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The Central Valley of California provides important breeding habitat to numerous species of wetland-dependent birds, despite the loss of over 90% of naturally occurring wetlands. A majority

of shorebirds breeding in this region rely on shallow-flooded habitat adjacent to sparsely vegetated uplands as provided by rice (*Oryza sativa*), managed wetlands, and other habitats. We estimated the current extent of potential breeding shorebird habitat provided by rice and managed permanent and semi-permanent wetlands in each of four major planning regions of the Central Valley, and estimated the average breeding densities and current population sizes of two species of shorebirds: the Black-Necked Stilt (*Himantopus mexicanus*) and American Avocet (*Recurvirostra americana*). Using a population status framework based on principles of conservation biology, we estimated that stilt populations are small (<10,000 individuals) or very small (<1,000 individuals) in three of the four planning regions, and avocet populations are *small* or very small in all four planning regions. We then used the framework to define long-term (100-year) population objectives for stilts, avocets, and a third species, Killdeer (*Charadrius vociferous*), designed to meet our long-term conservation goal of supporting self-sustaining, genetically robust, and resilient populations of breeding shorebirds in the Central Valley. We also estimated the long-term species' density and wetland habitat objectives necessary to achieve the population objectives for all three species. The corresponding short-term (10-year) conservation objectives are to restore semi-permanent wetlands to provide an additional 11,537 ha (28,508 ac) of habitat for breeding shorebirds (by planning region: 2,842 ha in Sacramento, 2,897 ha in Yolo–Delta, 2,943 ha in San Joaquin, and 2,855 ha in Tulare), and to enhance existing habitat to support density objectives. Our approach provides a transparent, repeatable process for defining science-based conservation objectives for breeding shorebirds and their habitats in the Central Valley, which can help unite stakeholders around common goals and motivate conservation actions.

Copyright Information:

RESEARCH

Population and Habitat Objectives for Breeding Shorebirds in California's Central Valley

Khara M. Strum*[,1], Kristen E. Dybala[2], Monica N. Iglecia[3], and W. David Shuford[2]

ABSTRACT

The Central Valley of California provides important breeding habitat to numerous species of wetland-dependent birds, despite the loss of over 90% of naturally occurring wetlands. A majority of shorebirds breeding in this region rely on shallow-flooded habitat adjacent to sparsely vegetated uplands as provided by rice (*Oryza sativa*), managed wetlands, and other habitats. We estimated the current extent of potential breeding shorebird habitat provided by rice and managed permanent and semi-permanent wetlands in each of four major planning regions of the Central Valley, and estimated the average breeding densities and current population sizes of two species of shorebirds: the Black-necked Stilt (*Himantopus mexicanus*) and American Avocet (*Recurvirostra americana*). Using a population status framework based on principles of conservation biology, we estimated that stilt populations are small (<10,000 individuals) or very small (<1,000 individuals) in three of the four planning regions, and avocet populations are small or very small in all four planning regions. We then used the framework to define long-term (100-year) population objectives for stilts, avocets, and a third species, Killdeer (*Charadrius vociferous*), designed to meet our long-term conservation goal of supporting self-sustaining, genetically robust, and resilient populations of breeding shorebirds in the Central Valley. We also estimated the long-term density objectives and wetland habitat objectives necessary to achieve the population objectives for all three species. The corresponding short-term (10-year) conservation objectives are to restore permanent and semi-permanent wetlands to provide an additional 11,537 ha (28,508 ac) of habitat for breeding shorebirds (by planning region: 2,842 ha in Sacramento, 2,897 ha in Yolo–Delta, 2,943 ha in San Joaquin, and 2,855 ha in Tulare), and to enhance existing habitat to support density objectives. Our approach provides a transparent, repeatable process for defining science-based conservation objectives for breeding shorebirds and their habitats in the Central Valley, which can help unite stakeholders around common goals and motivate conservation actions.

KEY WORDS

Breeding shorebirds, Central Valley, population objective, habitat objective, population estimate, stilt, avocet, killdeer

INTRODUCTION

The Central Valley's climate and soils make it one of the most fertile agricultural regions in the world, and it provides over one-third of the vegetables produced in the United States (NASS 2016). It is also home to nearly 6.5 million people. Historically, the Central Valley included an estimated one million ha (2.4 million ac) of lacustrine wetlands that flooded annually and contained one of the largest extents of naturally occurring, year-round, and freshwater flooded habitat west of the Great Lakes (Garone 2006). Today, the Central Valley has lost over 90% of this habitat to agriculture, channelization, and urban development (Frayer et al. 1989), and flooded habitat is now largely provided by irrigated agriculture and managed wetlands.

Although renowned for the impressive numbers of waterfowl and shorebirds that use the region in winter and during migration, the Central Valley also provides breeding habitat for seven species of shorebirds (Hickey et al. 2003), including the American Avocet (*Recurvirostra americana*), Black-necked Stilt (*Himantopus mexicanus*) and Killdeer (*Charadrius vociferous*). The Central Valley currently supports nearly 24% and 17% of the national population of breeding American Avocets and Black-necked Stilts, respectively (Shuford et al. 2007; USSCPP 2015). Given the changes to the extent, spatial distribution and types of available habitat, current populations of breeding shorebirds are likely smaller than they were historically (Page and Gill 1994). Further, the most recent compilation of population trends and status for shorebirds in the United States listed the American Avocet as vulnerable to climate change, and the Killdeer as a common species in decline (USSCPP 2015). Thus, there is a need to protect and restore flooded habitat in the Central Valley during the shorebird breeding season.

The Central Valley Joint Venture (CVJV) — a coalition of 20 state and federal agencies, private conservation organizations and one corporation — provides guidance on goals and objectives for avian conservation in California's Central Valley. In 2006, the CVJV's second implementation plan addressed conservation objectives for breeding shorebirds (CVJV 2006). Lacking information that links breeding

shorebird population size to habitat area, the CVJV defined 5-year wetland habitat restoration objectives based on doubling the annual average rate of wetland restoration (CVJV 2006); no population or long-term conservation objectives were defined.

Here, we describe our process for setting long-term (100-year) and short-term (10-year) conservation objectives for shorebirds breeding in permanent and semi-permanent managed wetlands, while accounting for birds using rice fields and other flooded habitats in the Central Valley. Our goal was to achieve self-sustaining, genetically robust, and resilient populations of breeding shorebirds in the Central Valley. We estimated the current extent of available habitat for breeding shorebirds and the current population size and density of two species, and provide available information on a third species. We then estimate the long-term species density and wetland habitat objectives required to achieve the long-term population objective — as well as the corresponding short-term objective that can be used to track progress toward the 100-year objective — for all three species. Our approach provides a transparent, repeatable process for setting population, density, and habitat objectives that are based on the best available information and can be used to unite stakeholders around common conservation goals.

MATERIALS AND METHODS

Study Area

California's Central Valley, surrounded by mountains except at its western drainage into San Francisco Bay, averages 644 km (400 mi) from north to south and 64 km (40 mi) east to west. The region is divided into two lesser valleys, the Sacramento Valley in the north, and the San Joaquin Valley in the south. Each valley is drained by a river of the same name which converge in the Sacramento–San Joaquin River Delta and flow through San Francisco Bay into the Pacific Ocean; the Tulare Basin, the southern portion of the San Joaquin Valley, is hydrologically closed. The ranges of average temperatures are similar between the Sacramento (5 °C to 23 °C) and San Joaquin (6 °C to 25 °C) valleys, though average annual rainfall is higher in the Sacramento Valley (51 cm) compared to the San Joaquin Valley (< 23 cm; Heitmeyer et al.

1989) and the latter is more water-limited than the former.

The outer boundary of the CVJV is largely delineated by the Jepson Great Central Valley Region, and the CVJV primary focus area includes the valley floor (Hickman 1993; Figure 1). For the purposes of conservation planning, the CVJV focus area is divided into ten basins. For breeding shorebirds, the basins were consolidated into four major planning regions: the Sacramento (American, Butte, Colusa, Glenn, and Sutter basins), Yolo–Delta (Yolo and Delta basins), San Joaquin (San Joaquin Basin), and Tulare (Tulare Basin) planning regions (Figure 1). The Suisun planning region was not included in our analysis.

Focal Species

We evaluated three species of breeding shorebirds: Black-necked Stilt (hereafter stilt) and American Avocet (hereafter avocet), which were considered in the 2006 CVJV Implementation Plan (CVJV 2006), and Killdeer. These three species breed in similar habitats in the Central Valley (including rice fields and wetlands) but vary in nest site preferences. Stilts prefer to nest on small islands or on a mound above water (Robinson et al. 1999), avocets nest on dry, sparsely vegetated ground adjacent to shallow water (Ackerman et al. 2013), and killdeer nest on gravelly substrate near water or in upland habitats (Jackson and Jackson 2000). Though seemingly slight, these differences in nest site selection can have large implications on nest success and the conservation measures needed for each species (Iglecia et al. 2014). We considered stilt, avocet, and killdeer as focal species because they are sufficiently common and widespread throughout the Central Valley to be used to evaluate the effects of management actions in focal habitats (see below).

Four additional shorebird species breed regularly in the Central Valley: Snowy Plover (*Charadrius nivosus*), Spotted Sandpiper (*Actitis macularius*), Wilson's Snipe (*Gallinago delicata*) and Wilson's Phalarope (*Phalaropus tricolor*; CVJV 2006). We considered these species beyond the scope of this analysis either because they have small, localized breeding populations or nest in specialized habitats outside of the managed wetlands, rice, and other flooded habitats addressed here.

Focal Habitats

The composition, extent, and timing of flooded habitats in the Central Valley have changed drastically over time. Historically, the Central Valley contained large expanses of wetland habitat created by rainfall and snowmelt. Wetland extent was dynamic, varying from year to year with precipitation, and generally swelled with winter rains and spring snowmelt from the Sierra Nevada, gradually receding to the smallest extent in late summer or fall, before the onset of the next rainy season (TBI 1998; Duffy and Kahara 2011). Most runoff is now captured in reservoirs and other infrastructure, mitigating the extent of flooding after heavy rains, and with it some of the temporal variation in habitat availability.

The habitat types currently available to shorebirds in the Central Valley during the peak breeding season (mid-April through mid-July) include permanent and semi-permanent managed wetlands, rice fields in production, sewage ponds, water storage facilities, evaporation ponds, agricultural canals, and compensation wetlands (Shuford et al. 2007). Surveys of breeding shorebirds in the Central Valley in 2003 found 80% of stilts and 66% of avocets in rice and managed wetlands, respectively (Shuford et al. 2007). Two types of managed wetlands provide flooded habitat during the shorebird nesting season. Semi-permanent wetlands are generally flooded from October through late June or early July, and permanent wetlands remain flooded year-round (CVJV 2006; Iglecia and Kelsey 2012). Thus, we considered permanent and semi-permanent managed wetlands (combined and hereafter referred to as semi-permanent wetlands) and rice as focal habitats and accounted for focal species' use of other habitats.

Current Status

Focal Habitats

To estimate the current extent of semi-permanent wetlands in the Central Valley and in each planning region, we used a Geographic Information System (GIS) layer produced from 2009 satellite imagery (Petrik et al. 2014), supplemented by an estimate of wetland acres restored between 2009 and 2015 (2016 email from D. Fehringer, Ducks Unlimited, to
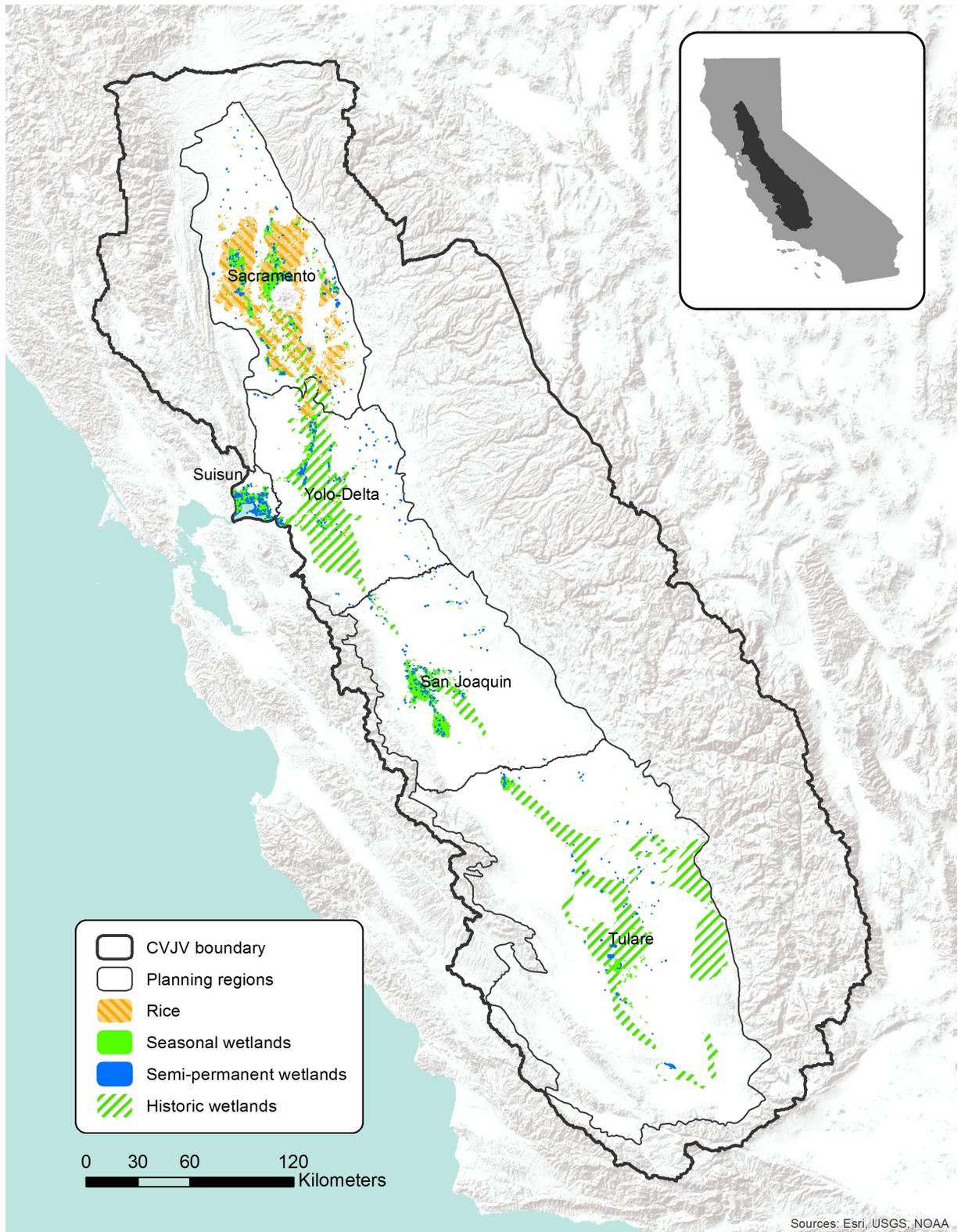
Figure 1 Central Valley Joint Venture boundary and breeding shorebird planning regions with current extent of focal habitats (rice and semi-permanent wetlands), current seasonal wetlands, and historic extent of wetland habitat. The Suisun planning region was not included in our analysis.

K. Dybala, unreferenced, see "Notes"). For rice, we compiled state-wide survey statistics from 2007 to 2014 (NASS 2016), which provided the best estimate of the annual total area planted in California. Using a GIS layer that represented the consistent spatial distribution of rice between 2007 and 2014 in California (The Nature Conservancy, unpublished data, see "Notes"), we then calculated the proportion of rice pixels within each planning region. We used the proportions to allocate state-wide totals among the planning regions, which in turn allowed us to estimate the 2007–2014 average extent of planted rice within each planning region.

Species Densities, Population Sizes, and Trends

To estimate the current breeding population size and density of focal species of shorebirds in each region of the Central Valley, we first compiled available information on the abundance or density of each species in rice and semi-permanent wetlands. Shuford et al. (2007) conducted surveys of stilts and avocets during the breeding season in rice and semi-permanent wetlands in 2003. Density estimates for both species were reported by county from surveys of rice fields in the Sacramento and Yolo–Delta planning regions, and count totals were reported from surveys of rice fields in the San Joaquin planning region. Where count totals in rice were reported, we calculated county densities by dividing count totals by the area of rice grown in each county in 2003 (NASS 2016). We then estimated the overall average breeding density in rice in each planning region by weighting the county densities in each planning region by the amount of rice grown in each county in 2003. Because Yolo County is split between the Sacramento and Yolo–Delta planning regions, we split the amount of rice grown in Yolo County evenly between the two regions.

Similarly, we estimated the breeding densities of stilts and avocets in semi-permanent wetlands in Central Valley planning regions by dividing count totals from surveys of semi-permanent wetlands in each planning region as reported in Shuford et al. (2007) by the estimated area of semi-permanent wetlands in each planning region in 2009 (Petrik et al. 2014). We assumed that wetlands flooded at the time of year when surveys were conducted (May–June)

were semi-permanent wetlands, and we excluded counts of avocets and stilts from the compensation wetland category in the Tulare Basin planning region that were considered outliers by Shuford et al. (2007). Because the CVJV modified planning region boundaries between 2006 and 2016 and moved the Yolo Basin from the Sacramento planning region into the Yolo–Delta planning region, we estimated the number of birds in semi-permanent wetlands in the Yolo Basin by applying the proportion of semi-permanent wetlands in the Yolo Basin relative to the rest of the Sacramento planning region, as defined in 2009, to counts of stilts and avocets from wetlands in the Sacramento planning region. We subtracted the result from count totals of the Sacramento planning region and added it to count totals of the Yolo–Delta planning region for both stilts and avocets to account for changes to the planning region boundaries. We used the 2009 wetland estimate because previous estimates of Central Valley semi-permanent wetland extent (CVJV 2006) are higher, and may have included the entire area of wetland management units rather than only the flooded area. We also assumed that the area of semi-permanent wetlands did not change substantially between 2003 and 2009. We did not include estimates of additional wetland area restored since 2009 in calculations of overall wetland density.

From the regional density estimates in rice and semi-permanent wetlands, we calculated an overall average breeding density for stilts and avocets in each focal habitat type in the Central Valley. We then extrapolated the overall average breeding densities across the current estimates of each focal habitat area to estimate the total current breeding population size of stilts and avocets in rice and semi-permanent wetlands in the Central Valley. To this estimate we added counts of birds in other habitats not accounted for in rice and wetlands (Shuford et al. 2007) to obtain an overall population estimate of stilts and avocets in the Central Valley.

We are unaware of any comparable broad-scale surveys for breeding populations of killdeer in the Central Valley. However, we estimated the breeding density of killdeer in rice using counts from bi-weekly surveys conducted at 16 farms in the Glenn–Colusa Irrigation District located in the Sacramento planning region in June of 2013

and 2014 (Iglecia et al. 2014; Audubon California, unpublished data, see "Notes"). We applied the density estimate to each county in each planning region, and estimated the overall average breeding density in rice in each planning region by weighting the county densities by the amount of rice grown in each county in 2014 (NASS 2016). We then calculated an overall average breeding density for killdeer in rice in the Central Valley, and extrapolated the overall average breeding density across the current estimate of rice area to estimate the total current breeding population size of killdeer in rice in the Central Valley.

To examine long-term population trends for each of our three focal species, we compiled trend estimates from Breeding Bird Survey (BBS) data in the Coastal California Bird Conservation Region (BCR 32), which encompasses the Central Valley and coastal slope and Coast Ranges of central and southern California (Sauer et al. 2014). We recognize that the BBS is not an ideal survey method for breeding shorebirds, yet we are unaware of other sources of data for long-term population trends in the Central Valley (Shuford et al. 1998). Using both the full duration of BBS data (1968–2013) and data from the most recent decade available (2004–2013; Sauer et al. 2014), we converted the annual average growth rates (AG) of each focal species to a total percent change per decade (G10) using the equation:

$$G10 = ((1 + AG/100)^{10} - 1) \times 100$$

Population Status

To place our population size and trend estimates in a broader context, we assessed the status of focal species populations by applying a population status framework derived from general principles of conservation and population biology (Dybala et al. 2017, this volume). The framework was structured as a hierarchy of increasing population sizes that mark milestones in the process of becoming a self-sustaining, genetically robust, and ecologically functional population, along with general hypotheses for the orders of magnitude at which most populations are expected to reach each status (Table 1). Additionally, two modifiers describe *steeply declining* populations, which are at high risk of extinction or extirpation regardless of population

size, and *resilient* populations, with more than one self-sustaining sub-population to hedge against environmental catastrophes in one part of the range (Table 1).

We applied the population status framework to the estimated current population size of stilts and avocets in the Central Valley, as an indicator of the ability of the Central Valley to support robust populations of breeding shorebirds. Although we examined the status of each regional population individually, we considered the entire Central Valley as one breeding population since shorebirds can opportunistically find and use ephemeral habitat on the landscape (Skagen 2006; Barbaree et al. 2013). Avocets can disperse to new breeding areas as far as 480 km away (Robinson and Oring 1997), potentially linking otherwise isolated breeding populations (Robinson and Oring 1996; Plissner et al. 2000), and, in years when the reclaimed lake-bed in the Tulare Basin floods from extreme rainfall and snowmelt, large numbers of shorebirds congregate in the area (Shuford et al. 2007) that would presumably otherwise be dispersed in other parts of the Central Valley.

Conservation Objectives

Density Objectives

Semi-permanent wetlands are generally managed as deep-water habitats with patches of tall, dense vegetation (e.g. tules [*Schoenoplectus* spp.] or cattails [*Typha* spp.]), and shallow areas exist mainly along edges. Seasonal wetlands are typically drained in March, before or at the beginning of shorebird nesting, providing shallow-water habitat for a limited amount of time (Iglecia and Kelsey 2012). Thus, we assumed: that managed wetlands do not provide adequate habitat for nesting shorebirds (Shuford et al. 2007; Iglecia et al. 2014), that densities in semi-permanent wetlands in the Central Valley are lower than what is possible in higher-quality breeding habitat, and that habitat restoration and enhancement of existing wetlands would result in higher breeding densities. We examined the range of breeding densities observed for stilts and avocets in each of the four planning regions in both semi-permanent wetlands and rice (Table 3) and proposed an initial hypothesis that a 50% increase of the overall average density of each species in semi-permanent

Table 1 Population status framework. Source: Dybala et al. (2017, this volume).

Population status	Description	Population 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

wetlands in the Central Valley could be achieved through enhanced management of existing wetlands and restoration of high-quality wetlands. Though it is unclear how much of an increase in breeding densities can be reasonably achieved throughout the Central Valley, very high densities have been achieved locally in wetlands managed exclusively for breeding shorebirds (Davis et al. 2008) and in private wetlands (2015 email from C. Hickey, Point Blue Conservation Science, to K. Strum, unreferenced, see "Notes") in the Tulare Basin. An emphasis on habitat enhancement to achieve higher densities may minimize the total extent of restoration required and, potentially, be a more efficient use of resources. Thus, we proposed relatively high density objectives, while recognizing that they may require revision as additional information about the breeding densities that can be achieved becomes available. We could not use the same approach to set a density objective for killdeer because we lacked estimates of density in semi-permanent wetlands and overall population size. Instead, we used the habitat objectives as determined for stilts and avocets (see below) to estimate the overall average killdeer density required in semi-permanent wetlands to achieve the population objective.

Population Objectives

To achieve the long-term goal of self-sustaining, genetically robust, and ecologically functional populations of each focal breeding shorebird species in the Central Valley, the long-term population objectives for each species should include stable or increasing population trends, and reach the *large* population size threshold (Table 1). Based on the historical (pre-1900) extent of Central Valley wetlands (DGP–GIC 2003; Figure 1; Table 2) and the estimated loss of over 90% of historical wetland habitat (Frayer et al. 1989), we assumed comparable reductions in populations of breeding shorebirds, and that historical population sizes would have reached the threshold for *large* (Table 1). Thus, we set long-term (100-year) Central Valley population objectives for each focal species at the threshold for a *large* population (>50,000 individuals). Achieving the long-term goal of *resilient* populations requires more than one *viable* or *large* regional population to improve the species' ability to recover from local disturbances or disasters and we set long-term population objectives at the *viable* threshold (>10,000 individuals) for each planning region.

Table 2 Breeding shorebird habitat estimates (A) and objectives (B) in each of four Central Valley Joint Venture planning regions (excluding Suisun). Estimates include the current (2015) extent of semi-permanent wetlands, the 2007–2014 average extent of planted rice, and the historical (pre-1900) extent of wetlands. Objectives include the overall long-term (100-year) semi-permanent wetland habitat objectives, estimated additional wetlands needed (restoration), and corresponding short-term (10-year) wetland restoration objectives.

	(A) Estimated extent, ha (ac)				(B) Wetland objectives, ha (ac)		
	Current			Historical	Long-term		Short-term
Planning region	Wetlands	Rice	Total	Wetlands	Overall	Restoration	Restoration
Sacramento	2,164	206,339	208,503	145,737	30,588	28,424	2,842
Yolo–Delta	1,623	10,907	12,530	271,241	30,588	28,965	2,897
San Joaquin	1,162	1,836	2,998	33,560	30,588	29,426	2,943
Tulare	2,037	0	2,037	386,465	30,588	28,551	2,855
Central Valley total	6,987	219,082	226,069	837,003	122,352	115,367	11,537
	(17,265)	(541,363)	(558,629)	(2,068,279)	(302,338)	(285,078)	(28,508)

Table 3 Current estimates of regional breeding population densities (birds per 100 ha) for each focal species in semi-permanent wetlands and rice, shown with the overall average density for the Central Valley and the long-term (100-year) density objective for semi-permanent wetlands (habitat objectives were not set for rice). Data from Shuford et al. (2007) were used to calculate current densities unless otherwise noted. See see "Materials and Methods" for more information.

	Semi-permanent wetlands			Rice [a]		
Planning region	Black-necked Stilt	American Avocet	Killdeer [b]	Black-necked Stilt	American Avocet	Killdeer [c]
Sacramento	8.8	5.5	—	9.4	1.4	3.3
Yolo–Delta	3.4	2.2	—	36.3	9.4	4.5
San Joaquin	30.5	39.2	—	1.5	0.9	3.3
Tulare [d]	87.6	45.5	—	n/a	n/a	n/a
Average density	34.2	22.0	—	10.6	1.8	3.3
Density objective	51.2	33.0	34.6	n/a	n/a	n/a

a. Weighted densities.
b. No data available for killdeer breeding densities in wetlands; overall wetland density objective for killdeer calculated using habitat objective for avocets.
c. Weighted densities calculated from surveys in the Glenn–Colusa Irrigation District (Audubon California, unpublished data, see "Notes").
d. No rice grown in the Tulare Basin.

Long-Term (100-year) and Short-Term (10-year) Habitat Objectives

Conservation efforts may not affect the overall extent or management of rice and other habitats over the long-term, and we assumed no change to the extent or management of these habitats, and, in turn, no change to the estimated current numbers of each focal species breeding in rice and other habitats. Therefore, we assumed that the population objectives would be achieved through restoration of semi-permanent wetlands and enhanced management of existing wetlands to meet density objectives and that semi-permanent wetlands would support at least 50%

of the population objectives (CVJV 2006). Thus, we defined the long-term habitat objective for wetlands in the Central Valley by estimating the minimum area of semi-permanent wetland habitat required for both stilts and avocets to achieve the Central Valley population objective of 50,000 individuals, assuming each species reaches their density objectives, and the population supported by rice and other habitats remains stable. We used the habitat objective, as estimated for stilts and avocets, to calculate the density of killdeer needed in semi-permanent wetlands to reach the population objective, assuming the population supported by rice remains stable. We also defined a long-term restoration objective—a

subset of the overall habitat objective—as the additional wetland habitat needed to support the population objective by taking the difference between the long-term habitat objectives and current extent of semi-permanent wetlands. We distributed the habitat objectives among the four planning regions to ensure each regional population reached the threshold for a *viable* population (>10,000 individuals). To track progress toward the long-term habitat objective, we defined a short-term (10-year) restoration objective that represents one-tenth of the long-term restoration objective.

RESULTS

Current Status

Focal Habitats

The current extent of available habitat for breeding shorebirds in the Central Valley varied among the four planning regions. Excluding the Suisun planning region, there was an estimated 6,260 ha (15,469 ac) of semi-permanent wetland habitat in 2009, to which we added an estimate of 727 ha (1,796 ac) of semi-permanent wetlands restored between 2009 and 2015, and 219,082 ha (541,363 ac) of rice (Table 2). Nearly 92% of available habitat was in the Sacramento planning region, and 99% of the habitat in that region was flooded rice. Semi-permanent wetlands accounted for only 3% of the total nesting habitat available in the Central Valley, and was distributed more evenly throughout the Central Valley with 31%, 23%, 17%, and 29% in the Sacramento, Yolo–Delta, San Joaquin, and Tulare planning regions, respectively (Table 2).

Species Densities, Population Sizes, and Trends

The overall average breeding densities of stilt and avocet in semi-permanent wetlands in the Central Valley were similar, at 34.2 and 22.0 birds per 100 ha, respectively (Table 3); however, regional density estimates varied widely. Density estimates in semi-permanent wetlands were highest for both species in the Tulare planning region and lowest in the Yolo–Delta planning region. Killdeer densities in semi-permanent wetlands of the Central Valley are unknown. Breeding densities in rice were generally lower than in semi-permanent wetlands. All three

focal species' densities in rice were highest in the Yolo–Delta planning region; stilt and avocet densities were lowest in rice in the San Joaquin planning region (Table 3).

We estimated a total current population of 31,647 stilts and 11,153 avocets in the Central Valley. Of these, 5,952 stilts and 5,664 avocets were accounted for in flooded habitats other than rice and semi-permanent wetlands (Shuford et al. 2007), and nearly 90% of individuals using other habitats were found in the Tulare planning region. As a result of variation in species densities and available habitat, current population estimates for stilts and avocets also varied regionally (Table 4; Figure 2). Stilt populations were concentrated in the Sacramento planning region, which supported 62% of the Central Valley population, whereas the majority (54%) of avocets were concentrated in the Tulare planning region. Current population sizes for killdeer are unknown. Breeding Bird Survey population trends in the wider Coastal California Bird Conservation Region (BCR 32) from 1968–2013 were declining for all three focal species, and significant for killdeer; killdeer also met the criterion for *steeply declining* during the most recent decade for which data are available (2004–2013; Table 4).

Population Status

Including rice, wetlands, and other habitats, the current estimated total population of stilts and avocets in the Central Valley met the threshold for *viable* populations (>10,000 individuals; Table 4; Figure 2); however, without accounting for birds in other habitats, the avocet population would be considered *small* (<10,000 individuals). At the planning region level, both stilts and avocets had *small* or *very small* (<1,000 individuals) populations in the Yolo–Delta, San Joaquin, and Tulare planning regions. The Sacramento planning region was the only planning region that supported a *viable* population for any focal species (Table 4; Figure 2).

Conservation Objectives

Density Objectives

We set long-term breeding density objectives for stilts and avocets in semi-permanent wetlands that were

Table 4 Current population estimates (rice, semi-permanent wetlands and other habitats combined) for each species in each planning region (A). Cumulative percent change in population and 95% confidence intervals calculated from Breeding Bird Survey (Sauer et al. 2014) trend estimates in the Coastal California Bird Conservation Region (BCR 32) over two time-periods: 1968–2013 and 2004–2013 (B). The annual growth rates (AG) from the BBS were converted to a cumulative percent change over 10 years (G10) using the equation: $G10 = ([1+AG/100]10 - 1) \times 100$.

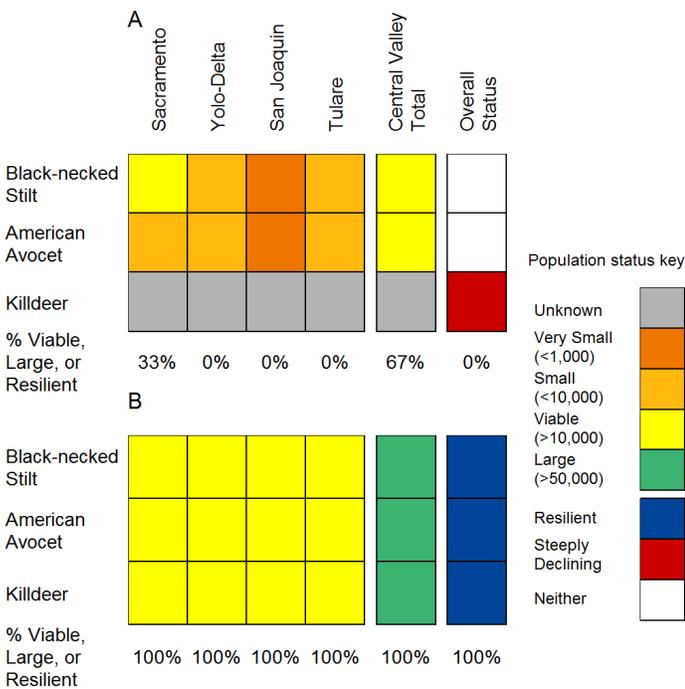| (A) Current population estimates			
Planning region	**Black-necked Stilt**	**American Avocet**	**Killdeer**
Sacramento	19,709	3,172	—
Yolo–Delta	4,099	1,114	—
San Joaquin	744	793	—
Tulare	7,095	6,074	—
Central Valley total	31,647	11,153	—
(B) Growth rates (95% CI)			
1968–2013	− 15.3 (− 33.7, 7.5)	− 23.5 (− 45.4, 5.3)	− 14.1 (− 21.3, -5.8)
2004–2013	− 17.3 (− 50.7, 26.5)	− 24.8 (− 61.1, 39.6)	− 30.9 (− 49.2, -5.1)

Figure 2 Current population estimates (**A**) and population objectives (**B**) for three species of breeding shorebirds in semi-permanent wetlands and rice fields of California's Central Valley, with population framework ranking from Dybala et al. (2017). See Table 1 for more information.

50% higher than the current overall average density (Table 3), but still lower than or equal to observed breeding densities in the Tulare planning region (2015 email from C. Hickey, Point Blue Conservation Science, to K. Strum, unreferenced, see "Notes"). The overall density objective for killdeer in wetlands was similar to estimates for stilts and avocets (Table 3).

Long-Term Population and Habitat Objectives

Assuming no changes to existing shorebird nesting habitat in rice and other habitats, and that long-term density objectives in semi-permanent wetlands are achieved, we estimated that meeting the long-term population objectives for all three focal species will require the restoration of at least 115,367 ha (285,078 ac) of semi-permanent wetlands, in addition to enhanced management of existing semi-permanent wetlands, to provide a total of 122,352 ha (302,338 ac) of semi-permanent wetland habitat for breeding shorebirds in the Central Valley (Table 2). This overall habitat objective is based on the relatively low current population size and density of avocets (Table 4; Figure 2). For each focal species to achieve the *viable* population threshold in each planning region, additional habitat should be restored such that each planning region has approximately one-quarter of the overall habitat objective (Table 2). To meet the long-term (100-year) population objectives,

we estimated that 11,537 ha (28,508 ac) of semi-permanent wetlands need to be restored each decade to meet breeding shorebird habitat needs (Table 2). When the long-term density and habitat objectives are achieved, all three focal species will have *viable* regional populations that will contribute to improved resilience in the Central Valley (Figure 2).

DISCUSSION

We expanded upon the CVJV's previous effort to set conservation objectives for breeding shorebirds (CVJV 2006) by defining population, density, and habitat objectives using a structured framework (Dybala et al. 2017, this volume), and a transparent, repeatable process for setting science-based conservation objectives that can be used to align multiple stake-holders around common goals in discussions about resource concerns. Restoration of new wetlands and enhancement of existing wetlands to support the focal species addressed here may provide habitat for other wildlife, including other waterbirds (Shuford and Dybala 2017, this volume), of which two of the focal species are state-threatened and four are Species of Special Concern in California (Shuford and Gardali 2008), and the giant garter snake (*Thamnophis gigas*), a state-threatened species that requires flooded habitat, particularly from March through October (Halstead et al. 2010). Providing additional wildlife habitat may also benefit economies of local communities as people take advantage of increased recreational opportunities for wildlife viewing (USFWS 2014).

Measuring Success

The contribution of newly restored and of enhanced existing semi-permanent wetlands toward the short-term (10-year) and long-term (100-year) habitat objectives can be estimated as the additional extent of open and shallow-water habitat with suitable nesting substrate available during spring and summer (April–July). Suitable nesting substrate includes islands with bare ground and adequate slope, surrounded by water for the duration of the nesting season to provide some protection from terrestrial predators (Dahl et al. 2003) that can severely reduce nest success (Alberico 1993; Herring et al. 2011; Macdonald and Bolton 2008). Strategies

for increasing the amount of semi-permanent wetlands in the Central Valley over the long term include conservation easements, habitat mitigation, and long-term conservation programs that require incorporation of shorebird nesting habitat.

In addition to tracking restoration and enhancement of suitable nesting habitat, measuring success will require monitoring species' densities and population sizes over time to gauge progress toward the objectives. To meet conservation objectives for breeding shorebirds, density objectives must be supported on both existing semi-permanent wetlands and on those restored in the future. Management of semi-permanent wetlands to support density objectives may require modifications to contemporary management regimes to provide adequate breeding shorebird habitat. However, other species rely on semi-permanent wetlands as currently managed, and assessing the potential trade-offs of changes in management will be necessary.

Another option for supporting breeding shorebirds and their habitat is the creation of reverse-cycle wetlands (wetlands flooded in spring and summer), which are managed with relatively shallow water (15–20 cm; Iglecia and Kelsey 2012) and may be more suitable for breeding shorebirds. Reverse-cycle wetlands can provide breeding habitat to other wetland birds and early fall migrants (Iglecia and Kelsey 2012) and, in extreme precipitation years, reverse-cycle wetlands could be flooded with excess water flows, which may provide additional environmental benefits, including groundwater recharge.

Managing habitat specifically for the benefit of breeding shorebirds can also have dramatic effects. Extensive efforts have been undertaken to provide safe nesting habitat for breeding shorebirds in the Tulare Lake Drainage District (TLDD), including the construction of suitable nesting habitat with a controlled water supply, electric fencing, and predator hazing. Density estimates derived from counts of the TLDD wetland reported in Shuford et al. (2007) were nearly 21 times higher for stilts and 80 times higher for avocets than the overall average semi-permanent wetland density for the Central Valley. The feasibility of such habitat management at large scales is unlikely; however, if current densities on the TLDD wetland could be extended to new wetlands,

approximately 2,300 ha (5,683 ac) would be sufficient to support the population objectives, a substantially smaller area than our current habitat objectives. The TLDD wetland provides an example of how modifying contemporary wetland management can improve nesting habitat for breeding shorebirds and increase nest success (Davis et al. 2008), and could be used to weigh trade-offs of large-scale wetland restoration with smaller-scale intensively managed wetland units. This approach may also help alleviate the strain that large-scale wetland restoration would put on an already limited water supply.

The distribution of habitat on the landscape may play an important role in meeting population objectives. We set regional habitat objectives to meet the *viable* population threshold in each planning region for each focal species, and allocated habitat evenly among the four planning regions. Small adjustments could be made based on the feasibility of habitat restoration or the distribution of focal species most in need while maintaining *viable* populations in each planning region. Further, despite the strong dispersal ability of shorebirds, the spatial distribution of habitat within each planning region may also affect habitat use and subsequent achievement of density and population objectives (Reiter et al. 2015). We recommend creating and restoring habitat in areas that cluster habitat and maximize connectivity of semi-permanent wetlands and other shorebird breeding habitat.

Research Needs

We used the best available information to estimate current populations of two species and set density, population, and habitat objectives for three species of breeding shorebirds in the Central Valley, and we recognize the limitations of the data we used for these analyses. For example, we included killdeer as a focal species despite the limited availability of data on this species in the Central Valley. Killdeer are often overlooked in field research and assumed to be common, yet trends in BCR 32 indicate the species is declining over the long and short term (Sauer et al. 2014; Table 4), and nationally, it is considered a common species in decline (USSCPP 2015). We assume the density objective for killdeer is conservative since we lack data for killdeer nesting

in other habitats. Consequently, we recommend including killdeer in future breeding shorebird research, which would allow estimates of the current breeding population size and density, and thus subsequent revision of the density and habitat objectives.

The density objectives (Table 3) represent hypotheses for densities that can be achieved in the Central Valley, and would benefit from validation through monitoring the response of shorebird densities to habitat restoration and enhancement. Current densities of stilts and avocets in wetlands in the southern Central Valley (San Joaquin and Tulare planning regions) were higher than in other regions, contributing to relatively high density objectives (Table 3). However, a separate study on 21 private wetlands in the Tulare planning region in May and June from 2005–2008 (2015 email from C. Hickey, Point Blue Conservation Science, to K. Strum, unreferenced, see "Notes") found a higher density of stilts—125.5 birds per 100 ha (95% CI: 74.4, 211.5 birds per 100 ha)—than our density estimates for any planning region, and an avocet density—21.5 birds per 100 ha (95% CI: 9.1, 50.1 birds per 100 ha)—similar to our density objective. These density estimates from private wetlands provide evidence that semi-permanent wetlands can be managed for the benefit of breeding shorebirds. An assessment of management practices on private wetlands may reveal beneficial management practices that could be applied to private and public wetlands elsewhere in the Central Valley. Nonetheless, the long-term density objectives for focal species may need to be revised as further information about breeding shorebird densities in high-quality habitat in the Central Valley becomes available.

We focused habitat objectives for breeding shorebirds on semi-permanent wetlands, rather than rice and other habitats, because wetlands have the greatest potential for increasing both long-term habitat availability and quality through management actions, especially given the economic and climatic challenges faced by agriculture (Johnston and Carter 2000). Yet, we accounted for the large extent of habitat provided by rice and other habitats, and recognize that management of cultivated fields can influence habitat quality and focal species density, and that short-term on-farm habitat programs may temporarily reduce

pressure on semi-permanent wetlands to support increases in populations (WHEP 2015). Additional research on population trends, nest success, and chick survival would inform best management practices for breeding shorebird habitat in both rice and wetlands. Further, an assessment of how breeding shorebirds are distributed on the landscape, throughout semi-permanent wetlands, rice, and other habitats can inform the placement of restored wetlands and enhancement efforts in the future.

Finally, in setting habitat objectives for breeding shorebirds, we assumed no loss of currently available breeding habitat in rice. However, persistent drought conditions in California will place further pressures on water allocations; 2015, the fourth year of drought, brought a 25% reduction (56,251 ha [139,000 ac]) in the amount of planted rice in the Central Valley which, in 2012, was over 226,624 ha (560,000 ac; NASS 2016). As water becomes scarcer and more expensive, farmers may shift to other, more profitable crops, such as tree crops, that have little habitat potential for breeding shorebirds and other waterbirds. Scenario planning, used to predict future conditions under differing extremes (Peterson et al. 2003), could be employed to understand the effects of climate change, water availability, and crop conversion on habitat availability for breeding shorebirds and other waterbirds, allowing for a better understanding of how and where to manage for breeding shorebird habitat.

CONCLUSIONS

Despite the loss of over 90% of naturally occurring wetlands (Frayer et al. 1989), the Central Valley still provides important habitat for breeding shorebird populations in semi-permanent wetlands, rice, agriculture, and other habitats. Meeting population objectives for breeding shorebirds requires the creation of additional wetland habitat with shallow, open-water, and appropriate nesting substrate during spring and summer, and management of existing wetlands to support density objectives. Creation of new wetlands and enhanced management of existing wetlands could benefit other wildlife species and provide ecosystem and economic benefits to surrounding communities. The population status framework allowed for development of habitat and

population objectives using a repeatable yet flexible process and provides unifying goals for stakeholders.

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