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ASSESSING THE BENEFITS OF USDA CONSERVATION PROGRAMS IN THE UPPER KLAMATH RIVER BASIN AND CENTRAL VALLEY OF CALIFORNIA ON ECOSYSTEM SERVICES (RWO 84)

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Executive summary

Heavy wetland losses in the Upper Klamath River Basin (UKRB) and Central Valley of California (CVC) have impacted ecosystem services. In the UKRB of southern Oregon, wetland losses are believed to have contributed to poor water quality in Upper Klamath Lake. The Lake's water quality conditions result in kills and low juvenile recruitment of endangered fish species, the Lost River sucker and shortnose sucker. Wetland restoration through programs such as the Wetlands Reserve Program (WRP) is considered important for reducing nutrient and sediment loads to Upper Klamath Lake and thus improving lake water quality. Climate change in the mid-21st century in the Upper Klamath Basin could result in changes in streamflow amount and timing. Streamflow and climatic changes could also influence wetland extent by altering evaporation, precipitation and flooding patterns.

We used a watershed model calibrated for the Sprague River, one of three main tributaries to Upper Klamath Lake, to assess historic water quality benefits of wetlands, and potential future changes to flow, sediment, and nutrients under future climate and hypothetical wetland losses. Our findings suggest that at the outlet of the Sprague River watershed (1) present-day wetlands and riparian zones substantially reduce nutrient

loads; (2) mid-21st century nutrient loads could increase significantly during the wet season, or be similar to historic conditions; (3) the combined impact of climate change and wetland losses on nutrient loads could be large, even if the effects of climate alone are small; (4) in-stream total phosphorus (TP) concentrations from hypothetical wetland losses under future climate would increase most during large floods; and (5) hypothetical loss of riparian wetlands in both headwaters and lowlands could increase outlet TP loads by a similar amount under future climate, but these increases would likely occur for distinct reasons.

In the CVC, restored wetlands are believed to provide many of the ecosystem services lost when wetlands were drained for agriculture and urban development. While intensively managed restored wetlands and flooded croplands of the CVC undoubtedly support millions of wintering waterfowl and waterbirds, benefits to non-target wildlife during other times of the year are less clear. Furthermore, multi-year droughts are expected to occur more frequently in the CVC, potentially impacting water availability for wetland management. We conducted 640 bird surveys on restored wetlands experiencing varying levels of management in the summers of 2008 and 2009. Greater than 91,000 individual migratory and resident birds representing 193 species and 10 foraging guilds were recorded. Unlike in the fall and winter months, management intensity was not the primary determinant of avian occupancy or diversity in the summer. Results indicated that wetland area, vegetation zone complexity, proportion of shallow emergent vegetation, proportion of deep emergent vegetation and adjacent grain crops all positively influenced occupancy by most avian guilds.

We also modelled habitat quality for waterfowl, shorebirds and upland birds in the CVC. Our models indicate that most bird habitat lies in northern CVC in the Sacramento subbasin. However, the northern CVC is also prone to significant fluctuations in habitat availability, particularly for wetland dependent waterfowl and shorebirds. Wetlands Reserve Program easements supported approximately 1% of waterfowl habitat, 0.7% of shorebird habitat and 1.3% of upland bird habitat in the CVC between 2007 and 2014.

Section 1: Upper Klamath River Basin - Introduction and Background

Deteriorating water quality in Upper Klamath Lake has had negative effect on the entire Klamath Basin ecosystem with annual cyanobacteria blooms dominated by *Aphanozomenon flos-aquae* leading to severe dissolved oxygen fluctuations, basic pH, elevated ammonia concentrations and increased levels of algal hepato-toxins. The Upper Klamath River Basin (UKRB) contains the largest remaining habitat for the federally listed endangered Lost River and shortnose suckers, as well as redband and bull trout (Risley and Laenen 1999, Connelly and Lyons 2007). Declining lake water quality has been implicated in juvenile sucker mortality and occasional adult fish kills (Carpenter et al. 2009, Boyd et al. 2002). Poor water quality in Upper Klamath Lake also influences the lower Klamath River, impacting federally listed Coho Salmon, Chinook Salmon and other fish species.

Upper Klamath Lake receives most of its inflow from the Sprague, Williamson and Wood Rivers (Risley and Laenen 1999, Connelly and Lyons 2007). Reaches of the Sprague River are listed as impaired under section 303(d) of the Clean Water Act for degraded water quality, which may be associated with increased sediment and phosphorus loading (Boyd et al. 2002). Although Upper Klamath Lake was historically eutrophic because of phosphorus-rich volcanically derived soils, today Upper Klamath Lake and adjoining Agency Lake are both hyper-eutrophic due to algal blooms from high nutrient loading (Boyd et al. 2002). The drainage of 10,000 ha of former wetlands that historically surrounded the lake is thought to have contributed to eutrophication.

A variety of restoration programs and projects have been implemented along the UKRB to improve the health of the ecosystem. These include Klamath Watershed Partnership assessments of site-specific riparian and upland conditions; USDA administered Wetlands Reserve Program (WRP), Conservation Reserve Program (CRP), and Environmental Quality Incentives Program (EQIP); and USFWS-funded restoration of floodplain connectivity, fence construction for livestock management, and streambank stabilization (Rabe and Calonje 2009). These efforts are believed to provide direct and indirect benefits to aquatic ecosystem health. However, their effectiveness at mitigating impacts to water quality and habitat have not been evaluated (NewFields River Basin

Services and Kondolf, 2012). In addition, quantification of restoration effects will provide important justification for continued financial and community support in the watershed. Regional climate change models forecast increases in air temperature and changes in precipitation and vegetation patterns in the Klamath River Basin in the future (Records et al., 2014). The potential impacts to regional water quality and endangered fish populations from climate change are unknown.

Degraded water quality in Upper Klamath Lake is a central obstacle in restoring the Klamath River ecosystem. Evaluating the potential role of wetland restoration and conservation in improving water quality in the lake requires a strategic, holistic approach that considers the cumulative amount and spatial distribution of conservation programs such as WRP. To be lasting, such a strategic approach must also consider how ecosystem services may change with future climate in the region. A strategic approach can inform managers of the degree of success of conservation programs in providing ecosystem services and help guide future conservation planning, as well as maximize the effectiveness of implemented conservation projects.

We calibrated a Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998) for flow, sediment, total nitrogen (TN), and total phosphorus (TP) at four locations throughout the Sprague River Basin at a monthly timestep, for approximately ten years (2001-2010). The Sprague River watershed was selected for modeling because it contributes a significant amount of external phosphorus inputs to Upper Klamath Lake (Boyd et al., 2002), contains a number of Wetlands Reserve Program easements (U.S. Department of Agriculture Natural Resources Conservation Service, 2011), and has an extensive flow and water quality dataset for model calibration (Records, 2013).

Following model calibration, we simulated removal of all wetlands in the watershed and associated percent changes in sediment and nutrient loads at the Sprague River for 2001-2010 (Records, 2013). Additionally, we forced the calibrated SWAT model for the Sprague River watershed (described above) with six future climate simulations for the 2040s (2030-2059) (Records et al., 2014). These future climate simulations were representative of extremes in temperature change (1.0-3.1 °C) and a range of precipitation change (-0.4 to +11.1%) over the Sprague River watershed between the historic period recommended as a baseline (1950–2005) and the 2040s. We assessed future climate effects on flow and water quality alone, and in combination with hypothetical wetland loss scenarios designed to evaluate watershed sensitivity to joint climate and land use changes. Additionally, we evaluated under what scenarios of wetland loss, and under what flow conditions, water quality at the Sprague River outlet might be most sensitive.

1.1. Upper Klamath River Basin Study Area

The Sprague, Williamson and Wood Rivers are located within the Cascade physiographic region of southern Oregon and are the three major rivers flowing into Upper Klamath and Agency Lakes. Collectively these three river subbasins encompass an area of about 8,300 km^2. Soils of the area are of volcanic, alluvial and wetland or lake bed origin. Topography of the lower portions of these subbasins is relatively flat and supports agriculture, while the upper portions are forested. Elevation ranges from 1,250 to 1,400 m in the lower subbasins to over 2,000 m in the upper portions. Palustrine emergent wetlands once covered expansive areas of these subbasins, but most have been converted to agricultural lands. However, restoration of these wetlands to a more natural state is being undertaken. USDA enrolled roughly 1,600 ha in conservation programs to restore or enhance wetlands between 2001 and 2006. California and Oregon with major rivers draining the basin.

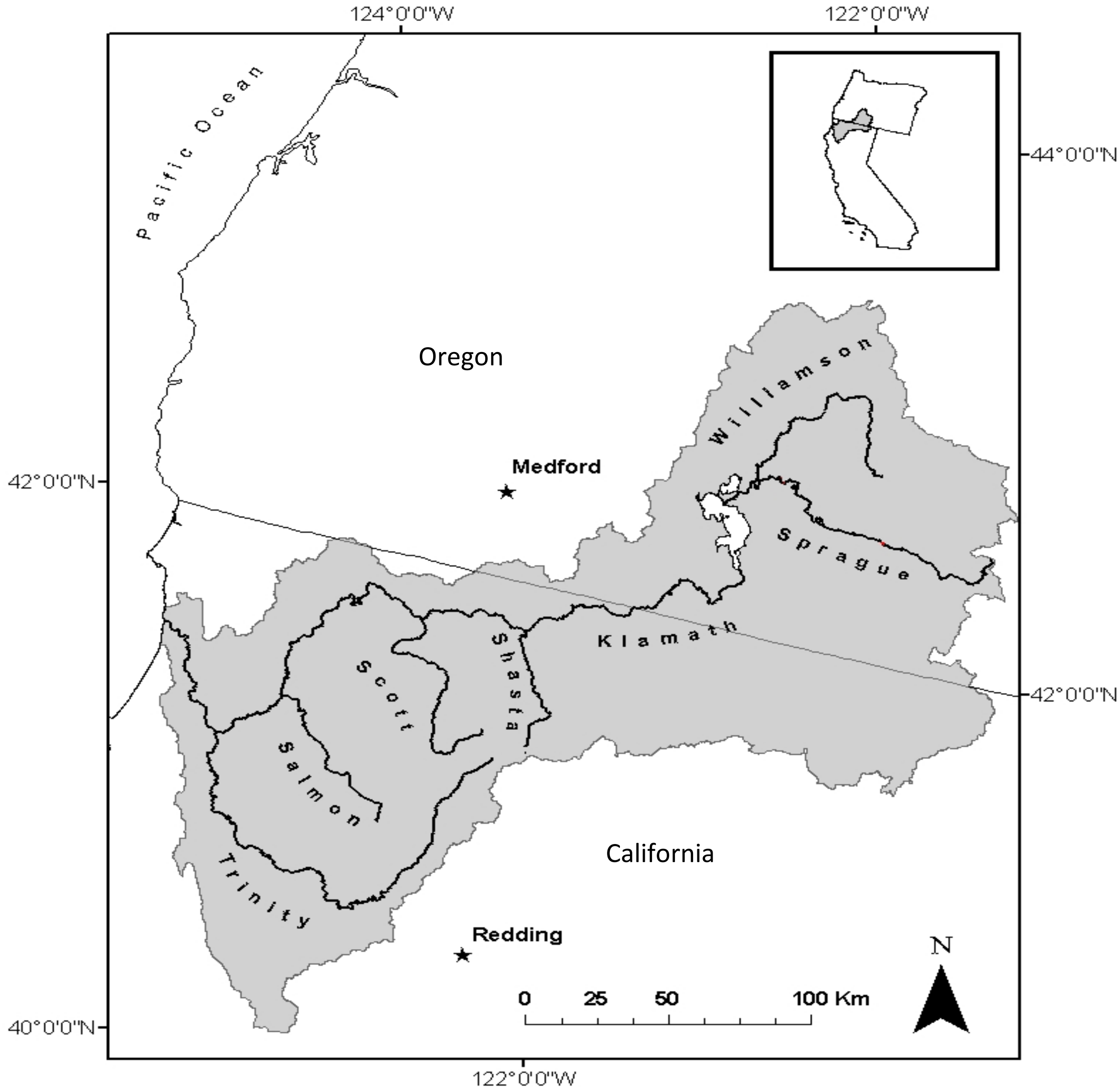


Figure 1. Map of the Klamath Basin in Oregon and California.

Section 2: Quantification of watershed-scale water quality benefits of wetlands and riparian areas in the Upper Klamath River Basin (summarized from Records et al., 2013).

Objective: Quantify watershed-scale water quality benefits provided by wetlands & riparian areas in the Upper Klamath River Basin (UKRB), including those restored or enhanced by USDA.

2.1 Methods

To achieve this objective, we calibrated a SWAT model for flow, sediment, total nitrogen (TN), and total phosphorus (TP) at four locations throughout the Sprague River Basin at a monthly timestep, for six years (2001-2006), and validated the model for an additional four years (2007-2010) (flow at the South Fork of the Sprague River was calibrated and validated during a different time period due to data availability). Model setup inputs, calibration datasets, and model parameters used to simulate wetland restoration and management are detailed in Records (2013) and Records et al. (2014). Model performance was generally adequate for most constituents. Following model calibration, we simulated removal of all wetlands in the watershed and associated percent changes in sediment nutrient loads at the Sprague River for 2001-2010 (Records, 2013). Changes in TP loading at the Sprague River outlet are of particular interest, because reductions in TP loads are believed to be necessary to improve Upper Klamath Lake water quality (Boyd et al., 2002).

After consideration, the Sprague River alone was selected for modeling rather than the other main tributaries of Upper Klamath Lake, the Wood and Williamson Rivers. The Williamson River is not believed to be an important contributor to poor water quality in Upper Klamath Lake on a per-unit-area basis (Boyd et al., 2002), and water quality data in the Williamson River watershed are extremely limited and likely not adequate to support model calibration. The Wood River watershed does contribute higher per-unit-area phosphorus loads to Upper Klamath Lake. However, much of the Wood River is heavily regulated, and the necessary detailed data on flow withdrawals and return flows were not available for the extended time period that would be required for model calibration (pers.

comm., Graham Matthews and Associates, November 2011). The Sprague River watershed contributes a significant amount of external phosphorus inputs to Upper Klamath Lake (Boyd et al., 2002), contains a number of Wetlands Reserve Program easements (U.S. Department of Agriculture Natural Resources Conservation Service, 2011), and has an extensive flow and water quality dataset for model calibration (Records, 2013), and so was well suited to this modeling approach.

2.2. Key Findings

Present-day wetlands provide important water quality benefits in the Sprague River watershed. These wetlands, which include WRP and are primarily riparian, may have reduced mean annual total nitrogen (phosphorus) loads at the outlet of the Sprague River Watershed by 27% (42%), and sediment by 9% (Records, 2013). These findings are corroborated by similar statistically-based estimates for a similar time period (reductions of TN 16%, and TP of 40%) (Aquatic Ecosystem Sciences LLC et al., 2012).

Section 3: Effects of potential future climate on flow and water quality in the Sprague River (summarized from Records et al. 2014).

Objective: Characterize potential changes in stream flow, sediment, and nutrient loads under future climate and present-day wetland extent.

3.1. Methods

To achieve this objective, we forced the calibrated SWAT model for the Sprague River watershed (described above) with six future climate simulations for the 2040s (2030-2059) (Records et al., 2014). The 2040s is a useful planning horizon for the Pacific Northwest and is approximately the period when GCM climate projections begin to markedly diverge from each other (Salathé Jr. et al., 2007; Mote and Salathé Jr., 2010). The future climate scenarios were derived from a statistical downscaling of general circulation model (GCM) data from the Coupled Model Intercomparison Project 5 (CMIP5), which represents the newest generation of future climate models. The climate scenarios were bias-corrected to stations within and near the watershed; details are available in Records et al. (2014).

From 14 candidate GCMs, we selected three that were representative of extremes in temperature change (1.0-3.1 °C) and a range of precipitation change (-0.4 to +11.1%) over the Sprague River watershed between the historic period recommended as a baseline (1950–2005) and the 2040s. We used two Representative Concentration Pathways (RCPs 4.5 and 8.5) for a total of six distinct climate scenarios in this study (Table 1). RCP 8.5 represents a continuation of our current trajectory of emissions (a business- as-usual scenario), and RCP 4.5 represents an optimistic future pathway of coordinated global policy and emissions (Taylor et al., 2012).

In this analysis, we assumed that land cover and land use (including wetlands), management and conservation practices were unchanged between the historic and future period. We used a two-tailed Mann–Whitney–Wilcoxon test to assess whether annual and monthly average flow and total load of sediment, TN, and TP for the 2040s at the Sprague River outlet under a given climate projection and wetland scenario differed from a future baseline with no wetland losses (*n*=30 and *n*=52, respectively, annually and for each calendar month, α = 0.1).

Table 1. General circulation models (GCMs) and Representative Concentration Pathways (RCPs) used in scenario analysis using the downscaled Coupled Model Intercomparison Project 5 (CMIP5) outputs from Multivariate Adapted Constructed Analogs (MACA). Absolute change in average annual temperature ("ΔT") and percent change in average annual total precipitation ("% Change P") are shown between the future period 2030-2059 and historic period (1950-2005). Values are averaged from daily 4 km gridded data over the entire Sprague River watershed. Excerpted from Records et al. (2014).

GCM Abbreviation	Full GCM name	Country	RCP	ΔT (°C)	% Change P
INMCM4	Institute of Numerical Mathematics 4	Russia	4.5	1	-0.4
			8.5	1.4	-3.5
MIROC5	Model for Interdisciplinary Research on Climate 5	Japan	4.5	1.9	1.6
			8.5	2.1	0
CanESM2	Canadian Earth System Model 2	Canada	4.5	2.6	8.9
			8.5	3.1	11.1

3.2. Key Findings

There is large uncertainty in the magnitude of future changes in streamflow, and this is reflected in uncertainties in future changes in sediment and nutrient loads (Figure 2). Future average annual runoff was significantly different from the historic period for only two of the six climate scenarios (p <0.05), in which future runoff was higher; however, four of the six future climate scenarios were not significantly different from simulated historic conditions.

However, most simulations showed significant seasonal changes. Flow increased from October through March and in most simulations was significantly different from the baseline for all or some of these months (p<0.1). Percent changes in nutrient loads were generally proportional to changes in flow, with the exception of a much warmer and wetter climate simulation, which showed disproportional increases in sediment.

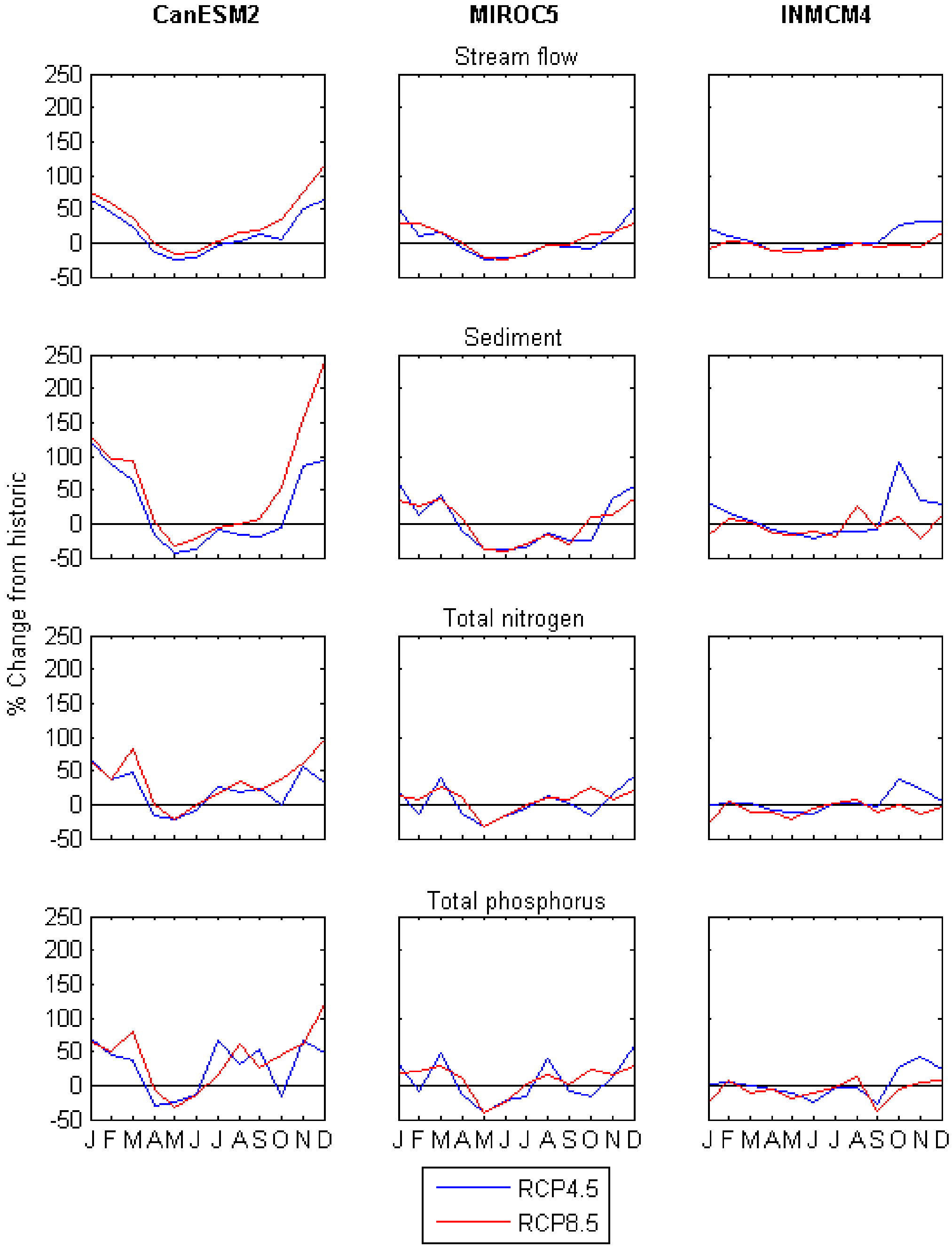


Figure 2. Percent change in simulated average monthly stream flow, sediment, and nutrients at the Sprague River outlet under three general circulation models (GCMs) and two Representative Concentration Pathways (RCPs). Changes are between long-term monthly averages for 1954–2005 and 2030–2050 hydrologic model simulations forced with GCM climate data and baseline wetland extent. Excerpted from Records et al. (2014).

Section 4: Combined water quality impacts of climate change and wetland loss in the Sprague River watershed (summarized from Records et al. 2014).

Objective: Determine the impact of climate change combined with wetland loss on sediment and nutrient loads, and if it differs for riparian areas on small versus large streams.

4.1. Methods

Changes in wetland water balance under projected climate could alter wetland extent or cause wetland loss (e.g., via increased evapotranspiration and lower growing season flows leading to reduced riparian wetland inundation) or altered land use patterns (Records et al., 2014). We do not yet have tools to predict watershed-scale climate change sensitivity of wetland extent or hydroecological functions related to water quality. However, we can gain a better understanding of system vulnerability by assessing stream water quality sensitivity to hypothetical scenarios of wetland loss under future climate.

Accordingly, we assessed four hypothetical wetland loss scenarios under two of our six climate projections to determine potential water quality effects under diverse future climate conditions. These two climate scenarios represent extremes in temperature and precipitation change, and are here referred to as the "warmer–wetter" (RCP 8.5 CanESM2) and "warmer–drier" (RCP 8.5 INMCM4) scenarios. For comparability, we employed the same wetland loss scenarios for both climate projections. While patterns of wetland change could be distinctly different under the "warmer–wetter" or "warmer–drier" projection, modeling of such changes was beyond the scope of this study.

The four wetland loss scenarios consisted of the following: (1) depressional wetlands only – all depressional wetland volumes, surface areas, and drainage areas were set equal to 0, and no riparian wetlands were lost; (2) depressional and first-order wetlands – as for scenario 1, with all filter strip widths ("FILTERW" parameter in the SWAT management file) set equal to 0 in the computational units of the model that drained to first-order streams; (3) depressional, first and second-order wetlands – as for scenario 2 but for all model computational units draining to first and second-order streams; and (4) all wetlands – all depressional and riparian wetlands removed from the model, including wetlands along third- order and greater (hereafter "lowland") streams and wetlands along any other waterways (i.e. canals). All stream orders follow the Strahler stream order system. Detailed descriptions of wetland parameters altered in model setup and wetland loss scenarios are provided in Records et al. (2014).

Results of these scenarios are reported as the percent change between the simulated future period with no wetland loss, versus the simulated future period with a given wetland loss scenario. Reported significant differences are from the Mann-Whitney-Wilcoxon test, with $\alpha = 0.1$ and n=30 for both future scenarios.

4.2. Key Findings

The combined impact of climate change and wetland losses on nutrient loads could be large, even when future water quality conditions under no wetland loss are similar to the past (Figure 3). Total wetland loss increased average annual TN by 23% and TP by 58% above future loads with no wetland loss under the "warmer–drier" scenario, compared to 31% and 97 %, respectively, under the "warmer–wetter" scenario. In the warmer–drier simulation, annual TP and TN loads without wetland loss were not significantly different from the past. However, any losses in addition to depressional and first-order wetlands yielded future TP loads significantly different from historic climate (p<0.1).

Results also suggested that loss of riparian wetlands in headwaters and lowlands could increase outlet TP loads by a similar magnitude, but likely by distinct mechanisms. Lowland and "other" riparian wetlands drain less area than first-order streams (26% versus 64% of the watershed) but comprise more of the watershed's riparian buffer area (58% versus 25 %). The near-equal increases in TP loads caused by riparian wetland loss in first-order and lowland/ "other" streams could be due to the greater percentage of riparian area along lowland streams, combined with higher TP loading per unit area in the valley bottoms.

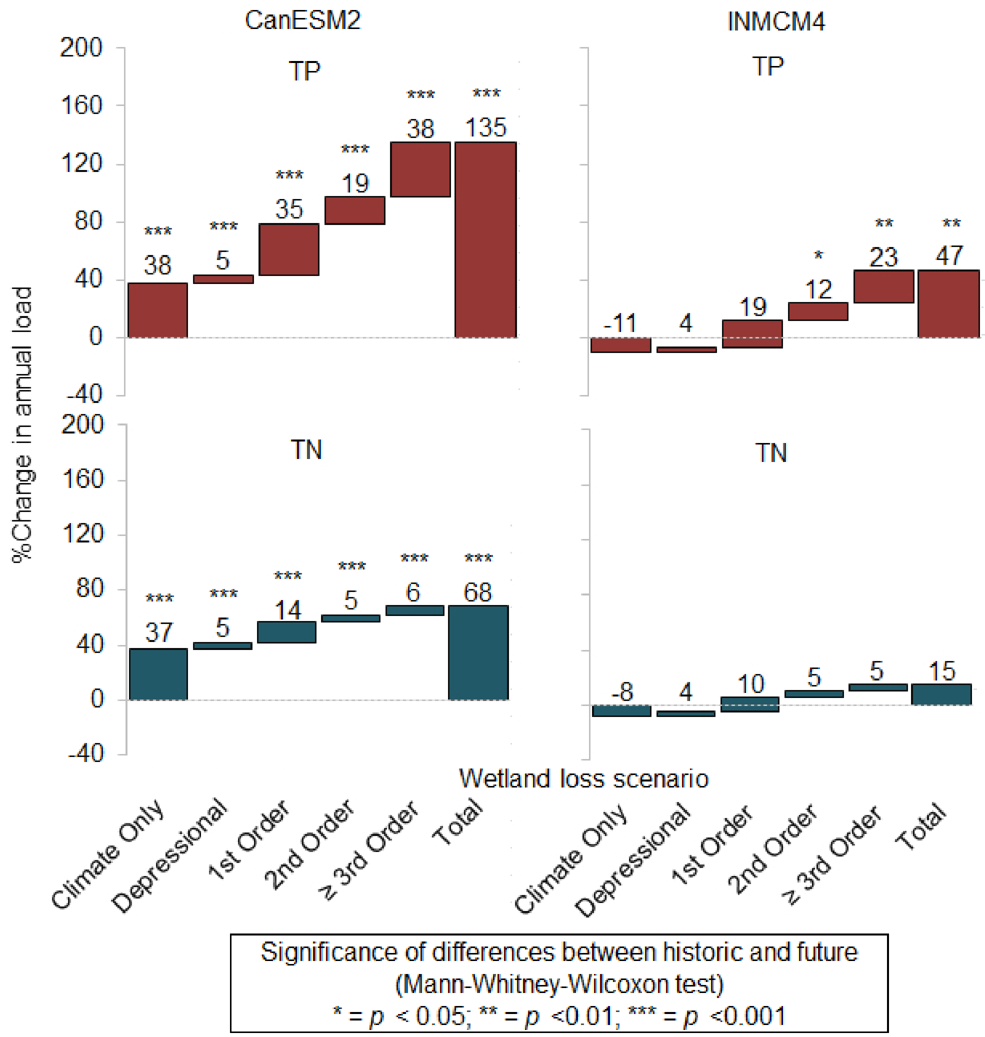


Figure 3. Percent change in simulated average annual loads of total phosphorus (TP) and total nitrogen (TN) at the Sprague River outlet under wetland loss scenarios for the period 2030–2059 for two general circulation models under Representative Concentration Pathway (RCP) 8.5, compared to historic climate (baseline wetland extent, 1954–2005). Excerpted from Records et al. (2014).

Section 5: Sensitivity of TP loads to flow condition under future climate and wetland loss (summarized from Records et al. 2014).

Objective: Evaluate the sensitivity of TP loads to wetland loss under future climate and a variety of flow conditions, and under what flows impacts of a particular wetland loss scenario were the greatest.

5.1. Methods

A load duration curve shows the percent of time that a given pollutant load threshold has been equaled or exceeded, and it can be used to assess at what flow conditions water quality is impaired (USEPA, 2007). We used load duration curves to assess the combined impacts of climate change and wetland loss on TP under a range of flow magnitudes. The load duration curve threshold was calculated as the total load for a given day's simulated flow under the target TP concentration of 66 ppb, which is essentially the regional background concentration (Boyd et al., 2002; Aquatic Ecosystem Sciences LLC et al., 2012).

For each of the two climate projections (warmer–wetter and warmer–drier), we classified daily simulated historic and future TP loads under wetland loss scenarios into typical load duration curve zones. These standard zones are based on the exceedance probability of a load's corresponding daily average stream flow: high (0–10 %), moist (10–40 %), mid-range (40–60 %), dry (60–90 %), and low (90–100%) (USEPA, 2007). Within each load duration curve zone, or flow class, we used the Kruskal–Wallis test to determine whether the six groups of daily loads (baseline wetlands under historic climate, baseline wetlands under future climate, and the four wetland scenarios under future climate) had the same medians.

5.2. Key Findings

Wetland loss had the most impact on TP loads during floods (high-magnitude, low-probability flows), and increases in TP loads were due almost entirely to increases in TP concentrations (Figure 4). For each flow class within the load duration curve (high, moist, mid-range, dry, and low, described above) loads were significantly different from each other under the six wetland scenarios (baseline wetlands under historic climate, baseline wetlands under future climate, and the four wetland loss scenarios under future climate). At higher flows, a greater proportion of the total flow is surface runoff, and the bulk of P transport occurs (Withers and Jarvie, 2008), so the loss of riparian wetlands has a much greater impact during floods. This is particularly relevant because more frequent flooding may occur under climate change (Solheim et al., 2010).

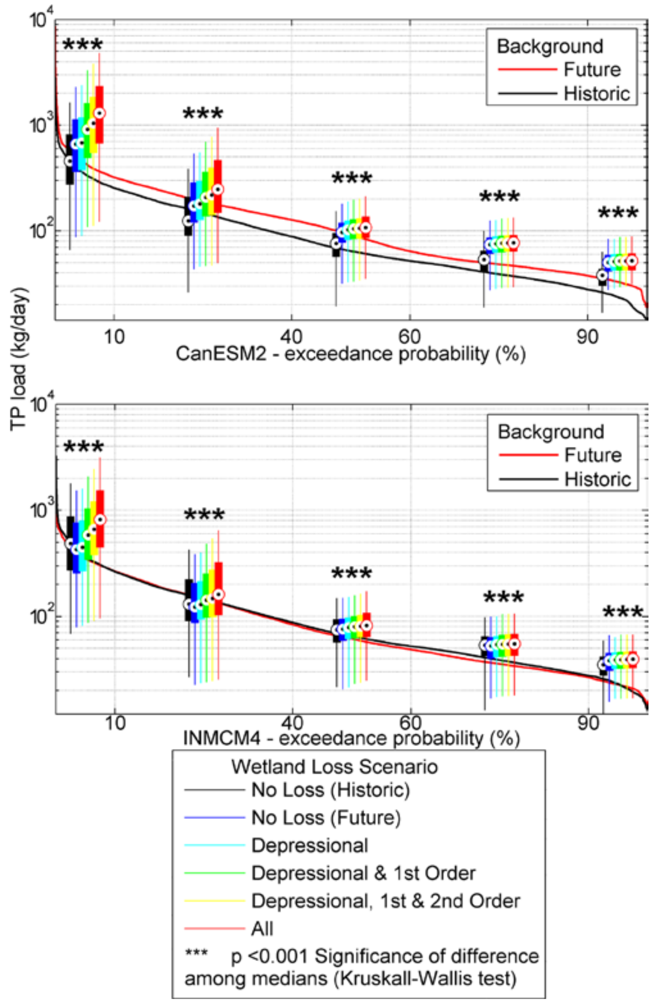


Figure 4. Annual TP load duration curves under two general circulation models for the historic period (1954–2005) and for Representative Concentration Pathway (RCP) 8.5 future period (2030–2059). Box centers show medians, and whiskers show the 25th and 75th percentiles of daily simulated loads in five flow classes. As there is inherent uncertainty in the modeling framework, we draw the reader's attention to the relative rather than absolute differences between scenarios and time periods. Excerpted from Records et al. (2014).

Section 6: Central Valley of California- Introduction and Background

Climate is the primary determinant of water availability in the Central Valley of California; however, state legislation governing water appropriation also influences management of restored wetlands, limiting access to surface water by individual landowners. Restored wetlands of the Central Valley were constructed to replace the thousands of wetland acres lost to agriculture and human settlement. More than 95% of all depressional wetlands and 98% of riparian wetlands in California were lost between 1800 and 1980 (Dahl 1990, CVJV 2006, Garone 2011). The passage of the Swamplands Act in 1850 and subsequent revisions resulted in extensive alterations to natural hydrology through the creation of reservoirs and channelization of the Central Valley's main rivers. Altered flows in the Sacramento and the San Joaquin rivers resulted in drastic reductions in natural overbank flooding that fed adjacent wetlands (Schoenherr 1992, Hartman and Goldstein 1994).

Most remaining wetlands in the Central Valley now rely on artificial water deliveries to maintain their hydrology (CVJV 2006). Despite this, the Central Valley remains the most important waterfowl wintering area for the Pacific Flyway (Gilmer et al. 1982) and supports greater than 400 other resident and migratory bird species (CVBC 2013). Central Valley wetlands are internationally renowned for supporting a great abundance and diversity of birds. About a third of California's threatened, endangered, or special concern bird species rely on or are commonly associated with wetland habitats (CDFW 2013). The Central Valley is also one of the most important inland sites for shorebirds in western North America (Hickey et al. 2003). About 33 shorebird species migrate through the Klamath Basin and the Central Valley or winter in the Central Valley. Total shorebird abundance in the Central Valley during the early 1990s averaged 134,000 in August, 211,000 in November, 303,000 in January, and 335,000 in April (Shuford et al. 1998).

About two thirds of restored wetlands in the Central Valley are under private management (CVJV 2006). Managing wetlands for waterfowl can be water intensive, requiring regular irrigation over the summer when conditions are driest to germinate high densities of seed producing plants. In the fall when most migrating birds arrive to overwinter, artificial flooding is applied. These practices, carried out annually are often referred to as "moist-soil management" (Fredrickson and Taylor 1982). Moist-soil management also involves practices such as disking, mowing, burning and herbicide application to maintain a desired vegetation composition and eliminate invasive plants. Though ultimately beneficial to wintering waterfowl, the impacts of these activities on non-target avian occupancy and diversity in other periods of the year is unclear. Wetland drainage, mowing, disking and burning to modify and control vegetation growth in the spring and throughout the summer may have negative implications for nesting and brood rearing birds. Conversely, irrigation during the summer may prove attractive to birds by providing a source of surface water when conditions are otherwise dry.

Multiyear droughts are a natural occurrence in California and are expected to recur in the future. Between 2000 and 2014, the Central Valley experienced severe to exceptional drought over the summer and fall in 9 out of 14 years (NDMC 2015). Moreover, growing competition for limited water resources by cities and agriculture may result in fewer managed wetlands. A survey of wetlands restored under the U.S. Department of Agriculture's Wetlands Reserve Program (WRP) in 2008 found that between 10-30% of restored wetlands were unmanaged, while another 20-48% were only sporadically managed, raising questions as to their value to birds, particularly waterfowl (Duffy et al. 201). The largest proportion of unmanaged wetlands lay in the Tulare subbasin in the southern Central Valley, a region prone to drought and water shortages (Kahara et al. 2012).

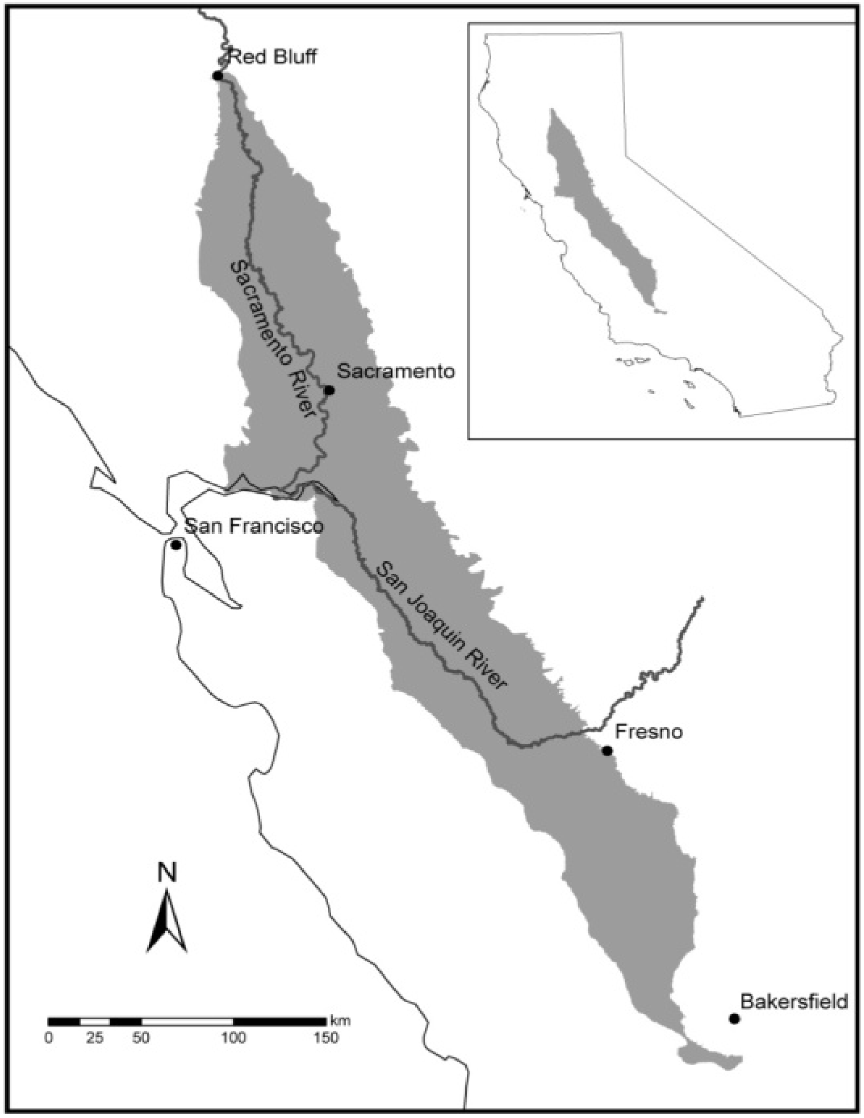
In addition to wetlands, waterfowl and waterbirds in the Central Valley are known to rely heavily on rice fields and postharvest flooded cropland, where they forage on waste grain over fall and winter months (Fleskes et al. 2012). It is estimated that rice and postharvest flooded cropland provide over 60 percent of waterfowl food resources over the winter (Petrie and Petrik 2010). No studies have examined the influence of adjacent land use on wetland occupancy over the summer when the availability of wetland habitats in the Central Valley is relatively low.

6.1. Central Valley of California Study Area and Methods

The Central Valley of California (CVC) is an elongated sedimentary basin about 640 km long, 88 km wide, covering an area of 5.4 • 10^6 ha (Figure 5). It is often subdivided into the Sacramento River Valley in the north and San Joaquin and Tulare Valleys in the south. Topography is relatively flat throughout the valley, with elevation ranging from 120 m in the north and south to below sea level near San Francisco Bay. Climate of the valley is Mediterranean with warm, dry summers and mild, wet winters. Air temperature varies little throughout the valley with average July highs being 37.1 ^oC in both Bakersfield and Red Bluff, while average December lows in Bakersfield (2.9 ^oC) and are only slightly warmer than in Red Bluff (2.3 ^oC). Annual precipitation, however, exhibits a distinct gradient and ranges from 16 cm in Bakersfield, 46 cm in Sacramento, to 92 cm in Red Bluff. Throughout the valley, more than 90% of annual precipitation falls as rain during November – May.

Wetlands in the CVC are primarily freshwater marshes with either seasonal or semi-permanent hydrologic regimes, riparian wetlands, or vernal pools. Most can be classified as palustrine wetlands of different water regimes (e.g. seasonal, semi-permanent). Freshwater wetlands once covered about 1.6 • 10^6 ha or 30% of the CVC. Human influence on CVC habitats dates back thousands of years. Conversion of wetlands to agricultural production became widespread in the 1850s and continued through the 1920s. By 1920, 70% of the wetland area in the CVC had been modified by levees, drainage, and local water diversion projects. More recent analyses estimated that 95% of wetlands, 98% of riparian habitats and 64% of grasslands in the CVC have been lost (Central Valley Joint Venture 2006).

Today, the vast majority of land in the CVC, 94%, is privately owned, including important wildlife habitats such as wetlands, riparian forest and grasslands. Agricultural development in the CVC is intensive, with about 3.0 • 10^6 ha (56%) of the valley classified as irrigated or non-irrigated farmland. Wetlands Reserve Program (WRP) restoration activities have focused restoring or enhancing wetland habitats on these private agricultural lands, and primarily on creation of heterogeneous micro and macro topography features such as islands, ponds and swales to enhance wildlife habitat.

Figure  5. Map of California with the Central Valley offset.

Chapter 7: Impacts of management on non-target avian species use of restored wetlands in California's Central Valley, USA

Objective: To assess the relative impact of management, landscape and on-site habitat characteristics on non-target avian occupancy and diversity over the summer.

7.1. Methods

In 2008 between 10 April and 30 July, we surveyed 60 units on 26 wetlands restored under the WRP program and one unit on Kern National Wildlife Refuge. In 2009, we surveyed 11 units on the same number of WRP wetland units between 19 April and 16 July. Most WRP easements were a combination of upland habitat and wetland cells or units. Wetland units facilitated management by breaking up large areas of land that were managed individually, creating a mosaic of habitats at different stages of succession. Units were separated by 1 – 2 meter high levees with water control structures that allow managers to manipulate water depth and duration.

For this study, we defined management intensity as the degree to which each unit was subjected to moist-soil management techniques that involve annual spring drainage, summer irrigation, winter flooding and some form of vegetation management (e.g. disking, burning or mowing). The most intensively managed wetland units used a combination of all the moist-soil management techniques on an annual basis every year since restoration. Intermediately managed wetland units had employed some or all of the moist-soil management techniques at least 50% of the time since restoration. Un-managed wetlands had never had any moist-soil management techniques applied to them. We selected restored wetland units that best represented each of three management intensity categories.

Individual wetland units were searched from various vantage points for optimal survey coverage. We used a stratified random sampling approach to select wetland units across three primary gradients; 1) management intensity; where each wetland unit was assigned one of three categorical rankings (Table 2) based on Natural Resources Conservation Service (NRCS) assessments, 2) restoration age; where wetland units were classified into two broad age classes, relatively young (five years or less since restoration at time of sampling) and relatively old (greater than five years since restoration at time of sampling), and 3) precipitation. The climatic gradient was represented by three subbasins from north to south; the Sacramento, San-Joaquin and Tulare (Figure 6). Most wetland units ranged in age from 0 (sites that had been restored within 12 months of this project's surveys) to 12 years.

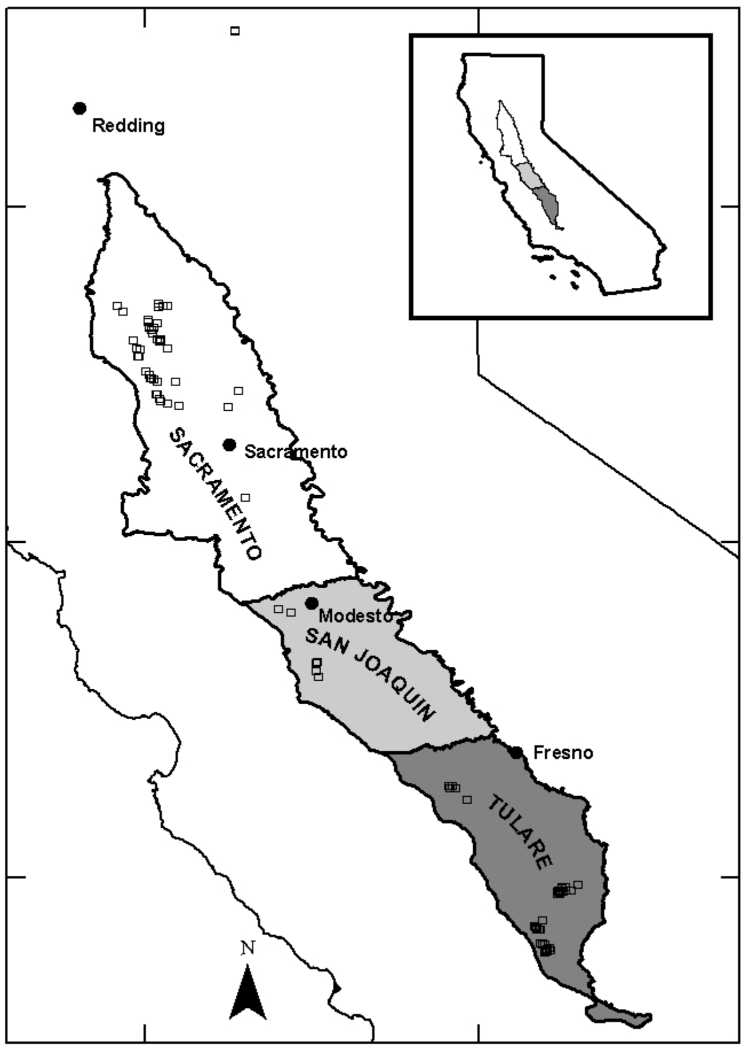


Figure 6. Location of 2008 and 2009 sampling sites (squares) in the Central Valley of California (CVC). For this study, the CVC was divided into three major sub-basins shown from north to south; Sacramento (white); San Joaquin (light gray) and Tulare (dark gray) (Central Valley Joint Venture , shapefile format).

Table 2. Criteria for classification of restored wetlands in the Central Valley of California into management intensity categories.

Management Intensity	**Criteria**
Unmanaged/Low management	No active management following restoration or less than 50% of time since restoration. No recent flooding or drainage.
Intermediate management	Flooded, drained annually, or more than 50% of time since restoration. Intermittent weed control and emergent cover management.
Intensive management	Flooded, drained annually since restoration. Regular weed control, moist soil management, emergent cover. Mowed, disked, burned, grazed, chemical weed control.

7.1.1. Bird surveys

We used area-search methods (Ralph et al. 1993) to survey all birds in wetland units approximately once every three weeks. This survey interval allowed us to visit all the wetland units in our study area as well as conduct enough surveys at each wetland unit to capture seasonal bird use through the survey period. All surveys began within half an hour after local sunrise and were conducted by experienced observers equipped with spotting scopes. Survey duration varied with number of birds and size of the wetland. All bird species seen or heard in the wetland, including those aerial feeding, were recorded. Flying birds, other than those foraging aerially, were not recorded. Species counts were obtained for large flocks by estimating the number of birds within a section of the entire flock and extrapolating to the entire size of the flock. Call playbacks were not used in this study, so secretive marsh birds may have been underestimated. We quantified abundance (total number of individuals and total by foraging guild), species richness and estimated diversity using the Shannon-Wiener index. Species were grouped into 11 foraging guilds (Appendix

I), comprised of species that share behavioral traits and have similar environmental requirements (Hickey et al. 2008).

7.1.2. Habitat surveys

Upland and wetland area within each wetland unit was estimated by measuring the distance between the perimeter levee and the surface water present at the center of the unit, which was assumed to be the lowest elevation. Uplands were distinguished from wetlands by the preponderance of flood intolerant plants and grasses. Locations dominated by flood-tolerant plants were classified as wetland. Wetland units were further subdivided into zones of vegetation guilds based on their tolerance for flooding depth and duration; moist soil, shallow emergent vegetation, deep emergent vegetation and open water zones based on the plant communities present at the time of sampling. Vegetation sampling plots were located within each visible zone along four transects per unit. The beginning of each transect at the outermost zone was located at one of the four cardinal directions and was oriented along a depth gradient towards the innermost zone. We walked inward toward the center of the wetland unit until either open water was encountered, indicating the deepest part of the unit, or no change in vegetation was detected. In the latter instance, transect lengths were limited to 100 m, and distances between transects were not fixed. Local variables recorded at each site were width (m) of all vegetation zones bisected by transects and water depth (cm). The number of vegetation guilds or zones was used as an indicator of habitat complexity. Proportion of each vegetation zone was estimated by dividing the area of each habitat by the area of the entire unit sampled.

We extracted land use information from a 10-km radius buffer around the perimeter of each wetland unit in ArcMap 9.3 ™ (ESRI, Redlands CA) using 2008 and 2009 Cropland Data Layers (CDLs) for California (http://www.nass.usda.gov/research/Cropland/SARS1a.htm). We extracted the CDL grid layer overlain by unit buffers and estimated area (m^2) covered by each agricultural and non-agricultural land-use category. We estimated coverage of each land use category within the buffer area. Individual crop and cover types were then grouped into 11 categories and their area summed by category (Appendix II). Wildlife use of rice, corn and grains is notably greater than other cultivated crops (Ackerman et al. 2006, CVJV 2006), we therefore analyzed these separately.

7.1.3. Management practices

We ranked WRP unit management intensity in two ways. First, Natural Resources Conservation Service biologists with firsthand knowledge of each WRP ranked each WRP based on the criteria provided in Table 2. Second, we interviewed landowners and managers about management practices applied to each WRP easement. Interviews consisted of a series of questions regarding specific management practices pertaining to hydrology (frequency of flooding and draining), grazing (species, frequency), mosquito abatement (pesticide application) and weed control (herbicide application, mowing, disking or burning) (Kahara et al. 2012). Questions were presented to elicit either a yes (1) or no (0) response to provide a binary dataset. We then used discriminant function analysis (DA) to identify the suite of management practices that best described the management categories assigned *a priori* by NRCS biologists, which we assumed to be subjective, but accurate. The DA indicated that the management intensity groupings defined by NRCS biologists were best distinguished by whether or not sites were; 1) annually flooded, 2) managed specifically for wintering waterfowl or 3) received burn treatments. Managers of sites categorized as intensively managed by NRCS staff responded were most likely to respond affirmatively to these three questions.

7.2. Data Analysis

7.2.1. Species Richness and diversity

We compared species richness and diversity (Shannon-Weiner index) across management intensities, subbasins and restoration ages. The Shannon-Wiener (S-W) index is also a measure of entropy (uncertainty) that reflects differences in proportional abundances of birds. Smaller S-W values indicate unequal proportional abundance of species within the community and dominance by one or a few species.

7.2.2. Local habitat variables

We compared local (on-site) habitat characteristics across management intensities using a Kruskal-Wallis one way analysis of variance. The analysis was used to detect differences in vegetation zone variability, water depth or proportion of vegetation zones.

7.2.3. Occupancy Models

We used the program PRESENCE (version 3.1; United States Geological Survey, Patuxent Wildlife Research Center, Laurel, MD) to model site occupancy (ψ) and distinguished between models using Akaike's Information Criterion corrected for small sample sizes (AIC_C; Burnham and Anderson 2002). Covariates were selected *a priori* based on our observations in the field and previous research (Kahara et al. 2012). Our surveys were restricted to the period following spring migration and before fall migration and therefore assumed a closed population (MacKenzie et al. 2002).

Sites were considered occupied by a guild if at least one species within the guild was detected. If no species of a particular guild was detected on any visit, the site was considered unoccupied by that guild. Probability of occurrence was modeled as a function of each covariate described in Appendix II both individually and in combination to identify the model with the lowest AIC_C value (reduced model). If the AIC_C value of any given model was greater than the reduced model, then that variable was eliminated from further consideration. If two of the retained variables were correlated (Pearson correlation coefficient $r \geq |0.7|$), the variable with the higher AIC_C value was eliminated. Models were ranked from lowest to highest AICc value and the "best" model (lowest AICc value) reported.

7.3. Key Findings

Moist soil management practices are designed to maximize food production, while also creating suitable habitat for multiple avian species (Fredrickson and Taylor 1982). Previous studies established that actively managed wetlands are used more often and support greater numbers of waterfowl and waterbirds than unmanaged wetlands (Kaminski et al. 2006, Kahara et al. 2012). However, it is also possible that intensive management practices create unfavorable conditions for non-target species in periods leading up to the arrival of wintering waterfowl. We completed 508 bird surveys on 61 sites in 2008, and 132 surveys on 11 sites in 2009. A total of 203 species were detected in 2008 and 120 species in 2009. We counted 54,412 birds in 2008 and 27,411 in 2009. Our results do not indicate any negative impact of intensive management practices on use by wetland or non-wetland dependent avian species over the summer. Conversely, lack of management did not affect diversity or occupancy over the summer. Avian occupancy of restored wetland units was more likely to be a function of wetland size and vegetation composition.

Most surveyed sites in both years were intermediately managed (42% in 2008, 45% in 2009), followed by intensively managed (22, 4) and unmanaged (13, 2). Intensively managed sites were older and smaller than intermediate and unmanaged sites (Table 3). Intensively managed sites had the most shallow marsh vegetation (6.1%), though surprisingly not much greater than un-managed sites (5.7%). Habitat complexity was the most important variable determining wading bird, marsh bird, and shorebird occupancy and an important variable for all wetland-related guilds except geese. The most important variable describing goose occupancy was subbasin (e.g. Sacramento, San Joaquin or Tulare). Moist soil, shallow emergent vegetation, and grain crops within 10 km were the most important variables describing diving birds, dabbling ducks, and aerial predators, respectively. It came as a surprise that some un-managed wetlands held more and deeper water over the summer than intermediately or intensively managed wetlands. Therefore in this case, lack of management did not necessarily preclude the presence of water. Sources of water to un-managed sites were not determined in this study, however, we speculated that some water may have arrived as spring runoff from adjacent uplands or seepage from drainage and irrigation canals via leaky water control structures. Though not clear in this study, the presence of water could have enhanced vegetation diversity on un-managed sites creating attractive habitat to a broader suite of species.

Table 3. Relative size and restoration age of restored wetlands in the Central Valley of California in 2008 and 2009.

Management Intensity	***n***	**Average size, ha (±SE)**	***n* by age category**	
			Young	Old
Unmanaged	15	329 (7.4)	9	6
Intermediate	31	334 (4.9)	22	9
Intensive	26	31 (0.2)	11	15

Our results suggest that at least over the summer, non-target avian species occupancy on restored wetlands will not be affected by water diversion curtailments during drought periods. This is an important finding, especially considering that wetlands in the Central Valley often go unmanaged as water diversion curtailments go into effect. The Central Valley experienced severe to exceptional drought over the summer and fall in 9 out of 14 years between 2000 and 2014 (NDMC 2015). Multiyear droughts are a natural occurrence in California and are expected to recur in the future. Moreover, growing competition for limited water resources by cities and agriculture may result in fewer managed wetlands. A survey of wetlands restored under the Wetlands Reserve Program (WRP) in the Central Valley found that during the summers of 2008 and 2009, 10% to 30% were unmanaged, while another 20% to 48% were managed only sporadically (Duffy et al. 2011). The largest proportion of unmanaged wetlands lay in the Tulare subbasin in the southern Central Valley, a region that is prone to water shortages (Kahara et al. 2012).

Section 8: Models of Ecosystem Service Response to WRP in the Central Valley of California (CVC)

Objectives: To determine suitability of avian habitat across the Central Valley and the contribution of wetlands restored under the WRP in providing avian habitat. To assess the impacts of the multi-year drought on avian habitat in the CVC.

8.1. Methods

We used the Habitat Quality module of the Integrated Valuation of Environmental Services and Tradoffs (InVEST) modeling platform version 3.1.1 (Natural Capital Project 2014) to estimate waterfowl, shorebird and upland bird habitat in the CVC. We modelled habitat quality in relatively normal climatic years (2007-2009) and in years when the majority of the Central Valley of California(CVC) was classified under extraordinary drought for two or more consecutive years (2013 and 2014; NDMC 2015). We created land cover data layers using the National Agricultural Statistics Service (NASS) cropland data layers for each year. Data layers were reclassified in ArcMap 10.1 ™ (ESRI, Redlands CA) into 11 broad categories (Table 4). Areas enrolled under WRP were identified using a shapefile obtained from the USDA Natural Resources Conservation Service staff. We then estimated the quantity of avian habitat suitability in the years 2007, 2008, 2009, 2013 and 2014 using an output cell size of 50m and a half-saturation constant of selected as described in Sharp et al. (2014) for each guild. Output data layers were then used to create maps of habitat suitability in the Sacramento, San Joaquin and Tulare subbasins and within WRP easements.

Table 4: National Agricultural Statistics Service (NASS) cropland data layer reclassification classes and land uses covered by each class for this study.

Class	**Land use**
Back	Background, barren, clouds/no data, non-agricultural, undefined, perennial ice/snow
Corn	Corn, sweet corn, pop or orn corn
Grains	Sorghum, barley, durum wheat, spring wheat, winter wheat, other small grains, double crop winter wheat, rye, oats, millet, buckwheat, triticale
Grass	Speltz, other hay, non-alfalfa, sod, grass seed, switch grass, fallow idle cropland, shrubland, grass, pasture
Rice	Rice
Trees	Forest, cherries, peaches, apples, Christmas trees, other tree crops, citrus, pecans, almonds, walnuts, pears, deciduous forest, evergreen forest
Developed	Developed, developed open space, developed low intensity, developed medium intensity, developed high intensity
Other crops	Cotton, soybeans, sunflower, peanuts, tobacco, mint, canola, flaxseed, safflower, rape seed, mustard, alfalfa, camelina, sugar beets
Water	Water, aquaculture, open water
Wetlands	Wetlands, herbaceous wetlands
Woody wetlands (Riparian)	Woody wetlands

8.1.1. Waterfowl

In the waterfowl category we included dabbling and diving ducks as well as geese species recorded during surveys conducted in 2008 and 2009 by Kahara et al. (2012)(Appendix I). Habitat was ranked by importance ranging from 1 (low importance) to 3 (very high importance). High importance waterfowl habitat was defined as all wetlands (including herbaceous and woody). Rice, open water and aquaculture were also considered to be habitat, but were ranked as medium importance relative to wetlands as they may not provide adequate vegetation cover. Finally corn, grains and grass were also classified as low importance habitat as they may be used occasionally to provide food or roosting habitat for a few species of ducks and geese. The modeling platform InVEST assumes that habitats are influenced by nearby threats on the landscape and their potential suitability is degraded the closer they are to potential threats. We developed GIS threat layers reclassified from the NASS cropland data layers and mapped on a binary scale (0/1). Threats included (1) cropland, (2) trees and (3) developed areas. Cropland (under the “other crops” class in Table 6) was considered a threat to waterfowl habitat quality due to the potential for disturbance due to mechanical soil preparation (tillage, plowing, disking, etc.) and agro-chemical application (herbicide and pesticide spraying). Mechanical soil preparation may also increase the risk of sedimentation to adjacent water and wetlands. Trees including tree crops were considered a threat due to their potential to provide perches for aerial predators that prey upon waterfowl. Finally developed areas were identified as threats due to disturbance from vehicular traffic and other human activities.

Croplands were considered to be threats up to a maximum distance of 5km from habitats due to the application of aerial agro-chemicals. Development was considered a disturbance up to 5km due to the potential for noise pollution and feral predators. Lastly, trees were considered a threat up to 2km. Threat weight was set at 0.3 for all threats. We specified that each threat decay linearly to zero over the maximum distance specified linear decay of each threat.

8.1.2. Shorebirds

We based the shorebird category on approximately 32 species surveyed in 2008 and 2009 by Kahara et al. (2012) (Appendix I). High importance shorebird habitat was defined as rice paddies and grain cropland. Wetlands were ranked below rice and grains, while open water and woody wetlands were the least favorable. We assumed that shorebirds in the CVC are attracted to moist areas with sparse vegetation and shallow water ≤10cm deep. Irrigated rice paddies and grain fields may offer suitable conditions despite the potential for disturbance. Though the shorelines of wetlands may offer some habitat when irrigated, water depths may be too deep for shorebird use. Threats to shorebirds included (1) cropland, (2) trees and (3) developed areas, mainly due to their potential to create disturbance particularly to nesting and brood rearing birds. Crops were considered threats due to their potential to create disturbance due to mechanical soil preparation and agro-chemical application. Trees including tree crops were considered a threat due to their potential to provide perches for aerial predators that prey upon shorebirds. Finally developed areas were identified as threats due to disturbance from vehicular traffic and other human activities.

Croplands were considered to be threats up to a maximum distance of 5km from habitats due to the application of aerial agro-chemicals. Development was considered a disturbance up to 5km due to the potential for noise pollution and feral predators. Lastly, trees were considered a threat only up to 2km. Threat weight was set at 0.3 for trees, 0.5 for developed areas and 0.8 for cropland, with a linear decay rate to zero over the maximum distance specified.

8.1.3. Upland Birds

The upland bird category was based on approximately 109 species of upland birds, aerial feeders and aerial predators recorded during surveys conducted by in 2008 and 2009 by Kahara et al. (2012)(Appendix I). We modelled upland bird habitat for the years 2007, 2008, 2009 and 2014. Optimal upland bird habitat criteria was fairly broad including at the highest level, non-tree crop forests and riparian wetlands. Grasslands, tree crops and wetlands were included in the next tier of habitat. Finally grain crops and open water were classified as low quality habitat. The only threat we included to upland birds was development, due to the potential for human disturbance. Development was considered a threat up to a maximum distance of 5km due to the potential for noise pollution and feral predators.

7.2 Key Findings

7.2.1 Waterfowl Results

Overall, the model estimated about 318,660 ha of wetland bird habitat in the CVC in 2007 and 80,438ha in 2014 classified as low or intermediate quality suggesting a 75% decline in habitat. No habitat was classified as high quality in either year. The Sacramento subbasin accounted for 92% and 83% of all habitat in the CVC in 2007 and 2014. This is followed by the San Joaquin subbasin with just 6% in 2007 and 15% in 2014. While the least amount of waterfowl habitat was in the Tulare subbasin accounting for 2% in both 2007 and 2014. Waterfowl habitat declined in all subbasins in the CVC between 2007 and 2014 (Figure 7). The Sacramento subbasin lost the most habitat (225,337 ha) followed by the San Joaquin and finally the Tulare which lost 5,724 ha. Wetlands Reserve Program easements supported about 4,186 ha and 607 ha of waterfowl habitat in 2007 and 2014 respectively, which made up 1.3% and 0.8% of all waterfowl habitat available in the CVC.

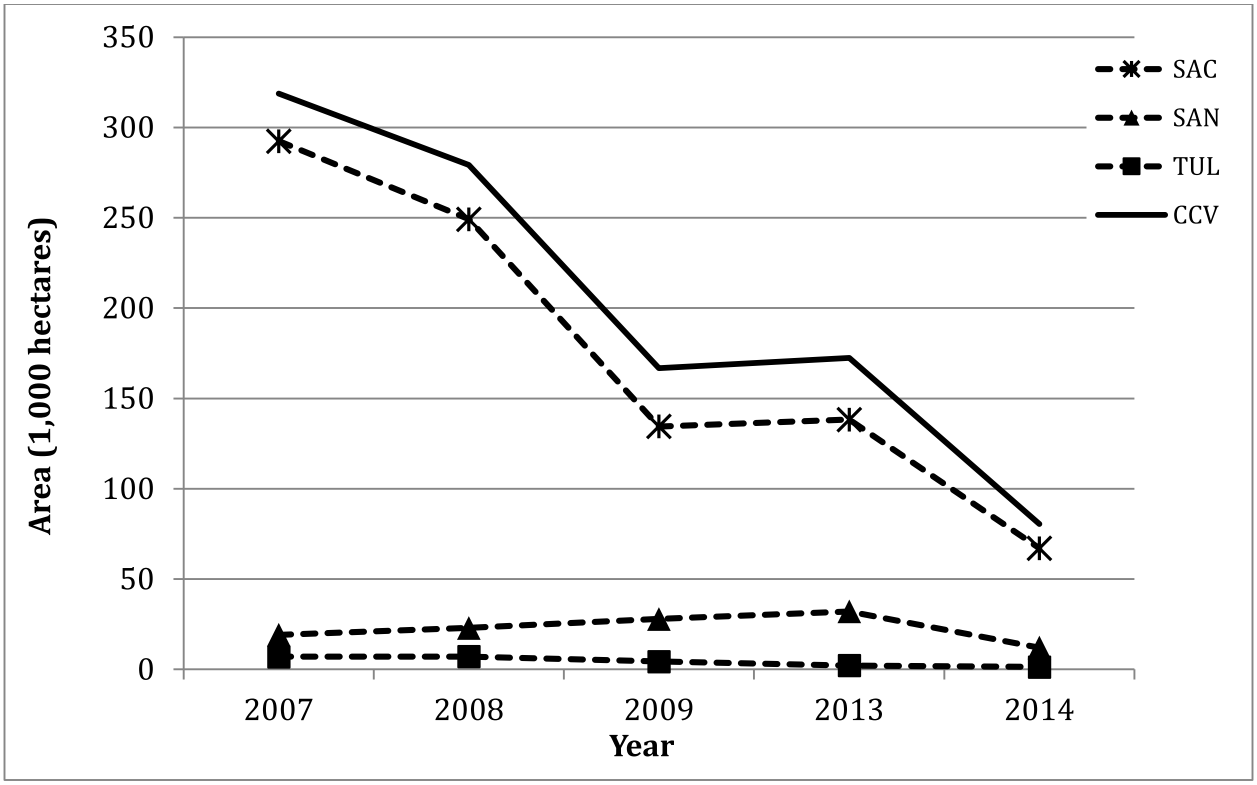


Figure 7: Optimal waterfowl habitat in the Central Valley of California (CVC) and in each of the three major subbasins in the CVC; SAC = Sacramento subbasin; SAN = San Joaquin subbasin and; TUL = Tulare subbasin.

7.2.2 Shorebird Results

Most shorebird habitat was classified as intermediate quality and no habitats were classified as high quality. Overall, shorebird habitat in the CVC did not decline by much (1%). The steepest decline occurred in the Sacramento subbasin (15%), while in other subbasins, shorebird habitat actually increased (35% in the San Joaquin subbasin and 14% in the Tulare subbasin) between 2007 and 2014. The model results indicate variable trends of increase and decline in habitat. In 2007, there was 549,064 ha of shorebird habitat, which increased to 711,884 ha in 2009. This was followed by a sharp drop in the amount of shorebird habitat at some period between 2009 and 2013. Shorebird habitat then increased in 2014 to 552,501 ha (Figure 8). The Sacramento subbasin accounted for the majority of shorebird habitat in all years, while the amount in the San Joaquin and Tulare subbasins were similar. Wetlands Reserve Program easements supported approximately

4,630 ha and 3,285 ha in 2007 and 2014 making up 0.8% and 0.6% of all shorebird habitat in the CVC. In 2013, WRP supported only 1,010 ha, which was 0.4% of shorebird habitat in the CVC.

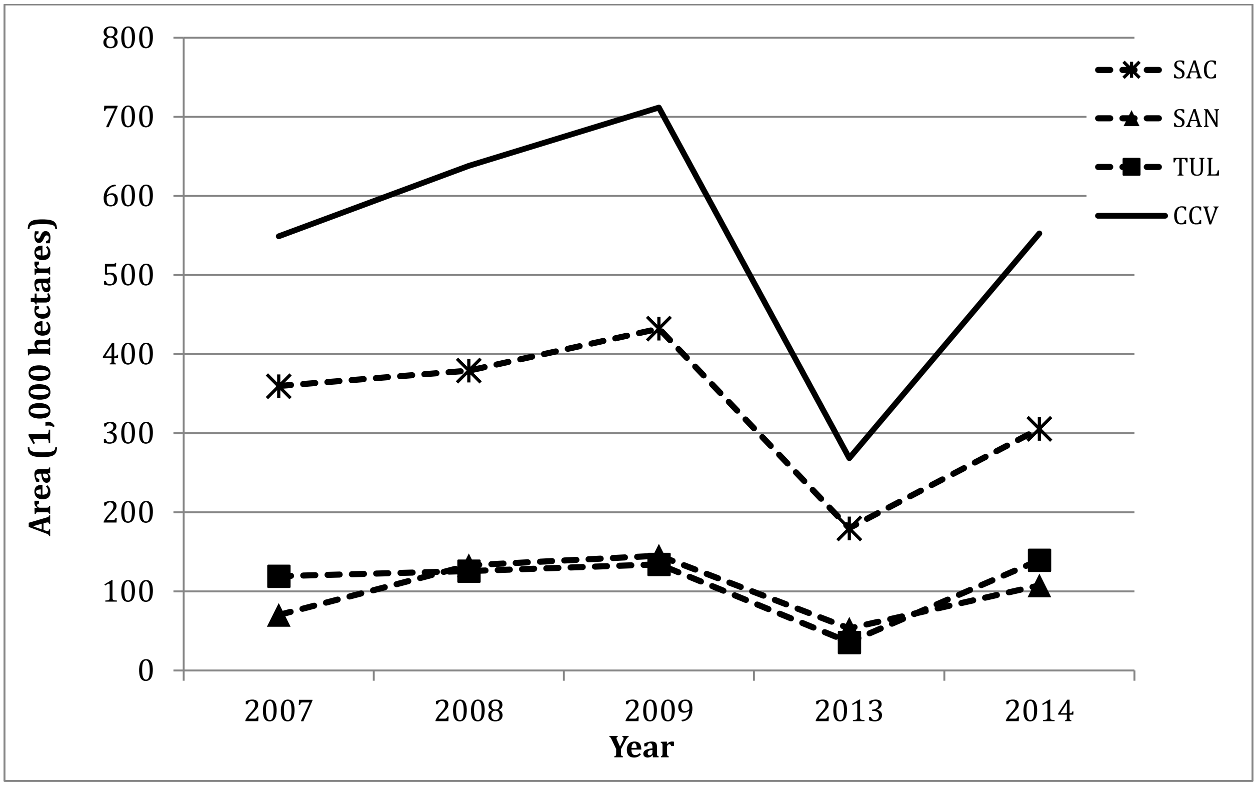


Figure 8. Optimal shorebird habitat in the Central Valley of California (CVC) and in each of the three major subbasins in the CVC; SAC = Sacramento subbasin; SAN = San Joaquin subbasin and; TUL = Tulare subbasin.

7.2.3 Upland bird Results

The model estimates that the CVC held 1,454,451 ha of upland bird habitat in 2007 and 1,673,844 ha in 2014 signifying a 13% increase (Figure 9). Most habitat was classified as low to intermediate, however, some high quality habitat occurred in years 2008, 2009 and 2014. Most upland bird habitat was in the Sacramento subbasin in the northern CVC. In 2007 the model estimates that there were approximately 18,607 ha of upland bird habitat on WRP easements while in 2014 there was 23,208 ha, an increase of 19.8%. This constitutes 1.3% and 1.4 % of upland bird habitat in the CVC in 2007 and 2014.

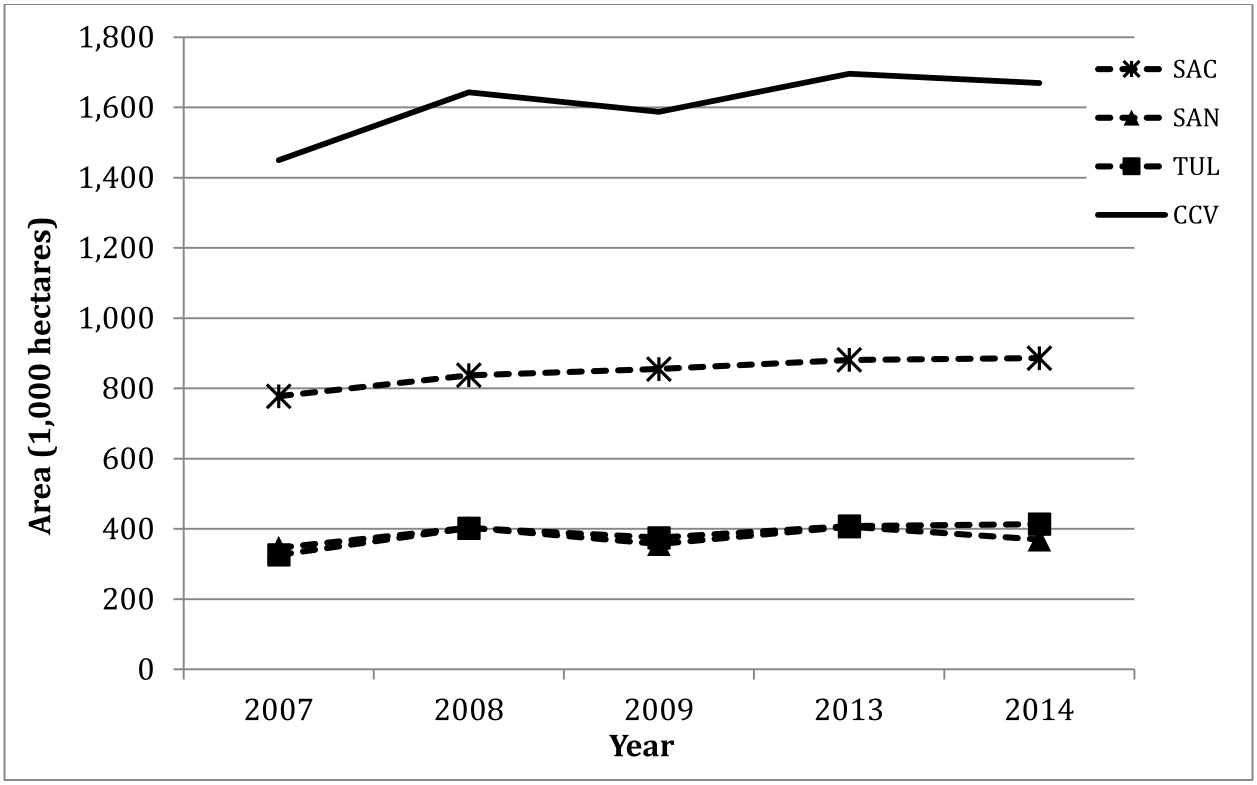


Figure 9. Optimal upland bird habitat in the Central Valley of California (CVC) and in each of the three major subbasins in the CVC; SAC = Sacramento subbasin; SAN = San Joaquin subbasin and; TUL = Tulare subbasin.

Our models indicate that most bird habitat lies in the northern CVC in the Sacramento subbasin. However, the northern CVC is also prone to significant fluctuations in habitat availability, particularly to wetland dependent waterfowl and shorebirds. We did not assess the impacts of the drought on management, however, our results suggest that surface water curtailments may have impacted wetlands by limiting water availability for irrigation and flooding during the growing season. Impacts on shorebirds may have been buffered by availability of irrigated rice and grain crops despite drought conditions. Future availability of irrigated crops such as rice may be decline as the multi-year drought forces further restrictions on water use by farmers.

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APPENDIX I: Species observed during surveys conducted in 2008 and 2009 on Wetland Reserve Program easements and categorized by foraging guild.

Foraging Guild	**Species recorded**
Aerial Feeder	ash-throated flycatcher, bank swallow, barn swallow, black tern, cliff swallow, dusky flycatcher, lesser nighthawk, northern rough-winged swallow, olive-sided flycatcher, Pacific-slope flycatcher, Say's phoebe, tree swallow, Vaux's swift, ,violet-green swallow, Western kingbird, Western wood-pewee, white-throated swift
Aerial Predator	American kestrel, bald eagle, barn owl, burrowing owl, Cooper's hawk, great horned owl, golden eagle, loggerhead shrike, merlin, northern harrier, peregrine falcon, prairie falcon, red-shouldered hawk, red-tailed hawk, sharp-shinned hawk, Swainson's hawk, white-tailed kite
Large Wader	black-crowned night-heron, cattle egret, great blue heron, great egret, green heron, sandhill crane, snowy egret, white-faced ibis
Dabbling Duck	green-winged teal, american wigeon, blue-winged teal, cinnamon teal, fulvous whistling-duck, gadwall, mallard, northern pintail, northern shoveler, wood duck
Geese/Swan	Canada goose, greater white-fronted goose, ross's goose, snow goose
Gull	California gull, herring gull, ring-billed gull
Marsh Bird	American bittern, American coot, common moorhen, common yellowthroat, marsh wren, red-winged blackbird, sora, tricolored blackbird, , Virginia rail, yellow-headed blackbird
Plunge Diver	belted kingfisher, caspian tern, Forster's tern, osprey
Surface Diver	American white pelican, bufflehead, canvasback, Clark's grebe, double-crested, cormorant, eared grebe, horned grebe, lesser scaup, pied-billed grebe, redhead, ring-necked duck, ruddy duck, Western grebe

APPENDIX I: Species observed during surveys conducted in 2008 and 2009 on Wetland Reserve Program easements and categorized by foraging guild.

Foraging Guild	**Species recorded**
Shorebird	American avocet, black-bellied plover, black-necked stilt, , greater yellowlegs, killdeer, long-billed curlew, long-billed dowitcher, least sandpiper, lesser yellowlegs, marbled godwit, pectoral sandpiper, red-necked , sanderling, short-billed dowitcher, semipalmated plover, snowy plover, solitary sandpiper, spotted sandpiper, stilt sandpiper, Western sandpiper, whimbrel, willet, Wilson's phalarope, Wilson's snipe, Western/least sandpiper
Upland Bird	acorn woodpecker, American crow, American goldfinch, American pipit, American robin, Anna's hummingbird, black-chinned hummingbird, Bewick's wren, brown-headed cowbird, black-headed grosbeak, blue grosbeak, black phoebe, brewer's blackbird, brewer's sparrow, Bullock's oriole, bushtit, California towhee, California quail, cedar waxwing, chipping sparrow, common raven, downy woodpecker, European starling, fox sparrow, golden-crowned sparrow ,greater roadrunner, grasshopper sparrow, great-tailed grackle, hermit warbler, house finch, horned lark, house sparrow, house wren, lark sparrow, lazuli bunting, lesser goldfinch, Lincoln's sparrow, mourning dove, Northern flicker, Northern mockingbird, Nuttall's woodpecker, oak titmouse, orange-crowned warbler, ruby-crowned kinglet, ring-necked pheasant, savannah sparrow, song sparrow, spotted towhee, Swainson's thrush, Townsend's warbler, turkey vulture, vesper sparrow, warbling vireo, white-breasted nuthatch, white-crowned sparrow, Western bluebird, Western meadowlark, Western scrub-jay, Western tanager, wild turkey, Wilson's warbler, wrentit, yellow-breasted chat, yellow-billed cuckoo, yellow-billed magpie, yellow-rumped warbler, yellow warbler

APPENDIX II. Temporal, local (on site), and landscape (within 10 km of the sampling site) covariates used in modeling wetland bird guild site occupancy of restored wetlands in the Central Valley of California, USA, 2008 and 2009. Landscape variables are proportional to the area of the buffer around each Wetland Reserve Program (WRP) site. Local variables are proportional to the area of the WRP unit sampled.

Covariate	**Scale**	**Description**	**Source**
AREA	Temporal	Size in hectares/100	Field data collection
YEAR	Temporal	Year samples collected (2008 or 2009)	Field data collection
AGE	Temporal	Time since restoration (Young/Old)	Field data collection
MANAGE	Local	Management intensity (see Table 2)	Field data collection
SUBBASIN	Landscape	Latitudinal placement by sub-basin	Field data collection
VISIT	Temporal	Chronological order of sampling visits	Field data collection
RICE	Landscape	Proportion of rice	Cropland Data Layer
CORN	Landscape	Proportion of corn	Cropland Data Layer
ROW	Landscape	Proportion of row crops	Cropland Data Layer
GRAINS	Landscape	Proportion of grain/seed crops	Cropland Data Layer
TREE	Landscape	Proportion of tree crops	Cropland Data Layer
CULCROP	Landscape	Proportion of cultivated cropland	Cropland Data Layer
OTHER	Landscape	Proportion of all remaining crops	Cropland Data Layer
UNCULT	Landscape	Proportion of non-forested, undeveloped upland	Cropland Data Layer
WOODS	Landscape	Proportion of forest/woodland	Cropland Data Layer
SHRUB	Landscape	Proportion of surrounding scrub-shrub and herbaceous vegetation	Cropland Data Layer
WETLD	Landscape	Proportion of wetlands	Cropland Data Layer
DEV	Landscape	Proportion of urban/developed areas	National Land Cover Dataset
HABV	Local	Number of wetland zones present used as an indicator of habitat complexity	Field data collection
DEPTH	Local	Average open water depth/100	Field data collection
PPNUP	Local	Proportion of upland/grassland relative to the area of the site	Field data collection
PPNMS	Local	Proportion of moist soil relative to the area of the site	Field data collection
PPNSE	Local	Proportion of shallow emergent vegetation relative to the area of the site	Field data collection
PPNDE	Local	Proportion of deep emergent vegetation relative to the area of the site	Field data collection
PPNOW	Local	Proportion of open water relative to the area of the site	Field data collection