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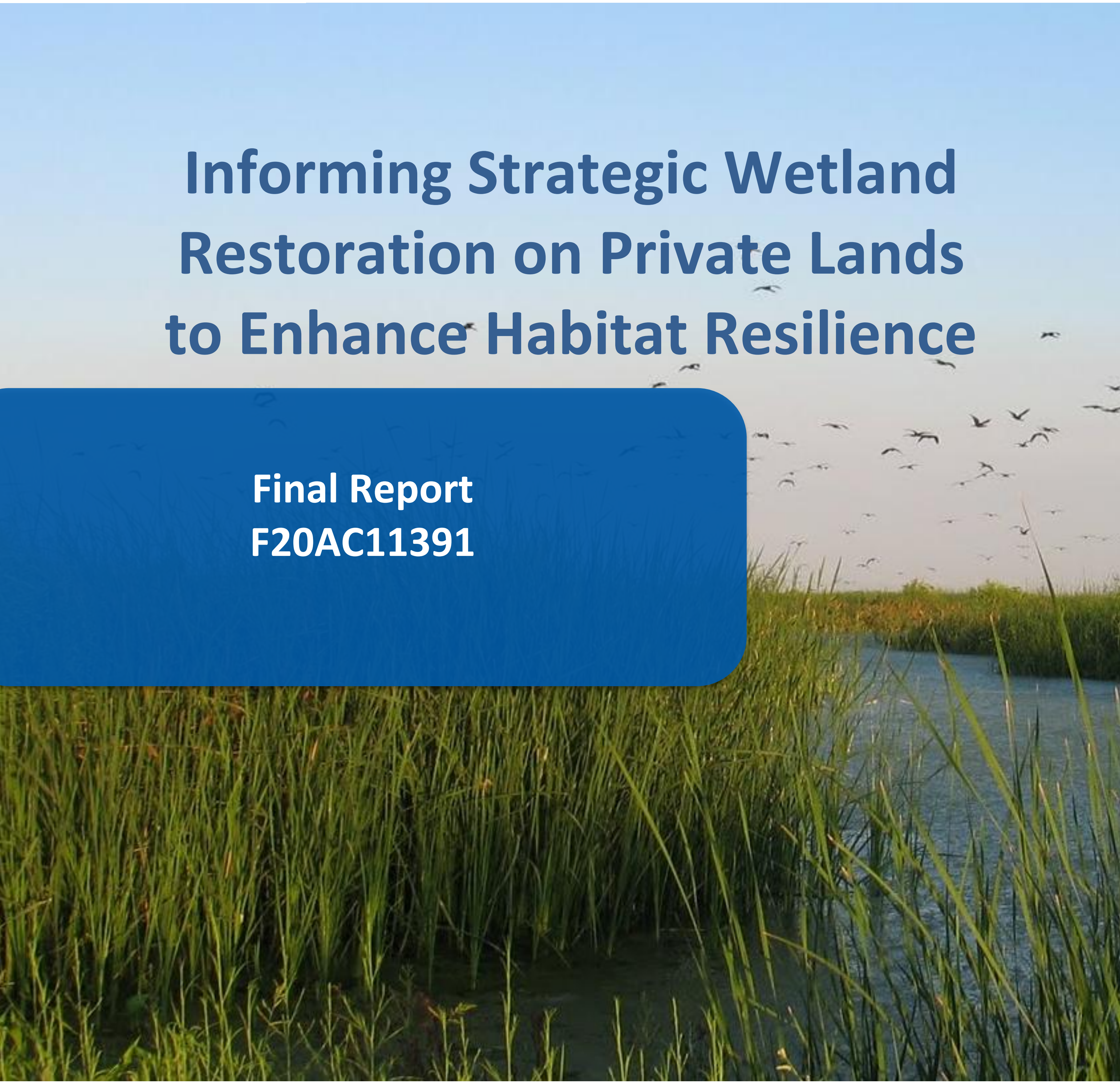
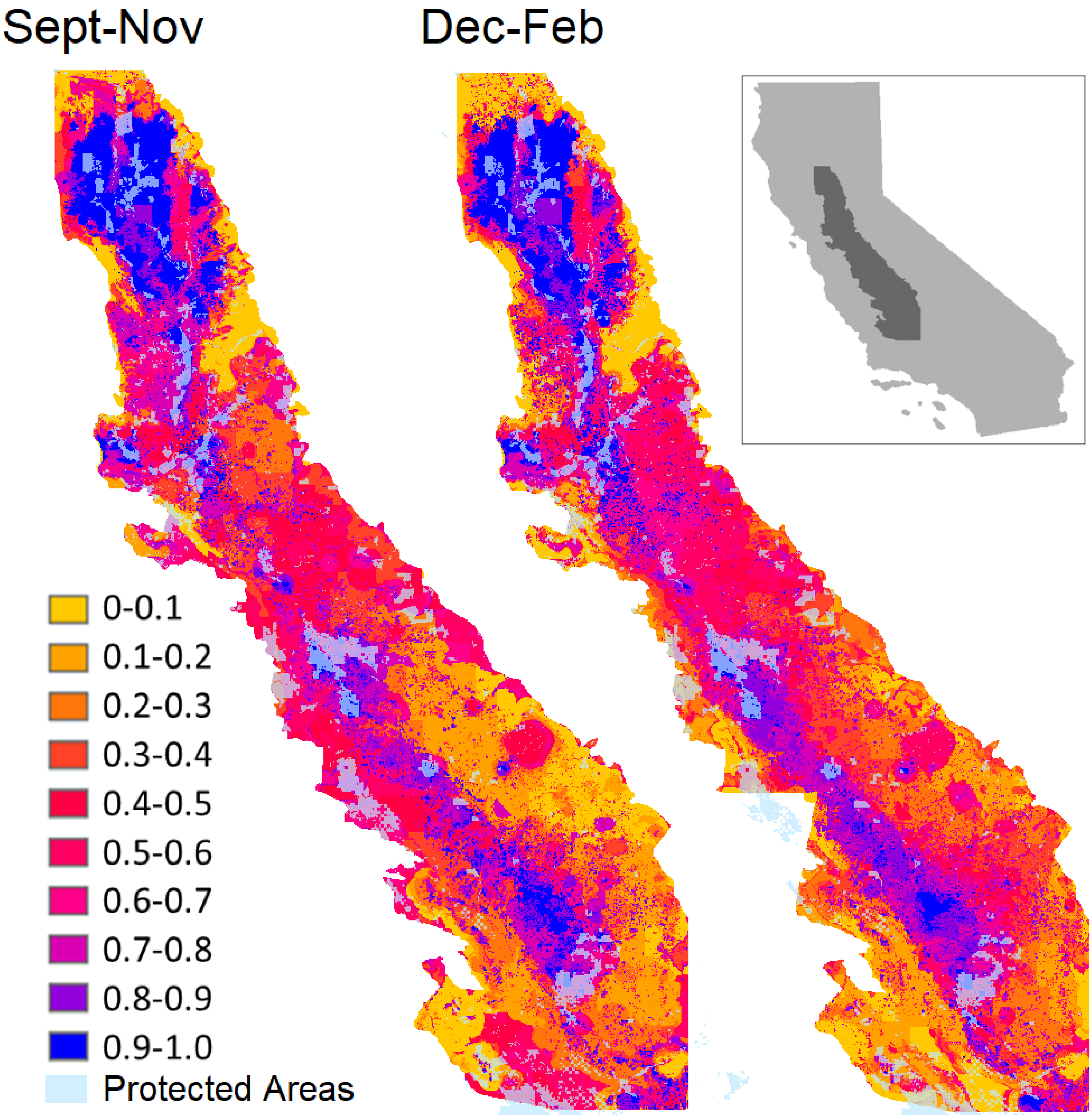


Informing Strategic Wetland Restoration on Private Lands to Enhance Habitat Resilience

Final Report
F20AC11391

December 2025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Protected Areas

Informing Strategic Wetland Restoration on Private Lands to Enhance Habitat Resilience in the Central Valley of California

Final Report 2025

F20AC11391

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Point Blue Conservation Science – Point Blue's 160 scientists work to reduce the impacts of climate change, habitat loss, and other environmental threats while developing nature-based solutions to benefit both wildlife and people.

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Summary

Background and Purpose

This report outlines a comprehensive spatial prioritization effort designed to help the U.S. Fish and Wildlife Service's Partners for Fish and Wildlife Program strategically identify and evaluate wetland restoration opportunities on private lands across California's Central Valley that provide the greatest conservation benefits.

Approach

We combined existing species distribution models with the Zonation spatial prioritization algorithm to identify high-value restoration areas. The analysis evaluated habitat suitability for eight waterbird species and the federally threatened giant garter snake across four seasons. Three scenarios were examined: current land cover conditions, future flooding predictions (incorporating climate change and land-use changes to 2041), and simulated wetland restorations across 96,395 potential 90-acre sites.

Key Findings

Current Conditions: The largest blocks of unprotected high-priority habitat given the current landcover and flooding patterns occur in the northern Sacramento Valley, particularly around Gray Lodge Wildlife Management Area, and Sacramento and Delevan National Wildlife Refuges. The distribution of priority habitat remains relatively stable across fall, winter, and spring seasons. Much existing high-quality habitat is already protected, though significant conservation gaps remain.

Species Influence: Including giant garter snakes shifted priority areas substantially toward the Sacramento Valley due to their limited range. Bird-only prioritizations distributed priority more evenly across the Central Valley. Given the current landscape, the Tulare Basin shows lower overall priority but contains important seasonal habitats, particularly around the former Tulare Lake. However, the Tulare Basin has the potential for high suitability if restoration is conducted there. See restoration potential below.

Future Scenarios: Predicted water availability increase priority in the Sacramento Valley, where less conversion to unsuitable perennial crops is expected. The Tulare Basin faces potential increases in orchards, making current restoration efforts there more urgent to prevent habitat loss.

Restoration Potential: Simulations of new wetland restorations revealed that shorebird priority areas concentrate in the southern Central Valley near former Tulare Lake, while duck priority areas are more evenly distributed. Combined prioritizations identified high-value restoration opportunities across multiple regions, with particularly large patches in the Tulare Basin.

Management Implications

Our analysis highlights a fundamental decision for limited resource allocation: invest in "tried-and-true" high-priority areas (primarily Sacramento Valley) where past efforts have succeeded and where restorations may also benefit the giant garter snake or pursue "biggest-improvement" opportunities in currently lower-priority regions like Tulare Basin before irreversible land-use conversion occurs.

Recommendations

- Post-restoration monitoring to evaluate restoration effectiveness in different landscape contexts
- Considering seasonal patterns when selecting restoration sites, though high-priority areas show considerable overlaps across seasons
- Using provided prioritization maps and R-based tools to evaluate specific restoration proposals
- Balancing species-specific needs (particularly for threatened garter snakes) against broader waterbird conservation goals

All spatial data products, prioritization maps, and analysis tools have been provided to support ongoing decision-making by the Partners Program in targeting restoration investments for maximum wildlife benefit.

Introduction

Within the USFWS Habitat Restoration Division in the Pacific Southwest Region (Region 8), the United States Fish and Wildlife Service's (USFWS) Partners for Fish and Wildlife Program (Partners Program) is tasked with planning, designing, and implementing habitat restoration projects on private lands in support of the USFWS's local, regional, and national priorities. The Partners Program is specifically mandated to manage priority species, priority habitats, and the National Wildlife Refuge System (Barry 2017). This mission includes enhancing and restoring priority habitats for functional connectivity and ecosystem services. A key challenge to this mission is determining which restoration projects are most likely to have the largest benefit in a particular area. To address this challenge, we describe the creation of prioritization maps which combine habitat modeling and subsequent spatial prioritization of waterbirds and snakes in the Central Valley of California. The resulting map products can then be used to determine restoration priorities within the Partners program.

The Pacific Flyway Management Region within Region 8 is a semi-arid region that is a nexus for water resources in California (Tanaka et al. 2006, Lund et al. 2007). Due to development and agriculture, 90% of the naturally occurring wetlands in California's Central Valley have been lost. Despite this loss, the region supports critical habitat for migratory waterfowl and shorebirds through a system of managed wetlands and post-harvest flooded agriculture (CVJV 2020). Beyond waterbirds, the region supports freshwater dependent aquatic and terrestrial species, including the giant garter snake, a species listed as federally "threatened" (Howard et al. 2015).

In its most recent strategic plan, the Partners Program seeks to restore or enhance 2,950 acres of managed seasonal and semi-permanent wetlands in the Pacific Flyway Management Region. However, to make the most of these restorations the Partners Program is looking to use Strategic Habitat Conservation (SHC) coupled with Landscape Conservation Designs (LCD) to provide a clear framework for setting priorities, evaluating scenarios, choosing projects, and evaluating and learning from the implemented projects. Specifically, the program seeks a quantitative estimate of what locations will provide the greatest conservation benefit to multiple wetland-dependent species.

Spatially explicit conservation prioritization has increasingly been used to identify strategies to support landscape-scale decision-making to meet multiple objectives in the face of great uncertainty and multiple constraints (Letomaki and Moilanen 2013). Common algorithms for conservation prioritization include Marxan, C-Plan, and Zonation (Kukkala and Moilanen 2017). We used Zonation which has been used across a wide variety of systems, including: forest tree conservation in Finland (Arponen et al. 2012), ecosystem services in Europe (Kukkala and Moilanen 2017), and forest bird conservation in North America (Stralberg et al. 2015). A similar landscape-scale analysis, taking advantage of existing data and biological observations is needed for the Central Valley to prioritize where to put water and wetland habitat and how to optimize multiple-benefits.

Recent collaborations between Point Blue Conservation Science, USFWS, USGS, and The Nature Conservancy have developed tools to determine where, when and how to restore and manage water and wetlands to maximize benefit for wildlife. In particular, the team has sought to find locations that maximize habitat benefits for waterfowl, shorebirds and the giant garter snake in the face of annual variation and long-term change in climate and land-use. This work has resulted in the development of a system to track water and wetlands in the Central Valley – Water Tracker (www.pointblue.org/watertracker) – and the application of these data to understand the impact of extreme drought and incentive programs on wetland habitat (Reiter et al. 2015, 2018). Additionally, we have developed data sets on the distribution of moist soil seed wetland plants and their annual productivity for the period 2007-2024 (Byrd et al. 2020; Point Blue, unpublished data). Using these wetland habitat data we constructed suitability models for waterfowl (Conlisk et al. 2023), shorebirds (Conlisk et al. 2021), and giant garter snakes. Finally, we have created future projections of the land use and water availability in the Central Valley (Wilson et al. 2021). Decisions on where to put restoration today should consider plausible scenarios of the future landscape to ensure there is value in that restoration for both today and 20-25 years from now (the duration of conservation easement on private lands; see Veloz et al. 2011). Taken together, the existing spatial products on habitat and species distributions in the Central Valley offered the opportunity for a robust spatial prioritization analysis that includes: (i) habitat suitability under existing land cover, (ii) habitat suitability combined with future, predicted flooding, and (iii) habitat suitability assuming conversion of existing land cover to wetlands.

Study Area

Bounded by the Transverse, Sierra Nevada, Klamath, Cascade, and Coastal Range mountains, the California Central Valley extends approximately 400 km north to south and from 50 to 100 km east to west (Reiter et al. 2018). This wide, flat valley is an area of high agricultural productivity within a Mediterranean-type climate. Surface water in the Central Valley is largely fed by melted snowpack and stored in an extensive dam and levee system. Roughly 250 different crops are grown in the Central Valley, with rice cultivation dominating the northern portion of the Central Valley, called the Sacramento Valley. Less than 10% of the original Central Valley wetland area remains and these remaining wetlands are heavily managed by public and private owners. Waterbirds were sampled throughout the Central Valley, using a combination of 2006 and 2020 CVJV boundaries (CVJV 2006 and 2020). Giant garter snakes were sampled in the Sacramento Valley within the region outlined in the draft Recovery Plan for the Giant Garter Snake (US Fish and Wildlife Service, 2011).

Objectives and Approach

We leveraged the existing data and models to develop tools to enable the Partners Program to be more strategic in where to target restoration by developing an approach to help determine where to prioritize new restorations. To do this we have completed the following objectives:

1. Worked with the Partners Program to clearly identify the restoration objectives and goals of the prioritization.
2. Combined existing suitability maps using spatial prioritization techniques to identify relative priority for conservation across the landscape given different weighting of target species under current and two future land-use and climate change scenarios (20–30-year time horizon).
3. Extracted spatial priority data from all prioritizations for all non-protected private lands
4. Developed framework for Partners to leverage new spatial prioritization data sets to evaluate the value of proposed wetland restorations in areas that are not currently wetlands.

Objectives 1 - 3

Methods

Bird Species Distribution Models

Below we briefly describe the species distribution models. Additional methodological details of the bird species distribution models can be found in Conlisk et al. 2021 and Conlisk et al. 2023.

Bird data

We modeled habitat for three common migratory dabbling duck species: Northern Shoveler (*Spatula acuta*), Green-winged Teal (*Anas. crecca*), and Northern Pintail (*A. clypeata*). We also modeled five species of shorebirds: Dunlin (*Calidris alpina*), Black-necked Stilt (*Himantopus mexicanus*), American Avocet (*Recurvirostra americana*), and Long- and Short-billed Dowitchers considered as a single taxon (*Limnodromus griseus* and *L. scolopaceus*). These species were chosen because they are abundant and there was ample occurrence data, making them good indicators of wetland health within the Central Valley during the non-breeding season. The shorebird species also represent different migratory strategies, with Avocets and Stilts breeding in the region (Shuford et al. 2004) and Dunlin and Dowitchers breeding in arctic and sub-arctic regions and tending to move in larger flocks (Shuford et al. 1998a). We defined the nonbreeding season for ducks as all months except May-August. For Dunlin, Avocet, and Stilts, we considered all months except May and June; for Dowitchers, because of biases in the data, we considered all months except May through September. To model suitability, we used the community science eBird reference dataset (ERD) from 2000-2016 (Sullivan et al. 2009) and scientist-collected, structured datasets from 2010-2014 (see Conlisk et al. 20221, 2023 for more details on bird data).

Covariate data

We considered numerous covariates likely to influence the distribution of the species of interest in our models. To estimate surface water in the Central Valley, we used estimates of surface water every 16 days provided by Landsat satellite data (Reiter et al. 2015). Long-term average flooding was derived by averaging the 16-day satellite water estimates within a given month across 2001-2017. To determine flooding in otherwise suitable habitat, we overlaid average surface water layers on land cover data from the National Cropland Data Layer (USDA 2014). The result of multiplying a map of the fraction of time the landscape was flooded (ranging from 0 to 1) with binary cover type maps were layers that described fractional flooding in suitable land cover types (listed in Appendix A, Table A1).

We then matched bird observations to the average flooding conditions within the month of the bird observation (e.g., for a bird observed in December, we took the average flooding for the 17 Decembers from 2001-2017). For each observed bird location, we calculated landscape characteristics at two scales: the scale of the bird observation (0.25-km radius) and within a 5-km radius around a given observation. The result was the amount of flooded habitat (e.g. flooded wetlands, flooded rice, flooded corn, and flooded row field or grain crops) within a 0.25-km and 5-km radius around a given bird observation (see Appendix A, Table A2 for complete list of covariates).

In addition to calculating the proportion of flooding within each of the cover types, we considered some non-water related covariates including road density, observation type (eBird or structured), and maximum temperature observed for that month and year (Flint and Flint 2014). We did not include month as a covariate because we found that surface water availability was sufficient to capture the seasonal signal. We targeted the non-breeding season (all months except May and June for shorebirds and May through August for ducks) because our target species populations are most abundant in the Central Valley during the non-breeding season.

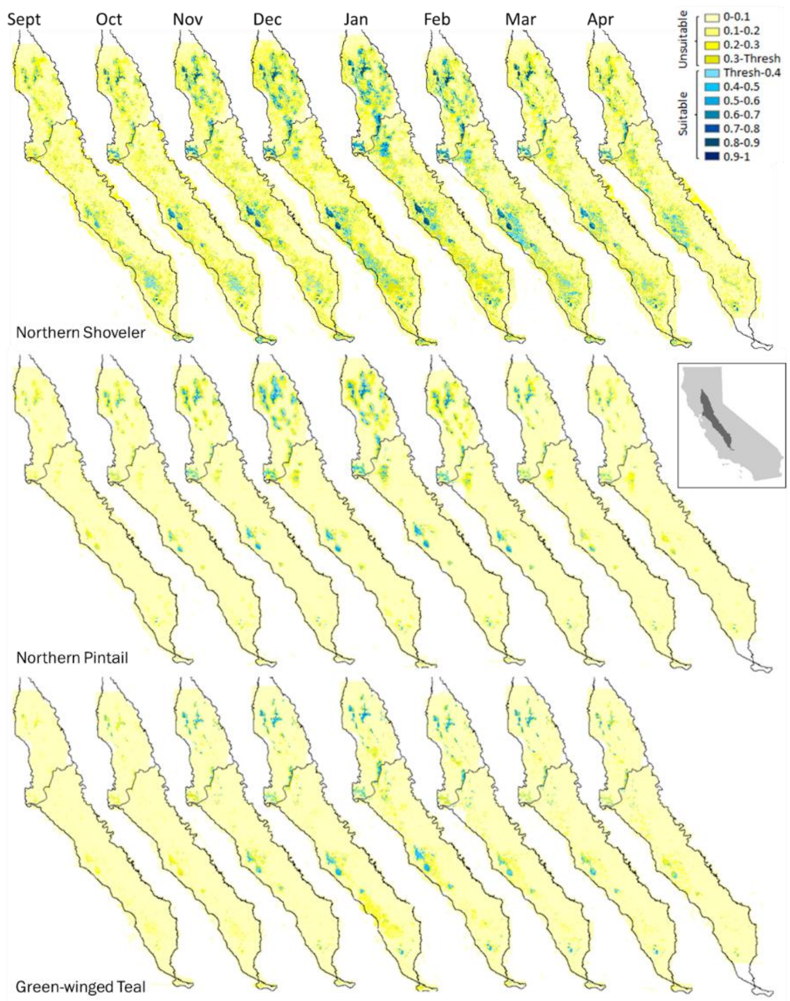

Figure 1. Monthly predictions of suitable habitat for Northern Shoveler (top), Northern Pintail (middle), and Green-winged Teal (bottom). Inset shows California (light gray) and 2006 Central Valley Joint Venture boundaries (dark gray) used for duck suitability predictions.

Statistical approach

We used boosted regression trees (Elith et al. 2008) to model species occurrence (namely presence or absence) weighted by the natural log of abundance. Model output, which we call "suitability", can be interpreted as the likelihood of recording a species present at the location in each month. Because of differences in land cover composition in the North and South portions of the Central Valley, we created an ensemble of two models with restricted spatial extent (similar methodology was employed in Fink et al. 2010).

Bird distribution maps

Duck and shorebird species distribution maps under the current landscape cover types are shown in Figures 1-3.

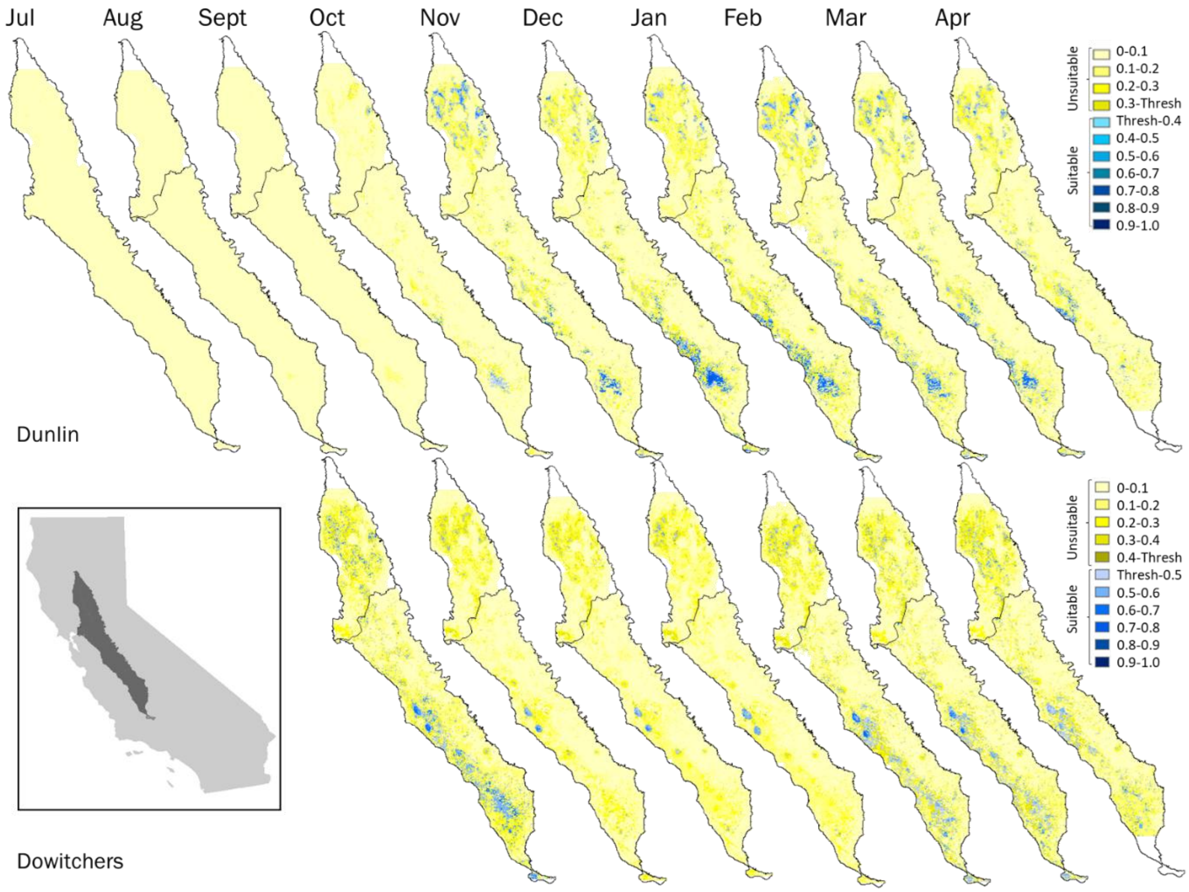

Figure 2. Monthly predictions of suitable habitat for Dunlin (top) and Dowitchers (bottom). No predictions were made for Dowitcher from July-September because of bias in the observation data. Inset map shows California (light gray) and 2006 Central Valley Joint Venture boundaries (dark gray) used for shorebird suitability predictions.

Snake Species Distribution Models

Below we describe the species distribution models for the giant garter snakes (*Thamnophis gigas*). We provide more detail for the snake modeling than for the birds because the methods for the garter snake models have not been published elsewhere.

Giant Garter Snake Data

Giant garter snake data were collected from 2003-2013 in locations of rice agriculture or restored marsh habitat suitable for occupancy by giant garter snakes (Halstead et al., 2010, Halstead et al. 2014). The exact duration and intensity of snake sampling across transects was highly variable due to the different management and research objectives of the sampling. Typically, floating funnel traps were deployed along transects, where a transect was composed of several traps placed in a line at 10-20-meter intervals, typically along a canal or drainage. Most transects (4513 of 8687 transect-days) had 50 traps, but 15 transects had fewer than 10 traps and some transects had up to 246 traps. A total of 294 transect-years were sampled, with some sites being sampled across multiple years.

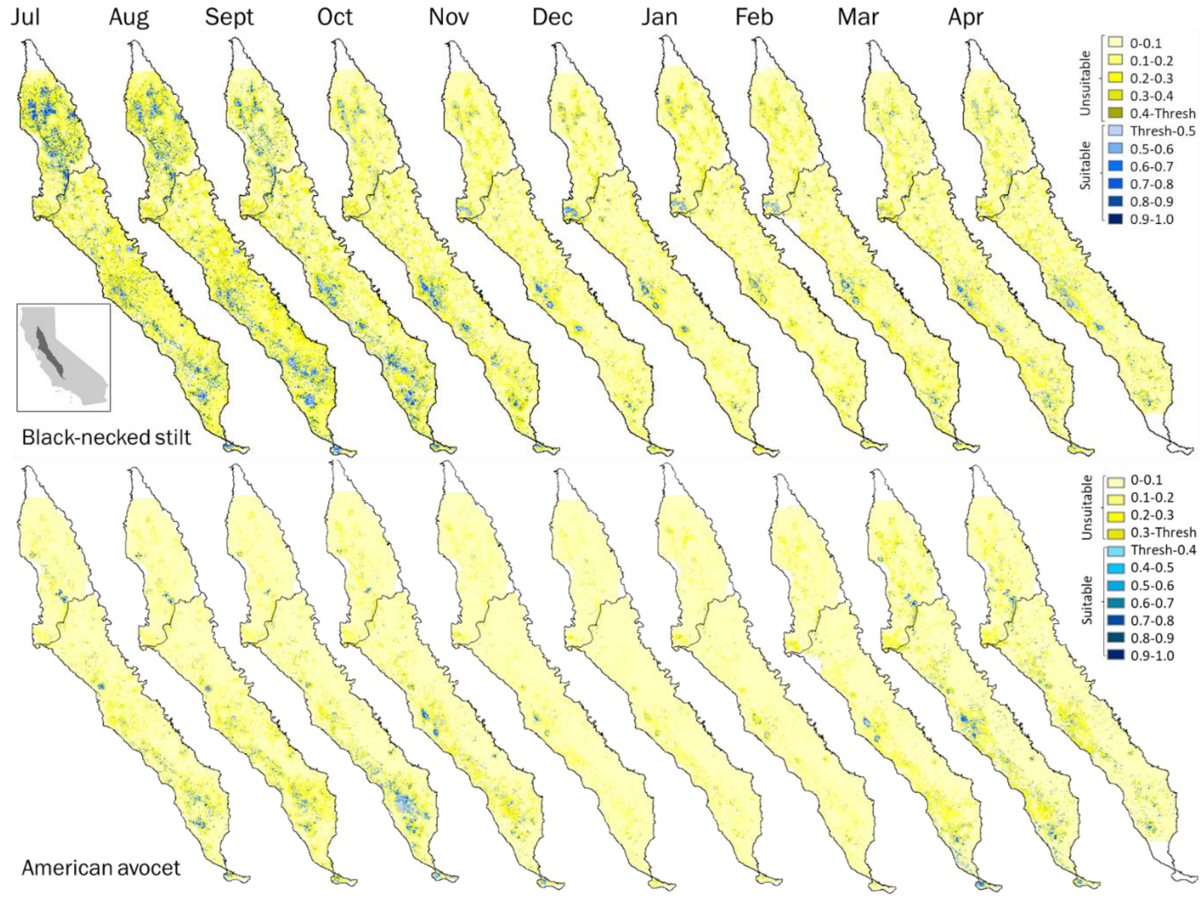

Figure 3. Monthly predictions of suitable habitat for Black-necked Stilt (top) and American Avocet (bottom). Inset map shows California (light gray) and 2006 Central Valley Joint Venture boundaries (dark gray) used for shorebird suitability predictions.

Traps were set up for anywhere between 1 to 151 days starting as early as 9 April and ending as late as 17 October. We truncated the observation period to only the days when >75% of the traps on the transect were open. The median number of days that a transect was open was 19, but we had 14 transects open more than 100 days and 66 transects open fewer than 10 days. Figure 4 shows the temporal sampling for each of the transects. Excessively long transects were divided into smaller transects, as we expected similarity of environmental conditions to decay with distance.

The original dataset recorded the number of snakes caught on each trap, however, we found that negative binomial and Poisson models (zero-inflated and otherwise) did not meet the test assumptions. Thus, we only modeled presence and absence, where a snake was "present" in a transect if at least one snake was observed along the transect.

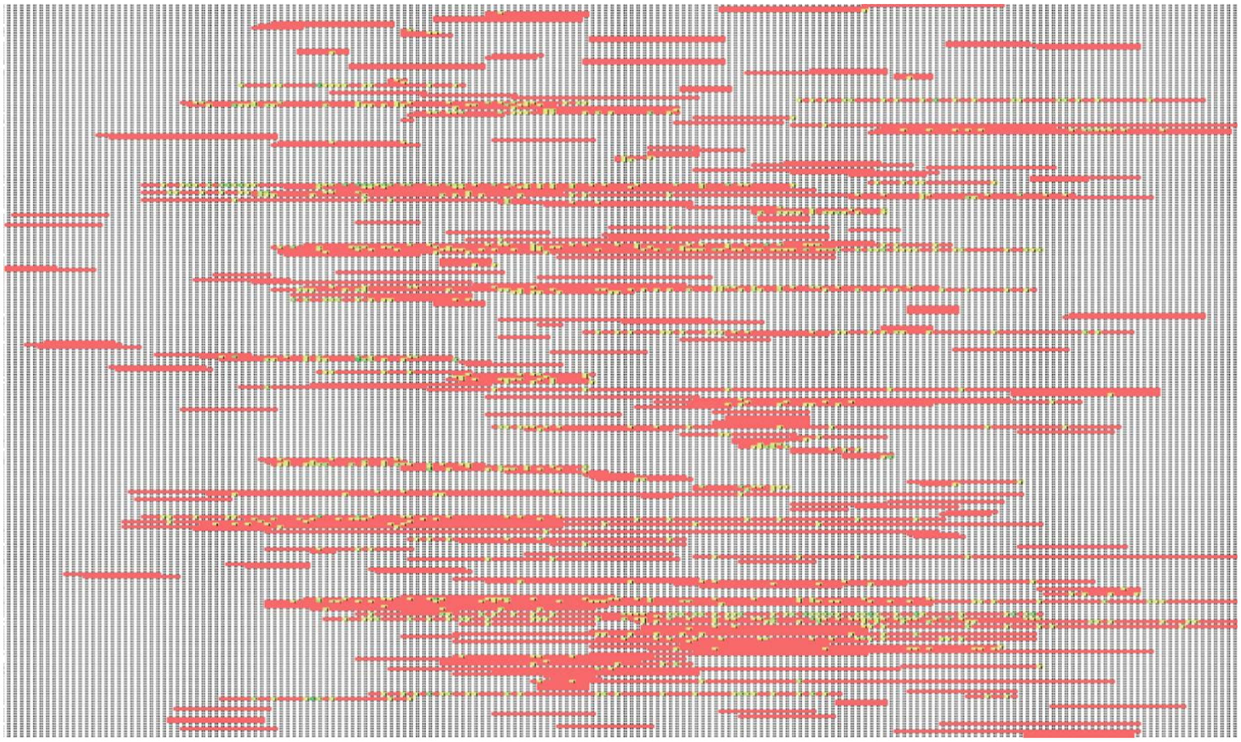

Figure 4. Trapping effort for Giant Garter Snake. Each row is a transect-year. Each cell in the row is a day. The first column (far left) is 9 April, and the last column (far right) is 17 October. The red cells in the table are locations where snakes were not observed. The green cells in the table are locations where snakes were observed.

Covariate Data

Like shorebirds, we assumed that habitat suitability would be defined by the amount of flooded habitat within a radius around a given snake observation. Unlike birds, giant garter snakes have limited dispersal ability and are most active in the late spring, summer, and early fall (April-October). We assumed that the long-term average in the timing of flood-up and drying would be important across snakes' active period. Thus, we considered the average fractional flooding (from 2001-2011) in rice and wetlands habitat within a 1-km buffer around all the traps on a transect for every two-week window from 1 March to 15 October. In particular, we were interested in whether the timing of flooding within wetlands and rice strongly influenced snake presence.

Statistical analysis

We used mixed effects binomial models with transect and year as random effects to account for repeated observations across years and transects. Considering all two-week windows of flooded rice and wetlands for March through October resulted in too many covariates for a dataset that recorded snake presence on only 293 transects. To reduce the number of variables, we performed univariate tests on each of the two-week flooding variables. We choose the four best flooded rice and wetlands covariates and put every combination of one rice and one wetlands covariate in a model with stream and canal covariates, phenological variables (where timing of rice and wetlands green-up may be related to snake suitability), the number of traps, and day-of-year. We found that the phenological "green-up" variables and stream variables were unimportant and did not consider them further. The final model was chosen based on having the lowest Akaike's Information Criterion (AIC; Burnham and Anderson 2002).

Model validation and performance

To determine whether the model had reasonable power to discriminate between locations where snakes were present or absent, we calculated AUC values across with-held validation data for each of the four basins in which a snake had been observed (American, Butte, Colusa and Sutter basins). The AUCs across the American, Butte, Colusa, and Sutter basins were 0.69, 0.89, 0.48, and 0.72, respectively. We also calculated the AUC for validation datasets across each of the ten years in the dataset. The mean AUC across the ten years was 0.64 (with range 0.44-0.81).

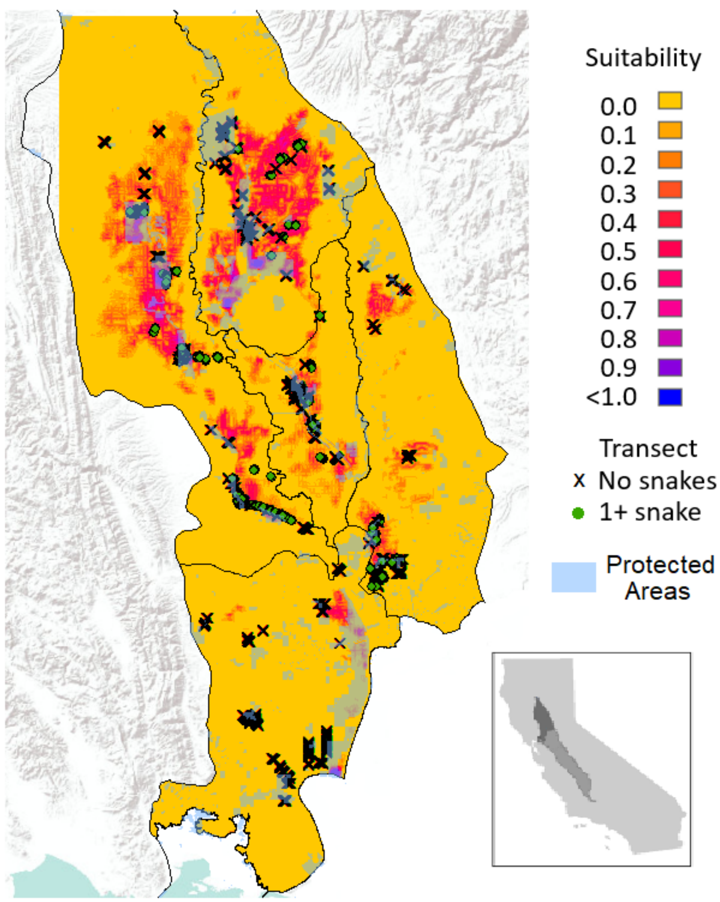

Figure 5. Map of suitable snake habitat, locations where snakes were present (green dots) and absent (black x's), and protected areas (light blue overlay). Inset map shows California (light gray), 2006 Central Valley Joint Venture boundaries (medium gray), and Sacramento Valley boundaries (dark gray) used for snake modeling.

Incorporating Future Flooding Resiliency

Below we briefly describe land use change models. Additional methodological details can be found in Wilson et al. (2022).

Land Use Change Modeling

In the future, urbanization, agricultural transitions, and water availability are likely to impact the availability of flooded habitat for shorebirds and waterfowl. The vulnerability of habitat within the Central Valley of California was analyzed using a land use change model (LUCAS, Sleeter et al. 2015) coupled with a water allocation model (WEAP, Matchett et al. 2015, 2017). Two potential future themes - water availability and conservation management - were crossed to yield four scenarios: (1) high water and poor management, (2) high water, good management, (3) low water, poor management, and (4) low water, good management (Wilson et al. 2022). In this analysis, we used the fourth scenario and considered model results for the year 2041.

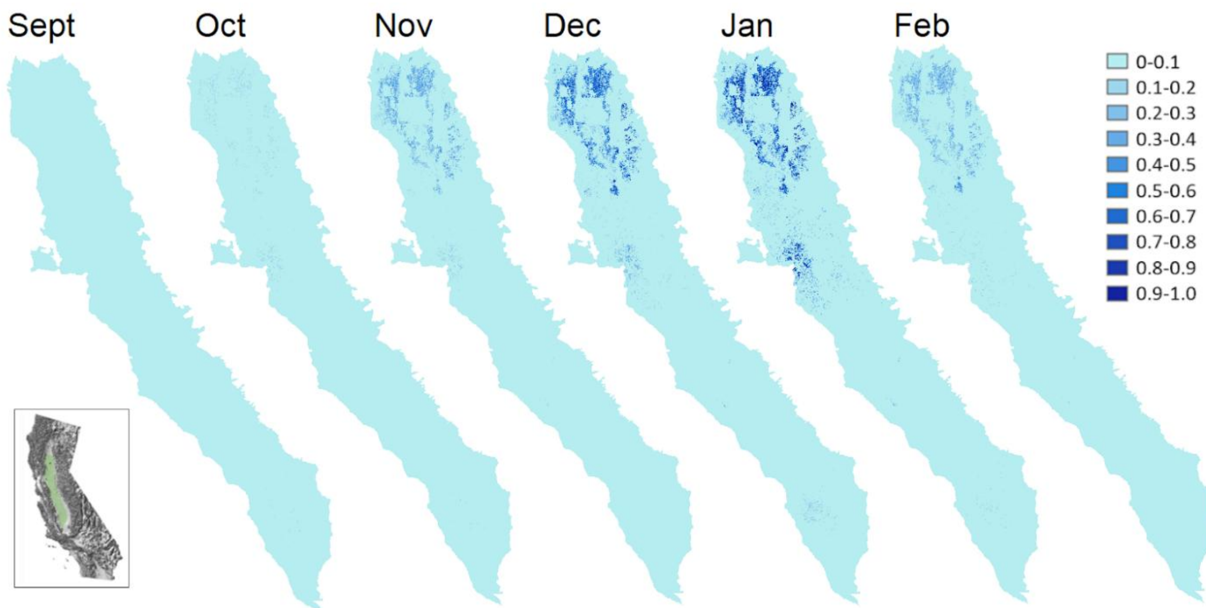

Figure 6. Map of predicted water availability in suitable crop cover types (rice, corn, field, row, and grain) in the Central Valley from September-February 2041. Legend describes the likelihood (0-1) that the region will be flooded each month. Inset map shows California (gray) and the Central Valley (light green).

Future Flooding

We used outputs from the Wilson et al. (2022) models to estimate the locations that are likely to remain as suitable habitat in addition to the fraction of the time that portion of the landscape is likely to be flooded (Figure 6). Locations that were still suitable cover types in the modeled year 2041 were then multiplied by the predicted flooding in the same year. In spatial prioritizations the locations that were suitable habitat and flooded in 2041 were given higher weights. Future flooding maps were very similar to existing flooding with loss of flooded habitat around the borders of where current flooding occurs. There was no predicted flooding in suitable crop types in March through August. In the future scenario that we used which included low water but good wetland management, flooding in March and April was preferentially allocated to wetlands leaving little flooding in crops. Because of the lack of flooding in March through August, we only considered the future maps for September through February (fall and winter), months during which the garter snake was largely inactive.

Spatial Prioritization

Algorithm

We used the Zonation 4 software to prioritize habitat across our nine focal species and the four seasons. The algorithm proceeds by iteratively removing the least valuable grid cells from the landscape according to user-specified priorities and landscape connectivity (Moilanen et al. 2005, 2007, 2014 and van Teeffelen & Moilanen 2008). The result is a map that gives every pixel a score based on when the pixel was removed from the landscape. Grid cells with low values were removed early (e.g. a value of 0.10 means that the grid cell was removed when only

10% of grid cells had been removed) and high values were removed later (e.g. a value of 0.90 means only 10% of grid cells remained as potentially more valuable).

We used the core-area zonation (CAZ) where priority is decided based on the maximum suitability value of a cell across species. This allows grid cells to be kept because they are the core area of at least one of the species being considered. Connectivity can be accounted for in many ways. We used the default "edge removal" feature which preferentially removes grid cells on the edge of the area remaining at each removal step.

Weighting

We created prioritization maps for each of four seasons considering the current cover type and future cover types. Species were weighted based on their activity during each of the four seasons: spring, summer, fall, and winter. Seasons were defined based on the precipitation and irrigation regimes in the Central Valley and the activity of the different species across the different months.

The months of September through November were considered the fall season (Table 1). During these months, the water that is on the landscape is almost exclusively provided by post-harvest rice irrigation and wetland management. American Avocet, Black-necked Stilt, Dowitchers, and dabbling ducks are active on the landscape. Dunlin start to arrive in the Central Valley in late fall (October or November). Thus, we weighted all the birds equally except for Dunlin which were weighted at half of what the other birds were weighted due to their late arrival. Snakes were considered in this season although they are decreasing in activity moving into November.

Water during the winter season (December through February) is provided by rainfall and intentional flooding. During this season all the ducks and shorebirds are using the Central Valley extensively and so we weighted each of these species equally. The garter snake is not active in the winter and thus was not considered in this season.

Spring was defined as the months of March through May, a window when post-harvest flooding of rice goes away as fields are prepped for planting. Shorebirds and ducks are still active during this season and so they were weighted equally. Garter snakes are starting to emerge from hibernation and early season water availability has been found to be very important to garter snakes. Thus, we weighted the snake as equally important to the combined weightings of the birds. The high weighting of garter snakes is justified because of the snake's federal listing as vulnerable. However, we also considered a prioritization that did not include the snake so that the fall and winter bird models can be compared to similar models in spring and summer.

Rice fields are typically fully flooded by June and remain so as rice plants grow through August. Thus, we define the summer months as June through August. During this time, the garter snake is the most important species for prioritization because this is its most active season. During this time, garter snakes were weighted as twice as important as Avocet and Stilt, the waterbirds present in the Central Valley at this time.

Weightings refer to the overall weight summed across the months. For the birds we have one suitability map for each of three months in fall (Sept-Nov) and winter (Dec-Feb) and two months in the spring season (March and April). For snakes we have a single habitat map across the entire year. Thus, during the spring season there is a single map for the garter snake and two monthly

(March and April) maps for each of the bird groups. In this season, the bird maps were multiplied by 0.5 so that the overall species weighting for a given bird species sums to one. Note that snake habitat was only predicted in the Sacramento Valley. Thus, the, in all scenarios, bird species were the only species defining habitat prioritization in the southern Central Valley.

Table 1. Species weighting across the season. BNST = black-necked stilt, AMAV = American avocet, DUNL = dunlin, DOWI = dowitcher, NOPI = Northern pintail, NSHO = Northern Shoveler, GRTE = Green-winged teal, and GGS = giant garter snake.

Seasons	Weights BNST	AMAV	DUNL	DOWI	NOPI	NSHO	GRTE	GGS	Future Flooding
Sept-Nov	1	1	0.5	1	1	1	1	6.5	0
Dec-Feb	1	1	1	1	1	1	1	0	0
Mar-May	1	1	1	1	1	1	1	7	0
June-Aug	1	1	0	0	0	0	0	4	0
Seasons	**Weights BNST**	**AMAV**	**DUNL**	**DOWI**	**NOPI**	**NSHO**	**GRTE**	**GGS**	**Future Flooding**
Sept-Nov	1	1	0.5	1	1	1	1	1	6.5
Dec-Feb	1	1	1	1	1	1	1	0	8

Predicted future flooding within the Central Valley occurred almost exclusively September through February (see Figure 6). Thus, we only considered future flooding in the fall and winter seasons, where it was weighted as equally important as all waterbirds combined (Table 1).

Spatial comparison

We randomly selected 100,000 points across the Central Valley and extracted the priority value for each of the prioritization layers and seasons calculated above. On these extracted values, we calculated the correlation coefficient across the different prioritization layers. A high correlation signified that the information contained in one layer (e.g. a layer for the waterbirds only in Dec-Feb) was similar to another layer (e.g. a layer for the waterbirds only in Mar-May). Thus, either layer could be used in prioritizations with little loss of information.

Conservation gaps

We summarized the distribution of prioritization values by regions, seasons, scenario and conservation status (conserved vs. non-conserved) to better understand how well current conservation is capturing the priority landscapes for shorebirds, ducks and garter snakes.

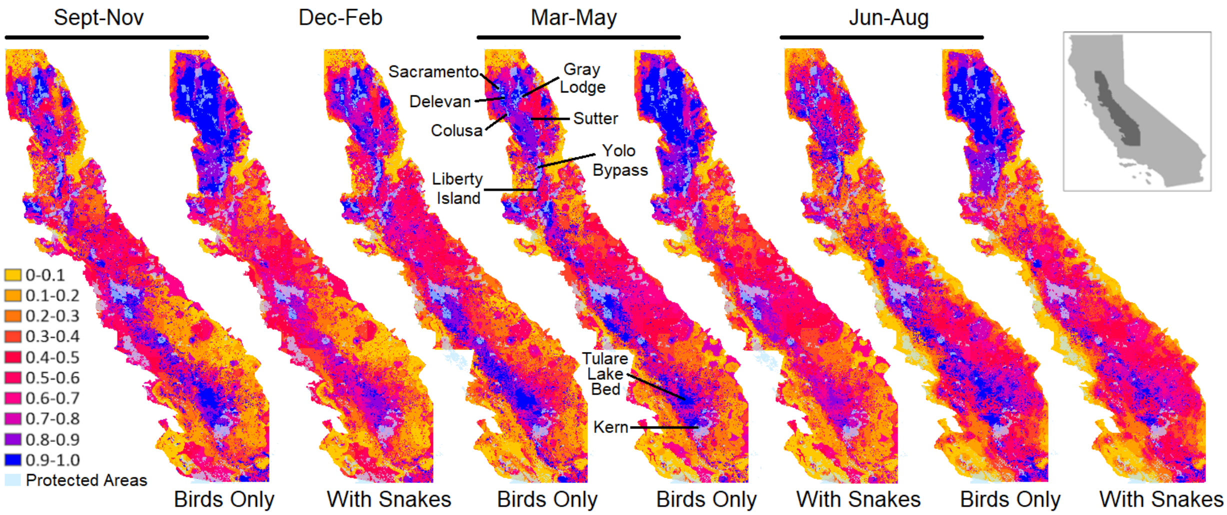

Figure 7. Prioritization maps from lowest priority (0, yellow) to highest priority (1, blue). Two maps were produced for March-May, June-August, and September-November: one map looked at priority areas for birds only and the other map included snakes in prioritization. Inset map shows California (light gray) and the 2020 Central Valley Joint Venture boundaries (medium gray) where prioritizations were run. Light blue, semi-transparent overlay shows protected areas and easements from California Protected Areas Database (CPAD: www.calands.org/cpad/).

Results

Prioritization Assuming Current Land Cover

Prioritization of current suitable habitat across nine species and four seasons, we see large blocks of high-priority habitat in the northern Sacramento Valley (Figure 7). The largest contiguous area of high-priority habitat is centered on and between Gray Lodge, Sacramento, and Delevan Refuges. Additionally, there are blocks of multi-species, high-priority habitat near and between Colusa and Sutter Refuges, in private wetlands within the Colusa Basin, and along a north-south line along the Sacramento River from the Yolo Bypass Wildlife Reserve to the Liberty Island Ecological Reserve. Much of the highest priority habitat is already protected (light blue areas on Figures 7-9). Comparing suitability predictions for the nine species in Figures 1-3 and 5 to the multi-species prioritization in Figure 7, we see that the multi-species prioritization includes areas where bird species are expected to share suitable habitat (largely in wetlands) as well as “buffers” around these areas occurring within suitable agricultural cover (largely rice habitat). South of Sacramento Valley there are blocks of high-priority habitat around Grasslands, in agricultural lands that were formerly Tulare Lake, and Kern and Pixley Wildlife Refuges.

Relative to the spring, summer, and fall seasons, there is more high priority habitat in the winter in the row, field, and grain crops north of former Tulare Lake. Comparing prioritization across seasons only for waterbirds (Figure 7), we see that high-priority habitat in the Sacramento Valley is relatively stable. If we compare regions where high-priority habitat is predicted across all four seasons, we see the most consistent high-priority habitat in the Sacramento Valley (black areas in Figure 8). However, the summer season (June-August) has less high-priority suitable habitat in

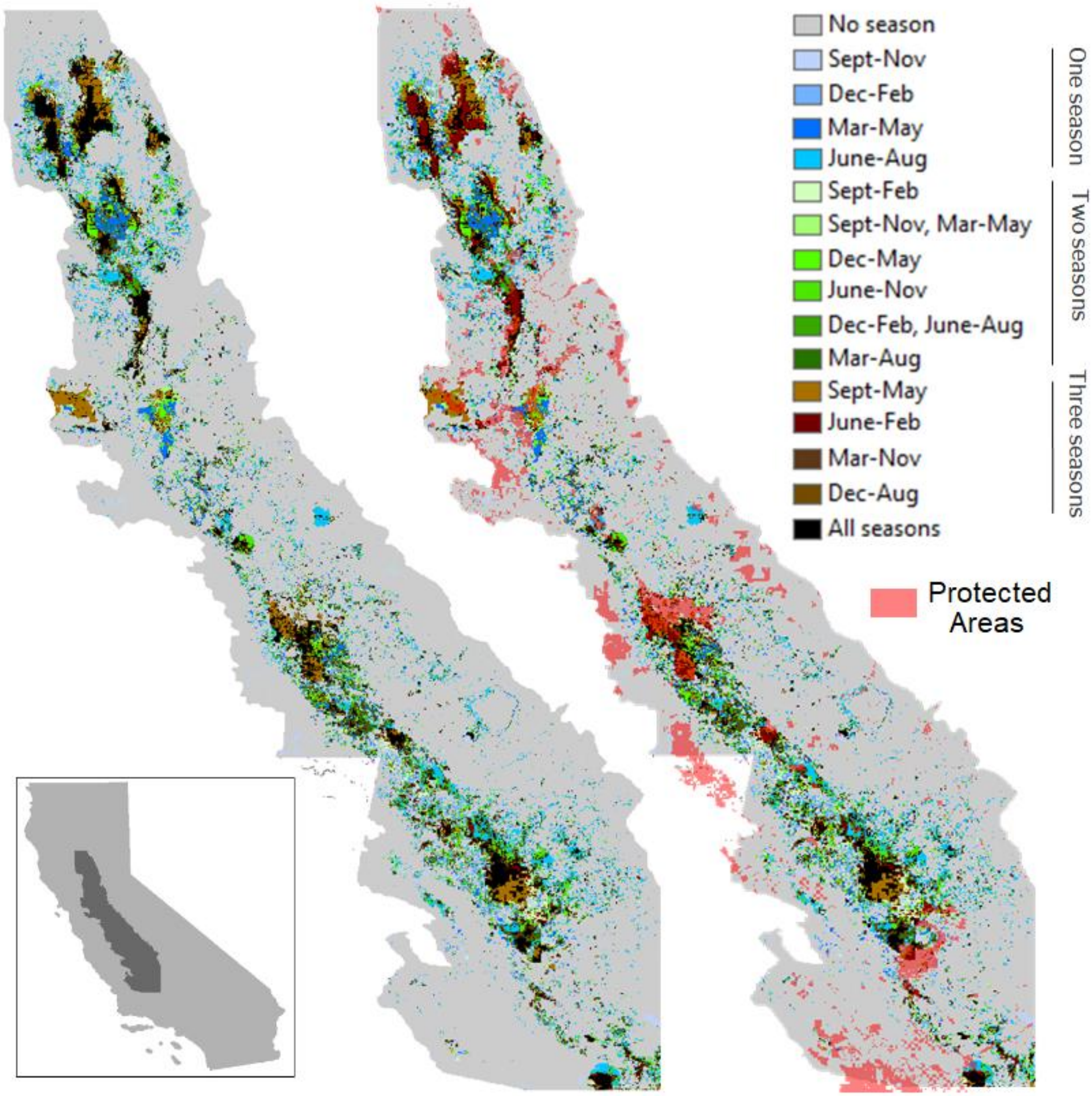

Figure 8. Overlapping high priority (priority values > 0.85) regions across seasons (only for birds). Blue areas were high priority areas in one season, green were high priority in two seasons, brown areas were high priority in three seasons, and black were high priority in all seasons. The map on the right adds an overlay of protected areas. Inset map shows California (light gray) and new Central Valley Joint Venture boundaries (medium gray).

the Sacramento Valley and Grasslands (Figure 7). The spring season (March-May) also has more high-priority habitat around private agriculture and wetlands in the Delta region. In general, there is less seasonal variability in high-priority habitat in the Sacramento Valley compared to the rest of the Central Valley, although there are some areas, especially in the former Tulare Lake and Kern Refuge regions where high-priority habitat is predicted across all four seasons (Figure

8). Most of the Grasslands region is only considered high priority in three seasons across September-May (Figure 8).

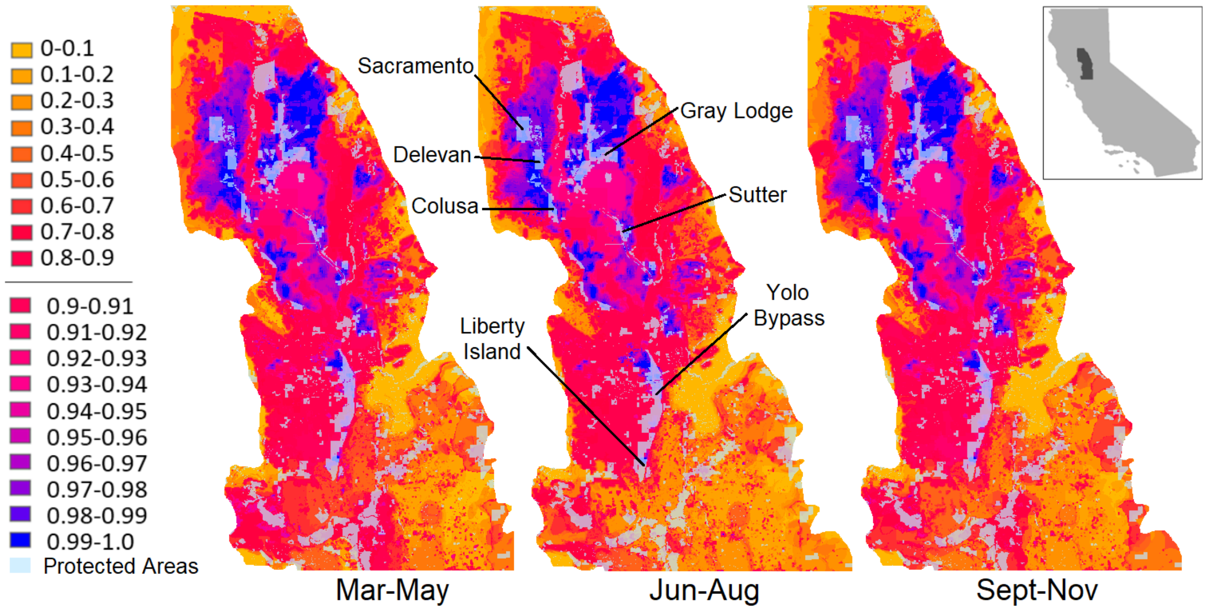

Figure 9. Map of prioritization in the Sacramento Valley for the two prioritizations that included the snake habitat models: priority ranges from low (0) to high (1). Inset map shows California (light gray) and area of Sacramento Valley shown in the main maps (medium gray). Light blue, semi-transparent overlay shows protected areas and easements from CPAD.

In addition to the areas that have high priority across all four seasons (black areas on Figure 8), there are many areas that are high priority across September-May and a few areas (near former Tulare Lake) that are high priority from June-February. Thus, if a region is high priority for three seasons, it is probably fall, winter, and spring (September-May). Regions that are high priority for two seasons are scattered throughout the landscape with a slightly higher incidence of locations that are high priority for winter and spring (December-May). Regions that are high priority in a single season are also scattered throughout the landscape and can fall in any season, although there is a big block of habitat that is suitable from March-May in the Sacramento Valley. Not surprisingly, the seasonal comparison in Figure 8 suggests that the most consolidated habitat is centered around the seasons when the birds are most active - fall through spring.

Comparing the prioritizations that include snakes to those that do not include snakes, we see that the addition of snakes significantly increases the amount of high-priority habitat in the Sacramento Valley compared to the rest of the Central Valley (Figures 8 and 9). This is even more apparent in the histograms of habitat priority values across the four CVJV basins: Sacramento Valley, Yolo-Delta, San Joaquin, and Tulare basins (Figures 10-13). Because there is no snake habitat in the southern Central Valley, this region decreases in priority when snakes are added to the prioritization. When we zoom into the region for spring and summer models (Figure 9), we see that areas around wetlands and near canals in rice agriculture provide the highest priority habitat for snakes and waterbirds combined.

Bird habitat in the Sacramento Valley is relatively well-protected compared to bird habitat in the Tulare basin; this can be seen by comparing the relative height of the black areas to the gray bars at the highest priority values in Figure 10 versus Figure 13. When snakes are added to prioritization, priority values in the Sacramento Valley increase considerably and the relative portion of high-priority areas that are protected goes down (second column in Figure 10). A similar phenomenon happens when future flooding is added to prioritizations in the Sacramento Valley (third column in Figure 10). The San Joaquin and Yolo-Delta basins (Figures 11 and 12) have a relatively high proportion of protected areas for birds, but lower overall priority scores than the Sacramento Valley, especially when snakes of future flooding are added to prioritizations. In the Tulare basin (Figure 13), most protected areas have low priority values, suggesting that protected areas were designed for wildlife other than waterbirds. Overall, there are still many high priority areas throughout the Central Valley that are unprotected (Figures 10-13).

Prioritization Assuming Future Flooding Given Land Use and Climate Change

Adding predictions of future flooding, given land use and climate change, resulted in more high-priority habitat in the Sacramento Valley (Figure 14). This occurred because future flooding is largely predicted in the Sacramento Valley where there is less conversion from annual to perennial crops and more water expected to be available for agriculture under predicted drier conditions. Prioritization maps that include future water predictions yield spatial patterns of high priority habitat somewhere between the waterbird-only and waterbird-snake prioritizations (comparing Figure 7 to Figure 14). This can also be seen in the histograms in Figures 10-13.

Similarity Across Prioritizations

Across 100,000 randomly selected points in the Central Valley, we calculated the correlation coefficient of habitat prioritization across different prioritizations and seasons. When comparing two maps of the same season, the highest correlations in prioritization values occurred between (i) the current birds-only models versus with birds-only with future flooding (correlation greater than 0.96), and comparing (ii) the birds-only to the garter snake models (correlation greater than 0.79). Comparing across the seasons, there were greater similarities between (i) fall and winter, and (ii) winter and spring (correlation greater than 0.65). The lowest correlations occurred between (i) summer and fall and (ii) spring and summer (correlation less than 0.59). These patterns held when comparing across waterbirds-only, future flooding, and waterbirds and garter snake comparisons.

Conservation gaps

Overall, across most regions, seasons and scenarios there is still a relatively large proportion of the high priority areas that are unconserved (Figures 10-13). Notable deviations include the highest priority areas in fall, winter and spring in the Sacramento Valley, Yolo-Delta and the San Joaquin Valley, when 50% or more of the priority habitat is conserved. In the Tulare Basin, the highest proportion of conserved areas are generally low priority for the species we considered. Interestingly, when including giant garter snake, the percent of the conserved high priority areas increases in both the fall and spring in the Yolo-Delta and San Joaquin Basins, though overall the amount of high priority habitat decreases, as garter snakes are not in these basins. The opposite is apparent in the Sacramento Valley Basin, where the overall amount of high priority habitat increased and thus the fraction of high-quality habitat that is conserved is less when including garter snakes.

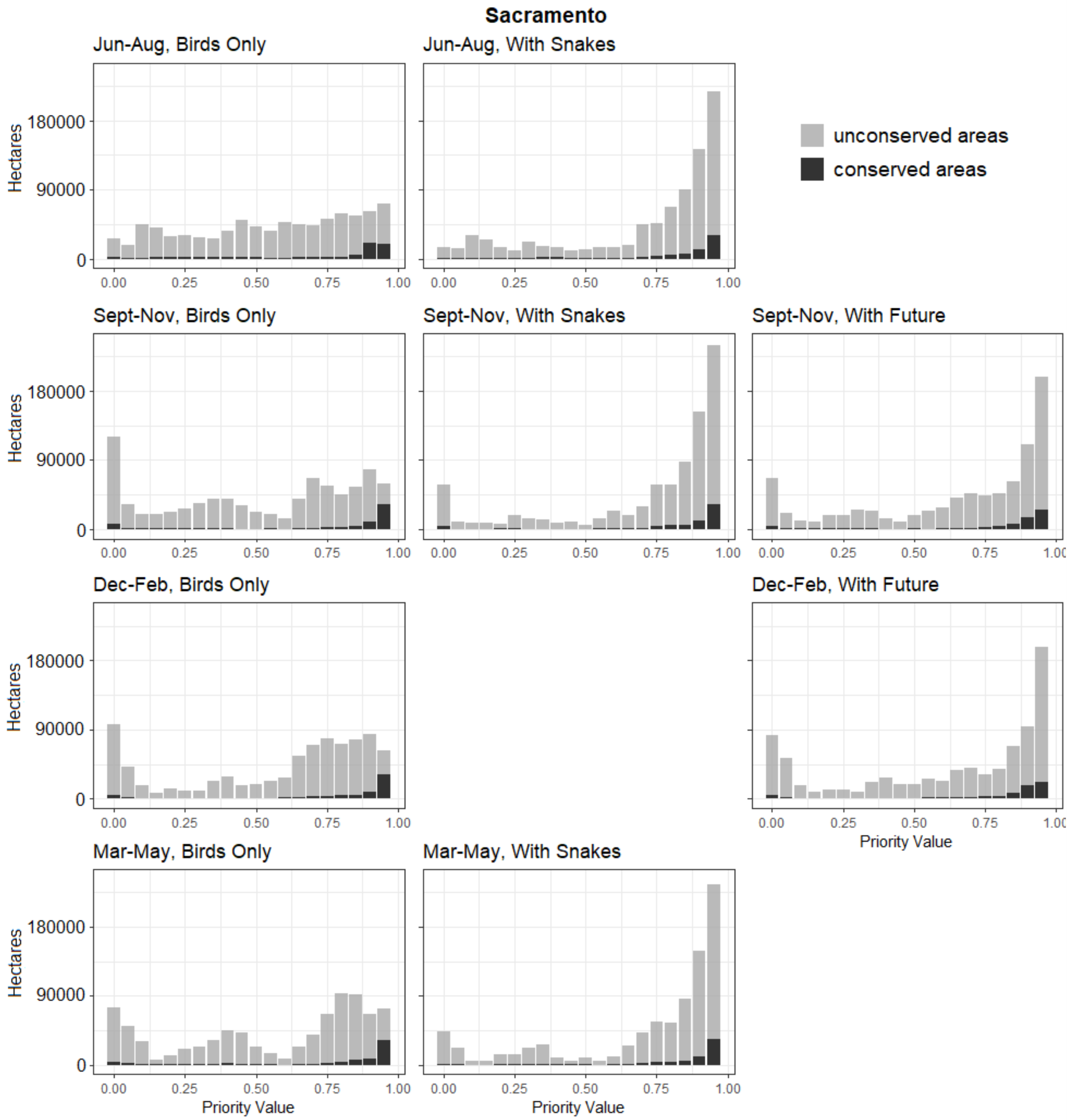

Figure 10. Histograms of priority values across 30-meter pixels in the Sacramento Valley in conserved (black) and unconserved (gray) areas. The seasons are displayed across the rows, starting with summer at the top. The first column shows prioritization with the birds only, the second column with birds and snakes and the third column with the future flooding layers included. There are gaps in the top, third, and last row because these prioritizations were not run.

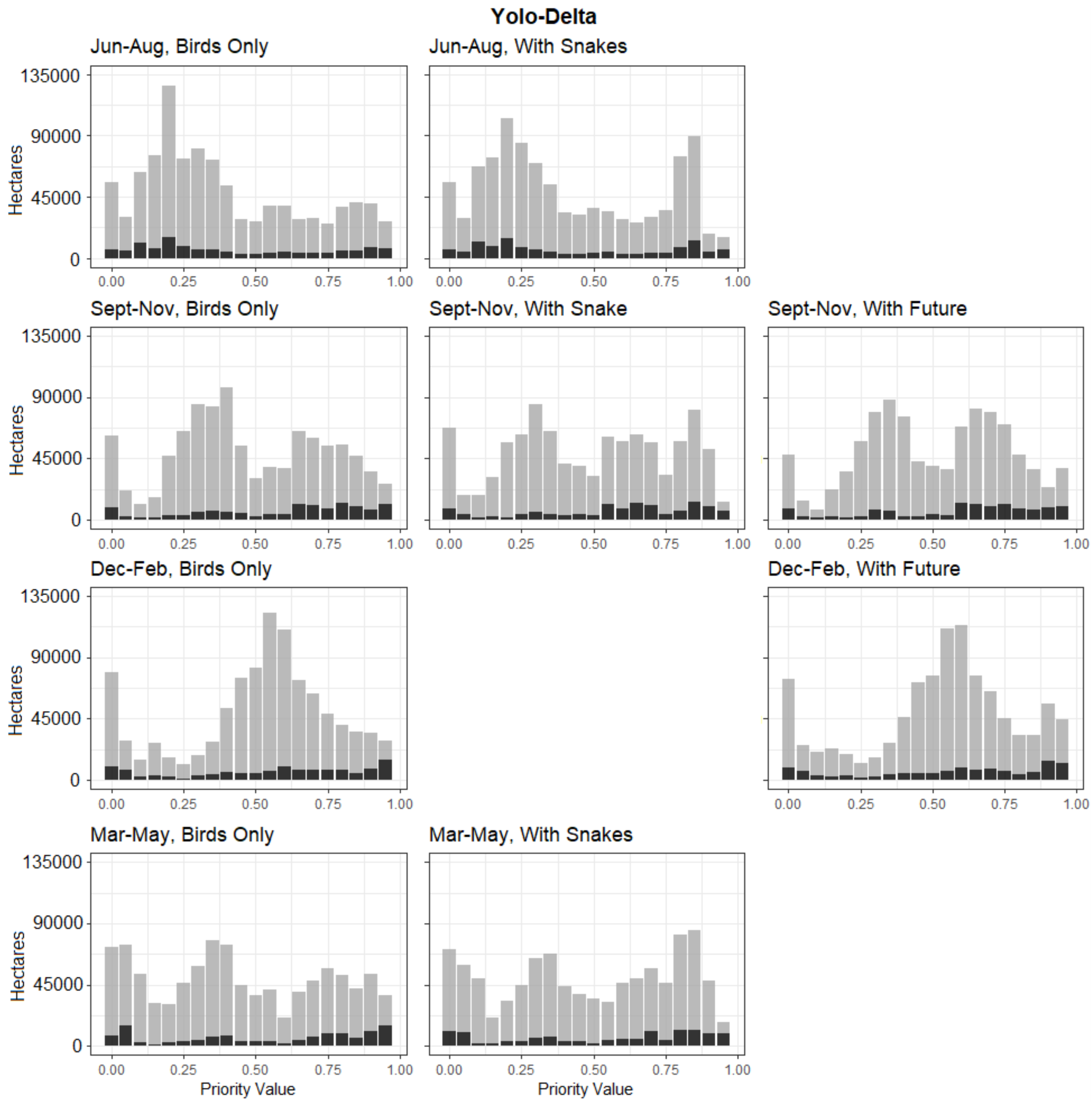

Figure 11. Histograms of priority values across 30-meter pixels in the Yolo-Delta basin in conserved (black) and unconserved (gray) areas. The seasons are displayed across the rows, starting with summer at the top. The first column shows prioritization with the birds only, the second column with birds and snakes and the third column with the future flooding layers included. There are gaps in the top, third, and last row because these prioritizations were not run.

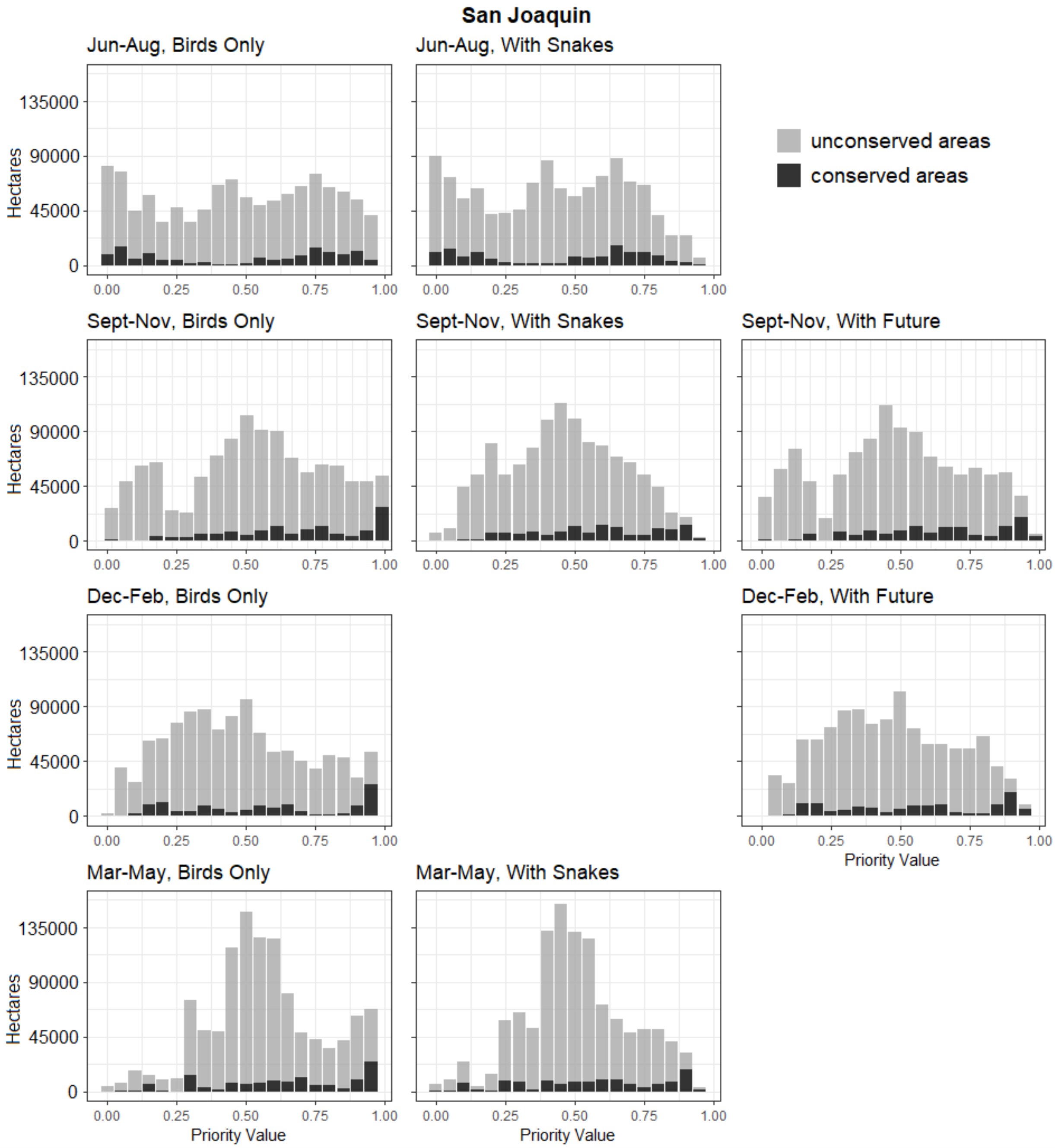

Figure 12. Histograms of priority values across 30-meter pixels in the San Joaquin basin in conserved (black) and unconserved (gray) areas. The seasons are displayed across the rows, starting with summer at the top. The first column shows prioritization with the birds only, the second column with snakes and the third column with the future flooding layers included. There are gaps in the top, third, and last row because these prioritizations were not run.

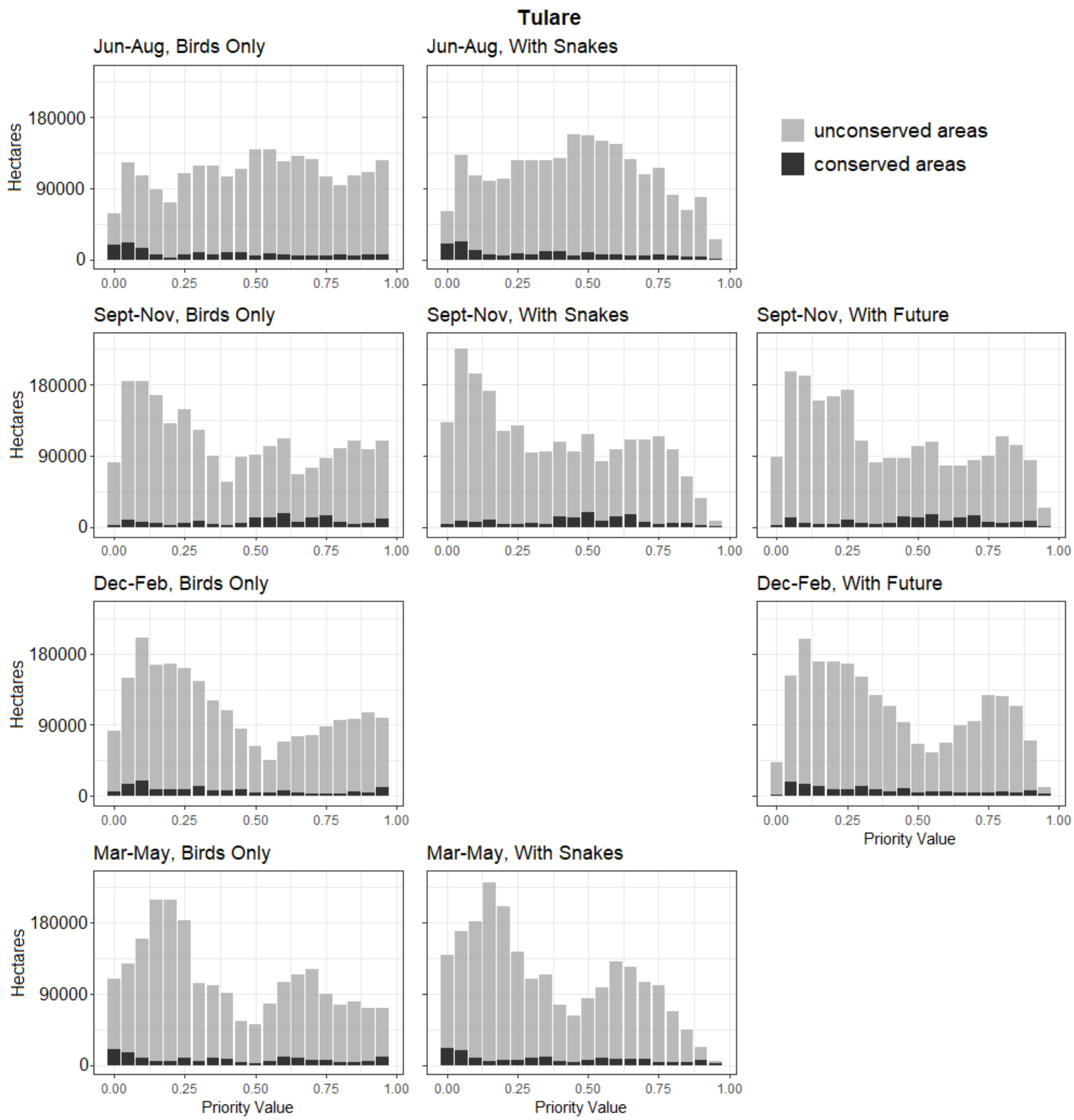

Figure 13. Histograms of priority values across 30-meter pixels in the Tulare Basin in conserved (black) and unconserved (gray) areas. The seasons are displayed across the rows, starting with summer at the top. The first column shows prioritization with the birds only, the second column with birds and snakes and the third column with the future flooding layers included. There are gaps in the top, third, and last row because these prioritizations were not run. There is a region of the Tulare Basin that did not have flooding data available for December-May (see "Tulare Lake Bed" label in Figure 7). For consistency across seasonal comparison of histograms, this region was also cut out of months June-November before generating histograms.

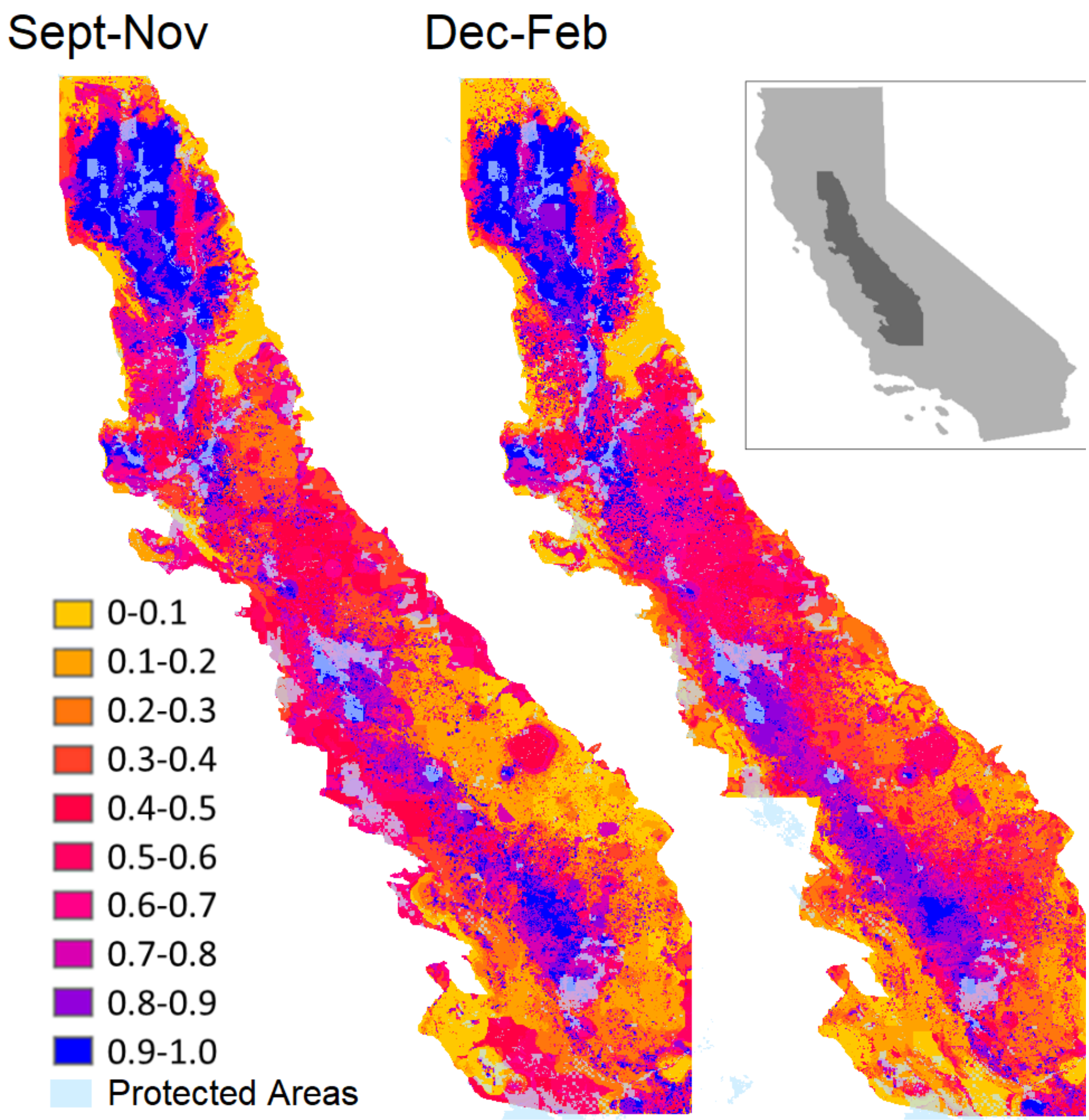

Figure 14. Map of prioritization in the Central Valley for the two prioritizations that included the future flooding models: priority ranges from low (0) to high (1). Inset map shows California (light gray) and the Central Valley shown in the main maps (dark gray). Light blue, semi-transparent overlay shows protected areas and easements from CPAD.

Table 2. Correlation in high-priority habitat across the different maps in Figures 7, 9, and 10.

	Birds Only				Future Flooding		With Garter Snake		
	Sept-Nov	**Dec-Feb**	**Mar-May**	**Jun-Aug**	**Sept-Nov**	**Dec-Feb**	**Mar-May**	**Jun-Aug**	**Sept-Nov**
Sept-Nov	1.000	0.721	0.692	0.532	0.963	0.701	0.568	0.445	0.790
Dec-Feb		1.000	0.725	0.682	0.741	0.982	0.657	0.642	0.690
Mar-May			1.000	0.588	0.705	0.721	0.860	0.536	0.627
Jun-Aug				1.000	0.530	0.662	0.517	0.875	0.504
Sept-Nov					1.000	0.755	0.620	0.500	0.827
Dec-Feb						1.000	0.675	0.653	0.702
Mar-May							1.000	0.688	0.787
Jun-Aug								1.000	0.681
Sept-Nov									1.000

Discussion

Overall, we found a larger fraction of high priority habitat in the Sacramento Valley, especially when giant garter snake habitat or future flooding were added to the prioritization (Figures 7 and 14). We also found that a higher fraction of high-quality habitat was conserved (through easements, state and federal refuges, etc.) in the Sacramento Valley compared to the rest of the Central Valley (Figures 10-13), especially when the prioritizations considered only birds under current land use (far left columns in Figures 10-13). This suggests that conserved areas in the Sacramento Valley were likely created explicitly to protect bird habitat. While conserved areas do incorporate some snake habitat (Figure 5), there is room for additional conservation in the Sacramento Valley to protect snakes.

Values judgements are required in any prioritization and one of the most fundamental judgements is which species to include. In this report, including snake habitat into the prioritization resulted in a shift of high priority habitat into the Sacramento Valley. Focusing on snake habitat is justified given that giant garter snakes are federally listed as threatened. However, giant garter snakes have a very specific life history that does not necessarily make them a good umbrella species for other wetland-dependent wildlife in the Central Valley. Focusing prioritization on waterbirds alone likely represents a greater suite of species that might benefit from restored wetlands. Which species to consider should also depend on seasonality. During the summer, many shorebird and duck species migrate away from the Central Valley. In contrast, summer is the season when giant garter snakes are the most active. Thus, one might want to protect habitats to benefit both snakes in the summer and birds in the winter. Finally, giant garter snakes are not very mobile. Thus, any new habitat that is created for giant garter snakes may go unused if snakes aren't able to move to the newly restored habitat.

Determining how to use a map of high priority habitat requires additional decisions about how to allocate resources. For example, should the Partners Program invest in locations that have received prior investments and are now ranked as high priority? In the prioritizations presented here, these "tried-and-true" locations lie in the Sacramento Valley. In contrast, should the Partners Program invest in locations that currently have low priority but, if restored, might result in the largest change in habitat priority? Tulare Basin contains such "biggest-improvement" locations, potentially because resources haven't previously been allocated to the Tulare Basin. In the interests of public support for any conservation efforts, it might make sense to allocate resources equitably across the Central Valley. See objective 4 below for more information on selecting places with the potential for being a high priority.

Including information on future flooding suggests that water availability will be highest in the Sacramento Valley in the future. Like the arguments in the previous paragraph, these predictions can be viewed in two ways: (i) as emphasizing the importance of restoration in the Sacramento Valley, or (ii) as suggesting an urgent need to restore wetlands in the Tulare Basin before land is converted to perennial crops unsuitable to waterbirds. The future flooding predictions incorporated both climate-driven changes to water availability as well as predicted increases in orchards. Water may be more plentiful in the Sacramento Valley in the coming decades, arguing for increased restoration in this region. However, assuming business as usual, agricultural practices in the Tulare Basin are expected to shift towards an increase in perennial crops unsuitable for waterbirds. If we do not view orchardization as inevitable, our results would argue for urgent restoration in the Tulare Basin to prevent orchardization.

Monitoring could aid decisions about whether to restore habitat in the Sacramento Valley versus the Tulare Basin. New restoration sites can be placed both in locations adjacent to previous restorations and in locations that currently have relatively little wetland footprint. The efficacy of these new restoration sites in both "tried-and-true" versus "biggest improvement" sites can be compared to each other and to data from bird monitoring in rice fields. Studies have found considerable benefit of rice fields that are flooded for post-harvest decomposition (Reynolds et al. 2017, Golet et al. 2018). Further, strategic monitoring of new restoration sites might be able to determine the importance of the land use types adjacent to new restoration sites. In the Tulare Basin there are more low priority areas than any of the other regions. Thus, while there are potential high priority restoration sites in the Tulare Barin, these high priority sites may be near locations with very low priority. Post-restoration monitoring could determine whether restoration sites adjacent to low priority habitat (e.g. orchards) provide suitable habitat. These monitoring activities would be especially important given the expectation of additional orchards in the future. Finally, such post-restoration analyses would represent a valuable contribution to the scientific literature on conservation and restoration.

Looking across seasons, there are a lot of locations that have high priority in all four seasons. In general, there were a lot of similarities across the different prioritization layers (Table 2), suggesting that one does not have to choose between preserving high priority habitat in one season versus another. Of the locations that saw some seasonal changes, the Yolo-Delta regions saw increased moderate priority habitat in winter while the San Joaquin Basin saw a slight decrease. The San Joaquin Basin also saw an increase in moderate priority habitat late in the spring season consistent with shorebird tracking that found shorebirds in the Grasslands Ecological Area tended to stay there throughout the water year (Barbaree et al. 2018). While the Tulare Basin had the largest fraction of low priority habitat across seasons, the former Tulare Lakebed was a location with high priority habitat across seasons. Currently, there is no protected habitat in the former lakebed. Except for the Tulare Lakebed (Figure 8), locations where high priority habitat occurred in all four seasons were protected.

In summary, this report describes where and when, given recent historic land use, high priority habitat occurs throughout the Central Valley for (i) waterbirds, (ii) waterbirds and giant garter snakes, and (iii) waterbirds and giant garter snakes given predicted future water availability. We find that habitat suitability is fairly constant across seasons. With the addition of snakes or future flooding, there is a shift of high priority habitat into the Sacramento Valley. While the maps produced with this report suggest locations of high priority habitat, ultimately, the decision of where to devote restoration resources depends on value judgements. We recommend post-restoration monitoring to determine the efficacy of restoration efforts.

Objective 4

Introduction

We developed an approach for the Partners program to compare potential new restorations based on their predicted wildlife benefit. The prioritization results above are helpful for identifying those places that are currently managed in a way that is compatible with the focal wetland wildlife species and are not protected and thus are high priority for conservation. However, the layers used in the initial prioritizations are based on current land use and recent historic patterns of flooding at that location. Thus, landowners that might want to restore a wetland on land that is not a wetland and that has not been historically flooded or have a wildlife friendly cover type would receive a low priority score. Below we detail the development of spatial data layers and a data summary framework to enable the Partners program to develop "restoration value scores" for any place in the Central Valley that could conceivably be converted to a wetland.

Methods

To provide a system to evaluate potential wetland restorations, we simulated the effects of restoring a managed wetland on 96,395 90-acre plots across the Central Valley. We limited our analysis to areas that could be feasibly restored using several criteria. Using seven years of Cropscape data (NASS 2024), we categorized pixels into habitat classes based on the land cover they were assigned in the majority of years. We included areas that we classed as hosting suitable agriculture, which included rice, corn, alfalfa, other cereal grains, and other field/row crops. We excluded developed areas, barren or rocky lands, woody vegetation, and more permanent agriculture (e.g., vineyards and orchards) (see Appendix A, Table A1 for a full breakdown of cover types). We included existing wetlands but simulated a seasonal wetland flooding regime which then accounts for that wetland being "restored" under the partners program (see additional details below). We further limited the footprint by removing sites with a slope of over 10% thus excluding the Sutter Buttes. The resulting area that we evaluated for the suitability of potential wetland restoration can be seen in Figure 15.

Wetland Restoration Simulations

To simulate the restored wetland, we assumed that the wetland would be flooded in a way that is consistent with the hydrological patterns in other seasonally managed wetlands of that region (Reiter et al. 2018). We calculated the average flooding profile of existing managed wetlands within each CVJV sub-basin and then applied this fractional water coverage by month (July - May) for the simulated restoration. Developing these maps of relative value for all potential restoration sites was very computationally intensive. It was necessary to compute neighborhood statistics for each changed landcover type within a 5 km radius for each month around each potential restoration site. This step produced over 24 million landcover layers (7 landcovers, 12 months, 3 scales, 96,395 sites). We predicted the habitat value for each of the species (5 shorebirds - American Avocet, Black Necked Stilt, Dunlin, Dowitchers spp. (Long-billed and Short-billed; 3 waterfowl - Northern Pintail, Northern Shoveler, Green-winged Teal).

Because the creation of a new wetland has the potential to improve the suitability of the landscape surrounding that new patch of habitat, particularly if the adjacent lands are potentially suitable for shorebirds and waterfowl, and it may be worth considering the improved landscape in the scoring, for each simulated wetland restoration we calculated suitability within the restoration unit as well as the suitability within 250 and 5000 m surrounding the restoration given the occurrence of the restoration. The combination of all these scores can be considered the total potential enhancement to the landscape as the result of the restoration.

The combined wetland simulations produced 252 layers of potential bird suitability, one for each month (12), species (7), and scale (3). We summarized these results by season using an average across included months (Fall = September – November, Winter = December – February, Spring = March – May, Summer = June – August).

Prioritization

To further distill the results, we conducted a prioritization analysis using the seasonal species suitability scores. We combined the predicted layers with the program Zonation 5 (v2.0; Moilanen et al, 2022; note – Zonation 4 used in the analysis above has been deprecated). We weighted species by season using the weights detailed in Table 3 to account for months in which certain species are not present (or present in lower numbers). We considered each species group individually by season and then also across the full year. Weights for the full year were generated as the sum of the seasonal weights across species (Table 3). We also generated prioritizations for the species groups (shorebirds and ducks) combined for each season and the full year.

We completed prioritizations using two spatial scales. The first scenario considered the suitability within the footprint of the simulated restoration. The second scenario included the benefit to the surrounding landscape. For the combined scale scenario, we gave equal weights to the interior and landscape suitability scores. To do so, we rescaled mean suitability at the 5000 m level to the range of the interior suitability and used equal weights in the Zonation algorithm.

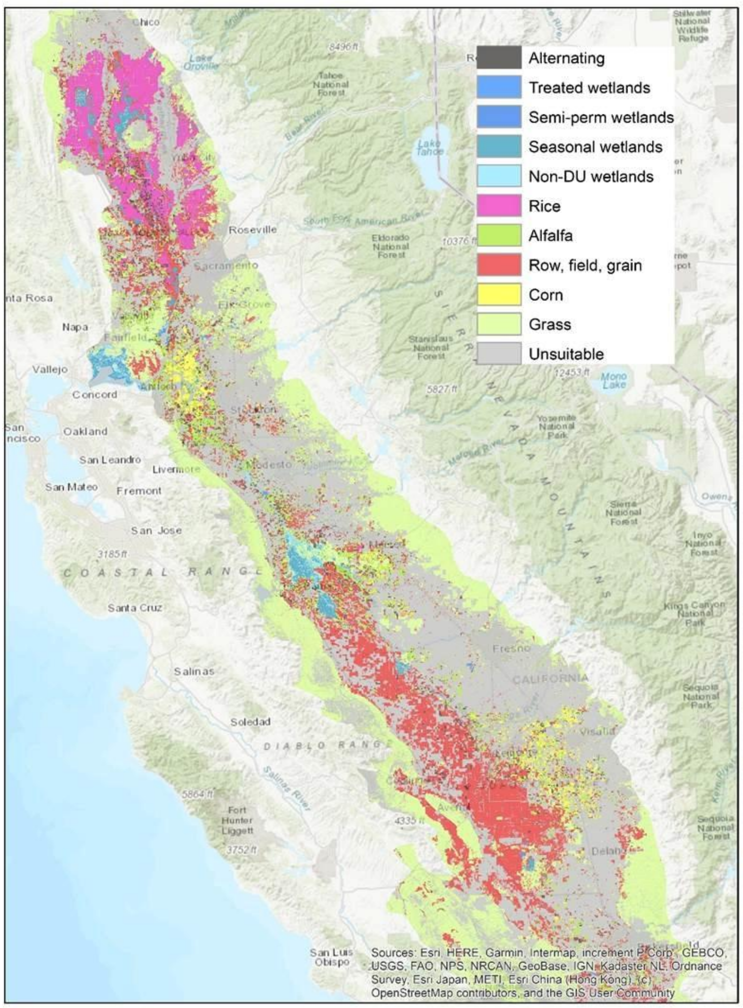

Figure 15. Distribution of potentially suitable land covers for wetland restoration used to simulate restorations. In addition to the "Unsuitable" cover type, all existing wetlands and grasslands were excluded from the simulations.

Table 3. Species weighting across the season. BNST = black-necked stilt, AMAV = American avocet, DUNL = dunlin, DOWI = dowitcher, NOPI = Northern pintail, NSHO = Northern Shoveler, and GRTE = Green-winged teal. Sums of weights by season and group are given for cross season prioritizations.

Season	Weights									
	BNST	AMAV	DUNL	DOWI	NOPI	NSHO	GRTE	All	Shorebirds	Ducks
Sept-Nov	1	1	0.5	1	1	1	1	6.5	3.5	3
Dec-Feb	1	1	1	1	1	1	1	7	4	3
Mar-May	1	1	1	1	1	1	1	7	4	3
June-Aug	1	1	0	0	0	0	0	2	2	0

Finally, we tested two different ways of computing prioritizations in Zonation. The first mode (CAZMAX) is equivalent to the Core Area Zonation algorithm used by Zonation 4 in the first section of our report. The second mode, CAZ2, is a modified version of the Core Area Zonation algorithm and is new to Zonation 5. As described by Moilanen et al. (2024), CAZMAX places higher priority on preserving the core area of all species, which has the effect of prioritizing areas that may be very good for rare species but less good for more common ones.

CAZ2 balances these two priorities more evenly, resulting in higher average habitat quality across all species. The second mode (CAZ2) is recommended as the most robust method of analysis and is the default in Zonation 5 (Moilanen et al, 2024). It is also especially appropriate to analyses that use suites of more common species as indicators, as higher average suitability is desirable. Therefore, we present the results of the CAZ2 method here. In total, we produced 120 prioritization layers.

Software

The majority of our workflow was conducted in the R software environment (v 4.2.1; R Core Team, 2023). Within R, we made extensive use of the following packages to create and run our restoration simulations: dismo (Hijmans et al, 2022), gbm (Ridgeway and Developers, 2022), future (Bengtsson, 2021), and terra (Hijmans, 2022). We used the packages dplyr (Wickham et al, 2025), tidyr (Wickham et al, 2025), and ggplot2 (Wickham, 2016) for data analysis and visualization. Code development, data analysis, and visualization was conducted in the RStudio IDE (Posit Team, 2025). Future efforts to simulate restorations under updated landscapes could take advantage of Point Blue's new cloud-based system BidRunner.

We created the prioritization layers using the program Zonation 5, v 2.0 (Moilanen et al, 2022). We used the program R to create the input layers, settings files, and make the system calls to Zonation. We used ArcGIS Pro for examining the predictions and creating maps.

Results

Wetland Restoration Simulations

All 84 maps of suitability by species, season, and spatial scale are presented in Appendix B. Correlations between the suitability within the restored wetlands and the 250 m landscape buffer were extremely high (>0.995 for all species). In contrast, correlations between interior suitability and the 5000 m landscape buffer averaged 0.706. We therefore excluded the 250 m layers from the subsequent prioritization analysis. The species-specific suitability maps in Appendix B highlight the similarity between the interior suitability and the 250 m buffer but the relatively low suitability across the whole valley in the surrounding 5000 m despite the restoration.

Prioritization

The prioritization results highlighted differences in potential value to shorebirds and ducks across the Central Valley. When looking across all seasons, shorebird priority areas were generally much higher in the southern part of the Central Valley near the former Tulare Lake (Figure 16; 0 = low priority, 100 = high priority). Ducks, however, had zones of high priority in the Sacramento Valley, the southern portion of the Sacramento-San Joaquin Delta, and in the Tulare Basin (Figure 17). When combined we found high priority areas across regions of the Central Valley though some of the largest patches of high priority in the Tulare Basin (Figure 18). Overall, the distribution of priority areas for shorebirds was relatively consistent across seasons (see Appendix B). However, for ducks the Tulare Basin in the southern Central Valley has relatively less high priority areas in the winter compared to other seasons and they were largely constrained to areas around existing wetlands complexes. All 36 maps of Zonation priority by species group, season, and spatial scale are presented in Appendix B.

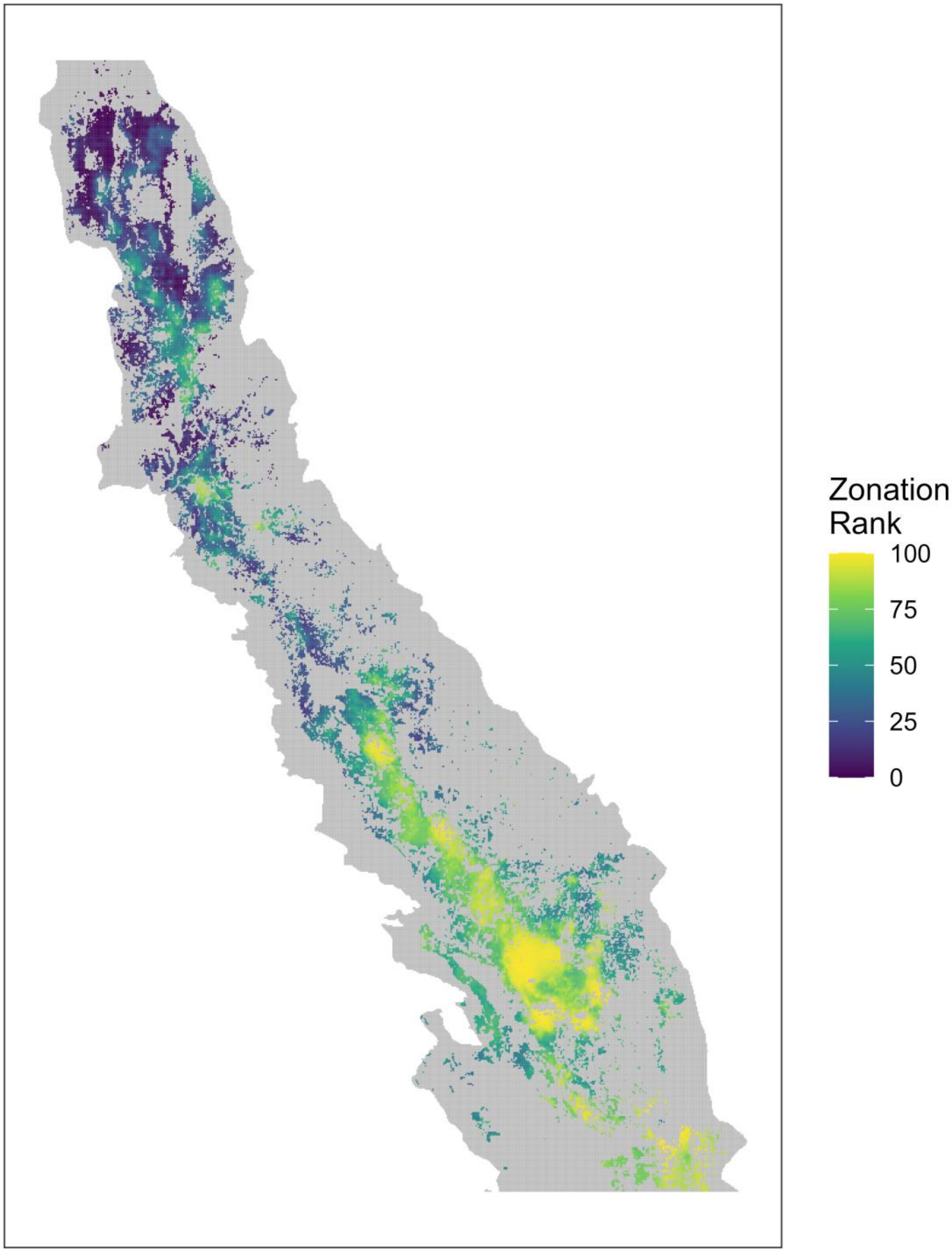

Figure 16. Prioritization across all seasons and all shorebird species in simulated wetland restorations. Equal weights are given to the restored wetland's interior value and landscape value. Yellow is high priority, greens/teals are moderate priority and blues/purples are relatively low priority.

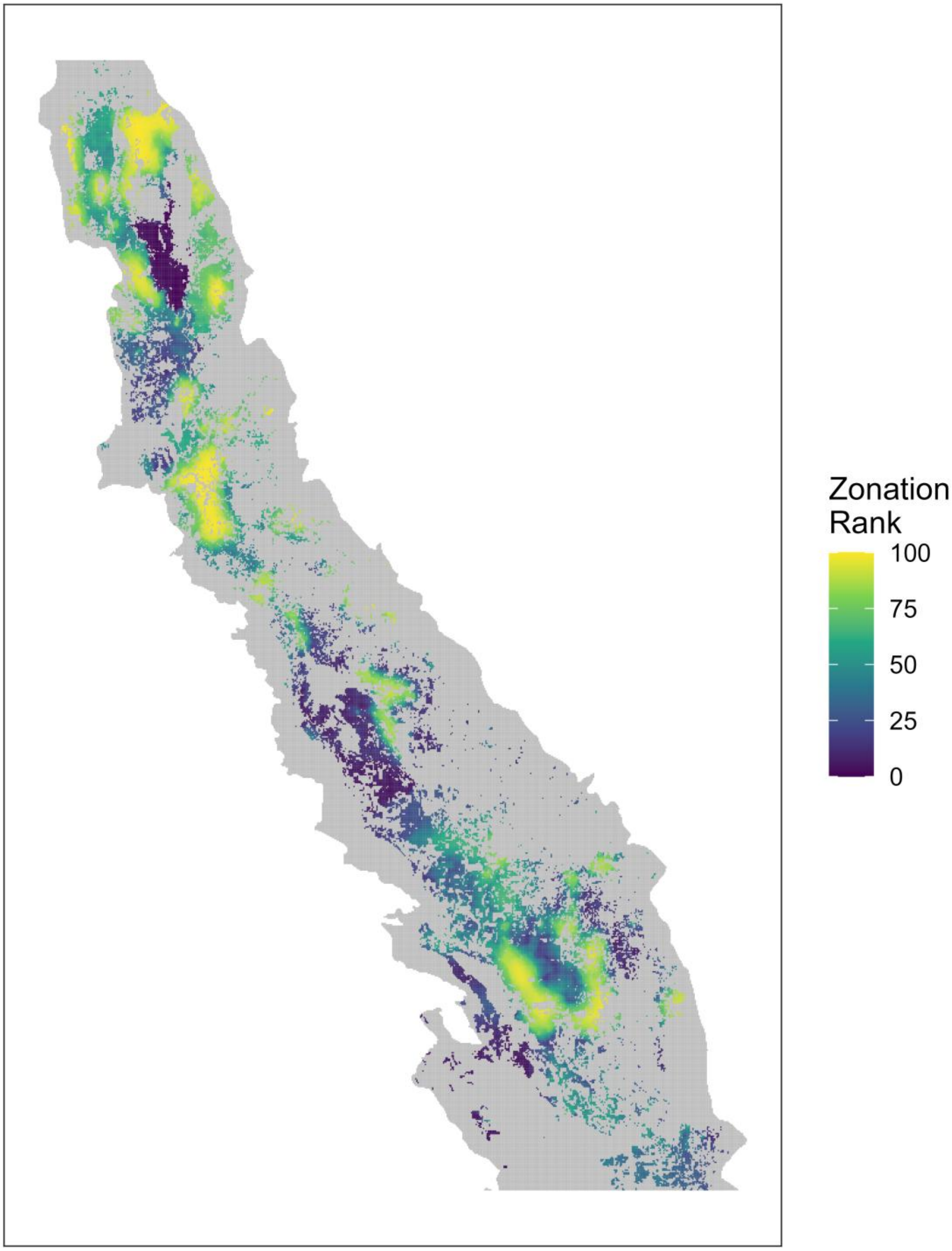

Figure 17. Prioritization across all seasons and all duck species in simulated wetland restorations. Equal weights are given to the restored wetland's interior value and landscape value. Yellow is high priority, greens/teals are moderate priority and blues/purples are relatively low priority.

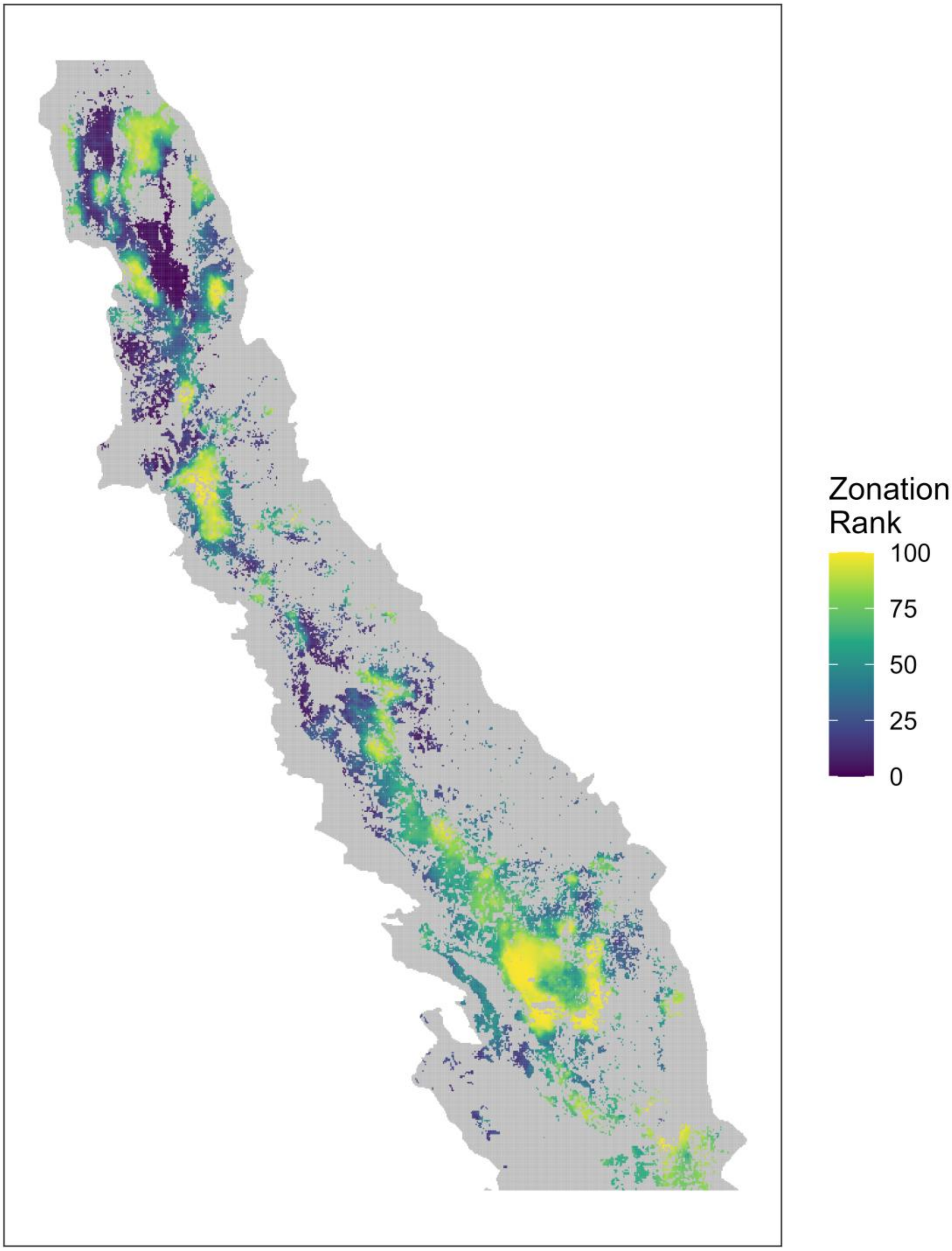

Figure 18. Prioritization across all seasons and all species in simulated wetland restorations. Equal weights are given to the restored wetland's interior value and landscape value. Yellow is high priority, greens/teals are moderate priority and blues/purples are relatively low priority.

Data Access & Summaries

We have provided all final prioritization maps from both the assessment of the recent historic and future flooding landscapes (Objectives 1 – 3) and the simulations of restored wetlands (Objective 4). We have included image files (png), raster files for ArcPro (.tif), and GoogleEarth compatible files (kmz).

Data

Spatial data files can be downloaded using the Google drive links below.

Objectives 1 – 3

Geotiffs
https://drive.google.com/drive/folders/1OPVrA3WXlmCJGyeBfGHMIfnP06Vr3hv9?usp=sharing

Static Maps
https://drive.google.com/drive/folders/1lySZfBIXY8rCZmO6GDojiu1V59jJBJEl?usp=sharing

Google Earth Files (KML/KMZ)
https://drive.google.com/drive/folders/1DMmM5M68Wp3k89V0hJGUWniJvCN09WFD?usp=sharing

Objective 4

Geotiffs
https://drive.google.com/drive/folders/1YrErob51_qZar2r2eVkJHtsS1bJsBFvx?usp=sharing

Static Maps
https://drive.google.com/drive/folders/1CU56Qe9OYcxoKut2fAEY03uIYTa1fcOM?usp=sharing

Google Earth Files (KML/KMZ)
https://drive.google.com/drive/folders/1zKLoQTYNTcplpm4kFrK6XbZwUTrv6vVR?usp=sharing

Summary Code

To enable the Partners program to access and summarize results of spatial prioritization when considering different restoration options, we developed some simple annotated scripts using Program R. R scripts for accessing and summarizing prioritization files provide a flexible and reasonably easy framework for getting the needed data for ranking potential restoration sites. The code allows Partners staff to load the spatial boundaries of the areas to be evaluated and to select the prioritization scenario they would like to include in their assessment (e.g., which species groups, which seasons, local or landscape scoring, etc.). Focal statistics are calculated for the spatial area(s) of interest including the mean, median and standard deviation of the prioritization score for each potential restoration area. Partners staff will only need to download the prioritization layers for the Google drive folders specified above and then point the R-code to the appropriate localized folder for code to work.

The code is available in a GitHub repository here: https://github.com/pointblue/cv-wetland-restoration-summarization. Details on the functionality and use of these scripts are found in Appendix C. This information is also available in the repository's README file. Any changes made after publication of the report will be documented there.

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Appendices

Appendix A – Methodological Details

Table A1. Categorization and inclusion of landcover types from USDA's CropScape layer for shorebird and duck suitability models. All landcovers were grouped into similar types (Category) and suitable categories were used in the analysis (Included = TRUE).

Code	Name	Category	Included
1	Corn	Corn	TRUE
2	Cotton	Field/Row Crop	TRUE
3	Rice	Rice	TRUE
4	Sorghum	Field/Row Crop	TRUE
5	Soybeans	Field/Row Crop	TRUE
6	Sunflower	Field/Row Crop	TRUE
10	Peanuts	Field/Row Crop	TRUE
11	Tobacco	Field/Row Crop	TRUE
12	Sweet Corn	Corn	TRUE
13	Pop or Orn Corn	Corn	TRUE
14	Mint	Field/Row Crop	TRUE
21	Barley	Grains	TRUE
22	Durum Wheat	Grains	TRUE
23	Spring Wheat	Grains	TRUE
24	Winter Wheat	Grains	TRUE
25	Other Small Grains	Grains	TRUE
26	Dbl Crop WinWht/Soybeans	Grains	TRUE
27	Rye	Grains	TRUE
28	Oats	Grains	TRUE
29	Millet	Field/Row Crop	TRUE
30	Speltz	Grains	TRUE
31	Canola	Field/Row Crop	TRUE
32	Flaxseed	Field/Row Crop	TRUE
33	Safflower	Field/Row Crop	TRUE
34	Rape Seed	Field/Row Crop	TRUE
35	Mustard	Field/Row Crop	TRUE
36	Alfalfa	Alfalfa	TRUE
37	Other Hay/Non Alfalfa	Grass/Pasture	TRUE
38	Camelina	Field/Row Crop	TRUE
39	Buckwheat	Grains	TRUE
41	Sugarbeets	Field/Row Crop	TRUE
42	Dry Beans	Field/Row Crop	TRUE
43	Potatoes	Field/Row Crop	TRUE
44	Other Crops	Field/Row Crop	TRUE
45	Sugarcane	Field/Row Crop	TRUE
46	Sweet Potatoes	Field/Row Crop	TRUE
47	Misc Vegs & Fruits	Field/Row Crop	TRUE
48	Watermelons	Field/Row Crop	TRUE
49	Onions	Field/Row Crop	TRUE

Table A1. Categorization and inclusion of landcover types from USDA's CropScape layer for shorebird and duck suitability models. All landcovers were grouped into similar types (Category) and suitable categories were used in the analysis (Included = TRUE).

Code	Name	Category	Included
50	Cucumbers	Field/Row Crop	TRUE
51	Chick Peas	Field/Row Crop	TRUE
52	Lentils	Field/Row Crop	TRUE
53	Peas	Field/Row Crop	TRUE
54	Tomatoes	Field/Row Crop	TRUE
55	Caneberries	Field/Row Crop	TRUE
56	Hops	Vineyard/Shrub	FALSE
57	Herbs	Field/Row Crop	TRUE
58	Clover/Wildflowers	Grass/Pasture	TRUE
59	Sod/Grass Seed	Grass/Pasture	TRUE
60	Switchgrass	Grass/Pasture	TRUE
61	Fallow/Idle Cropland	Field/Row Crop	TRUE
63	Forest	Forest	FALSE
64	Shrubland	Shrubland	FALSE
65	Barren	Barren	FALSE
66	Cherries	Orchard	FALSE
67	Peaches	Orchard	FALSE
68	Apples	Orchard	FALSE
69	Grapes	Vineyard/Shrub	FALSE
70	Christmas Trees	Tree Farm	FALSE
71	Other Tree Crops	Tree Farm	FALSE
72	Citrus	Orchard	FALSE
74	Pecans	Orchard	FALSE
75	Almonds	Orchard	FALSE
76	Walnuts	Orchard	FALSE
77	Pears	Orchard	FALSE
82	Developed	Developed	FALSE
83	Water	Water	FALSE
87	Wetlands	Wetland	FALSE
88	Nonag/Undefined	Undefined	FALSE
92	Aquaculture	Semi-Ag	FALSE
111	Open Water	Water	FALSE
112	Perennial Ice/Snow	Barren	FALSE
121	Developed/Open Space	Developed	FALSE
122	Developed/Low Intensity	Developed	FALSE
123	Developed/Med Intensity	Developed	FALSE
124	Developed/High Intensity	Developed	FALSE
131	Barren	Barren	FALSE
141	Deciduous Forest	Forest	FALSE
142	Evergreen Forest	Forest	FALSE
143	Mixed Forest	Forest	FALSE
152	Shrubland	Shrubland	FALSE

Table A1. Categorization and inclusion of landcover types from USDA's CropScape layer for shorebird and duck suitability models. All landcovers were grouped into similar types (Category) and suitable categories were used in the analysis (Included = TRUE).

Code	Name	Category	Included
176	Grass/Pasture	Grass/Pasture	TRUE
190	Woody Wetlands	Wetland	FALSE
195	Herbaceous Wetlands	Wetland	FALSE
204	Pistachios	Orchard	FALSE
205	Triticale	Grains	TRUE
206	Carrots	Field/Row Crop	TRUE
207	Asparagus	Field/Row Crop	TRUE
208	Garlic	Field/Row Crop	TRUE
209	Cantaloupes	Field/Row Crop	TRUE
210	Prunes	Orchard	FALSE
211	Olives	Orchard	FALSE
212	Oranges	Orchard	FALSE
213	Honeydew Melons	Field/Row Crop	TRUE
214	Broccoli	Field/Row Crop	TRUE
215	Avocados	Orchard	FALSE
216	Peppers	Field/Row Crop	TRUE
217	Pomegranates	Orchard	FALSE
218	Nectarines	Orchard	FALSE
219	Greens	Field/Row Crop	TRUE
220	Plums	Orchard	FALSE
221	Strawberries	Field/Row Crop	TRUE
222	Squash	Field/Row Crop	TRUE
223	Apricots	Orchard	FALSE
224	Vetch	Field/Row Crop	TRUE
225	Dbl Crop WinWht/Corn	Corn	TRUE
226	Dbl Crop Oats/Corn	Corn	TRUE
227	Lettuce	Field/Row Crop	TRUE
228	Dbl Crop Triticale/Corn	Field/Row Crop	TRUE
229	Pumpkins	Field/Row Crop	TRUE
230	Dbl Crop Lettuce/Durum Wht	Field/Row Crop	TRUE
231	Dbl Crop Lettuce/Cantaloupe	Field/Row Crop	TRUE
232	Dbl Crop Lettuce/Cotton	Field/Row Crop	TRUE
233	Dbl Crop Lettuce/Barley	Field/Row Crop	TRUE
234	Dbl Crop Durum Wht/Sorghum	Grains	TRUE
235	Dbl Crop Barley/Sorghum	Grains	TRUE
236	Dbl Crop WinWht/Sorghum	Grains	TRUE
237	Dbl Crop Barley/Corn	Corn	TRUE
238	Dbl Crop WinWht/Cotton	Grains	TRUE
239	Dbl Crop Soybeans/Cotton	Field/Row Crop	TRUE
240	Dbl Crop Soybeans/Oats	Field/Row Crop	TRUE
241	Dbl Crop Corn/Soybeans	Corn	TRUE
242	Blueberries	Vineyard/Shrub	FALSE

Table A1. Categorization and inclusion of landcover types from USDA's CropScape layer for shorebird and duck suitability models. All landcovers were grouped into similar types (Category) and suitable categories were used in the analysis (Included = TRUE).

Code	Name	Category	Included
243	Cabbage	Field/Row Crop	TRUE
244	Cauliflower	Field/Row Crop	TRUE
245	Celery	Field/Row Crop	TRUE
246	Radishes	Field/Row Crop	TRUE
247	Turnips	Field/Row Crop	TRUE
248	Eggplants	Field/Row Crop	TRUE
249	Gourds	Field/Row Crop	TRUE
250	Cranberries	Field/Row Crop	TRUE
254	Dbl Crop Barley/Soybeans	Grains	TRUE

Table A2. Covariates included in bird suitability models.

Covariate	Scale	Notes
Flooded seasonal & semipermanent wetland	250 / 5000 m	
Flooded rice	250 / 5000 m	
Flooded corn	250 / 5000 m	
Flooded row, field, and grain crops	250 / 5000 m	
Flooded non-rice crops	250 / 5000 m	
Flooded treated wetlands	250 / 5000 m	
Swamp timothy seed head mass	250 / 5000 m	Waterfowl only
Watergrass/smartweed greenness index	250 / 5000 m	Waterfowl only
Rice aboveground wet biomass	250 / 5000 m	Waterfowl only
Corn aboveground wet biomass	250 / 5000 m	Waterfowl only
Road density	5000 m	
Maximum temperature	250 m	

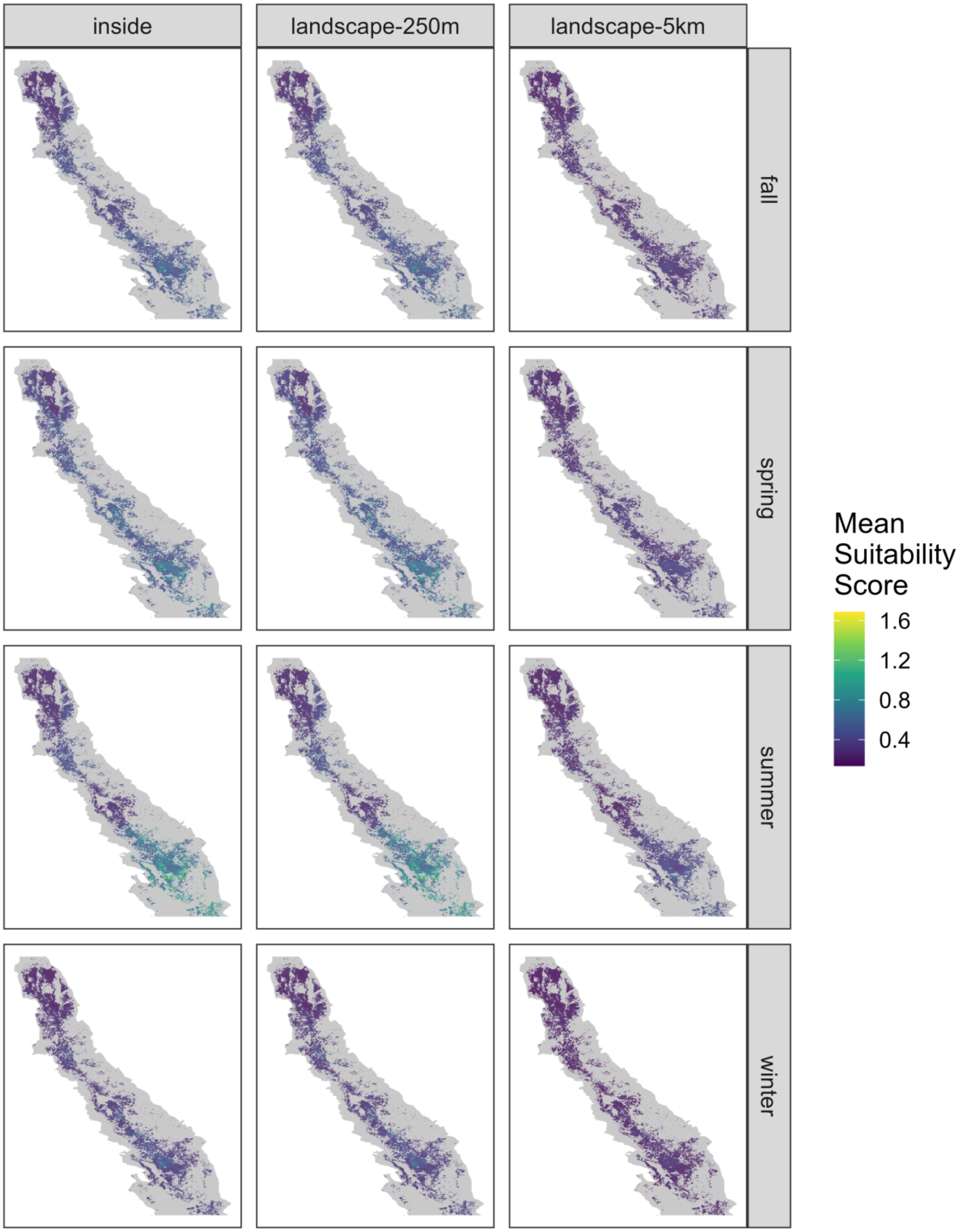
Appendix B – Extended Wetland Restoration Simulation Results

Species Suitability

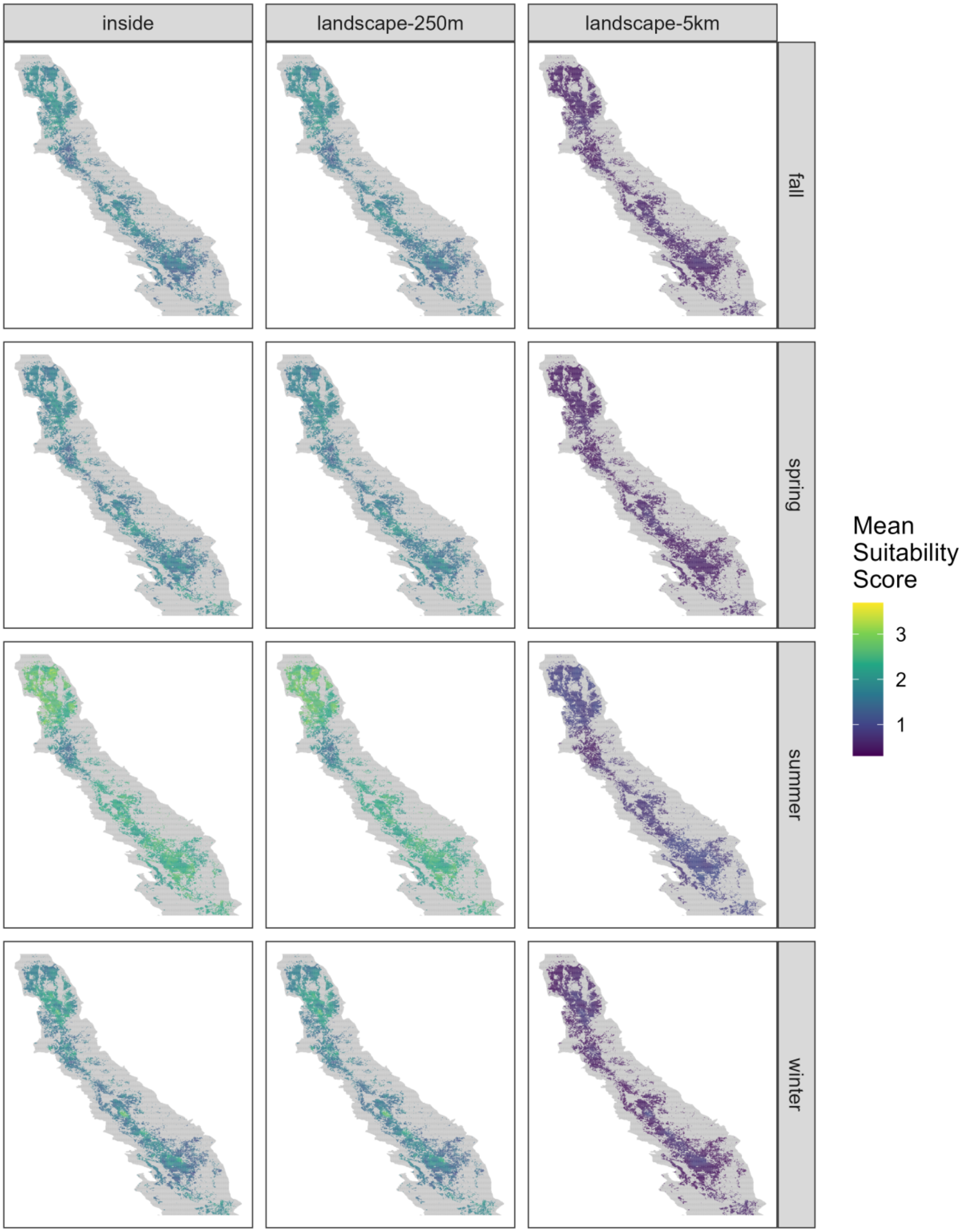
The figures below show the predicted mean seasonal suitability for each of eight bird species evaluated when a 90-acre patch of land was simulated to be restored as a seasonal wetland in California's Central Valley. Each seasonal suitability is presented at three spatial scales: inside the restoration, within 250 m of a restored wetland, and within 5000 m of a restored wetland. Note that Dowitcher spp. includes both Long-billed and Short-billed dowitchers.

Within a species, the suitability scale is shared across all seasons and spatial scales. Yellow indicates high suitability, green – blue moderate suitability, and purple low suitability.

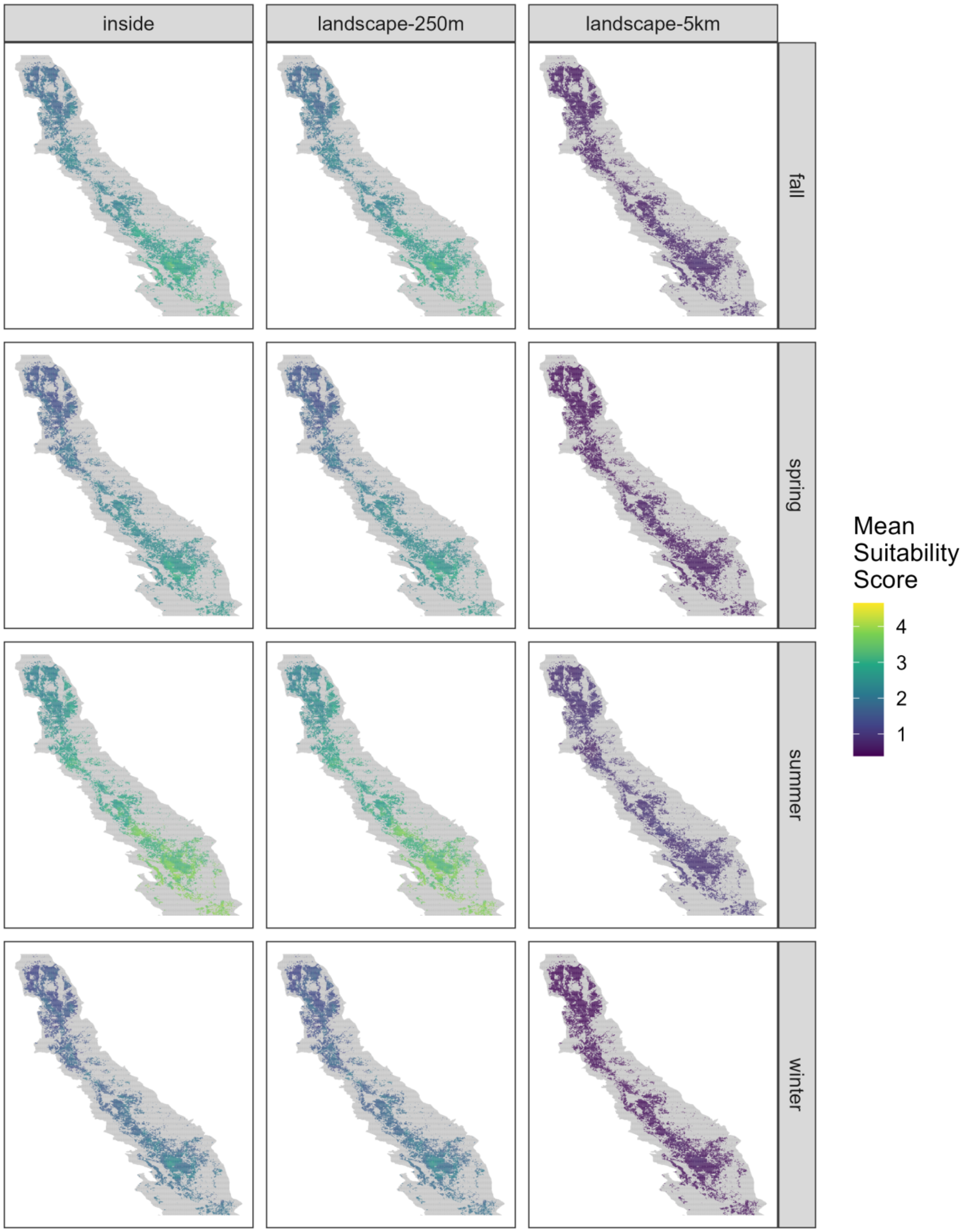
American Avocet



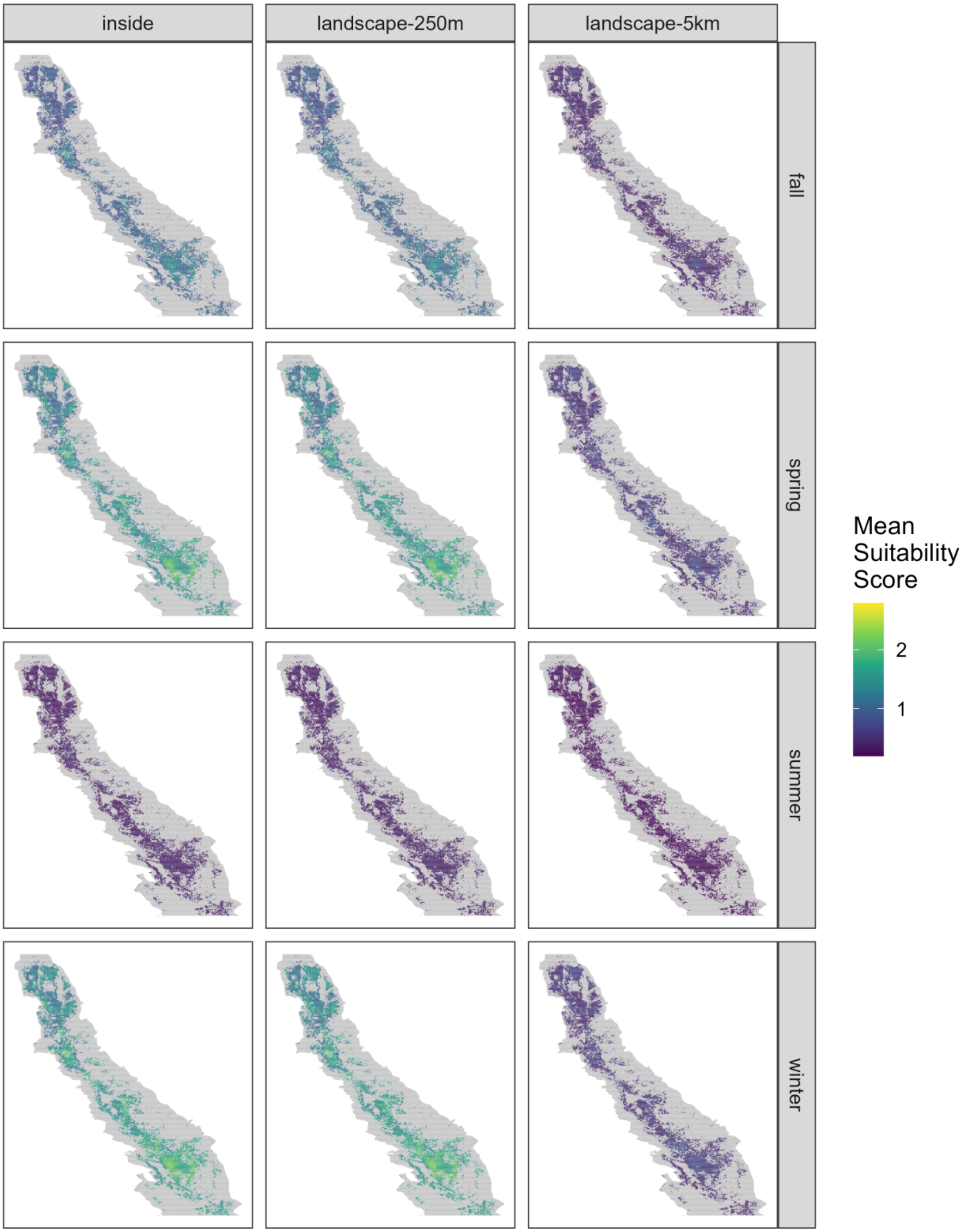
Black-necked Stilt

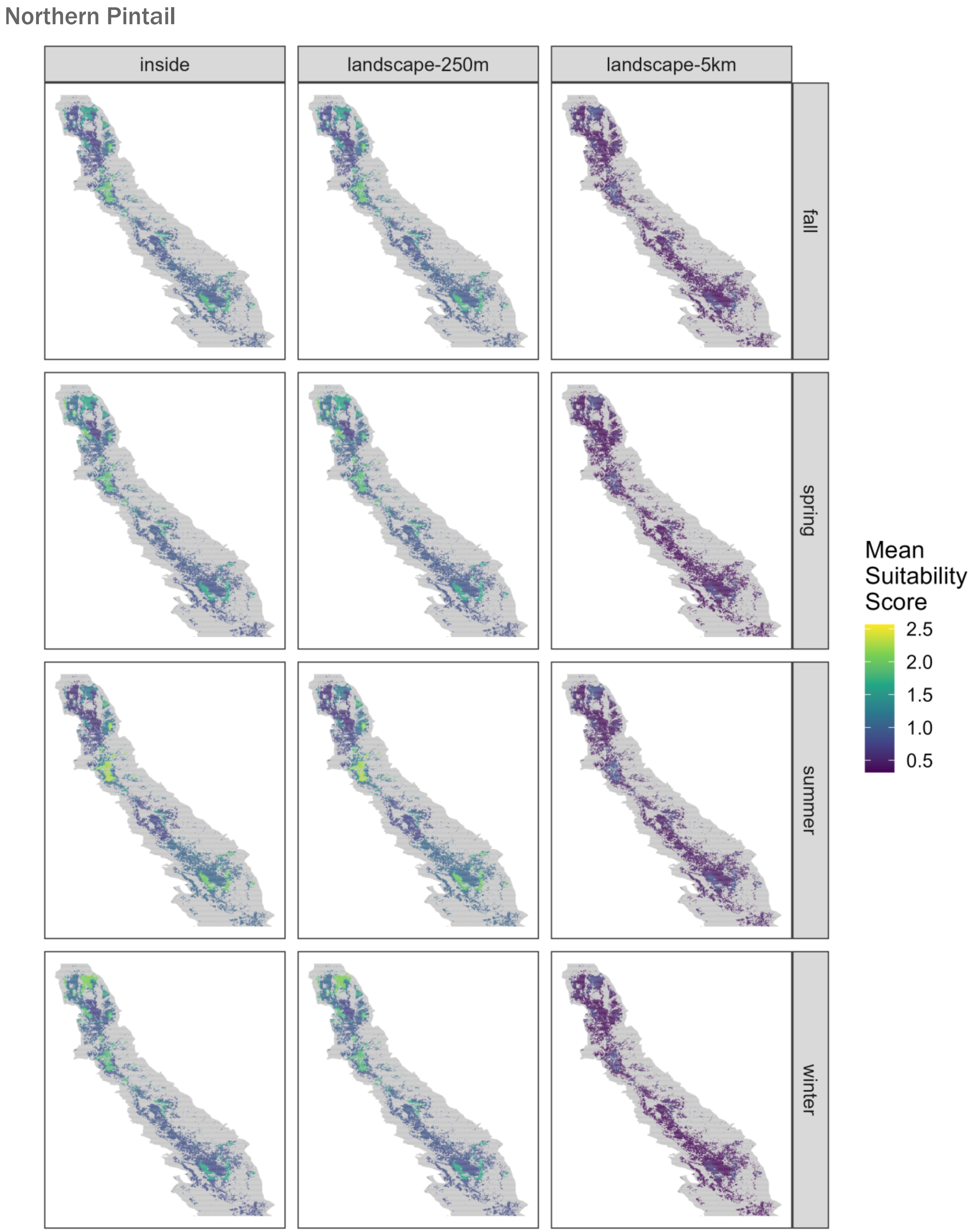


Dowitcher spp. (Long-billed and Short-billed)

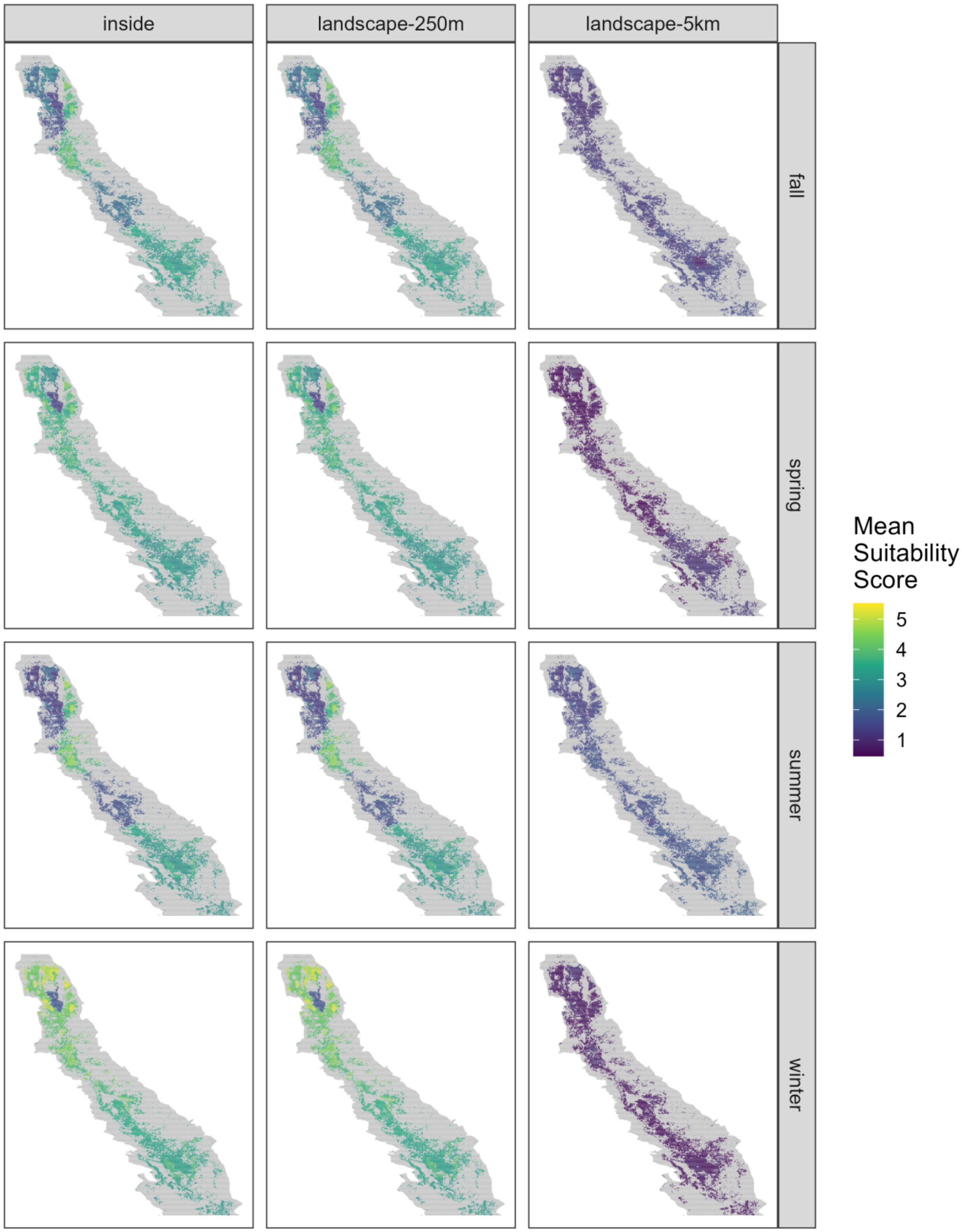


Dunlin

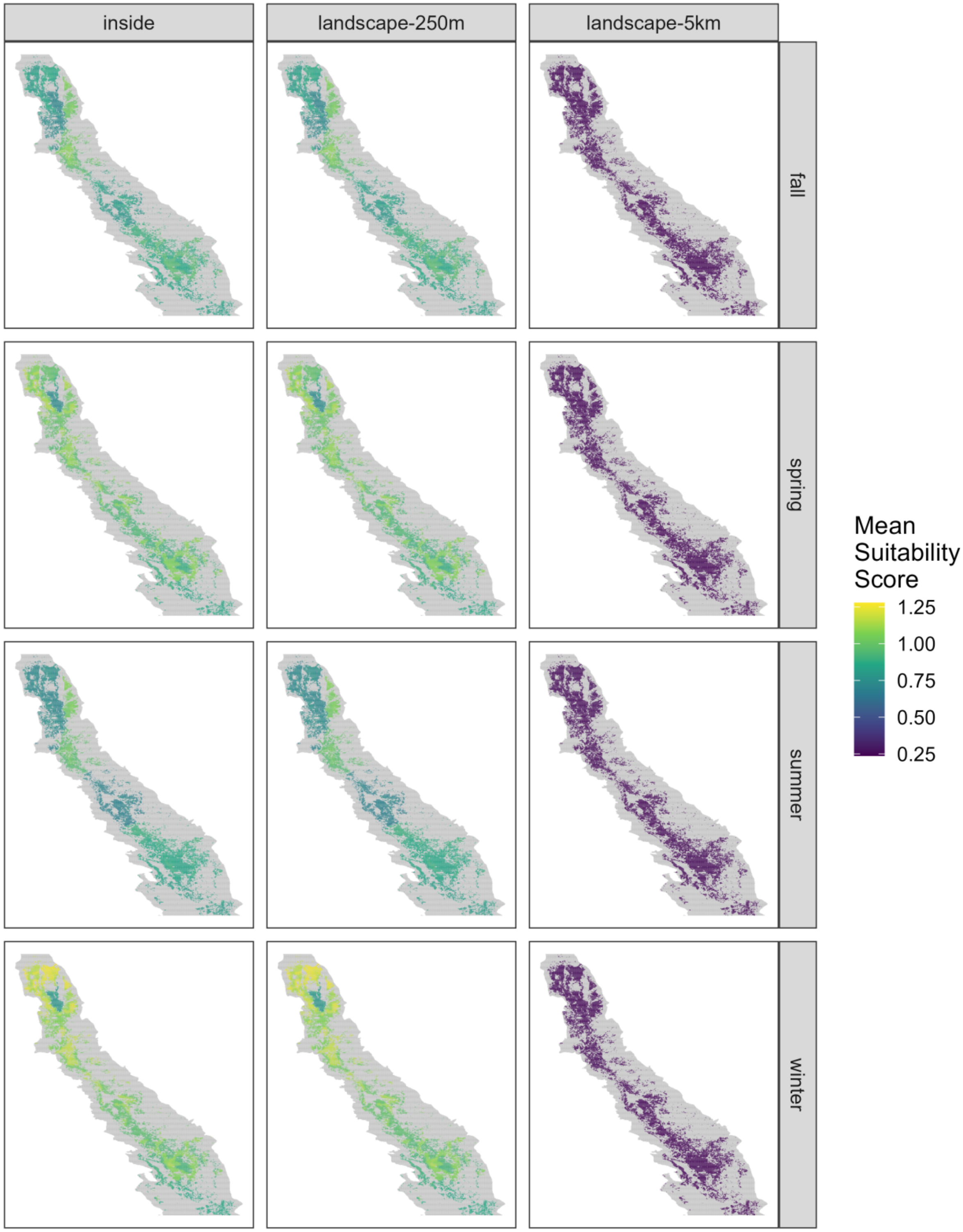

inside
landscape-250m
landscape-5km
fall
spring
summer
winter
Mean Suitability Score
2
1


Northern Pintail
inside
landscape-250m
landscape-5km
fall
spring
summer
winter
Mean Suitability Score
2.5
2.0
1.5
1.0
0.5

Northern Shoveler



Green-winged Teal

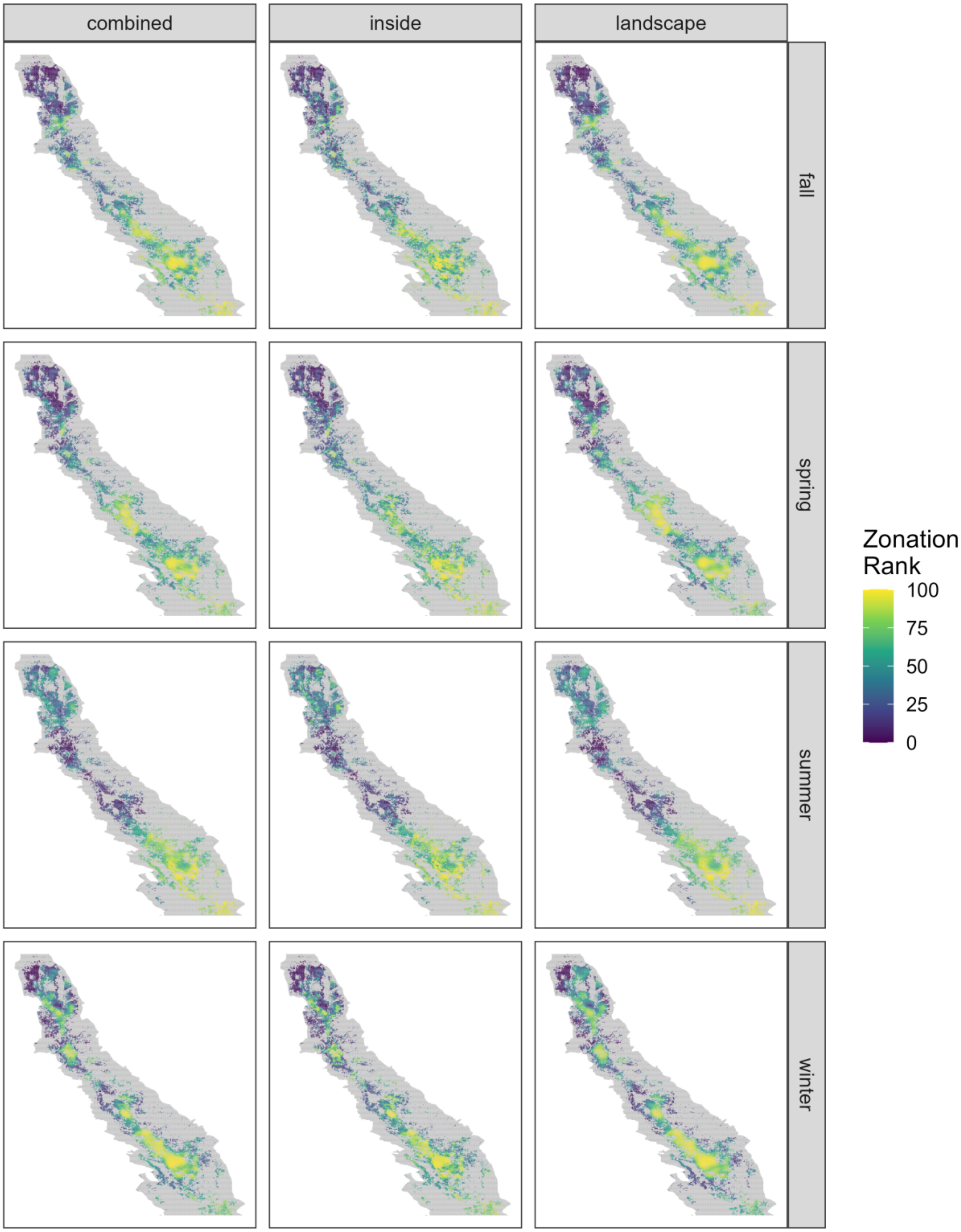


Zonation Prioritization

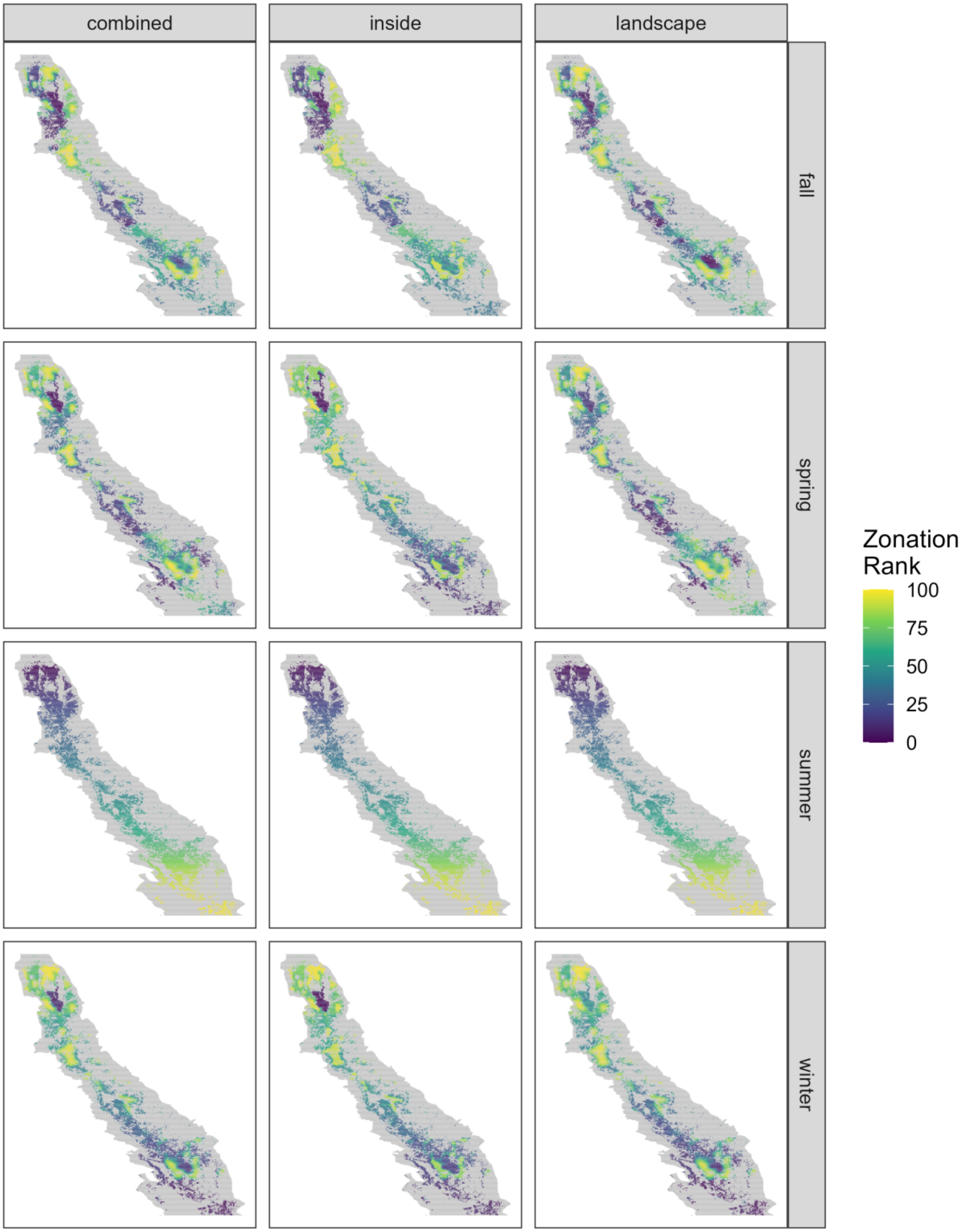
The figures below show the calculated zonation priority ranking for bird species evaluated when a 90-acre patch of land was simulated to be restored as a seasonal wetland in California's Central Valley. One plot shows the priority when considering only the shorebirds (American Avocet, Black-necked Stilt, Long- and Short-billed Dowitchers, and Dunlin), one only ducks (Northern Pintail, Northern Shoveler, and Green-winged Teal), and one all species combined. Each zonation priority ranking is shown when considering three different scores: suitability inside the restoration, within 5000 m of a restored wetland (landscape), and the combined suitability from inside and within 5000 m of the restored wetland.

The zonation priority is a ranking from 0 – 100, with 100 being the most valuable. Yellow indicates relatively high priority, green – blue moderate priority, and purple low priority.

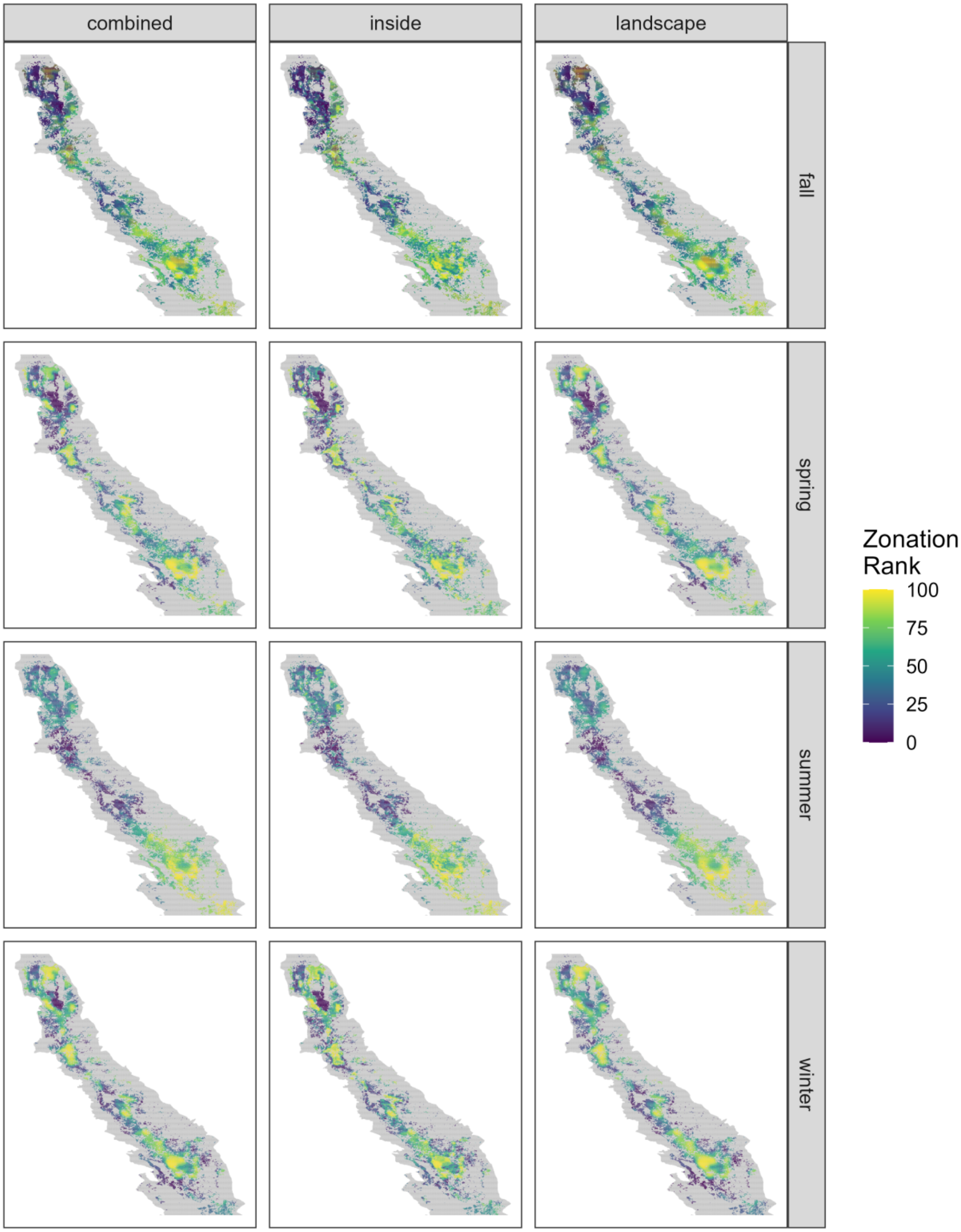
Shorebirds


combined
inside
landscape
fall
spring
summer
winter
Zonation Rank
100
75
50
25
0

Ducks


combined
inside
landscape
fall
spring
summer
winter
Zonation Rank
100
75
50
25
0

All Species


combined
inside
landscape
fall
spring
summer
winter
Zonation Rank
100
75
50
25
0

Appendix C – Summarization Tools

Overview

This appendix describes and provides the standard operating procedure for summarizing wetland restoration priority in California's Central Valley. The data to be summarized were produced by Point Blue Conservation Science for USFWS; please see the report Informing Strategic Wetland Restoration on Private Lands to Enhance Habitat Resilience in the Central Valley of California (Reiter et al, 2025) for details. This tool was developed from code used by Point Blue's new cloud-based system BidRunner.

The summarization tool is code written in the R programming environment (R Core Team, 2025). This tool is best used by someone with a working familiarity with R because there is no standalone app or graphical interface. The scripts must be run via an IDE such as RStudio (recommended), command line, or copy/pasted from a text editor. Summarization parameters must be edited using RStudio, Notepad++, or similar. Additionally, some basic troubleshooting issues may arise (e.g., the need to download any missing packages, occasional updates if the version of R is updated, etc.). Point Blue Conservation Science is available to provide support — please contact Nathan Elliott (nelliott-CTR@pointblue.org) or Matt Reiter (mreiter@pointblue.org) as needed.

This information is also available in the GitHub repository's README file (see below). Any changes made after publication of this report will be documented there.

Software Requirements

R version 4 or later

- Recommended: > 4.2
- Download R for your operating system from https://cran.rstudio.com/

R packages

- terra
- tidyverse (dplyr, tidyr, ggplot2)

Program to read and edit .R code files

- Recommended: RStudio Desktop
- Download from https://posit.co/download/rstudio-desktop/

Downloading

The code is accessed via a public GitHub repository here: https://github.com/pointblue/cv-wetland-restoration-summarization.

Data are in a Google drive folder here: https://drive.google.com/drive/folders/1D7Nt-MfsbY6vKwraz94I0gHp32F_-aqH?usp=drive_link

File Structure

The default name of the root folder is that of the GitHub repository: cv-wetland-restoration-summarization. You can rename this if desired. Within this folder are the following folders and files:

- code: folder containing the .R code files used to summarize the data
    - functions: folder containing the custom functions called by the R scripts. You shouldn't need to modify these for most uses.
    - 00_definitions.R: script file containing the basic directory and data definitions. You probably won't need to open this unless you have a non-standard file path setup.
    - 01_download_data.R: script file that will download the required prioritization data. Only needs to be run once.
    - 02_summarize_by_polygons.R: script file that will summarize your polygon file. You will edit this file to specify the shapefile to summarize and change any of the default summary parameters.

- data: folder containing the raster layers of bird suitability and wetland prioritization
    - current_wetland_priority: layers of prioritization ranking using current landcover (Objectives 1 – 3). GeoTiffs, floating point, INT4S, range 0 – 1.
    - future_wetland_priority: layers of prioritization ranking using future flooding scenarios (Objectives 1 – 3). GeoTiffs, floating point, INT4S, range 0 – 1.
    - simulated_wetland_priority: layers of prioritization ranking using simulated wetland restorations. GeoTiffs, floating point, INT4S, range 0 – 1.
    - simulated_wetland_suitability: layers of bird suitability using simulated wetland restorations. GeoTiffs, floating point, INT4S, range 0 – 9.

- inputs: folder in which you will place the shapefile(s) to summarize
    - clean: folder that contains the cleaned versions of the shapefiles being summarized (possible changes: fixing geometry, reprojecting, renaming columns)

- outputs: folder to which the summaries will be written. Each shapefile that is summarized will generate a sub-folder named after the shapefile.

- .gitignore.txt: text file specifying files to exclude from the GitHub repository

- cv-wetland-restoration-summarization.Rproj: an R Project file for ease of editing and running the script files

- LICENSE: file containing the code license (MIT)

- README.md: text file containing more detailed information about the project. It contains the information in this appendix and will be updated with any changes made after the publication of this report.

Running the Summarization

1. Ensure you have the required software installed (see software requirements above)

2. Download the code from https://github.com/pointblue/cv-wetland-restoration-summarization.
    a. Clone the repository using Git, GitHub Desktop, or another tool
    b. **OR** download the source code manually from the latest release. The zip file that is downloaded will have the code and Objective 4 spatial data.

3. Download the data for Objectives 1 – 3. Layers from Objective 4 are included in the repository; layers from 1 – 3 are too large for GitHub and must be downloaded separately.
    a. Run the script 01_download_data.R (easiest)
    b. **OR** download manually from the Google drive link above
        i. Navigate to Recent Historic Landscape (Conlisk) / GeoTiff
        ii. Download the seven layers that begin with AllBirds to cv-wetland-restoration-summarization\data\current_wetland_priority
        iii. Download the two layers that begin with Future to cv-wetland-restoration-summarization\data\future_wetland_priority

4. Place the shapefile you want to generate summaries for in cv-wetland-restoration-summarization/inputs.
    a. Shapefile should have a projection of UTM Zone 10N using the WGS 84 datum
    b. Shapefile should have a unique ID column
    c. These parameters will be checked during the summary, corrected automatically if possible, and notify you of an error if there's a problem

5. Prepare the summarization
    a. Open the file 02_summarize_by_polygons.R
    b. Change any of the parameters that control what data are summarized and how the output is presented. The default is to generate everything. These parameters include
        i. the name of the shapefile you are summarizing
        ii. name of the column that contains the name of the polygon unit
        iii. names of columns that you want in the final summary files
        iv. what scenarios and layers are summarized: prioritization using current landcover ('current'), prioritization using future flooding ('future'), suitability of restored wetlands ('restored_suitability'), and prioritization using restored wetlands ('restored_priority')
        v. what summary stats are generated (mean, standard deviation, median, minimum, maximum)
        vi. whether to produce graphs
        vii. whether to produce maps
        viii. the format of the output table ('wide' or 'long')
        ix. whether to overwrite existing outputs
    c. Save the file after you've made the changes you want

6. Run the summarization script 02_summarize_by_polygons.R