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RESEARCH

Population and Habitat Objectives for Avian Conservation in California's Central Valley Riparian Ecosystems

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ABSTRACT

Riparian ecosystems provide important ecosystem services and recreational opportunities for people, and habitat for wildlife. In California's Central Valley, government agencies and private organizations are working together to protect and restore riparian ecosystems, and the Central Valley Joint Venture provides leadership in the formulation of goals and objectives for avian conservation in riparian ecosystems. We defined a long-term conservation goal as the establishment of riparian ecosystems that provide sufficient habitat to support genetically robust, self-sustaining, and resilient bird populations. To achieve this goal, we selected a suite of 12 breeding riparian landbird focal species as indicators of the state of riparian ecosystems in each of four major Central Valley planning regions. Using recent bird survey data, we estimated that over half of the regional focal species populations are currently small (< 10,000) and may be vulnerable to extirpation, and two species have steeply declining population trends. For each focal species in each region, we defined long-term (100-year) population objectives that are intended to be conservation endpoints that we expect to meet the goal of genetically robust, self-sustaining, and resilient populations. We then estimated the long-term species density and riparian restoration objectives required to achieve the long-term population objectives. To track progress toward the long-term objectives, we propose short-term (10-year) objectives, including the addition of 12,919 ha (31,923 ac) of riparian vegetation in the Central Valley (by planning region: 3,390 ha in Sacramento, 2,390 ha in Yolo–Delta, 3,386 ha in San Joaquin, and 3,753 ha in Tulare). We expect that reaching these population, density, and habitat objectives through threat abatement, habitat restoration, and habitat enhancement will result in improvements to riparian ecosystem function and resilience that will benefit other wildlife populations and the people of the Central Valley and beyond.

KEY WORDS

Avian conservation, California, Central Valley Joint Venture, conservation objectives, focal species, habitat restoration, riparian ecosystems, riparian landbirds

INTRODUCTION

The Central Valley was once a vast mosaic of riparian forest, wetlands, and uplands, supported by the regular meandering and flooding of the Sacramento and San Joaquin rivers and their tributaries. Today, over 95% of historical riparian forests have been lost (Katibah 1984; TBI 1998; RHJV 2004). There is strong interest in restoring these riparian ecosystems, which can provide important ecosystem services and recreational opportunities for people, and habitat for wildlife communities (Naiman et al. 2010). In recent decades, government agencies and private organizations have worked together to protect and restore riparian ecosystems by planting riparian vegetation, restoring or mimicking natural hydrology, and reconnecting floodplains and habitat fragments (RHJV 2004; Golet et al. 2008). In 2006, the Central Valley Joint Venture (CVJV) published its second implementation plan, which for the first time included conservation goals for breeding riparian landbirds (CVJV 2006).

Protecting, restoring, and managing Central Valley riparian ecosystems can increase connectivity, restore ecosystem processes, and improve ecosystem function, in turn, providing habitat for wildlife. Here, we defined a goal of establishing riparian ecosystems with sufficient habitat to support genetically robust, self-sustaining, and resilient breeding bird populations. In working toward achieving this goal, we expect the condition of Central Valley riparian ecosystems to improve, in turn, benefitting riparian wildlife communities beyond birds. Further, because restored rivers and floodplains provide recreational opportunities as well as water quality improvement, groundwater recharge, and flood protection (Naiman et al. 2010), we expect that achieving these outcomes will benefit the people of the Central Valley and beyond.

Achieving this broad conservation goal requires defining specific, measurable conservation objectives (CMP 2013), such as population size and habitat area objectives (Sanderson 2006). In 2006, the CVJV defined population size objectives for breeding riparian landbird focal species as indicators of the state of Central Valley riparian ecosystems (CVJV 2006). These population objectives were derived from estimates of potential population sizes, assuming all historical riparian vegetation not already permanently lost to urban areas could be restored. However, we recognized that restoring all historical vegetation is unrealistic given existing and projected changes in land use, climate, and water supply (CNRA 2009; Hobbs et al. 2009; Ahrens and Pine 2014). Further, restoring all historical riparian vegetation may not be necessary to achieving the goal of genetically robust, self-sustaining, and resilient populations.

Here, we describe our process for setting long-term (100-year) and short-term (10-year) conservation objectives for landbirds breeding in Central Valley riparian ecosystems (Figure 1). We evaluate the current state of Central Valley riparian ecosystems in each of four planning regions, including the current extent of riparian vegetation, and the current population density and size of 12 riparian focal species. We define long-term population objectives for each species in each region, which are based on principles of conservation biology and are intended to be conservation endpoints that we expect to meet the goal of genetically robust, self-sustaining, and resilient populations. We then estimate the long-term species density and riparian restoration objectives required to achieve the long-term population objectives, as well as the corresponding short-term density and habitat objectives that can be used to track progress toward the long-term objectives. Our approach provides a transparent, repeatable decision-making process for setting population, density, and habitat objectives that are based on the best available data.

METHODS

Study Area

The Central Valley of California is a large valley bounded by the Sierra Nevada Mountains to the east and the Coast Ranges to the west. The valley is subdivided into the Sacramento Valley to the north and the San Joaquin Valley to the south,

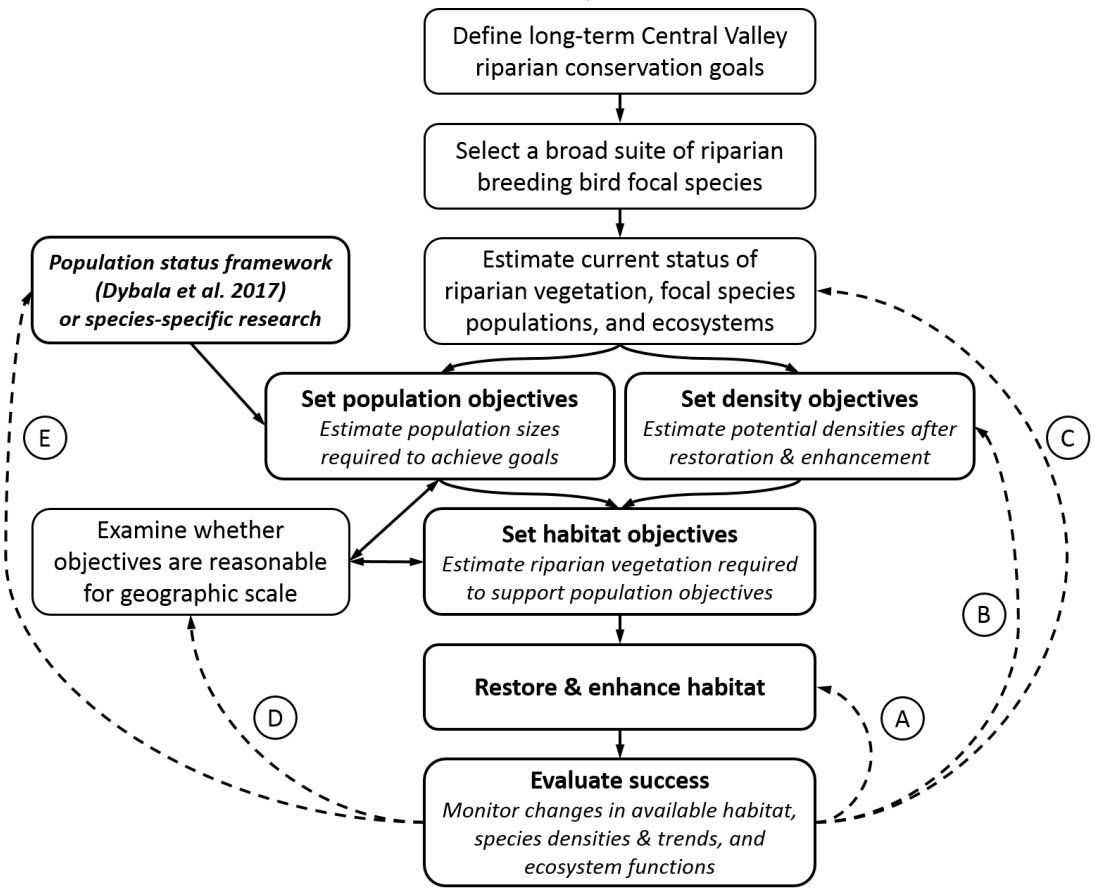

Figure 1 Conceptual diagram illustrating the process used for setting conservation objectives for riparian landbirds in California's Central Valley, beginning with defining long-term conservation goals. Dashed arrows indicate where the results of monitoring progress toward achieving the objectives can be incorporated into (A) evaluations of restoration project success, (B) revising density objectives, (C) revising estimates of the current vegetation extent, population sizes, and ecosystem status, as well as potentially (D) re-evaluating whether the objectives are still reasonable for the geographic scale of the planning region, and (E) incorporating new information into the population status framework and revising population objectives.

each drained by a major river of the same name. The confluence of these two rivers forms the San Francisco Bay–Delta. The southern tip of the Central Valley, the Tulare Basin, is hydrologically distinct and separated from the rest of the San Joaquin Valley; it is a terminal basin, and its rivers once drained into Tulare Lake and several smaller lakes and sloughs. Except in significant flood years, the Tulare Basin is now mostly dry as a result of water diversion and conversion to agriculture. The geographic scope of the CVJV extends across the full extent of the Central Valley floor and beyond, with a primary focus area largely delineated by the Jepson ecoregion boundaries for the Great Central Valley province (Figure 2; Hickman 1993). This primary focus area is further subdivided into four major planning regions: Sacramento, Yolo–Delta, San Joaquin, and Tulare.

Focal Species

The seven focal species in the 2006 CVJV implementation plan (CVJV 2006) included Western Yellow-billed Cuckoo, Yellow-breasted Chat, Yellow Warbler, Common Yellowthroat, Black-headed Grosbeak, Song Sparrow, and Spotted Towhee (all scientific names are provided in Table 1). These species were selected because they: (1) use riparian vegetation as a principal breeding habitat in the Central Valley, (2) warrant special management

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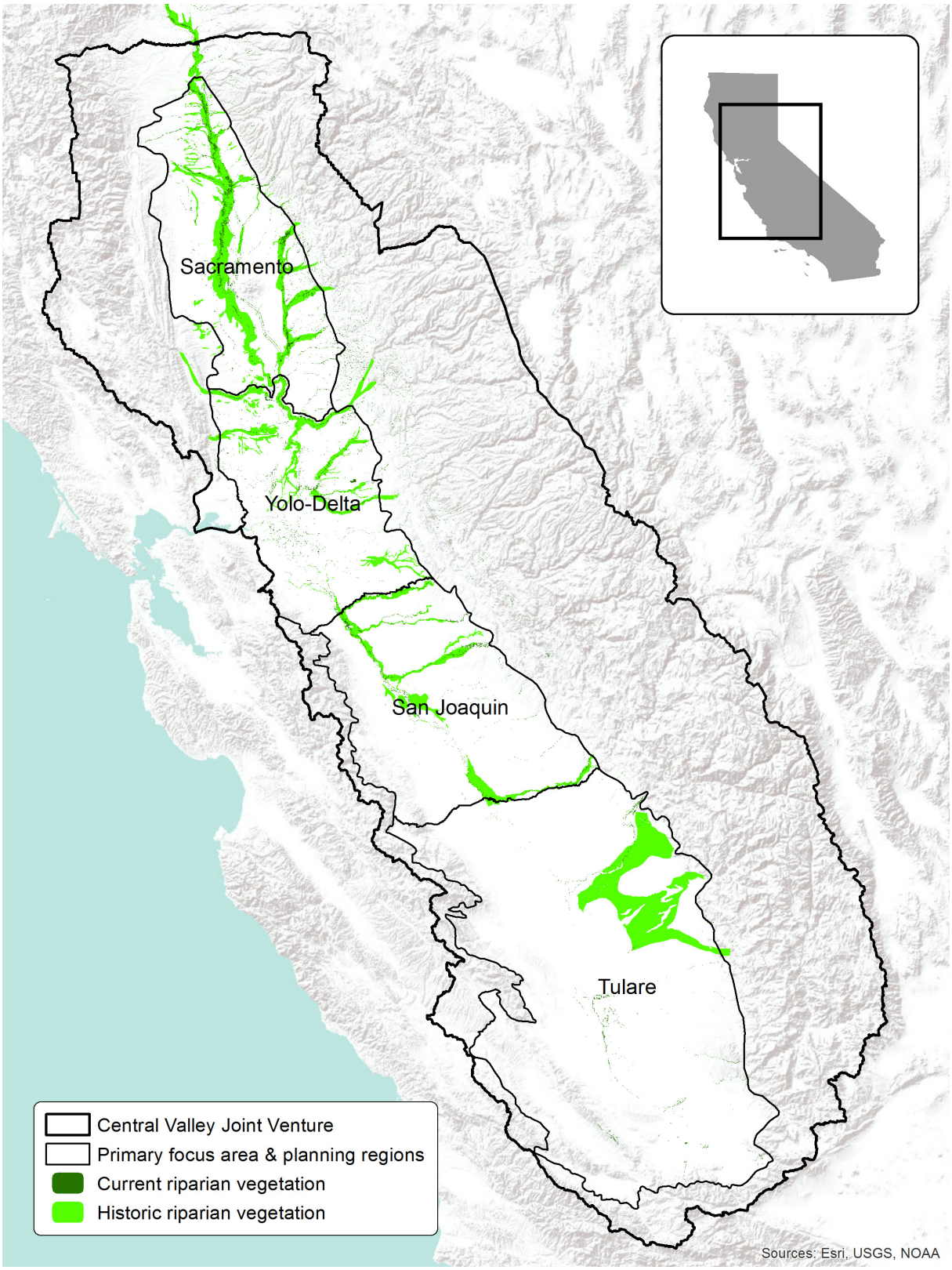

Figure 2 Central Valley Joint Venture perimeter and primary focus area, divided into four planning regions. Also shown are estimated areas of historical (pre-1900) and current riparian vegetation.

status or have experienced population declines or reductions in breeding range in the Central Valley, and/or (3) are useful for monitoring the effects of management actions in Central Valley riparian ecosystems, in part because they are common enough to provide sufficient sample sizes for analyses. These focal species also represent a range of life histories and vegetation associations (Table 1), providing information about different aspects of Central Valley riparian ecosystems.

To this original set of focal species, we added five species that extend the range of life histories and vegetation associations represented. These were: Nuttall's Woodpecker and Ash-throated Flycatcher, which are the only cavity nesters among the focal species, and which require relatively mature riparian forest; Bank Swallow, a California threatened species dependent on steep eroding river banks in which they establish colonies of nest burrows, and which require unrestrained rivers and streams that allow natural river processes, including meander migration; and two species associated with dense, shrubby, early- to mid-successional riparian vegetation: Lazuli Bunting, which has been declining in the Sacramento Valley (Gardali et al. 2006), and the federally and state endangered Least Bell's Vireo. Because birds are recognized as good indicators of ecosystem condition (Carignan and Villard 2002; Ortega–Álvarez and Lindig–Cisneros 2012), and because we deliberately

Table 1 Focal species conservation status, life history traits, and vegetation associations

Species common name (Latin name; 4-letter code)	Conservation status [a]	Migratory status	Nest substrate	Habitat and vegetation associations
Least Bell's Vireo [b] (*Vireo bellii pusillus*; LBVI)	FE, SE, CCV	Migrant	Shrub	Dense, shrubby early- to mid-successional riparian
Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*)	FT, SE, CCV	Migrant	Tree	Large contiguous patches of riparian forest, esp. cottonwood-willow
Bank Swallow [b] (*Riparia riparia*; BANS)	ST	Migrant	Burrow	Cut banks, dependent on meander migration, colonial breeder
Yellow-breasted Chat (*Icteria virens*; YBCH)	SSC	Migrant	Shrub	Dense, shrubby riparian thickets
Lazuli Bunting [b] (*Passerina amoena*; LAZB)		Migrant	Herb, shrub	Open scrubby and early-successional riparian, edges
Yellow Warbler (*Setophaga petechia*; YEWA)	SSC	Migrant	Shrub	Riparian thickets, esp. willows
Common Yellowthroat (*Geothlypis trichas*; COYE)		Migrant	Herb, shrub	Dense understory and ground cover, esp. near river edges and wetlands
Black-headed Grosbeak (*Pheucticus melanocephalus*; BHGR)		Migrant	Tree	Complex habitat with large trees and dense understory
Nuttall's Woodpecker [b] (*Picoides nuttallii*; NUWO)		Resident	Tree, 1° cavity	Mature riparian woodland
Ash-throated Flycatcher [b] (*Myiarchus cinerascens*; ATFL)		Migrant	Tree, 2° cavity	Mature, open riparian woodland
Song Sparrow (*Melospiza melodia*; SOSP)	SSC [c], CCV [c]	Resident	Herb, shrub	Dense understory
Spotted Towhee (*Pipilo maculatus*; SPTO)		Resident	Ground	Dense understory and ground cover

a. Conservation status designations include federally endangered or threatened species (FE, FT), state endangered or threatened species (SE, ST), state bird species of special concern (SSC), and species ranked among the most vulnerable to climate change (CCV; Gardali et al. 2012).
b. Additional focal species included since the 2006 implementation plan.
c. In the Central Valley, only the Suisun and Modesto subspecies are considered SSC or ranked as CCV.

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selected a suite of focal species with diverse riparian vegetation associations, we assumed that the state of these twelve focal species will collectively be a good indicator of the state of Central Valley riparian ecosystems.

Current Status

Riparian Vegetation

We estimated the current extent of riparian vegetation in each region of the Central Valley using four geographical information system (GIS) vegetation layers recently published in 2011 and 2014 from field data and aerial imagery collected in 2005, 2009, and 2012 (CDFW, unreferenced, see "Notes"), that together provided a relatively recent fine-scale vegetation map that covers much of the Central Valley primary focus area. From these, we created a single riparian vegetation layer, and we intersected this layer with the region boundary polygons to estimate the current total area of riparian vegetation in each region.

Species Densities, Population Sizes, and Trends

For most of the focal species, we estimated average breeding densities by analyzing recent breeding season (May–June) point count data, including:

1. Data collected in the Sacramento and San Joaquin regions along the main stems of the Sacramento and San Joaquin rivers (2012–2013; Point Blue Conservation Science, unreferenced, see "Notes"),
2. Data collected in the Yolo–Delta region along the Cosumnes (2010) and Mokelumne rivers (2008, 2010; Point Blue Conservation Science, unreferenced, see "Notes"),
3. Data collected in the Yolo–Delta region along Putah Creek (2011–2013; MWFB, unreferenced, see "Notes"), and
4. Data collected at other locations throughout the Yolo–Delta region (2010–2014; CDWR, unreferenced, see "Notes").

We are not aware of any comparable data from the Tulare region. To standardize across all of these data sources, our analysis included only birds detected within the first 5 minutes of each survey and within 100 m of the survey point.

Using our riparian vegetation layer, we evaluated the vegetation within 100 m of each point count station. We excluded points for which the surrounding vegetation was <10% riparian, and to further limit the influence of points with relatively little riparian vegetation, we weighted the survey effort at each of the remaining points by the percent of the surrounding vegetation that was riparian. Using the R packages "Distance" and "mrds" (Buckland et al. 2001; Laake et al. 2015; Miller 2015), we pooled all of the point count data to fit detection functions for each species and to estimate average species densities (individuals ha^{-1}) in each region. We then estimated regional population sizes by extrapolating regional density estimates across our estimate of the current total area of riparian vegetation in each region. We also evaluated long-term population trends by compiling trend estimates in the Coastal California Bird Conservation Region (BCR 32) from Breeding Bird Survey (BBS) data (Sauer et al. 2014).

We could not use this approach to estimate current population sizes or evaluate long-term population trends for Bank Swallow, Western Yellow-billed Cuckoo, or Least Bell's Vireo, which had few or no detections in either the point count or the BBS data. For Bank Swallow and Western Yellow-billed Cuckoo, we looked to population size and trend estimates from recent focused surveys (BANS–TAC 2013; Dettling et al. 2015; CDWR, unreferenced, see "Notes"). Least Bell's Vireo has been largely extirpated from the Central Valley and detections are rare (Howell et al. 2010), so we assumed that current population sizes in all Central Valley regions are near zero.

Central Valley Riparian Ecosystems

Because we used the focal species as indicators of the state of Central Valley riparian ecosystems, we evaluated the collective status (population size and trend) of all the focal species populations. In lieu of species- or population-specific information on the genetic diversity, population viability, and ecological function of each focal species, we applied a population status framework that is derived from general principles of conservation and population

biology (Dybala et al. 2017, this volume). The framework is structured as a hierarchy of four population size categories that mark milestones in the process of becoming a genetically robust, self-sustaining, and resilient wildlife population, and presents general hypotheses based on recent research for the orders of magnitude at which most vertebrate wildlife populations are expected to reach each population status (Table 2). In addition, two modifiers describe *steeply declining* populations, which are at high risk of extirpation regardless of population size, and *resilient* populations, which are more capable of recovering from an environmental catastrophe in one part of the range if they have more than one self-sustaining sub-population. Thus, although the birds in each of the Central Valley planning regions are not likely to be isolated biological populations, achieving the goal of *resilient* focal species populations requires the population status of each region to be evaluated independently. Therefore, we applied the framework to each regional focal species population, and we considered each focal species to be resilient in the Central Valley if it had at least two regional populations that were *viable* (> 10,000) or *large* (> 50,000; Table 2). We then evaluated all the populations within each region as an indicator of the state of riparian ecosystems in each region.

Conservation Objectives

Density Objectives

Because riparian habitat in the Central Valley is highly fragmented and degraded, we assumed that the current breeding densities (individuals ha^{-1}) of some of the focal species are likely to be lower than would be expected for high-quality riparian vegetation, and that habitat enhancement and restoration will increase these densities. Therefore, we examined Breeding Bird Census (BBC) data, a standardized spot-mapping effort used to estimate breeding densities (Gardali and Lowe 2006). We compiled density estimates from plots in riparian vegetation in the western U.S., 1988–2009. Because census plots are of unknown habitat quality with unknown history, we hypothesized that densities in high-quality riparian vegetation would be above the average of the BBC densities. Therefore, we set the density objective for each species as the 75th percentile of the observed BBC densities. However, in cases where a species' current density in one of the Central Valley regions already exceeded this objective, we raised the density objective for that region to be equal to maintaining the current density. For the Tulare region, for which no current density estimates were available, we set density objectives equal to objectives in the adjacent San Joaquin Valley region.

Table 2 Population status framework. Source: Dybala et al. (2017, this volume)

Population status	Description	Proposed thresholds
Very small	Expected to be well below minimum viable population size (MVP), and at increased risk of inbreeding depression in the short term.	< 1,000
Small	May be below MVP and vulnerable to extirpation through environmental and demographic stochasticity and long-term loss of genetic diversity.	< 10,000
Viable	Expected to meet or exceed MVP, reducing vulnerability to environmental and demographic stochasticity and preserving genetic diversity.	> 10,000
Large	Expected to be well above MVP, minimizing vulnerability to environmental and demographic stochasticity, preserving genetic diversity, and improving ability to maintain key ecological interactions and functions.	> 50,000
Additional modifiers		**Criteria**
Steeply declining	Increased risk of extinction or extirpation until the causes of the decline are addressed, no matter the population size.	> 30% decline in 10 years (observed or projected)
Resilient	Multiple viable or large populations to hedge against environmental catastrophes.	Viable populations (> 10,000) in more than one region

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We could not use this approach to set density objectives for Bank Swallow and Western Yellow-billed Cuckoo, which had no density estimates in the BBC data. Density objectives are less applicable to colonial nesting species such as Bank Swallow, which is expected to respond more to the availability of suitable nesting sites than to the addition of riparian vegetation area. For Western Yellow-billed Cuckoo, densities are difficult to estimate because of their secretive nature, weak territorial behavior, and small population size, and are, therefore, highly variable (Hughes 2015). We thus treated Bank Swallow and Western Yellow-billed Cuckoo separately (see "Special Status Species").

Long-Term Population and Habitat Objectives

To achieve the long-term goal of genetically robust and self-sustaining populations of each focal species, the long-term population objectives should include stable or increasing population trends and reach at least the population size threshold for *viable* populations (Table 2). However, populations should ideally be well above the minimum threshold for *viable* (Sanderson 2006), minimizing the consequences of short-term population declines and improving the ability to maintain key ecological interactions and functions. Further, achieving the long-term goal of *resilient* populations requires multiple *viable* or *large* populations, to guard against environmental catastrophes in any one region. Therefore, our approach was to set population objectives for multiple stable or increasing regional populations of each focal species that are at least *viable* and preferably *large*.

Because so much historical riparian vegetation has been lost (Katibah 1984), we assumed that many of the focal species populations are currently limited by the availability of suitable breeding habitat. To examine whether *viable* or *large* population objectives are reasonable for regions of this size, we first examined whether each region had the historical capacity to support *large* populations. As an estimate of historical capacity, we compiled the results of three recent historical vegetation mapping efforts to estimate the historical extent of riparian vegetation in each of the regions (TBI 1998; GIC 2003; Whipple et al. 2012). Assuming focal species would historically have had densities similar to the density objectives, we estimated the number of the focal species which would historically have had *large* populations in each region. Because some of this historical capacity may have been permanently lost as a result of urbanization, we also estimated whether each region still has the potential capacity to support *large* populations. We overlaid the historical extent of riparian vegetation with the projected extent of urban areas by the year 2050 (Landis and Reilly 2003) and subtracted any historical riparian vegetation mapped within the projected urban area. Again, assuming focal species will achieve the density objectives, we estimated the number of the focal species which could still potentially reach *large* populations in each region.

Excluding Bank Swallow and Western Yellow-billed Cuckoo (treated separately in "Special Status Species" below), our next step was to set specific regional population objectives for each of the 10 other focal species. After examining several alternative approaches, we set regional population objectives that would minimize the additional habitat required to meet three criteria: (1) all regional populations at least reach the threshold for *viable*, (2) most focal species (7 out of 10) reach the threshold for *large* in each region, and (3) each focal species has at least one *large* regional population. We achieved this by first calculating the minimum area of riparian restoration that would be required to meet Criterion 2 in each region, assuming each species reached their regional density objectives. Where necessary, we added any additional area required to meet Criterion 1. For any remaining species that still did not meet Criterion 3, we determined which region would require the least additional area to reach the threshold for a *large* population.

Special Status Species

Most of the focal species do not have a special legal status, but, for the three species that do, we examined existing conservation strategies and recovery plans to identify existing population and habitat objectives tailored to those species. For example, Bank Swallow is a California threatened species with an existing conservation strategy tailored to its colonial nesting habits, for which simple density and habitat area

objectives are not applicable. Therefore, we adopted the objectives set out in this plan for the Sacramento region (BANS–TAC 2013). Except for a few juvenile specimens collected in the San Joaquin Valley, there is little evidence that Bank Swallow colonies historically existed in the Yolo–Delta, San Joaquin, or Tulare regions (Laymon et al. 1987). Thus, we did not set Bank Swallow population objectives for these regions.

The recovery plan for Least Bell's Vireo, a federal and state endangered species currently extirpated from the Central Valley, does not provide specific population objectives (USFWS 1998). However, we were able to estimate density objectives for this species using BBC data, which were comparable to the other focal species, suggesting that similar habitat acreages will work for this species once populations are established. Therefore, we included Least Bell's Vireo in the population and habitat objective-setting process described above, treating it like the other focal species that have no special status.

Western Yellow-billed Cuckoo is a California endangered species and was recently designated as a federal threatened species, but no recovery plan yet exists. We assume future recovery plans will include the results of detailed analyses tailored to this species, but, until then, we propose a preliminary population objective of *viable* (10,000) for all four regions. Because density objectives for Yellow-billed Cuckoo are highly variable and difficult to estimate (Hughes 2015), we used the habitat objectives set by the other focal species to estimate the average Cuckoo densities that would be required to achieve a population status of *viable* in each region.

Short-Term Objectives

Short-term objectives provide a milestone against which progress toward achieving the long-term objectives can be measured. We assumed a 10-year period for the short-term objectives, and, within this period, we assumed we would need to achieve 1/10th of the long-term habitat and density objectives to stay on track toward the long-term objective.

RESULTS

Current Status

We estimated a current total of 57,307 ha (141,608 ac) of riparian vegetation in the CVJV primary focus

Table 3 Regional riparian vegetation (A) estimates and (B) objectives. Estimates of potential riparian vegetation reflect the historical extent minus projected losses to urbanization by 2050.

(**A**) Riparian vegetation estimates, ha (ac)

Region	Current	Historical (pre-1900)	Potential
Sacramento	27,477	172,492	170,129
Yolo–Delta	13,302	95,914	78,962
San Joaquin	10,096	80,167	71,310
Tulare	6,432	163,540	125,339
Total	57,307 (141,608)	512,112 (1,265,454)	445,740 (1,101,446)

(**B**) Riparian vegetation objectives, ha (ac)

Region	Long-term riparian objective (100-year)	Estimated restoration needed (100-year)	Short-term restoration objective (10-year)
Sacramento	61,379	33,902	3,390
Yolo–Delta	37,201	23,899	2,390
San Joaquin	43,960	33,863	3,386
Tulare	43,960	37,528	3,753
Total	186,499 (460,848)	129,192 (319,240)	12,919 (31,923)

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Table 4 Current estimates of (A) regional breeding population densities [a] and (B) regional breeding population sizes of riparian landbird focal species, shown with 95% confidence intervals.

Focal species	Sacramento		Yolo–Delta		San Joaquin		Tulare [b]	
(**A**) Density (individuals ha^{-1})								
YBCH	0.108	(0.055–0.211)	0.037	(0.015–0.091)	0.025	(0.009–0.071)		
LAZB	0.441	(0.296–0.657)	0.067	(0.036–0.125)	0.052	(0.024–0.112)		
YEWA	0.037	(0.010–0.131)	0.569	(0.378–0.856)	0.557	(0.331–0.938)		
COYE	0.223	(0.135–0.367)	0.342	(0.238–0.492)	0.482	(0.318–0.730)		
BHGR	2.177	(1.844–2.569)	0.805	(0.627–1.035)	0.655	(0.509–0.842)		
NUWO	0.677	(0.544–0.842)	1.344	(1.100–1.643)	0.519	(0.406–0.663)		
ATFL	1.231	(1.050–1.444)	2.139	(1.764–2.594)	1.137	(0.934–1.385)		
SOSP	0.006	(0.001–0.034)	3.334	(2.648–4.199)	4.337	(3.507–5.363)		
SPTO	5.274	(4.653–5.978)	5.353	(4.560–6.285)	5.768	(4.975–6.687)		
(**B**) Population size (thousands)								
LBVI	~0		~0		~0		~0	
YBCU	<0.10		~0		~0		~0	
BANS	17.32	(10.95–21.82)[c]	~0		~0		~0	
YBCH	2.96	(1.52–5.79)	0.50	(0.21–1.21)	0.26	(0.09–0.72)	0.16	(0.06–0.46)
LAZB	12.12	(8.14–18.04)	0.89	(0.48–1.66)	0.53	(0.25–1.13)	0.34	(0.16–0.72)
YEWA	1.01	(0.28–3.60)	7.57	(5.03–11.38)	5.62	(3.34–9.47)	3.58	(2.13–6.03)
COYE	6.12	(3.72–10.08)	4.55	(3.16–6.55)	4.87	(3.22–7.37)	3.10	(2.05–4.69)
BHGR	59.81	(50.67–70.58)	10.71	(8.33–13.77)	6.61	(5.14–8.50)	4.21	(3.28–5.42)
NUWO	18.6	(14.96–23.14)	17.88	(14.63–21.85)	5.24	(4.10–6.69)	3.34	(2.61–4.26)
ATFL	33.83	(28.84–39.68)	28.45	(23.46–34.51)	11.48	(9.43–13.98)	7.32	(6.01–8.91)
SOSP	0.18	(0.03–0.93)	44.35	(35.22–55.85)	43.79	(35.41–54.15)	27.89	(22.55–34.49)
SPTO	144.92	(127.86–164.25)	71.21	(60.66–83.59)	58.24	(50.23–67.52)	37.10	(32.00–43.01)

a. Densities could not be estimated from point count data for Western Yellow-billed Cuckoo, Bank Swallow, and Least Bell's Vireo as a result of few or no detections.
b. No recent data were available for the Tulare region; Tulare population size estimates are based on San Joaquin density estimates.
c. The Bank Swallow population size estimate for the Sacramento region is based on a 50% occupancy rate of burrows counted on the Sacramento and Feather rivers in 2012, while the range given is based on the range of observed burrow occupancy rates (31.6%–63%; BANS–TAC 2013).

area, which is unevenly distributed among the four planning regions (Figure 2; Table 3). Nearly half (48%) lies within the Sacramento region; the Tulare region has just 11%. Extrapolating these vegetation totals across current average density estimates for all but the special status species (Table 4A), breeding population size estimates ranged from just 160 individuals (95% CI: 60–460) for Yellow-breasted Chat in the Tulare region to 144,920 individuals (95% CI: 127,860–164,250) for Spotted Towhee in the Sacramento region (Table 4B). Among the BBS trend estimates for the BCR 32, we detected a significant long-term increase for Common Yellowthroat, and significant long-term declines for Yellow-breasted Chat and Black-headed Grosbeak (Appendix A). However, the rates of decline estimated were relatively slow (< 12% over 10 years) and did not meet the criteria for *steeply declining* status.

Long-term surveys of Bank Swallow nest burrows along the Sacramento River (1986–2014) have documented two periods of steep decline. Beginning

with an estimated population size in 1986 of 25,192, the population declined through 1998 at an average rate equivalent to 75.2% over 10 years (BANS–TAC 2013). The population rebounded until 2001, after which the population again declined at an average rate equivalent to 30.7% over 10 years, to an estimated 12,810 in 2014 (BANS–TAC 2013; CDWR, unreferenced, see "Notes"). For Western Yellow-billed Cuckoo, intensive surveys conducted along the Sacramento and Feather rivers in 2012–13 estimated fewer than 30 pairs, down from an estimated 29 to 60 pairs in 1977 and 120 pairs in 1972 (Dettling et al. 2015). Because of the uncertainty in estimates of population size and the long-term trends, we assumed the current population size in this region is < 100 and *steeply declining*. Both Bank Swallow and Western Yellow-billed Cuckoo are rare outside the Sacramento region, and we assumed that breeding population sizes in all other regions are near zero.

Fitting the population size and trend estimates into the population status framework, we estimate that only four regional populations are currently *large* (> 50,000 individuals), while over half of the regional populations are currently *small* or *very small* (Figure 3A). Because we expect the status of the focal species populations to reflect the status of regional riparian ecosystems, we expect riparian ecosystems in the Sacramento and Yolo–Delta regions to be in fair condition, with 45% to 50% of the regional populations having *viable* or *large* status. In comparison, we estimated that the San Joaquin region had 27% and the Tulare region had only 18%

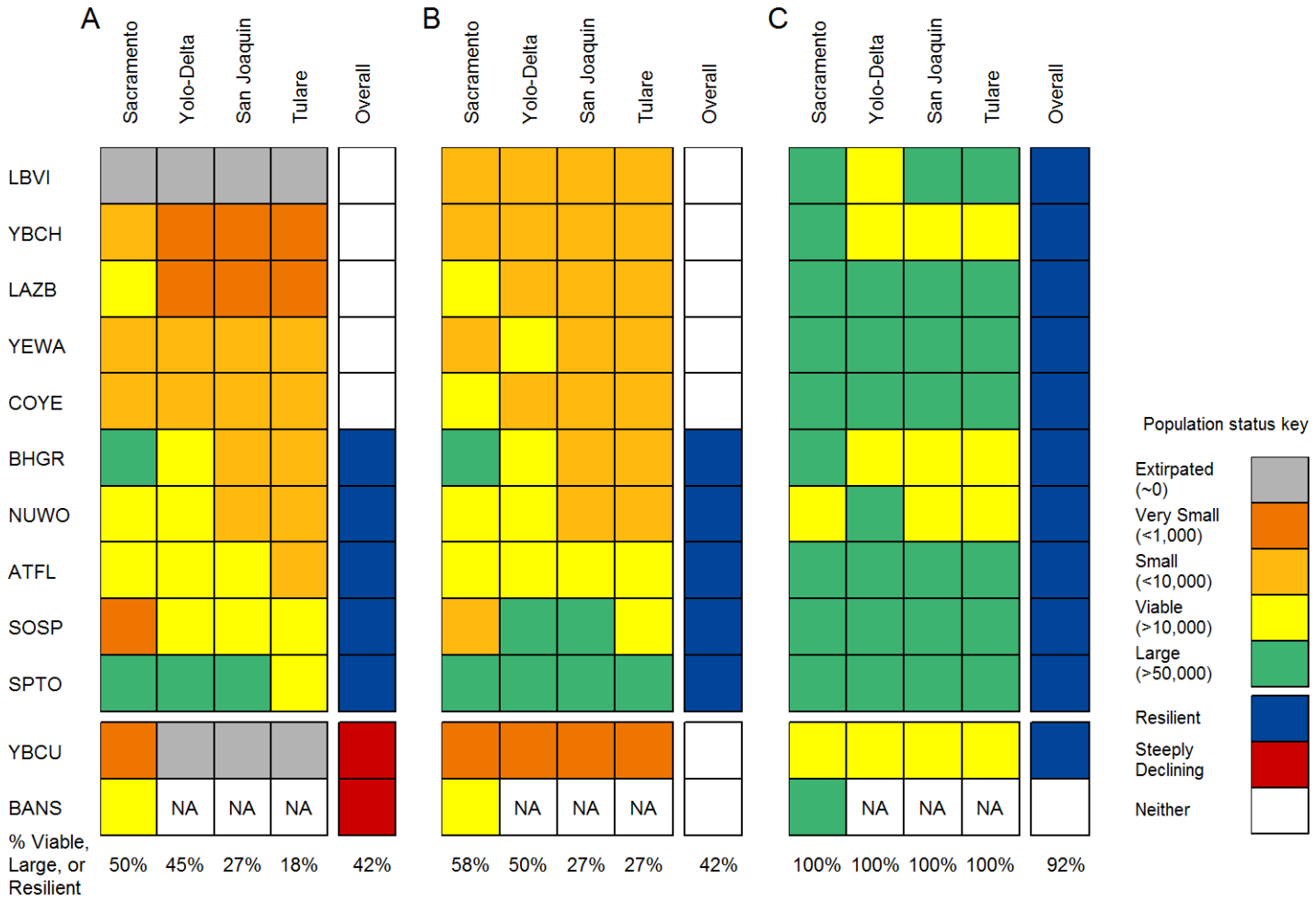

Figure 3 Evaluation of each regional focal species population for (**A**) current population status; (**B**) projected population status if short-term (10-year) habitat and density objectives are achieved; and (**C**) long-term (100-year) population objectives.

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viable or *large* focal species populations. Considering the Central Valley as a whole, 42% of the 12 focal species are currently considered *resilient*, with *viable* or *large* populations in more than one region, and both Bank Swallow and Western Yellow-billed Cuckoo are *steeply declining*.

Conservation Objectives

Density Objectives

We expected that current densities for some species in the Central Valley would be unusually low, as a result of habitat fragmentation and degradation. Density estimates compiled from the BBC data indicated that this was the case for many of the focal species (Appendix A). For example, Yellow-breasted Chat densities in all Central Valley regions were less than the 25th percentile of density estimates in the BBC data (Figure 4). In contrast, other focal species densities exceeded BBC density estimates in all regions of the Central Valley (e.g., Spotted Towhee) or some regions (e.g., Black-headed Grosbeak). Because we set density objectives equal to the higher of the 75th percentile of the BBC density estimates or the current regional density estimate, density objectives for some focal species varied by region (Table 5A).

Long-Term Population and Habitat Objectives

Using reconstructed historical vegetation layers (Figure 2), we estimated a total of 512,112 ha (1,265,454 ac) of historical riparian vegetation in the CVJV primary focus area, of which 445,740 ha (1,101,446 ac) remained potential riparian vegetation after projected losses to urbanization (Table 3) were considered. If focal species historically occurred at densities similar to the density objectives, we found that all four regions of the Central Valley had the historical capacity to support *large* populations, and still retain the potential capacity to support *large* population of most of the focal species (Appendix B). Thus, these results suggest that *large* population objectives are reasonable for management areas of this spatial scale.

The long-term population objectives are designed to ensure that each region will support *large* populations of most focal species (7 of 10), while each species has

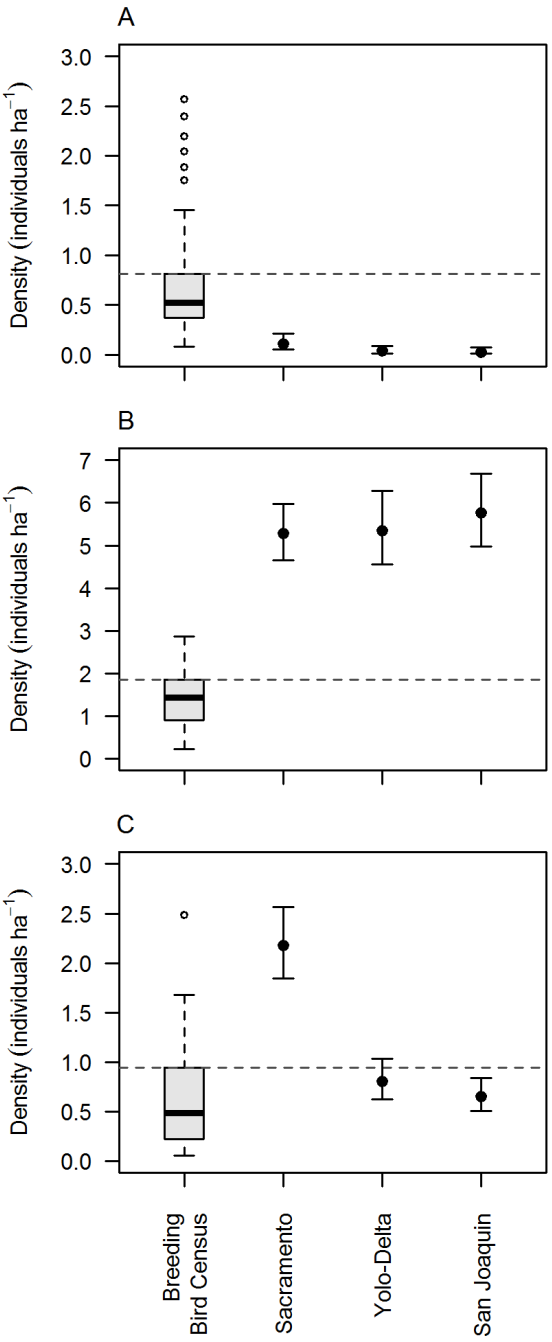

Figure 4 Comparison of Breeding Bird Census (BBC) and current Central Valley regional average density estimates for three example species: (**A**) Yellow-breasted Chat, (**B**) Spotted Towhee, and (**C**) Black-headed Grosbeak. Also shown are the 75th percentiles of the BBC densities (horizontal dashed line), which were adopted as the regional density objectives unless the current regional density estimate was already higher (see text).

Table 5 Regional species density objectives (individuals ha^{-1}). (A) long-term (100-year) objectives and (B) short-term (10-year) objectives

Focal species	Sacramento	Yolo–Delta	San Joaquin	Tulare [c]
(A) Long-term objectives				
LBVI	1.228	1.228	1.228	1.228
YBCU [d]	0.163	0.269	0.227	0.227
YBCH	0.815	0.815	0.815	0.815
LAZB	1.509	1.509	1.509	1.509
YEWA	1.376	1.376	1.376	1.376
COYE	1.497	1.497	1.497	1.497
BHGR	2.177 [b]	0.945	0.945	0.945
NUWO	0.677 [b]	1.344 [b]	0.562	0.562
ATFL	1.231 [b]	2.139 [b]	1.137 [b]	1.137 [b]
SOSP	2.997	3.334 [b]	4.337 [b]	4.337 [b]
SPTO	5.274 [b]	5.353 [b]	5.768 [b]	5.768 [b]
(B) Short-term objectives				
LBVI	0.123	0.123	0.123	0.123
YBCU [d]	0.016	0.027	0.023	0.023
YBCH	0.178	0.115	0.104	0.104
LAZB	0.548	0.211	0.198	0.198
YEWA	0.171	0.650	0.639	0.639
COYE	0.350	0.458	0.584	0.584
BHGR	2.177 [b]	0.819	0.684	0.684
NUWO	0.677 [b]	1.344 [b]	0.523	0.523
ATFL	1.231 [b]	2.139 [b]	1.137 [b]	1.137 [b]
SOSP	0.306	3.334 [b]	4.337 [b]	4.337 [b]
SPTO	5.274 [b]	5.353 [b]	5.768 [b]	5.768 [b]

a. Note: No density objectives were set for the Bank Swallow.
b. Current regional density estimate that is higher than the 75th percentile of density estimates in the Breeding Bird Census data, so that the objective is to maintain current densities.
c. Density objectives for the Tulare region were set equal to objectives for the adjacent San Joaquin region.
d. Density objectives for Western Yellow-billed Cuckoo were set using a different process than all other focal species, based on the average densities required to achieve a viable population size once the habitat objectives are achieved (see text).

at least one *large* regional population (Figure 3C). Because density objectives varied regionally (Table 5A), the minimum area of riparian vegetation required to reach *large* populations for most species in each region generally would also allow each species to have at least one *large* regional population (Figure 5). However, because Yellow-breasted Chat had very low density objectives in all regions, additional riparian vegetation was required to ensure it had at least one *large* regional population. Because the Sacramento region currently has the most riparian vegetation of any planning region (Table 3), it would require the least additional riparian vegetation to achieve a *large* Chat population. Therefore, we increased the habitat objective in the Sacramento region to meet this requirement.

The final long-term (100-year) habitat objectives required to meet the population objectives in each region total 186,499 ha (460,848 ac) of riparian

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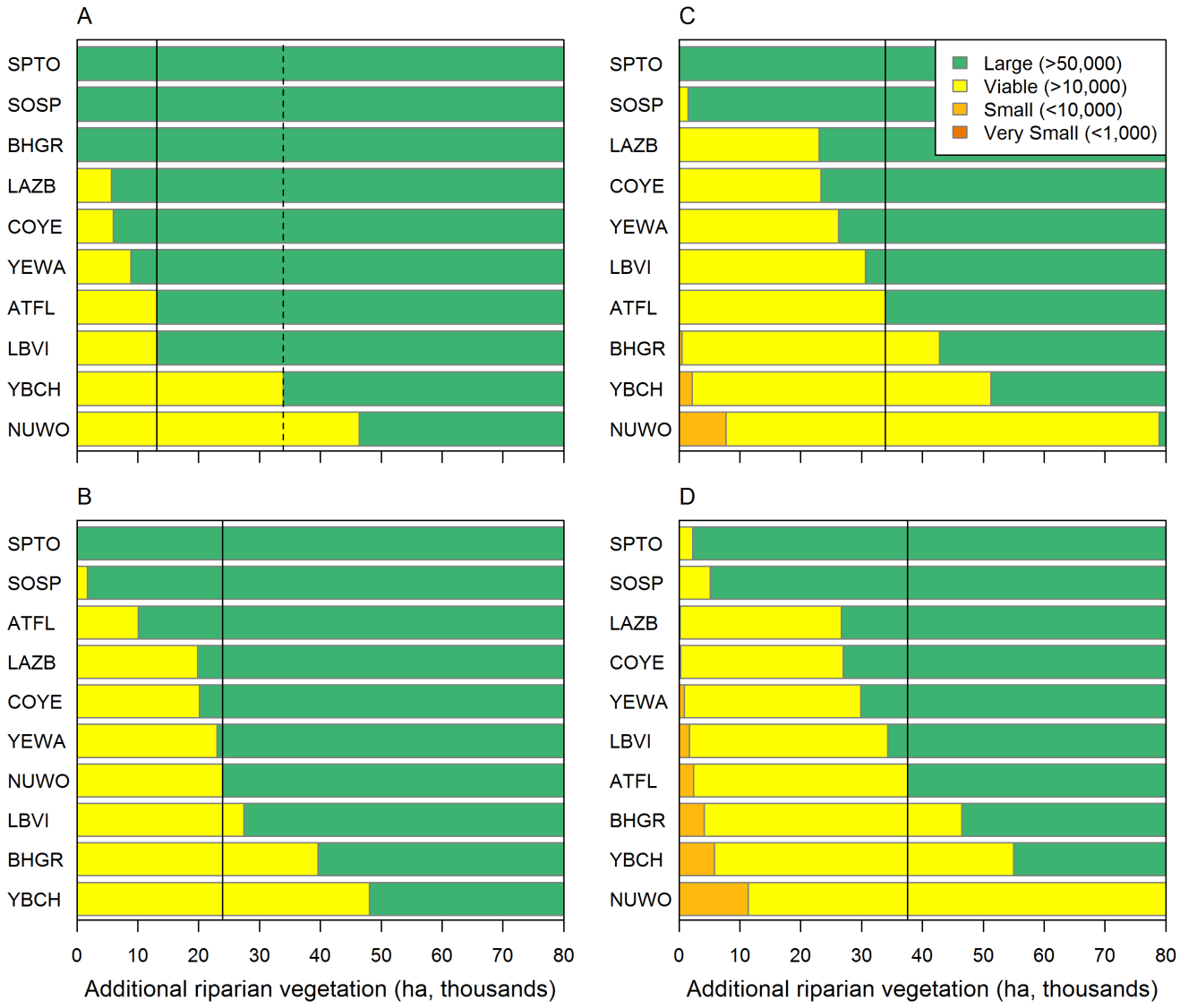

Figure 5 Projected changes in regional focal species population status as additional riparian vegetation is restored (ha, thousands), assuming density objectives are achieved and existing riparian vegetation is not lost: (**A**) Sacramento, (**B**) Yolo–Delta, (**C**) San Joaquin, and (**D**) Tulare planning regions. The solid vertical lines indicate the minimum additional area required to achieve large populations for most focal species (7 out of 10) in each region. The dashed vertical line in the Sacramento region indicates the further addition required to achieve one large regional population for Yellow-breasted Chat. Note: Species are sorted from highest to lowest density objectives, which vary by region.

vegetation, ranging from 37,201 to 61,379 ha (91,926 to 151,671 ac) by region (Table 3). These objectives are considerably higher than the extent of riparian vegetation that currently exists in each region, suggesting that substantial riparian restoration is needed in all regions, but they are also much lower than the estimated extent of historical riparian vegetation in the Central Valley. When the long-term density and habitat objectives are achieved, we expect that the number of focal species considered *resilient*, with *viable* or *large* populations in more than one region, will increase from 5 to 11 (Figure 3C).

Special Status Species

As discussed above, we used the objectives set out in the existing conservation strategy for Bank Swallow, which included a population objective of 50,000 (equivalent to *large*) for the Sacramento Valley (BANS–TAC 2013). Because Bank Swallow depend on suitable nesting sites in cut banks created by river flows, the long-term habitat objectives include:

1. removal of 56 miles of river bank revetment to promote meander migration and the formation of new cut-bank breeding habitat,
2. using set back levees and conservation easements to increase the meander belt by 12,000 ac, and
3. modifying flow regimes that allow river processes to maintain and improve Bank Swallow nesting habitat without inundating streamside burrows during the breeding season.

For Western Yellow-billed Cuckoo, we set a preliminary population objective of reaching the threshold for *viable* (> 10,000) in all four regions of the Central Valley. To reach these population sizes when the long-term riparian habitat objectives for these regions has been achieved would require average densities of approximately 0.16 individuals ha^{-1} in the Sacramento region, 0.27 individuals ha^{-1} in the Yolo–Delta region, and 0.22 individuals ha^{-1} in the San Joaquin and Tulare regions (Table 5B). These densities are well within the range of observed densities, which can exceed 1 individual ha^{-1} (Hughes 2015). However, this species requires large, contiguous patches of riparian habitat adjacent to water, exceeding 5 to 15 ha in area and 100 m in width (Gaines 1974; Dettling et al. 2015). Thus, population densities in the subset of riparian patches that are large enough to be suitable for Yellow-billed Cuckoos will likely need to be higher than this average estimate.

Short-Term Objectives

As a milestone for achieving the long-term objectives within a 100-year time frame, we set short-term (10-year) objectives for each region equal to one-tenth of the improvement required to reach the long-term population, density, and habitat objectives. For example, the short-term density objectives are equal to one-tenth of the difference between the current density and the long-term density objective (Table 5B). Assuming no currently existing riparian vegetation is lost, the short-term riparian restoration objectives total 12,919 ha (31,923 ac), ranging from 2,390 to 3,753 ha (5,906 to 9,274 ac) by region (Table 3). When the short-term density and habitat objectives are achieved, we aim for a reduction in the number of *steeply declining* populations from two to 0, the transition of six *very small* regional populations to *small*, three *small* populations to *viable*, and three *viable* populations to *large* (Figure 3B).

DISCUSSION

Birds have been used in many landscapes as indicators of ecosystem condition. Here, we have built upon the CVJV's approach of using a set of focal species that use riparian ecosystems in different ways, which we expect will collectively reflect the condition of Central Valley riparian ecosystems and the broader landscape. We expanded the original set of focal species to better reflect a wide range of ecosystem attributes, and we used a transparent, science-based process to develop population, density, and habitat objectives to meet the long-term goal of genetically robust, self-sustaining, and resilient focal species populations (Figure 1). Protecting, restoring, and managing Central Valley riparian ecosystems to support this set of focal species will provide high-quality habitat for other animals and plants that together will contribute in many ways to the prosperity and quality of life in the Central Valley. These benefits include reducing flood risk, improving water quality, and recharging groundwater (Naiman et al. 2010), supporting pollinators and organisms that help control agricultural pests (Kremen et al. 2002; Buddle et al. 2004), as well as increasing property values, providing recreational opportunities, and attracting wildlife watchers who help support local economies (Carver 2013; Carver and Caudill 2013; Liu et al. 2013).

Measuring Success

We expect that restoring high-quality riparian vegetation, particularly when strategically located to reduce fragmentation, will result in an improvement

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in species densities, and in turn help achieve the population objectives. Consequently, the contribution of individual riparian restoration projects to achieving the long-term (100-year) population objectives can be estimated in terms of progress toward the habitat objectives, the density objectives, or both. The area of restored riparian vegetation contributes directly toward the short- and long-term habitat objectives, and, when combined with current density estimates, its contribution toward the population objectives can be estimated as the additional number of birds that may be supported by the new area. Local bird surveys would allow the direct estimation of local species densities to evaluate the success of an individual restoration project against the density objectives and to estimate the project's actual contribution toward the population objectives (Figure 1A).

A complementary approach to riparian vegetation restoration is to enhance existing riparian vegetation, such as through invasive species removal, or to enhance riparian ecosystem processes, such as mimicking natural river flows and allowing meander migration. This approach may be particularly important to achieving the density and population objectives of focal species populations that are currently extirpated, *very small*, or *steeply declining* (Figure 3A). For example, the primary cause of the decline in the Bank Swallow population is hypothesized to be the unmitigated loss of nesting habitat, including regulated river flows that destroy existing nests, and the addition since 1970 of 42 miles of rock revetment placed on the Sacramento River and 12 miles on the Feather River that limits the creation of new nests (BANS–TAC 2013). Thus, stabilizing the Bank Swallow population likely requires prioritizing the removal of river bank revetment and promoting meander migration of rivers, as outlined in the existing conservation strategy (BANS–TAC 2013) and summarized above.

Similarly, Least Bell's Vireo, Yellow-breasted Chat, and Lazuli Bunting are all associated with scrubby, early- to mid-successional riparian vegetation (Table 1). Lack of disturbance to riparian vegetation, such as through flooding, likely contributes to a relatively low percentage of riparian scrub in the Central Valley, and thus the low densities and *very small* populations of these species. Further, promoting natural river processes may improve the conditions for further riparian restoration and management, such as through sediment deposition, groundwater recharge, and seed dispersal (Florsheim and Mount 2003; Opperman 2012), ultimately benefitting all riparian species. For these kinds of riparian enhancement projects, local bird surveys would allow the change in local species densities or the establishment of new breeding colonies to be documented, and thus the contribution of these projects toward achieving the population objectives to be estimated.

Measuring success will also require continued monitoring of the riparian breeding bird community and the extent of riparian vegetation throughout each region, to estimate changes in average densities and total population size (Figure 1C). A standardized bird survey effort at randomized locations throughout each region would provide a robust estimate of regional average species densities and how they change over time. Paired with efforts to track riparian restoration projects and map the extent of riparian vegetation in each region, changes in total population size and status—and thus changes in the condition of regional riparian ecosystems—can be monitored.

Research Needs

We assumed that many current species densities would be lower than normal as a result of the extensive fragmentation and degradation of riparian vegetation, and the density objectives (Table 5B) represent hypotheses for densities that can be achieved in the Central Valley. However, these hypotheses will need to be tested by monitoring changes in average species densities as riparian restoration and enhancement continues (Figure 1B). For example, we expect most species densities to increase in response to these efforts, but it is possible that some focal species currently with relatively high densities (e.g., Spotted Towhee) may be benefitting from marginal riparian vegetation, such that their densities are actually above normal. Thus, these densities may actually decline with riparian restoration. Ultimately, if the density objectives prove to be too low for many species, such that species are already achieving higher densities than expected,

achieving the long-term population objectives may not require as much additional riparian vegetation, thus allowing the habitat objectives to be revised downward. On the other hand, if these density objectives prove to be unreasonably high for some species, the habitat objectives may need to be revised upward.

In addition, we set the long-term population objectives for each region, rather than for the Central Valley as a whole, in part because the long-term goal was to achieve *resilient* populations with *viable* or *large* sub-populations in each region, and in part because we estimated that each region still has the potential capacity to support *large* populations (Appendix B). However, our estimation of potential capacity includes only the projected urban expansion, and does not include potential effects on riparian ecosystems and hydrology that result from climate change or other projected changes in each region. For example, some projected changes to precipitation and groundwater storage suggest that the Tulare region may become much more water-limited (CDWR 2013), possibly limiting the potential capacity of the Tulare region to support riparian vegetation. Continued monitoring of riparian ecosystems in each region, and projecting future changes will be important in determining whether the potential capacity of any region has changed, and whether the population objectives should therefore be revised (Figure 1D).

The long-term population objectives are based on general hypotheses for the orders of magnitude required to achieve genetically robust, self-sustaining, and resilient populations (Dybala et al. 2017, this volume; Table 2). They are based on principles of conservation biology and are derived from the best available data, but may require revision if new species- or population-specific information becomes available (Figure 1E). For example, new population viability analyses could indicate that smaller population sizes can be considered *viable*, or new information about important ecological functions could indicate the minimum population size that should be considered *large*. Finally, achieving these population objectives is never a guarantee of species persistence. It will be important to continue to monitor riparian bird populations, test our assumptions, reduce uncertainties, and revise our estimates of what is required to achieve genetically robust, self-sustaining, and resilient populations.

CONCLUSIONS

Riparian ecosystems in the Central Valley have lost a large percentage of their historical vegetation, and currently support mostly *small* and *very small* populations of riparian breeding birds, including two populations that are *steeply declining*. However, Central Valley riparian ecosystems still have the potential to support genetically robust, self-sustaining, and resilient populations of riparian-dependent species. By working toward achieving these population, density, and habitat objectives through threat abatement, habitat restoration, and habitat enhancement, we expect riparian ecosystem function and resilience to improve, benefitting, in turn, other wildlife populations and the people of the Central Valley and beyond.

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