Abundance Patterns of Landbirds in Restored and Remnant Riparian Forests on the Sacramento River, California, U.S.A.

Thomas Gardali,[1,2] Aaron L. Holmes,[1] Stacy L. Small,[3] Nadav Nur,[1] Geoffrey R. Geupel,[1] and Gregory H. Golet[4]

Abstract

Riparian vegetation along the Sacramento River—California's largest river—has been almost entirely lost, and several wildlife species have been extirpated or have declined as a result. Large-scale restoration efforts are focusing on revegetating the land with native plants. To evaluate restoration success, we conducted surveys of landbirds on revegetated and remnant riparian plots from 1993 to 2003. Our objectives were to estimate population trends of landbirds, compare abundance patterns over time between revegetated and remnant riparian forests, and evaluate abundance in relation to restoration age. Of the 20 species examined, 11 were increasing, 1 was decreasing (Lazuli Bunting [*Passerina amoena*]), and 8 showed no trend. The negative trend for Lazuli Bunting is consistent with information on poor reproductive success and with Breeding Bird Survey results. There was no apparent guild association common to species with increasing trends. Nine species were increasing on revegetated and remnant plots, four were increasing on revegetated plots only, three were increasing on remnant plots only, the Lazuli Bunting was decreasing on both, and three species were stable on both. Although many species were increasing at a faster rate on revegetated plots, their abundance did not reach that of the remnant plots. For revegetated plots, "year since planting" was a strong predictor of abundance trends for 13 species: positive for 12, negative for 1. Our study shows that restoration activities along the Sacramento River are successfully providing habitat for a diverse community of landbirds and that results from bird monitoring provide a meaningful way to evaluate restoration success.

Key words: birds, California, Central Valley, indicator, monitoring, restoration, riparian, Sacramento River.

Introduction

The Sacramento River—California's largest river—has been severely impacted by a wide variety of activities including habitat conversion, water diversion and regulation, mining, pollution, and the introduction of nonindigenous invasive species. The once vast riparian forests have been reduced to small, widely spaced, remnant patches, and it is estimated that only about 2% of the original forest area remains (Katibah 1984). Furthermore, massive changes to the natural hydrologic regime have rendered this once dynamic system relatively stable. Historically, the river would regularly break its banks, meander up to several kilometers over the course of a single year, and inundate thousands of hectares. The result was a mosaic of habitat types that included seasonal and permanent wetlands, oxbow lakes, and forests in a dynamic array of seral stages (Katibah 1984; Mount 1995).

Paralleling the loss and degradation of habitat and ecosystem function have been the loss and decline of numerous wildlife species in the Sacramento Valley. For example, Thick-tailed chub (*Gila craisicauda*), Least Bell's Vireo (*Vireo belli pusillus*), and Willow Flycatcher (*Empidonax traillii*) have been extirpated. The abundance of Chinook salmon (*Oncorhynchus tshawytscha*) has declined more than 75% since the 1950s (Yoshiyama et al. 1998), and both the winter and spring runs have federal U.S. status (endangered and threatened, respectively). Valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*), endemic to upland riparian areas of California's Central Valley, was listed as federally threatened in 1980. Two birds that still breed in the Sacramento Valley have been listed as state threatened (Bank Swallow [*Riparia riparia*]) and state endangered (Western Yellow-billed Cuckoo [*Coccyzus americanus occidentalis*]).

Despite the degraded condition of the Sacramento River system, opportunities for its restoration exist (Griggs 1993). In 1988 The Nature Conservancy, U.S. Fish and Wildlife Service, California Department of Fish and Game, and the California Department of Parks and Recreation launched the Sacramento River Project (SRP), which aims to restore the riparian ecosystem from Red Bluff to Colusa (Fig. 1; Golet et al. 2003). In general, the

[1] PRBO Conservation Science, 3820 Cypress Drive #11, Petaluma, CA 94954, U.S.A.
[2] Address correspondence to T. Gardali, email tgardali@prbo.org
[3] Division of Biological Sciences, University of Missouri, 105 Tucker Hall, Columbia, MO 65211, U.S.A.
[4] The Nature Conservancy, Chico, CA 95928, U.S.A.

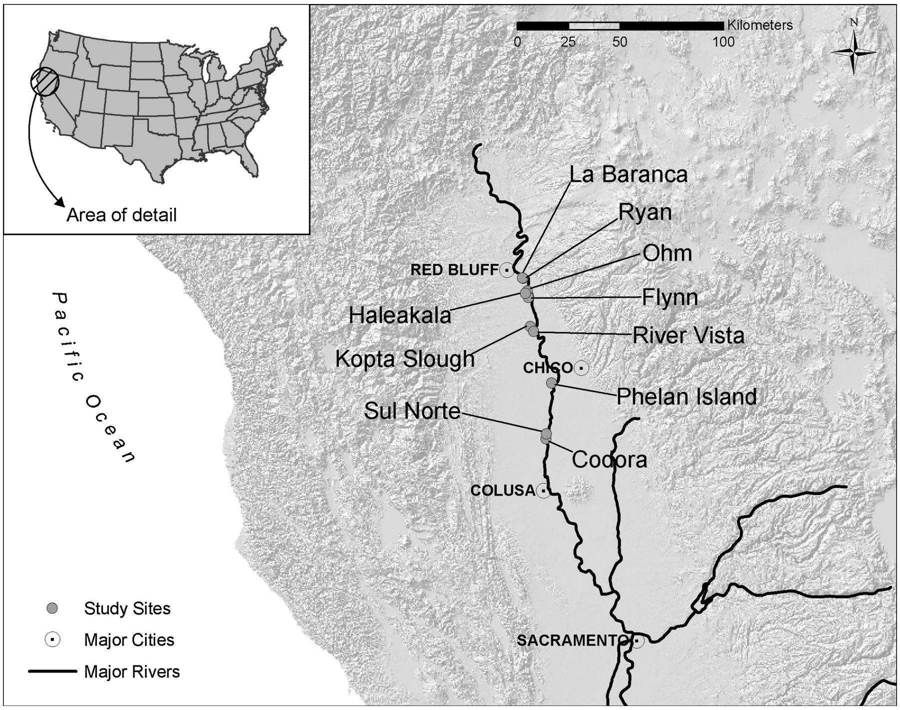

Figure 1. Map of the study area and study sites along the Sacramento River, California.

SRP has implemented the following restoration strategies (from Golet et al. 2003): (1) acquiring flood-prone lands, giving priority to those that contain and/or border remnant riparian vegetation; (2) revegetating land with native trees, shrubs, and understory plants; and (3) restoring natural river processes.

Restoration projects such as the SRP benefit from the inclusion of studies that evaluate whether a project's goals have been achieved (Block et al. 2001; Elzinga et al. 2001; SER 2002; Ruiz-Jaen & Aide 2005); one of the many goals of the SRP is to restore habitat for birds (Golet et al. 2003). A few studies have identified birds as useful means for evaluating the performance of riparian restoration projects (Kus 1998; Kus & Beck 2003), and birds in general may be good indicators of environmental condition (Carigan & Villard 2002).

We assessed bird use of restoration sites as a measure of SRP success by (1) comparing abundance trends on remnant and revegetated sites and (2) determining annual rate of change in bird abundance in relation to age of revegetation. To help interpret these results we estimated overall population trends of landbirds at all our study sites combined, and compared these long-term trends with an independent measure (the Breeding Bird Survey [BBS]; Sauer et al. 2001) at several spatial scales. Unlike short-term "snapshot" studies (e.g., Fletcher & Koford 2003; Kus & Beck 2003; Longcore 2003; Stevens et al. 2003; Waltz & Covington 2004), longer-term trend analyses provide information to evaluate whether restoration is following its intended trajectory (SER 2002).

We made the assumption that changes in landbird abundance following revegetation were in part attributable to changes in vegetation structure and that patterns of change depended upon species- and guild-specific habitat requirements. For example, ground- and canopy-nesting species may respond at different rates or times in a restoration site's history. Fortunately, the general habitat requirements of many birds are relatively well known (Poole & Gill 1992–2002).

Implicit in this study was investigating the usefulness of birds to measure the performance of habitat restoration.

Methods

Study Sites

We surveyed birds at 10 sites (Table 1) along the Sacramento River between Red Bluff, Tehama County, and Colusa, Colusa County, California (Fig. 1), an area encompassing approximately 160 km (100 river miles). Deciduous fruit and nut orchards dominated the landscape around our study sites, with smaller areas of field crops, pasture, rice fields, and urban/residential development. The majority of remnant riparian vegetation, classified as mixed riparian forest (Sawyer & Keeler-Wolf 1995), comprised Cottonwood (*Populus fremonti*), *Salix gooddingii, S. exigua, S. lasiolepis* (Willows), Valley oak (*Quercus lobata*), Ash (*Fraxinus latifolia*), Walnut (*Juglans hindsii*), Maple (*Acer negundo*), and Sycamore (*Platanus racemosa*). Interspersed with this mixed forest type were

Table 1. Site name, number of points clustered by site, treatment type, and number of years surveyed in the Sacramento Valley, California.

Site Name	*No. of Points*	*Treatment*	*Years*
Codora	5	orchard	1994–2001
	3	revegetation	1998–2001
	6	remnant	1994–2001
Flynn	4	revegetation	1998–2003
	5	remnant	1993–2003
	5	remnant	1993–2003
Haleakala	5	orchard	1993–2001
	5	remnant	1993–2001
Kopta Slough	5	revegetation	1996–2003
	3	revegetation	1996–2003
	4	revegetation	1996–2003
	3	remnant	1996–2003
La Baranca	5	remnant	1993–2001
	5	remnant	1993–2001
	5	remnant	1993–2001
Ohm	6[a]	remnant	1993–2003
	4[b]	remnant	1993–2003
	4	remnant	1995–2003
River Vista	4	revegetation	1993–2003
	5	revegetation	1993–2003
	5	revegetation	1993–2003
Ryan	4[c]	orchard	1993–2001
	4[d]	remnant	1993–2001
Phelan Island	5	revegetation	1994–2003
	4	revegetation	1994–2003
	5	revegetation	1994–2003
	5	revegetation	1994–2003
Sul Norte	5	remnant	1994–2003
	5	remnant	1994–2003

[a] Four points in 2001; 5 in 2000, 2002, 2003.
[b] Five points in 1993, 1994, 1997.
[c] Five points in 1993, 2000, 2001.
[d] Three points in 1999, 2000, 2001.

relatively pure stands of cottonwood, willow, and Valley oak.

Details of initial restoration techniques are described in Alpert et al. (1999). In general, the restoration sites had recently been under agricultural production and had been cleared of all native vegetation; most were adjacent to remnant forest. The sites were prepared for restoration plantings by a combination of disking, burning, furrowing, leveling, and spraying with an herbicide. Many of the early sites were planted with 10 woody species (5 trees and 5 shrubs), and later the number in the planting mix reached 37 with the inclusion of many herbaceous species (e.g., Mugwort [*Artemisia douglasiana*], Goldenrod [*Solidago* sp.], Santa Barbara sedge [*Carex barbarae*], and Hoary nettle [*Urtica dioica*]). All vegetation was collected from local natural stands, and planting densities and design were variable among sites and years.

Study Species

Study species were breeding in our study areas (as determined by their presence on territories throughout the breeding season, mist-net captures, and nesting observations) and had (1) sufficient sample sizes on surveys to calculate trends; (2) collectively represented a range of life history characteristics or functional groups; and (3) included species of interest, especially those identified as focal species in the California Partners in Flight Riparian Bird Conservation Plan (RHJV 2004). Extant special status species, Bank Swallows and Western Yellow-billed Cuckoos, were excluded because neither is reliably surveyed by point counts. Scientific names, guild associations, and life history characteristics are noted in Appendix 1.

Field Methods

We estimated the relative abundance of birds using point counts (Ralph et al. 1993, 1995). We established a series of point count survey stations approximately 200 m apart (Table 1; Ralph et al. 1993, 1995). 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 m 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.

Statistical Analyses

Survey points were clustered according to location, habitat type (i.e., orchard, remnant, and restoration), and the year of restoration planting (Table 1). Clusters averaged five points, but ranged from three to six, and a given site could contain two to three such clusters. In grouping points we assumed a sampling unit comparable in scale to that of the restoration plantings. The cluster was our unit of analysis and was treated as statistically independent. Because the standard error of the mean detections per point is inversely proportional to the square root of the number of points, all analyses were weighted by the square root of the number of points within a cluster (Neter et al. 1990). To control for number of survey visits per year (see above) we divided the total number of detections by the number of surveys conducted that year.

We log transformed abundance indexes to calculate population trends. Resultant log-linear models assume a constant rate of change (increases or decreases by a certain percent per year; Nur et al. 1999). Thus, the dependent variable in initial models was ln(mean detections per visit per point + 0.06667). The constant, 0.06667, was the smallest nonzero value the index could take on and was based on the average size of our clusters (five points) across all three visits (i.e., one detection/three visits/five survey points; Nur et al. 1999).

We used linear regression (Neter et al. 1990) to develop several sets of models for each species: (1) overall log-linear trend of bird populations in relation to year, using data from all sites; (2) log-linear trend of populations in relation to calendar year within remnant riparian and restored riparian, regardless of restoration age; differences in these habitat-specific trends were then tested using an F test; and (3) log-linear trend of bird populations in relation to the age of restoration plantings, regardless of calendar year. Where any of the initial models failed to meet assumptions of parametric analysis, we attempted models with alternative transformations of bird abundance (square root, then reciprocal) as well as untransformed abundance indexes.

In addition, for model sets 1 and 3 (above), we examined quadratic and cubic relationships with year and restoration age, respectively, and again tried alternative transformations where a quadratic or cubic term was significant but models did not meet assumptions of linear models with log-transformed abundance data. It is important to keep in mind that where a higher order relationship was present, it did not change the overall trend estimate derived from the log-linear model, but simply provided more information on the shape of the relationship between population size and year or restoration age. Residuals of all models were assessed for distribution problems using formal tests (sktest, hettest; STATACORP) and further evaluated graphically using residual plots. In most cases, residuals were consistent with assumptions of normality and equal variance. In a few cases they were not, although in these cases models were highly significant and there was no question as to interpretation. Nevertheless, the F test used in linear-model analysis is robust to deviations from normality (Seber 1977); thus, we are confident that p values obtained provide reasonably good approximate values. Statistical significance was assumed at an alpha level of 0.05.

Breeding Bird Survey

We compared our overall trends to those from the BBS using data from 1993 to 2002 for routes: (1) in the Central Valley (Sacramento and San Joaquin valleys); (2) all of California; and (3) the larger region including British Columbia, Washington, Oregon, and California (Sauer et al. 2001). The BBS is a breeding season survey widely used to analyze changes in population sizes of birds in North America (e.g., Robbins et al. 1989; Peterjohn et al. 1995) and as a benchmark against which to compare population trend estimates (e.g., Holmes & Sherry 2001; Ballard et al. 2003). Concordance between our results and BBS would suggest that some larger, regional, or even global phenomena account for any observed population trends, rather than the revegetation.

Results

Overall Population Trends

Data from all survey locations—remnant, revegetated, and orchard—indicated that 11 of the 20 species examined increased during our study, whereas only one, the Lazuli

Table 2. Estimated linear trends for 20 species detected by point count surveys in the Sacramento Valley, California, from 1993 to 2003, and trends from the Breeding Bird Survey from 1993 to 2002 in (1) California (CA), (2) British Columbia, Washington, Oregon, and California combined (BPC), and (3) in the entire Central Valley (CV) of California, which includes the Sacramento and San Joaquin valleys.

		95% Confidence Interval		*Breeding Bird Survey*		
Species	*Trend %*	*Low*	*High*	*CA, Trend % (Variance)*	*BPC, Trend % (Variance)*	*CV, Trend % (Variance)*
Mourning Dove	0.06	−3.04	3.26	1.50† (0.70)	1.31* (0.43)	2.17 (2.23)
Nuttall's Woodpecker	1.08	−1.33	3.55	0.63 (1.69)	0.60 (1.75)	3.58 (6.14)
Downy Woodpecker	8.45***	6.04	10.92	0.92 (7.89)	−4.00* (4.10)	3.43 (263.94)
Western Wood-Pewee	2.87*	0.47	5.33	−0.74 (0.69)	0.60 (0.51)	—
Ash-throated Flycatcher	5.18***	2.43	8.00	−2.00* (0.92)	−1.93* (0.90)	−1.15 (0.30)
Western Kingbird	4.41**	1.38	7.53	0.35 (0.64)	−0.21 (0.41)	1.40 (1.23)
Western Scrub-Jay	3.62**	0.89	6.42	−0.95 (0.50)	−0.85 (0.45)	0.53 (1.32)
Oak Titmouse	2.50†	−0.12	5.20	−1.90* (0.75)	−1.90* (0.76)	−1.20 (47.20)
Bewick's Wren	8.11***	5.60	10.68	0.93 (1.43)	0.94 (1.33)	−0.75 (116.47)
House Wren	10.11***	7.14	13.15	−7.14*** (2.69)	−7.06*** (1.15)	−2.02 (44.68)
American Robin	1.51	−1.46	4.57	0.33 (0.41)	−0.16 (0.08)	3.87 (6.58)
European Starling	2.49†	−0.20	5.24	−1.67 (2.06)	−1.90* (0.65)	−3.97 (11.22)
Spotted Towhee	8.52***	5.69	11.44	0.20 (0.99)	0.18 (0.36)	−3.53 (30.08)
Black-headed Grosbeak	6.00***	3.28	8.79	−3.68*** (0.46)	−1.39* (0.36)	−5.77 (58.07)
Lazuli Bunting	−5.04**	−8.15	−1.82	−0.43 (1.06)	−0.52 (0.57)	−18.60* (11.11)
House Finch	0.70	−2.60	4.11	−2.66** (0.73)	−0.70 (0.82)	−1.54 (2.83)
Bullock's Oriole	5.27***	2.58	8.04	−3.21*** (1.09)	−1.89* (0.58)	−5.17* (3.36)
Brown-headed Cowbird	2.19	−1.10	5.59	−0.52 (1.95)	−3.40*** (0.53)	−1.34 (11.66)
Common Yellowthroat	3.99**	1.53	6.50	3.51 (20.98)	−0.45 (1.15)	32.52 (328.62)
American Goldfinch	2.59	−1.28	6.61	6.27† (14.76)	−1.17 (3.82)	11.72† (22.82)

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; †$p < 0.1$.

Bunting, declined (Table 2). There was little agreement between our results for those species with significant trends and data from the BBS at any spatial scale (Table 2). In fact, five species that increased in our dataset showed significant declines at one or more of the BBS spatial scales. The Lazuli Bunting was the only exception, showing declines in both our data and the BBS Central Valley region.

The annual rate of increase across our study areas ranged from 2.87% for the Western Wood-Pewee to 10.11% for the House Wren (Table 2). The species with increasing trends were diverse in their life history characteristics (Table 2; Appendix 1).

Fifteen species had nonlinear relationships with year: eight quadratic and seven cubic (Table 3). Six of the quadratic trends were positive and two were negative, and six of the cubic trends were negative and one was positive (Table 3). For two species, Lazuli Bunting and Brown-headed Cowbird, the trends were negative but quadratic accelerating (Table 3). For example, the Lazuli Bunting showed an increase in the early years, peaking in 1997 followed by a decrease. No species were negative quadratic decelerating. Five species were positive quadratic accelerating, whereas one, the Western Scrub-Jay, was positive but quadratic decelerating (Table 3).

To examine patterns of abundance related to year, we calculated a minimum and maximum year for each species. This analysis shows when the maximum or minimum of the estimated trend was reached. The models suggest that several species were at their minimum in 1995 or 1996, whereas most peaked in the latter years of the study (Table 3).

Remnant versus Revegetation

Of the 20 species examined, 9 were increasing on remnant and revegetated plots, 4 on revegetated plots only, 3 on remnant plots only, and 3 were stable on both and 1—the Lazuli Bunting—was declining on both (Table 4; Fig. 2). Although declining on both, the Lazuli Bunting was more abundant on the revegetated plots and was the only species to show this pattern.

When there were significant differences between the slopes of the trend lines (nine cases), all but two indicated steeper increases on revegetated plots (Table 4). The exceptions were House Wren and European Starling (secondary cavity nesters). Species increased on the revegetated plots at rates that ranged from 6.89% annually for the Western Scrub-Jay to as high as 26.88% for the Spotted Towhee (Table 4). On the remnant plots the rates of increase were slower than on revegetated plots and ranged from 4.18% for Western Scrub-Jay to 16.49% for House Wren (Table 4). Species increasing on revegetated plots showed a wide range of life history characteristics, and no clear guild response patterns emerged. For example, open-cup, ground-nesting species such as the Spotted Towhee and cavity tree/snag-nesting species such as the Ash-throated Flycatcher were both increasing.

Age of Revegetation

Twelve of the 20 species examined increased as a function of the age of revegetation (Table 5; Figs. 3 & 4). Three others—Western Scrub-Jay, Oak Titmouse, and American Robin—also increased, although relationships with revegetation age were not conclusive based on alpha levels that fell slightly short of statistical significance (Table 5). Four species—Mourning Dove, Western Kingbird, European Starling, and House Finch—showed no trend related to revegetation age. The Lazuli Bunting was the only species declining.

The rate of increase ranged from 7.61% for the Common Yellowthroat to 26.58% for the Spotted Towhee

Table 3. Species that deviated from a constant rate of change (nonlinear), shape of relationship, local minimum and maximum, overall model r^2, and the relative coefficient of determination (RCD) for year trend.

Species	*Shape*	*Minimum Year*	*Maximum Year*	r^2	*RCD*[a]
Mourning Dove	cubic (+)	1995	2000	0.46	0.13
Nuttall's Woodpecker	cubic (−)	1996	2002	0.71	0.20
Downy Woodpecker	cubic (−)	1994	2001	0.43	0.06
Western Wood-Pewee[b]	quadratic (+)	1997	—	0.67	0.09
Ash-throated Flycatcher	cubic (−)	1996	2003	0.54	0.08
Western Scrub-Jay	quadratic (+)	—	2000	0.42	0.05
Bewick's Wren	quadratic (+)	1995	—	0.79	0.06
House Wren	quadratic (+)	1995	—	0.70	0.04
American Robin	cubic (−)	1995	2000	0.71	0.09
European Starling	cubic (−)	1996	2001	0.44	0.11
Spotted Towhee	quadratic (+)	1996	—	0.78	0.14
Lazuli Bunting	quadratic (−)	—	1997	0.48	0.24
House Finch	cubic (−)	1996	2001	0.43	0.06
Bullock's Oriole	quadratic (+)	1995	—	0.54	0.02
Brown-headed Cowbird	quadratic (−)	—	1998	0.33	0.08

The RCD is the variance not attributable to transect that is explained by year. All models were $n = 268$ and included a transect main effect (28 degrees of freedom).
[a] RCD for the effect of year trend.
[b] Square root transformed.

Table 4. Estimated linear trend for species in remnant and revegetated riparian habitat in the Sacramento Valley, California, from 1993 to 2003.

	Remnant			*Revegetated*			
Species	*Trend %*	*Low*	*High*	*Trend %*	*Low*	*High*	*p*
Mourning Dove	4.01†	−0.38	8.60	3.42	−3.24	10.55	0.8876
Nuttall's Woodpecker	2.44	−0.48	5.45	10.10***	5.28	15.13	0.0083
Downy Woodpecker	11.35***	7.79	15.02	7.94**	2.67	13.84	0.3059
Western Wood-Pewee	2.33	−0.69	5.44	11.13***	6.11	16.38	0.0035
Ash-throated Flycatcher	5.12**	1.27	9.13	8.85**	2.75	15.32	0.3189
Western Kingbird	7.90***	3.56	12.41	1.48	−4.47	8.12	0.1108
Western Scrub-Jay	4.18*	0.30	8.21	6.89*	0.81	13.34	0.4679
Oak Titmouse	1.79	−2.01	5.74	5.57†	−0.45	11.96	0.3053
Bewick's Wren	7.33***	4.06	10.70	25.45***	19.61	31.57	<0.0001
House Wren	16.49***	11.82	21.35	8.59**	1.95	15.66	0.0670
American Robin	5.03*	0.86	9.36	6.03†	−0.38	12.86	0.8006
European Starling	6.61***	2.95	10.41	−2.72	−7.83	2.68	0.0055
Spotted Towhee	5.83**	2.15	9.65	26.88***	20.13	34.01	<0.0001
Black-headed Grosbeak	6.22***	2.91	9.63	15.45***	9.95	21.22	<0.0001
Lazuli Bunting	−5.26*	−9.85	−0.49	−10.97**	−17.50	−3.91	0.1809
House Finch	−2.07	−6.59	2.66	2.61	−4.61	10.37	0.2907
Bullock's Oriole	5.02*	1.21	8.97	10.05**	3.95	16.51	0.1760
Brown-headed Cowbird	1.10	−3.35	5.75	11.02**	3.57	19.00	0.0269
Common Yellowthroat	4.41*	0.070	8.25	7.61*	1.78	13.78	0.2070
American Goldfinch	1.01	−4.03	6.31	11.75**	3.27	20.93	0.0353

The p values are for differences in these habitat-specific trends from an F test.
$*p < 0.05$; $**p < 0.01$; $***p < 0.001$; $^{\dagger}p < 0.1$.

(Table 5) and, as in our other analyses, a diverse group of species responded positively as revegetation sites matured (Table 5; Appendix 1).

Six species appeared to respond in a nonlinear fashion to revegetation age: four quadratic and two cubic (Table 6; Fig. 3). Three of the quadratic trends were negative and one was positive, and one cubic trend was negative and one positive (Table 6). Thus, abundance of those six species did not exhibit a constant rate of change as a function of revegetation. There was no pattern for years of minimum or maximum abundance across species (Table 6).

Discussion

Population Trends

Over half of the species showed increasing population trends at our sites in the Sacramento Valley. To put these results into context, we compared them to the BBS during the same time period and found essentially no agreement at any scale—in fact, a few species showed opposite patterns. This suggests that restoration activities within the Sacramento Valley may be influencing population dynamics documented here because larger scale phenomena do not appear to be responsible for the overall trends we report. The Central Valley region of the BBS is one where we might have expected to see agreement with our results but did not. This may be because the BBS is not doing a good job at sampling many populations in the Central Valley (e.g., high variance in the data); BBS survey routes are on roads whereas most extant and restored riparian habitat is away from roads. Additionally, the Central Valley BBS region contains both the Sacramento and San Joaquin valleys. For the Lazuli Bunting, however, both Central Valley BBS and our data indicated population declines (see below for discussion of Lazuli Bunting).

The shape of the overall trend for many species was not linear, suggesting variation in the factors that influence annual rates of change. For example, the trend shapes indicated accelerating population increases in more recent years, or, in the case of Lazuli Bunting, showed an accelerating decline. Although our surveys began in 1993, most species reached their minimum abundance around 1995 or 1996 regardless of the shape of the trend. This was true for year-round residents as well as for migratory species. We do not know why this was, but we hypothesize that some large-scale phenomenon such as climate may have been responsible.

Remnant versus Revegetation

Restoration work along the Sacramento River is providing suitable nesting and foraging habitat for a diverse group of birds, as indicated by increasing trends on revegetated plots. Interestingly, species also increased in remnant riparian forests, although usually at slower rates, which suggests that revegetation efforts are benefiting riparian bird communities as a whole in the Sacramento Valley. Other studies have made similar conclusions for riparian birds in other areas (e.g., Twedt et al. 2002; Kus & Beck 2003). Habitat features may also be changing on remnant plots that could account for changes in abundance there.

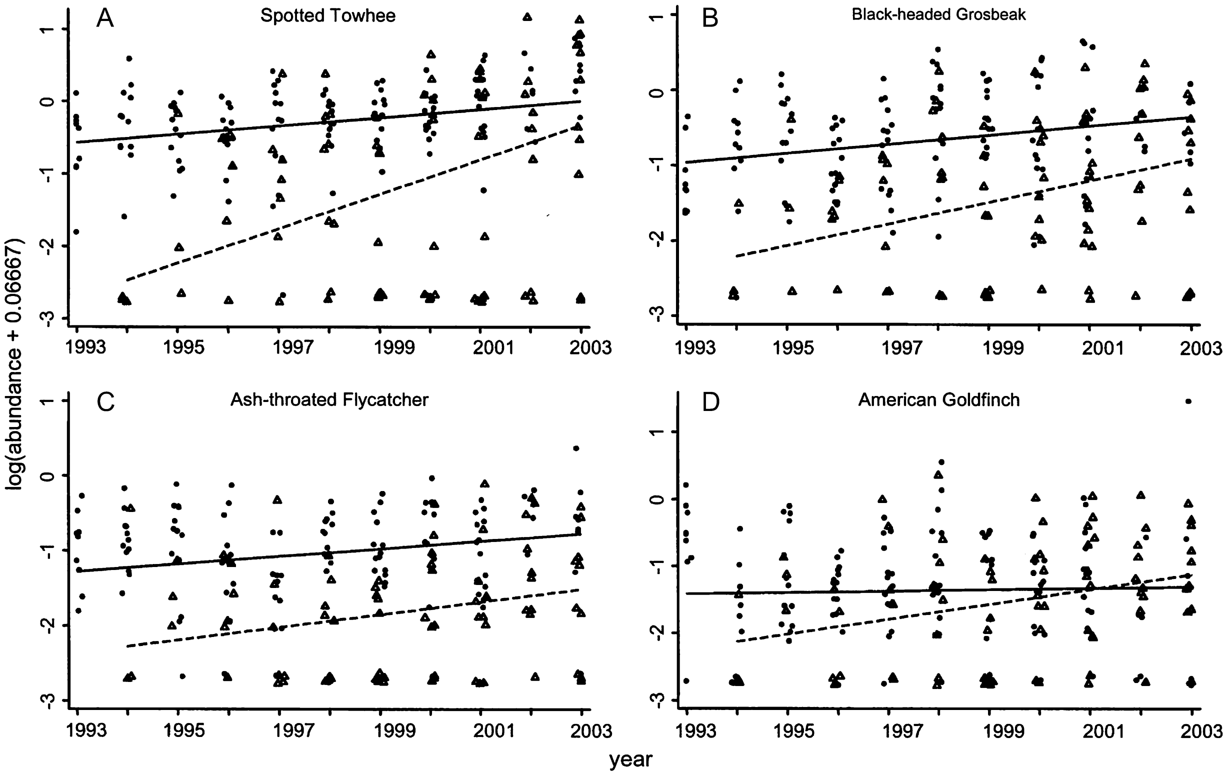

Figure 2. Point count detections of Spotted Towhees (A), Black-headed Grosbeaks (B), Ash-throated Flycatchers (C), and American Goldfinches (D) in remnant (solid line, circles) and revegetated (dashed line, triangles) riparian forests in the Sacramento Valley, California from 1993 to 2003. Line shows values predicted from log-linear regression. Each circle and triangle represents datum from 1 year for each site (points are jittered to better show data).

For example, many cavity-nesting species were increasing at faster rates in remnant habitat, perhaps reflecting an increase in the conditions necessary for cavity excavation as these sites matured further.

We used remnant riparian forests for comparison because the goal of restoration is usually to create habitat conditions structurally and functionally equivalent to lost or threatened "natural" habitats. In the Sacramento River system, however, using extant riparian forests for reference is potentially problematic in part because they are mostly mature, whereas revegetation plots represent habitats in early- to mid-seral stages. Because the historic nature of the river system was dynamic, and the result was a mosaic of vegetation in several seral stages, old mature forests should not be the primary goal of habitat restoration in the Sacramento Valley (Golet et al. 2003). Many bird species in fact rely on early-seral habitat for breeding. Nevertheless, analyses presented here show that almost all species were stable or increasing in the remnant riparian forests, suggesting that they may indeed be good reference sites, at least in terms of bird abundance (i.e., populations are not slowly being extirpated).

There is likely a relationship between bird abundance on the remnant and revegetated plots due to their geographic proximity. The strategy of the SRP is to obtain and restore land adjacent to existing forest (Golet et al. 2003), and most of our sites had both treatment types. Kus (1998) found that the occupation of restored riparian sites by the endangered Least Bell's Vireo was accelerated by the presence of adjacent mature habitat that contained established breeding populations of vireos. This situation likely occurred at our sites as well; individuals from remnant plots dispersed into the newly revegetated sites. Although the close proximity of treatments may be beneficial for reestablishing populations, it can cloud interpretation of results due to spatial dependence among sites (Block et al. 2001). For example, we expected population increases in revegetated plots but were surprised to find that several species were also increasing in remnant forest plots.

Age of Revegetation

We found that the abundance of several species increased as restoration sites matured. Although we did not formally test the relationship of bird abundance and vegetation growth and structure, it was clear that dramatic changes to the vegetation occurred following planting (Fig. 4). Hence, we suggest that vegetation growth was primarily responsible for the patterns reported here. Our results are consistent with those of other studies that related changes in vegetation following restoration to changes in bird abundance (e.g., Kus 1998; Krueper et al. 2003; Kus & Beck

Table 5. Trend (annual rate of change) in relation to years since restoration planting, 95% confidence interval, p value for years since restoration term, model r^2, and relative coefficient of determination (RDC) for restoration year.

Species	Trend %	95% Confidence Interval Low	95% Confidence Interval High	p	Model r^2	RCD*
Mourning Dove	3.59	−3.33	10.99	0.3124	0.19	0.01
Nuttall's Woodpecker	10.01	5.27	14.95	<0.0001	0.42	0.17
Downy Woodpecker	7.77	3.36	12.38	0.0007	0.47	0.12
Western Wood-Pewee	10.84	5.86	16.05	<0.0001	0.67	0.13
Ash-throated Flycatcher	8.60	2.03	15.59	0.0103	0.39	0.07
Western Kingbird	1.43	−5.22	8.54	0.6779	0.33	0.00
Western Scrub-Jay	6.70	−0.15	14.02	0.0553	0.27	0.05
Oak Titmouse	5.28	−0.71	11.63	0.0840	0.22	0.04
Bewick's Wren	25.74	19.03	32.84	<0.0001	0.70	0.31
House Wren	8.39	3.84	13.14	0.0004	0.45	0.15
American Robin	6.10	−0.16	12.75	0.056	0.27	0.05
European Starling	−2.67	−6.20	−0.98	0.1474	0.28	0.03
Spotted Towhee	26.58	17.99	35.80	<0.0001	0.72	0.21
Black-headed Grosbeak	15.72	9.12	22.73	<0.0001	0.65	0.15
Lazuli Bunting	−10.91	−18.0	−3.09	0.0078	0.35	0.10
House Finch	2.39	−4.61	9.90	0.5079	0.36	0.00
Bullock's Oriole	10.24	3.77	17.10	0.0020	0.53	0.12
Brown-headed Cowbird	11.07	3.01	19.77	0.0070	0.43	0.08
Common Yellowthroat	7.61	1.18	14.44	0.0203	0.67	0.04
American Goldfinch	11.84	3.51	20.83	0.005	0.26	0.11

All models included a transect term (11 degrees of freedom) and were $n = 83$.
*RCD for the effect of number of years since planting.

2003). Many of our species showed a positive linear relationship to revegetation age, indicating a relatively constant rate of population increase during the years of study. The nonlinear results for others, however, revealed interesting patterns in relation to revegetation age. For example, House and Bewick's wrens did not show up on revegetated plots until plantings were 10 and 5 years old, respectively, but then increased dramatically. We think it likely that appropriate breeding habitat features were not present earlier because both species use tree cavities or crevices for nesting, including those found in mature trees, stumps, and flood debris. Alternatively, food or foraging substrate may have been inadequate in the early stages of restoration plantings for these wrens.

Use of the revegetated habitat likely differed among species and changed over time. Kus (1998) showed that Least Bell's Vireo use of restored habitat for foraging and nesting depended on the age and foliage cover characteristics (amount and height of cover). We suspect that cavity-nesting species were using the revegetated habitat primarily for foraging until sites matured enough to provide natural cavities (at age 8–10 years; PRBO, unpublished data). Most of the other species both nested and foraged on the restoration plots (PRBO, unpublished data).

Lazuli Bunting

The Lazuli Bunting, though increasing until about 1997, was the only species to show a significant decline during our study period. BBS data for the Central Valley region also show a decline, indicating that this species is in trouble in California's Central Valley. We suspect that poor reproductive success is responsible for these declines. Nest survival (the probability that a nest will fledge at least one young) in the Sacramento Valley was only 11.7% from 1993 to 1997 due to the combined effects of nest predation and parasitism by Brown-headed Cowbirds (Gardali et al. 1998). This level of nest survival is well below estimates for other open-cup nesting species that are increasing at our sites in the Sacramento Valley, e.g., 53% for Black-headed Grosbeak (PRBO, unpublished data) and approximately 24% for Spotted Towhee (Small 2005). The difference may be attributable to the level and impact of cowbird nest parasitism. For example, parasitism rates were 87% for the Lazuli Bunting (Gardali et al. 1998) and only 38% for the Spotted Towhee (Small 2005). Gardali et al. (1998) suggested that with such a low estimate of nest survival, it is unlikely that Lazuli Bunting populations in the Sacramento Valley are self-sustaining. Hence, the *amount* of habitat per se may not be a population-limiting factor for Lazuli Bunting, and restoration and management for this species may require focusing on landscape-level processes. For example, active management of nest predators and Brown-headed Cowbirds may be needed in the short-term to prevent further loss of Lazuli Buntings.

Birds as Indicators of Restoration Success

The goal of most restoration projects is to recover an ecosystem's structure and function to recreate natural

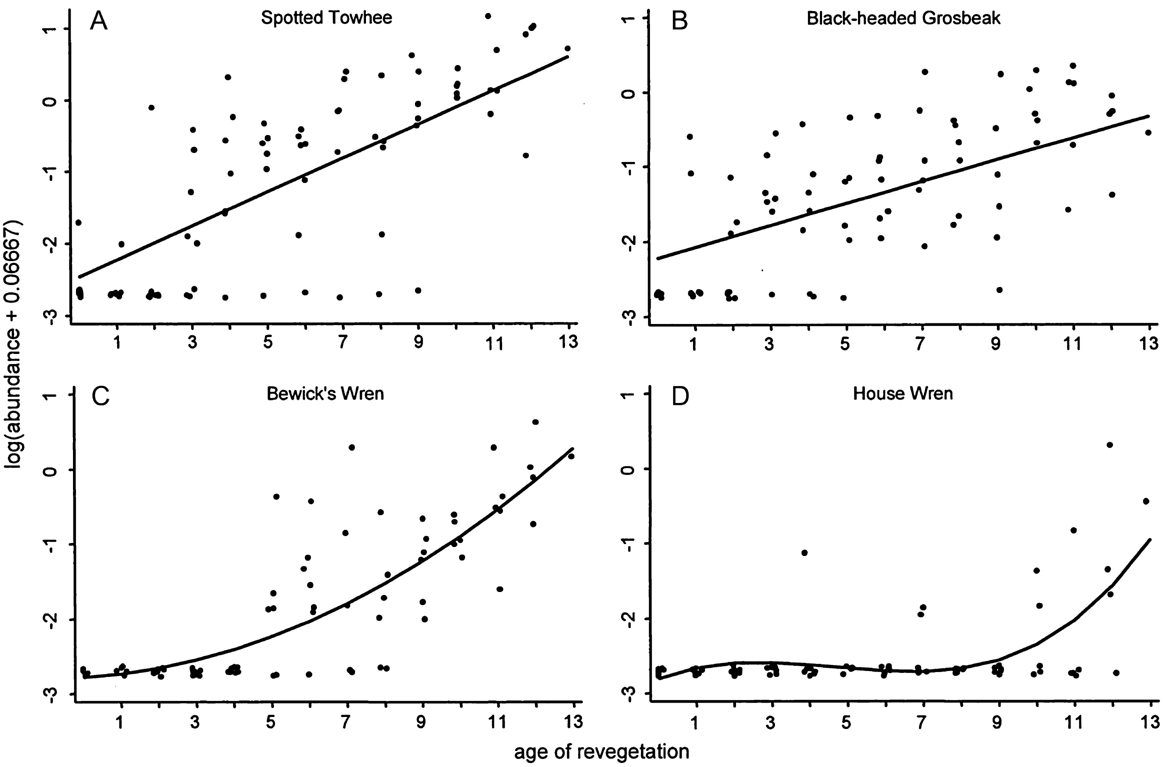

Figure 3. Point count detections of Spotted Towhees (A), Black-headed Grosbeaks (B), Bewick's Wrens (C), and House Wrens (D) in relation to age of revegetation. Lines show values predicted from log-linear regression; quadratic fit for Bewick's Wrens and cubic fit for House Wrens. Each circle represents datum from 1 year for each site.

conditions. An important assumption of ecological restoration is that it provides appropriate habitat for native species. Unfortunately, restoration projects are often designed with little consideration for their effects on wildlife (Block et al. 2001). Others are developed specifically to provide habitat for a single imperiled species (Kus 1998). Restoration success can only be measured relative to reference habitat, and restoration projects need to have clear objectives and associated performance standards.

Are birds good indicators of restoration success? Although our study was not designed to answer this question, the results provide interesting insights. We analyzed populations of individual bird species with different life history characteristics. The benefit of this approach was that we could look for patterns of response common to species with similar habitat requirements, which could in turn yield valuable information about the condition of different attributes within the revegetated areas. Kus and Beck (2003) used a guild approach—grouping species by habitat preference, habitat structure association, and foraging mode—to evaluate riparian restoration in a similar manner. Our species by species approach provides information similar to theirs without formally grouping abundance across taxa and has the added benefit of elucidating species-specific patterns. For example, it is important to know that the Lazuli Bunting is declining; grouping it with

Table 6. Species that deviated from a constant rate of change (nonlinear) in relation to years since restoration (with planting year set as 0), shape of relationship, local minimum and maximum, overall model r^2, and the relative coefficient of determination (RCD) for years since planting.

Species	*Shape*	*Minimum Year*	*Maximum Year*	r^2	*RCD**
Western Scrub-Jay	quadratic (−)	—	8	0.40	0.37
Bewick's Wren	quadratic (+)	−1	—	0.74	0.04
House Wren	cubic (+)	7	3	0.59	0.17
American Robin	cubic (−)	10	2	0.34	0.26
Lazuli Bunting	quadratic (−)	—	4	0.44	0.17
Bullock's Oriole	quadratic (−)	7	5	0.57	0.19

The RCD is the variance not attributable to transect that is explained by year. All models were $n = 83$ and included a transect term (11 degrees of freedom).
*RCD for the effect of year trend.

Figure 4. Representative images depicting a newly planted site (A), a 2-year-old site with recently mowed rows (B), and a 13-year-old site (C).

other species could have produced misleading results. Other authors have suggested that birds provide excellent indicators of ecological integrity and as such may be ideal study organisms for monitoring that aims to maintain or restore ecosystems (Carigan & Villard 2002). Birds make good indicators primarily because they have been shown to respond to changes in the environment over multiple spatial scales (Temple & Wiens 1989). From a practical perspective, they are well suited for monitoring because (1) they announce their presence vocally making them relatively easy to detect and identify; (2) they can be surveyed efficiently (i.e., cost effectively) over very large areas; (3) demographic parameters underlying population trends can be assessed directly; and (4) researchers using landbird monitoring protocols benefit from the existence of standardized programs and guidelines that aid in repeatability and interpretation of results. Further, landbird monitoring allows for the relatively easy collection of data on multiple species thereby enhancing their effectiveness as indicators; most authors (reviewed in Carigan & Villard 2002) recommend selecting a wide variety of indicator taxa that collectively occupy a broad range of habitats, have a wide range of ecological requirements, and depend on specific ecological processes. It is typically assumed that the recovery of faunal communities follows the establishment of vegetation (Toth et al. 1995; Young 2000). In general our results support this assumption. However, it is possible that revegetation could produce habitat structure superficially similar to remnant/reference habitat and yet still not support bird populations as in reference sites. For example, if this study had focused on monitoring habitat characteristics alone, instead of bird population responses, the threshold effects of habitat maturation (e.g., on Bewick's and House wrens) would likely have been missed. Likewise, the presence of limiting factors in addition to amount of habitat (decline of Lazuli Bunting) would not have been detected.

We found that abundance levels on revegetation sites were approaching those of reference sites, which indicates that the restoration process is following its intended trajectory (SER 2002). Only long-term population monitoring can yield such results, and although 11 years is relatively long for a large-scale riparian restoration site, future monitoring is needed to document population and community response patterns as the restoration sites mature. And to date, only extant Sacramento Valley breeders have recolonized restoration sites, so that the longest range goal has yet to be attained—recolonization by locally extirpated riparian breeders.

Despite the fact that bird abundance as measured in our study and others appears to provide valuable information on the performance of restoration, there are important caveats worth mentioning. Using bird abundance as the only performance measure assumes that more birds equates to higher quality habitat. This assumption may not be true (Golet et al. 2003), and information on reproductive success and survival would help to validate this. In fact, the best measure of restoration success is one that determines whether restored conditions support viable populations. Hence, we strongly recommend collecting data on various demographic rates. Finally, we do not know if birds are a good indicator for other taxonomic groups or ecosystem processes. We agree with Ruiz-Jaen and Aide (2005) that restoration success should be measured by looking at multiple ecological attributes and compare restoration sites with greater than two reference sites. We extend this recommendation to include long-term monitoring of these attributes.

Conclusions

Riparian restoration in the Sacramento Valley has been largely successful in terms of providing habitat for a diverse community of breeding landbirds. Our results suggest that restoration efforts in the Sacramento Valley are on their intended path. Long-term population monitoring is essential to providing information on restoration progress, and data on reproductive success and adult survival could provide even better indicators of bird response to revegetation. Data from other taxonomic groups (e.g., mammals, invertebrates) could help to evaluate our results and support our conclusion that these revegetation efforts are providing habitat for a spectrum of wildlife.

It is important to estimate abundance trends for a suite of species with diverse life history requirements, for example, some species may be good indicators for early-seral conditions, others for later seral stages. However, more years of study are needed to determine when abundances peak, stabilize, or decline; this will contribute to managing for multiple-seral stages. Finally, without a species-specific approach, we might have overlooked the decline of Lazuli Bunting.

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Appendix 1. Common and scientific names of species used in all analyses.

Species	*Scientific Name*	*Nest Type*	*Nest Height in Meters (n)*	*Migratory Status*	*Foraging Mode*
Mourning Dove	*Zenaida macroura*	OC	1.5 (59)	RES	GG
Nuttall's Woodpecker*	*Picoides nuttallii*	CAV	10.3 (30)	RES	BG
Downy Woodpecker	*Picoides pubescens*	CAV	8.9 (11)	RES	BG
Western Wood-Pewee	*Contopus sordidulus*	OC	12.2 (56)	NEO	HHG
Ash-throated Flycatcher*	*Myiarchus cinerascens*	CAV	9.0 (13)	NEO	HHG
Western Kingbird	*Tyrannus verticalis*	OC	10.8 (61)	NEO	HHG
Western Scrub-Jay*	*Aphelocoma californica*	OC	3.7 (22)	RES	GG/FG
Oak Titmouse*	*Baeolophus inornatus*	CAV	6.5 (14)	RES	FG
Bewick's Wren*	*Thryomanes bewickii*	CAV	1.4 (5)	RES	GG/FG
House Wren	*Troglodytes aedon*	CAV	7.5 (25)	RES	GG/FG
American Robin	*Turdus migratorius*	OC	5.0 (44)	RES	GG/FG
European Starling*	*Sturnus vulgaris*	CAV	12.5 (22)	RES	GG/FG
Spotted Towhee	*Pipilo maculates*	OC	0.32 (127)	RES	GG
Black-headed Grosbeak*	*Pheucticus melanocephalus*	OC	3.5 (165)	NEO	FG
Lazuli Bunting	*Passerina amoena*	OC	2.3 (127)	NEO	GG/FG
House Finch	*Carpodacus cassinii*	OC	6.7 (44)	RES	GG/FG
Bullock's Oriole	*Icterus bullockii*	PEN	10.4 (51)	NEO	FG
Brown-headed Cowbird	*Molothrus ater*	N/A	N/A	SD	GG
Common Yellowthroat*	*Geothlypis trichas*	OC	0.27 (18)	SD	FG
American Goldfinch	*Carduelis tristis*	OC	2.4 (36)	SD	FG

Nest type: OC, open cup; CAV, cavity; PEN, pendulum. Nest height is based on our unpublished data from the Sacramento Valley and represents the range of most common heights. Migratory status: NEO, neotropical migrant; RES, year-round resident; SD, short-distant migrant. Foraging mode: GG, ground glean; BG, bark glean; HHG, hawk or hover glean; FG, foliage glean. Species with an asterisk are either California Partners in Flight riparian or oak woodland focal species (CalPIF 2002; RHJV 2004).