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Wildlife Response to Riparian Restoration on the Sacramento River

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ABSTRACT

Studies that assess the success of riparian restoration projects seldom focus on wildlife. More generally, vegetation characteristics are studied, with the assumption that animal populations will recover once adequate habitats are established. On the Sacramento River, millions of dollars have been spent on habitat restoration, yet few studies of wildlife response have been published. Here we present the major findings of a suite of studies that assessed responses of four taxonomic groups (insects, birds, bats, and rodents). Study designs fell primarily into two broad categories: comparisons of restoration sites of different ages, and comparisons of restoration sites with agricultural and remnant riparian sites.

Older restoration sites showed increased abundances of many species of landbirds and bats relative to younger sites, and the same trend was observed for the Valley elderberry longhorn beetle *(Desmocerus californicus dimorphus)*, a federally threatened species. Species richness of landbirds and ground-dwelling beetles appeared to increase as restoration sites matured. Young restoration sites provided benefits to species that utilize early successional riparian habitats, and after about 10 years, the sites appeared to provide many of the complex structural habitat elements that are characteristic of remnant forest patches. Eleven-year old sites were occupied by both cavity-nesting birds and special-status crevice-roosting bats. Restored sites also supported a wide diversity of bee species, and had richness similar to remnant sites. Remnant sites had species compositions of beetles and rodents more similar to older sites than to younger sites.

Because study durations were short for all but landbirds, results should be viewed as preliminary. Nonetheless, in aggregate, they provide convincing evidence that restoration along the Sacramento River has been successful in restoring riparian habitats for a broad suite of faunal species. Not only did the restoration projects provide benefits for special-status species, but they also appeared effective in restoring the larger native riparian community. Increases in bird abundance through time were observed both at restoration sites and in remnant habitats, suggesting that restoration efforts may be having positive spillover effects, although observed increases may have been caused by other factors.

Although positive overall, these studies yielded some disconcerting results. The Lazuli Bunting *(Passerina amoena)* declined at restoration sites and remnant habitats alike, and certain exotic invasive species, such as black rats, appeared to increase as restoration sites matured.

KEYWORDS

Bat, bee, beetle, bird, floodplain, insect, monitoring, restoration, riparian, rodent, Sacramento River, Valley elderberry longhorn beetle.

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INTRODUCTION

In recent decades, large-scale ecological restoration projects have become increasingly common (Holl et al. 2003). Yet following implementation, most projects have little or no monitoring associated with them (National Research Council [NRC] 1992; Bernhardt et al. 2005) despite widespread recognition of its importance (Society for Ecological Restoration [SER] 2004; Ruiz-Jaen and Aide 2005). There is typically little documentation of the effectiveness of restoration activities, and little is learned about whether and when target wildlife species respond (Block et al. 2001). When monitoring does take place, quantifiable success criteria are rarely defined. Opportunities to improve restoration practices are thus being lost. Reviews of restoration projects demonstrate that outcomes are highly variable (Kondolf and Micheli 1995), and much could be gained by identifying the factors that determine whether or not project goals are met (Gibbs et al. 1999). Such an understanding is critical, not only for making restoration projects more successful and cost-effective, but also for maintaining public and political support for their continued implementation.

On the Sacramento River, millions of dollars have been invested in floodplain restoration with the goal of revitalizing riparian habitats for native species. Yet there has been minimal published documentation of effectiveness beyond limited information on vegetation response. The vegetation studies examined factors affecting the performance of planted species in the first years following planting (Hujik and Griggs 1995a, 1995b; Griggs and Peterson 1997; Alpert et al. 1999), and over the longer term (Griggs and Golet 2002). Additionally, Holl and Crone (2004) characterized factors that influence the natural recruitment of native understory plant species at restoration sites. It has been assumed that target fauna will recover if suitable habitats are restored, yet this assumption has not been adequately tested on the Sacramento River, or elsewhere (Hilderbrand et al. 2005).

There are surprisingly few peer-reviewed studies on wildlife response to riparian restoration. Rarer still are articles that synthesize studies of restoration response across multiple taxa. Only one published manuscript—on landbirds (Gardali et al. 2006)—and two published notes—on bees (Williams 2007), and rodents (Golet et al. 2007)—have directly measured wildlife response at Sacramento River riparian restoration sites, despite the restoration of thousands of hectares of floodplain habitat since 1989 (see below). Many other studies have been conducted, and reports have been produced, yet prior to this paper, they had not been synthesized and made widely accessible.

Here we present the major findings from studies of four taxonomic groups: insects (Hunt 2004; River Partners 2004; Williams 2007), birds (Gardali et al. 2004; Gardali et al. 2006; Gardali and Nur 2006), bats (Stillwater Sciences et al. 2003), and rodents (Golet et al. 2007; Koenig et al. 2007). For all taxa studied, we both draw information from the above-listed publications and reports, and present new results. In introducing the studies, we discuss the value of the different taxa as indicators of restoration success. Then, we present the results of the individual studies, and offer an initial assessment of how well Sacramento River restoration sites are meeting the habitat needs of the river's native riparian taxa. Recognizing that our assessment needs to be made more rigorous and comprehensive, we close this article with a discussion of future monitoring needs.

Background of Sacramento River Restoration

The Sacramento River is an important river in California from both an environmental and an economic perspective, but it is severely degraded relative to its historical condition. Prior to European settlement, the river was lined by approximately 324,000 hectares of riparian habitat; however, over 95% of this habitat has been lost to logging, agriculture, urban development, and flood control and power-generation projects (Katibah 1984). The loss and degradation of riparian habitat has diminished the river's ability to support viable wildlife populations, and encouraged the invasion and proliferation of non-native species. At-risk special-status terrestrial taxa in the region include diverse species of birds (e.g., western yellow-billed cuckoo *[Coccyzus americanus occidentalis]*, Swainson's hawk *[Buteo swainsoni]*, and bank swallow *[Riparia riparia]*); mammals (e.g., western mastiff bat *[Eumops perotis]*, Yuma myotis *[Myotis yumanensis]*); and insects (e.g., valley elderberry longhorn beetle *[Desmocerus californicus dimorphus]*) (CALFED 2000a).

In 1986, state and federal agencies and non-government organizations began to implement management programs aimed at improving the health of the river. Senate Bill 1086 was passed by the California legislature, and called for the formation of the Upper Sacramento River Fisheries and Riparian Habitat Council. In 1987, by the authority provided under the Fish and Wildlife Act of 1956, the Endangered Species Act of 1973, and the Emergency Wetlands Resources Act of 1986, the U.S. Congress authorized the establishment of the U.S. Fish and Wildlife Service (USFWS) Sacramento River National Wildlife Refuge (the Refuge). In 1989, the Refuge was established. Its goal is to provide up to 7,284 hectares of habitat for endangered and threatened species, migratory birds, and anadromous fishes (USFWS 2005). As of 2007, the Refuge consisted of 3,837 hectares of riparian and agricultural habitats, owned in fee title, and distributed among 26 individual units. An additional 518 hectares is held by the Refuge as a ranch easement. The other major aggregation of conservation land along the middle river is the California Department of Fish and Game (CDFG) Sacramento River Wildlife Area, which, in 2007, consisted of 1,658 hectares distributed among 13 units.

The Nature Conservancy (TNC), a non-profit environmental organization, launched the Sacramento River Project (the Project) in 1988. Key Project partners include the USFWS, the U.S. Army Corps of Engineers, the CDFG, the California Department of Water Resources, the California Department of Parks and Recreation, the California Wildlife Conservation Board, River Partners, and the Sacramento River Conservation Area Forum. The main goal of the Project is to develop and implement a "single blueprint" for ecosystem restoration and management on the main stem of the Sacramento River, so that different efforts along the river work collaboratively in support of a unified conservation vision.

The Project has focused on restoration along the meandering reach of the Sacramento River, between the towns of Red Bluff and Colusa (~161 river km, Figure 1), because degradation in this reach is largely reversible. Farms (as opposed to cities) have replaced floodplain forests, and levees, where present, are often set back from the river by appreciable distances. In some areas, bank revetment (riprap) is absent, and the natural processes of bank erosion and point bar deposition are still intact (Buer et al. 1989; Singer and Dunne 2001). All of the USFWS Refuge

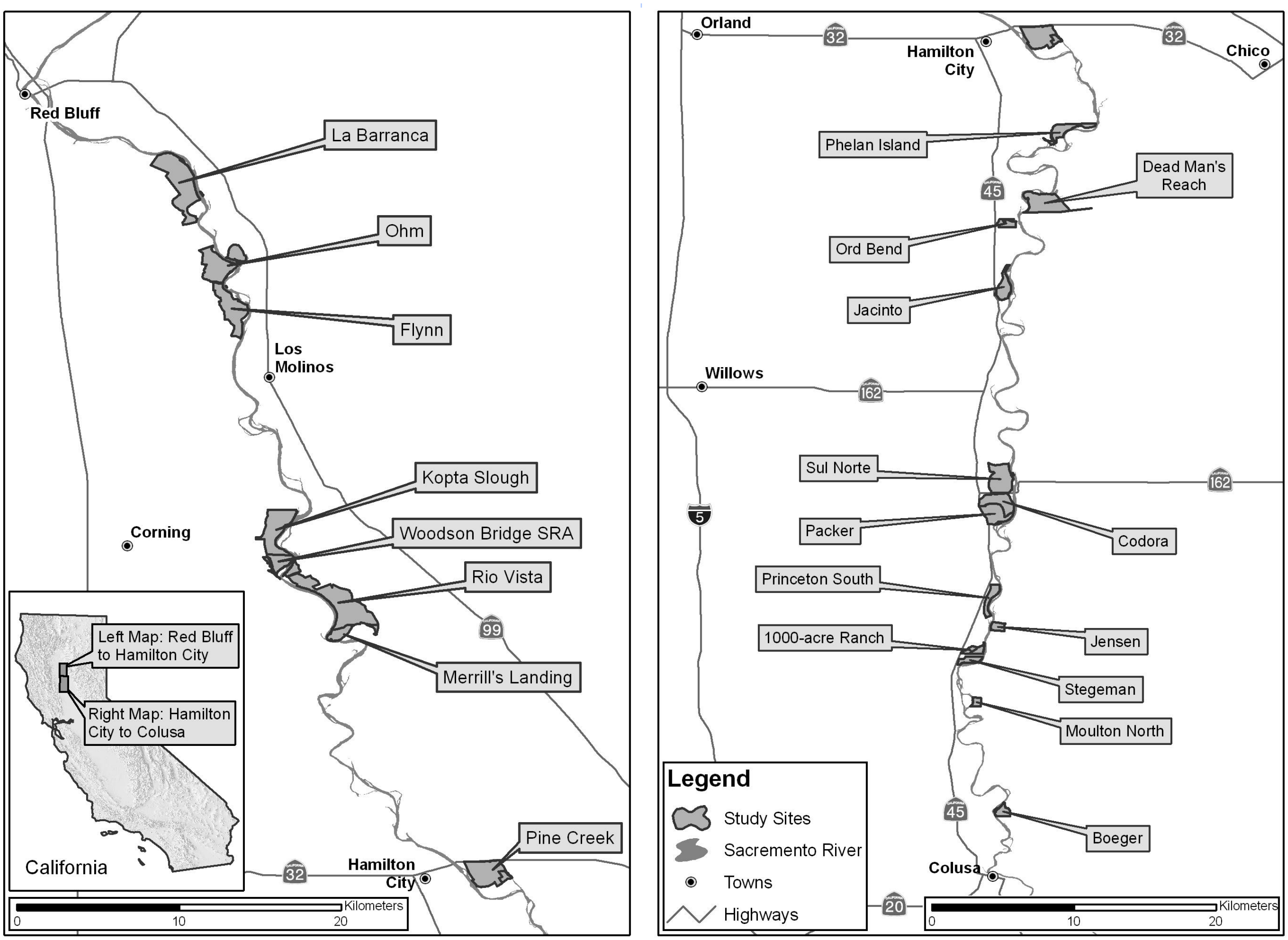

Figure 1. Locations of study sites within the 161-river km Sacramento River Project area, California. The left map shows the northern half of the Project area and the right map depicts the southern half.

and the CDFG Sacramento River Wildlife Area are contained within the Red Bluff to Colusa stretch.

The Project's strategies for restoring the Sacramento River include:

1. Conserving flood-prone lands, giving priority to those that contain and/or border remnant riparian habitats (Project partners have acquired ~5,424 ha in fee title since 1988; Figure 2A)
2. Increasing habitat connectivity and patch size by revegetating land with native species (Project partners have planted ~2,337 ha with >1 million trees since 1989; Figure 2B)
3. Restoring natural river processes (e.g., flooding, meander migration, sediment transport) on conservation lands while simultaneously promoting flood damage reduction for agricultural properties and important human infrastructure (e.g., roads and bridges).

OVERVIEW OF STUDY METHODS

Study Sites and Sampling Periods

In total, 21 field sampling locations spanned the length of the Project area (Figure 1). All of the restoration sites were previously in agriculture, most commonly as walnut or almond orchards, before being revegetated with local ecotypes of indigenous trees, shrubs, and understory species. For information on revegetation methods and approaches see Griggs and Peterson (1997) and Alpert et al. (1999). Restoration sites are located in low-lying floodplain areas embedded in a landscape matrix of natural remnant habitats, fallow land, and agriculture (see Figure 1 in Holl and Crone 2004); none are in close proximity to urban areas or dense residential settlements. Agriculture consists primarily of orchard, row, and field crops, although a few areas are managed as irrigated pasture for livestock.

Years of study varied, but were between 1993 and 2005 (Table 1). Field sampling for all but the landbird study took place in 1 year or less. Consequently, results from individual studies should be viewed as preliminary; however, the collective weight of evidence they present is considerable.

Study Designs and Performance Metrics

Several study designs were used. Some studies simply compared restoration sites of different ages (Figure 3) to determine if older sites provide more benefits to wildlife than younger sites. Others compared wildlife use patterns at restoration sites with those at older remnant riparian forests that were never used for agriculture. Some studies also drew comparisons with agricultural sites. Comparisons among different site types (agriculture, restoration, and remnant) are informative because they enable us to determine if wildlife use patterns at restoration sites are more similar to patterns observed at remnant forest sites than at agricultural sites. If so, then this is one measure of restoration success. It should be understood, however, that from an ecological standpoint, conditions in remnant forests are not ideal. All remnant sites are subjected to a highly altered flow regime, and are degraded to varying degrees with invasive species. Most are also highly fragmented.

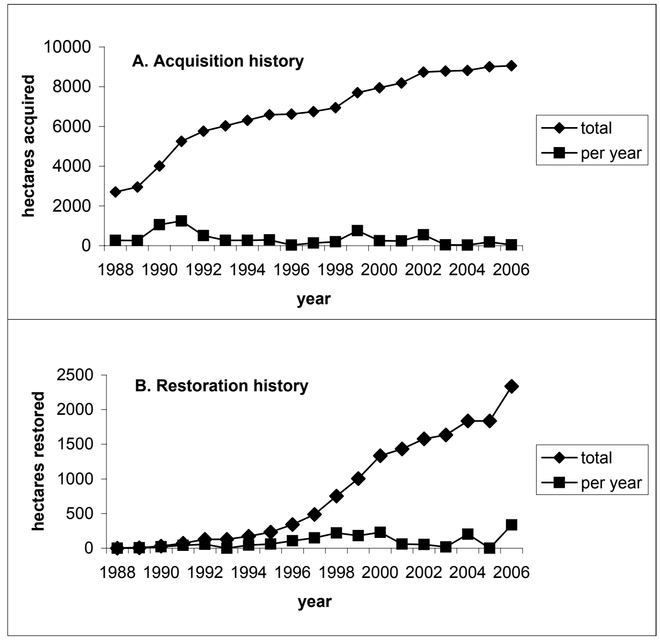

Figure 2. Amount of land A) acquired for riparian habitat conservation; and B) planted with native riparian species within the Sacramento River Project area, California.

Various performance metrics were used to assess restoration success in the different studies. Included were assessments of species richness, abundance, percent occupancy, community composition, adult survival, and reproductive success.

CASE STUDIES

Insects

Insects have tremendous taxonomic and functional diversity, and play essential roles in ecosystems as pollinators, predators, prey, herbivores, and scavengers. Hence, they are useful focal species for studies that seek to characterize the degree to which ecosystem function is restored in restoration projects (Wilson 1987; Williams 1993). However, in a review of 68 restoration case studies, only 32% measured some component of arthropod diversity (Ruiz-Jaen and Aide 2005). Restoration monitoring programs often exclude insects for several reasons: they are small, innocuous, and generally viewed as non-char-

Table 1. Landcover types and taxa studied at each of the field sampling locations for the studies profiled in this paper. Some sites had multiple landcover types present. Many of the restoration sites were composed of sets of fields that were planted over a series of years. The locations of these sites along the Sacramento River are depicted in Figure 1. Sites are listed according to their locations on the river, from north to south.

Site Name	Landcover Types Sampled (years planted)	Taxa Studied (years sampled)
La Barranca[a]	Walnut orchard	Bats (2002), birds (1993–2001)
	Restoration site (1997–2003)	Bees (2003)
	Remnant riparian	Bees (2003), birds (1993–2001)
Ohm[a]	Walnut orchard	Birds (1993–2001)
	Remnant riparian	Birds (1993–2001)
Flynn[a]	Restoration site (1996-2000)	Bees (2003), birds (1998–2003), VELB[d] (2003)
	Remnant riparian	Bees (2003), birds (1998–2003)
Kopta Slough[b]	Restoration site (1989-1992)	Beetles (2000–2001), birds (1996–2003), rodents (2005)
Woodson Bridge SRA	Remnant riparian	Bats (2002), bees (2003), birds (1996–2003), rodents (2005)
Rio Vista[a]	Restoration site (1993-2000)	Bees (2003), beetles (2000–2001), birds (1993–2003), VELB (2003)
Merrill's Landing[c]	Remnant riparian	Beetles (2000–2001), rodents (2005)
Pine Creek[a, c]	Restoration site (1997-1999)	Bees (2003), beetles (2000–2001)
	Remnant riparian	Bees (2003), beetles (2000–2001)
Phelan Island[a, e]	Restoration site (1991-2002)	Bats (2002), bees (2003), beetles (2000–2001), birds (1994–2003), rodents (2005), VELB (2003)
	Remnant riparian	Bats (2002), bees (2003), beetles (2000–2001), birds (1994–2003), rodents (2005)
Dead Man's Reach[a]	Walnut orchard	Bats (2002)
Ord Bend[a]	Restoration site (1999)	VELB (2003)
Jacinto[c]	Restoration site (2001)	Rodents (2005)
Sul Norte[a]	Remnant riparian	Birds (1994–2003)
Codora[a]	Walnut orchard	Birds (1994–2001)
	Restoration site (2000)	Birds (1998–2001)
	Remnant riparian	Birds (1994–2001)
Packer[a]	Restoration site (2000)	VELB (2003)
Princeton South[c]	Restoration site (2001)	Rodents (2005)
Jensen[b]	Walnut orchard	Rodents (2005)
1000-acre Ranch[b]	Prune orchard	Rodents (2005)
Stegeman[c]	Remnant riparian	Rodents (2005)
Moulton North[c]	Restoration site (2002)	Rodents (2005)
Boeger[b]	Field crop	Rodents (2005)

a Units of the USFWS Sacramento River National Wildlife Refuge Complex
b Parcels currently managed (Kopta Slough) or owned (all others) by The Nature Conservancy
c Units of the Department of Fish and Game Sacramento River Wildlife Area
d Valley elderberry longhorn beetle
e Parcel owned by the Sacramento and San Joaquin Drainage District

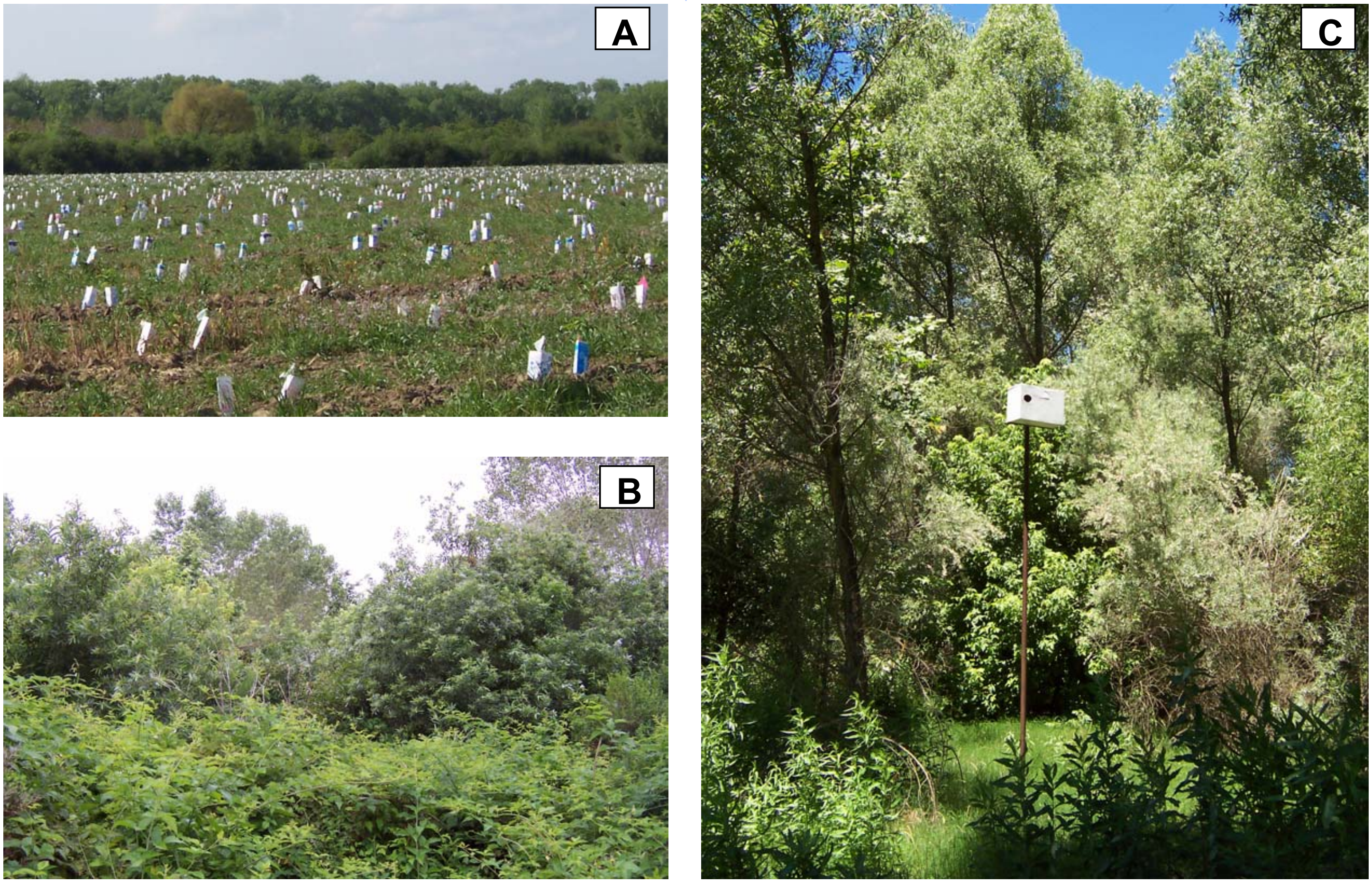

Figure 3. Sacramento River riparian restoration sites of varying ages: (A) New mixed riparian forest at USFWS Hartley Island Unit planted by The Nature Conservancy (TNC). Milk cartons are used to protect young plants from herbicides (applied for 3 years to control weeds) and summer sun (photo taken April 2005); (B) Six-year old restoration site at the DFG Beehive Bend Unit, planted by River Partners (photo taken June 2006); and (C) Fifteen-year old restoration site at DWR Phelan Island River Unit, planted by TNC, with barn owl nest box (photo taken June 2006). Photos by G. Golet.

ismatic; the functional roles that individual species play in ecosystem processes are often not well understood; and the sheer diversity of taxa may be overwhelming to the researcher (Williams 2000).

On the Sacramento River, three investigations of terrestrial insect responses to restoration have focused on individual taxa or specific insect orders. These include studies of the federally threatened Valley elderberry longhorn beetle (VELB), ground-dwelling beetles, and bees.

Valley Elderberry Longhorn Beetle

The VELB is a federally threatened endemic species of California's Central Valley that occupies blue elderberry *(Sambucus mexicana)* shrubs during all stages of its life cycle (Barr 1991). We monitored VELB abundance in 2003 to determine the extent to which restoration sites were providing habitat for this species (River Partners 2004).

Surveys were conducted in 24 fields of varying ages (2–10 years post planting, mean 4.8 yrs) at five restoration sites spanning 106 kilometers along the Sacramento River (Table 1, Figure 1). Approximately

10% (7,600) of the elderberry bushes that were planted at these sites were examined for VELB exit holes, which are distinctive and diagnostic of VELB presence (Lang et al. 1989; Barr 1991). VELB pupae inhabit the pith of elderberry branches where they feed and undergo metamorphosis before emerging as adults. Survey starting points were randomly chosen. Surveyors searched for exit holes in elderberry shrubs with stems greater than 1 inch in diameter. When exit holes were found, the status of the elderberry bush was characterized, and distance to the ground, stem width, and hole dimensions were measured.

A total of 449 exit holes were observed in 299 planted elderberry shrubs (4% of those surveyed, River Partners 2004). Older restoration sites had significantly higher levels of VELB occupancy ($F_{1,\,17}$ = 10.0, P = 0.006, Figure 4), suggesting that VELB colonize and proliferate at restoration sites as the plant community matures. There was no site effect on colonization rate ($F_{4,\,17}$ = 0.36, P = 0.83), and sites with high rates of colonization did not tend to have more remnant riparian habitat surrounding them than sites with low colonization rates ($F_{1,\,17}$ = 1.3, P = 0.26). Nor did colonizations within the sites appear to be more frequent at bushes closer to a remnant habitat edge. Collectively, these results suggest that proximity to remnant habitat was not an influencing factor,

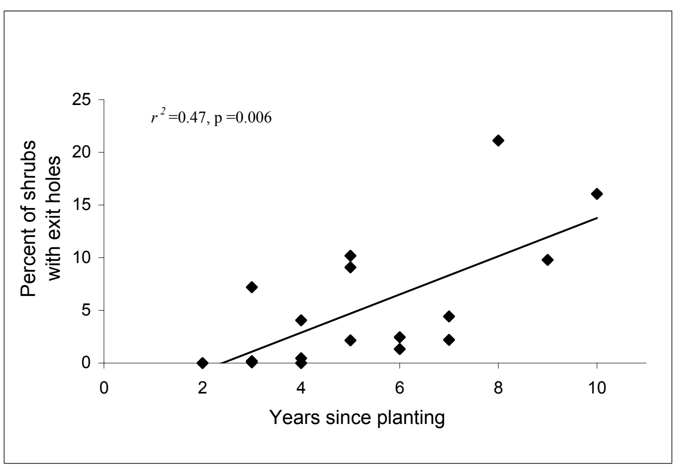

Figure 4. Percent of elderberry shrubs with exit holes diagnostic of Valley elderberry longhorn beetle emergence. All shrubs surveyed were within the Sacramento River Project area, California.

and that VELB did not face dispersal distance limitations when colonizing Sacramento River restoration sites. However, on other Central Valley rivers, habitat connectivity has been shown to influence VELB distribution (Talley 2007). The difference in study results may be due to the Sacramento River having relatively more or better-distributed VELB habitat than the other rivers, or it may simply be a function of our study having insufficient statistical power or inadequate design to test for such an effect.

Ground-Dwelling Beetles

In another study conducted to address insect response to restoration, ground-dwelling, surface-active beetle assemblages (Order: *Coleoptera*) were compared among restoration sites of different ages and remnant riparian habitats (Hunt 2004). In contrast to the VELB study, which was conducted to ascertain whether or not restoration efforts were successful in promoting the recovery of a single special-status species, this investigation was initiated to more broadly assess ecosystem response by characterizing the distribution and abundance patterns of a diverse taxonomic group.

Sampling was conducted from December 2000 through November 2001 with pitfall traps at three young riparian restoration sites (1–3 years old), three older riparian restoration sites (6–10 years old), and three remnant riparian forests (>25 years old) along a 31-km stretch of the Sacramento River (Table 1). At each site, 12 traps were placed 15 meters apart in a 3 × 4 grid. Traps were left open for collections for 7 consecutive days each month. Following collection, beetles were identified to the lowest taxonomic level practicable, and then classified as morphospecies (Sensu Oliver and Beattie 1996a; 1996b).

In total, 24,626 individual beetles were collected, representing 188 distinct morphospecies. Mean monthly species richness differed significantly among habitat types ($F_{2,\,6}$ = 17.9, P = 0.003, Figure 5), with remnant riparian habitats having significantly higher species diversity than either young or older restoration sites (Bonferroni pairwise comparisons probabilities 0.003 and 0.019, respectively). In addition, a Bray-Curtis cluster analysis demonstrated that different habitat

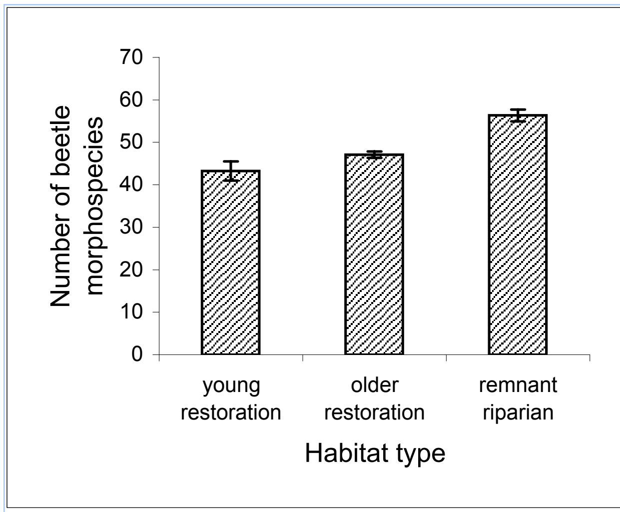

Figure 5. Ground-dwelling beetle species richness (mean ± SE) at young restoration sites, older restoration sites, and remnant habitats within the Sacramento River Project area, California.

types contain characteristic groupings (Figure 6). Coleoptera species assemblages appear to transition predictably as a function of forest age such that older restoration sites were more similar to remnant riparian sites than were young restoration sites. Young restoration sites showed greater differences in composition through time than did older restoration sites and remnant riparian forest habitats, and a significant response to forest type was observed among 37 morphospecies (Hunt 2004).

Bees

Bee (Order: *Hymenoptera*) species richness was compared within 1-ha plots at five 8-year-old restoration sites and five remnant riparian forest/scrub habitats geographically paired along 72 river kilometers (Table 1 in Williams 2007). Paired sites were separated by 0.5–3.8 km. Plots were surveyed every 6 weeks from late February through August, 2003 (five sampling periods). At each site, bees were netted at flowering plants and captured in 30 water-filled pan traps spaced regularly along two crossed 100-m transects (see http://online.sfsu.edu/~beeplot/ for details on trapping methods). Abundance of all plant species within the plots was measured with quadrat sampling.

Results suggest that restored sites are providing habitat for a wide diversity of bee species (Williams 2007). Bees of a variety of life-histories were captured: 5% social to some degree, 73% solitary/gregarious, and 13% cleptoparasitic. Mean species richness pooled from netting and pan traps was not statistically different between restored (mean = 39, SE = 6.5) and remnant (mean = 42, SE = 1.6) sites ($t = 0.335$, $df = 4$, $P = 0.78$). Interestingly, the 8-year-old restoration sites contained many different bee species than what were identified at remnant habitats (Sorensen index mean ± SE similarity between paired sites = 0.45 ± 0.022). Bee communities sampled with netting at restored and remnant sites cluster separately, based on non-metric multi-dimensional scaling (Figure 7A), such that only about half of the bee species among paired sites overlapped. Such differences highlight the importance of a mosaic landscape composed of habitat in different successional stages for promoting species diversity. One cause of dissimilarity between bees from restored and remnant sites may be differences in flowering plant communities at these two site types (mean similarity 0.32 ± 0.043, Sorensen index; Figure 7B). However, paired sites with greater similarity of plants did not have more bee species in common with one another (Williams 2007), suggest-

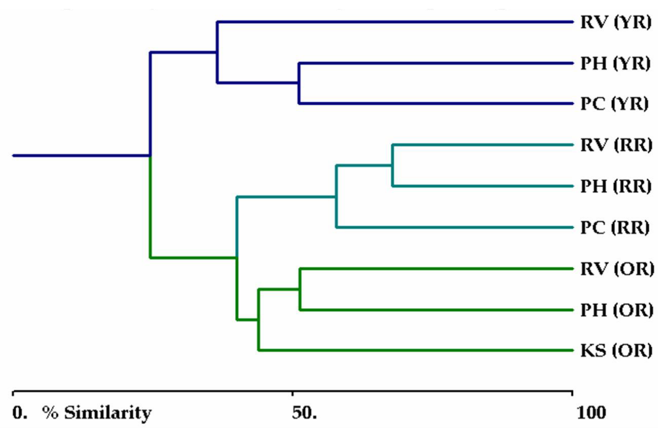

Figure 6. Cluster analysis (Group Average Link) of Bray-Curtis values for year-end totals of Coleopteran sample assemblages collected within the Sacramento River Project area, California. Forest types are defined as: YR = Young restoration; OR = Old restoration; RR = Remnant riparian forest. Site locations are as follows: KS = Kopta Slough; RV = Rio Vista; PC = Pine Creek; PH = Phelan Island (reprinted from Hunt [2004] with permission).

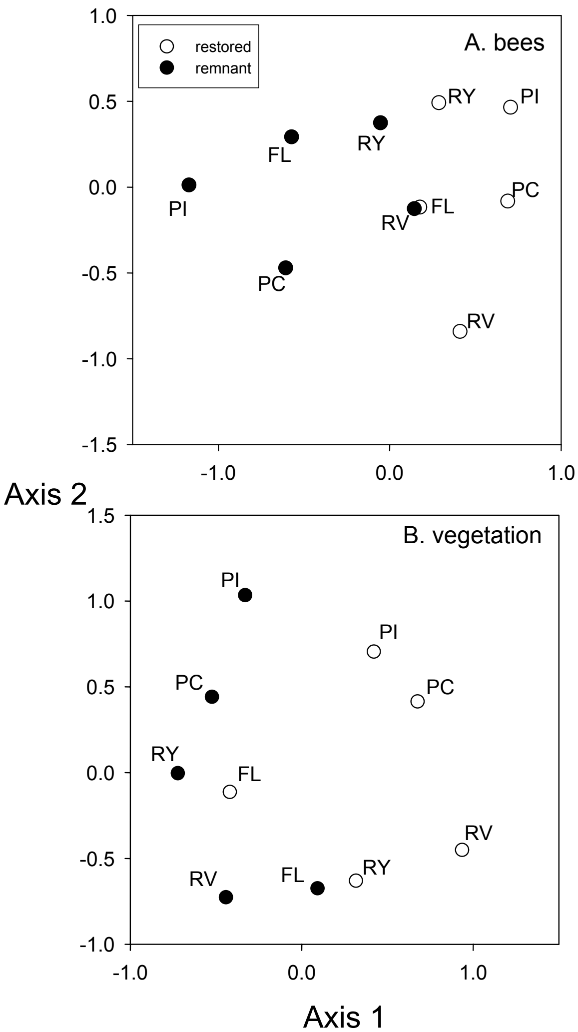

Figure 7. Non-metric Multidimensional Scaling (NMDS) plots of bee and vegetation communities at restoration and remnant sites within the Sacramento River Project area, California. Values based on season-long totals using Sorensen-Bray-Curtis dissimilarity values. Sites are FL = Flynn, PI = Phelan Island, PC = Pine Creek, RV = Rio Vista, LA = La Barranca.

ing that other factors also influence the distribution of bees among Sacramento River habitat types.

Birds

Birds are valuable indicators of ecological integrity (Carignan and Villard 2002). Their communities are often diverse, yet individuals can easily be detected and readily distinguished to species level. Because they have fairly specific habitat requirements, high levels of energy expenditure, and are high on the food chain, they provide useful information about ecosystem function (Sekercioglu 2006). Bird data may be widely comparable due to standardized field (Ralph et al. 1993) and analysis methods (Nur et al. 1999). Also, with many birds it is possible to directly assess vital rates (e.g., fecundity, survival), so factors driving population dynamics may be determined. For all these reasons, birds can be useful indicators of restoration success. Yet, identifying the underlying causes for patterns observed in bird data is not always easy. Birds—especially migratory birds—respond to the environment at multiple spatial and temporal scales (Temple and Wiens 1989), and thus may be strongly influenced by factors outside of any one study area.

The Sacramento River Project area hosts many special-status bird species (Table 2) and is used by many species during all seasons of the year, providing important habitat for breeding, dispersal, migration, and over-wintering (Gaines 1977). Indeed, riparian areas are considered to be the most critical habitats for landbirds in all of California (Manley and Davidson 1993; DeSante and George 1994).

Landbirds

In 1993, PRBO Conservation Science (PRBO) initiated systematic studies of landbirds (passerines and near-passerines) in the Sacramento River Project area. Since then, landbird monitoring has been ongoing, at various levels of intensity, in both restored and remnant riparian habitats (Table 1). Monitoring efforts have focused most consistently on estimating bird abundance and community composition by conducting point counts (Ralph et al. 1993), and relating these parameters to site-specific habitat characteristics (Nur et al. 2004).

To conduct point counts, we established a series of survey stations approximately 200 meters apart (Ralph et al. 1993). Point count stations were surveyed three times during the breeding season from 1993 through 2001, and twice in 2002 and 2003. The duration of each count was 5 minutes, and all birds seen or heard were recorded. We used only those birds noted within 50 meters of the observer, and assumed that detection probabilities were similar within this distance among habitat types and years. Counts began at dawn and continued up to 4 hours past sunrise (see Gardali et al. [2004]; Gardali et al. [2006]; and Gardali and Nur [2006] for additional study details).

To characterize vegetation at each point count station, we used a modified version of the relevé method (Ralph et al. 1993). In brief, vegetation was assessed using a relevé, a plot with a 50-meter radius (0.785 ha) centered on the point count location. Several characteristics of the plots were recorded including maximum tree dbh (diameter breast height), presence of water, and the cover and height of each vegetation stratum. Within each vegetation stratum, species composition was determined, as was species richness and percent cover for trees and shrubs.

Additional monitoring was conducted to estimate reproductive success and adult survival for a subset of species with sufficient sample sizes (Small and Gardali 2004; Gardali and Nur 2006). Nest monitoring allows measures of nest success at specific sites and in specific habitat, and provides information on population health of landbirds (Nur et al. 1999). Nest finding and monitoring followed Breeding Biology Research and Monitoring Database (BBIRD) protocol (Martin et al. 1997) and guidelines outlined in Martin and Geupel (1993). All nests found were checked at least once every 4 days to determine outcome (fledge or fail) and, when appropriate, cause of failure. To minimize human disturbance, visits to nests were brief. Researchers caused very little disturbance to vegetation in the nest area, and did not check nests when predators were detected nearby.

We provide reproductive success estimates by calculating daily nest survival rates using the Mayfield method (Mayfield 1975; Johnson 1979). This method incorporates the number of days that each observed nest remained active (from the find-date) to calculate the daily survival probability. The daily survival probability is raised to the power of the total number of days in the nesting period (laying, incubation, and nestling phases), which differs by species, to obtain the overall nest survival estimate for the entire nest period.

To estimate adult survival rates, we sampled Black-headed Grosbeaks and Spotted Towhees with standardized-effort mist-netting (Monitoring Avian Productivity and Survivorship protocol; DeSante et al. 2000). One 12-meter, 36-millimeter-mesh mist-net was operated at each of 10 net sites for 5 morning hours per day, for 1 day during each of 10 consecutive 10-day periods. Starting dates were in early May, and operation continued through the 10-day period, ending in early August. Nets were opened 45 minutes before sunrise, and kept open for 5 hours. Captured birds were banded with standard USFWS bands, measured, and released immediately.

Results indicate that restoration sites are providing habitat for a diverse community of landbirds. Species richness increased as the sites matured ($\beta = 0.86$, SE $= 0.084$, 95% CI $= 0.69–1.02$, adjusted $r^2 = 0.55$, $P < 0.0001$; Figure 8), and the abundance of many species, with diverse life-history requirements, has dramatically increased as the sites have aged (Figure 9; Gardali et al. 2006). An exception is the Lazuli Bunting *(Passerina amoena)*, which has been declining at both restoration sites and in remnant habitats (Gardali et al. 2006). The increase in species richness at restoration sites is apparently due to certain species (e.g., House Wren *[Troglodytes aedon]*) being absent until the structural complexity of the sites increase beyond some threshold amount. Nur et al. (2004) found that the abundance

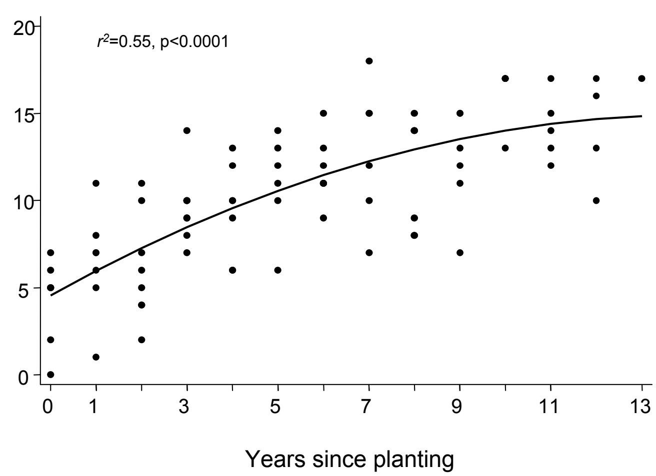

Figure 8. Landbird species richness at restoration sites of varying ages within the Sacramento River Project area, California.

Table 2. Special-status wildlife and fish species of the Sacramento River Project area, California and their observed patterns of use on restoration sites. Several of the less common and/or more cryptic species have not yet been observed; however, their occurrence is likely based upon established habitat requirements and home ranges. Restoration actions were designed to benefit these and other more common species. Definitions of the acronyms used in this table appear at the end of the table on the following page.

SPECIES	STATUS			DOCUMENTED USES ON RESTORATION SITES
	NGO[a]	STATE	FEDERAL	
BIRDS				
American white pelican *(Pelecanus erythrorhynchos)*	–	SSC (1)	–	Foraging in adjacent waterbodies
Double–crested cormorant *(Phalacrocorax auritus)*	–	SSC (2)	–	Foraging in adjacent waterbodies
Great egret *(Ardea alba)*	–	CDFS	–	Foraging
Great blue heron *(Ardea herodias)*	–	CDFS	–	Foraging
Snowy egret *(Egretta thula)*	USBCWL	–	–	Foraging
Cooper's hawk *(Accipiter cooperii)*	–	SSC (2)	–	Nesting
Sharp–shinned hawk *(Accipiter striatus)*	–	SSC (3)	–	Yes
Bald eagle *(Haliaeetus leucocephalus)*	–	SE, CDFS, SFP	FT	Nesting, foraging in adjacent waterbodies
Golden eagle *(Aquila chrysaetos)*	–	SSC (3), CDFS, SFP	PR, BLMS	Yes
Osprey *(Pandion haliaetus)*	–	SSC (2), CDFS	–	Nesting, foraging in adjacent waterbodies
Northern harrier *(Circus cyaneus)*	–	SSC (2)	–	Nesting, foraging
Swainson's hawk *(Buteo swainsoni)*	USBCWL, AW	ST	FSC, FWSBCC	Foraging
White–tailed kite *(Elanus leucurus)*	–	SFP FSC	–	Foraging
Peregrine falcon *(Falco peregrinus)*	–	SFP, CDFS	FWSBCC	Yes
Merlin *(Falco columbarius)*	–	SSC (1)	–	Yes
Caspian tern *(Sterna caspia)*	–	–	FWSBCC	Foraging in adjacent waterbodies
Western yellow–billed cuckoo *(Coccyzus americanus occidentalis)*	–	SE FSC, FSS,	FC, FWSBCC	Nesting, foraging
Short–eared owl *(Asio flammeus)*	USBCWL, AW	SSC (2)	–	Foraging
Long–eared owl *(Asio otus)*	–	SSC (2)	–	Not yet observed
Rufous hummingbird *(Selasphorus rufus)*	USBCWL, AW	–	FSC, FWSBCC	Yes
Allen's hummingbird *(Selasphorus sasin)*	USBCWL, AW	–	FSC	Not yet observed
Nutall's woodpecker *(Picoides nuttallii)*	USBCWL, AW	–	–	Nesting, foraging
Olive–sided flycatcher *(Contopus cooperi)*	USBCWL, AW	SSC	FSC, FWSBCC	Foraging
Willow flycatcher *(Empidonax traillii)*	USBCWL, AW	SE	FSC, FSS	Foraging
Loggerhead shrike *(Lanius ludovicianus)*	–	SSC	FSC, FWSBCC	Foraging
Bank swallow *(Riparia riparia)*	–	ST	FSC	Nesting, foraging
Yellow warbler *(Dendroica petechia)*	–	SSC (2)	–	Foraging
Yellow–breasted chat *(Icteria virens)*	–	SSC (2)	–	Nesting, foraging

a Non-governmental organization
b Status proposed
c Species occurrence documented from museum (historical) record only

Table 2. (continued)

SPECIES	STATUS			DOCUMENTED USES ON RESTORATION SITES
	NGO[a]	STATE	FEDERAL	
MAMMALS				
Townsend's big–eared bat[c] *(Corynorhinus townsendii)*	WBWGHP	SSC	FSC, FSS, BLMS	Not yet observed
Western mastiff bat *(Eumops perotis)*	WBWGHP	SSC	FSC, BLMS	Foraging
Pallid bat *(Antrozous pallidus)*	WBWGHP	SSC	FSS, BLMS	Foraging
Western red bat *(Lasiurus blossevillii)*	WBWGHP	SSC[b]	FSS	Roosting, foraging
Small–footed myotis[c] *(Myotis ciliolabrum)*	–	–	FSC, BLMS	Not yet observed
Long–eared myotis[c] *(Myotis evotis)*	–	–	FSC, BLMS	Not yet observed
Fringed myotis[c] *(Myotis thysanodes)*	WBWGHP	SSC[b]	FSC, BLMS	Not yet observed
Long–legged myotis[c] *(Myotis volans)*	WBWGHP	SSC[b]	FSC	Not yet observed
Yuma myotis *(Myotis yumanensis)*	–	–	FSC, BLMS	Foraging
Ringtail *(Bassariscus astutus)*	–	SFP	–	Yes
REPTILES				
Northwestern pond turtle *(Clemmys marmorata marmorata)*	–	SSC (2)	FSC, FSS	Breeding, foraging in adjacent waterbodies
FISHES				
Chinook salmon *(Oncorhynchus tshawytscha)* Central Valley Spring–run	–	ST	FT, FSS	Migrating through adjacent waterbodies
Chinook salmon *(Oncorhynchus tshawytscha)* Sac. River Winter–run	–	SE	FE	Migrating through adjacent waterbodies
Chinook salmon *(Oncorhynchus tshawytscha)* Central Valley Fall /late Fall–run	–	SSC (2)	FSC, FC, FSS	Migrating through adjacent waterbodies
Central Valley steelhead *(Oncorhynchus mykiss)*	–	–	FT	Migrating through adjacent waterbodies
Green sturgeon *(Acipenser medirostris)* – Southern District Population	AFSE	SSC (1)	FT	Migrating through adjacent waterbodies
Hardhead *(Mylopharodon conocephalus)*	–	SSC (3)	FSS	Occupying adjacent waterbodies
River lamprey *(Lampetra ayersi)*	–	SSC (3)	FSC	Migrating through adjacent waterbodies
Sacramento splittail *(Pogonichthys macrolepidotus)*	–	SSC (1)	FSC	Migrating through adjacent waterbodies
INVERTEBRATES				
Valley elderberry longhorn beetle *(Desmocerus californicus dimorphus)*	–	–	FT	Breeding, foraging

STATUS CODE DEFINITIONS

NGO[a]:
AFSE American Fisheries Society Endangered http://www.fisheries.org
AW Audubon Watch List http://www.audubon.org/bird/watchlist/index.html.
USBCWL United States Bird Conservation Watch List http://www.abcbirds.org/watchlist/index.htm.
WBWGHP Western Bat Working Group High Priority http://www.wbwg.org.

STATE:
CDFS California Department of Forestry Sensitive http://www.fire.ca.gov/ResourceManagement/pdf/FPA200301.pdf
SE State Endangered
SFP State Fully Protected http://www.leginfo.ca.gov/cgi-bin/calawquery?codesection=fgc.
SSC State Species of Special Concern, numbers in parentheses refer to ranking (1 = highest) http://www.dfg.ca.gov/hcpb/species/ssc/ssc.shtml.
ST State Threatened

FEDERAL:
BLMS Bureau of Land Management Sensitive http://www.or.blm.gov/Resources/special-status_species/CAIB99-86.htm.
FC Federal Candidate (for FE or FT status)
FE Federally listed, Endangered
FSC Federal Species of Concern http://sacramento.fws.gov/es/spp_lists/animal_sp_concern.cfm
FSS Forest Service Sensitive http://www.fs.fed.us/r5/projects/sensitive-species/
FT Federally listed, Threatened
FWSBCC Fish and Wildlife Service Birds of Conservation Concern http://migratorybirds.fws.gov/reports/bcc2002.pdf.
PR Protected under Golden Eagle Protection Act

of several species (e.g., Ash-throated Flycatcher *[Myiarchus cinerascens]*, Tree Swallow *[Tachycineta bicolor]*) was positively associated with tree height and/or canopy cover, factors that typically increase as restoration sites mature. At about 10 years, restoration sites begin to be occupied by primary cavity-nesting species (e.g., Nuttall's Woodpecker *[Picoides nuttallii]*). Comparisons between restored and remnant forests showed that the abundances of many bird species in older restoration sites approached values observed in remnant habitats. Interestingly, abundances of many species studied were also increasing at remnant forest sites—although usually at a slower rate (Gardali et al. 2006). These results suggest that restoration efforts may be producing positive spill-over effects for bird populations in the larger Sacramento Valley, although other factors (e.g., climate, conditions in wintering areas, etc.) may also be responsible.

With the bird studies, we are fortunate to have additional measures of restoration success besides species richness and abundance. These measures were developed for two species which were sufficiently common to allow sufficient sample sizes of nests to be monitored, and adults to be captured: the Black-headed Grosbeak *(Pheucticus melanocephalus)*, a neotropical migrant; and the Spotted Towhee (*Pipilo maculatus*), a year-round resident.

The Black-headed Grosbeak had survival rates at a restoration site that were slightly lower than what was observed at two remnant sites, and considerably higher than a third grazed remnant site (Figure 10; Gardali and Nur 2006). For the Spotted Towhee, results were less encouraging. Adult annual survival for this species was lower at the restoration site than at two remnant sites, and nearly identical to the grazed remnant site (Figure 10). Reasons for the different survival response of these species remain to be determined; however, it is plausible that the lack of a well-developed native understory layer at the restora-

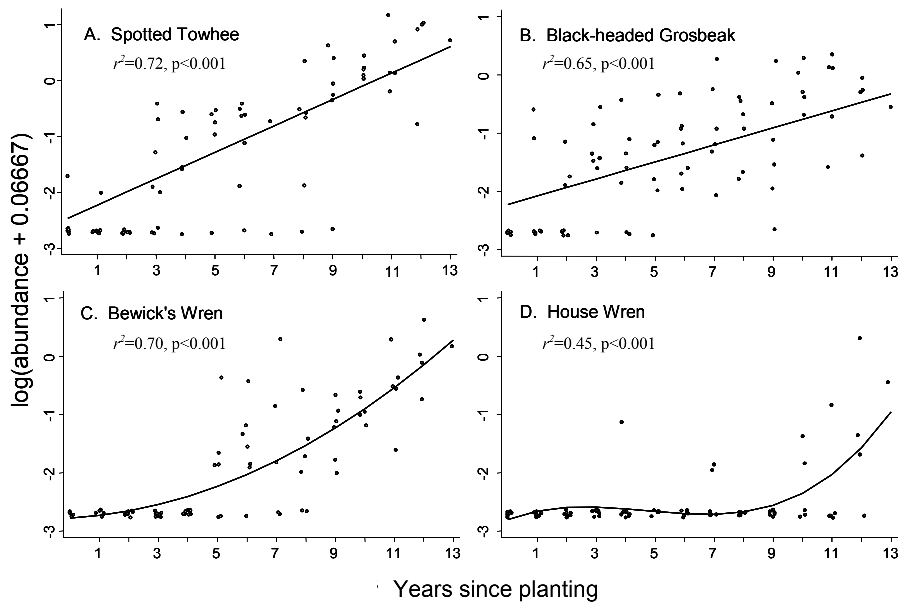

Figure 9. Abundance (point count detections) of four landbirds in relation to years since planting at restoration sites within the Sacramento River Project area, California. Lines show values predicted from log-linear regression; quadratic fit for Bewick's Wren and cubic fit for House Wren. Each point represents datum from 1 year for each site (reprinted from Gardali et al. [2006] with permission).

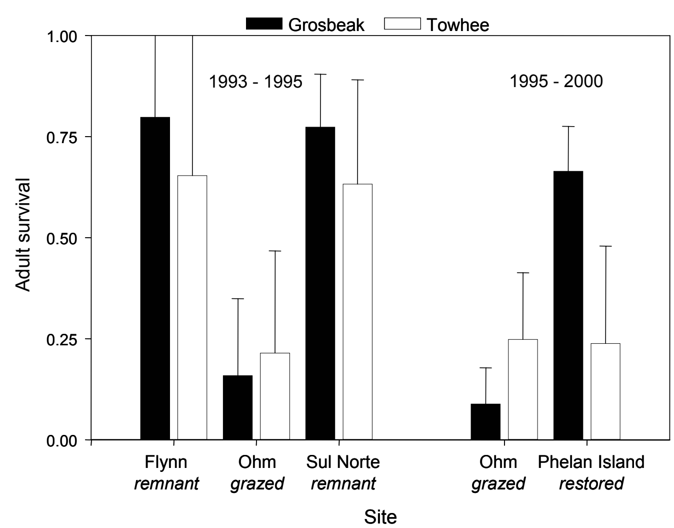

Figure 10. Site-specific adult survival of Black-headed Grosbeaks and Spotted Towhees at four sites within the Sacramento River Project area, California. Site types are indicated on the x-axis below the site names (reprinted from Gardali and Nur [2006] with permission).

tion site affected the understory-nesting towhee more than the mid-canopy-breeding grosbeak.

Reproductive success of Black-headed Grosbeaks, as measured by daily survival rates of nests (Mayfield 1975; Johnson 1979) for all years combined, was not statistically different between restored (mean = 0.97, SE = 0.004) and remnant sites (mean = 0.96, SE = 0.009, t = 0.34, df = 2423, P = 0.74, Figure 11A). Rates varied annually, however 95% confidence intervals for restored and remnant sites overlapped in all years. For Spotted Towhees, daily nest survival rates were also not statistically different between restored (mean = 0.94, SE = 0.012) and remnant sites (mean = 0.91, SE = 0.011) over all years combined (t = -1.3, df = 989, P = 0.19).

Daily nest survival rates can also be summarized in terms of overall nest survival for the entire nest period. For Black-headed Grosbeaks, overall nest survival, averaged across all years, was 44% in remnants (CI = 26–63%) and 40% in restored habitat (CI = 36–54%). For Spotted Towhees, the rates were much lower: 9.6% in remnants (CI = 5.0–18%) and 18% in restored sites (CI = 9.1–36%). Towhee daily nest survival rates were thus well below the benchmark value of 42% that is often used in comparative studies of open-cup nesting passerines (Martin 1992).

Analyses of bird habitat relationships in restored and remnant riparian habitats along the Sacramento River and other locations in the Central Valley have confirmed the importance of plant understory and overall structural and compositional diversity. For example, the abundance of several landbird species was strongly related to cover of blackberry (*Rubus* spp.), mugwort *(Artemisia douglasiana)*, and herbs (Nur et al. 2004). Based in part upon these findings and recommendations from Riparian Habitat Joint Venture (RHJV 2003), starting in 1999, an understory component was added to the restoration plantings. Currently, nine native herbaceous species are planted at TNC's restoration sites (Table 3), with the exact number and assortment varying from site to site depending upon local conditions.

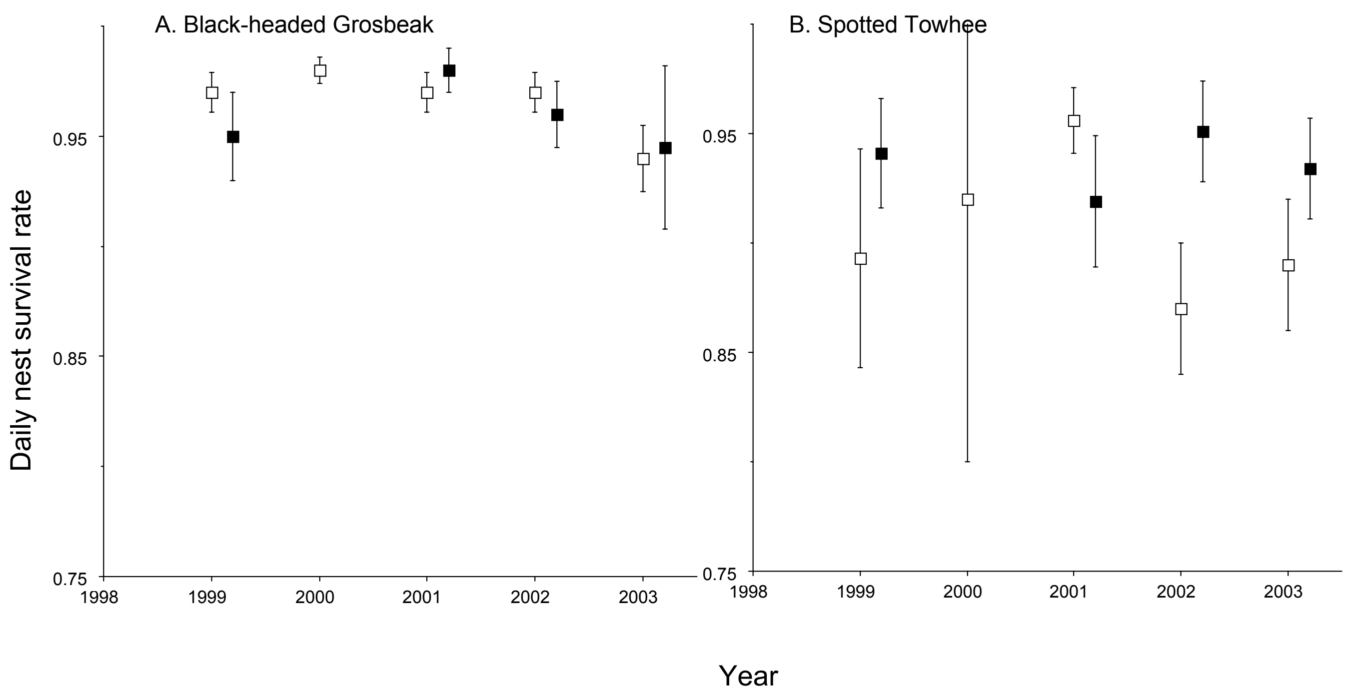

Figure 11. Mayfield estimates of nest survival rates for: (A) Black-headed Grosbeak; and (B) Spotted Towhee at restoration and remnant sites within the Sacramento River Project area, California. Solid squares identify restoration sites, and hollow squares indicate remnant sites. Vertical bars indicate 95% confidence intervals.

Table 3. Species planted at Sacramento River riparian restoration sites. All species are planted by hand, except seed-propagated species, which are planted with a rangeland drill. Seed-propagated species are planted between rows of hand-planted species, or by themselves in grassland settings. To match Sacramento River ecotypes, all cuttings and seed sources are obtained locally. Nomenclature is based on the Jepson Manual (Hickman 1993). There are no universally accepted standards for common plant names in English. When available, common names correspond to those used in the Jepson Manual (Hickman 1993). Otherwise, they follow Oswald (2002).

Scientific name	Common name	Growth form	Propagation method
Acer negundo var. *californicum*	Box-elder	Tree	Container
Alnus rhombifolia	White alder	Tree	Container
Aristolochia californica	California pipevine	Vine	Container
Artemisia douglasiana	Mugwort	Herb	Container
Baccharis pilularis	Coyote-brush	Shrub	Container
Baccharis salicifolia	Mule's-fat	Shrub	Container
Carex barbarae	Santa Barbara sedge	Sedge	Container
Carex praegracilis	Clustered field sedge	Sedge	Container
Cephalanthus occidentalis var. *californicus*	California button-willow	Shrub	Container
Clematis ligusticifolia	Virgin's-bower	Vine	Container
Elymus glaucus ssp. *glaucus*	Blue wild-rye	Grass	Container or seed
Fraxinus latifolia	Oregon ash	Tree	Container
Euthamia occidentalis	Western goldenrod	Herb	Container
Hordeum brachyantherum ssp. *branchyanterum*	Meadow barley	Grass	Seed
Leymus triticoides	Alkali ryegrass	Grass	Container or seed
Lupinus ssp.	Lupine	Herb	Container
Muhlenbergia rigens	Deergrass	Bunchgrass	Container
Nassella pulchra	Purple needlegrass	Bunchgrass	Container or seed
Oenothera elata ssp. *hirsuitissima*	Hairy evening-primrose	Herb	Container
Quercus lobata	Valley oak	Tree	Container
Populus fremontii ssp. *fremontii*	Fremont's cottonwood	Tree	Cutting
Platanus racemosa	Western sycamore	Tree	Cutting
Rosa californica	California rose	Shrub	Container
Rubus ursinus	California blackberry	Shrub/Vine	Container
Salix exigua	Sandbar willow	Tree/Shrub	Cutting
Salix goodingii	Goodding's black willow	Tree	Cutting
Salix laevigata	Red willow	Tree/Shrub	Cutting
Salix lasiolepis var. *lasiolepis*	Arroyo willow	Tree/Shrub	Cutting
Salix lucida ssp. *lasiandra*	Yellow willow	Tree/Shrub	Cutting
Sambucus mexicana	Blue elderberry	Shrub	Container
Toxicodendron diversilobum	Western poison-oak	Shrub/Vine	Container
Urtica dioica ssp. *holosericea*	Hoary creek nettle	Herb	Container
Vitis californica	California wild grape	Vine	Container

Small Mammals

Although there are no special-status rodent species in the Sacramento River Project area, much valuable information can be gained by studying this group. In floodplain systems, rodents are an important functional group that has been shown to influence vegetation patterns (Anderson and Cooper 2000). Because they are a primary prey source for many higher trophic-level organisms, their abundance and distribution provides information about food availability. Also, because rodents typically have high reproductive capacity, they may be one of the first resident groups to signal changing habitat conditions (Bock et al. 2002), including those at restoration sites.

In recent years, bats have received increased attention, reflecting a wider recognition of their role in ecosystem function (Wickramasinghe et al. 2003). Although relatively little was known about the bat assemblage in the Central Valley when this study was initiated (Pierson et al. 2000), there were several compelling reasons to think that bats as a group might serve as valuable indicators of restoration success. Because bats are volant, and even the smallest species can travel large distances, they have the potential to respond quickly to changes in habitat quality, disappearing when habitat is lost, and recruiting readily when suitable conditions return. Because bats use echolocation for navigation and foraging, they can be monitored acoustically using relatively inexpensive hardware that records and stores their calls, and that can operate for a number of nights without human attendance (Waldren 2000). Also, because many species rely on both aquatic and terrestrial habitat features, concentrating foraging over lentic or lotic areas, and using tall riparian forests for roosting and breeding, they can be valuable ecological indicators of both aquatic and terrestrial ecosystem health.

Rodents

Rodents are the focus of several management concerns on the Sacramento River. From a biodiversity standpoint, there is a concern that restoration may cause increases in the abundance of undesirable non-native species, such as house mouse *(Mus musculus)* or black rat *(Rattus rattus)*. Another concern, expressed by farmers, is that restoration activities may lead to increases in the abundance of agricultural pest species (e.g., California vole *[Microtus californicus]*, squirrels).

To address these concerns, small mammal distribution and abundance were assessed at agricultural and remnant forest habitats and at young (3–4 years) and older (12–5 years) restoration sites (Table 1). Three replicates of each site type were sampled with Sherman live traps (Wiener and Smith 1972) during spring and fall of 2005. At each site, we sampled for 5 consecutive days using 100 traps arranged in a 10 × 10 trap grid, with traps spaced 10 meters apart. See Koenig et al. (2007) and Golet et al. (2007) for additional study details.

The results of this 1-year study should be viewed as preliminary, given that small mammal abundances are known to be highly variable in riparian settings (Anderson et al. 2000). Nonetheless, our results suggest that rodent distribution and abundance are strongly influenced by changing habitat conditions (species × habitat type interaction, $F_{12, 335} = 10.5$, $P < 0.001$, Figure 12), and that there are clear habitat preferences among species: Deer mouse *(Peromyscus maniculatus)* and house mouse were most common in disturbed agricultural lands; California vole was abundant at young restoration sites where thick thatch layers were often present; western harvest mouse *(Reithrodontomys megalotis)* was common in both the older restoration sites and in remnant habitats with thick herbaceous layers and dense aboveground structure; and black rat was abundant in remnant riparian forest habitats where tightly closed canopies support their arboreal life-style.

A positive outcome of the restoration effort was a decline in the abundance of the non-native house mouse, a species common in human-altered habitats, and a concomitant increase in western harvest mouse, a native species less commonly found around human settlements. A less encouraging outcome was the steady increase in exotic black rat abundance associated with site maturation. This increase may adversely affect area landbirds, as previous research

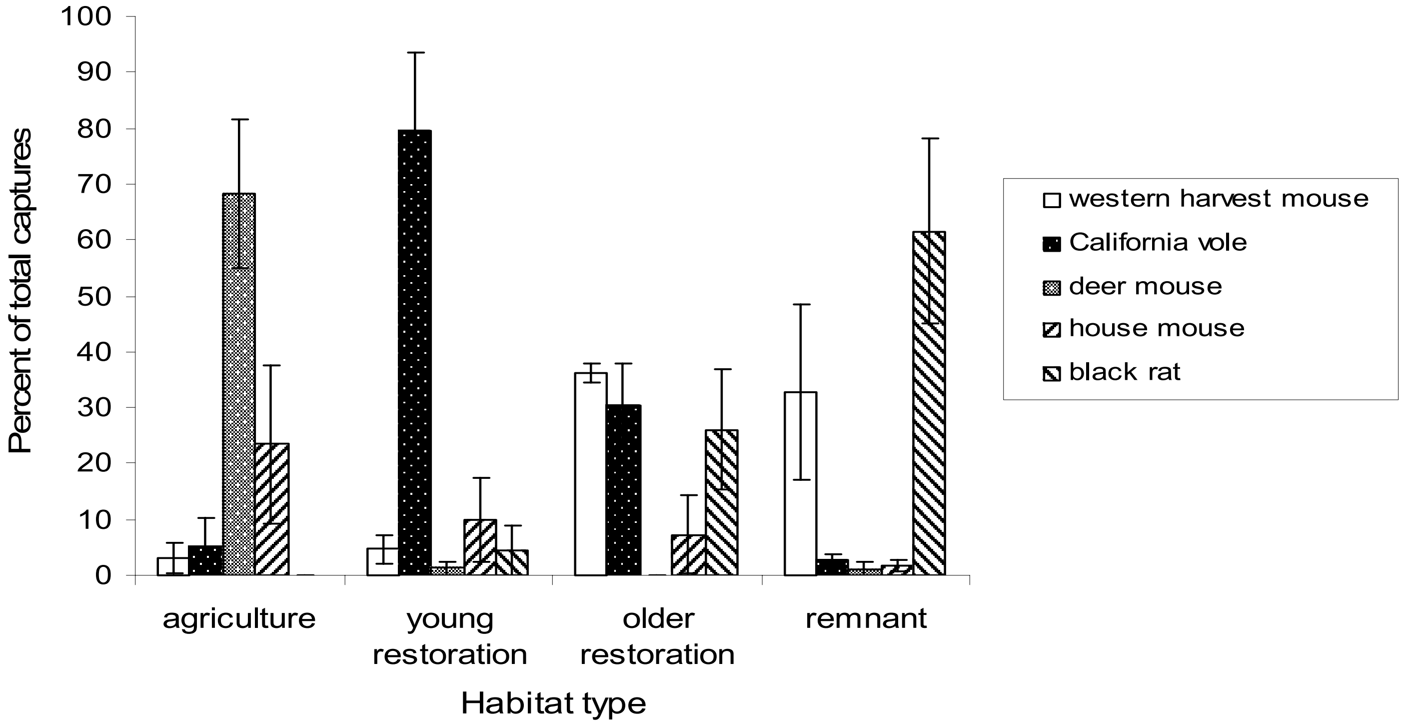

Figure 12. Number of animals captured (mean ± SE) in small mammal live traps at four habitat types within the Sacramento River Project area, California.

has demonstrated black rats to be a potentially potent nest predator on the Sacramento River (Small 2005) and in other woodland settings (Brown et al. 1998; VanderWerf 2001). Also, black rats may limit the recovery of bats, of which there are nine special-status species along the river (Table 2), through predation at cavities, crevice roosts, and maternity sites. Bat young are initially flightless and defenseless, and females give birth only once in a year. Although rats have been reported to cause extinctions of both birds (Blackburn et al. 2004) and bats (McKean 1975), more research is needed to determine the magnitude of their effects in this and other systems (Towns et al. 2006).

Results also suggest that young restoration sites may be a source of agricultural pests, as vole populations were the highest in this habitat type. Impacts to neighboring farms, while potentially significant, may be relatively short-lived, however, because vole abundance drops off dramatically as the restoration sites mature, after 12–15 years (Figure 12). Nonetheless, we recommend that Barn Owl (*Tyto alba)* nest boxes be erected at young restoration sites to help control voles, the most common prey of Barn Owls on Sacramento River agricultural properties and restoration sites (Golet and Bogiatto unpublished data). Overall, a significant difference was found among site types (agricultural, young restoration, older restoration, and remnant) in the abundance of different species captured ($F_{3,\ 335} = 10.5$, $P < 0.001$). As restoration sites matured, abundances declined, such that older restoration sites and remnant habitats had abundance levels similar to agricultural lands—although species composition was markedly different. Significant differences in abundance were found among species ($F_{4,\ 335} = 10.3$, $P < 0.001$), with voles being the most captured species overall. Approximately three times as many captures were made in the fall ($F_{1,\ 351} = 9.1$, $P = 0.003$), than in the spring, but not for all species (significant species × season interaction, $F_{4,\ 335} = 8.6$, $P < 0.001$). To a large degree, this increase was due to summer breeding, as ~50% of the fall captures were immature animals.

Bats

A short-term investigation of bat response to restoration was conducted in fall 2002 (Stillwater Sciences et al. 2003). The investigation, with the aid of the Anabat detection system, assessed bat activity at orchards, young and older restoration sites, and mature riparian remnant habitats. Anabat systems record ultrasonic echolocation calls by using a sophisticated ultrasonic microphone and cassette-tape interface (Waldren 2000). Identifying bat species based upon echolocation calls relies on a number of call or pulse parameters, including base frequency, call shape (slope as measured in octaves per second and overall pattern), pattern of calls within a sequence, interpulse interval, and call duration.

Because night-to-night variation in bat activity at individual sites can be high, valid comparative data are best obtained by many nights of repeated sampling at replicate locations (Hayes 1997; Ballantyne and Sherwin 1999). We deployed three Anabat II ultrasound detectors (Titley Electronics, Ballina, NSW, Australia) at each site over extended periods. Two replicate orchard and mature riparian forest sites were sampled over one long period (September 12–13 through October 21–22, 2002), and young and older restoration sites were sampled over two short periods (September 12–14 and September 26–27). Detectors were directed upward at 45° and mounted on transducers atop aluminum poles to decrease unwanted detections from ground-dwelling insects (e.g., crickets). To analyze the data, we used both generalized filters detecting all bat calls and specific ones for particular species or family groups.

Bat activity was higher in mature riparian forests than in orchards (Stillwater Sciences et al. 2003). Intermediate levels of activity were observed at restoration sites, with the older site (planted in 1991) tending to have higher levels of activity than the newly planted site ($F_{1,7}$ = 4.7, P = 0.067, Figure 13). Interestingly, bat activity patterns declined at all restoration site sampling locations from the first sampling period to the second (2 weeks later). And although this difference was not statistically significant ($F_{1,7}$ = 2.3, P = 0.17, Figure 13), it nonetheless suggests that it is important to collect data concurrently when drawing comparisons between sites. Higher recorded activity levels are strongly suggestive of higher bat abundances, although, theoretically, they may also result simply from higher calling rates.

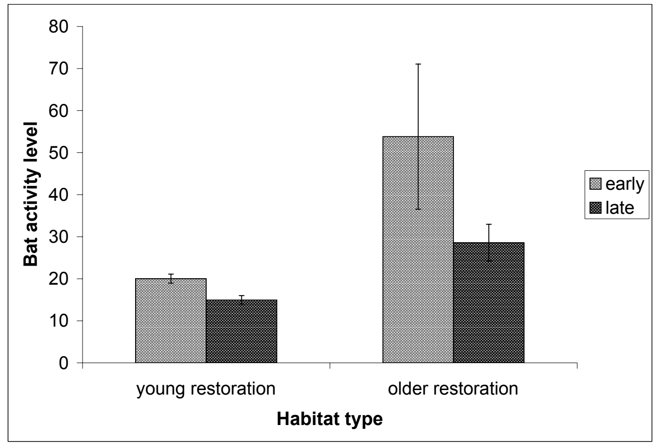

Figure 13. Bat activity levels (mean ± SE) at young (planted in 2002) and older (planted in 1991) restoration sites within the Sacramento River Project area, California. Bat activity is defined as the mean number of acoustic files per sampling period. "Early" refers to the September 12–14, 2002 sampling period, and "late" refers to the September 26–27, 2002 sampling period. At each site, detectors were deployed at three locations.

Visual observations confirmed that bats were roosting in the 11-year-old cottonwood trees at the older restoration site, and foraging at canopy level upon emergence. Some species (e.g., Pallid bat *[Antrozous pallidus]*) recorded at the older restoration site were not detected at the newer site. No red bat activity was recorded at the newly-planted 2002 forest immediately after sunset, but both the 1991 forest and the adjacent mature forest showed a peak in activity immediately following sunset, suggesting that red bats were roosting in the latter two habitat types. Also, researchers were able to identify California myotis *(Myotis californicus)* emerging from near the tree canopy. While the western red bat roosts in foliage, California myotis is thought to roost in crevices (e.g., under bark or in cracks formed by broken limbs), suggesting that restoration sites that are just over a decade old are already developing such features.

Differences in bat activity levels between the plots planted in 1991 and 2002 can be partially accounted for by the fact that the 1991 restoration plot offers roosting habitat while the 2002 plot does not; however, there also appeared to be more foraging activity at the 1991 plot. The implication is that the older restoration sites provide richer habitat overall for many species compared to the newly-planted sites.

Four special-status species (western mastiff bat, pallid bat, western red bat *[Lasiurus blossevillii]*, and yuma myotis) were detected through capture or by visual or acoustic record at riparian forest habitats in this study.

DISCUSSION AND CONCLUSIONS

Favorable Overall Response to Restoration

Collectively, these studies provide convincing evidence that riparian restoration along the Sacramento River has been successful in restoring a broad suite of faunal species. Not only were the restoration projects successful in providing habitat for special-status species (e.g., VELB, yellow-billed cuckoo, western red bat), but they were also highly effective in revitalizing the larger native riparian community. And the response has been rapid, with many species of diverse taxa colonizing the site in the first few years after implementation. Cavity-nesting birds (e.g., Nuttall's Woodpecker) and crevice-roosting bats (e.g., California myotis)—species often associated with mature forest features—began to occupy the restoration sites in fewer than 10 years. These observations are consistent with the very high rates of growth measured among floodplain trees at Sacramento River restoration sites (Griggs and Golet 2002).

Our results also suggest that local restoration projects may be producing positive spill-over effects. Increases in abundances of several bird species, for example, are taking place not only locally at the restoration sites, but also across the larger riparian landscape (Gardali et al. 2006). This macro-scale response is likely due to increases in riparian habitat patch sizes (and coincident reductions in habitat fragmentation) across the Project area, as strategically located agricultural lands are being replaced with habitat to both connect and expand existing remnants. However, a temporal trend caused by other factors (e.g., favorable climatic conditions) could also explain this pattern.

Although positive overall, some of these monitoring results provide cause for concern. The landbird study suggested that special attention be paid to the Lazuli Bunting because its population is declining in restoration sites, remnant habitats, and across the entire Central Valley. Hence, the amount of habitat may not be a population-limiting factor for Lazuli Bunting. Restoration and management for this species may require research on how invasive species (e.g., Brown-headed Cowbird *[Molothrus ater]*) shape the quality of the habitat. The rodent study warned that black rats, a potentially harmful predator, may increase as riparian forests expand along the river. More work is needed to determine whether rats are negatively impacting birds, bats, or other riparian species. As with problematic non-native plants (e.g., *Arundo donax, Lepidium latifolium*), certain animal populations may need to be curtailed via control measures.

A Conservation Vision for the Sacramento River

Having restoration sites provide suitable habitats for native species in the near term is only one part of a larger conservation vision for the Sacramento River. Equally important is that natural riverine processes (e.g., flooding, erosion) be sufficiently operational. This is needed so that these sites, and their remnant counterparts, can be rejuvenated, lost, and created as is necessary to meet the diverse life-history needs of the native species that have evolved in the system (i.e., Attribute 9 of restored ecosystems, SER 2004). While continued low-level habitat management (e.g., control of invasive species) may be necessary, our conservation vision for the Sacramento River is that it be managed to provide functional habitats over the long term for native species without continued replanting. Indeed, if present-day restoration sites require extensive replanting in the future, then our long-term conservation goals will remain unmet. To prevent this, the river's habitat-forming processes must be actualized. The floodplain must remain hydraulically connected to the river, limited meander must be permitted, and, ultimately, the flow regime must be managed to meet ecological as well as human needs.

Future Monitoring Needs

Localized monitoring confirms that Sacramento River restoration efforts are benefiting wildlife; however, additional monitoring is needed. Researchers need to better characterize the variability in response at restoration sites, and identify what makes some restoration sites more successful than others. Also, there is a need for a longer time series of data collection and more robust sample sizes for some studies and taxa. What will happen at these sites as they continue to mature, and as the planted individuals senesce and die? What plants will colonize, and what consequences will this have for wildlife? Although VELB are responding favorably to planted elderberry under current conditions, what will happen when forests mature around the planted bushes? Can conditions for natural recruitment of elderberry, and other important plants, be met in this highly regulated system? Long-term monitoring is also needed to characterize the response to restoration of species that exhibit high annual variation in measured parameters. These species include migratory birds and fish that are strongly influenced by factors outside of the project area, as well as species (e.g., rodents) that are strongly affected by natural riverine disturbances such as flooding.

For some taxa, it would be highly beneficial to expand upon the initial surveys profiled in this paper simply to gain more information about how they interface with habitats along the river. In particular, more studies should be conducted on bats. Although we know that several special-status bats use the riparian zone extensively, we do not have a good sense for the life-history requirements of individual species, nor do we know enough about how habitat use patterns vary seasonally. Studies of landbirds provide a good example of the richness of information that can come from conducting research during the breeding, migration, and wintering periods.

For comparison purposes, future studies should also be conducted in young riparian forests that have naturally recruited. All of the studies profiled in this paper drew comparisons between restoration sites and mature riparian forests, yet younger natural sites likely have different wildlife use patterns than mature stands. Young natural sites typically have lower elevations relative to the river than either restoration sites or older natural stands, and this likely influences a variety of physical, chemical, and biological processes which have important consequences for wildlife.

Because the remnant habitats of the Sacramento River are degraded by a variety of factors (e.g., altered/arrested flooding and erosion patterns due to dams and riprap), they cannot be viewed as true experimental controls, or representative of reference conditions. More research should be conducted to help identify factors that limit the viability of species that inhabit these sites, and to determine the extent to which present conditions could be improved, both at the remnant sites and at the restoration sites to which they are compared.

In addition to increased site-based monitoring, we also need to determine how successful horticultural restoration projects have been at achieving recovery goals (e.g., CALFED [2000b] goals for habitat and native at-risk species) at the landscape scale. Researchers should use remote sensing and field-based monitoring data to better characterize existing habitats, and to identify factors that influence species abundance, distributions, fecundity, and survival at a variety of habitat types (e.g., restoration, agricultural, and remnant) over the larger riparian landscape. Only by examining the system as a whole can we define the relative contribution that horticultural restoration projects are making to ecosystem recovery. A holistic approach to monitoring will provide the added benefit of allowing us to characterize the overall health of the river and track changes through time.

Future monitoring of wildlife response to restoration should include studies of special-status aquatic and semi-aquatic organisms, such as Chinook salmon *(Oncorhynchus tshawytscha)* and northwestern pond turtle *(Clemmys marmorata marmorata)*. Studies should be initiated to determine to what degree replacing floodplain agricultural land with natural riparian habitats confers benefits to these species. It is expected that restoration projects improve water quality and provide the river with beneficial inputs of terrestrially-derived prey and woody debris (NRC

2002), yet these assumptions have not been adequately tested on the Sacramento River.

Although much of the research conducted to date has focused on evaluating the effects of horticultural restoration, future monitoring should also be directed at understanding how the ecosystem responds to projects (e.g., levee setbacks, riprap removal) that restore natural river processes of bank erosion, flooding, and meander migration. Revitalization of natural processes is difficult to accomplish on highly managed river systems such as the Sacramento; however, it may be achieved when large blocks of land are assembled through conservation purchases (e.g., the Hamilton City J-levee project, USACE 2004; Golet et al. 2006). As such projects move forward, it is imperative that they have sufficient monitoring associated with them so that opportunities for learning can be realized, and restoration can become more successful and cost-effective.

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REFERENCES

Alpert P, Griggs FT, Peterson DR. 1999. Riparian forest restoration along large rivers: initial results from the Sacramento River Project. Restoration Ecology 7(4):360–368.

Anderson DC, Cooper DJ. 2000. Plant-herbivore-hydroperiod interactions: effects of native mammals on floodplain tree recruitment. Ecological Applications 10(5):1384–1399.

Andersen DC, Wilson KR, Miller MS, Falck M. 2000. Movement patterns of riparian small mammals during predictable floodplain inundation. Journal of Mammalogy 81(4):1087–1099.

Ballantyne F, Sherwin RE. 1999. The use and abuse of echolocation data to infer patterns of bat activity. Bat Research News 40:161.

Barr CB. 1991. The distribution, habitat and status of the Valley Elderberry Longhorn Beetle *Desmocerus californicus dimorphus*. Sacramento (CA): U.S. Fish and Wildlife Service Report. 134 p.

Bernhardt ES, Palmer MA, Allan JD, Alexander G, Barnas K, Brooks S, Carr J, Clayton S, Dahm C, Follstad-Shah J, Galat D, Gloss S, Goodwin P, Hart D, Hassett B, Jenkinson R, Katz S, Kondolf GM, Lake PS, Lave R, Meyer JL, O'Donnell TK, Pagano L, Powell B, Sudduth E. 2005. Synthesizing U.S. river restoration efforts. Science 308(Apr 29/5722):636–637.

Blackburn TM, Cassey P, Duncan RP, Evans KL, Gaston KJ. 2004. Avian extinction and mammalian introductions on oceanic islands. Science 305(24 Sep/5692):1955–1958.

Block WM, Franklin AB, Ward Jr. JP, Ganey JL, White GC. 2001. Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. Restoration Ecology 9(3):293–303.

Bock CE, Vierling KT, Haire SL, Boone JD, Merkle WW. 2002. Patterns of rodent abundance on open-space grasslands in relation to suburban edges. Conservation Biology 16(6):1653–1658.

Brown KP, Moller H, Innes J, Jansen P. 1998. Identifying predators at nests of small birds in a New Zealand forest. Ibis 140(2):274–279.

Buer K, Forwalter D, Kissel M, Stohler B. 1989. The middle Sacramento River: human impacts on physical and ecological processes along a meandering river. In: Abell DL, editor. Proceedings of the California riparian systems conference: protection management and restoration for the 1990s; 1988; Sep 22–24; Davis. Albany (CA): U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, General Technical Report No. PSW-110. p 22–32.

CALFED 2000a. Multi-species conservation strategy. Sacramento (CA): CALFED Bay Delta Program. Available from: http://calwater.ca.gov/calfed/library/library_archive_ERS.html

CALFED 2000b. Ecosystem restoration program plan. Strategic plan for ecosystem restoration. Sacramento (CA): CALFED Bay Delta Program. Available from: http://calwater.ca.gov/content/Documents/ERPP_Vol_3.pdf

Carignan V, Villard M-A. 2002. Selecting indicator species to monitor ecological integrity: a review. Environmental Monitoring and Assessment 78(1):45–61.

DeSante DF, Burton KM, Velez P, Froehlich D. 2000. MAPS manual: 2000 protocol. Point Reyes Station (CA): The Institute for Bird Populations.

DeSante DF, George TL. 1994. Population trends in the landbirds of western North America. In: Jehl Jr. JR, Johnson NK, editors. A century of avifaunal change in western North America. Proceedings of an international symposium at the centennial meeting of the Cooper Ornithological Society; 1993 Apr 17; Sacramento. Studies in Avian Biology No. 15. Cooper Ornithological Society. p 173–190.

Gaines DF. 1977. The valley riparian forests of California: their importance to bird populations. In: Sands A, editor. Riparian forests in California: their ecology and conservation. Davis (CA): University of California, Davis Institute of Ecology publication No.15. p 57–85.

Gardali T, Holmes AL, Small SS, Nur N, G.R. Geupel, and G.H. Golet. 2006. Abundance patterns of landbirds in restored and remnant riparian forests on the Sacramento River, California, U.S.A. Restoration Ecology 14(3):391–403.

Gardali T, Nur N. 2006. Site-specific survival of Black-headed Grosbeaks and Spotted Towhees at four sites within the Sacramento River, California. The Wilson Journal of Ornithology (previously known as The Wilson Bulletin) 118(2):178–186.

Gardali T, Small SL, Nur N, Geupel GR, Ballard G, Holmes AL. 2004. Monitoring songbirds in the Sacramento Valley (1993–2003): population health, management information, and restoration evaluation. PRBO Conservation Science unpublished report, Contribution No. 1233.

Gibbs, JP, Snell HL, Causton CE. 1999. Effective monitoring for adaptive wildlife management: lessons from the Galápagos Islands. Journal of Wildlife Management 63(4):1055–1065.

Golet GH, Roberts MD, Larsen EW, Luster RA, Unger R, Werner G, White GG. 2006. Assessing societal impacts when planning restoration of large alluvial rivers: a case study of the Sacramento River Project, California. Environmental Management 37(6):862–879.

Golet GH, Werner G, Bogiatto RJ, Hunt JW, Koenig D. 2007. Effects of riparian restoration on abundances of small mammal agricultural pest species (California). Ecological Restoration 25(2):136-137.

Griggs, FT, Golet GH. 2002. Riparian valley oak (*Quercus lobata*) forest restoration on the middle Sacramento River. In: Standiford RB, McCreary D, Purcell KL, technical coordinators. Proceedings of the fifth symposium on oak woodlands: oaks in California's changing landscape; 2001 Oct 22-25; San Diego. Albany (CA): U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. General Technical Report No. PSW-GTR-184. p 543–550.

Griggs FT, Peterson DR. 1997. Evaluation of techniques and costs for valley oak riparian forest restoration on the Sacramento River. In: Pillsbury

NH, Verner J, Tietje WD, technical coordinators. Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues. Albany (CA): U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. General Technical Report No. PSW-GTR-160. p 289–295.

Hayes JP. 1997. Temporal variation in activity of bats and the design of echolocation monitoring studies. Journal of Mammalogy 78(2):514–52.

Hickman JC, ed. 1993. The Jepson manual: higher plants of California. Berkeley (CA): University of California Press. p 1400.

Hilderbrand RH, Watts AC, Randle AM. 2005. The myths of restoration ecology. Ecology and Society 10(1):19. [Online]. Available from: http://www.ecologyandsociety.org/vol10/iss1/art19/

Holl KD, Crone EE. 2004. Applicability of landscape and island biogeography theory to restoration of riparian understorey plants. Journal of Applied Ecology 41(5):922–933.

Holl KD, Crone EE, Schultz CB. 2003. Landscape restoration: moving from generalities to methodologies. Bioscience 53(5):491–502.

Hujik P, Griggs FT. 1995a. Cutting size, horticultural treatments affects survival and growth of riparian species (California). Ecological Restoration (previously known as Restoration and Management Notes) 13(2):219–220.

Hujik P, Griggs FT. 1995b. Field-seeded riparian trees and shrubs thrive in non-irrigated plots (California). Ecological Restoration (previously known as Restoration and Management Notes) 13(2):220–221.

Hunt JW. 2004. Comparison of Epigeal beetle assemblages in remnant and restored riparian forests on the middle Sacramento River, California [M.S. thesis]. Chico (CA): California State University, Chico. p 84.

Johnson DH. 1979. Estimating nest success: the Mayfield method and an alternative. The Auk 96(4):651–661.

Katibah EF. 1984. A brief history of riparian forests in the Central Valley of California. In: Warner RE, Hendrix KM, editors. California riparian systems: ecology conservation and productive management. Berkeley (CA): University of California Press. p 23–29.

Koenig DA, Hunt JW, Wood DM, Bogiotto RJ, Altier L. 2007. Examination of potential agricultural pest mammal species associated with riparian habitat restoration projects along northern California's Sacramento River. Report to The Nature Conservancy.

Kondolf, GM, Micheli ER. 1995. Evaluating stream restoration projects. Environmental Management 19(1):1–15.

Lang FJ, Jokerst JD, Sutter GE. 1989. Habitat and populations of the Valley Elderberry Longhorn Beetle along the Sacramento River. In: Abell, DL, technical coordinator. Proceedings of the California Riparian Systems Conference: protection, management, and restoration for the 1990s; 1988; Sep 22–24; Davis. Albany (CA): U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. General Technical Report No. PSW-110.

Manley P, Davidson C. 1993. Assessing risks and setting priorities for neotropical migrant birds in California. In: Sharply ES, editor. 1994. The neotropical migrant bird reference book, Vol. II. San Francisco: (CA) U. S. Department of Agriculture Forest Service, Region 5.

Martin TE. 1992. Breeding productivity considerations: what are the appropriate habitat features for management? In: Hagan JM, Johnston DW, editors. Ecology and conservation of neotropical migrant birds. Washington, DC: Smithsonian Institution Press. p 455–473.

Martin TE, Geupel GR. 1993. Nest monitoring plots: methods for locating nests and monitoring success. Journal of Field Ornithology 64(4):507–519.

Martin TE, Paine C, Conway C, Hochachka WM, Allen P, Jenkins W. 1997. The breeding biology research and monitoring database (BBIRD) field protocol. U. of Montana Cooperative Wildlife Research Unit. Unpublished manual.

Mayfield HF. 1975. Suggestions for calculating nest success. The Wilson Journal of Ornithology (previously known as The Wilson Bulletin) 87(4):456–466.

McKean JL. 1975. The bats of Lord Howe Island with descriptions of a new Nyctophiline bat. Australian Mammalogy 1(4):329–332.

National Research Council (NRC). 1992. Restoration of aquatic ecosystems. Washington (DC): The National Academies Press.

National Research Council (NRC). 2002. Riparian areas: functions and strategies for management. Washington (DC): The National Academies Press.

Nur N, Ballard G, Geupel GR. 2004. The response of riparian bird species to vegetation and local habitat features in the Central Valley, California: a multi-species approach across spatial scales. In: Gardali T, Small SL, Nur N, Geupel GR, Ballard G, Holmes AL, editors. Monitoring songbirds in the Sacramento Valley (1993–2003): population health, management information, and restoration evaluation. PRBO Conservation Science unpublished report, Contribution No. 1233.

Nur N, Jones SL, Geupel GR. 1999. A statistical guide to data analysis of avian monitoring programs. Washington (DC): U.S. Department of the Interior, Fish and Wildlife Service. Biological Technical Publication No. BTP-R6001-1999.

Oliver I, Beattie AJ. 1996a. Invertebrate morphospecies as surrogates for species: a case study. Conservation Biology 10(1):99–109.

Oliver I, Beattie AJ. 1996b. Designing a cost-effective invertebrate survey: a test of methods for rapid assessment of biodiversity. Ecological Applications 6(2):594–607.

Oswald VH. 2002. Selected plants of northern California and adjacent Nevada. Studies from the Herbarium: Number 11. Chico (CA): California State University, Chico. p 451.

Pierson ED, Rainey WE, Corben C. 2000. Distribution and status of red bats, *Lasiurus blossevillii*, in California. Report to the Species Conservation and Recovery Program, Habitat Conservation Planning Branch, California Department of Fish and Game, Sacramento, CA.

Ralph CJ, Geupel GR, Pyle P, Martin TE, DeSante DF. 1993. Handbook of field methods for monitoring landbirds. Albany (CA): U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. General Technical Report No. PSW-GTR-144.

RHJV (Riparian Habitat Joint Venture). 2003. Version 2.0. CalPIF riparian bird conservation plan: a strategy for reversing the decline of riparian associated birds in California. California Partners in Flight. Available from: http://www.prbo.org/calpif/downloads.html

River Partners. 2004. Survey of planted elderberry on Sacramento River National Wildlife Refuge riparian restoration sites for use by Valley Elderberry Longhorn Beetles. Tehama, Butte, and Glenn Counties, CA. Report to the U.S. Fish and Wildlife Service.

Ruiz-Jaen MC, Aide TM. 2005. Restoration success: how is it being measured? Restoration Ecology 13(3):569–577.

Sekercioglu CH. 2006. Increasing awareness of avian ecological function. Trends in Ecology & Evolution 21(8):464–471.

Singer MB, Dunne T. 2001. Identifying eroding and depositional reaches of valley by analysis of suspended-sediment transport in the Sacramento River, California. Water Resources Research 37(12):3371–3381.

Small SL. 2005. Mortality factors and predators of Spotted Towhee nests in the Sacramento Valley, California. Journal of Field Ornithology 76(3):252–258.

Small SL, Gardali T. 2004. Regional population growth rates of Black-headed Grosbeaks nesting in California riparian forests. In: Gardali T, Small SL, Nur N, Geupel GR, Ballard G, Holmes AL, editors. Monitoring songbirds in the Sacramento Valley (1993–2003): population health, management information, and restoration evaluation. PRBO

Conservation Science unpublished report, Contribution No. 1233.

Society for Ecological Restoration (SER) International Science and Policy Working Group. 2004. The SER International Primer on ecological restoration [Internet]. [cited May 2007]. Tuscon (AZ): Society for Ecological Restoration International. Available from: http://www.ser.org/content/ecological_restoration_primer.asp

Stillwater Sciences, Rainey W, Pierson E, Corben C, Power, M. 2003. Sacramento River ecological indicators pilot study. Report to The Nature Conservancy, Chico California.

Talley TS. 2007. Which spatial heterogeneity framework? Consequences for conclusions about patchy population distributions. Ecology (6)88:1476–1489.

Temple SA, Wiens JA. 1989. Bird populations and environmental changes: can birds be bio-indicators? American Birds 43(2):260–270.

Towns DR, Atkinson IAE, Daugherty CH. 2006. Have the harmful effects of introduced rats on islands been exaggerated? Biological Invasions 8(4):863–891.

U.S. Army Corps of Engineers (USACE). 2004. Hamilton City flood damage reduction and ecosystem restoration, California. Final Feasibility Report and Environmental Impact Statement/Environmental Impact Report. Sacramento (CA): U.S. Army Corps of Engineers, Sacramento District.

U.S. Fish and Wildlife Service (USFWS). 2005. Sacramento River National Wildlife Refuge Final Comprehensive Conservation Plan. Final June 2005. Prepared by California/Nevada Refuge Planning Office, Sacramento, CA and Sacramento National Wildlife Refuge Complex, Willows, CA.

VanderWerf EA. 2001. Rodent control decreases predation on artificial nests in O'ahu 'Elepaio habitat. Journal of Field Ornithology 72(3):448–457.

Waldren DW. 2000. Anabat bat detection system: description and maintenance manual. Portland (OR): U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. General Technical Report No. PNW-GTR-502.

Wickramasinghe LP, Harris S, Jones G, Vaughan N. 2003. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. Journal of Applied Ecology 40(6):984–993.

Wiener JG, Smith MH. 1972. Relative efficiencies of four small mammal traps. Journal of Mammalogy 53(4):868–873.

Williams KS. 1993. Use of terrestrial arthropods to evaluate restored riparian woodlands. Restoration Ecology 1(2):107–118.

Williams, KS. 2000. Assessing success of restoration attempts: what can terrestrial arthropods tell us? In: Keeley JE, Baer-Keeley M, Fotheringham CJ, editors. 2nd interface between ecology and land development in California. USGS Open-File Report 00-62. p 237–244.

Williams NM. 2007. Restoration of native bee pollinators within the Sacramento River system (California). Ecological Restoration 25(1):67–68.

Wilson EO. 1987. The little things that run the world (the importance of conservation of invertebrates). Conservation Biology 1(4):344–346.