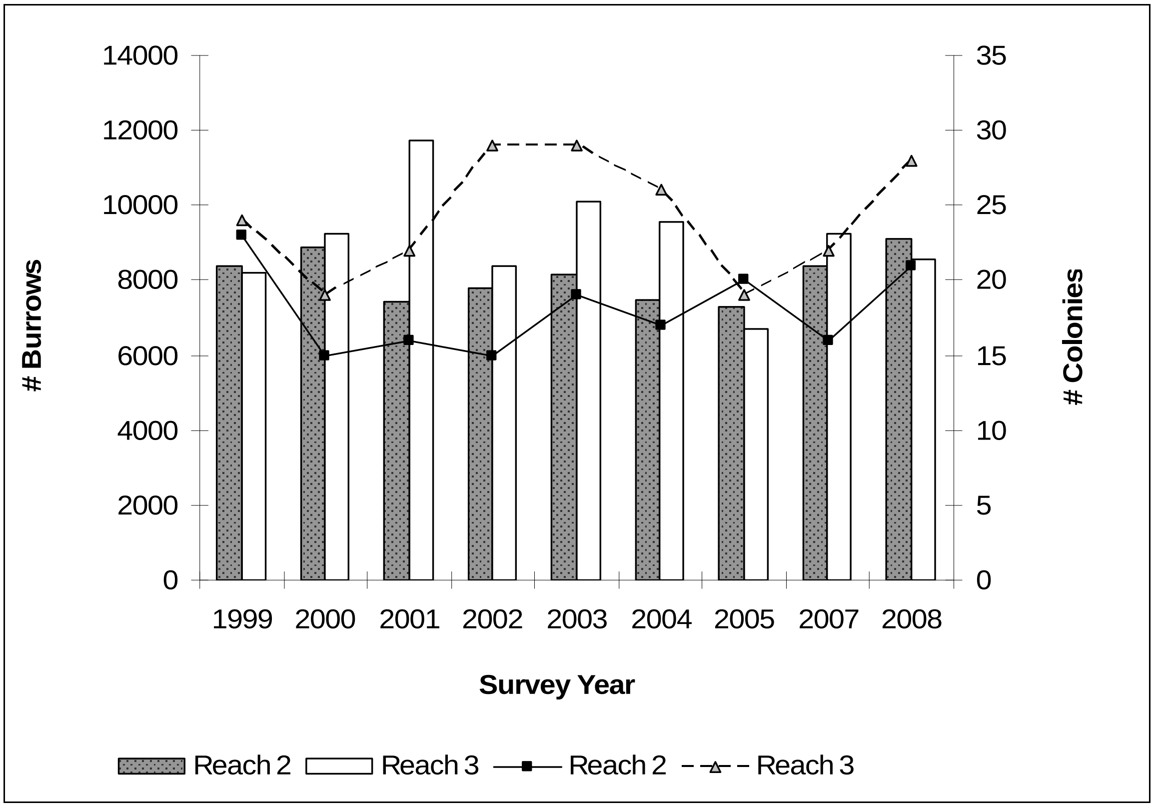

Figure 10. Number of burrows (bars, 1st Y-axis) and colonies (lines, 2nd Y-axis) in Reach 2 and Reach 3 in each survey year. Reach 3 has more burrows in six of the nine survey years and more colonies in all years with the exception of 2005

Colony persistence

Across all survey years there were a total of 118 colonies classified by persistence categories, with the majority of the colonies (N = 67) active for only 1-2 years (Table 8). There was a consistent tendency for colony size (numbers of burrows) to increase with persistence (Table 8, Figure 12). Appendix C shows each reach by its persistence category and the number of years of activity across the entire study area, RM 244 through RM 144.

Colonies persisted from 1 through 10 years in each Reach. Reach 3 supported more colonies in each persistence category, except the CAA category (8-10 years of activity), compared to Reach 2 (Table 8). However, there were no significant differences in mean

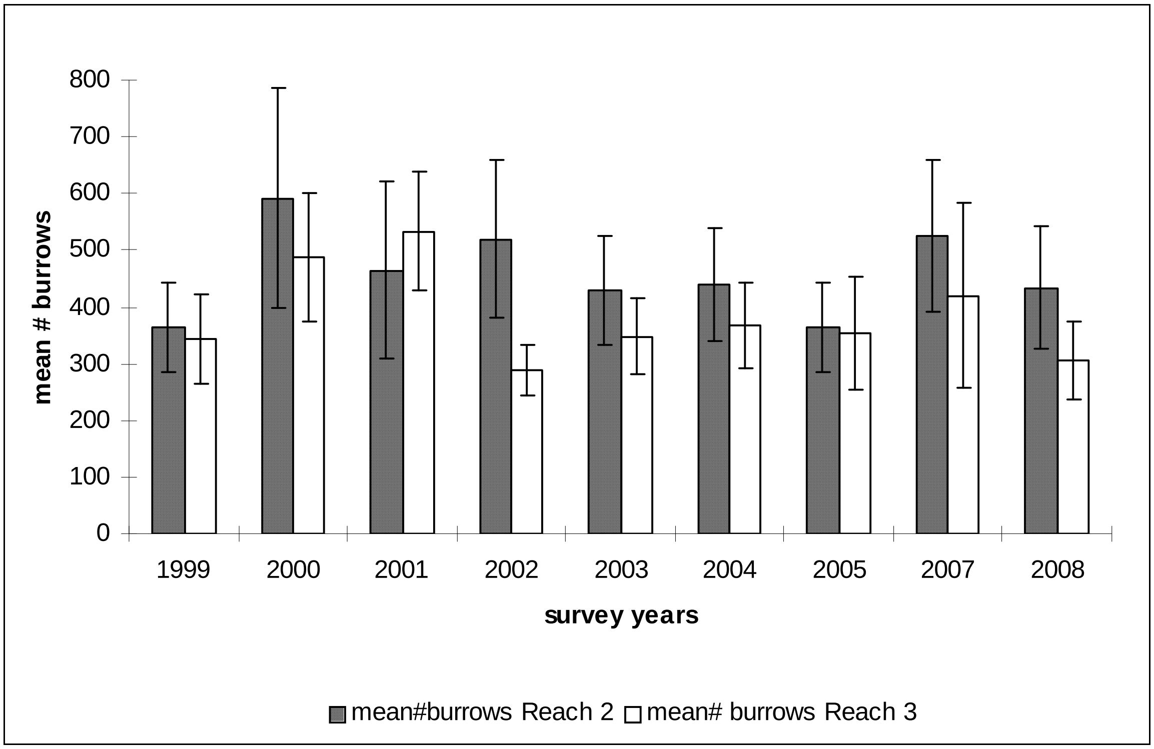

Figure 11. Mean colony size (number of burrows) with standard error bars for each survey year in Reach 2 and Reach 3. Reach 2 has larger colonies (more burrows per colony) than Reach 3 in all survey years with the exception of 2001

Table 6. Total number and percentage (%) of each colony size category, Small (S=10-130), Medium (M=131-375), Large (L=376-1000) and Extra Large (XL>1000), in Reach 2 and 3 across all survey years

Size category	Reach 2 # colonies	Reach 3 # colonies
Small	52 (33)	75 (34)
Medium	42 (26)	72 (33)
Large	47 (29)	54 (25)
Extra Large	20 (12)	18 (8)

Table 7. Mean colony size (number of burrows) in Reach 2 and Reach 3 and difference between the means. This paired T-test data table shows the colony average (number colonies divided by number of burrows) is larger for all years in Reach 2 except for 2001

Survey Year	Reach 2 Mean Colony Size	Reach 3 Mean Colony Size	Mean Difference Colony Size R2-R3
1999	364	343	21
2000	591	487	104
2001	465	533	-68
2002	519	289	230
2003	430	348	82
2004	440	368	72
2005	364	353	11
2007	525	420	105
2008	434	295	139

burrow numbers between Reach 2 and 3 ($F = 0.1012$, $p = 0.7505$, Table 9). The difference in mean number of burrows between persistence categories was significant ($F = 33.7120$, $p = < 0.0001$, Table 9), with the mean number of burrows significantly higher in CAA colonies (persisting 8-plus years), than all other persistence categories (Figure 12). Colonies in the FAA group (5-7 years of activity) were also significantly higher than those colonies that persisted from 1-4 years (C and OAA groups).

Flow and colony relationships

Mean winter flow in the study area was highest in 2006 with flows recorded between 37,000 and 40,500 cfs (Figure 13). In years 1999, 2000 and 2004, mean winter flows averaged between 23,000 and 25,000 cfs. Low flow years, 2001, 2005, 2007 and 2008, averaged between approximately 9,000 and 11,000 cfs. As expected, averaged winter flows were generally highest at the most downstream gauges, BTC (RM 168) and ORD (RM 184), respectively. However, in nine out of the 10 years, the most upstream VIN gauge (RM 218) reported higher flows than the HMC (RM 199) gauge approximately 17

Table 8. Summary breakdown of each colony persistence category in Reach 2 and Reach 3 in all survey years. The colony count, mean number of burrows and standard deviation (SD) and range of burrows are included for each category. The four persistence categories indicate how many years a colony was active: casually active (C, 1-2 years), occasionally active (OAA, 3-4 years), frequently active (FAA, 5-7 years) and consistently active (CAA, 8-10 years) in each Reach 2 and 3

Study Reach	Reach 2					Reach 3				
Persistence Status	C	OAA	FAA	CAA	Total	C	OAA	FAA	CAA	Total
Colony Counts (N)	22 (49)	7 (16)	7 (16)	9 (20)	45	45 (61)	10 (13)	11 (15)	7 (10)	73
Mean # Burrows	195	198	318	699		146	278	403	620	
SD	212	191	272	600		151	353	374	368	
Max # Burrows	970	840	1130	2770		850	1840	1420	3640	
Min # Burrows	10	40	20	40		10	10	10	50	

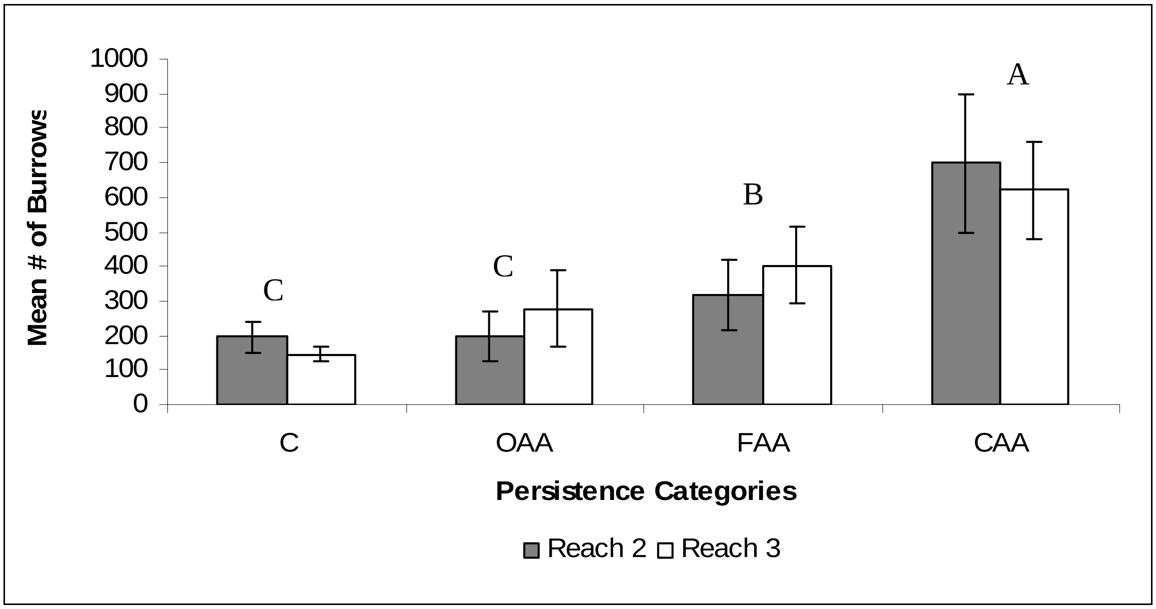

Figure 12. Mean number of burrows (± SE) in each persistence category. Colonies that persist longer are on average larger (have more burrows).Colony persistence categories; casually active (C, 1-2 years), occasionally active (OAA, 3-4 years), frequently active (FAA, 5-7 years) and consistently active (CAA, 8-10 years) in each Reach 2 and 3, with standard error bars. Letters above the persistence categories are the results of a Tukey analysis. Letters not connected by the same letter show that burrow means in the categories are significantly different

river-miles downstream. In all years, the difference in flow between gauges ranged from 418 cfs in 2007 to 4,470 cfs in 2000. The average flow difference between the gauges in each survey year was just less than 2,400 cfs (Figure 13).

With respect to maximum flow in the study area, the two highest peak events occurred in water years 2006 and 2004 with maximum flow at the VIN gauge (RM 218) of 140,000 and 114,000 cfs, respectively (Figure 14). Years 2000, 2002, 2003 had maximum flows of over 80,000 cfs. The lowest flow datum was recorded in 2007 at approximately 40,000 cfs. Maximum flow differences between the gauges were variable but most pronounced in the highest flow years 2004 and 2006. The VIN gauge recorded higher flows of 18,400 and 32,000 cfs, respectively, than any of the downstream gauges (Figure 14).

Table 9. Two-way ANOVA table testing the difference in burrow numbers as a dependent variable of persistence category and reach, and the interaction of both. Significant at $p < 0.05$. Tukey Kramer analysis – letter not connected by the same letter are significantly different. *Burrow means are based on transformed data

Source of Variation	*DF*	*SS*	*F*	*p*
Persistence Category	3	116.44848	33.7120	<.0001
Reach	1	0.11658	0.1012	0.7505
Reach x Persistence Category	3	4.56418	1.3213	0.2671
Error	372	428.32279		
Total	379	564.13421		
Persistence categories	Tukey–Kramer HSD			*Burrow means
CAA	A			6.06
FAA		B		5.56
OAA			C	4.93
C			C	4.58

Mean winter flows were a weak predictor of the number of burrows (R^2 = 0.000296) or the number of colonies (R^2 = 0.00039) each year. Similarly, maximum flows were a poor predictor of the numbers of colonies (R^2 = 0.007921) or burrows (R^2 = 0.00004) each year (Figures 15 and 16).

The one-way ANOVAs to test differences in flows between the persistence categories were both significant (Tables 10 and 11). Mean winter flows were significantly lower (F = 25.3981, p = <.0001) in the CAA persistence category (8-10 years of persistence) than in all other categories. Although winter flow was significantly different, it was only 746 cfs lower than the FAA category that had the highest mean winter flow (Table 10). The maximum peak flows also differed significantly (F = 4.6225, p = 0.0034) between the CAA category and the FAA and C categories (Table 11). The lowest mean winter flow was 19,792 cfs

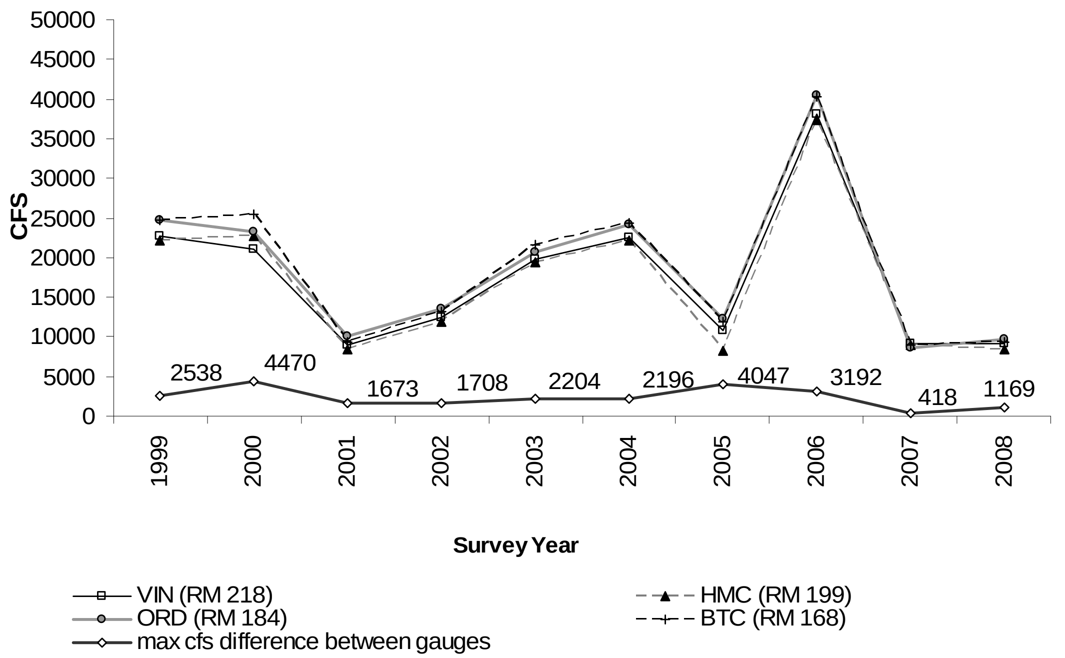

Figure 13. Mean winter flow (December – April) in cubic feet per second (cfs) for survey years 1999-2008 at four gauges on the Sacramento River and maximum (cfs) difference between gauges by year. Gauges from upstream to downstream are VIN (RM 218), HMC (RM 199), ORD (RM 184) and BTC (RM168), respectively

(Table 10) in the CAA category, and the mean maximum flow occurred in this category at 79,237 cfs (Table 11).

There were no significant differences between either mean winter or peak flow rates in relationship to the different colony sizes (Tables 12 and 13).

Relationship between erosion, sinuosity and overstory vegetation and colony persistence categories

River sinuosity was slightly higher in the randomly selected portions of the river in 2007, but not significantly greater than in 1997 (T = 1.5017, p = 0.1412, Figure 17). Mean sinuosity in relationship to the Bank Swallow persistence categories was highest in the

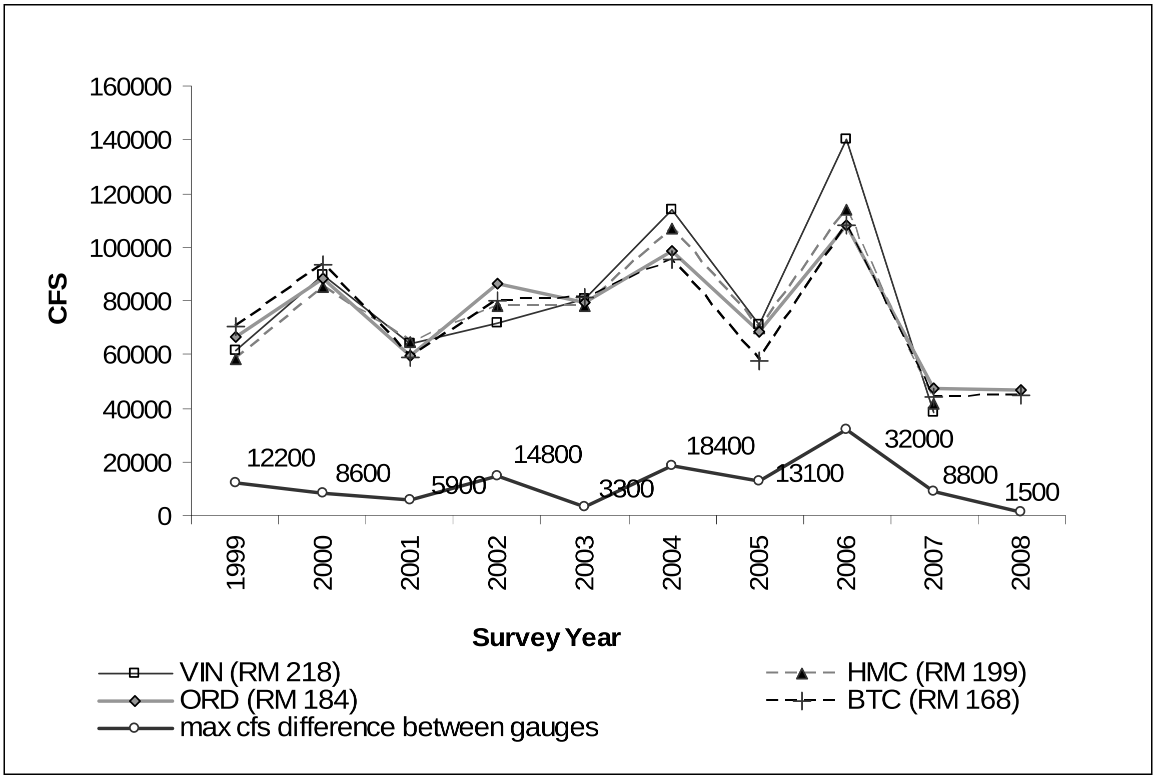

Figure 14. Maximum peak flow in cubic feet per second (cfs) for survey years 1999-2008 at four gauges on the Sacramento River. Maximum cfs difference between gauges by year is also depicted. Gauges from upstream to downstream are VIN (RM 218), HMC (RM 199), ORD (RM 184) and BTC (RM168), respectively

following order, FAA, CAA, OAA, and C, but not significantly so ($F = 0.2295$, $p = 0.875$, Figure 17).

Bank Swallow colonies were documented at 10 of the 11 erosion sites. Numbers of colony persistence categories included seven CAA, one FAA, one OAA and one C (Figure 18). The distances eroded from most to least at each persistence category were in this order: OAA, CAA, FAA, C, and the site with no colonies (Figure 18). The CAA categories were located at sites that eroded an average distance of 144 feet (43.9 meters, $n = 7$, $SD = 60$') over the four mapped years (2000-2004). These distances ranged from 78-237 feet (23-72 meters). The single colony and no colony sites eroded 46 and 47 feet (approximately 14

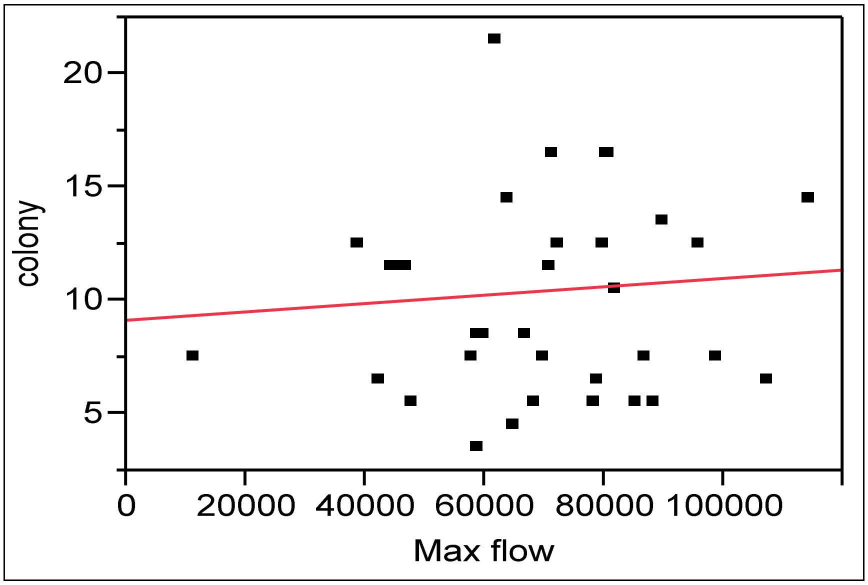

Figure 15. Scattergram and best fit line regressing number of colonies with peak flow. The analysis shows that peak flow is a poor predictor of number of colonies each year (R^2=0.007921)

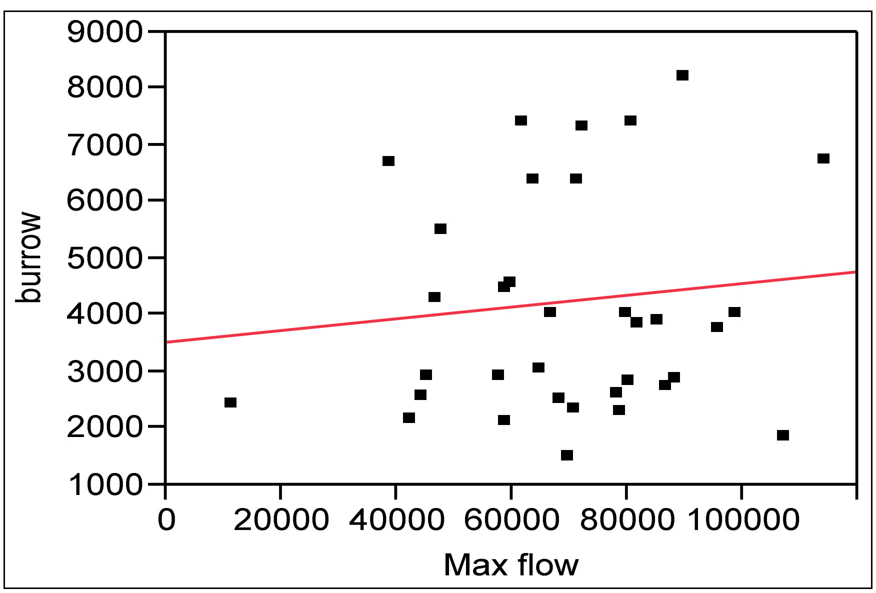

Figure 16. Scattergram and best fit line regressing number of burrows with peak flow. The analysis shows that peak flow is a poor predictor of number of colonies each year (R^2=0.00004)

Table 10. One-way ANOVA results and means comparisons testing the differences in mean winter flow rates (December – April) between persistence categories: C, OAA, FAA, CAA. The model is significant at $p < 0.05$. Tukey- Kramer results indicate that mean winter flows were significantly lower in the CAA then all other categories. Letters not connected by the same letter are significantly different

Source of variation		*DF*	*SS*	*MS*	*F*	*p*
Persistence		3	42446638	14148879	25.3981	<0.0001

Years Persistence Category	Tukey-Kramer HSD		*N*	Mean Winter Flow (cfs)	Std Error	Lower 95%	Upper 95%
C (1-2)	A		86	20430.6	80.484	20272	20589
OAA (3-4)	A		61	20492.7	95.564	20305	20681
FAA (5-7)	A		101	20538.8	74.268	20393	20685
CAA (8-10)		B	132	19792.5	64.964	19665	19920

Table 11. One-way ANOVA results and means comparisons testing the differences in maximum winter flow rates (December – April) between persistence categories: C, OAA, FAA, CAA. The model is significant at $p < 0.05$. Tukey- Kramer results indicate that maximum flows were significantly higher in the CAA then C and FAA categories. Letters not connected by the same letter are significantly different

Source of variation		*DF*	*SS*	*MS*	*F*	*p*
Persistence		3	52097622	17365874	4.6225	0.0034

Persistence Categories	Tukey-Kramer HSD		N	Mean Maximum Flow (cfs)	Std Error	Lower 95%	Upper 95%
CAA (8-10)	A		132	79237.2	168.70	78905	79569
OAA (3-4)	A	B	61	78946.9	248.17	78459	79435
C (1-2)		B	86	78462.2	209.01	78051	78873
FAA (5-7)		B	101	78405.1	192.86	78026	78784

Table 12. One-way ANOVA testing the mean difference in maximum winter flow in relationship to four Bank Swallow size categories: S, M, L and XL. The model is significant at $p < 0.05$. Means with the same letter were not significantly different based on Tukey- Kramer comparisons

Source of variation		*DF*	*SS*	Mean Square	*F*	*P*
Colony Size		3	18879685.	16293228	1.636	0.1804

Colony Size	Tukey-Kramer	N	Mean Max Flow (cfs)	Std Error	Lower 95%	Upper 95%
XL (>1000)	A	37	79340.3	322.37	78706	79974
L (376-1000)	A	95	78955.4	201.18	78560	79351
S (10-130)	A	127	78683.1	174.00	78341	79025
M (131-375)	A	121	78616.8	178.26	78266	78967

Table 13. One-way ANOVA results and means comparisons testing the differences in mean winter flow rates (December – April) between size categories: S, M, L and XL. The model is significant at $p < 0.05$. Means with the same letter were not significantly different based on Tukey- Kramer comparisons

Source of variation		*DF*	*SS*	Mean square	*F*	*p*
Colony Size		3	111248736	37082912	0.9323	0.4251

Persistence Categories	Tukey-Kramer	N	Mean Winter Flow (cfs)	Std Error	Lower 95%	Upper 95%
L (376-1000)	A	94	16659.6	650.5	15381	17939
M (131-375)	A	121	15734.5	573.3	14607	16862
S (10-130)	A	127	15414.9	559.6	14315	16515
XL (>1000)	A	38	15030.3	1023.1	13019	17042

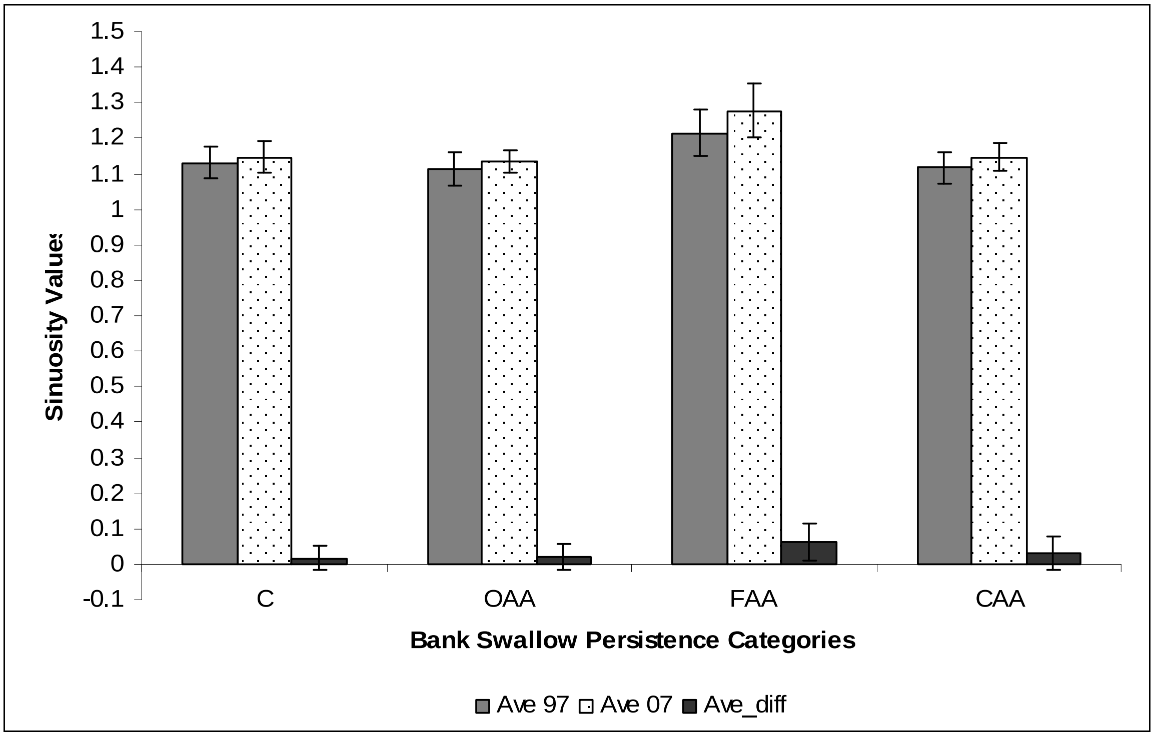

Figure 17. Sinuosity values (unit-less, Y-axis) for 1997 and 2007 and the difference between the two years, with standard error bars, at each of the four colony persistence categories; C, OAA, FAA, and CAA. There was slightly more sinuosity (curviness of the river channel) at the FAA categories, those areas with 5-7 years of Bank Swallow activity. Ten colonies were randomly selected at each persistence category along the entire study reach

meters) respectively, over the four years. The site where there were no colonies had riprap located 400 feet upstream and downstream from the center point.

All of the persistence categories were most associated with “native vegetation” groups, herbaceous/scrub mix and riparian forest (Figure 19). Colonies that persisted the longest (CAA) had the highest association with grassland/scrub (118 acres or 50%) and secondly with riparian forest (61 acres or 28%), while the other three categories had a higher association with riparian forest followed by herbaceous scrub (Figure 19). The OAA category had the highest association with riparian forest (98%) followed by deciduous orchard (14%).

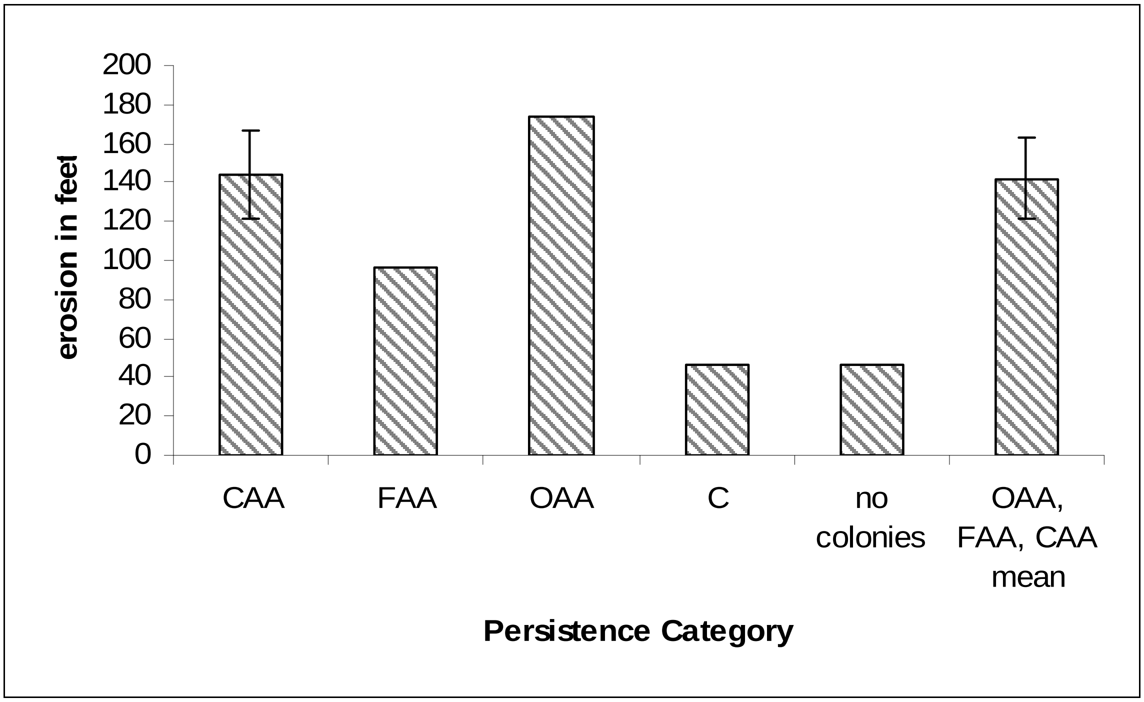

Figure 18. Distance in feet of bank erosion between years 2000-2004 at 11 selected sites where erosion was measured by the Department of Water Resources. Erosion was higher at sites with 3-10 years of activity (OAA, FAA, and CAA), then at a colony with 1 year of activity and a site where no colonies were documented. The numbers above the columns represent the number of colonies in each persistence category found at the 11 erosion sites

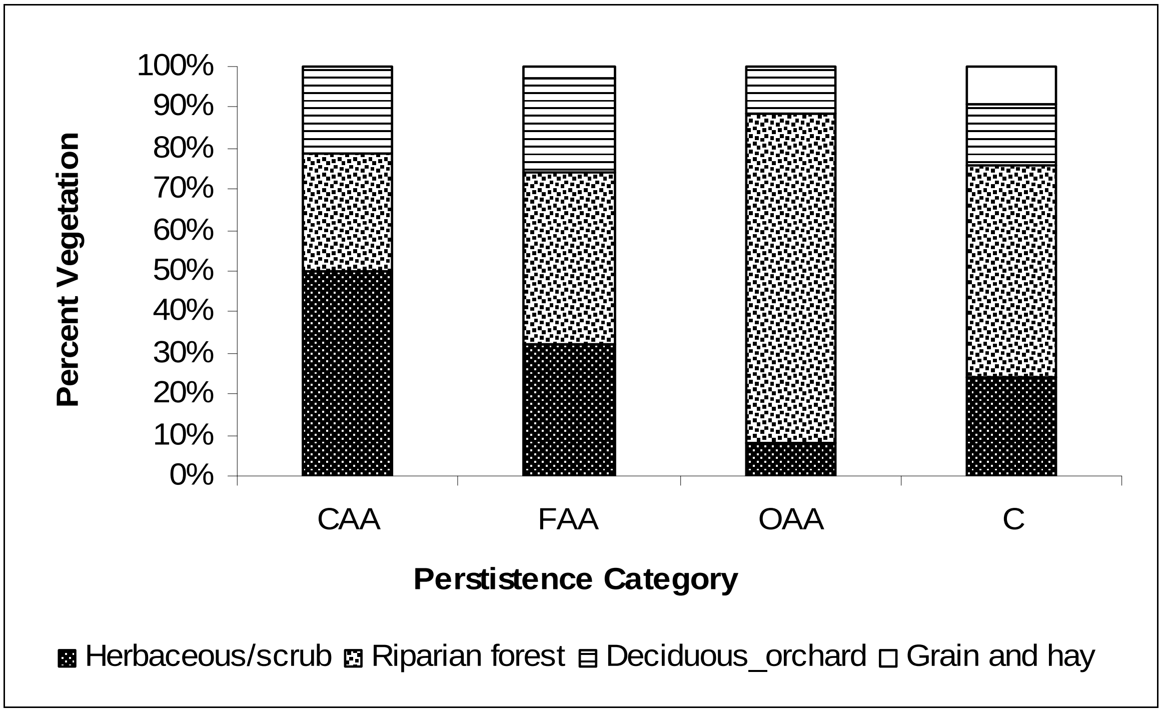

Figure 19. The number of acres of five categories of overstory vegetation in a 300-foot buffer around each Bank Swallow colony persistence category. Native riparian habitats, grasslands/scrub and riparian forest comprised the bulk of overstory vegetation where colonies were active

CHAPTER V

DISCUSSION

Variation in annual colony size and persistence in the study area and reaches

The Sacramento River Bank Swallow population fluctuated over the nine survey years between an estimated 14,000 and 19,000 burrows; there were no significant differences in mean number of burrows over all survey years. There were no discernable temporal trends related to the number of colonies, colony size (number of burrows) and persistence in the 10-year survey period with the population averaging 42 colonies (*SD* = 5.2) and 17,182 burrows (*SD* = 1,502). The distribution of the colony sizes; S, M, L, XL, did not vary significantly between years. Similarly, the four persistence categories: C, OAA, FAA and CAA, were present throughout the 100-mile study reach. These trends suggest that the population decline noted in the late 1980’s has not continued over the last 10 years. However, it is critical to note that the mean number of burrows in 1999-2008 remains 29% below the 24,110 burrows estimated on the 100-mile reach in 1986. Further, the two independent PVAs conducted for the Sacramento River Bank Swallow suggested that with the current numbers, the population is vulnerable to extinction within the next 50 years.

The distribution of all colony sizes was similar each year over the entire survey period indicating that the various colony sizes are a regular and vital component of annual and long-term Bank Swallow dynamics on the Sacramento River. The continued presence of different colony sizes may be an adaptation to inhabiting unpredictable nesting resources, such as seen on the Sacramento River. Freer (1977) suggests the variable distribution of Bank Swallow colonies and sizes might be an adaptation to increase the probability that the best nesting locations are used to avoid nest site conflicts. Other research suggests that colony sizes may be a heritable preference; swallows seek the size colonies they were hatched from (Brown and Brown, 2000).

Results from this study and other research for the Sacramento River Bank Swallow population (Garrison *et al*., 1987; Garrison, 1991) show that although colonies ranged from 10 to over 3,000 burrows, over 60% of the colonies were in the small and medium sized categories (10-340 burrows with the majority from 50-340 burrows). There is a steep decline in colony numbers that are larger than 340 burrows. This distribution may indicate an optimal colony size and/or constraints related to erosional processes that limit the area of available habitat. Serrano et al. (2005) found that survival probability is higher in large colonies of Lesser Kestrels (*Falco naumanni*) and suggest there is likely an optimal colony size where individuals experience highest breeding success; but optimal colony size was undetermined. The research on cost and benefits of colony size is varied. Increased colony size has been correlated with increased competitive interactions between swallows for mates, nest sites and nesting materials, and ectoparasite transmission (Hoogland and Sherman, 1976). Freer (1977) citing Darling (1938) reports that colony size has been related to greater social stimulation leading to greater breeding synchrony and higher reproductive success; the larger the colony the more synchronized the temporal pattern of nesting and fledging, which reduces exposure to predation when the nestlings are most vulnerable.

For the Sacramento River Bank Swallow population we do not know the relative contribution of the various colony sizes to overall population dynamics and therefore there is a vital need to research the dynamics (e.g., productivity, survivorship, nestling fitness, ectoparasite load, and occupancy) of each colony size.

Spatially within the 100-mile study area subset into the two distinct reaches, Reach 2 and Reach 3, there were some significant differences in colony parameters. Reach 3 had significantly more colonies compared to Reach 2 whereas Reach 2 had significantly larger colonies. Larger colonies in Reach 2 may indicate better resources and/or more conducive river processes that support large colonies than what is found in Reach 3. For example, Reach 2 may have a more dynamic channel or widespread erosional processes (exposing larger bank surface) than Reach 3 due to greater tributary input, six versus one, respectively. Higher cut banks in Reach 2 may also provide a larger burrowing surface but these areas may be more limited due to geologic differences (more volcanic deposits). In contrast, downstream Reach 3 with almost 50% more small and medium size colonies than Reach 2, has one major tributary, is lower gradient, more widely meandering, and has finer and less gravelly soils. Further, vegetation mapped in 1999 showed that Reach 3 had more than double the percentage of riparian vegetation and three times less agricultural landcover than in Reach 2 (Table 1), which could potentially create a greater amount but smaller patches of suitable burrowing habitat exposed by more localized, rather than widespread, erosion. Conversely, the features found in Reach 2 (high tributary input, higher gradient, coarser soils, less riparian landcover) might contribute to less stable banks and more widespread erosion.

Colony size has been linked to colony persistence (Garrison, 1999; Moffatt *et al.*, 2005). Moffatt *et al.* (2005) revealed in their research for the Sacramento River Bank Swallow population that the probability of colony extinction increased with decreasing colony size (i.e., number of burrows), indicating larger colonies persist longer than smaller colonies. My results showed that colonies can persist in an area from seven to possibly 10 years and indicated that longer persisting colonies had on average a greater number of burrows. Approximately 30% of the categorized colonies were persistent for over 3 years but over half (57%) of the total colonies were viable only 1-2 years. Garrison (1999) also indicated that some colonies were known to persist up to seven years but 2-3 years was more typical.

There was no significant difference in colony persistence categories between reaches however; Reach 3 had a higher percent (61%) of short-term, smaller colonies compared to Reach 2. Almost nine miles of active Bank Swallow habitat were mapped in Reach 3 as compared to only one mile of active habitat in Reach 2 (Table 1). Together, the distribution of smaller colonies and the amount of mapped habitat may indicate ephemeral localized erosional events are more common in Reach 3 as noted above.

The positive relationship between large colony size and persistence revealed in my research suggests frequent and likely more widespread erosional events (exposing more bank surface) have occurred along the riverbanks where colonies persist. In contrast, short-term colonies also tended to be smaller and many were likely taking advantage of small, but newly eroded bank surfaces. Swallows colonize localized pockets of freshly eroded surfaces exposed by bank undercutting orchards or forest or between failing riprapped banks (pers. obs.). Banks that are not refreshed quickly, within 2 to 3 years, lose their nesting quality; they have a higher ectoparasite load (Freer, 1977, 1979; Blem, 1979; Garrison, 1989, 1991, 1998, 1999; Schlorff, 1997), become hardened, with increased slope and vegetation growth (Figure 2) allowing for increased predation. Long-term colony persistence in any given area then must be a result of erosion caused by physical processes and features including river flow, channel morphology, and vegetation type.

Annual variation among colony sizes appears to be the norm. Although larger colonies tended to be more persistent, colony size varied in each year of persistence. For example, a CAA colony 189.7R active for 10 years consisted of all four size categories with the smallest being 90 burrows (S) in 2005 and the largest being 2,130 burrows (XL) in 2000. Similarly, although the majority of colonies (59%) persisting only 1 or 2 years were small, 41% were medium (n = 26) and large (n = 9) colonies. Garrison's (1998) compilation of international Bank Swallow research cited eight studies ranging from two to 17 years of monitoring which illustrated similar annual variation in colony sizes in single site persistent colonies. Individual colonies vary annually due to numerous factors including predation, habitat conditions, and wintering and migration events (Garrison, 1998).

Colony persistence in relation to sinuosity and erosion

Both reaches continue to be actively dynamic with sinuous channels, evidenced by scars in the floodplain and current straight and meandering stretches. In a meandering river, channel shifts are caused primarily by erosive forces undercutting the outside bend of the meander loop (Gordon *et al.*, 2004). Sinuosity is also influenced by vegetation, soils, and natural or created geologic control (e.g., volcanic deposits and riprap) and driven by flow. Despite placement of rock which stabilizes the channel, sinuosity and channel migration rate may not have decreased because bank erosion has increased with conversion of forests to agriculture (pers. comm. E. Larsen, 2009), which reduces channel stability. Results of this study show that sinuosity increased very slightly from 1997 to 2007 at analyzed colony locations. Sinuosity values did not show an increasing pattern with increasing colony persistence; however, FAA categories (5-7 years) were associated with higher sinuosity values than any other category. Both FAA and CAA (5-10 years of activity) persistence categories had greater sinuosity differences between 1997 – 2007, likely pertaining to erosion.

Similarly erosion, the main process in the creation of Bank Swallow habitat, showed no hierarchical pattern in relation to long-term persistence, although the erosion distance was greatest at sites persisting three plus years. Also, the three long-term categories (OAA, FAA and CAA) combined ($n = 8$) eroded an estimated 100 feet more in four years than the colony that lasted one year and in the site where there were no colonies documented (Figure 18).

Variation in flow and relationships to colonies

River flow, the force behind erosion, has been moderated since construction of the Shasta Dam in 1944. Larsen and others research (2006) shows that erosion may occur locally anywhere above 14,000 cfs, depending on the duration of the flows. Buer *et al.* (1989) measured bank erosion at 67 sites on the Sacramento River determined that longer duration of flow above an erosion threshold (> 13,000 cfs) caused local erosion. High winter and spring flows resulted in more bank erosion than low summer flows. In my study, the mean winter flows for the dry years 2001, 2005, 2007, and 2008 did not even reach the local erosion threshold, but higher mean daily flows did contribute to the mean monthly flow values, some for an extended duration. For example, for five days in January 2007 (a dry year), mean daily flow values documented at the Ord Ferry (ORD) gauge were well above the erosion threshold ranging from 17,400 cfs to 46,600 cfs (CDWR, 2009).

However, of all factors that influence bank erosion, flow magnitude may be the most significant (Larsen *et al.*, 2006). Bankfull flows are known to cause widespread erosion (Buer *et al.*, 1989; Larsen *et al.*, 2006; Stillwater Sciences, 2007). On the Sacramento River bankfull flows vary dependent of location but historically ranged between just over 80,000 cfs (Snowden, 2002; Larsen, 2006; Stillwater Sciences, 2007) to 110,000 cfs at Ord Ferry (Buer *et al.*, 1989) with a recurrence interval of approximately every 1.5- 2.0 years (Snowden 2002; Larsen *et al.*, 2006; Stillwater Sciences, 2007). Since the construction of Shasta Dam and flood control structures over the last 62 years, bankfull flows have been reduced to approximately 61,000 cfs at Red Bluff (Snowden, 2002; Larsen *et al.*, 2006) although 88,000 cfs has been documented at this site (Stillwater Sciences, 2007). During the driest survey years in my study, peak flows ranged from 38,000 - 70,800 cfs, within the range documented to cause both local and more widespread erosion. Garrison *et al.* (1989) suggested that dry years may produce a larger number of small colonies due to localized erosion, whereas wet years may produce a larger number of large colonies due to widespread erosion through the system. My results did not show a relationship with either number of colonies or colony size in relation to mean winter flow or maximum flow. Though survey years 2000 and 2008 might support Garrison's theory. In 2008, a dry year, 49 colonies were documented, the highest number recorded with the second lowest mean colony size during the nine year survey period, indicating many but smaller colonies. Further, during 2000, a wet year, with the highest mean and peak flows recorded during the surveyed years, only 34 colonies with the highest mean colony size were documented, indicating fewer but larger colonies. Other years were variable. Moffat *et al.* (2005) observed that high flows released pre-breeding season (during winter/spring) increased both colonization and extinction probabilities for the Sacramento River Bank Swallow population. The explanation is that existing unoccupied colonies (which could be used again) would go extinct by erosion processes, but in turn this process would create fresh burrowing surfaces for incoming breeding birds (Moffat *et al.*, 2005). Based on these studies and additional investigations conducted on the Sacramento River, Stillwater Sciences (2007) suggested flow parameters for inclusion in the Bank Swallow HSI.

Colony relations to bank overstory vegetation

As noted, vegetation influences the physical nature of riparian systems; mature riparian vegetation lined banks indicate that banks are stable (Murdock *et al.,* 1996; Gordon *et al.*, 2004). Riparian vegetation increases channel roughness, effectively deflecting flows to the central channel, reducing velocity and shear stress along the bank (Wynn, 2006). So, vegetated banks can influence channel planform, such as affecting sinuosity by hindering chute cutoffs, a process that results in a straighter channel. Agricultural floodplains are 80-150% more erodable than riparian forest floodplains (Larsen *et al.*, 2006). Therefore, highly erodable agricultural landscapes may increase suitable habitats for the Bank Swallows. However, they may be more prone to bank collapse during late spring and early summer flows.

The results of this research showed that all persistence categories were associated most with riparian habitats, both herbaceous/scrub and forest. The colonies that persisted the longest (8-10 years) were associated most with herbaceous/scrub. This habitat type, likely consisting of meadows, open areas such as fallow fields and native grasslands and potentially wetlands and open water, have greater erosion potential then riparian forests. They are also all important foraging areas for all swallows, including the Bank Swallows (Stoner, 1936;

Gross, 1942; Freer, 1977; Garrison, 1999). Freer (1977) noted that bank swallows in her study rarely foraged over the woodlands but made direct foraging flights over meadows. Moffatt *et al.* (2005) suggested that on the Sacramento River, colony extinction increased with distance to grassland, relating that to distance to foraging area. Garrison *et al.* (1987) also found that the majority (~56%) of the Sacramento River colonies were adjacent to open grass fields.

There may be another reason as to why swallow colonies are associated with grassland and open habitat types. Banks with a sod layer versus those with obstructions such as tree roots and irrigation plumbing (found in orchards) may be easier to burrow into (Freer 1977; Garrison, 1999). Research has found that burrows with large sand grains and gravels, rocks, roots and other obstructions cause abandonment of the burrowing effort (Heneberg, 2001, 2009). Also vegetation overhanging burrows, as seen in undercut orchards and riparian stands, can provide burrow access to predators.

Conclusions

The results of this research based on the spatial distribution of colony location, size and persistence, confirm that the entire study reach from Red Bluff to Colusa is invaluable Bank Swallow nesting habitat. Both reaches contributed in slightly different ways to population persistence; Reach 2 with larger colonies and Reach 3 with more colonies. The contribution of the four colony sizes and persistence categories were distributed fairly evenly across all years and within each reach, indicating all colony sizes and length of activity are important to annual dynamics and stability of this population. Large colonies may produce more offspring in any given year where bank area is greater and erosional processes are consistent. For example, the annual population estimated in 2000 where 47% of the colonies consisted of Large and X-large colonies might have increased productivity due to high social stimulation as suggested by Freer (1977). However, these annual populations consisting of few, large colonies are at greater risk of a significant population crash during stochastic events such as high flows in the nesting season; an event that occurred in the summer of 1998 (Silveira, 2008). Implications of climate change such as decreased snowpack and increased rainfall could exacerbate this possibility of large flows and releases from Shasta Dam. While small colonies are not persistent at specific locations, they are persistent through time. Small colonies are highly mobile and exhibit the flexibility to colonize localized and ephemeral habitat patches that are randomly exposed in any given year. Further, if colony size preference is a heritable trait as suggested by Brown and Brown (2000), all colony sizes must be given equal regard when managing for the Bank Swallow. Consideration of these colony characteristics is essential to inform river policy and management of the Bank Swallow; it clarifies the necessity to retain all existing and potential future habitat, no matter how expansive–or small–the bank.

Colony size and persistence suggests that the study area supports a heterogeneous mix of viable habitat. Both reaches also have physical similarities and differences. The entire study area is a current and historic meandering channel driven primarily by river flow, geologic control, soil type and vegetation. Reach 2 has greater tributary input, higher cut banks and slightly steeper gradient which possibly resulted in larger exposed bank surface and could explain the larger colony sizes observed here. However, Reach 2 also consists of more volcanic deposits which could hinder burrowing activity in some areas. Reach 3 soils are finer and less gravelly than in Reach 2 possibly providing a more suitable burrowing substrate. The greater number of colonies distributed throughout Reach 3 may indicate less concentrated suitable habitat. However, both reaches have extensive channel lengths armored with riprap (Table 1) which acts as geologic control and halts erosion and river meander. At least since 1999, there was a higher percentage of riparian vegetation (primarily forest and scrub) in Reach 3, possibly supporting more stabilized banks with patchier habitat, than in Reach 2.

Winter flows did not vary greatly among reaches and may be difficult to assess in relation to Bank Swallow colonies. The irregular sequence of increases and decreases in downstream flow likely reflects the tributary inputs and flood control and irrigation systems throughout the study reach as water is redirected and distributed through bypasses and weirs (Figure 4). Specifically between the Vina and Hamilton City gauges, the Glenn - Colusa Irrigation District removes water at approximately RM 205, just upstream of the HMC gauge. Also the Vina gauge is approximately four and two river miles below Thomes and Deer creeks, respectively, which are considered major tributaries of the Sacramento River (Sacramento River Area Conservation Forum, 2003; Figure 4).

I did not compare sinuosity and erosion between reaches but these datasets could be explored further. Although the sample size was small, not surprising, where colonies persisted longer, more erosion occurred.

We will never know the historic population of Bank Swallow on the Sacramento River prior to the first comprehensive survey in 1986, but one can surmise. Riparian vegetation was expansive and varied along the river. Both reaches had extensive riparian forest (Sacramento River Conservation Area Forum, 2003) which controls river meander and may have been more difficult to burrow under. However, the meandering character of the river and periodic flooding undoubtedly exposed fresh bank surface on a regular basis. Important swallow foraging habitat would have consisted of native grasslands and vast marshlands in the basins flanking the river (Holmes *et al.*, 1915; Sacramento River Conservation Area Forum, 2003; Burkett and Conlin, 2006). River modification began in the mid 1800s with gold mining and continued with conversion of riparian forests to agriculture, and irrigation and flood control systems (Snowden, 2002); all practices which may have contracted or expanded nesting habitat. Interestingly, in Grinnell and Miller's account of the Bank Swallow in "The Distribution of the Birds of California" (1944), the Sacramento River proper is not mentioned as a part of the geographic range. Though whatever habitat was available was likely reduced due to the moderation of flows associated with Shasta Dam construction and related infrastructure. Further declines probably occurred in combination with the intense rocking that began in the 1970s and 1980s, and blatant destruction of viable colonies during armoring activities (Remsen, 1978; Schlorff, 1997; Stillwater Sciences, 2007; Garcia *et al.*, 2008). The most recent PVA indicated that the Sacramento River Bank Swallow population was likely reduced by 50% from bank armoring (Girvetz, 2007). It is well known that the Bank Swallow was extirpated from southern and central coastal and inland California from channelization of rivers and loss of wetland habitats and development throughout the state (Remsen, 1978; Laymon *et al.*, 1987; Schlorff, 1997).

Currently, the breeding California population of Bank Swallows is persisting at its western limits, with few colonies populating coastal bluffs along the Pacific and opportunistically colonizing anthropogenic habitats where possible. A recent example occurred in San Joaquin County where no colonies have been previously documented, a new 2009 colony was reported in an active mine (pers. comm., J. Rowoth, 2009). Yet success and long-term persistence of these manmade habitats are problematic. A colony established in an active mine is in constant threat of being destroyed by sand removal during the breeding season. Human activities in Northern California have put tremendous pressure on the swallow, constricting their western range limits even further.

Future research

There is a pressing need to understand the physical features that define viable Bank Swallow habitat on the Sacramento River. Banks where colonies persist should be studied intensely for the erosional potential and processes that occur there, soil types, summer and winter flows, overstory vegetation, and bank parameters (slope, aspect, length, etc). These banks that support existing colonies should also be tested with Garrison's HSI (1989, which has never been field tested) to confirm its ability to quantify suitable habitat, and updated with additional parameters if necessary. Studied colonies should also include a proportional number of short-term, smaller colonies based on their high annual contribution to the Sacramento River Bank Swallow population. Different sized colony parameters should be compared and contrasted. A better understanding of the relationship between local flow dynamics and erosional processes is also needed. The sinuosity dataset could be more thoroughly researched in relation to Bank Swallow colonies. My research involved random sample of 10 colonies in each persistence category (N = 40). Analyzing the entire reach with all colonies associated with persistence categories (N = 118) and a sampling of areas where bank swallows were not documented, may show different evidence if colony persistence is related to sinuosity.

Additionally, the entire reach should be mapped for what appears to be potential habitat even if it is not in use during the nesting season. Annual variations in available habitat would vary considerably based on river flow and physical and geomorphic properties of each reach.

An effort to map both active and “available” habitat on the reaches occurred in 1989 (Sacramento River Area Conservation Forum, 2003). In Reach 2 almost one mile of active habitat and nine miles of inactive habitat were recorded versus five miles of active and two miles of inactive habitat in Reach 3 (Table 1). One other attempt in 1994 mapped an equal combination of about 10 miles of available and active habitat in Reach 2 with no efforts conducted in Reach 3 (Table 1). The results of these mapping attempts show a large amount of “inactive habitat,” which may be necessary to support the current population. Since no significant population change was observed over the study period, exposure of more habitat might be necessary for the population to increase. Existing rock should be evaluated and removed where no longer necessary or where there are progressive alternatives. The 2008 PVA showed that removing rock would be an effective way to increase the Sacramento River Bank Swallow population (Girvetz, 2007). Rock removal has successfully exposed habitat in the past and it is still considered to be a management tool. In 1999, the Sacramento River National Wildlife Refuge removed a private levee and riprap at RM 233. The following spring an estimated 2,770 burrows were documented at this site (Golet *et al.*, 2003; Silveira, 2008), the second largest colony counted during the 10-year survey period, 1999-2008. Further, location of rock removal should be evaluated for maximum benefit to swallows. Szep (1991) found a direct relationship between the number and distribution of potential breeding sites (based on bank height and length) and the number and distribution of colonies along a 586 km reach of the River Tisza in Hungary: greater numbers of birds were concentrated where greater expanses of bank occurred. One way to accomplish long stretches of habitat is to expose rocked banks that are near long expanses of bank habitat.

My study only focused on nine years of an 18-year dataset. The remaining nine years should undergo quality assurance and control, so the population trends can be revealed for the entire survey period. Current methods used to estimate Bank Swallow populations; timing of annual surveys, and burrow occupancy rates are based on results from dated research. It is critical to review the timing of colony activity, burrow occupancy, measures of reproductive success (clutch size) that will give insight to current population dynamics, and potentially clarify the dynamics of colony size. Overstory vegetation should be added to the criteria collected during annual surveys. The one-time annual survey is a snapshot of the seasonal population and does not provide an accurate picture as to how the colonies may change throughout the season. For example, for Bank Swallow management, it is imperative to know how changes in summer flow and stage may impact the colonies. An additional end of season survey might be added to determine colony fate. Experimental releases of high winter flows could be incorporated in management plans (Moffatt *et al.*, 2005; Stillwater Sciences, 2007; Garcia *et al.*, 2008). My method of associating specific gauges (and associated flow values) with colony location and number of burrows at each colony is a crude and oversimplified method of analysis, due to the variety of local conditions at each site. Not only are there local differences in flow input (tributaries) and outputs (distributaries) along the river, but other factors including soils, channel morphology, geology, and vegetation would influence the rate of erosion . A more refined method might be developed to examine flow as a specific parameter at colony sites.

Spatial and temporal patterns not identified in my study, may reflect a variety of unknown factors that may be difficult to identify including the fate of birds on their wintering grounds and during migration. For the Bank Swallow though, if we are determined to welcome them back to the Sacramento River each spring, the focus of the responsible agencies and the Bank Swallow Working Group should be to ensure the habitat along the river is of the quality and quantity necessary to support a population increase.

Conservation concerns

Of greatest concern with the Sacramento River population of Bank Swallows are the lack of population increase and the continued threat to their habitat by bank rocking projects. An additional 80,000 feet of rock will be placed on the river in the next several years (United States Army Corps of Engineers, 2007). Any loss of erodable bank is a loss of existing or potential habitat. Even with a moderate amount of mapped inactive habitat we have observed no observable growth in this population. Although my research shows that colony and burrow numbers fluctuate annually the population remains below the initial numbers documented in 1986 declining by 20% (2001) to as low as 42% (2005) of the original estimation of 24,110 burrows in the 100-mile study reach (this study; Garcia *et al.*, 2008; CDFG, unpubl. survey data). The lack of growth in this population may be a symptom of range limitations, exacerbated by range contraction. Studies show that populations on their range boundaries, particularly those using marginal habitats, may have very low rates of increase (Lawton, 1993). Perhaps the banks of the Sacramento River have become marginal as nesting habitat now occurs between large areas of rock, and is not refreshed at the same rate it was pre-Shasta dam. Both PVAs show the population is in serious threat of decline based on the estimated number of swallows and the amount of riprap, current through 2005, along the study reach (Buechner, 1992; Girvetz, 2007). Girvetz (2007) suggests that the Sacramento River is only able to support smaller populations due to density dependence from the limited carrying capacity of remaining habitat. More riprap has been laid down and more is planned.

Conservation opportunities and challenges

On the Sacramento River, riparian and floodplain restoration began in 1989 with success demonstrated through use of restoration sites by landbirds (Gardali *et al.*, 2006) and other taxa including invertebrates and mammals (Golet *et al.*, 2008). Ultimately, habitat restoration which includes river processes that allow channel migration and floodplain reworking, must be implemented to recover the Bank Swallow on the Sacramento River. Both types of restoration, re-vegetation of native grasslands and levee removal for main channel contact with the natural river bank, have demonstrated success through the establishment and persistence of Bank Swallow colonies (Luster, 2006; Silveira, 2008; USGWS, 1999a, 1999b). To fully recover the Sacramento River Bank Swallow population, bank armor will have to be removed and levees set back to provide a 100-year meanderbelt. Results would benefit the Bank Swallow and other riparian wildlife, fish and vegetation. The locations and amount of rock to be removed will be determined through the best science. However, as demand for water and land increases, State and federal water conveyance and flood control projects will continue to stress and threaten the Sacramento River ecosystem affecting fish, wildlife, plants, their habitats, and the processes which maintain them. The challenge to protect and conserve Bank Swallow breeding habitat will be great and accomplished only through cooperation of State, federal, private (non-profit conservation, landowners, and other stakeholders), and academic interests where technical expertise can advise policy makers to plan and implement science-based projects consistent with the goals for Bank Swallow recovery.

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APPENDIX A

SUMMARIZED TIMELINE OF EVENTS AND

RESEARCH DISCUSSED IN THESIS

Year	Event	Author
1944	Shasta Dam completed to provide irrigation and navigation systems enhanced, flood control and power production	ACOE
1978	BANS listed as second priority species of concern	Remsen
1986	Senate Bill 1086 passed to restore fisheries and riparian habitat on the Sacramento River and tributaries	CA legislature
1986, 1987	Initial studies on BANS colony- Red Bluff to Verona	Garrison et al.
1986-present	Annual surveys begin- Red Bluff to Colusa with random monitoring to include entire Redding to Verona reach and the Feather River	CDFG, USFWS, CDWR
1987	Statewide survey: 70% of CA population found in Sacramento and Feather Rivers	Laymon et al.
1988	Sacramento River project focus on restoration of ecosystem from Red Bluff to Colusa	USFWS, CDFG, TNC, River Partners
1989	California population listed as Threatened	CDFG
1989	Habitat Suitability Index developed for BANS	Garrison
1992	First Bank Swallow Population Viability Analysis (PVA) developed incorporating environmental stochasticity	Buechner
1992	Bank Swallow Recovery Plan	CDFG
1999	USFWS Sacramento NWR Complex begins partnership with CDFG in BANS surveys and colony locations are identified using GPS.	USFWS
2001	USFWS Sacramento NWR removes a privately constructed levee at the Flynn Unit; subsequent BANS colony in 2002 is the second largest colony recorded.	USFWS
2003	Sacramento River Conservation Area Forum Handbook publishes guidelines to protect and restore the “inner river zone”	SRCAF
2005	Research investigating the value of restoration of hydrologic and landscape heterogeneity for BANS colonies on the Sacramento River	Moffat et al.
2006	Bank armoring eliminates almost a mile of erodable bank and consistently used Bank Swallow habitat at RM 182	CDWR

Year	Event	Author
2007	Holistic research emphasizing focal species including the Bank Swallow for conservation and management of the Sacramento River	Stillwater Sciences
2007	Bank armoring eliminates ~ 1500 lineal feet of previously used Bank Swallow habitat on wildlife refuge	CDWR
2007	Bank Swallow Working Group formed of agencies and nonprofits to address swallow conservation and management issues	SRCAF
2007	CDWR begins participation in surveys and develops GIS savvy methods collecting additional colony parameters	CDWR
2007	Sacramento River Bank Protection Project: Phase II supplemental authorization: plans to install and repair approximately 16 miles of rock, some within the 100-mile study reach	ACOE
2007	Second PVA developed: BANS population response to armored and natural (unrocked conditions) on the Sacramento River	Girvetz
2008	Synthesis of BANS monitoring surveys and recent research including conservation and management recommendations	Garcia et al.

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APPENDIX B

SUMMARY OF RESEARCH QUESTIONS,
STATISTICS AND DATA SETS USED
IN THIS THESIS

Research Investigation	Statistical Analysis	Dataset
Differences in burrow numbers between reaches and years	2-way ANOVA: reach and year effects on burrow numbers, Tukey HSD test	GIS shapefile Colony dataset 1999-2009
Differences in number of burrows, colonies and average colony size between reaches over all survey years	2 Wilcoxon signed rank tests (burrows and ave. colony size), 1 paired T-test (colonies) correlation and regression analysis, testing relationship between average colony size and colony number	GIS shapefile Colony dataset 1999-2009
Differences in annual and reach distribution of colony size categories	Contingency table Chi-square test	Colony dataset: subset into four size categories
Differences in burrow numbers between colony persistence categories	2-way ANOVA: reach and persistence category effects on burrow numbers, Tukey HSD test	Colony dataset: subset into four persistence categories
Relationships in winter flows and colony and burrow numbers in each survey year	4 bivariate correlations and regression analyses	Colony dataset and CDWR flow data for all survey years
Differences in winter flows for colony size categories	One-way ANOVA, Tukey HSD test	Colony dataset: subset into four size categories and CDWR flow data for all survey years
Differences between winter flows for colony persistence categories	One-way ANOVA, Tukey HSD test	Colony dataset: subset into four persistence categories and CDWR flow data for all survey years
Difference between 2007 and 1997 river channel sinuosity	Paired T-test	UCD sinuosity GIS shapefile with sinuosity values

Research Investigation	Statistical Analysis	Dataset
Differences between colony persistence categories and river channel sinuosity	One-way ANOVA,	Colony dataset: subset into four persistence categories and UCD sinuosity GIS
Differences at erosion sites and relationship to colony persistence categories	Descriptive and graphical	Colony dataset: subset into four persistence categories and CDWR erosion shapefile
Differences in overstory vegetation at each colony persistence category	Descriptive and graphical	Colony dataset: subset into four persistence categories and GIC landuse shapefile (CWDR landuse classification)

APPENDIX C

The location on the Sacramento River (reach, river mile and bank side) and number of years each persistence category had Bank Swallow activity. Persistence categories are those casually active (C, 1-2 years), occasionally active (OAA, 3-4 years), frequently active (FAA, 5-7 years) and consistently active (CAA, 8-10 years).

Reach 2	C	OAA	FAA	CAA
242.5L	1			
241.6L		4		
239.5L	2			
239.2R			6	
238R	1			
238.2R	1			
237.6L	1			
236R	1			
236.6R				8
235.2R		3		
234.9R				7
233.8L				9
232L			6	
232.8R				8
231.8L		3		
231.3L	1			
228L				8
227.3L			5	
226R	2			
226L	1			
226.6R	2			
226.2R	1			
226.2L		4		
224.8L			5	
221.4L				8
219.8R		4		
218.5L	1			
216.4L	1			
212L				9
211.1R				8
210.6L	2			
210.2L		3		
209R	1			
208L	1			
207.8L	2			
205.5R			6	

Reach 2	C	OAA	FAA	CAA
205.5L		4		
202.4R	1			
201R	1			
201.7L	1			
200.8L	2			
198.9L			5	
195R			5	
195.5L	1			
195.4L				8
Reach 3	**C**	**OAA**	**FAA**	**CAA**
193.1R				8
192L				8
192.3L	2			
189.7R				9
187.7R	2			
185.9R	2			
185.1L				8
184.7R	1			
184.5R	2			
183.7R	1			
183.5R		4		
182.5L				9
181.5R			6	
181.2R	1			
178L	1			
177L	1			
176.8L	1			
175.8L	1			
175.5L		4		
174.2L			6	
173R	2			
173.8R	1			
173.7R	1			
173.5R	1			
172.5R		4	6	
171.8L			6	
171.4R	1			
171.2R			6	
170L		3		
170.5L	1			
169.6R		3		
168.8L	1			
168.3R	1			
168.2R	2			

Reach 3	C	OAA	FAA	CAA
167L		4		
166R		4		
166.7L	1			
166.5R	1			
166.5L	2			
165.2L				9
162.7L			5	
162.5L		4		
161.6R			7	
161.3L		3		
159R	1			
158.4R	1			
158.3L	2			
157R	1			
157L	1			
157.1L	1			
156.8L	1			
156.7R		3		
156.6L			6	
156.3R			7	
155L	1			
155.8L	1			
155.6R			5	
154.8R	1			
154.6L	2			
153.9R	1			
153.8L	1			
152.5R	1			
150.8R	1			
150.4L	2			
147.2L	1			
146.4L				8
146.1L	1			
145.7L			6	
145.4R	3			
145.4L	1			
145.2L	2			
144.9R	1			

APPENDIX D

SUMMARIZED METADATA

(FGDC ESRI format) for DGThesis_BANS99-08 ArcGIS 9.3 Shapefile

THEME KEYWORD: Bank Swallow, *Riparia riparia*, CDFG and USFWS annual monitoring, Sacramento River, colony location, colony size

THEME THESAURUS: Bank Swallow biology, ecology, population and location trends

PLACE KEYWORD: Tehama County, Butte County, Glenn County, Colusa County, Red Bluff to Colusa, California

PLACE THESAURUS: Sacramento River Area, Central Valley, California

ABSTRACT: ABSTRACT: This DRAFT data set includes 380 records expanding nine years of Bank Swallow monitoring data from 1999-2008 (no 2006 data) on the Sacramento River from Red Bluff to Colusa (100 river miles [RM]) as collected by California Department of Fish and Game (CDFG), US Fish and Wildlife Service (USFWS), and California Department of Water Resources (CDWR). Colony locations were GPS'd and identified by RM. The number of active burrows was estimated and recorded at each colony. The data set is a merge of five separate GIS shapefiles: DFG_bankswallow_1986_2003 (CDFG), 2004_bankswallow_DWR_Nad83 (CDWR), swallowonly_2005 (USFWS), Bank_Swallow_Colonies_2007 (USFWS) and SacBANS_08Survey_Reach2and3_pts (CDWR 2008). Elements in each file underwent a QA/QC process by comparing field data ("rawdata") to annual draft reports ("draft reports") prepared by CDFG, and then to attribute files in each GIS file. Coordinates for each colony location were also examined for their placement on the river by using a 1991 River Mile shapefile, a 2004 NAIP, and digitized channel boundaries (1896-1997, 1999, and 2004) for the project area. These sources were provided by CDWR. All changes made to the original GIS files are noted in this data set under the column "DGqaqc_08." Changes include renaming of colony locations (RM labels), burrow number and bank side corrections, and new coordinates that had been transcribed incorrectly on field maps or in GIS files. Additional attributes: ColonyID_1, persist, and size, were added for the purpose of analysis for the thesis project.

PURPOSE: The shapefile was created for a Thesis project, "Spatial and Temporal Patterns of the Bank Swallow on the Sacramento River, 1999-2008." The shapefile provides a quality assured dataset for future Bank Swallow research.

ACCESS CONSTRAINTS: These data are to be used by CSU Chico student Dawn Garcia for her graduate studies. The agencies CDFG, USFWS, and CDWR will receive a copy for their files and will assign restricted use due to the sensitivity of the subject (Bank Swallows are a CA threatened species- 1992).

USE CONSTRAINTS: Limited by permission by the above agencies.

SUPPLEMENTAL: How Colony Locations were Collected (summarized based on 2008 email from J. Isola-USFWS)
1999 -2001: We used a hand-held Rockwell GPS (military grade) to calculate UTM coordinates. USFWS personnel (most often done by M.Carpenter/J. Isola over the years) read them off of the GPS unit and R. Schlorff recorded them on paper with the remaining colony attribute data. Navigation (and RM estimation) was done by visual estimation from a paper Sacramento River Atlas (USFWS personnel - most often done by J. Silveira over the years), and recorded by R. Schlorff.
2002-2004: Located colonies using a Garmin Etrex, paper data sheets, and the paper atlas.
2005: USFWS Downloaded waypoints in an electronic format, used a blue Garmin E-trex Legend. Data downloaded and converted to a shapefile format using the Minnesota DNR Garmin program. Colony attributes (burrow estimates, etc) were recorded on paper by R. Schlorff. Navigation (and RM estimation) was done by visual estimation from a paper Sacramento River Atlas (USFWS personnel), and recorded by R. Schlorff. I produced a shapefile with colony attributes by comparing draft report to electronic data.
2007: This is the first year data were collected into the Trimble GeoXM GPS unit. Data was recorded directly into a data dictionary and collected attributes Navigation and RM estimation was done on the fly (on the Trimble unit), by using an uploaded shapefile that included the river channel, USFWS & CDFG properties, and river miles. Data downloaded and converted to a shapefile using GPS Pathfinder software.
2008: This is the first year data were collected directly into ArcMap, using DWR's laptop, ArcMap software, and aerial imagery to digitize colony locations and record colony attributes while on site. Day 1 was recorded by J. Isola into both ArcMap, and onto the Trimble GeoXM (for later technique comparison). Day 2 was recorded by A. Henderson into ArcMap only. Because the data was collected directly into ArcMap, no data downloading or transformation was necessary. DWR was responsible for cleaning up the dataset and creating the accompanying metadata.

ATTRIBUTES (15)
FID: Internal feature number.
Shape: Feature geometry (POINT)
RivBank: side of bank colony was located with downstream flow; R=right bank, L=left bank
Ownership: owner property where colony was documented
Year: year of survey
DGqaqc_08: quality assurance and control notes and changes to original files
NUMBURROW: number of active burrows in the colony
OBSDATE: survey date
Unit_name: Name of refuge property where colony was located
X: easting
Y: northing
RivMile: river mile where colony was located to 0.1 mile
ColonyID_1: River mile ID given to colonies persisting over 1 year for analysis purposes only
Persist: the category acronym given to colonies persisting from 1-2 years (C), 3-4 years (OAA), 5-7 years (FAA) and 8-10 years (CAA). For analysis purposes only.
Size: the category given to identify the size of a colony based on number of : small (S, 1-130 burrows), medium (M, 131-375 burrows), large (L, 376-1000 burrows) and extra large (XL, >1000 burrows). For analysis purposes only.