Final Project Report
Q1996022

Trade-offs and Co-benefits of Landscape Change Scenarios in the Sacramento-San Joaquin River Delta

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Final Project Report:

Trade-offs and Co-benefits of Landscape Change Scenarios on Bird Communities and Ecosystem Services in the Sacramento-San Joaquin River Delta

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Prepared by

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Executive Summary

Achieving the long-term vision of a resilient Sacramento-San Joaquin River Delta ecosystem requires meeting multiple goals simultaneously, including self-sustaining wildlife populations and thriving communities of people, in an evolving landscape (Figure 1). However, to effectively plan and implement policies and land management decisions intended to achieve multiple goals, it is essential to be able to identify the potential trade-offs of changes to the landscape across multiple goals (Gardali et al. 2021). To help meet this challenge, support effective policy and resource management decisions, and address several science priorities identified in Science Action Agendas (DSC 2017, 2022a), we built on our partnerships in the Delta and broader Central Valley, and on our expertise in multiple-benefit conservation and avian ecology in agricultural landscapes, to address two main goals: (1) identify Priority Bird Conservation Areas in the Delta to support effective restoration and management decisions, and (2) develop a science-based framework for forecasting the net benefits or trade-offs of proposed or anticipated landscape changes on multiple goals. The ultimate goals of this project were to support communication among Delta community members about the projected synergies and trade-offs among multiple metrics, facilitate the identification of, and community support for, solutions to address these trade-offs, and thereby support effective decision-making and policy to reach the Delta Plan's multiple goals.

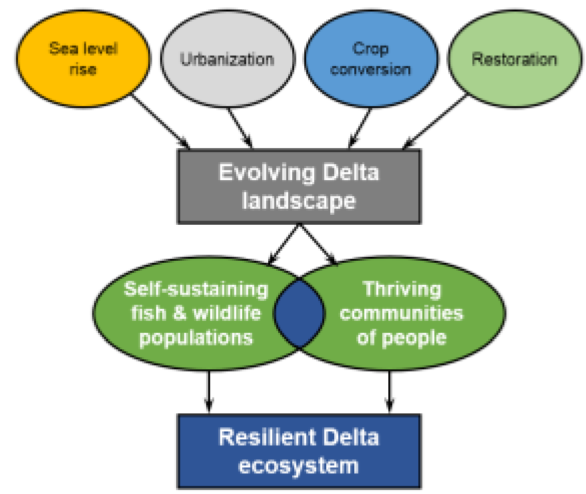


Figure 1. Conceptual diagram

Objectives & Tasks

- **Synthesize scientific information on indicators of ecosystem services associated with land cover types that occur in the Delta (Task 2):** Completed entirely with cost share, for this task we synthesized the current state of the science on a range of metrics representing multiple ecosystem services associated with different land cover types in the Central Valley. We produced a Science Synthesis Report describing the sources of data, methods of analysis, and resulting estimates of the contribution of each land cover type across metrics and potential synergies and trade-offs among them (Peterson et al. 2020).
- **Map the high priority bird conservation areas in the Delta (Task 3):** For this task, we built on extensive bird survey data collected throughout the Delta and surrounding areas to develop and refine models for predicting the spatial distribution of riparian landbird species and groups of waterbird species throughout the Delta, which we then used to identify Priority Bird Conservation Areas. We produced a preliminary report followed by a draft manuscript describing the bird surveys, analyses, and results (Dybala et al. In review - A), as well as associated supporting data and GIS files (Dybala et al. 2023a, 2023b, 2023c, 2023d, 2023e).

- **Evaluate the net impact of scenarios of landscape change on bird populations and ecosystem services (Task 4):** We coordinated with key partners to select drivers of landscape change in the Delta that were relevant to consider (habitat restoration, perennial crop expansion, and a combination of the two), develop spatially-explicit scenarios of landscape change representing the influence of each driver, and then estimate the net impacts of each scenario on metrics representing four categories of benefits: agricultural livelihoods, water quality, climate change resilience, and biodiversity support. We produced a preliminary report followed by a draft manuscript describing the development of scenarios, selection and refinement of metrics, and estimation of the net impacts of each scenario (Dybala et al. In review - B), as well as associated supporting data (Dybala 2023a, 2023b, 2023c).
- **Develop a flexible, science-based framework for assessing the trade-offs and co-benefits of landscape changes (Task 5):** We generalized the methods used in the scenario analyses above to develop an open-source R package to serve as a general framework for assessing the benefits and trade-offs of landscape change (Dybala 2023d). The framework is freely available to download and use, and it allows our analyses to be readily reproduced, but is also designed to be flexible for accommodating future expansions and refinements with updated data, metrics, species, or scenarios. Its development is also described in the draft manuscript mentioned above (Dybala et al. In review - B).
- **Engage with stakeholders and resource managers to demonstrate the need to consider trade-offs and co-benefits in making land use decisions and provide training in how to use our science-based framework (Task 6):** We communicated with key partners about the overall project concept and in the selection and development of scenarios to evaluate, including the Delta Stewardship Council, California Department of Fish and Wildlife, Delta Conservancy, Central Valley Joint Venture Lands committee, and Migratory Bird Conservation Partnership (including The Nature Conservancy and Audubon California). We also shared the results of the scenario analyses, illustrating the ways in which resource management and policy decisions can result in trade-offs and co-benefits for bird populations and ecosystem services, through presentations as part of the "Slough-Side Chat" series, CDFW Conservation Lecture series, and a Central Valley Joint Venture board meeting.
- **Disseminate results to the broader scientific community (Task 7):** We communicated our results to the broader scientific community, through presentations at the Bay-Delta science conference (2021) and the North American Congress for Conservation Biology (2022), as well as developing two draft manuscripts for publication (as described above).

Key Results

- **Priority Bird Conservation Area:** We identified a total of 26,019 ha of Priority Bird Conservation Area in the Delta, which represent the most important places in the Delta to protect and manage as well as strategic areas where adjacent restoration could expand valuable habitat. A few existing protected areas and easements were highlighted as a priority for both riparian landbirds and waterbird groups, including the Yolo Bypass Wildlife Area and nearby conservation easements, Cosumnes River Preserve, Stone Lakes National Wildlife Refuge, and bufferlands surrounding the Sacramento County Regional Sanitation District, indicating that continued protection and effective management of these areas is a critical strategy for the conservation of riparian landbirds and waterbirds in the Delta. In addition, approximately 28% of the total Priority Bird Conservation Area also fell within one of the Delta's Priority Habitat Restoration Areas, providing insights into strategic areas where restoration could expand existing patches of particularly valuable habitat. However, over 60% of the Priority Bird Conservation Area is not protected, indicating a vulnerability to changes in land cover or land use that should be considered in conservation plans and strategies (see Recommendations section below).

- **Net impacts of habitat restoration and perennial crop expansion scenarios:** We confirmed that scenarios of projected or anticipated changes to the Delta landscape would result in a mix of net benefits and trade-offs when multiple metrics are considered, and that it would be possible to estimate the net direction, magnitude, and uncertainty in the projected difference in multiple metrics from a baseline landscape. We estimated that meeting the Delta Plan's targets for non-tidal wetland and riparian restoration by 2050 would result in a substantial net increase in biodiversity support benefits, with no significant benefits or trade-offs in metrics representing water quality, climate change resilience, and agricultural livelihood benefits. In contrast, if recent rates of conversion to perennial crops continue through 2050, with or without simultaneously meeting restoration objectives, we projected significant benefits to agricultural livelihoods but trade-offs in both water quality (in terms of net increases in the estimated annual application rates of known groundwater contaminants and chemicals known to pose a "high" or "moderate" risk to aquatic organisms) and resilience to extreme drought and heat expected under climate change. Perennial crop expansion alone was not projected to significantly impact total biodiversity support benefits, though it would impact individual riparian landbird species and waterbird groups, and the combination of perennial crop expansion with habitat restoration would provide less biodiversity support benefits than restoration alone. Thus, our results indicated the effects of meeting habitat restoration targets would be partially offset by continued perennial crop expansion, with implications for restoration and land management strategies.
- **Framework for evaluating multiple benefits:** We generalized our scenario analyses to develop a science-based framework for evaluating multiple benefits and trade-offs, demonstrating the integration of multiple types of data and models into a common framework and addressing key gaps in scientific information identified by the Delta's Science Action Agendas (DSC 2017, 2022a). Our resulting R package is freely available to use and supports incorporating new data, models, and metrics and evaluating new scenarios, thereby facilitating ongoing coordination and integration of data among the Delta's research community. Our framework is designed to complement the Delta Landscape Scenario Planning Tool (DLSPT), an ArcPro Toolbox, which represented a great advance in supporting the analysis of the impacts of land cover changes on multiple metrics, largely aimed at land managers and reflecting landscape ecology metrics (SFEI 2022). Here we sought to integrate additional types of data, models, and metrics in a more open-source framework that could facilitate collaborative, ongoing refinement and improvement among the Delta research community. We look forward to continuing to build on this framework in collaboration with other researchers across disciplines.

Evaluation

Although progress on this project was slowed during the initial waves of the COVID-19 pandemic in 2020, and the development of spatially-explicit scenarios of landscape change took longer than initially anticipated, we were ultimately successful in achieving all of our objectives on time. This project successfully provided new insights into Priority Bird Conservation Areas in the Delta and the separate and combined impacts of habitat restoration and perennial crop expansion on multiple categories of benefits, as well as the data, models, and tools to forecast the net impacts of new landscape change scenarios on multiple metrics. This project also laid the foundation for an open-source framework for integrating multiple data sources and models and the transparent, repeatable methods for projecting their response to alternative scenarios of landscape change. Communications with resource managers, key stakeholders, and the broader scientific community about this project have been very supportive, with numerous ideas suggested for additional metrics to include in future phases of developing this framework.

Recommendations

The results of our analyses represent the most current state of the science on the areas with a high confidence of importance to bird conservation and the projected benefits and trade-offs of landscape change across multiple metrics and scenarios, but our results are not the final word on conservation strategy or resource management decisions within the Delta's evolving landscape. They provide a foundation of data, methods, and tools on which further collaborative efforts can build. To apply our results to resource management and conservation decisions in the Delta and build on them to continue filling science needs, we make several recommendations:

- **Incorporate Priority Bird Conservation Areas in conservation strategies and scenario analyses.** Bird conservation is a core component of meeting goals for the Delta ecosystem and is likely to benefit bird populations well beyond the boundaries of the Delta. Protected areas and conservation easements were highlighted as among the Priority Bird Conservation Area for both riparian landbirds and waterbirds, and we recommend continued protection and effective management of these areas as a critical strategy for the conservation of riparian landbirds and waterbirds in the Delta. In addition, we recommend prioritizing restoration and enhancement efforts adjacent to one of the Priority Bird Conservation Areas, to expand existing patches of particularly valuable habitat wherever feasible. However, we emphasize that the Priority Bird Conservation Areas were estimated as the top 5% highest priority for the current landscape, and are not necessarily fixed in space, particularly for the more than 60% that are not currently protected. They may be vulnerable to changes in land cover or threats such as increasing flood risk from sea level rise. We recommend considering the impact of landscape change scenarios on the habitat value of the Priority Bird Conservation Areas, a step that was beyond the scope of the current project, and we recommend that conservation strategies in the Delta plan for mitigating the loss of some of this valuable habitat, such as through restoration or enhancement efforts that would improve habitat valuable in less vulnerable locations.
- **Define bird conservation objectives.** We identified Priority Bird Conservation Areas as the most important 5% of the landscape for riparian landbirds and waterbird groups, giving equal weight to each species or group. However, the Delta provides habitat to a very large, diverse

community of birds (Dybala et al. 2020) and these Areas do not yet address all bird groups of conservation interest (e.g., raptors, or species associated with tidal marsh). In addition, the decisions to apply equal weights to all species and select a 5% threshold were arbitrary due to the lack of bird conservation objectives and priorities specific to the Delta. Although fairly comprehensive bird conservation objectives have been developed for the Central Valley, including the Delta (CVJV 2020), we recommend that more specific priorities and objectives are defined for the Delta. They should specify which species or groups are most important to meeting goals for the Delta ecosystem and be designed to reflect the relative importance of the Delta in providing habitat to certain species or groups within the larger context of conservation goals and plans for California, the Central Valley, and the San Francisco Estuary. For example, if the Delta provides core habitat for a species that is not widely available elsewhere (e.g., Sandhill crane; Veloz et al. 2017), it may be a higher priority for the Delta and should carry more weight in the prioritization analyses. In addition, defining habitat objectives by species or group would inform whether protecting and managing the top 5% and/or meeting existing habitat restoration targets will be sufficient to meet conservation goals, particularly because the value of the additional habitat projected from the habitat restoration scenario may be partially offset by perennial crop expansion or other changes to the landscape.

- **Develop additional metrics, models, and scenarios to include in the framework.** To further improve the value and relevance of this framework, we recommend identifying, developing, and adding new metrics, models, and scenarios to better represent the broad range of values important to Delta communities, performance measures related to Delta Plan goals, and proposed or anticipated changes to the landscape. For example, new metrics could address habitat for other flora and fauna, recreational opportunities (Mickel et al. 2019), applied water use (DWR c2022), or greenhouse gas emissions (SFEI 2022). The challenge with developing any new metric lies in ensuring comparable data coverage for all of the major land cover classes, and particularly those that will be the focus of any scenario analyses. For example, we excluded tidal wetland restoration from our habitat restoration scenario due to a lack of data to support estimating the anticipated biodiversity support benefits; an important extension of this framework currently in development is the collection of new survey data and development of spatial distribution models for tidal marsh species that will allow future analysis of the net benefits of tidal marsh restoration. In addition, we focused our assessment of livelihoods on the agricultural sector, but information about other sectors could be incorporated if comparable data are available, such as jobs, wages, and economic value related to tourism and conservation in the Delta.
- **Refine existing metrics.** Due to uncertainty in several of the metrics we evaluated, some of our projections for the net impact of each scenario were not statistically different from zero, even where the magnitude of the projected change represented more than a 5% change from the baseline conditions, a change we assumed represented a practically meaningful impact to the Delta ecosystem. Future refinement of these metrics could reduce this uncertainty. For example, incorporating additional years of employment, crop production value, and pesticide application data could result in more precise estimates of the values of each metric associated with each land cover class. Alternatively, developing spatially-explicit models predicting the value of each metric as a function of factors beyond land cover class could refine our projections.

Addressing the goals of Proposition 1

Proposition 1 provided funding to implement the three objectives of the California Water Plan, including more reliable water supplies, the restoration of important species and habitat, and a more resilient and sustainably managed water infrastructure (Water Code § 79701(e)). A portion of the funding was designated for competitive grants for multibenefit ecosystem and watershed protection and restoration projects in accordance with statewide priorities (Water Code § 79730), including funds made available to the California Department of Fish and Wildlife for scientific studies and assessments that support the Delta Science Program (Water Code § 79738 (a) (3)). In accordance with the goals of Proposition 1 and the objectives of the California Water Plan, this project addressed components of all 5 of the priority science actions areas that were identified in the inaugural Science Action Agenda for the Delta Science Plan because of their importance to informing resource management decisions (DSC 2017):

1) Invest in assessing the human dimensions of natural resource management decisions;
2) Capitalize on existing data through increasing science synthesis;
3) Develop tools and methods to support and evaluate habitat restoration;
4) Improve understanding of interactions between stressors and managed species and their communities; and
5) Modernize monitoring, data management, and modeling.

In addition, this project addressed three more science priorities that have since been identified in the updated Science Action Agenda (DSC 2022a), including:

6) Provide accessible, relevant data for measuring the changing Delta;
7) Develop tools for integrative planning; and
8) Assess trade-offs and multiple benefits of planned and ongoing management actions and policies.

We note that this final priority is identified as the ultimate goal of all other science priorities, to provide a strong scientific basis for decision-making and policy.

To contribute to these priority science action areas, the Delta Science Plan, and the ultimate goal of providing a strong scientific basis for decision-making and policy, this project:

- Capitalized on existing data to produce a science synthesis (#2) summarizing estimates for multiple metrics representing ecosystem services that are associated with land cover classes throughout the Central Valley, which were then further tailored for the Delta. Metrics were chosen to support the assessment of the human dimensions of natural resource management decisions (#1), such as metrics representing the contributions of land cover classes to agricultural livelihoods, as well as to evaluate the resilience of the landscape to climate change stressors (#4).
- Capitalized on and synthesized existing bird survey data (#2) to produce modern species distribution models and a prioritization analysis (#5) for selected riparian landbird species and waterbird groups. We used these results to identify Priority Bird Conservation Areas, which provide insights into the most important areas to protect and manage for birds, but also support habitat restoration decisions (#3) by indicating locations where adjacent restoration is likely to have the most benefit.

- Applied the data and models developed above to assess trade-offs and multiple benefits of planned and ongoing management actions and policies (#8), including an evaluation of the impacts to human dimensions (#1), biodiversity support goals (#3), resilience to climate change stressors (#4), and risk to water quality from pesticide application rates.
- Integrated the data, models, and analyses described above into a common framework as an R package that supports integrative planning (#7). The framework facilitates the evaluation of landscape change scenarios and forecasting the trade-offs and multiple benefits of each scenario on each metric, and is designed to be readily updated to incorporate new data, metrics, models, and scenarios as needed to provide a strong scientific basis for decision-making and policy. The R package and associated data and models were all made accessible (#6) through public data repositories.

The goals of this project were to facilitate a more comprehensive multi-dimensional understanding of the direction and magnitude of potential impacts of decisions and policies in the Delta (#8), and thereby facilitate communication among Delta community members about the projected synergies and trade-offs among goals and the identification of and community support for solutions to address these trade-offs. The ultimate goals of this project were to support effective decision-making and policy to reach the Delta Plan's multiple goals, and in so doing, contribute to California Water Plan objectives.

Task Reports

Task 2. Science Synthesis: Ecosystem Services Indicators Associated with Different Land Cover Types

Note: This task was funded entirely through other funding sources.

2.1 Objective

Synthesize the current state of the science on metrics of ecosystem services (ES) by land cover/land use type, allowing estimation of net changes in ES resulting from projected changes in the landscape (in Task 4 below).

The following text and figures are reproduced and adapted from Peterson et al. (2020), which provides more extensive detail.

2.2 Background & Methods

The Central Valley of California is one of the most heavily modified landscapes in the world, with millions of acres of semi-arid grassland, desert, mesic, wetland, and riparian areas transformed into an irrigated crop production powerhouse through large-scale infrastructure and irrigation projects. Despite its reputation as an agricultural "sacrifice zone", it remains an area of conservation focus for its varied, unique, and vibrant ecosystems, from rare vernal pools and serpentine grasslands to the extensive networks of riverine systems, riparian forests, and wetlands that converge at the Sacramento-San Joaquin Delta. While the importance of these natural areas for human-valued functions such as water supply and quality regulation, biodiversity, culture, and recreation is well established, the dominance of agricultural land covers in the Central Valley underscores the need to understand to what extent they contribute to or detract from ecosystem functions beyond crop production.

Much of the information that is available on the potential benefits from agricultural and natural land covers is not centralized. Instead, disparate reports from research activities that vary in geographic location, scope, and timeframe constitute the bulk of the literature. Furthermore, most studies implement a particular suite of metrics to characterize benefits or trade-offs provided by a land cover depending on the objectives of the study. Therefore, a synthesis of information on multiple benefits that aggregates metrics into a single database with comparable units of measure is an important step towards incorporating multiple benefits research into concerted planning and policy-making efforts for a multifunctional Central Valley landscape.

We performed a rapid evidence assessment following a consistent search strategy and pre-determined inclusion/exclusion criteria. We limited the results of the literature search to peer-reviewed publications from 2010-2020 with a geographic focus on the Central Valley, including the Sacramento-San Joaquin Delta. We extracted published, quantitative estimates of benefits and/or trade-offs associated with individual land covers and compiled a database consisting of metrics on: 1) climate regulation (e.g., greenhouse gas emissions, carbon storage/sequestration), 2) economy (e.g., livelihoods, production value), 3) environmental health (e.g., pollution, pesticide load), 4) water (e.g., water quality, water use), and 5) wildlife, specifically value for avian conservation. We also consulted expert panels in the fields of agricultural ecology and conservation to assess: 1) avian conservation value, and 2) vulnerability to the impacts of climate change of each of the land covers. Finally, we produced a spatially-explicit model using publicly-available datasets to visualize the distribution of ecosystem benefits and trade-offs, including carbon storage potential, air and water quality, groundwater recharge, and socio-cultural benefits.

2.3 Results & Discussion

We found substantial variation across land covers in the multiple benefits and trade-offs they provided. For example, orchard crops are notable for their contributions to agricultural production value and agricultural livelihoods, but these benefits were offset by potential trade-offs in air quality metrics, nitrate leaching risk, and consumptive water use (Figure 2). We found that the agricultural land covers most likely to be associated with multiple benefits were alfalfa, rice, and rangelands/pastures (including shrublands and oak woodlands managed for grazing). Alfalfa was associated with benefits such as carbon sequestration and managed aquifer recharge potential, along with minor support for biodiversity, although trade-offs such as nitrous oxide emissions from mature stands and high consumptive water use were also noted. Flooded rice systems were notable for their high value for wildlife, particularly waterfowl, shorebirds, and waterbirds, along with their economic value in the form of relatively high wages for agricultural labor, although methane emissions and consumptive water use were also a concern. Grasslands, including rangelands and pastures managed for livestock production as well as unmanaged grasslands, had high potential benefits for climate regulation via carbon storage and sequestration in soils and belowground biomass, along with high value for biodiversity and support of valuable agricultural pollination services.

The spatial distribution of benefits and trade-offs was highly heterogeneous, although in many cases a north-south trend was evident with areas in the northern Central Valley/Sacramento Valley exhibiting more relative benefits than areas in the southern Central Valley/San Joaquin Valley (Figure 3). Multiple benefit hotspots, or areas where the mean of all metrics exceed 0.8 on the normalized scale, coincided with wetlands adjacent to the Sacramento-San Joaquin Delta, but also includes wetland and riparian areas in Glenn and Colusa counties and areas where orchard and rice land covers predominate. In contrast, coldspots, or areas where the mean of all benefits metrics was less than or equal to 0.2 on the normalized scale, were more frequent in the San Joaquin Valley and tended to coincide with areas of predominantly cotton and field crop production, as well as some areas of perennial crop production and fallow land (or land in

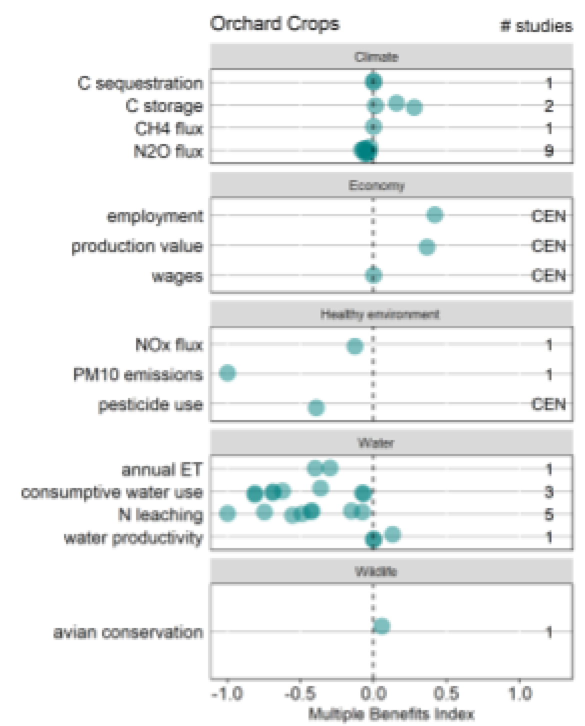


Figure 2. Comparative analysis of benefits and tradeoffs from orchard crops in the Central Valley, CA. The Multiple Benefits Index represents the proportion of the highest recorded measurement of that metric across land covers, with negative values representing metrics considered a tradeoff and positive index values representing a benefit. Numbers in the right-hand column of each panel are the number of unique studies that reported on the metric/land cover combination, or observations derived from census/survey instruments (CEN).

use by the oil industry) in Kern county. While these patterns of benefit and tradeoff distributions may be partially attributable to the distribution of land covers in the same areas, it is also important to consider other factors such as geologic history, crossover of benefit/tradeoff metrics from adjacent regions and land covers, density of urban areas, industrial activities, and regional topography and hydrology when interpreting overall benefit/tradeoff distributions.

Our ability to draw general conclusions on the relative benefits or trade-offs associated with Central Valley land covers was limited by the single-intervention nature of most of the quantitative research available on benefit/tradeoff related metrics. Experimental designs often must restrict activities to a single or few related land covers and investigate the impacts of an intervention on the metric of interest. For the purposes of cross-system comparisons, there were very few studies that addressed variability in benefit/tradeoff metrics across multiple land covers from a multiple benefits or multi-functional landscapes perspective. Many studies were focused on a few key metrics of known importance for a particular land cover, e.g., methane emissions in rice, rather than a broader survey of potential benefits and trade-offs. Furthermore, most experimental analyses are spatially biased and not representative of the entire Central Valley landscape. These challenges highlight the need for more research on human-valued benefits across land covers from a multiple benefits perspective, preferably with a common set of metrics and indicators relevant to most or all of the land covers under consideration.

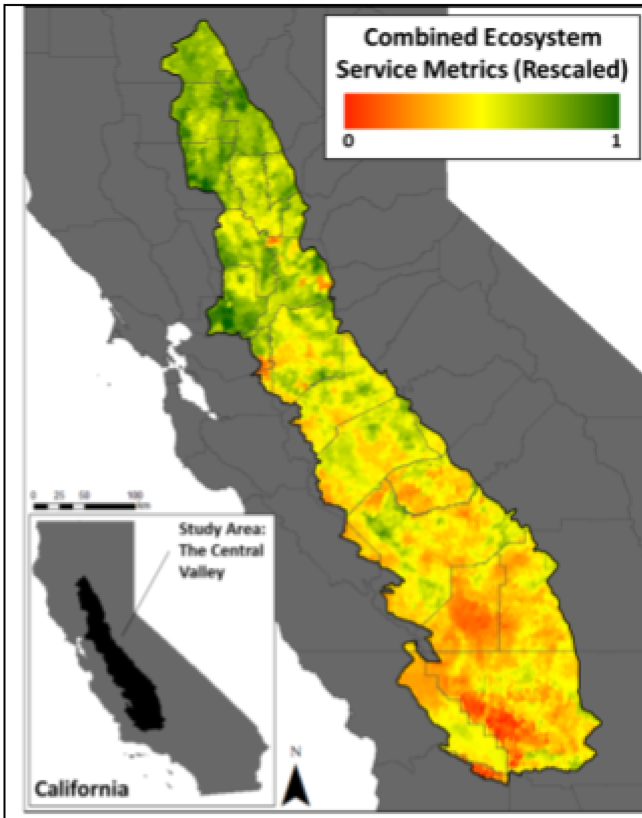


Figure 3. Spatial distribution of benefit metrics, combined and rescaled. The metrics included (and their source data) were: air quality (HPI); water quality (HPI); combined air and water quality; groundwater recharge potential (SAGBI); groundwater depletion (DWR); tree canopy cover (HPI); overcrowding (HPI); annual SOC storage excluding the Delta (SSURGO); SOC accumulation potential (SSURGO, SPARCS-LCA); annual aboveground biomass C accumulation (SSURGO, SPARCS-LCA); crop productivity (CCC, CDL); habitat quality (CDFW-ACE); percent riparian area (NHD, CDL).

The resulting report synthesizes the most recent, Central-Valley-specific literature available on multiple benefit and tradeoff metrics. Section I presents individual land cover profiles, with a compilation of published, quantitative estimates for benefit/tradeoff metrics relative to other land covers, and where relevant, discussion of additional metrics not included in benefit/tradeoff analysis. Section II provides further details on a benefit/tradeoff analysis across land covers using data extracted from the published literature, along with the results of expert panel scoring on relative avian conservation value and climate change vulnerability among land covers. Finally, Section III presents results for spatial models of benefits and tradeoff metrics, including carbon storage, air, water, and habitat quality, groundwater recharge potential, and socio-cultural benefits across the Central Valley. Appendices are included for detailed coverage of methods for the rapid evidence assessment, benefit/tradeoff analyses, and index development. In addition, the complete database and R scripts associated with this report are freely available in the Dryad data repository (see below).

2.4 Conclusions

We initially hypothesized that individual land cover/land use types in the Delta and broader Central Valley provide different amounts of ecosystem services and disservices, such as by contributing more or less to air pollution, greenhouse gas (GHG) emissions, or water quality. The results of our science synthesis support this hypothesis, and the idea that the multiple benefits and trade-offs of proposed or anticipated changes in land cover can be forecasted and considered in resource management decisions.

2.5 Deliverables

Report:

Peterson C, Marvinney E, Dybala K. 2020. Multiple Benefits from Agricultural and Natural Land Covers in the Central Valley, CA. Sacramento, CA: Migratory Bird Conservation Partnership. Available from: http://www.prbo.org/refs/files/12650_PetersonCA2020.pdf.

Supporting data:

Peterson, C, Marvinney E, Dybala K. 2020. Multiple Benefits from Agricultural and Natural Land Covers in the Central Valley, CA. Dryad Dataset. doi:10.25338/B8061X

Task 3. Statistical Analysis: Spatial Modeling and Prioritization for Bird Conservation

3.1 Objective

Develop and refine models for predicting the spatial distribution and abundance of riparian and waterbird species throughout the Delta, allowing identification of high priority areas for bird conservation and (in Task 4 below) estimation of net changes in bird distributions resulting from projected changes in the landscape.

The following text and figures are reproduced and adapted from Dybala et al. (In review - A), which provides more extensive detail.

3.2 Background & Methods

Featuring a diverse mosaic of land cover classes, and located at the confluence of several rivers, California's Sacramento–San Joaquin Delta provides key habitat for an abundant and diverse bird community (Dybala et al. 2020). Despite extensive modifications from the historical Delta landscape (Whipple et al. 2012; DSC 2022b), more than 50,000 ha of wetlands, grasslands, shrublands, and forest continue to support the bird community (Schwenkler 2019), and some agricultural crops are also able to provide suitable habitat for some species (Swolgaard et al. 2008; Pandolfino and Smith 2011; Shuford et al. 2019; Peterson et al. 2020). In addition, the Delta has been repeatedly highlighted as a bird conservation priority, both currently and under future climate change (Stralberg et al. 2011; Veloz et al. 2017; Point Blue Conservation Science c2020). Thus, effective planning and implementation of strategies for bird conservation in the Delta are likely to be valuable well beyond the boundaries of the Delta by contributing to meeting broader regional conservation goals for the San Francisco Estuary and Central Valley (CVJV 2020; San Francisco Estuary Partnership 2022), statewide conservation goals laid out in California's 30x30 Initiative (CNRA 2022), and habitat for the millions of birds migrating along the Pacific Flyway each year (Rosenberg et al. 2016; Senner et al. 2016; NAWMP 2018).

Within the Delta's boundaries, providing bird habitat and migratory corridors are listed among the sub-goals for protecting, restoring, and enhancing the Delta ecosystem (Water Code § 85302(e) and § 85054 DSC 2013). Core strategies for achieving these and other ecosystem goals include prioritizing the protection and restoration of land where possible to restore ecosystem function, reestablishing land-water connections, and restoring native vegetation and habitat for native species over large scales (DSC 2022b). Specific targets for the net increase in native vegetation communities by 2050 have been recently adopted, and six Priority Habitat Restoration Areas have been identified as offering the most promising opportunities for restoring ecosystem function at appropriate elevations (DSC 2022b). To ensure these conservation and restoration priorities will benefit birds, they could be further refined by better characterizing the current distributions of bird species in the Delta and the specific areas of the Delta landscape that provide high conservation value for diverse species. Prioritizing the protection, enhancement, and effective management of these areas, as well as the restoration of adjacent areas to enlarge them and improve connectivity between them, is likely to provide the most benefit to the Delta bird community.

To inform conservation, management, and restoration plans in the Delta, we synthesized data from 2,547 surveys for riparian landbirds conducted at 716 unique locations throughout the Central Valley during the breeding season (May and June), 2011–2019, and 7,820 surveys for waterbirds conducted at 504 unique locations in the Delta during the fall (July 15–November 15) and winter (November 17–March 5) seasons, 2013–14 and 2014–15. The riparian landbird surveys consisted of point counts, the majority of which were collected as part of a broad-scale monitoring effort in the Central Valley to establish baseline information on the population density and distribution of riparian birds. The waterbird surveys were conducted as part of a study to examine the relative value of wetlands and agricultural crops to waterbirds in the Delta (Shuford et al. 2019), and thus survey locations consisted of stratified random samples intended to cover a range of suitable land cover classes, including alfalfa, rice, irrigated pasture, and managed wetlands during the fall, as well as corn and winter wheat during the winter.

From these survey data, we developed predictive distribution models for nine riparian landbird species during the breeding season and six groups of waterbird species during each of the fall and winter seasons (Table 1). The waterbird groups were based on similar habitat requirements, foraging style, and diet (Shuford et al. 2019), and the six groups we selected represented 46 total species. We developed the species distribution models using boosted regression trees (BRT), and we fit all models in R (R Core Team 2021) using the R packages 'dismo' and 'gbm' (Greenwell et al. 2020; Hijmans et al. 2020). All models included presence/absence at each survey location as the response variable, survey effort as a predictor, and weights for each location based on the abundance index (Yu et al. 2020). Other predictors included a suite of metrics representing the landscape at each survey location. Because the probability of species or group presence is likely to be influenced by the surrounding landscape on multiple spatial scales (Seavy et al. 2009; Reiter et al. 2015; Shuford et al. 2016), we included as predictors both local metrics representing the area within which the bird survey took place and landscape metrics representing the broader surrounding area, derived from a combination of field observations during the bird surveys and remotely-sensed spatial layers. For quality assurance, we used cross-validation to minimize predictive error and optimize the number of trees, learning rate, and tree complexity allowed in the modeling process (Elith et al. 2008). We also assessed the accuracy of our models using cross-validated area under the receiver operating characteristic curve (AUC), which quantifies how well predictions discriminate observed presences from observed absences (Hanley and McNeil 1982).

We used the final models for each species and group (Dybala et al. 2023e) to project their probability of presence throughout the current Delta landscape (Dybala et al. 2023a, 2023b), and then applied a spatial prioritization algorithm implemented in Zonation 5 (Moilanen et al. 2022) to identify the areas of the current Delta landscape that are most important to protect and maintain to support each of these bird communities. To reflect their distinct seasonal habitat and conservation needs, we conducted separate prioritization analyses for riparian landbirds, waterbird groups in fall, and waterbird groups in winter. We defined Priority Bird Conservation Areas for riparian landbirds and waterbirds (in either season) as the pixels ranking in the top 5% from each analysis (Dybala et al. 2023c, 2023d). To further inform conservation strategies in the Delta and evaluate the vulnerability of these Priority Bird Conservation Areas to changes in land cover or use, we estimated the proportion of these pixels that fell within major land cover classes, existing protected areas and conservation easements (GreenInfo Network 2022a, 2022b), any of the six Priority Habitat Restoration Areas (DSC 2022b), or areas with a high (18-65%) or very high (>65%) risk of flooding over 10 years due to projections of sea level rise for 2050 (DSC 2021). We assumed that areas most vulnerable to changes in land cover or land use would include areas that were in agricultural land cover classes, not protected, not within Priority Habitat Restoration Areas, and/or at high or very high risk of frequent flooding with sea level rise.

Table 1. Study species included in the distribution modeling and prioritization analyses. **(A)** Riparian landbird focal species. **(B)** Waterbirds groups. Species with special conservation status include: [+]species listed as Threatened under the California Endangered Species Act (CDFW 2021) and *California Bird Species of Special Concern (Shuford and Gardali 2008).

A. Riparian landbird species	
Nuttall's Woodpecker (*Picoides nuttallii*)	*Yellow Warbler (*Setophaga petechia*)
Ash-throated Flycatcher (*Myiarchus cinerascens*)	Spotted Towhee (*Pipilo maculatus*)
Black-headed Grosbeak (*Pheucticus melanocephalus*)	*Song Sparrow (*Melospiza melodia*)
Lazuli Bunting (*Passerina amoena*)	*Yellow-breasted Chat (*Icteria virens*)
Common Yellowthroat (*Geothlypis trichas*)	
B. Waterbird groups	
Geese	**Cranes**
*Greater White-fronted Goose (*Anser albifrons*)	[+]Greater Sandhill Crane (*Antigone canadensis tabida*)
Snow Goose (*Anser caerulescens*)	*Lesser Sandhill Crane (*A. c. canadensis*)
Ross's Goose *(Anser rossii)*	**Shorebirds**
Cackling Goose (*Branta hutchinsii*)	Western Sandpiper (*Calidris mauri*)
Canada Goose (*Branta canadensis*)	Least Sandpiper (*Calidris minutilla*)
Dabbling ducks	Dunlin (*Calidris alpina*)
Wood Duck (*Aix sponsa*)	Black-necked Stilt (*Himantopus mexicanus*)
Gadwall (*Mareca strepera*)	American Avocet (*Recurvirostra americana*)
American Wigeon (*Mareca americana*)	Greater Yellowlegs (*Tringa melanoleuca*)
Mallard (*Anas platyrhynchos*)	Lesser Yellowlegs (*Tringa flavipes*)
Blue-winged Teal (*Spatula discors*)	Long-billed Dowitcher (*Limnodromus scolopaceus*)
Cinnamon Teal (*Spatula cyanoptera*)	Short-billed Dowitcher (*Limnodromus griseus*)
Northern Shoveler (*Spatula clypeata*)	Wilson's Snipe *(Gallinago delicata)*
Northern Pintail (*Anas acuta*)	**Herons/Egrets**
Green-winged Teal (*Anas carolinensis*)	Great Blue Heron (*Ardea herodias*)
Diving ducks	Great Egret (*Ardea alba*)
Canvasback (*Aythya valisineria*)	Snowy Egret (*Egretta thula*)
Ring-necked Duck *(Aythya collaris)*	Cattle Egret (*Bubulcus ibis*)
Lesser Scaup (*Aythya affinis*)	Green Heron (*Butorides virescens*)
Bufflehead (*Bucephala albeola*)	Black-crowned Night-Heron (*Nycticorax nycticorax*)
Common Goldeneye (*Bucephala clangula*)	
Hooded Merganser (*Lophodytes cucullatus*)	
Common Merganser (*Mergus merganser*)	
Ruddy Duck (*Oxyura jamaicensis*)	

*For Greater White-fronted Goose, only the Tule subspecies (*A. a. elgasi*) is considered a California species of special concern; for Song Sparrow, only the Suisun subspecies (*M. m. maxillaris*) and Modesto population (*M. m. mailliardi*) are considered California Bird Species of Special Concern.

3.3 Results & Discussion

The cross-validated area under the receiver operating characteristic curve (AUC) of the final models ranged 0.747–0.897 for riparian landbird species, and 0.705–0.978 for waterbird groups, all exceeding the threshold of 0.7 generally considered adequate for modeling species distributions (Swets 1988). All nine riparian landbird species were influenced by one or more of the predictors describing riparian vegetation cover; all but Yellow-breasted Chat were influenced by one of the predictors describing wetland cover; and distance to the nearest stream channel was influential for all but Spotted Towhee and Song Sparrow. In addition, All nine species were also influenced by one or both climate variables: total annual precipitation and average annual temperature. The distributions of most waterbird groups, in both fall and winter seasons, were most strongly influenced by the proportion of the survey area that was flooded. Several groups were also influenced by the land cover class of the survey area, and the interaction between land cover class and the proportion of the survey area that was flooded. In both seasons, cranes were more likely to be present closer to traditional nighttime roost sites.

We identified a total of 26,019 ha of Priority Bird Conservation Area in the Delta, defined as the most valuable 5% of the landscape for riparian landbirds, waterbirds, or both (Figure 4). These areas represent the most important places in the Delta to protect and manage as well as strategic areas where adjacent restoration could expand valuable habitat. In particular, we identified 601 ha (2.3% of the total) as a priority for both riparian landbirds and waterbirds, of which we estimated 87% were protected and 83% were wetlands (Table 2). The protected areas included the Yolo Bypass Wildlife Area and nearby conservation easements, Cosumnes River Preserve, Stone Lakes National Wildlife Refuge, and bufferlands surrounding the Sacramento County Regional Sanitation District. Our results indicated the success of these protected areas and easements in providing valuable habitat for both riparian landbirds and waterbirds, and that continued protection and effective management of these areas is a critical strategy for the conservation of riparian landbirds and waterbirds in the Delta. In addition, approximately 28% of the total Priority Bird Conservation Area fell within one of the Delta's Priority Habitat Restoration Areas (Table 2), providing insights into strategic areas where restoration could expand existing patches of particularly valuable habitat.

The dynamic nature of land cover in the Delta means that these highest priority areas are not necessarily fixed locations, especially for the more than 60% that are not currently protected and the 46% that are agricultural land (Table 2), which may be more vulnerable to changes in land cover or land use. To account for this continuously evolving landscape, strategies for bird conservation in the Delta should include assessment of the effects of likely scenarios of land cover change on bird distributions and the changing habitat value of these Priority Bird Conservation Areas. Planning should include mitigation for the loss of some of the Priority Bird Conservation Area through restoration and enhancement efforts that would improve habitat value in less vulnerable locations. The distribution models we developed can be useful in this planning process by projecting how species and group distributions may be affected by scenarios such as the completion of proposed habitat restoration projects or the continued expansion of perennial crops.

The results of these analyses represent the most current state of the science on the spatial distributions of riparian landbirds and waterbirds across the Delta and the areas with a high confidence of importance to bird conservation, but they are not the final word on bird conservation priorities and strategy within the Delta's evolving landscape. Our predictive models and approach to spatial prioritization provide a framework that can support collaborative efforts

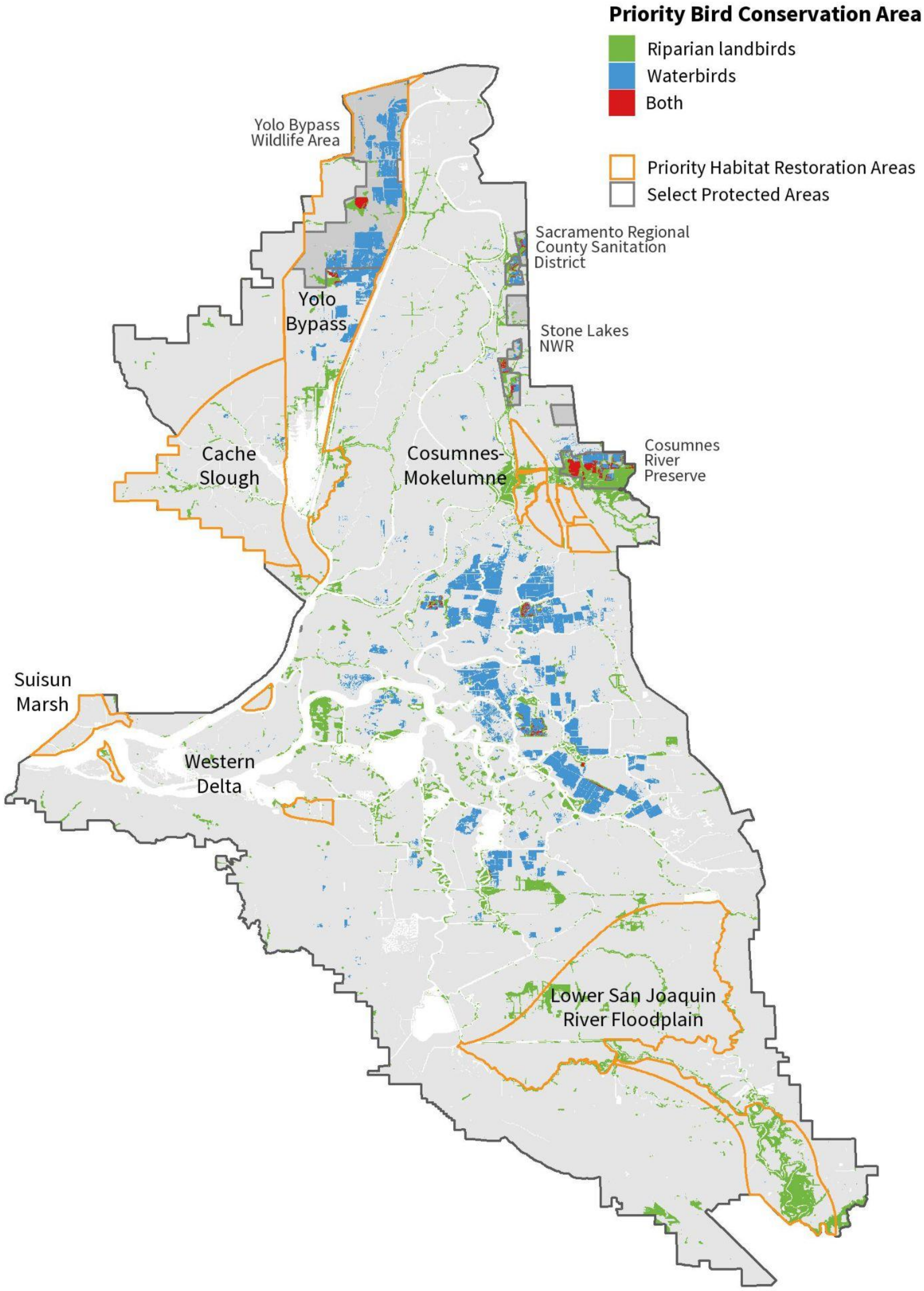


Figure 4. Priority Bird Conservation Areas identified for riparian landbirds, waterbirds, or both (Dybala et al. 2023d). Also shown are the six Priority Habitat Restoration Areas (labeled with black text) and four Select Protected Areas (labeled with gray text). To aid in orientation, open water is shown in white, and the remainder of the Delta is shown in gray.

Table 2. Characteristics of the Priority Bird Conservation Areas identified for riparian landbirds, waterbirds in either season, or both, including the total area (ha) and the total area (and %) falling within protected areas and conservation easements (GreenInfo Network 2022a, 2022b), within Priority Habitat Restoration Areas (DSC 2022b), or within areas that have a high risk of flooding under projected sea level rise by 2050 (DSC 2021). Also shown are the total area (and %) falling within one of the three most common land cover classes (wetlands, riparian, or corn) or all other agriculture.

	Total		Riparian landbirds		Waterbird groups		Both	
Total area (ha)	26,019		14,920		11,700		601	
Protected areas & conservation easements	10,254	(39%)	4,983	(33%)	5,794	(50%)	523	(87%)
Priority Habitat Restoration Areas	7,306	(28%)	4,541	(30%)	2,878	(25%)	113	(19%)
High flood risk with sea level rise	4,669	(18%)	3,436	(13%)	1,206	(5%)	27	(<1%)
Landcover								
Wetland	6,133	(24%)	2,368	(17%)	3,264	(29%)	501	(83%)
Riparian	5,925	(23%)	5,925	(41%)	0	(0%)	0	(0%)
Corn	5,984	(23%)	991	(7%)	4,959	(45%)	34	(6%)
All other agriculture	6,100	(23%)	3,157	(22%)	2,877	(26%)	66	(11%)

to define bird conservation priorities and objectives, including additional bird species. Our models can also be used to project how bird communities will respond to future changes in the Delta's landscape, allowing bird communities to be included in a Multiple-Benefit Conservation framework to identify synergies and trade-offs with other projected impacts of future landscape change (Gardali et al. 2021). These analyses help fill a science need that will facilitate bird conservation and the long-term vision of a resilient Sacramento-San Joaquin Delta ecosystem.

3.4 Conclusions

We initially hypothesized that: (1) The spatial distributions and abundances of bird populations can be predicted from a combination of local vegetation data and broader regional land cover and surface water data; and (2) Some parts of the Delta are currently a higher priority for bird conservation. Our results supported our hypotheses, with distribution models considered sufficiently adequate for predicting species presence, and spatial prioritization results that highlighted the importance of 26,019 ha within the Delta for bird conservation.

3.5 Deliverables

Manuscript:

Dybala KE, Sesser K, Reiter ME, Shuford WD, Golet GH, Hickey C, Gardali T. *In review - A.* Priority Bird Conservation Areas in California's Sacramento–San Joaquin Delta.

Report:

*Dybala KE, Sesser KA, Reiter ME. 2021. Spatial Modeling and Prioritization for Bird Conservation in the Delta: Summary of Task 3 for the project "Trade-offs and Co-benefits of Landscape Change Scenarios on Bird Communities and Ecosystem Services in the Sacramento-San Joaquin River Delta". Point Blue Conservation Science, Petaluma, CA.

**We consider the methods and results in the report to be preliminary and superseded by the manuscript.*

Spatial data:

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023a. Predicted probability of riparian landbird distributions in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Comprised of 9 raster geotiff layers:

- Ash-throated Flycatcher
- Black-headed Grosbeak
- Common Yellowthroat
- Lazuli Bunting
- Nuttall's Woodpecker
- Song Sparrow
- Spotted Towhee
- Yellow-breasted Chat
- Yellow Warbler

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023b. Predicted probability of waterbird group distributions in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Comprised of 11 raster geotiff layers:

- Dabbling Ducks (fall)
- Dabbling Ducks (winter)
- Diving Ducks (winter)
- Geese (fall)
- Geese (winter)
- Herons & Egrets (fall)
- Herons & Egrets (winter)
- Sandhill Cranes (fall)
- Sandhill Cranes (winter)
- Shorebirds (fall)
- Shorebirds (winter)

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023c. Spatial prioritization for bird conservation in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Comprised of 3 raster geotiff layers:

- Riparian landbird priority rank
- Waterbird group priority rank (fall)
- Waterbird group priority rank (winter)

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023d. Priority Bird Conservation Areas in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Comprised of 1 raster geotiff layer:

- Priority Bird Conservation Areas

Supporting data:

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023e. Distribution models for riparian landbirds and waterbirds in the Sacramento-San Joaquin Delta. Zenodo. doi:10.5281/zenodo.7531945

Comprised of 2 .RData files containing model objects:

- BRT_models_riparianlandbirds
- BRT_models_waterbirds
- METADATA.pdf

Task 4. Scenario Analysis: Net Impacts of Landscape Change Scenarios

4.1 Objective

Estimate the net impacts of landscape change scenarios on ecosystem services and on riparian and waterbird communities in the Delta.

The following text and figures are reproduced and adapted from Dybala et al. (In review - B), which provides more extensive detail.

4.2 Background & Methods

Conservation efforts are frequently recognized as having the potential to result in multiple benefits, and conservation planning on regional to continental scales are increasingly seeking to provide multiple benefits with their designs (CVJV 2020; United Nations 2020; U.S. DOI et al. 2021; CNRA 2022). As a leading example, California state law has defined two co-equal goals for the management of the Sacramento-San Joaquin River Delta of simultaneously improving the reliability of the state's water supply and protecting, restoring, and enhancing the Delta ecosystem, but also recognizes the importance of doing so in a manner that also protects and enhances its "unique cultural, recreational, ecological, and agricultural values as an evolving place" (California Water Code § 85054; DSC 2013). While achieving multiple goals simultaneously is an appealing proposition, social and ecological goals are often perceived as incompatible, both in the Delta (Milligan and Kraus–Polk 2017) and around the world (Guaita Martínez et al. 2019).

In an effort to clarify the strengths and challenges of achieving multiple conservation goals simultaneously, we recently proposed a definition for Multiple-Benefit Conservation as *conservation efforts designed to simultaneously benefit local communities of people, enhance ecological function, and improve habitat quality for fish and wildlife* (Gardali et al. 2021). This approach would require defining multiple goals at the start of a conservation effort and identifying and addressing trade-offs among goals in the design of the effort, and is distinct from efforts that have one primary goal but may produce desirable co-benefits as a side effect, or those that celebrate the achievement of easily compatible goals (win-wins) but do not consider the trade-offs (Gardali et al. 2021). The strengths of this approach include the opportunity to build support for conservation efforts by considering a more inclusive range of goals and values held by the local community and openly and collaboratively addressing trade-offs, but identifying and then finding solutions to address trade-offs remains a considerable challenge. Projecting the direction and magnitude of the potential impacts of a policy or management decision on multiple goals and values remains a key information gap that can limit adaptive management, impede communication and understanding among the local community, and contribute to conflict (Wiens et al. 2017; Guaita Martínez et al. 2019).To support the practice of Multiple-Benefit Conservation, we developed metrics and methods for forecasting the direction and magnitude of potential impacts of landscape change scenarios on multiple categories of benefits and identifying potential trade-offs.

With input from local agencies and organizations, including California Department of Fish and Wildlife, Delta Stewardship Council, Delta Conservancy, The Nature Conservancy, Audubon California, and the Central Valley Joint Venture Lands Committee, we first developed three spatially-explicit scenarios of landscape change in the Sacramento-San Joaquin River Delta (Figure 5). The first was a habitat restoration scenario representing the magnitude and approximate spatial distribution of landscape change that would occur by 2050 if the targets

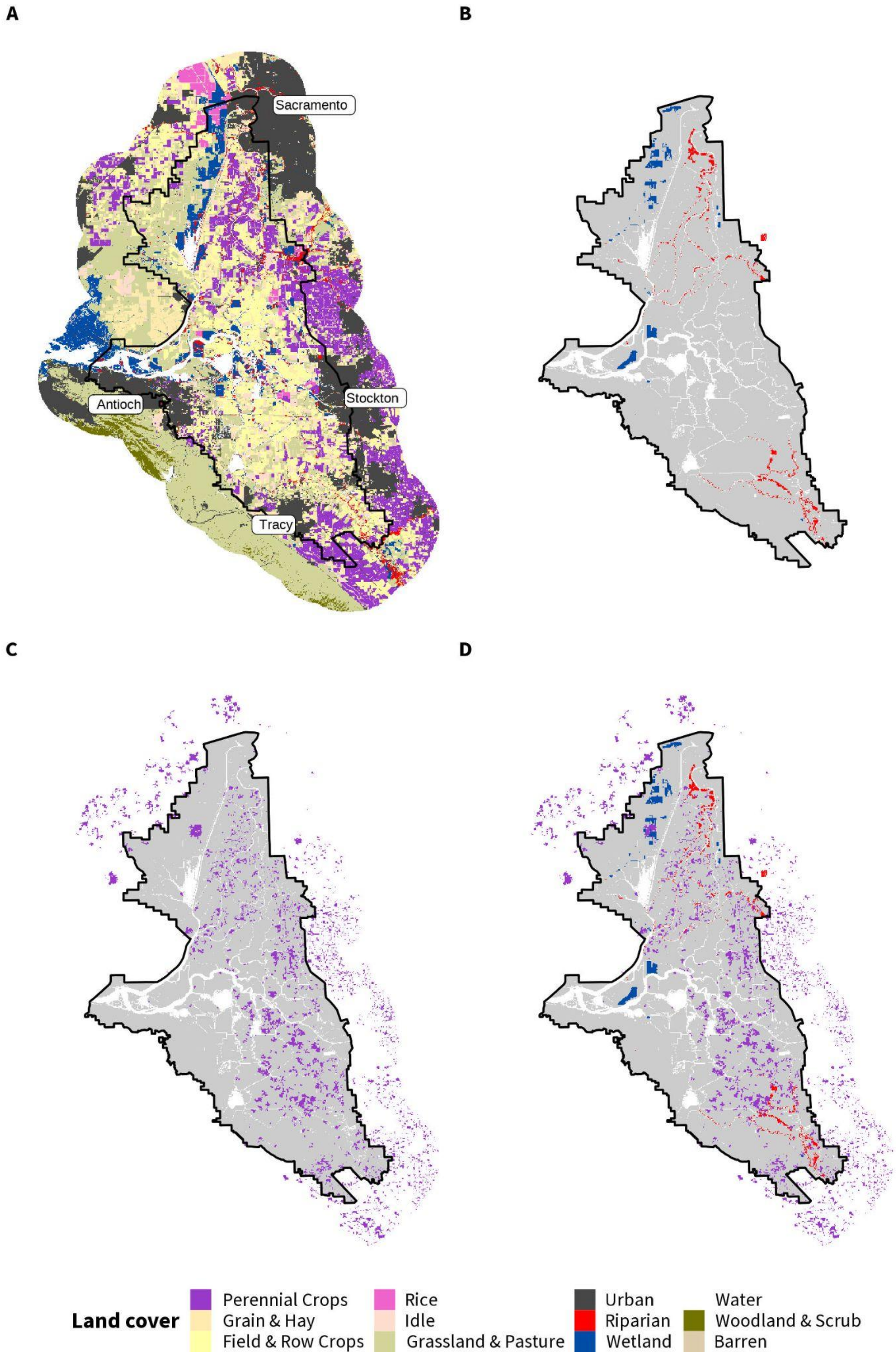


Figure 5. Representations of land cover in the Delta (Dybala 2023c). **(A)** Baseline as of 2018, showing major land cover classifications including primary summer crops. **(B)** New areas of riparian and non-tidal wetland added to meet habitat restoration objectives in Scenario 1. **(C)** New areas of perennial crops added in Scenario 2 to reflect recent rates of expansion. **(D)** Scenario 3, a combination of scenarios 1 and 2.

defined in the Delta Plan were met for non-tidal wetland and riparian vegetation restoration (DSC 2022b). We included in this scenario a combination of projects already planned or in-progress as well as randomly-selected candidate locations for additional restoration projects as needed to meet the targets, prioritizing candidate locations within the Delta's Priority Habitat Restoration Areas and protected areas, excluding areas designated for development, and deprioritizing areas currently in perennial crops. We then developed a spatially-explicit scenario representing the projected landscape change that would occur by 2050 if recent rates of conversion to perennial crops continue, based on recent projections (Wilson et al. 2021, 2022). Finally, although it was useful to examine the separate impacts of each of these drivers of landscape change, we also developed a third scenario representing a combination of both habitat restoration and perennial crop expansion.

To evaluate the impacts of each scenario across multiple dimensions of change, we selected several metrics within four benefit categories with relevance to the Delta's goals, informed by and refined from the results of Task 2 (Dybala 2023a):

- **Agricultural Livelihoods:** agricultural jobs (full time equivalents; FTE/ha/yr), annual wages (USD/FTE), and gross production value (USD/ha/yr), estimated as the average for each land cover class in the Delta, 2014-2020, from the Quarterly Census of Employment and Wages and County Agricultural Commissioners Reports (CDFA 2022; EDD 2022).
- **Water Quality:** in terms of the risk to water quality from the average pesticide application rate (MT/ha/yr) for each land cover class in the Delta from Pesticide Use Report Data 2014–2018 (CDPR 2022), for subsets of chemicals considered critical pesticides (DSC c2021), groundwater contaminants (CDPR 2022), and those that pose a "high" or "moderate" risk to aquatic organisms (Lu and Davis 2009).
- **Climate Change Resilience:** qualitative rank data (scored 1–10) representing the ability of each land cover class to tolerate extreme events, including drought, flood, or heat, derived from the expert opinion compiled in Task 2 and for Delta Adapts (DSC 2021).
- **Biodiversity Support:** total suitable habitat in the Delta for riparian landbird species and waterbird groups during the fall or winter, as predicted for each scenario by the distribution models developed in Task 3.

To develop a comprehensive evaluation of the net impacts of each scenario on each benefit category and metric, we first developed total landscape scores for each of the metrics in the agricultural livelihood, water quality, and climate change resilience categories (Table 3). For most of these metrics, we multiplied the per-ha estimate for each land cover class by its total area and summed over all land cover classes to represent the landscape total. For annual wages of agricultural workers, represented as an annual average by land cover class, we estimated the new average annual wage weighted by the proportion of each land cover class in the landscape. Similarly, for the climate change resilience scores, we estimated the average landscape score over all pixels in the landscape. From the total landscape scores for each metric, we calculated the net impact of each scenario on each metric (d_m) as the difference between the scores for each scenario and the baseline landscape, and we estimated the expanded uncertainty (U_m) in the d_m by propagating the standard errors of the per-ha values for each land cover class and using coverage factor $k = 2$, which provides a level of confidence approximately equal to 95%. Thus, for these metrics, we report on the interval $d_m \pm U_m$.

We separately evaluated the net impact of each scenario on the biodiversity support metrics by first fitting each of the distribution models to the predictors derived from each

Table 3. Landscape total scores for each metric in each benefits category, estimated for the baseline landscape and each scenario of landscape change. Each score is provided in its own units, along with the associated estimate of uncertainty where available.

Benefits Category & Metric	Units	Baseline	Scenario 1	Scenario 2	Scenario 3
Agricultural Livelihoods					
Agricultural jobs	FTE/yr	2,514 (144)	2,458 (142)	2,989 (215)	2,881 (207)
Mean annual wage	USD/FTE	38,727 (614)	38,698 (613)	38,487 (573)	38,474 (575)
Gross production value	USD, thousands/yr	814,558 (20,702)	797,689 (20,401)	956,472 (30,432)	923,077 (29,303)
Water Quality					
Critical pesticides	MT/yr	125.43 (9.89)	122.35 (9.67)	129.00 (9.10)	125.03 (8.90)
Groundwater contaminants	MT/yr	16.24 (2.13)	15.98 (2.09)	18.74 (2.07)	18.17 (2.02)
Risk to aquatic organisms	MT/yr	392.86 (16.78)	382.44 (16.38)	441.99 (17.85)	425.64 (17.29)
Climate Change Resilience					
Drought	mean score	5.62 (0.05)	5.56 (0.05)	5.41 (0.05)	5.36 (0.05)
Flood	mean score	5.90 (0.05)	5.96 (0.05)	5.83 (0.06)	5.91 (0.05)
Heat	mean score	6.94 (0.06)	6.94 (0.06)	6.69 (0.06)	6.72 (0.06)
Biodiversity Support					
Riparian landbird habitat	ha	201,883 (3,842)	207,878 (3,624)	197,488 (3,717)	206,046 (3,447)
Waterbird habitat (fall)	ha	25,068 (510)	28,955 (543)	24,245 (490)	28,092 (532)
Waterbird habitat (winter)	ha	55,603 (1,650)	59,447 (1,633)	54,270 (1,489)	57,809 (1,471)

scenario, and estimating the total area of suitable habitat in the Delta. As for the other metrics, we calculated the net impact of each scenario on each metric (d_m) as the difference between the scores for each scenario and the baseline landscape. However, here we estimated the uncertainty in d_m using a bootstrap resampling approach, which included resample the original bird survey data for each model 50 times, fitting distribution models to each resample, predicting the total area of suitable habitat for each scenario landscape under each model, and estimating d_m. We then used the 2.5 and 97.5 percentile values for the bootstrap estimates of d_m as an estimate of the 95% confidence interval.

To interpret the net impact of each scenario on each metric (d_m) in a common framework, we reversed the sign of d_m for the water quality metrics by multiplying by -1 so that an increase in pesticide application rates would represent an increasing risk to water quality. Thus, for all metrics, $d_m > 0$ represents a potential net benefit to the Delta ecosystem and $d_m < 0$ would represent a potential trade-off. In addition, for all metrics, we considered d_m to represent a statistically significant change from baseline conditions if the estimated confidence interval did not overlap zero, and we considered d_m to represent a practically significant change for the Delta ecosystem if it represented at least a 5% change from baseline conditions.

4.3 Results & Discussion

Under scenario 1, we estimated that meeting the restoration targets would result in a 48% increase in Riparian land cover and a 62% increase in Managed Wetland cover relative to the baseline landscape, and that these restorations would primarily come from existing Grassland & Pasture. We also noted that, after excluding areas designated for development, nearly all the area identified as suitable for riparian restoration would need to be restored to meet the restoration target, including areas outside the Delta Stewardship Council's priority habitat restoration area and areas currently classified as perennial crops in the baseline landscape. Under scenario 2, we estimated that continued perennial crop expansion would result in a 50% increase in the footprint of Perennial Crops by 2050, converting primarily from Field & Row Crops, Grassland & Pasture, and Idle land covers. Under the combined scenario 3, the net change in riparian and managed wetlands would match that of scenario 1, but the extent of perennial crops would be smaller, resulting in a 44% increase.

We projected that scenario 1 would result in statistically and practically significant increases in Biodiversity Support benefits by 2050, with no significant benefits or trade-offs projected for any metrics in any other category (Figure 6). For riparian landbirds, we estimated a statistically significant increase of 5,995 ha of suitable habitat (+3% from baseline; 95% bootstrap CI: 2,639–12,747), which was driven by statistically and practically significant increases in suitable habitat for 5 of the 9 focal species (Figure 7). For waterbirds, we estimated statistically and practically significant increases in suitable habitat of 3,877 ha during the fall (+16% from baseline; 95% bootstrap CI: 2,454–5,954) and 3,844 ha during the winter (+7% from baseline; 95% bootstrap CI: 1,219–5,750), including benefits projected for all groups except Cranes. The confidence intervals for all other metrics in all other categories overlapped zero, and represented changes of <5% from baseline conditions, indicating little effect of restoration projected for Agricultural Livelihoods, Water Quality, or Climate Change Resilience metrics.

Figure 6. Net impacts of each scenario on multiple benefits by category. (A) Scenario 1: Habitat restoration. **(B)** Scenario 2: Perennial crop expansion. **(C)** Scenario 3: Combination. Benefits categories include: Agricultural Livelihoods, with each metric shown in its own units; Water Quality, in terms of the annual total pesticides (MT) applied to the landscape by risk group, with the scores reversed such that a net reduction is shown as a positive benefit to water quality; Climate Change Resilience, in terms of the average landscape score on a scale of 1—10, where 10 is the most resilient; and Biodiversity Support, in terms of the estimated total amount of suitable habitat provided (ha, thousands). Each bar represents the estimated difference from baseline (d_m) for each scenario, with beneficial changes ($d_m > 0$) shown in blue and trade-offs ($d_m < 0$) in orange. Also shown is the estimated uncertainty in the difference (see Methods for details). We considered d_m to be statistically significant if the confidence interval did not overlap zero, and practically significant (*) if it represented more than a 5% change from the baseline.

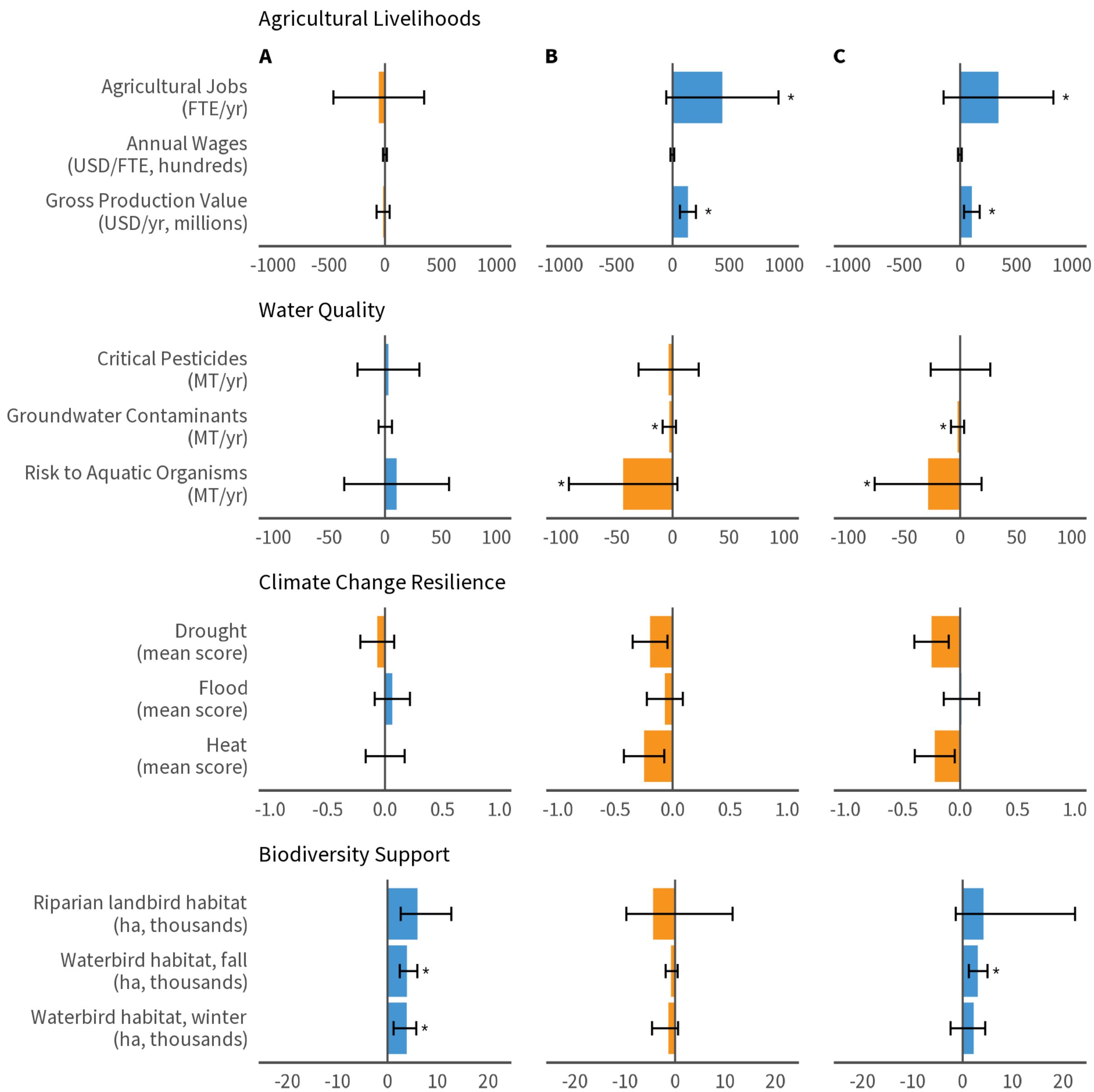
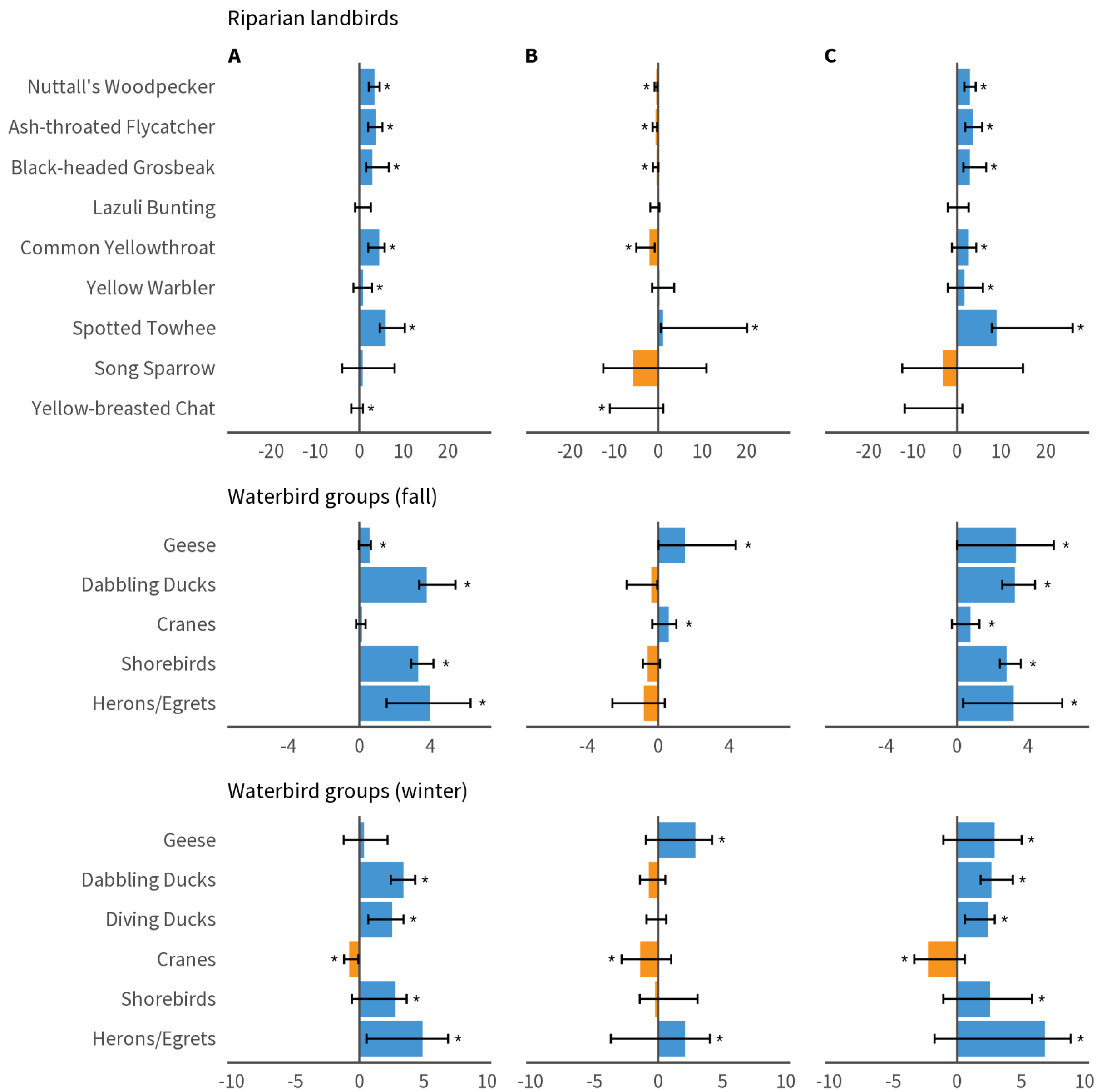


Figure 7. Net impacts of each scenario on individual riparian landbird species and groups of waterbird species. (A) Scenario 1: Habitat restoration. **(B)** Scenario 2: Perennial crop expansion. **(C)** Scenario 3: Combination. Bird species groups include: Riparian landbirds during the breeding season, Waterbird groups during the fall season, and Waterbird groups during the winter season. Each bar represents the estimated difference from baseline (d_m) in the total area of suitable habitat for each scenario (ha, thousands), with beneficial changes ($d_m > 0$) shown in blue and trade-offs ($d_m < 0$) in orange. Also shown is the estimated uncertainty in the difference (see Methods for details). We considered d_m to be statistically significant if the confidence interval did not overlap zero, and practically significant (*) if it represented more than a 5% change from the baseline.



In contrast, for scenarios 2 and 3, we projected a mix of benefits and trade-offs relative to baseline metrics. Both scenarios offered Agricultural Livelihood benefits, including statistically and practically significant increases in total gross production value per year, as well as increases in the average number of agricultural jobs per year that would be practically meaningful if there was less uncertainty in the underlying estimates. These projected benefits were somewhat larger under scenario 2, with 137.1 ± 71.3 USD/yr (millions) in gross production value (+17% from baseline conditions) and 444 ± 501 FTE/yr in agricultural jobs (+18%), than under scenario 3, with 104.3 ± 69.8 USD/yr (millions) in gross production value (+13%) and 342 ± 490 FTE/yr in agricultural jobs (+14%). However, scenario 3 also offered Biodiversity Support benefits, with a statistically and practically significant increase in suitable habitat only for waterbirds during the fall (3,024 ha; +12% from baseline conditions; 95% bootstrap CI: 1,233–4,959). We did not project statistically or practically significant benefits or trade-offs to the total area of suitable habitat for riparian landbirds or waterbirds during the winter under scenario 3, or for any Biodiversity Support metric under scenario 2. However, for individual species and groups of waterbirds, we projected more statistically and/or practically significant declines in suitable habitat under scenario 2 and increases under scenario 3. We also projected significant trade-offs for both scenarios 2 and 3 in terms of Water Quality and Climate Change Resilience metrics. These included practically (but not statistically) significant increases in the application rates of chemicals that would pose a risk to Water Quality, including 18% and 14% increases in the application rates of known groundwater contaminants and 11% and 7% increases in chemicals known to pose a high or moderate risk to aquatic organisms for scenario 2 and 3, respectively. In terms of Climate Change Resilience, we also projected small but statistically significant decreases in landscape-level tolerance to drought and heat under both scenarios.

The results of our scenario analyses confirmed the likelihood for landscape change to produce a complex mix of benefits and trade-offs. By estimating the direction, magnitude, and uncertainty of the impact of each proposed or anticipated scenario of landscape change, our framework provides a means to facilitate knowledge-sharing, informed decision-making, and future research priorities. It can also facilitate identifying and finding solutions to trade-offs in making decisions about policies and plans for land management in the Delta. For example, because the biodiversity support benefits of reaching the habitat restoration targets may be partially offset by the perennial crop expansion, as demonstrated in scenario 3, achieving biodiversity support goals might require increasing the size of the restoration targets, optimizing the location of restoration efforts to maximize their impact, and/or providing incentives not to convert to perennial crops in areas where they will have the most impact on habitat suitability.

4.4 Conclusions

We initially hypothesized that the Delta's landscape will continue to change over time, affecting both the provisioning of ecosystem services to the communities of people and the distribution of birds in the Delta. The scenarios we developed were based on anticipated changes to the landscape resulting from reaching habitat restoration targets and/or continued expansion of perennial crops, and our results supported our hypothesis that changes to the Delta landscape are expected to produce a mix of benefits and trade-offs that should be identified and considered in resource management decisions.

4.5 Deliverables

Manuscript:

Dybala KE, Sesser KA, Reiter ME, Hickey C, Gardali T. *In review - B.* Multiple-benefit Conservation in Practice: A Framework for Quantifying Multi-dimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta.

Report:

*Dybala KE. 2022. Net Impacts of Landscape Change Scenarios: Summary of Task 4 for the project "Trade-offs and Co-benefits of Landscape Change Scenarios on Bird Communities and Ecosystem Services in the Sacramento-San Joaquin River Delta". Point Blue Conservation Science, Petaluma, CA.

**We consider the methods and results in the report to be preliminary and superseded by the manuscript.*

Spatial data:

Dybala KE. 2023b. Multiple-benefit Conservation in Practice: Supplemental Spatial Data for Quantifying Multidimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta. Zenodo. doi:10.5281/zenodo.7672193.

Comprised of 4 raster geotiff layers:
- bio_1: annual mean temperature (C), 1970–2000 (WorldClim2; Fick and Hijmans 2017)
- bio_12: total annual precipitation (mm), 1970–2000 (WorldClim2; Fick and Hijmans 2017)
- streamdist: square-root of the distance (m) to the nearest stream (National Hydrography Dataset; USGS 2020)
- pwater_fall: mean probability of open surface water during the fall, 2013–2019 (Point Blue Water Tracker; Reiter et al. 2018)
- pwater_win: mean probability of open surface water during the winter, 2013–2019 (Point Blue Water Tracker; Reiter et al. 2018)
- METADATA.pdf

Dybala KE. 2023c. Baseline and projected future land use and land cover in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Comprised of 8 raster geotiff layers:
- baseline
- baseline_win
- scenario1_restoration
- scenario1_restoration_win
- scenario2_perennialexpand
- scenario2_perennialexpand_win
- scenario3_combo
- scenario3_combo_win

Supporting data:

Dybala KE. 2023a. Multiple-benefit Conservation in Practice: Metrics Data for Quantifying Multidimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta. doi:10.5281/zenodo.7504874.

Comprised of:
- metrics.csv: estimated mean value, standard error, and units for a range of metrics by land cover
- METADATA.pdf

Task 5. Science-based Framework Development: Flexible Adaptation to New Goals and Scenarios

5.1 Objective

Adapt the methods used in Task 4 above to develop a general framework for synthesizing and assessing trade-offs and co-benefits of landscape change, allowing these analyses to be repeated for new scenarios and additional ecosystem services or wildlife species.

5.2 Summary

To further support the practice of Multiple-Benefit Conservation, as described in Task 4, we developed the foundations of an open-source framework for forecasting the impacts of alternative scenarios on multiple metrics representing multiple categories of benefits and the identification of potential trade-offs. We generalized the approach and analyses developed in Task 4 to develop the customized R package "DeltaMultipleBenefits" (Dybala 2023d). It represents the foundation for an open-source framework to assess trade-offs and multiple benefits of planned and ongoing management actions and policies, a priority in the Science Action Agenda. It demonstrates the integration of quantitative and qualitative data as well as spatial models, defines an initial set of metrics representing a suite of benefits categories, and establishes transparent, repeatable methods for projecting their response to alternative scenarios of landscape change. The package contains a "vignette", which serves as a manual and tutorial illustrating the use of functions for preparing a new scenario of landscape change, applying existing metrics and species distribution models to the new scenario, and calculating the net change in each metric from our baseline landscape.

The DeltaMultipleBenefits package is designed to support the reproducibility of the analyses in Task 4, as well as their extension to include new metrics, models, or data sources, and their application to new scenarios, as they are identified and developed by members of the Delta research community. It can also be used to adapt our approach to Multiple-Benefit Conservation efforts in other regions. DeltaMultipleBenefits is also designed to complement the Delta Landscape Scenario Planning Tool (DLSPT), an ArcPro Toolbox, which represented a great advance in supporting the analysis of the impacts of land cover changes on multiple metrics, largely aimed at land managers and reflecting landscape ecology metrics (SFEI 2022). Here we sought to integrate additional types of data, models, and metrics in a more open-source framework that could facilitate collaborative, ongoing refinement and improvement among the Delta research community. Ultimately, the R package is intended to facilitate a more comprehensive multidimensional understanding of the direction and magnitude of the potential impacts of landscape change (proposed or anticipated), communication about the projected synergies and trade-offs among goals, and the identification of solutions to address these trade-offs.

5.3 Conclusions

Our initial premise was that scenarios of landscape change evolve rapidly over time, and our initial set of ecosystem services and wildlife species do not encompass every factor stakeholders, resource managers, and policy makers are interested in considering. The DeltaMultipleBenefits R package provides a flexible, open-source, science-based foundation for continuing to incorporate additional benefits categories, metrics, data, and models, and evaluating the net impacts of new scenarios.

5.4 Deliverables

Software & vignette:

Dybala KE. 2023d. DeltaMultipleBenefits: Projecting the Multiple Benefits of Land Cover Change in the Sacramento-San Joaquin River Delta. R package version 1.0.0. doi: 10.5281/zenodo.7718620. Available from: https://pointblue.github.io/DeltaMultipleBenefits.

Task 6. Stakeholder Engagement and Outreach

6.1 Objective

Communicate with interested stakeholder groups about the ways in which resource management and policy decisions can result in trade-offs and co-benefits for bird populations and ecosystem services.

6.2 Summary

We initially communicated and coordinated with key partners about the overall project concept and in the development of scenarios for evaluation, presenting the overall project goals, the vision of a flexible, science-based framework for identifying multiple benefits and trade-offs resulting from landscape change, and the draft approaches to developing each scenario. We sought feedback on the selection of scenarios to evaluate, how they were developed, and future directions for the project. These initial meetings included staff from the Delta Stewardship Council, California Department of Fish and Wildlife, Delta Conservancy, Central Valley Joint Venture Lands Committee, and Migratory Bird Conservation Partnership (including The Nature Conservancy and Audubon California).

Once the major analyses for this project were complete, we began giving presentations to members of the Delta community on the major findings of the Priority Bird Conservation Areas and the results of the scenario analyses, illustrating the ways in which resource management and policy decisions can result in trade-offs and benefits for bird populations and other metrics. Presentations included a "Slough-Side Chat" hosted by the Delta Science Program, a presentation to the Central Valley Joint Venture board, and a Conservation Lecture hosted by California Department of Fish and Wildlife Science Institute.

Beyond the scope of our grant agreement, we also included the concepts and results of this project in broader presentations on Multiple-Benefit Conservation to other community groups. These included a presentation as part of the Creek Speak seminar series hosted by the Putah Creek Council, a community presentation hosted by the Mid-Coast Watershed Council in Oregon, and a presentation to the Board of Point Blue Conservation Science.

6.3 Conclusions

Our initial premise was that the potential impacts of landscape change scenarios on bird species and ecosystem services are important for stakeholders, resource managers, and policy makers to incorporate into their decision making processes. Communications with resource managers and key stakeholders about this project have been very supportive, with numerous ideas suggested for additional metrics to include in future phases of developing this framework.

6.4 Deliverables

Outreach presentation materials:

Dybala KE. 2022. Multiple-Benefit Conservation in the Sacramento-San Joaquin Delta. Slough-Side Chat seminar series, hosted by the Delta Science Program. Nov 4, Virtual.

Dybala KE. 2023. Multiple-Benefit Conservation in the Sacramento-San Joaquin Delta. Central Valley Joint Venture Board Meeting. Feb 16, Cosumnes River Preserve.

Dybala KE. 2023. Multiple-Benefit Conservation in the Delta: Quantifying multidimensional impacts of landscape change. Conservation Lecture Series, hosted by the California Department of Fish and Wildlife Science Institute. Mar 13, Virtual.

Task 7. Disseminate Results to the Broader Scientific Community

7.1 Objective

Communicate to the broader scientific community about the ways in which resource management and policy decisions can result in trade-offs and co-benefits for bird populations and ecosystem services.

7.2 Summary

To ensure the concepts, approaches, and results of our project are accessible to the broader scientific community, we developed two draft manuscripts currently in review for publication. The first focuses on the results of Task 3, describing the development of the distribution models for riparian landbird species and waterbird groups, the prioritization analyses identifying Priority Bird Conservation Areas, and an evaluation of their characteristics (e.g., protected status, flood risk, and land cover class). The second focuses on the results of Task 4, describing the development of the landscape change scenarios, the metrics representing each benefit category, and analysis of the projected net impacts of each scenario on each metric.

We have also shared our results from Tasks 3 and 4 through presentations at scientific conferences. The results of Task 3 were presented at the virtual Bay-Delta science conference held in 2021, and the results of Task 4 were presented at the North American Congress for Conservation Biology held in Reno in 2022. Beyond the scope of our grant agreement, we also included the concepts and results of this project in broader presentations to the scientific community on Multiple-Benefit Conservation. These included a presentation as part of the Pacific Wildlife Research Centre seminar series, hosted by Environment and Climate Change Canada, and a presentation to Point Blue Conservation Science staff at an "All Staff" meeting.

7.3 Conclusions

Our initial premise was that the potential impacts of landscape change scenarios on bird species and ecosystem services, and methods for estimating these impacts, are important for the broader scientific community to incorporate into their research designs and policy recommendations. Communications about this project have been very supportive, with numerous ideas suggested for additional metrics to include in future phases of developing this framework.

7.4 Deliverables

Manuscripts:

Dybala KE, Sesser K, Reiter ME, Shuford WD, Golet GH, Hickey C, Gardali T. *In review - A.* Priority Bird Conservation Areas in California's Sacramento–San Joaquin Delta.

Dybala KE, Sesser KA, Reiter ME, Hickey C, Gardali T. *In review - B.* Multiple-benefit Conservation in Practice: A Framework for Quantifying Multi-dimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta.

Conference presentation materials:

Dybala KE. 2022. Multiple-Benefit Conservation in Practice: Quantifying Multi-dimensional Impacts of Landscape Change in the Sacramento-San Joaquin Delta of California. North American Congress for Conservation Biology, Jul 16-21, Reno, NV

Dybala KE, Sesser K, Reiter M. 2021. Identifying high priority areas for bird conservation in the Delta. Bay-Delta Science Conference. Apr 6-9, Virtual.

Complete List of Deliverables

Manuscripts:

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey C, Gardali T. *In review-A*. Priority Bird Conservation Areas in California's Sacramento–San Joaquin Delta.

Dybala KE, Sesser KA, Reiter ME, Hickey C, Gardali T. *In review-B*. Multiple-Benefit Conservation in practice: A framework for quantifying multi-dimensional impacts of landscape change in California's Sacramento–San Joaquin River Delta.

Reports:

*Dybala KE, Sesser KA, Reiter ME. 2021. Spatial Modeling and Prioritization for Bird Conservation in the Delta: Summary of Task 3 for the project "Trade-offs and Co-benefits of Landscape Change Scenarios on Bird Communities and Ecosystem Services in the Sacramento-San Joaquin River Delta". Point Blue Conservation Science, Petaluma, CA.

*Dybala KE. 2022. Net Impacts of Landscape Change Scenarios: Summary of Task 4 for the project "Trade-offs and Co-benefits of Landscape Change Scenarios on Bird Communities and Ecosystem Services in the Sacramento-San Joaquin River Delta". Point Blue Conservation Science, Petaluma, CA.

Peterson C, Marvinney E, Dybala K. 2020. Multiple Benefits from Agricultural and Natural Land Covers in the Central Valley, CA. Sacramento, CA: Migratory Bird Conservation Partnership. Available from: http://www.prbo.org/refs/files/12650_PetersonCA2020.pdf.

**We consider the methods and results in these reports to be preliminary and superseded by the corresponding manuscript.*

Outreach presentation materials:

Dybala KE. 2022. Multiple-Benefit Conservation in the Sacramento-San Joaquin Delta. Slough-Side Chat seminar series, hosted by the Delta Science Program. Nov 4, Virtual.

Dybala KE. 2023. Multiple-Benefit Conservation in the Sacramento-San Joaquin Delta. Central Valley Joint Venture Board Meeting. Feb 16, Cosumnes River Preserve.

Dybala KE. 2023. Multiple-Benefit Conservation in the Delta: Quantifying multidimensional impacts of landscape change. Conservation Lecture Series, hosted by the California Department of Fish and Wildlife Science Institute. Mar 13, Virtual.

Conference presentation materials:

Dybala KE. 2022. Multiple-Benefit Conservation in Practice: Quantifying Multi-dimensional Impacts of Landscape Change in the Sacramento-San Joaquin Delta of California. North American Congress for Conservation Biology, Jul 16-21, Reno, NV.

Dybala KE, Sesser K, Reiter M. 2021. Identifying high priority areas for bird conservation in the Delta. Bay-Delta Science Conference. Apr 6-9, Virtual.

Software & vignette:

Dybala KE. 2023d. DeltaMultipleBenefits: Projecting the Multiple Benefits of Land Cover Change in the Sacramento-San Joaquin River Delta. R package version 1.0.0. doi: 10.5281/zenodo.7718620. Available from: https://pointblue.github.io/DeltaMultipleBenefits

Spatial data:

Dybala KE. 2023b. Multiple-benefit Conservation in Practice: Supplemental Spatial Data for Quantifying Multidimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta. Zenodo. doi:10.5281/zenodo.7672193.

Dybala KE. 2023c. Baseline and projected future land use and land cover in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023a. Predicted probability of riparian landbird distributions in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023b. Predicted probability of waterbird group distributions in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023c. Spatial prioritization for bird conservation in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023d. Priority Bird Conservation Areas in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Supporting data:

Dybala KE. 2023a. Multiple-benefit Conservation in Practice: Metrics Data for Quantifying Multidimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta. doi:10.5281/zenodo.7504874.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023e. Distribution models for riparian landbirds and waterbirds in the Sacramento-San Joaquin Delta. Zenodo. doi:10.5281/zenodo.7531945

Peterson, C, Marvinney E, Dybala K. 2020. Multiple Benefits from Agricultural and Natural Land Covers in the Central Valley, CA. Dryad Dataset. doi:10.25338/B8061X

Literature Cited

[CDFA] California Department of Food and Agriculture. 2022. County Ag Commissioners' Data Listing. California Department of Food and Agriculture. [accessed 2022 Apr 22]. Available from: https://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/index.php.

[CDFW] California Department of Fish and Wildlife. 2021. State and Federally Listed Endangered and Threatened Animals of California. State of California Natural Resources Agency, Department of Fish and Wildlife, Biogeographic Data Branch. Available from: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=109405&inline.

[CDPR] California Department of Pesticide Regulation. 2022. Pesticide Use Report Data. California Department of Pesticide Regulation. [accessed 2022 Apr 22]. Available from: https://www.cdpr.ca.gov/docs/pur/purmain.htm.

[CNRA] California Natural Resources Agency. 2022. Pathways to 30x30: Accelerating Conservation of California's Nature. California Natural Resources Agency. [accessed 2022 Jul 20]. Available from: https://www.californianature.ca.gov/pages/30x30.

[CVJV] Central Valley Joint Venture. 2020. Central Valley Joint Venture 2020 Implementation Plan. Sacramento, CA: U.S. Fish and Wildlife Service. Available from: https://www.centralvalleyjointventure.org/science/2020-implementation-plan

[DSC] Delta Stewardship Council. 2013. The Delta Plan: Ensuring a reliable water supply for California, a healthy Delta ecosystem, and a place of enduring value. Sacramento, CA: Delta Stewardship Council. Available from: http://deltacouncil.ca.gov/delta-plan/

[DSC] Delta Stewardship Council. 2017. 2017-2021 Science Action Agenda: A Collaborative Road Map for Delta Science. Available from: https://scienceactionagenda.deltacouncil.ca.gov/pdf/2021-01-14-science-action-plan.pdf

[DSC] Delta Stewardship Council. c2021. Critical Pesticides. Available from: https://viewperformance.deltacouncil.ca.gov/pm/critical-pesticides

[DSC] Delta Stewardship Council. 2021. Delta Adapts: Creating a Climate Resilient Future. Public Review Draft. Delta Stewardship Council. Available from: https://deltacouncil.ca.gov/delta-plan/climate-change

[DSC] Delta Stewardship Council. 2022a. 2022-2026 Science Action Agenda: A Vision for Integrating Delta Science. Delta Stewardship Council. Available from: https://scienceactionagenda.deltacouncil.ca.gov/pdf/2022-2026-science-action-agenda.pdf

[DSC] Delta Stewardship Council. 2022b. Protect, Restore, and Enhance the Delta Ecosystem. Delta Plan, Amended. Sacramento, CA: Delta Stewardship Council. Available from: https://deltacouncil.ca.gov/delta-plan/amendments

[DWR] Department of Water Resources. c2022. Agricultural Land & Water Use Estimates. Sacramento, CA: California Department of Water Resources. Available from: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates

Dybala KE. 2023a. Multiple-benefit Conservation in Practice: Metrics Data for Quantifying

Multidimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta. doi:10.5281/zenodo.7504874.

Dybala KE. 2023b. Multiple-benefit Conservation in Practice: Supplemental Spatial Data for Quantifying Multidimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta. doi:10.5281/zenodo.7672193.

Dybala KE. 2023c. Baseline and projected future land use and land cover in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE. 2023d. DeltaMultipleBenefits: Projecting the Multiple Benefits of Land Cover Change in the Sacramento-San Joaquin River Delta. R package version 1.0.0. doi: 10.5281/zenodo.7718620. Available from: https://pointblue.github.io/DeltaMultipleBenefits

Dybala KE, Gardali T, Melcer R. 2020. Getting our heads above water: Integrating bird conservation in planning, science, and restoration for a more resilient Sacramento–San Joaquin Delta. SFEWS. 18(4). doi:10.15447/sfews.2020v18iss4art2

Dybala KE, Reiter ME, Hickey CM. In review - B. Multiple-benefit Conservation in Practice: A Framework for Quantifying Multi-dimensional Impacts of Landscape Change in California's Sacramento–San Joaquin Delta.

Dybala KE, Sesser K, Reiter M, Shuford WD, Golet GH, Hickey C, Gardali T. In review - A. Priority Bird Conservation Areas in California's Sacramento–San Joaquin Delta.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023a. Predicted probability of riparian landbird distributions in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023b. Predicted probability of waterbird group distributions in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023c. Spatial prioritization for bird conservation in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023d. Priority Bird Conservation Areas in the Sacramento-San Joaquin Delta. Petaluma, CA: Point Blue Conservation Science. Available from: https://wildlife.ca.gov/Data/BIOS.

Dybala KE, Sesser KA, Reiter ME, Shuford WD, Golet GH, Hickey CM, Gardali T. 2023e. Distribution models for riparian landbirds and waterbirds in the Sacramento-San Joaquin Delta. Zenodo. doi:10.5281/zenodo.7531945

[EDD] Employment Development Department. c2022. Quarterly Census of Employment and Wages (QCEW). California Employment Development Department. Available from: https://data.edd.ca.gov/Industry-Information-/Quarterly-Census-of-Employment-and-Wages-QCEW-/fisq-v939

Elith J, Leathwick JR, Hastie T. 2008. A working guide to boosted regression trees. Journal of

Animal Ecology 77(4):802–813. doi:10.1111/j.1365-2656.2008.01390.x

Fick SE, Hijmans RJ. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology. 37(12):4302–4315. doi:10.1002/joc.5086.

Gardali T, Dybala KE, Seavy NE. 2021. Multiple-Benefit Conservation defined. Conservation Science and Practice 3:e420. doi:10.1111/csp2.420

GreenInfo Network. 2022a. California Conservation Easement Database. [accessed 2022 Jul 15]. Available from: www.calands.org.

GreenInfo Network. 2022b. California Protected Areas Database. [accessed 2022 Jul 15]. Available from: www.calands.org.

Greenwell B, Boehmke B, Cunningham J, GBM Developers. 2020. gbm: Generalized Boosted Regression Models. R package version 2.1.8. Available from: https://CRAN.R-project.org/package=gbm

Guaita Martínez JM, de Castro-Pardo M, Pérez-Rodríguez F, Martín Martín JM. 2019. Innovation and multi-level knowledge transfer using a multi-criteria decision making method for the planning of protected areas. Journal of Innovation & Knowledge 4:256–261. doi:10.1016/j.jik.2019.01.001

Hanley JA, McNeil BJ. 1982. The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology. 143(1):29–36. doi:10.1148/radiology.143.1.7063747.

Hijmans RJ, Phillips S, Elith J, Elith JL. 2020. dismo: Species Distribution Modeling. R package version 1.3-3. Available from: https://CRAN.R-project.org/package=dismo

Lu Z, Davis G. 2009. Relative-Risk Evaluation for Pesticides Used in the Central Valley Pesticides Basin Plan Amendment Project Area. Rancho Cordova, CA: California Regional Water Quality Control Board, Central Valley Region.

Mickel A, Taylor S, Rollof D, Gregory S. 2019. Recreation & Tourism in the Delta: A Study of Preferences for Activities and Facilities, Information Sources, and Economic Contributions of Delta Events. Sacramento, CA: Delta Protection Commission. Available from: https://delta.ca.gov/wp-content/uploads/2020/09/Delta-Recreation-Report-508.pdf

Milligan B, Kraus–Polk A. 2017. Inhabiting the Delta: A landscape approach to transformative socio-ecological restoration. San Francisco Estuary and Watershed Science 15(3). doi:10.15447/sfews.2017v15iss3art3

Moilanen A, Lehtinen P, Kohonen I, Jalkanen J, Virtanen EA, Kujala H. 2022. Novel methods for spatial prioritization with applications in conservation, land use planning and ecological impact avoidance. Methods in Ecology and Evolution 13:1062–1072. doi:10.1111/2041-210X.13819

[NAWMP] North American Waterfowl Management Plan. 2018. 2018 NAWMP Update: Connecting People, Waterfowl, and Wetlands. Available from: https://nawmp.org/timeline/2018-update

Pandolfino ER, Smith Z. 2011. Central Valley winter raptor survey (2007 – 2010): Loggerhead Shrike habitat associations. Central Valley Bird Club Bulletin. 14:81–86.

Peterson C, Marvinney E, Dybala K. 2020. Multiple Benefits from Agricultural and Natural Land Covers in the Central Valley, CA. Sacramento, CA: Migratory Bird Conservation Partnership. Available from: http://www.prbo.org/refs/files/12650_PetersonCA2020.pdf

Point Blue Conservation Science. c2020. Modeling Bird Distribution Responses to Climate Change: A mapping tool to assist land managers and scientists in California. Available from: http://data.prbo.org/apps/ecn/index.php?page=ecn-areas-of-change-map

R Core Team. 2021. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. http://www.r-project.org

Reiter ME, Elliott NK, Barbaree B, Moody D. 2018. An automated open surface water tracking system for California's Central Valley. Report to the U.S. Fish and Wildlife Service. Petaluma, California: Point Blue Conservation Science. Available from: https://data.pointblue.org/apps/autowater/.

Reiter ME, Wolder MA, Isola JE, Jongsomjit D, Hickey CM, Carpenter M, Silveira JG. 2015. Local and landscape habitat associations of shorebirds in wetlands of the Sacramento Valley of California. Journal of Fish and Wildlife Management. 6(1):29–43. doi:10.3996/012014-JFWM-003

Rosenberg KV, Kennedy JA, Dettmers R, Ford RP, Reynolds D, Alexander JD, Beardmore CJ, Blancher PJ, Bogart RE, Butcher GS, Camfield AF, Couturier AR, Demarest DW, Easton WE, Giocomo JJ, Keller RH, Mini AE, Parjabi AO, Pashley DN, Rich TD, Ruth JM, Stabins H, Stanton J, Will T. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. Available from: https://partnersinflight.org/resources/the-plan/

San Francisco Estuary Partnership. 2022. 2022 San Francisco Estuary Blueprint (Comprehensive Conservation and Management Plan for the San Francisco Estuary). San Francisco, CA: San Francisco Estuary Partnership. Available from: https://www.sfestuary.org/estuary-blueprint/

Schwenkler J. 2019. Vegetation - Delta Vegetation and Land Use Update - 2016 [ds2855]. Available from: https://map.dfg.ca.gov/metadata/ds2855.html

Seavy NE, Viers JH, Wood JK. 2009. Riparian bird response to vegetation structure: a multiscale analysis using LiDAR measurements of canopy height. Ecological Applications. 19(7):1848–1857. doi:10.1890/08-1124.1

Senner SE, Andres BA, Gates HR. 2016. Pacific Americas shorebird conservation strategy. New York, NY: National Audubon Society. Available from: http://www.shorebirdplan.org

[SFEI] San Francisco Estuary Institute. 2022. Landscape Scenario Planning Tool User Guide. Version 2.0.0. Richmond, CA: San Francisco Estuary Institute.

Shuford WD, Gardali T. 2008. California Bird Species of Special Concern: A ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Game, Sacramento, California.

Shuford WD, Reiter ME, Sesser KA, Watts TC, Dhundale JA, Jongsomjit D, Hickey CM. 2016. Effects of local and landscape-scale factors on the distribution and abundance of waterbirds in agricultural and wetland habitats of the Sacramento–San Joaquin River Delta of

California. Petaluma, CA: Point Blue Conservation Science. Available from: http://www.prbo.org/refs/files/12398_Shuford_etal2016.pdf

Shuford WD, Reiter M, Sesser K, Hickey C, Golet G. 2019. The relative importance of agricultural and wetland habitats to waterbirds in the Sacramento–San Joaquin River Delta of California. San Francisco Estuary and Watershed Science. 17. doi:10.15447/sfews.2019v17iss1art2

Stralberg D, Cameron DR, Reynolds MD, Hickey CM, Klausmeyer K, Busby SM, Stenzel LE, Shuford WD, Page GW. 2011. Identifying habitat conservation priorities and gaps for migratory shorebirds and waterfowl in California. Biodiversity Conservation 20:19–40. doi:10.1007/s10531-010-9943-5

Swets JA. 1988. Measuring the Accuracy of Diagnostic Systems. Science. 240(4857):1285–1293. Available from: https://www.jstor.org/stable/1701052

Swolgaard CA, Reeves KA, Bell DA. 2008. Foraging by Swainson's Hawks in a vineyard-dominated landscape. Journal of Raptor Research 42:188–196. doi:10.3356/JRR-07-15.1

[USGS] U.S. Geological Survey. 2020. National Hydrography Dataset Best Resolution (NHD) for Hydrologic Units (HU) 4 - 1802, 1803, 1804, 1805. Available from: https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products.

[U.S. DOI] U.S. Department of the Interior, U.S. Department of Agriculture, U.S. Department of Commerce, Council on Environmental Quality. 2021. Conserving and Restoring America the Beautiful. Available from: https://www.doi.gov/sites/doi.gov/files/report-conserving-and-restoring-america-the-beautiful-2021.pdf

Veloz SD, Salas L, Elliott NK, Jongsomjit D, Shuford WD. 2017. Conservation reserve planning for wintering Sandhill Cranes in the Central Valley of California. Petaluma, CA: Point Blue Conservation Science.

Whipple AA, Grossinger RM, Rankin D, Stanford B, Askevold RA. 2012. Sacramento-San Joaquin Delta historical ecology investigation: Exploring pattern and process. Richmond, CA: San Francisco Estuary Institute-Aquatic Science Center. Available from: http://www.sfei.org/documents/sacramento-san-joaquin-delta-historical-ecology-investigation-exploring-pattern-and-proces

Wiens JA, Zedler JB, Resh VH, Collier TK, Brandt S, Norgaard RB, Lund JR, Atwater B, Canuel E, Fernando HJ. 2017. Facilitating adaptive management in California's Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science 15(2). doi:10.15447/sfews.2017v15iss2art3

Wilson TS, Matchett E, Byrd KB, Conlisk E, Reiter ME, Wallace C, Flint LE, Flint AL, Joyce B, Moritsch MM. 2022. Climate and land change impacts on future managed wetland habitat: a case study from California's Central Valley. Landscape Ecology 37:861–881. doi:10.1007/s10980-021-01398-1

Wilson TS, Matchett EL, Byrd K, Conlisk E, Reiter ME, Flint LE, Flint AL, Moritsch MM, Wallace C. 2021. Integrated modeling of climate and land change impacts on future dynamic wetland habitat – a case study from California's Central Valley. doi:10.5066/P9BSZM8R

Yu H, Cooper AR, Infante DM. 2020. Improving species distribution model predictive accuracy using species abundance: Application with boosted regression trees. Ecological Modelling. 432:109202. doi:10.1016/j.ecolmodel.2020.109202