RESEARCH ARTICLE

Evaluating Riparian Restoration Success: Long-Term Responses of the Breeding Bird Community in California's Lower Putah Creek Watershed

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ABSTRACT

Restoration of river processes and riparian vegetation is a high priority, particularly in the western United States, where it provides critical habitat for fish and wildlife along with many other environmental and economic benefits, yet few studies have quantified long-term responses of wildlife. We evaluated responses of the breeding bird community to restoration and management of the lower Putah Creek watershed in the Central Valley of California following the establishment of the Putah Creek Accord in 2000, an historic agreement designed to improve ecosystem structure and function and protect the livelihoods of farmers and residents along the lower creek. We surveyed the breeding bird community at 14 sites distributed over 38 km of the creek between 1999 and 2012, and we detected significant increases in the abundance of 27 breeding bird species as well as increases in the size and diversity of the entire breeding bird community, which could not be accounted for by broader regional trends or the influence of local nest box installation. Further, changes in the watershed favored riparian and woodland-associated species over synanthropic species. However, in comparison with Central Valley Joint Venture density objectives for seven riparian focal bird species, there is still considerable room for improvement, particularly at sites farthest downstream. Overall, our results echo shifts in the Putah Creek fish community and provide evidence that the Putah Creek Accord and subsequent management actions have contributed to a long-term improvement in riparian ecosystem condition for both aquatic and terrestrial organisms.

Keywords: avian conservation, Central Valley, habitat restoration, population trends, riparian landbirds

Restoration Recap

- Ecological restoration projects designed to benefit wildlife populations are not always successful, and positive responses cannot be taken for granted. Evaluating project success requires quantifying wildlife responses on appropriate temporal and spatial scales.
- We identified long-term increases in the abundance and diversity of the riparian breeding bird community in the lower Putah Creek watershed since 1999 prior to the start of riparian restoration efforts. These responses were similar to previously documented responses in the native fish community and indicated improvements in riparian ecosystem condition that benefited both terrestrial and aquatic wildlife.
- Comparisons of riparian breeding bird densities to regional Central Valley Joint Venture objectives indicate there is still room for further improvement, particularly at sites farthest downstream, but we consider restoration efforts thus far to have been successful in benefiting riparian bird populations.

Restoration of rivers and riparian ecosystems can provide multiple environmental and economic benefits: improvements to water quality and groundwater recharge (Naiman et al. 2010), habitat for fish and wildlife, including organisms that provide pollination and pest control services (Kremen et al. 2002, Buddle et al. 2004), and even increases in property values (Carver and Caudill 2013, Liu et al. 2013). Riparian restoration can also play an important role in climate change adaptation by sequestering carbon,

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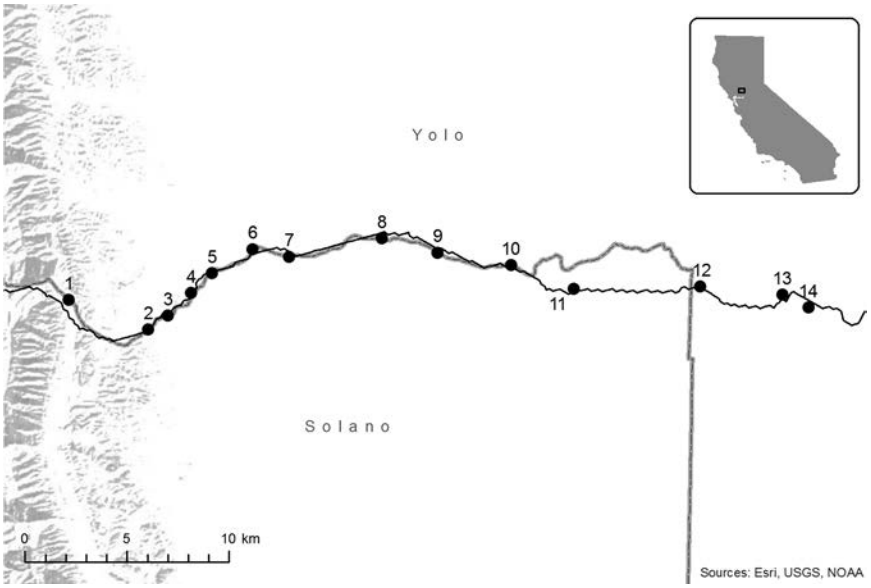

Figure 1. Lower Putah Creek watershed study area in the Central Valley of California, showing Putah Creek, flowing from west to east out of the California Coast Range along the boundary between Yolo and Solano counties, and the 14 study sites.

providing thermal refugia, and providing corridors that facilitate migration of species (Seavy et al. 2009, Capon et al. 2013, Matzek et al. 2015). Consequently, considerable time and resources have been invested in riparian restoration, particularly in the western United States where riparian vegetation has long been recognized as a biodiversity hotspot (Knopf et al. 1988, Knopf and Samson 1994).

Riparian restoration goals often include benefits to wildlife populations, but surprisingly few studies have quantified wildlife responses to riparian restoration (Golet et al. 2008). Wildlife are often assumed to respond soon after suitable vegetation cover and composition has been restored (the "Field of Dreams" hypothesis; Palmer et al. 1997), but when wildlife responses to restoration are evaluated, they are not always successful (Shanahan et al. 2011, Cristescu et al. 2013, Calhoun et al. 2014). Wildlife responses may be particularly difficult to predict in highly modified ecosystems, where human modifications such as dams and levees, or disturbances such as the spread of invasive species may not be fully reversible through restoration and management efforts (Hulvey et al. 2013). Consequently, if the goals of a restoration project include benefiting wildlife populations, it is essential to assess wildlife responses to restoration, especially on the spatial and temporal scales relevant to wildlife (George and Zack 2001).

We evaluated long-term responses of the breeding bird community to restoration efforts in the lower Putah Creek watershed, a highly-modified riparian ecosystem in California's Central Valley. Like many riparian ecosystems in the western United States, Putah Creek is dammed, and a majority of its water flow is diverted from the lower watershed, a narrow fringe of riparian forest embedded in a matrix of agricultural and urban lands containing an assemblage of native, non-native, and synanthropic species (i.e., species associated with urban, agricultural, and other human-modified areas; Truan et al. 2010, Moyle 2014). Restoration and management efforts were initiated in 2000, which have already resulted in shifts in the fish community towards dominance by native species (Kiernan et al. 2012). To assess the effectiveness of these efforts in improving ecosystem condition for terrestrial wildlife, we quantified long-term changes in the density and diversity of the breeding bird community, with a particular focus on riparian-dependent species.

Methods

Study Area and Data Collection

Putah Creek originates in California's Coast Range and flows east through two dams, along the border of Yolo and Solano Counties, to the Central Valley floor and the San Francisco Bay Delta (Figure 1). During a series of drought years in the late 1980s, the majority of Putah Creek went dry, prompting a landmark lawsuit that resulted in the signing of the Putah Creek Accord in 2000. The Putah Creek Accord is a historic agreement that established a minimum daily flow of 20–43 cfs to protect the ecosystem as well as the livelihoods of farmers and residents along the lower creek (Krovoza 2000, Sacramento County Superior Court 2002). The Accord has facilitated numerous ecosystem improvement actions, including changes to the water flow regime, realignment of the over-widened stream channel, and eradication of invasive plants followed by planting of native species (Moyle 2014).

We established 14 permanent study sites spanning the length of lower Putah Creek (approximately 30 km), beginning with eight sites established in 1999. We added four more sites in 2005 and two in 2006 as the number of participating landowners increased. All of the sites were characterized by a deeply-incised creek channel, a narrow floodplain, and a mature but narrow riparian forest. Vegetation composition was similar among sites, with nonnative species comprising approximately 50% of the plant cover (Truan et al. 2010). Sites varied in the width and depth of the creek channel, width of the vegetated corridor, adjacent land uses, and history of local impacts and management actions, but together they represented the full range of riparian habitat available to the breeding bird community along lower Putah Creek.

We conducted breeding season point count surveys annually from 1999 through 2012, except in 2004. Each site was surveyed two to four times during the breeding season (April 1–July 10), with each survey consisting of three to five point count stations located along the creek channel, spaced at least 200 m apart. During each 10-minute point count, skilled observers recorded all birds detected (excluding fly-overs) and their distances from the point (Ralph et al. 1993). We assigned each of the species in the data set to groups representing primary breeding habitat association (Cornell Lab of Ornithology 2013), and identified locally riparian-dependent species using our experience and a regional list of riparian focal species (Dybala et al. 2017). We excluded from our analysis migratory species not known to breed in the area, species with very few (< 40) total detections, and species unlikely to be effectively surveyed by point counts, including waterfowl, shorebirds, raptors, and owls. We also excluded Tree Swallow (*Tachycineta bicolor*) due to inconsistencies among observers in how they were recorded.

Statistical Analyses

We used distance sampling to estimate the abundance of each species in each site and year while accounting for differences in detection probabilities among species (Buckland et al. 2001). We fit uniform, half-normal, and hazard-rate detection functions with polynomial or cosine series expansion terms to the point count data for each species, and we selected the function with the lowest AIC score to estimate the number of individuals of each species per 100 ha at each site in each year (Thomas et al. 2010). To examine the temporal change in the abundance of each species, we modeled the abundance estimates as a function of year by fitting a generalized additive mixed model (GAMM) with a Poisson error distribution (Wood 2006). The model included a random intercept and slope for each site, to account for the variation in temporal change among sites, and a random intercept for each individual data point, to account for overdispersion (Browne et al. 2005).

We used nonparametric bootstrap to estimate the uncertainty in the trends, including the uncertainty in the abundance estimates for each site in each year (Thomas et al. 2004). For each of 1,000 bootstrap replicates, we resampled each of the abundance estimates, refit the GAMM, and estimated the annual average breeding density of each species in the lower Putah Creek watershed between 1999 and 2012. For each bootstrap replicate, we also estimated the average annual growth rate of each species from the ratio of the 1999 and 2012 average density estimates (Sauer and Link 2011). For all estimates, we report the median of the bootstrap replicates and the lower 2.5th and upper 97.5th percentiles as 95% confidence intervals.

For comparison, we collected trend estimates for each species over the same interval (1999–2012) in the broader Coastal California Bird Conservation Region (BCR 32) from the North American Breeding Bird Survey (NABCI 2000, Sauer et al. 2014). We examined correlations between local and regional annual growth rates, and because Breeding Bird Survey methods differ from ours, we also compared trends qualitatively, e.g., to determine what proportion of the species increasing locally were also increasing region-wide. In addition, we compared local density estimates for 2012 to short-term breeding density objectives set by the Central Valley Joint Venture (CVJV) for a suite of riparian focal species (Dybala et al. 2017). The CVJV has defined population, habitat, and breeding density objectives for riparian birds that reflect the estimated population sizes, riparian vegetation extent, and average breeding densities required to achieve a long-term conservation goal of riparian ecosystems that are capable of supporting genetically robust, self-sustaining, and resilient populations. Local breeding densities are expected to increase in response to improvements in habitat quality and reductions in habitat fragmentation, and thus provide metrics for evaluating changes in ecosystem condition, contributions to the CVJV's conservation objectives, and overall riparian restoration success.

We also examined the temporal change in the density and diversity of the entire breeding bird community and of each habitat association group. For each site in each year, we calculated the total abundance of all species per 100 ha and the Shannon index of diversity (Spellerberg and Fedor 2003). For each metric, we again fit a GAMM with either density or diversity as a function of year and included a random intercept and slope for each site. We repeated the nonparametric bootstrap with 1,000 replicates and again estimated the average annual growth rate of the density or diversity from the ratio of the 1999 and 2012 estimates.

Because artificial nest boxes were installed in the year 2000 at eight of the 14 sites, we anticipated a strong positive response in the densities of secondary cavity-nesters. To determine whether any of the trends in community density and diversity were primarily due to the response of secondary cavity nesters instead of other restoration and management efforts, we repeated the modeling to estimate average annual growth rate in the density and diversity of the breeding bird community and each habitat association group after excluding secondary cavity-nesters.

We conducted all analyses in R (R Foundation, Vienna Austria) using the packages "Distance" v. 0.9.3, "mrds" v. 2.1.12, "gamm4" v. 0.2–3, and "vegan" v. 2.0–9 (Oksanen et al. 2013, Wood and Scheipl 2014, Bates et al. 2015, Laake et al. 2015, Miller 2015, R Core Team 2015).

Results

Our study included 43 species of the lower Putah Creek breeding bird community (all scientific names are provided in Table 1), including one California Bird Species of Special Concern *Setophaga petechia* (Yellow Warbler; Shuford and Gardali 2008) and one California endemic species also considered to be climate change vulnerable, *Pica nuttalli* (Yellow-billed Magpie; Gardali et al. 2012). We assigned the majority of these species to one of three habitat association groups: riparian-dependent species (n = 14), woodland species (n = 16), and synanthropic species associated with human-modified areas (n = 6). The remaining seven species were associated primarily with scrub, grassland, and wetland habitats. Throughout the lower Putah Creek watershed, we detected significant increasing trends in the densities of 27 species and significant declines for 8 species (Table 1). The overall correlation between the local species trends and the corresponding regional species trends in the Coastal California Bird Conservation Region (BCR 32) was not significant (Pearson's r = 0.04, $p = 0.77$). Qualitatively, the results of Pearson's chi-squared test suggests that local and regional trends are independent ($\chi^2 = 3.02$, df = 4, $p = 0.55$); of the 27 species with significant increasing local trends, only seven had increasing regional trends and six actually had decreasing regional trends (Table 1).

The overall lack of correlation between local and regional species trends suggests that the local trends cannot entirely be accounted for by broader regional changes and instead are likely to reflect local changes to the ecosystem, including restoration efforts and the installation of nest boxes. To separate the contributions of local restoration and management efforts from the effects of the nest boxes, we identified nine species as secondary cavity nesters that could have benefited from the installation of nest boxes; eight of these nine species had significant increasing trends between 1999 and 2012 (Table 1). After excluding these species, the correlation between the local and regional trends remained non-significant (Pearson's r = 0.02, $p = 0.91$) and still appeared to be independent ($\chi^2 = 3.32$, df = 4, $p = 0.51$), indicating that local restoration and management efforts beyond the installation of nest boxes has contributed to the local trends.

The density of the entire breeding bird community along lower Putah Creek more than doubled during the study period, from a median in 1999 of 12.4 birds/ha (95% CI: 11.3–13.9) to 33.9 birds/ha (30.7–38.6) in 2012 (Figure 2A), with an average annual growth rate of 8.0% (7.0–9.1%; Table 2A). However, the growth in density of the entire community was not linear, reflecting the combined effect of non-linear growth rates in each individual species (Figures 2B–C). Some species had fairly steady growth (e.g., *Picoides nuttallii* [Nuttall's Woodpecker] and *Myiarchus cinerascens* [Ash-throated Flycatcher]), while the rate of growth for other species accelerated in the later years of the study (e.g., *Pipilo maculatus* [Spotted Towhee] and *Melospiza melodia* [Song Sparrow]), and still others had fairly complex patterns of growth (e.g., *Troglodytes aedon* [House Wren]).

By habitat association group, the densities of the riparian-dependent, woodland-associated, and synanthropic species also all increased between 1999 and 2012 (Table 2A). The density of the riparian-dependent species more than doubled, from a median in 1999 of 4.9 birds/ha (95% CI: 4.2–5.5) to 12.3 birds/ha (10.4–13.9) in 2012 (Figure 3A), at an average annual growth rate of 7.4% (5.9–8.8%; Table 2A). In contrast, the density of woodland-associated species quadrupled, from a median in 1999 of 3.4 birds/ha (95% CI: 2.9–4.1) to 14.8 birds/ha (13.1–17.1) in 2012, at a higher average annual growth rate of 11.9% (10.2–13.7%; Table 2A). However, five of the nine secondary cavity nesters in the breeding bird community were woodland-associated species, with some of the fastest average annual growth rates in the entire breeding bird community (Table 1). After excluding the secondary cavity nesters, the average annual growth rate in the density of the woodland group slowed considerably and was similar to that of the riparian-dependent species (Table 2B; Figure 3B). The density of synanthropic species remained relatively low throughout the study period, but did increase from a median in 1999 of 0.9 birds/ha (0.8–1.1) to 1.8 birds/ha (1.5–2.2) in 2012, at an average annual growth rate of 5.2% (2.6–7.8%; Table 2A). After excluding two secondary cavity nesters, there was no detectable change in the density of synanthropic species during the study period (Table 2B).

The Shannon diversity index of the breeding bird community along lower Putah Creek increased significantly between 1999 and 2012, with an average annual growth rate of 0.6% (0.1–0.9%; Table 2A). By habitat association group, the diversity index increased only for the woodland-associated species. However, after excluding secondary cavity nesters, diversity within the riparian-dependent group also increased significantly between 1999 and 2012, and at a faster average annual growth rate than the woodland-associated species (Table 2B). There was no detectable change in diversity within the synanthropic species group, either with or without secondary cavity nesters.

In comparison to the CVJV's density objectives for seven riparian focal species, median densities in the lower Putah Creek watershed in 2012 were lower for all but one (Nuttall's Woodpecker; Figure 4). However, there was considerable variation among sites in focal species densities, with several focal species reaching the density objectives at one or more sites in 2012. By 2012, the number of focal species reaching the density objectives had increased at most sites compared with 1999, with a greater number

Table 1. Comparison between lower Putah Creek, CA, trends and Breeding Bird survey regional trends for individual species in the lower Putah Creek breeding bird community, grouped by local breeding habitat associations and with secondary cavity nesting species marked. *Trends with confidence intervals that do not overlap zero. + Central Valley Joint Venture riparian focal species.

Habitat Association by Species	Local avg annual growth (%)		Regional BBS trend 1999–2012		2° Cavity Nester
Riparian-dependent					
Black-chinned Hummingbird (*Archilochus alexandri*)	–5.0	(–5.9, –4.2)*	1.8	(0.3, 3.5)*	
Nuttall's Woodpecker (*Picoides nuttallii*)+	2.3	(–0.3, 4.1)	0.9	(0.1, 1.7)*	
Western Wood-Pewee (*Contopus sordidulus*)	–9.7	(–12.5, –6.6)*	–1.6	(–2.2, –0.9)*	
Pacific-slope Flycatcher (*Empidonax difficilis*)	–8.6	(–12.5, –4.3)*	0.6	(–0.1, 1.4)	X
Ash-throated Flycatcher (*Myiarchus cinerascens*)+	5.6	(2.9, 7.7)*	0.7	(0.1, 1.2)*	X
Warbling Vireo (*Vireo gilvus*)	23.8	(17.0, 31.9)*	–1.4	(–2.3, –0.7)*	
Orange-crowned Warbler (*Oreothlypis celata*)	5.3	(0.7, 10.5)*	–1.1	(–2.0, –0.2)*	
Common Yellowthroat (*Geothlypis trichas*)+	4.5	(3.2, 6.3)*	3.3	(1.0, 5.7)*	
Yellow Warbler (*Setophaga petechia*)+	16.2	(11.9, 20.5)*	–0.6	(–1.6, 0.4)	
Spotted Towhee (*Pipilo maculatus*)+	31.2	(27.3, 35.4)*	0.2	(–0.4, 0.8)	
Song Sparrow (*Melospiza melodia*)+	23.0	(18.4, 27.6)*	0.2	(–0.5, 1.1)	
Western Tanager (*Piranga ludoviciana*)	0.4	(–3.9, 4.5)	0.9	(0.0, 1.9)*	
Black-headed Grosbeak (*Pheucticus melanocephalus*)+	2.2	(–1.9, 10.9)	–0.6	(–1.2, –0.0)*	
Blue Grosbeak (*Passerina caerulea*)	–5.1	(–41.3, –3.3)*	4.2	(2.4, 6.3)*	
Woodland					
Mourning Dove (*Zenaida macroura*)	5.8	(2.2, 9.4)*	–1.3	(–1.9, –0.8)*	
Anna's Hummingbird (*Calypte anna*)	–22.9	(–26.7, –18.9)*	1.6	(0.9, 2.4)*	
Acorn Woodpecker (*Melanerpes formicivorus*)	71.6	(51.1, 93.5)*	0.0	(–0.7, 0.7)	
Downy Woodpecker (*Picoides pubescens*)	13.5	(9.2, 18.1)*	–0.3	(–1.3, 0.6)	
Northern Flicker (*Colaptes auratus*)	–11.4	(–16.0, –6.9)*	0.1	(–0.7, 1.0)	
Black Phoebe (*Sayornis nigricans*)	7.3	(4.4, 9.9)*	2.1	(1.0, 3.2)*	
Yellow-billed Magpie (*Pica nuttalli*)	–11.9	(–16.5, –2.3)*	–1.9	(–3.0, –0.9)*	
Oak Titmouse (*Baeolophus inornatus*)	6.5	(–0.0, 12.2)	–2.1	(–2.9, –1.4)*	X
White-breasted Nuthatch (*Sitta carolinensis*)	51.8	(46.2, 57.8)*	0.7	(–0.5, 1.9)	X
Bewick's Wren (*Thyromanes bewickii*)	5.3	(2.4, 8.4)*	–0.3	(–1.3, 0.8)	X
House Wren (*Troglodytes aedon*)	70.7	(64.1, 78.2)*	–0.9	(–2.1, 0.2)	X
Western Bluebird (*Sialia mexicana*)	92.5	(67.1, 115.2)*	1.2	(0.4, 2.1)*	X
American Robin (*Turdus migratorius*)	17.6	(13.4, 21.9)*	1.1	(0.6, 1.6)*	
Bullock's Oriole (*Icterus bullockii*)	26.8	(21.7, 32.0)*	–1.6	(–2.2, –1.1)*	
Lesser Goldfinch (*Spinus psaltria*)	2.9	(1.4, 4.6)*	1.0	(–0.0, 2.1)	
American Goldfinch (*Spinus tristis*)	13.5	(7.6, 26.2)*	1.7	(0.3, 2.9)*	
Synanthropic					
American Crow (*Corvus brachyrhynchos*)	–0.9	(–7.4, 5.9)	0.9	(0.1, 1.7)*	
Northern Mockingbird (*Mimus polyglottos*)	20.1	(14.2, 28.1)*	1.6	(1.1, 2.0)*	
European Starling (*Sturnus vulgaris*)	4.4	(1.0, 8.1)*	0.1	(–0.6, 0.8)	X
Brewer's Blackbird (*Euphagus cyanocephalus*)	–20.8	(–25.3, –16.2)*	–2.2	(–3.0, –1.6)*	
House Finch (*Haemorhous mexicanus*)	10.6	(6.5, 14.8)*	–1.2	(–2.0, –0.6)*	
House Sparrow (*Passer domesticus*)	7.5	(5.5, 9.5)*	–1.4	(–2.1, –0.7)*	X
Other					
Western Kingbird (*Tyrannus verticalis*)	9.7	(2.6, 19.9)*	0.1	(–0.5, 0.6)	
California Scrub-Jay (*Aphelocoma californica*)	2.5	(0.7, 4.2)*	–0.1	(–0.7, 0.5)	
Bushtit (*Psaltriparus minimus*)	4.9	(1.6, 8.1)*	0.4	(–1.3, 2.4)	
Wrentit (*Chamaea fasciata*)	17.6	(12.1, 29.8)*	–0.5	(–1.2, 0.2)	
California Towhee (*Melozone crissalis*)	0.2	(–2.6, 3.5)	–0.4	(–0.9, 0.1)	
Red-winged Blackbird (*Agelaius phoeniceus*)	–2.6	(–16.5, 15.1)	–1.2	(–1.9, –0.5)*	
Brown-headed Cowbird (*Molothrus ater*)	1.6	(–1.2, 4.9)	0.3	(–0.4, 1.2)	

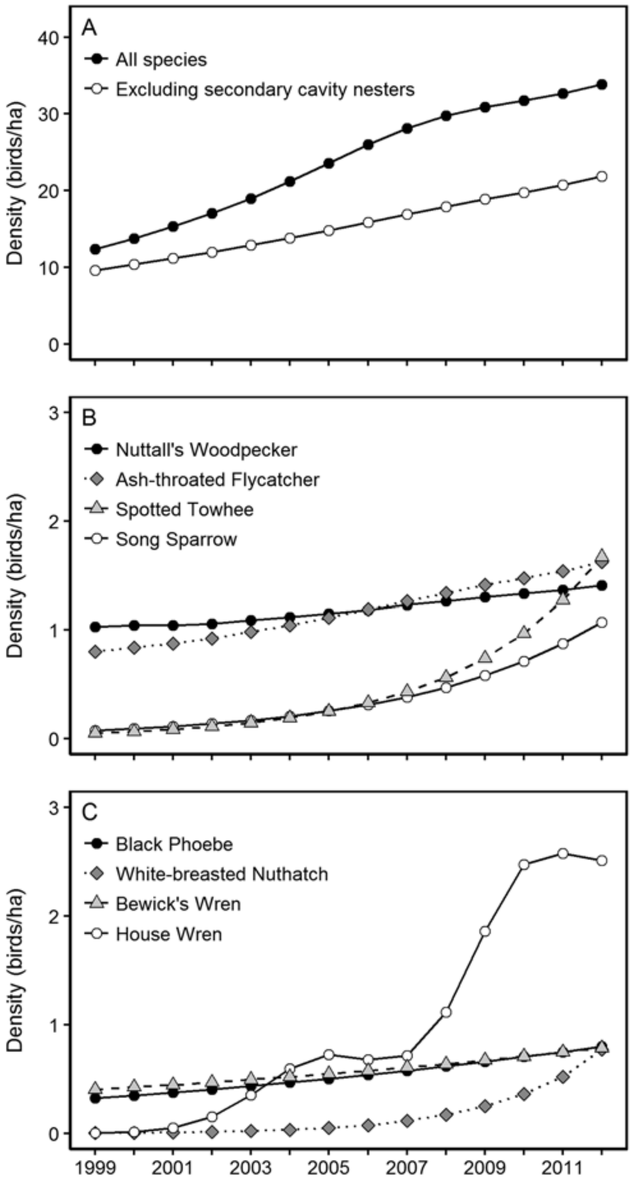

Figure 2. Long-term trends in the density (birds/ha) of the lower Putah Creek breeding bird community. A) The entire breeding bird community, including all species (filled points) and excluding secondary cavity nesters (open points). B) The four most abundant species in the riparian group in 2012. C) The four most abundant species in the woodland group in 2012.

of species reaching the density objectives at the upstream sites (Figure 5).

Discussion

We expected that restoration efforts in the lower Putah Creek watershed since the year 2000 would result in long-term improvements to the ecosystem's ability to support a robust and diverse riparian breeding bird community. Consistent with these expectations, we identified a strong increase in the overall density of the breeding bird community (Table 2A; Figure 2A), which could not be accounted for solely by broader regional trends or the response of secondary cavity-nesters to the installation of artificial nest boxes (Table 2B). Further, changes in the watershed have favored riparian-dependent and woodland-associated species, which had faster growth rates than species associated with human-modified areas, suggesting that restoration actions were benefiting target species over disturbance-tolerant species (Figure 3A). After excluding the influence of nest box installation on secondary cavity nesters, the diversity within the riparian group also increased significantly (Table 2B). Thus, changes in the watershed have not only benefited the most common riparian species, but less common riparian species as well.

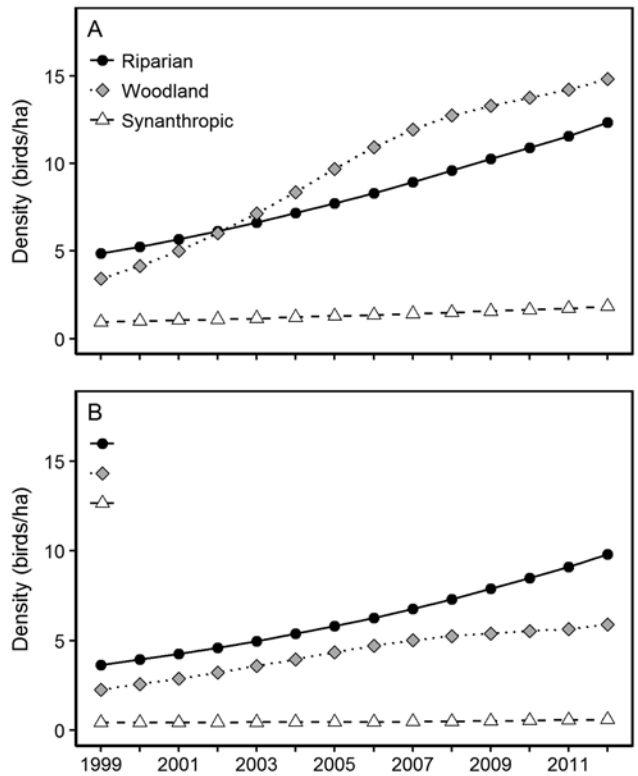

Figure 3. Long-term trends in the density (birds/ha) of the lower Putah Creek breeding bird community by habitat association group. A) Including all species. B) Excluding secondary cavity nesters.

Our results complement another long-term study of wildlife responses to riparian restoration on the Sacramento River (Gardali et al. 2006), which found increases in abundance for many landbird species following revegetation. Gardali et al. (2006) also found non-linear responses by several species, including a delayed response among secondary cavity nesters like House Wren, presumably reflecting the time required for suitable cavities to develop. In contrast, the installation of nest boxes in the lower Putah Creek watershed likely contributed to the immediate positive response by House Wren (Figure 2C), which

Table 2. Average annual growth rate and 95% confidence intervals for the density and diversity of the lower Putah Creek breeding bird community, 1999–2012. A) Growth rates calculated for all species in the breeding bird community and within each habitat association group. B) Growth rates re-calculated after excluding secondary cavity nesters. Also shown are the number of species in each group (n), and the number with increasing (+) and decreasing (–) growth rates with confidence intervals that do not overlap zero. *Trends with confidence intervals that do not overlap zero.

Groups	n	+	–	Density (birds/ha)		Diversity (inverse Simpson)	
A							
All species	43	27	8	8.0	(7.0, 9.1)*	0.6	(0.1, 0.9)*
Riparian	14	7	4	7.4	(5.9, 8.8)*	0.6	(–0.1, 1.2)
Woodland	16	12	3	11.9	(10.2, 13.7)*	1.3	(0.5, 2.1)*
Synanthropic	6	4	1	5.2	(2.6, 7.8)*	0.6	(–0.7, 1.9)
B							
All species	34	20	7	6.5	(5.3, 7.7)*	0.6	(0.1, 1.1)*
Riparian	12	6	3	7.9	(6.2, 9.7)*	1.4	(0.3, 2.3)*
Woodland	11	8	3	7.6	(5.6, 9.9)*	0.8	(0.0, 1.9)*
Synanthropic	4	2	1	2.9	(–0.2, 0.7)	–0.9	(–2.4, 0.8)

may have been previously limited by the availability of suitable cavities.

Despite these successes, the overall densities of six out of seven riparian focal species in 2012 had not yet met the CVJV's short-term density objectives (Figure 4). Further, there are additional CVJV riparian focal species such as *Icteria virens* (Yellow-breasted Chat), *Passerina amoena* (Lazuli Bunting), and *Vireo bellii pusillus* (Least Bell's Vireo) that have all at least attempted to nest along Putah Creek in recent years (Trochet et al. 2017), but were not addressed by this study because they remain too uncommon in the study area to estimate trends in breeding densities. Thus, our results suggest there is substantial room for further improvement in the ability of the lower Putah Creek watershed to support breeding riparian landbirds. We also detected declines in the abundances of several species, including several that were not declining region-wide (Table 1): *Archilochus alexandri* (Black-chinned Hummingbird), *Empidonax difficilis* (Pacific-slope Flycatcher), and *Passerina caerulea* (Blue Grosbeak) in the riparian group, and *Calypte anna* (Anna's Hummingbird) and *Colaptes auratus* (Northern Flicker) in the woodland group. However, all of these species were relatively uncommon at the start of the study in 1999, with median densities less than 0.05 individuals/ha. Thus, their negative annual percent growth rates reflect a relatively small change in absolute density, and particularly for the hummingbirds, could reflect changes in detection probabilities.

Thus far, restoration activities on Putah Creek have focused mainly on in-stream improvements to benefit fishes and other aquatic organisms, including channel realignment, removal of silt, installation of woody debris, as well as the removal of invasive vegetation followed by native plantings. Continuing these restoration activities and expanding them to include more floodplain habitat would likely further improve the ecosystem's ability to support a robust and diverse riparian breeding bird community. In particular, we recommend creating a rich mosaic of riparian vegetation including backwaters and braided stream habitat, reminiscent of historic conditions on Putah Creek (Trochet and Engilis 2014). We expect that increasing diversity in the composition and structure of riparian vegetation will further promote diversity in the riparian breeding bird community. For example, several riparian focal species are associated with early successional, scrubby riparian vegetation (Dybala et al. 2017), whereas Putah Creek is dominated by valley oak and cottonwood gallery forest. We also recommend that restoration plans incorporate climate-smart principles (Point Blue Conservation Science 2017), such as using climate change projections to assess which plant and wildlife species will be most vulnerable to future conditions and which sites will be most critical for restoration (Perry et al. 2015). We anticipate the monitoring of aquatic and terrestrial habitats to continue through at least 2027, providing a multi-decadal dataset that will continue to allow evaluation of the success of restoration efforts in improving riparian ecosystem condition.

Overall, our results provide evidence that riparian breeding birds have responded positively to restoration and management of the lower Putah Creek watershed, echoing concurrent shifts in the lower Putah Creek fish community. Prior to the Putah Creek Accord, native fishes were primarily restricted to the area immediately below the Solano Diversion Dam, but changes to the water flow regime and channel restoration resulted in cooler water temperatures extending farther downstream, in turn allowing native fishes to expand their distributions downstream and dominate the fish community along the entire upper two-thirds of Putah Creek (Kiernan et al. 2012). Similarly, we identified an increase in the density and dominance of riparian-dependent birds (Figure 3), with a greater number of riparian focal species reaching the density objectives at upstream sites (Figure 5). Together, our results provide evidence that the Putah Creek

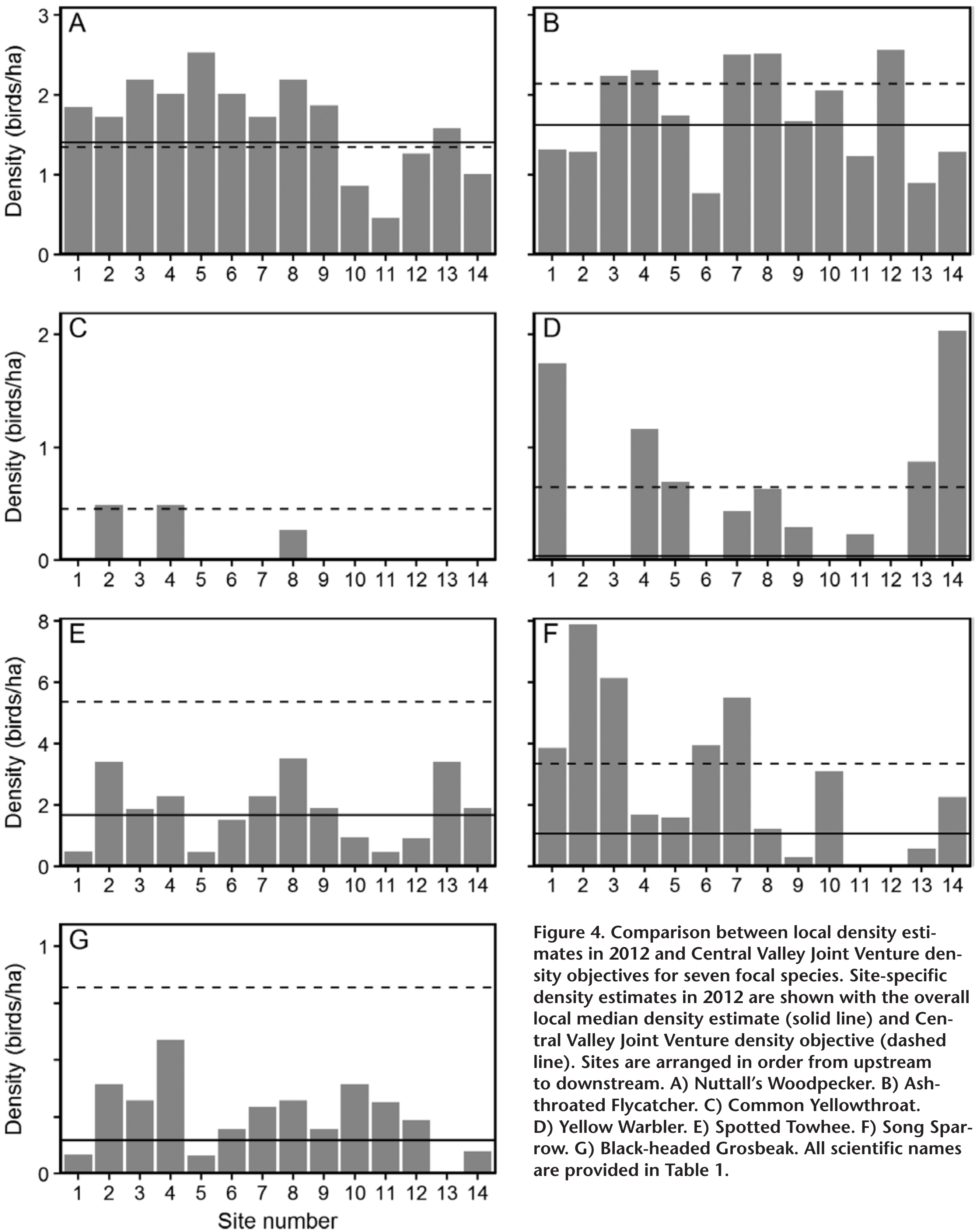

Figure 4. Comparison between local density estimates in 2012 and Central Valley Joint Venture density objectives for seven focal species. Site-specific density estimates in 2012 are shown with the overall local median density estimate (solid line) and Central Valley Joint Venture density objective (dashed line). Sites are arranged in order from upstream to downstream. A) Nuttall's Woodpecker. B) Ash-throated Flycatcher. C) Common Yellowthroat. D) Yellow Warbler. E) Spotted Towhee. F) Song Sparrow. G) Black-headed Grosbeak. All scientific names are provided in Table 1.

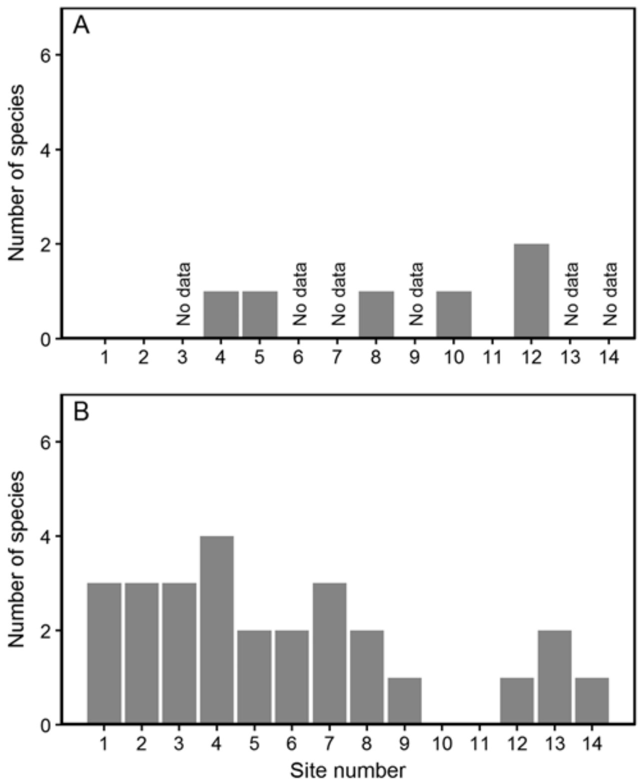

Figure 5. Number of focal species reaching the density objectives at each site in A) 1999 and B) 2012. Note that only 8 of the 14 sites were monitored in 1999.

Accord and subsequent management actions have been successful in making long-term improvements to the condition of the lower Putah Creek riparian ecosystem for both aquatic and terrestrial organisms.

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