JANUARY 2025

CALIFORNIA RICE FOOTPRINT
REPORT SUMMARY

A Conservation Footprint for California Rice

Acres, locations, and management practices of ricelands to support multiple species of wildlife in the Central Valley, California

A partnership of the University of California Davis
and Point Blue Conservation Science

Editors
John M. Eadie
Daniel S. Karp

Read the full report

Contributors

Francisco Bellido-Leiva, PhD, Research Scientist, Department of Wildlife, Fish & Conservation Biology, University of California Davis

Lee R. Burrows, BS, PhD candidate, Ecology Graduate Group, Department of Wildlife, Fish & Conservation Biology, University of California Davis

Kristen E. Dybala, PhD, Principal Ecologist, Point Blue Conservation Science

John M. Eadie, PhD, Distinguished Professor, Department of Wildlife, Fish & Conservation Biology, University of California Davis

Sean P. Fogenburg, PhD, Research Scientist, Department of Wildlife, Fish & Conservation Biology, University of California Davis

Daniel S. Karp, PhD, Associate Professor, Department of Wildlife, Fish & Conservation Biology, University of California Davis

Bruce A. Linquist, Professor of Cooperative Extension, Department of Plant Sciences, University of California Davis

Cory T. Overton, PhD, Wildlife Biologist, Western Ecological Research Center, U.S.G.S.

Andrew L. Rypel, PhD, Professor, Center for Watershed Sciences & Department of Wildlife, Fish & Conservation Biology, University of California Davis

Daniel A. Sumner, PhD, Distinguished Professor, Agricultural and Resource Economics, University of California Davis

Brian D. Todd, PhD, Professor, Department of Wildlife, Fish & Conservation Biology, University of California Davis

Robert G. Walsh, PhD, Avian Ecologist, Point Blue Conservation Science

Jessica Xu, PhD candidate, Agricultural and Resource Economics, University of California Davis

Contents

Executive Summary

Rice agriculture, especially winter-flooded rice fields, provides surrogate wetlands that host a diversity of species in the Central Valley. Rice fields are critical for Giant Gartersnakes, wintering waterfowl, wintering and breeding shorebirds, Sandhill Cranes, native fishes, and many other species. However, uncertainties in climate, water availability, agricultural crop markets, and urban expansion are precipitating changes in management practices increased variability and magnitude of fallowing, and, in some cases, crop conversion.

These uncertainties raise several important questions for both the rice industry and wildlife conservation:

1. How much rice is needed to meet minimum requirements for species of conservation concern in the California Central Valley?
2. How much planted rice needs to be flooded in winter and/or managed in specific ways to continue providing ecological benefits?
3. Are there specific locations where rice is especially needed to maintain high levels of wildlife abundance and diversity?
4. Finally, in the face of continuing challenges to agricultural and managed wetland habitats, which management practices, or suites of practices, are economically feasible to implement and benefit the greatest number of species, without negatively impacting other species?

This project represents an initial attempt to address these questions. We briefly review the agronomics, economics, and conversion risk of ricelands in the Central Valley of California. We first develop a single baseline mapping framework including multiple habitat components that could influence the abundance and distribution of various wildlife species. We then review the core needs of five key taxonomic groups (Giant Gartersnakes, wintering ducks, wintering and breeding shorebirds and Black Terns, Sandhill Cranes, and native fishes) with respect to ricelands. We go on to provide an estimate of the rice acreage, management actions, and locations that would be of greatest value to each group. We include an evaluation of the potential economic value of riceland habitats and wildlife to address potential social welfare gains from improved wildlife habitat populations. Finally, we synthesize key outcomes from our taxa-specific analyses to provide an evaluation of the rice footprint needed to support these taxonomic groups.

In addition to providing nutritious and healthy food for millions, the California rice industry is central to the rural economy of the Sacramento Valley and more broadly. Rice production itself supports about $1 billion of added economic value and more than 7,500 jobs when at full production. Rice planted acreage over the past decade has been highly variable from 250,000 to 540,000 acres (100,000 to over 215,000 ha), primarily due to drought and wet springs. Where rice is planted, about 50% of the land is flooded during winter to aid in rice straw decomposition and provide habitat. Management of these fields varies tremendously. Under current conditions, we found that there is little risk of conversion of ricelands to other field crops. Although there has been some replacement by orchard crops, this is limited and has occurred on the outer margins of the rice area and along the rivers.

We consolidated and updated multiple datasets to map habitat characteristics, spatial relationships, and temporal dynamics across the Central Valley. We used data from 2020 to 2024 to develop five distinct habitat scenarios representing a range of conditions, from favorable years with extensive rice planting (>500,000 rice acres in 2020/21 and 2023/24) to challenging years with reduced planting due to drought (~250,000 rice acres in 2022/23). This mapping effort provided the foundation for evaluating habitat needs across taxa.

With the draining and loss of much historical wetland habitat, flooded rice now provides critical surrogate habitat for the protected Giant Gartersnake. The recovery plan for the species recognizes the importance of flooded rice to Giant Gartersnake populations and calls for >80,000 acres of flooded rice along with protecting wetlands as part of a recovery strategy. Priorities to sustain populations include ensuring consistent planting and flooding of rice in parcels close to remaining wetlands, especially when those parcels currently support gartersnakes, as well as identifying ways of enhancing habitat — especially in canals — through earlier water availability in late March to April each year.

California's Central Valley serves as a vital wintering ground for millions of waterfowl along the Pacific Flyway. Flooded rice fields provide critical foraging habitat for waterfowl during winter. We used the SWAMP bioenergetic model to evaluate the amount and spatial distribution of rice acreage required to support duck population goals during the nonbreeding season. At 300,000 acres of planted rice, population sizes experienced steep declines dropping below 50% of target goals by early January, lipid reserves declined rapidly by January, and average flight distances exceeded 8 km by late January, forcing ducks to travel farther to forage. Conversely, with 500,000 acres of planted rice, populations remained near 100% of the target until late February and lipid accumulation continued, with reserves peaking in mid-January and sustained through March. Spatial analyses identified high-priority rice fields for conservation, with projected high-use areas concentrated near refuges and managed wetlands.

Rice serves important habitat to wetland-dependent birds year-round, including several shorebirds and nearly 100% of the Central Valley breeding habitat for Black Tern, a California Bird Species of Special Concern. A rice footprint of >426,043 ac (172,414 ha) is needed to maintain a Black Tern population above 1,000 individuals, reducing the risk of local extirpation and loss of genetic diversity. If habitat quality could be enhanced to restore breeding densities, a rice footprint of >472,794 ac (191,333 ha) may be sufficient to meet the CVJV's long-term population objective for Black Tern, provided flooding is maintained throughout the entire breeding season. A rice footprint of this size would also contribute to maintaining a breeding Black-necked Stilt population and would continue to provide substantial breeding habitat for American Avocet.

Rice provides more than half of the food energy supply needed to support the large, diverse community of shorebirds in the non-breeding season. For nonbreeding shorebirds, there were energy shortfalls during the fall and spring "shoulder" portions of every scenario that was explored. The rice footprint needed to support nonbreeding shorebirds depends on the extent that is winter-flooded, including winter-flooded fallow rice fields. A threshold for the midwinter peak of flooded rice and fallowed rice of 373,540 ac (151,167 ha) would support nonbreeding shorebird conservation objectives.

The vast majority of California's Sandhill Cranes winter in the Sacramento Valley and the Yolo-Delta region, where they make substantial use of rice farms for both foraging (unflooded conditions) and roosting (flooded conditions). The Greater subspecies is state-listed as threatened and the Lesser subspecies as a species of special concern. To accommodate cranes at recommended roosting densities, an estimate of 43,139 acres of flooded rice is needed in November, the month of maximum abundance, to complement other potential roosting habitat. 56,759 acres (22,970 ha) would be needed if no other roosting habitat was available. A mix of shallowly flooded and unflooded rice would best support cranes' needs for roosting and foraging habitat. Providing this habitat in the Yolo-Delta Region is a high priority because of high bird numbers and high roost suitability.

California's native fish populations are in a clear state of decline, but there is high potential to utilize winter-flooded rice fields as fish habitat. Flood extension management of ricelands for fishes promotes opportunities for growth and survival, primarily due to robust densities of zooplankton that naturally develop on fields (the primary food source of many native fishes including juvenile salmon). Mathematical salmon population models developed specifically for this report clearly show that successful implementation of flood extension practices for fishes could massively improve adult salmon numbers. This analysis indicates that all the Yolo and Sutter bypass acres — 74,000 acres (29,947 ha), of which 30,000 acres (12,141 ha) is rice — would be needed to nearly double the population cohort replacement rate. That said, rice alone cannot provide enough habitat for stable populations of fishes. As such, other complementary management actions (e.g., managing rice for 'fish food'), funding, and collaboration are needed to fully recover fish populations.

A wide range of methods and empirical sources document extensive economic support from society for wild species habitat. Applying this evidence to rice contexts suggests the economic value of rice farms as wildlife habitat may exceed hundreds of dollars per acre per year.

Summarizing, our estimates of the planted rice acreage needed for these taxonomic groups include: 30,000 ac for native fishes (only Yolo and Sutter bypasses are considered in this report), 43,139 ac (Sandhill Cranes), 80,000 ac (Giant Gartersnake), 373,540 ac of winter-flooded rice and flooded fallow rice fields (non-breeding shorebirds), 472,794 ac of planted rice (to restore populations of Black Terns and support other breeding shore birds), and 500,000 ac (non-breeding ducks). A minimum rice footprint could be determined as that which satisfies the minimum needs of the species with the largest acreage requirement — any reduction of rice below that target would impact at least that one species. Under this premise, a minimum footprint of ~470,000–500,000 acres would define the conservation footprint. We discuss several factors that will influence this estimate, and we consider a range of rice acreages where the amount of rice habitat is inadequate under all conditions (high risk), where there is risk of not meeting population objectives, especially when conditions are poor (insufficient), and where there is enough rice habitat to buffer populations under almost all conditions (sufficient).

A minimum footprint of **~470,000–500,000 acres** would define the conservation footprint.

We use our mapping analysis to identify rice locations that are high priority for multiple species. We emphasize that (1) these are not the only areas of conservation importance, (2) they are not weighted rankings of conservation value, and (3) they do not define the minimum footprint. Rather, we present these maps as tools for strategic conservation planning to identify focal areas where joint management may be most effective and/or where management trade-offs for different species may occur.

Finally, we identify research needs for each taxonomic group. We also describe next steps to develop a more refined rice conservation footprint using multi-objective decision analysis, expanding the species groups considered, enhancing economic and ecological data integration, as well as modeling and engaging stakeholders in key priority areas.

Introduction: A Need for Multi-species Conservation

John M. Eadie and Daniel S. Karp, Department of Wildlife, Fish & Conservation Biology, University of California Davis

Historically, extensive seasonal wetlands shaped the ecology and biodiversity of California's Central Valley (Frayer et al. 1989, Sterling and Buttner 2011, Central Valley Joint Venture 2020).

Fortunately, the emergence of rice agriculture, especially winter-flooded rice fields, created surrogate wetlands that now host an impressive diversity of species in the Central Valley, including globally-recognized spectacles of wildlife migration as well as several threatened and endangered species (Gilmer et al. 1982, Elphick and Oring 2003, Eadie et al. 2008, Elphick et al. 2010b, 2018, Shuford et al. 2019, Central Valley Joint Venture 2020, Casazza et al. 2021). Research and extensive monitoring by academic, government, industry, and NGO scientists in the Central Valley of California over the past several decades have documented numerous benefits of California rice to wildlife and the critical ecological functions and services that they provide (Table 2.1).

Ecological Value of California Rice	References (representative not exhaustive)
Occurrence of over 230 species in rice fields	(California Rice Commission 2011, Sterling and Buttner 2011)
Value of flooded rice fields as winter habitat for waterfowl, shorebirds, wading birds, and cranes as well as breeding habitat for some of these species	(Brouder and Hill 1995, Reid and Heitmeyer 1995, Elphick and Oring 1998, Eadie et al. 2008, Petrie and Petrik 2010, Sesser et al. 2016, 2018, Elphick et al. 2018, Casazza et al. 2021, Conlisk et al. 2023)
Importance of rice fields for shorebirds during fall and winter migration	(Shuford et al. 1998, Elphick and Oring 1998, Hickey et al. 2003, Elphick and Oring 2003, Elphick 2008, Elphick et al. 2010b, Petrie and Petrik 2010, Dybala et al. 2017, Elphick et al. 2018, Matchett and Fleskes 2018)
Value of residual rice grain as a food source for waterfowl and other species	(Miller et al. 1989, Reid and Heitmeyer 1995, Fleskes and Perry 2005, Fleskes et al. 2012, Matthews et al. 2018)
Importance of rice fields to endangered reptiles such as Giant Gartersnake	(Halstead et al. 2010, 2014, 2019, Wylie et al. 2010, Sterling and Buttner 2011, U.S. Fish and Wildlife Service 2017)
Value of winter-flooded rice fields for production of invertebrate food resources, fueling rapid growth and survival by juvenile salmonids prior to seaward migration	(Jeffres et al. 2008, 2020, Moyle et al. 2011, Garnache 2015, Katz et al. 2017, Corline et al. 2017, Sommer et al. 2020, Holmes et al. 2021, Tallman 2024, Rossi et al. 2024)
Effect of different post-harvest methods/ treatments on availability of waste grain and subsequent use by wildlife	(Miller et al. 1989, Day and Colwell 1998, Elphick and Oring 1998, Colwell and Taft 2000, Elphick and Oring 2003, Elphick 2004, Elphick et al. 2010b, Miller et al. 2010, Fleskes et al. 2012, Strum et al. 2014, Brogi et al. 2015, Sesser et al. 2018, 2018, Matthews et al. 2022a, Peterson et al. 2024, Conlisk et al. 2024)
Effect of drought and loss of flooded rice on observed and predicted wildlife populations	(Petrie et al. 2016, Reiter et al. 2018a, Halstead et al. 2019, Byrd et al. 2020, Matchett 2021, Kahara et al. 2022)
Bioenergetic modeling and scenario evaluation to evaluate and project consequences of changes in winter-flooded rice	(Petrie et al. 2016, Dybala et al. 2017, Central Valley Joint Venture 2020, Matchett 2021)
Analyses of the agronomic value of winter-flooding for growers, opportunities, and limitations of winterflooding and post-harvest management to benefits wildlife	(Day and Colwell 1998, Elphick 2000, Fitzgerald et al. 2000, Bird et al. 2000, Garr 2002, Elphick and Oring 2003, Van Groenigen et al. 2003, Anders et al. 2008, Brogi et al. 2015)

Table 2.1. Examples of research and ecological values provided by rice agriculture to wildlife.

Unquestionably, rice agriculture plays a significant role in providing food resources and habitat to many species of California native birds, reptiles, amphibians, and fishes. Winter-flooded rice fields, in particular, are critical for wintering waterfowl and shorebirds. Indeed, it is estimated that residual rice grain and benthic invertebrates in winter-flooded rice fields provide over half of all food energy resources needed by these species during the non-breeding season (Central Valley Joint Venture 2006a, 2020). Countless other waterbirds (e.g., cranes, terns, herons and egrets) likewise depend heavily on rice fields for nesting, foraging, and/or roosting throughout the year. Rice fields are also playing an increasingly important role in fish and reptile conservation, including endangered salmonids (Katz et al. 2017, Holmes et al. 2021, Rossi et al. 2024) and the Giant Gartersnake (Halstead et al. 2010, 2019, U.S. Fish and Wildlife Service 2017).

The effects of rice agriculture on California wildlife cascade to positively impact people. Indeed, California rice agriculture is not only a large and economically important agricultural commodity, it also provides myriad recreational opportunities for birdwatchers, hunters, and outdoor enthusiasts (Petrie et al. 2014b, Matthews and Sumner 2024). Leasing of hunting access can, in turn, be an important source of supplemental income for many rice farmers (Matthews 2019).

Yet many questions and challenges remain for the rice industry and the wildlife that depend on it. Specifically, uncertainties in climate, water availability, agricultural crop markets, and urban expansion are precipitating changes in management practices, increased variability and magnitude of fallowing, and, in some cases, crop conversion that may together have important consequences for Central Valley wildlife, not to mention the benefits that those wildlife provide to people (Elphick et al. 2010a, Stralberg et al. 2011, Joyce et al. 2011, Strum et al. 2013, Matthews 2019, Kahara et al. 2022, Donnelly et al. 2022, Conlisk et al. 2023, Peterson et al. 2024). There are also emerging questions and potential conflicts over novel wildlife conservation practices in ricelands; for example, changes in the timing, duration, and depths of fall, winter, and spring flooding that may benefit some species but harm others. In sum, despite the many ecological benefits of rice agriculture, uncertainty remains as to whether current acreage under current management practices will be sufficient to sustain California's Central Valley wildlife populations into the future.

Unquestionably, **rice agriculture plays a significant role** in providing food resources and wildlife habitat to many species of California native birds, reptiles, amphibians, and fishes.

Together, these uncertainties raise several important questions for both the rice industry and wildlife conservationists. First, how much rice is needed to meet minimum requirements for flagship species and species of conservation concern in the California Central Valley, both now and into the future? Second, of all the planted rice, how much needs to be flooded in winter and/or managed in specific ways to continue providing ecological benefits? Third, are there specific locations where rice is especially needed to maintain high levels of wildlife abundance and diversity? Finally, in the face of continuing challenges to agricultural and managed wetland habitats, which management practices, or suites of practices, are economically feasible to implement and benefit the greater number of species, without negatively impacting other species?

This project represents an initial attempt to address these questions. While many studies have examined the value of rice habitat to specific groups of wildlife species, few have done so in an integrated fashion — evaluating the benefits, constraints, and trade-offs for multiple wildlife species simultaneously. This is a much more challenging task, requiring a synthesis of the ecological, agronomic, economic, and management influences on multiple taxonomic groups as well as a synthetic evaluation of potential mutual benefits or trade-offs.

In the following report, we provide a review of the key issues facing several groups of wildlife that depend on rice fields. We then consider the needs of each group in terms of (i) the amount of rice needed, (ii) management practices on those fields that are most beneficial, and (iii) locations within the Central Valley that might have the greatest value for conservation. In doing so, we develop a footprint of the rice acreage needed to sustain multiple species of wildlife using ricelands in California. We refer to this as a "muddy footprint" because the complexity of such an undertaking precludes an exact accounting of the necessary acreage to support such diverse taxa. Instead, our goal was simply to provide an initial scoping of the acreage of rice and types of management that may be required. Future work would require sophisticated analyses that enable formal valuation of the habitat needs and ecosystem services provided by different taxa as well as evaluation of alternative habitat and policy allocations (Elphick 2004, Zhang et al. 2007, Kremen and Miles 2012, Sundar and Kittur 2013, Garnache 2015, Suddeth and Lund 2016, Kremen and Merenlender 2018, Chivenge et al. 2019, Dang et al. 2019, Ahmed et al. 2020, Lorenzón et al. 2020, Liu et al. 2020a, 2020b, Gao et al. 2023). Accordingly, our analyses at this stage are intended for general guidance rather than precise prescription or policy recommendations. Nonetheless, our analysis provides a first integrated evaluation of the needs of multiple species and, in doing so, provides a baseline footprint of the 'key rice acres' that may be most valuable for conservation purposes in the Central Valley.

> …our analysis provides a first integrated evaluation of the needs of multiple species and, in doing so, **provides a baseline footprint of the 'key rice acres'** that may be most valuable for conservation purposes in the Central Valley.

In this first iteration of the "muddy footprint", we evaluated the role of rice in supporting several key taxonomic groups: Giant Gartersnake, waterfowl, shorebirds, Black Tern, Sandhill Crane, and salmon. This list is not comprehensive of all species that rely on ricelands as habitat throughout the year, including other birds, amphibians, and invertebrates, and in some cases our analyses were limited to only one season. For example, we evaluated wintering waterfowl but we did not have the analytical framework to consider breeding waterfowl. These additional seasons and species should be considered in future analyses. This initial set of taxonomic groups were most suitable for an initial synthesis because all are species of important conservation and management concern in California, all depend on ricelands for some or all their annual cycle, and there is sufficient research on each group to enable analysis.

To set our analyses in context, we begin by briefly reviewing the agronomics, economics, and conversion risk of ricelands in the Central Valley of California. Because our analysis is necessarily spatially explicit, we then discuss our strategy for developing a single baseline mapping framework that included flooded and dry rice, other crops, managed wetlands, and other habitat components that could influence the abundance and distribution of various wildlife species. Next, we review the core needs for each taxonomic group with respect to ricelands and provide an estimate of the rice acreage, management actions, and locations that would be of greatest value to each group. We then include an evaluation of the potential economic value of riceland habitats and wildlife to attempt to address the social welfare gains from improved wildlife habitat populations and the potential for support for costly measures to maintain such habitat contribution in California rice fields.

Finally, and most importantly, we synthesize and distill key outcomes from our taxa-specific analyses. We first discuss the compatibility of current and emerging rice management practices; for example, which management practices are vital for each species and do they present trade-offs for managing multiple species simultaneously? Second, we assess priority rice locations; for example, which rice field locations within the valley provide the greatest benefits to the most species? Third, and finally, we provide a rough estimate of a rice acreage footprint that is needed to sustain desired wildlife species and populations within a viable rice production industry.

Many sections were written so that they could stand alone with their own figures, tables, appendices, and references to allow readers to focus on that element of the report. Accordingly, sections are relatively short, but are intended to be thorough and technical, often with accompanying appendices. A highlights section is included at the beginning of each section to emphasize the key results. That said, we encourage readers to consider the report in its entirety. This highly interdisciplinary effort engaged scientists and researchers with deep and distinct histories and expertise in their focal areas. There have been few similar attempts to integrate and synthesize across multiple taxonomic groups and management components at such a scale for an agricultural industry in California.

References

Ahmed, N., S. Thompson, B. Hardy, and G. M. Turchini. 2020. An ecosystem approach to wild rice-fish cultivation. Reviews in Fisheries Science and Aquaculture.

Anders, M. M., C. Van Kessel, and J. M. Eadie. 2008. Agronomic Impacts of Winter Wetland and Waterfowl Management in Ricelands. Page Conservation in Ricelands of North America. The Rice Foundation, Stuttgart, Arkansas.

Bird, J. A., G. S. Pettygrove, and J. M. Eadie. 2000. The impact of waterfowl foraging on the decomposition of rice straw: mutual benefits for rice growers and waterfowl. Journal of Applied Ecology 37:728–741.

Brogi, A., C. A. Pernollet, M. Gauthier-Clerc, and M. Guillemain. 2015. Waterfowl foraging in winter-flooded ricefields: Any agronomic benefits for farmers? Ambio 44:793–802.

Brouder, S., and J. Hill. 1995. Conjunctive use of farmland adds value: Winter flooding of ricelands provides waterfowl habitat. California Agriculture 49:58–64.

Byrd, K. B., A. A. Lorenz, J. A. Anderson, C. S. A. Wallace, K. A. Moore-O'Leary, J. Isola, R. Ortega, and M. E. Reiter. 2020. Quantifying drought's influence on moist soil seed vegetation in California's Central Valley through remote sensing. Ecological Applications 30:e02153.

California Rice Commission. 2011. Wildlife Known To Use California Ricelands—Species list. Page Species List.

Casazza, M. L., F. McDuie, S. Jones, A. A. Lorenz, C. T. Overton, J. Yee, C. L. Feldheim, J. T. Ackerman, and K. M. Thorne. 2021. Waterfowl use of wetland habitats informs wetland restoration designs for multi-species benefits. Journal of Applied Ecology 58:1910–1920.

Central Valley Joint Venture. 2006. Central Valley Joint Venture 2006 Implementation Plan: Conserving Bird Habitat. U.S. Fish & Wildlife Service, Sacramento, California.

Central Valley Joint Venture. 2020. Central Valley Joint Venture 2020 Implementation Plan. U.S& Wildlife Service, Sacramento, CA.

Chivenge, P., O. Angeles, B. Hadi, C. Acuin, M. Connor, A. Stuart, R. Puskur, and S. Johnson- Beebout. 2019. Ecosystem services in paddy rice systems. Pages 181–201 The Role of Ecosystem Services in Sustainable Food Systems. Elsevier.

Colwell, M. A., and O. W. Taft. 2000. Waterbird communities in managed wetlands of varying water depth. Waterbirds 23:45–55.

Conlisk, E. E., K. B. Byrd, E. Matchett, A. A. Lorenz, M. Casazza, G. H. Golet, M. D. Reynolds, K. A. Sesser, and M. E. Reiter. 2023. Changes in habitat suitability for wintering dabbling ducks during dry conditions in the Central Valley of California. Ecosphere 14:e4367.

Conlisk, E. E., G. H. Golet, M. Reynolds, N. Elliott, and M. E. Reiter. 2024. Factors influencing shorebird use of post-harvest flooded rice fields in California's Sacramento Valley. The Journal of Wildlife Management 88:e22661.

Corline, N. J., T. Sommer, C. A. Jefres, and J. Katz. 2017. Zooplankton ecology and trophic resources for rearing native fish on an agricultural floodplain in the Yolo Bypass California, USA. Wetlands Ecology and Management 25:533–545.

Dang, K. B., W. Windhorst, B. Burkhard, and F. Müller. 2019. A Bayesian belief network – based approach to link ecosystem functions with rice provisioning ecosystem services. Ecological Indicators 100:30–44.

Day, J. H., and M. A. Colwell. 1998. Waterbird communities in rice fields subjected to different post-harvest treatments. Waterbirds 21:185–197.

Donnelly, J. P., J. N. Moore, M. L. Casazza, and S. P. Coons. 2022. Functional Wetland Loss Drives Emerging Risks to Waterbird Migration Networks. Frontiers in Ecology and Evolution 10:844278.

Dybala, K. E., M. E. Reiter, C. M. Hickey, W. D. Shuford, K. M. Strum, and G. S. Yarris. 2017. A bioenergetics approach to setting conservation objectives for non-breeding shorebirds in California's Central Valley. San Francisco Estuary and Watershed Science 15.

Eadie, J., C. Elphick, K. Reinecke, and M. Miller. 2008. Wildlife values of North American ricelands. Pages 7–90 Conservation in Ricelands of North America: Current State of Our Knowledge and a Course for Future Research and Education. The Rice Foundation, Stuttgart, AR.

Elphick, C. 2000. Functional equivalency between rice fields and seminatural wetland habitats. Conservation Biology 14:181–191.

Elphick, C. 2008. Landscape effects on waterbird densities in California rice fields: taxonomic differences, scale-dependence, and conservation implications. Waterbirds 31:62–69.

Elphick, C., P. Baicich, K. C. Parsons, M. Fasola, and L. Mugica. 2010a. The future for research on waterbirds in rice fields. Waterbirds 33:231–243.

Elphick, C., T. R. Kelsey, Hickey, Catherine, P. Buttner, Strum, Khara, and Iglecia, Monica. 2018. Wetland bird conservation in California rice fields. Pages 293–296 Cranes and Agriculture: A Global Guide For Sharing The Landscape. Minuteman Press, Baraboo, Wisconsin.

Elphick, C., and L. W. Oring. 2003. Conservation implications of flooding rice fields on winter waterbird communities. Agriculture, Ecosystems & Environment 94:17–29.

Elphick, C. S. 2004. Assessing conservation trade-offs: identifying the effects of flooding rice fields for waterbirds on non-target bird species. Biological Conservation 117:105–110.

Elphick, C. S., and L. W. Oring. 1998. Winter management of California rice fields for waterbirds. Journal of Applied Ecology 35:95–108.

Elphick, C., O. Taft, and P. M. Loureno. 2010b. Management of rice fields for birds during the non-growing season. Waterbirds 33:181–192.

Fitzgerald, G. J., K. M. Scow, and J. E. Hill. 2000. Fallow season straw and water management effects on methane emissions in California rice. Global Biogeochemical Cycles 14:767– 776.

Fleskes, J. P., B. J. Halstead, M. L. Casazza, P. S. Coates, J. D. Kohl, and D. A. Skalos. 2012. Waste Rice Seed in Conventional and Stripper-Head Harvested Fields in California: Implications for Wintering Waterfowl. Journal of Fish and Wildlife Management 3:266–275.

Fleskes, J. P., and W. M. Perry. 2005. Change in area of winter-flooded and dry rice in the northern central valley of California determined by satellite imagery. California Fish and Game 91:207–215.

Frayer, W. E., D. D. Peters, H. R. Pywell, and W. R. Pywell. 1989. Wetlands of the California central valley: status and trends, 1939 to mid-1980's.

Gao, H., L. Dai, Q. Xu, P. Gao, and Z. Dou. 2023. Transforming agrifood systems in a win–win for health and environment: evidence from organic rice–duck coculture. Journal of the Science of Food and Agriculture 103:968–975.

Garnache, C. 2015. Fish, farmers, and floods: Coordinating institutions to optimize the provision of ecosystem services. Journal of the Association of Environmental and Resource Economists 2:367–399.

Garr, J. 2002. Rice enhancement project annual report. Rancho Cordova, CA.

Gilmer, D. S., M. R. Miller, R. D. Bauer, and J. R. Ledonne. 1982. California's Central Valley Wintering Waterfowl: Concerns and Challenges California's Central Valley Wintering Waterfowl: Concerns and Challenges. US Fish & Wildlife Publications. 41.

Halstead, B. J., J. P. Rose, G. A. Reyes, G. D. Wylie, and M. L. Casazza. 2019. Conservation reliance of a threatened snake on rice agriculture. Global Ecology and Conservation 19:00681.

Halstead, B. J., G. D. Wylie, and M. L. Casazza. 2010. Habitat suitability and conservation of the giant gartersnake (Thamnophis gigas) in the Sacramento valley of California. Copeia:591– 599.

Halstead, B. J., G. D. Wylie, and M. L. Casazza. 2014. Ghost of habitat past: historic habitat affects the contemporary distribution of giant garter snakes in a modified landscape. Animal Conservation 17:144–153.

Hickey, C. M., G. W. Page, W. D. Shuford, and S. Warnock. 2003. Southern Pacific Shorebird Conservation Plan: A strategy for supporting California's Central Valley and coastal shorebird populations. Stinson Beach, California.

Holmes, E. J., P. Safarinia, A. L. Rypel, M. N. Bell-Tilcock, J. V. Katz, and C. A. Jefres. 2021. Reconciling fish and farms: Methods for managing California rice fields as salmon habitat. PLoS ONE 16:e0237686.

Jefres, C. A., E. J. Holmes, T. R. Sommer, and J. V. E. Katz. 2020. Detrital food web contributes to aquatic ecosystem productivity and rapid salmon growth in a managed floodplain. PLoS ONE 15.

Jefres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes 83:449–458.

Joyce, B. A., V. K. Mehta, D. R. Purkey, L. L. Dale, and M. Hanemann. 2011. Modifying agricultural water management to adapt to climate change in California's central valley. Climatic Change 109:299–316.

Kahara, S. N., D. Skalos, B. Madurapperuma, and K. Hernandez. 2022. Habitat quality and drought effects on breeding mallard and other waterfowl populations in California, USA. The Journal of Wildlife Management 86:e22133.

Katz, J. V. E., C. Jefres, J. L. Conrad, T. R. Sommer, J. Martinez, S. Brumbaugh, N. Corline, and P. B. Moyle. 2017. Floodplain farm fields provide novel rearing habitat for Chinook salmon. PLoS ONE 12.

Kremen, C., and A. M. Merenlender. 2018. Landscapes that work for biodiversity and people. Science 362:eaau6020.

Kremen, C., and A. Miles. 2012. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecology and Society 17:40.

Liu, D., R. Tang, J. Xie, J. Tian, R. Shi, and K. Zhang. 2020a. Valuation of ecosystem services of rice–fish coculture systems in Ruyuan County, China. Ecosystem Services 41:101054.

Liu, X., B. R. Bakshi, B. Rugani, D. M. de Souza, J. Bare, J. M. Johnston, A. Laurent, and F. Verones. 2020b. Quantification and valuation of ecosystem services in life cycle assessment: Application of the cascade framework to rice farming systems. Science of the Total Environment 747:141278.

Lorenzón, R. E., E. J. León, M. Juani, A. H. Beltzer, P. M. Peltzer, R. C. Lajmanovich, and A. M. Attademo. 2020. Can agroecological management increase functional diversity of birds in rice fields? Revista de Biologia Tropical 68:873–883.

Matchett, E. L. 2021. Using High Resolution Satellite and Telemetry Data to Track Flooded Habitats, Their Use by Waterfowl, and Evaluate Effects of Drought on Waterfowl and Shorebird Bioenergetics in California. Open-File Report.

Matchett, E. L., and J. P. Fleskes. 2018. Waterbird Habitat in California's Central Valley Basins Under Climate, Urbanization, and Water Management Scenarios. Journal of Fish and Wildlife Management 9:75–94.

Matthews, L. 2019. Changing post-harvest practices, impacts on waste grain availability, and growers perspectives. Masters Thesis., University of California Davis, Davis, California, USA.

Matthews, L. J., M. Petrie, and J. M. Eadie. 2018. Impacts of Changing Post-harvest Agricultural Practices on Waste Grain Availability in California's Central Valley. Page Manuscript to be submitted to the Journal of Fish & Wildlife Management.

Matthews, L. J., M. Petrie, and J. M. Eadie. 2022. Impacts of Changing Post-harvest Agricultural Practices on Abundance of Waste Grain in California's Central Valley. Journal of Fish and Wildlife Management 13:320–333.

Matthews, W., and D. Sumner. 2024. Contributions of the California Rice Industry to the California Economy. University of California Davis.

Miller, M. R., J. D. Garr, and P. S. Coates. 2010. Changes in status of harvested rice fields in the. implications for wintering waterfowl. Wetlands 30:939–947.

Miller, M. R., D. E. Sharp, D. S. Gilmer, and D. Mulvaney. 1989. Rice Available To Waterfowl In Harvested Fields In The Sacramento Valley, California. California Fish and Game 75:113–123.

Moyle, P. B., J. V. E. Katz, and R. M. Quiñones. 2011. Rapid decline of California's native inland fishes: A status assessment. Biological Conservation 144:2414–2423.

Peterson, S. H., J. T. Ackerman, C. R. Schacter, C. A. Hartman, and M. P. Herzog. 2024. Bird habitat value and management priorities of the California Winter Rice Habitat Incentive Program. San Francisco Estuary and Watershed Science 22.

Petrie, M., M. Brasher, and D. James. 2014. Estimating the biological and economic contributions that rice habitats make in support of North American Waterfowl. The Rice Foundation, Stuttgart, Arkansas, USA.

Petrie, M. J., J. P. Fleskes, M. A. Wolder, C. R. Isola, G. S. Yarris, and D. A. Skalos. 2016. Potential effects of drought on carrying capacity for wintering waterfowl in the central valley of California. Journal of Fish and Wildlife Management 7:408–422.

Petrie, M. J., and K. L. Petrik. 2010. Assessing waterbird benefits from water use in California Ricelands:12.

Reid, F., and M. Heitmeyer. 1995. Sidebar: Waterfowl and rice in California's Central Valley. California Agriculture 49:62–62.

Reiter, M. E., N. K. Elliott, D. Jongsomjit, G. H. Golet, and M. D. Reynolds. 2018. Impact of extreme drought and incentive programs on flooded agriculture and wetlands in California's Central Valley. PeerJ 6:e5147.

Rossi, G. J., J. R. Bellmore, J. B. Armstrong, C. Jefres, S. M. Naman, S. M. Carlson, T. E. Grantham, M. J. Kaylor, S. White, J. Katz, and M. E. Power. 2024. Foodscapes for salmon and other mobile consumers in river networks. BioScience 74:586–600.

Sesser, K. A., M. Iglecia, M. E. Reiter, K. M. Strum, C. M. Hickey, R. Kelsey, and D. A. Skalos. 2018. Waterbird response to variable-timing of drawdown in rice fields after winter-flooding. PLOS ONE 13:e0204800.

Sesser, K. A., M. E. Reiter, D. A. Skalos, K. M. Strum, and C. M. Hickey. 2016. Waterbird response to management practices in rice fields intended to reduce greenhouse gas emissions. Biological Conservation 197:69–79.

Shuford, W. D., G. W. Page, and J. E. Kjelmyr. 1998. Patterns and dynamics of shorebird use of California's Central Valley. Condor 100:227–244.

Shuford, W. D., M. Reiter, K. Sesser, C. Hickey, and G. Golet. 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.

Sommer, T., B. Schreier, J. L. Conrad, L. Takata, B. Serup, R. Titus, C. Jefres, E. Holmes, and J. Katz. 2020. Farm to fish: Lessons from a multi-year study on agricultural floodplain habitat. San Francisco Estuary and Watershed Science 18:1–20.

Sterling, J., and P. Buttner. 2011. Wildlife Known To Use California Ricelands. Third. California Rice Commission, Sacramento, California.

Stralberg, D., D. R. Cameron, M. D. Reynolds, C. M. Hickey, K. Klausmeyer, S. M. Busby, L. E. Stenzel, W. D. Shuford, and G. W. Page. 2011. Identifying habitat conservation priorities and gaps for migratory shorebirds and waterfowl in California. Biodiversity and Conservation 20:19–40.

Strum, K. M., M. E. Reiter, C. A. Hartman, M. N. Iglecia, T. R. Kelsey, and C. M. Hickey. 2013. Winter management of California's rice fields to maximize waterbird habitat and minimize water use. Agriculture, Ecosystems & Environment 179:116–124.

Strum K. M., Sesser K., and Iglecia M. N. 2014. Waterbird Habitat Enhancement Program: Bird-friendly farming in California rice fields. California Rice Commission.

Suddeth, R., and J. Lund. 2016. Multi-Purpose Optimization for Reconciliation Ecology on an Engineered Floodplain— Yolo Bypass, California, USA. San Francisco Estuary and Watershed Science 14.

Sundar, K. S. G., and S. Kittur. 2013. Can wetlands maintained for human use also help conserve biodiversity? Landscape-scale patterns of bird use of wetlands in an agricultural landscape in north India. Biological Conservation 168:49–56.

Tallman, R. L. 2024. Outmigration Survival of Juvenile Chinook Salmon in Reconciled Ecosystems. UC Davis.

U.S. Fish and Wildlife Service. 2017. Recovery Plan for the Giant Garter Snake (Thamnophis gigas). U.S. Page 71 Fish and Wildlife Service, Pacific Southwest Region. Sacramento, California.

Van Groenigen, J. W., E. G. Burns, J. M. Eadie, W. R. Horwath, and C. Van Kessel. 2003. Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition. Agriculture, Ecosystems & Environment 95:289–296.

Wylie, G. D., M. L. Casazza, C. J. Gregory, and B. J. Halstead. 2010. Abundance and Sexual Size Dimorphism of the Giant Gartersnake (Thamnophis gigas) in the Sacramento Valley of California. Journal of Herpetology 44:94–103.

Zhang, W., T. H. Ricketts, C. Kremen, K. Carney, and S. M. Swinton. 2007. Ecosystem services and dis-services to agriculture. Ecological Economics 64:253–260.

Synthesis: A Conservation Footprint for California Rice

John M. Eadie[1], Daniel S. Karp[1], Kristen E. Dybala[2], Sean P. Fogenburg[1], Bruce A. Lindquist[1], Andrew L. Rypel[1],
Daniel A. Sumner[1], Brian. D. Todd[1], and Robert G. Walsh[2], University of California Davis[1] and Point Blue Conservation Science[2]

California's rice agriculture has enormous impact on the state's economy and employment, contributing over a billion dollars in direct and indirect economic activity and providing over 7,500 jobs. Equally important, California ricelands play a critical role in sustaining a diversity of wildlife and the ecological functions they provide.

Indeed, extensive studies over the past two decades have documented the value of ricelands to waterfowl, shorebirds, terns, cranes, snakes, and more recently, native fishes. However, the vast majority of prior studies focus only on single wildlife taxa, each with specific ecological requirements.

This report represents a first attempt to develop a fully integrated understanding of the ecological value of riceland, considering the mutual needs and potential compromises for many wildlife species simultaneously.

Specifically, our collective expertise in rice agriculture, economics, and one or more of five focal species groups allowed us to address three interrelated objectives:

1. Examine the compatibility of current and emerging rice management practices for conserving diverse wildlife species,
2. Identify priority rice locations for multi-species conservation, and
3. Estimate the 'footprint' of rice acreage needed to sustain desired wildlife species and populations within a viable rice production industry.

In this section, we synthesize and distill key outcomes from our taxa-specific analyses.

Compatibility of Rice Management Practices

The capacity of California's ricelands to conserve wildlife depends not only on the total acreage, but also how those fields are managed. Each species of wildlife has its own requirements in terms of water availability, water depth, timing of management actions in rice fields, and seasonal chronology that ultimately determine the number of acres and type of management required (summarized in Table 7.1). To determine the total rice footprint needed for conservation purposes, we must first consider the influence of different rice management actions. Which management practices are vital for each species? Can rice acres be shared among taxonomic groups or are the needs of different species so incompatible that rice must be managed in fundamentally different ways for different species? Overall, our analyses suggest that some practices are mutually beneficial for multiple species with minimal conflicts among species. Other practices, however, present potential conflict and thus necessitate compromises, consideration of alternative management practices, or additional acres to pursue multi-species conservation.

Winter Flooding

Among all the rice management practices considered, winter-flooding is by far the most valuable for almost every species group. The only taxa for which winter-flooding was not essential were the Giant Gartersnake — because they remain underground in brumation burrows during winter — and breeding Black Tern and shorebirds. Flooding over planted rice is useful

	Giant Gartersnake	Waterfowl	Shorebirds	Shorebirds Black Tern	Sandhill Crane	Juvenile Native Fishes	Zooplankton
Habitat Type	Foraging, basking, shelter	Foraging	Foraging	Nesting and foraging	Roosting	Rearing and foraging	Production
Target Season	Spring through Fall	Nonbreeding	Nonbreeding	Breeding	Nonbreeding	Winter and Spring	Winter and Spring
Start Date	April 1	August 15	July 1	May 1	October 1	January 1	October 1
End Date	November 15	March 31	May 15	August 10	March 15	March 1	March 30
Planted Rice Required	Yes	Yes	No	Yes	No	No	No
Target Acres (ha) of Planted Rice: Minimum	83,634 (33,845)	375,000 (151,757)		>426,043 (>172,414)		30,000 (12,140)	
Target Acres (ha) of Planted Rice: Optimum		500,000 (202,342)		472,794 (>191,333)			
Winter-flooding Required	No	Yes	Yes	No	Yes	Yes	Yes
Target Acres (ha) of Winter-flooded Rice: Minimum		212,002 (85,794)	373,540[2] (151,166)		43,139 (17,458)	30,000 (12,140)	
Target Acres (ha) of Winter-flooded Rice: Optimum		257,727 (104,298)					
Optimal Water Depth (in): Minimum	4	>1	>0	>0	>0	6	6
Optimal Water Depth (in): Upper Range	18	10	4	< vegetation height	8	>10	10
Connectivity to Channel Required	No	No	No	No	No	Yes	No

Table 7.1. Summary of habitat and rice field management suitability requirements for species groups considered in this report.

[1] We include Zooplankton production in this table because of the increasing interest in producing fish food in flooded rice fields (Section 5.5).

[2] This minimum refers to the mid-winter peak of typical winter-flooded rice, and fallowed rice fields can contribute to this total. This minimum does not include any additional targeted flooding during the fall and spring, such as through incentive programs, which also contribute valuable shorebird habitat.

for waterfowl and cranes, which utilize residual rice. Flooded fallow fields may still provide roosts for these groups, and they serve fishes and shorebirds that exploit invertebrates rather than rice directly. That said, management practices that reduce organic material and vegetation in the soil might impact the productivity of invertebrates, which may in turn reduce resources for shorebirds, waterfowl, fish, and other species. This is an emerging area of research need.

> California's rice agriculture has enormous impact on the state's economy and employment, **contributing over a billion dollars** in direct and indirect economic activity and **providing over 7,500 jobs**.

Feasibility—While the value of winter-flooding is clear, challenges exist with respect to long term feasibility and economics. Fewer growers may choose to winter-flood because of increasing water costs and reduced availability, especially during droughts. Instead, some growers are turning to other methods of straw management, such as baling or chopping and incorporating straw but leaving fields dry to decompose straw when naturally inundated by winter precipitation. Trading of against these costs are the potential benefits of revenues obtained from leasing fields and blinds for duck hunting. Compared to analyses conducted for the Central Valley Joint Venture's implementation plan, the extent of winter flooding in rice has declined in recent years from averages estimated for 2007–2014, putting more pressure on managed wetlands.

We did not evaluate the potential loss of winter-flooding. However, a recent analysis of the value of rice fields for waterfowl food production indicates that if flooded rice was not available, replacing that food base would require an additional 255,000 acres of managed wetlands at a cost of nearly $2.8 billion in 2010 dollars (Petrie and Petrik 2010). Adding the additional needs for other species groups (shorebirds, cranes, fish) would only magnify this cost. While the risk of conversion of rice to other crops is low, reductions in winter-flooding would significantly impact the value of existing ricelands for many groups of wildlife.

Timing of Initial Winter Flooding

While the optimal timing of initial winter-flooding varies among species, the conflicts that arise are more with water management necessary for rice production rather than conflicts among species, per se. A schematic of the months when each species requires winter-flooding, along with the typical schedule for rice field flooding (winter and growing season) is shown in Figure 7.1. Growers that choose to decompose waste grain through winter flooding typically begin flooding their fields in late October–early November. Acreage gradually increases through December. Fields are then drained in early to mid-February. For waterfowl, the greatest need for flooded foraging habitat is from September to the end of February. Flooded rice fields are not available in late September and early October; thus, local breeding birds and early migrating ducks rely heavily on managed wetlands during this period. Duck clubs are often flooded in early October to attract waterfowl prior to the hunting season.

Earlier flood-up in late July and August would clearly be beneficial for migrating shorebirds; however, rice is not harvested until early September through October. This is one of the two shoulder periods when bioenergetic models indicate a significant shortfall of foraging resources for shorebirds in every year. Sandhill Cranes arrive a bit later than shorebirds, with numbers increasing in September and October. The dry period in October prior to winter-flood-up thus represents a potential bottleneck for cranes. Correspondingly, in all but one scenario (2020–2021), there was a deficit of roosting habitat for cranes in October.

Managing fishes in rice fields requires a later flood-up schedule, with fish primarily using fields beginning in early January. Early fall flooding has the potential to produce dangerous temperature-oxygen conditions for fishes because of microbial decomposition of organic matter. That said, fish food programs to produce zooplankton could benefit from flooding earlier in October. Finally, as noted, Giant Gartersnakes do not depend on winter flooding; thus, the timing of winter flood-up does not impact them (though the timing of spring flood-up for rice planting certainly does; see below). Nonetheless, dry periods in September and October can impact Giant Gartersnakes, highlighting the importance of having nearby wetlands during this critical period.

Feasibility—Analyses of the timing of winter flood-up suggest that water would be available in late fall and winter for most species. However, the late summer to early fall period is a potential bottleneck for many species (late July–August for shorebirds and the Giant Gartersnake; September–October for Giant Gartersnake, shorebirds, cranes, and ducks). Agronomic constraints limit opportunities for earlier flood-up dates, since rice is still in the growing stages and cannot be harvested until October. Programs to incentivize flooding of fallow fields or uplands during late summer could be critical to support fall migrating shorebirds and the Giant Gartersnake (Halstead et al. 2010, Strum et al. 2013, Migratory Bird Conservation Partnership 2014, Golet et al. 2022). Managed wetlands that are flooded early play a crucial role during the fall dry period. For example, bioenergetic modeling indicates that ducks rely heavily on moist-soil seed resources in managed wetlands in September and October before flooded rice becomes available, and shorebirds rely heavily on both semi-permanent and seasonal managed wetlands in July through September (Dybala et al. 2017).

Timing of Winter Draining and Rice Planting

Farmers often need to drain fields by mid-February to provide sufficient time for fields to dry for field preparations to take place in March and April. Fields are then flooded and water-seeded from late April through May (with 50% of fields planted by May 12). Consequently, fields are often dry from March to May (Fig. 7.1). This creates challenges for several species. Giant Gartersnakes need water when they emerge from brumation in early April, yet rice fields are dry. This mismatch may reduce survival at a critical time when the snakes need aquatic habitat and food.

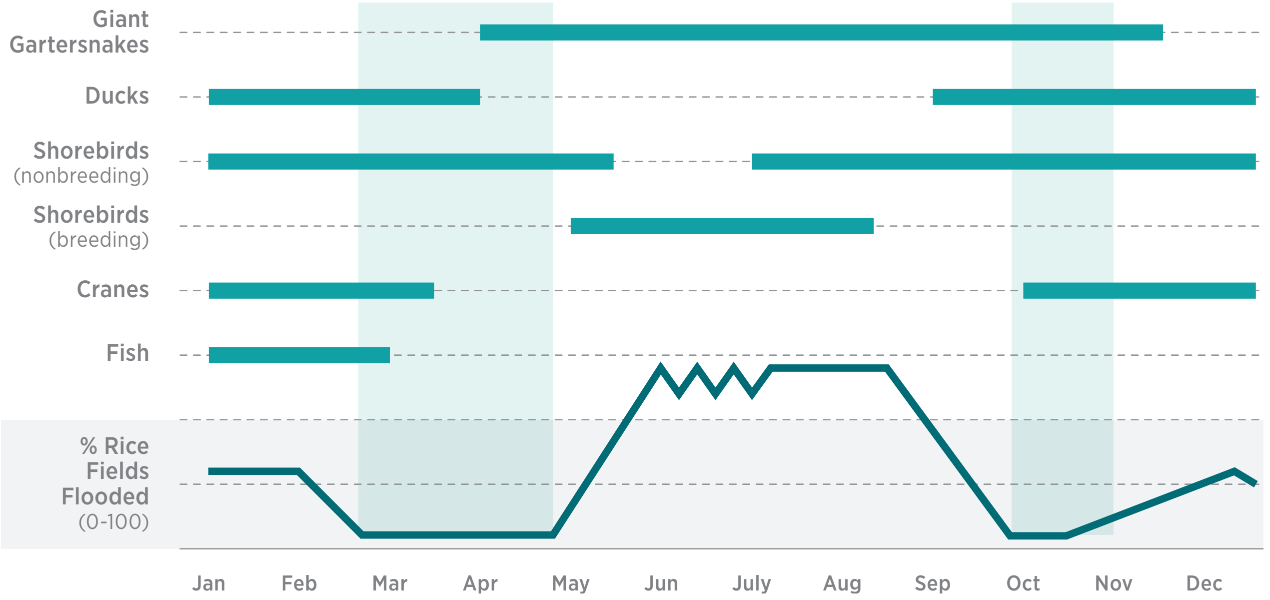

Figure 7.1. Schematic illustration of the timing of winter-flooding and needs for each focal wildlife group. Solid blue bars indicate periods when each species groups needs water in rice fields. The lower black line represents the chronology of flood-up and draining typical in California rice fields. The gray bars represent periods when several species groups require flooded fields but, without other conservation programs, fields would be dry.

Although many species of ducks begin spring migration in late February and March, the end of the winter season is when food supplies are most depleted, meaning that flooded fields could still be important at this time. Most duck clubs, however, are drained at the end of hunting season in late January. Later draining of rice would also be beneficial to non-breeding, spring migrating, and breeding shorebirds (Figure 7.1). The spring “shoulder” is the second period when there is a significant shortfall of foraging resources for shorebirds. Using a variable drawdown design, Sesser et al. (2018) found that delaying drawdown by even 3 weeks supported not only more shorebirds, but also more dabbling ducks and long-legged wading birds. Finally, growing fishes in flooded rice and/or producing fish food needs to conclude by March 1 or earlier.

Feasibility—Despite the potential benefits to multiple species of delayed drawdown, agronomic considerations limit the feasibility of this option. Because of plant growth requirements and the need to dry fields prior to preparation and seeding, it is difficult for growers to delay draining. There are some possible solutions. For example, one possibility is to flood irrigation canals earlier to provide some early habitat and satisfy Giant Gartersnake needs. In addition, programs such as BirdReturns (https://birdreturns.org/about/) and Bid4Birds have emerged to incentivize farmers to flood earlier or keep their fields flooded later for migratory birds if they have the ability to do so if, for example, their fields are planned to be idle or they know they can dry in time. Creating mosaics of rice fields with variable drawdown dates (e.g., Sesser et al. 2018) via appropriate incentives or easements could offset some of the loss of rice production from delayed draining and planting.

Winter Flooding Depth

Water depth emerged as perhaps the greatest issue of conflict among the five groups of wildlife species. Each taxon have distinct depth requirements for foraging, as illustrated in Figure 7.2 (depth data were derived from multiple sources: Elphick and Oring 1998, Colwell and Taft 2000, Elphick et al. 2010, Strum et al. 2013, Behney 2020, Conlisk et al. 2024).

Summarizing, shorebirds forage in the shallowest water from 0–4 inches. Some species can forage in deeper water, but depths beyond 8–9 inches are unusable for most species. Cranes likewise can use shallow water to forage. Deeper water can be used for roosting but not foraging. Preferable foraging depths for dabbling ducks are 4–10 inches. Deeper water is not accessible for foraging for most dabbling ducks, but can be used by some diving ducks, although we did not consider diving ducks in this report. Deeper water can be used by ducks for roosting. Giant Gartersnakes prefer water depths of 4–18 inches. Of all groups, fishes require the deepest water of 10–12 inches or deeper in flooded fields.

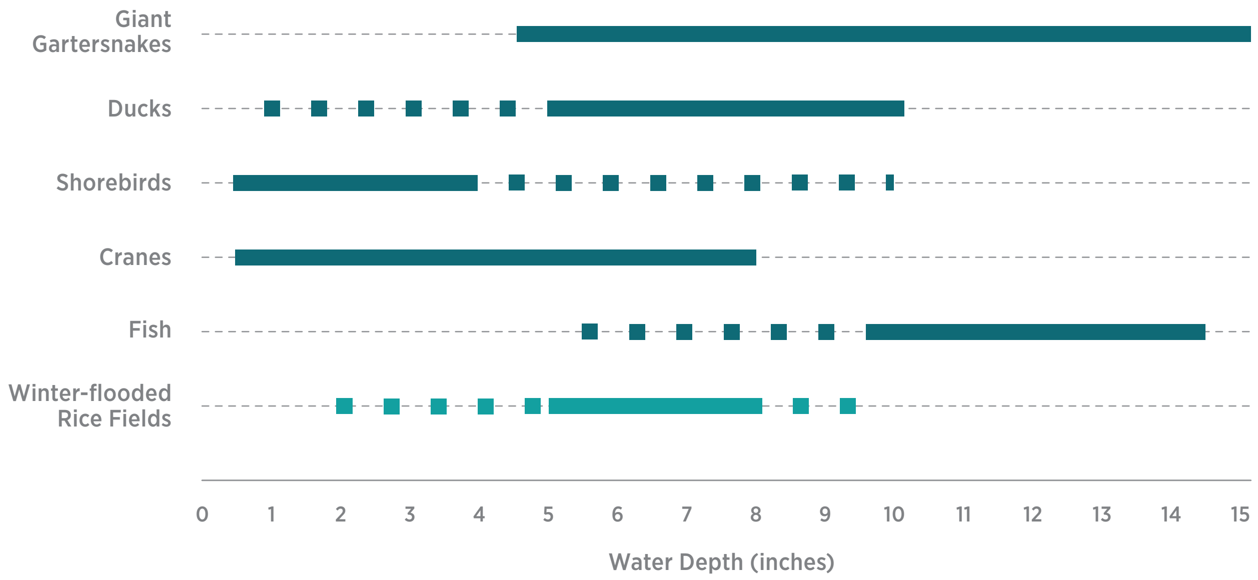

Figure 7.2. Schematic illustrating the range of water depths used for foraging by each species. Solid blue bars represent the typical preferred range of depths, dashed bars show additional depths that can be used but are not preferred. The black bar at the bottom shows the range of depths in most flooded rice fields, with dashed bars representing possible variation due to flooding schedules, evaporation, etc.

Feasibility—Differences in depth preferences reveal challenges facing rice growers and conservation managers in providing flooded habitat to meet the needs of all or most species. Depths of 4–8 inches provide suitable depths for Giant Gartersnakes, Sandhill Cranes, and dabbling ducks, but are too deep for many shorebirds and too shallow for fishes. Added to this are agronomic and economic challenges. Deeper flooding requires more water that must be maintained at that depth for three or more months, which can be very costly or even infeasible to obtain. Further, rice levees need to be reconfigured to hold deep water, which also incurs costs to growers. Conversely, if too little water is applied, straw decomposition may be less effective, and ducks would not be attracted, reducing opportunities to lease hunting blinds. Maintaining flood water at a shallow depth and re-irrigating could also be costly. Many growers avoid these costs by flooding more deeply at first and then gradually letting the water draw down.

Possible paths forward might be to create habitat mosaics of flooding depths that could satisfy all constituencies. Snakes could be supported in canals. Fields with a range of flooding depths and durations (e.g., Sesser et al. 2018), including management and flooding of fallow fields (Iverson et al. 2024b) could thus provide a range of conditions that meet the needs for multiple species and minimize additional water use and expense (Strum et al. 2013, Migratory Bird Conservation Partnership 2014, Golet et al. 2022). Fishes remain a concern because of their unique requirement of depths more than 10 inches, but this issue may be spatiotemporally constrained if the objective is only for flooding in the bypasses or flooding for fish food only within a specific distance from an outlet to a fish-bearing channel. That practice, however, will likely lead to additional trade-offs for fish, farmers, and duck clubs in the bypasses so further consideration will be needed (Sommer et al. 2001, Petrik et al. 2012, Howitt 2013, Suddeth and Lund 2016).

Other Rice Management Considerations

Our work suggests the timing, duration, and depth of flooding represent the most important rice management practices for wildlife conservation in California ricelands. These considerations extend into the growing season. For example, it is important to maintain consistent water levels for nesting Black Terns because active nests may be destroyed by rapidly raising water levels and mid-season draining is likely to increase the risk of nest predation (Shuford et al. 2001; Shuford and Dybala 2017).

> Among all rice management practices considered, **winter-flooding is by far the most valuable** for almost every species group.

Aside from water management, other rice management practices are likely also important, but were beyond the scope of this report. For example, the method of harvest (conventional vs. stripper header) and the wide variety of post-harvest practices can all affect the amount of residual rice grain available to be used by birds (Miller et al. 1989, Miller and Wylie 1996, Day and Colwell 1998, Elphick and Oring 1998, Elphick et al. 2010b, Fleskes et al. 2012, Strum et al. 2013, Sesser et al. 2016, Matthews 2019, Matthews et al. 2022b). Likewise, straw removal by baling or deep disking can influence the accessibility of residual rice grain to foraging birds (Matthews 2019).

Agrochemical applications in ricelands could also affect wildlife. Though not studied in California ricelands, agrochemicals are playing an important role in wildlife declines (Köhler and Triebskorn 2013, Hallmann et al. 2014, Li et al. 2020, Rigal et al. 2023, Molenaar et al. 2024). Pathways are complex and context dependent but likely occur via direct toxicity and/or via indirect reductions in invertebrate food bases. Indeed, a growing recognition of the importance of invertebrates in the diets of almost all species groups suggests that additional research is needed on how rice management practices generally affect invertebrate production. As many as 60 different species of arthropods have been recorded in California rice fields (https://agronomyrice.ucdavis.edu/sites/g/files/dgvnsk11966/files/inline-files/196740.pdf), and a diverse community of invertebrates has been identified in benthic core samples collected in Central Valley wetlands and flooded rice (Dybala et al. 2017). The ecology of these species in Central Valley wetlands and rice fields is poorly understood, despite their importance in the food web. While many of these species do not affect rice, ten are known to reduce rice productivity and yield (California Rice Production Workshop 2018, Espino et al. 2024). Research on the role of rice management practices and other environmental factors in driving the composition, abundance, and productivity of the invertebrate community would be valuable for identifying opportunities to reduce the abundance of specific species known to affect rice production while enhancing the abundance of other invertebrates, thereby increasing the food supply available to many of the species groups addressed here.

Finally, this report focuses on rice management activities, but the value of rice fields to wildlife is clearly influenced by the quality and quantity of adjacent habitats (Table 7.1). Nearby wetland areas are essential for foraging and roosting by waterfowl, shorebirds, and cranes, and provide critical foraging habitat in early fall when rice fields are not flooded. Giant Gartersnakes rely on wetland–rice mosaics to support their habitat needs year-round, and the proximity of rice fields to wetlands is critical for their movement and dispersal. If rice fields are isolated from wetlands, other types of land use can pose barriers to gartersnake movement. Upland areas likewise play a critical role for Giant Gartersnakes in their active season for sheltering, basking, and thermoregulating, as well as critical refuge over winter. Shorebirds, cranes, and waterfowl use uplands for nesting or roosting. That said, the extent to which different types of vegetation, levee/canal management, and maintenance activities affect wildlife use remains unclear.

Integrating Multiple Species Requirements

The ultimate challenge for any multi-species synthesis is to integrate the diverse needs of each group, assess their commonalities, and identify areas of conflict. Ideally, formal multi-objective decision analysis would be used (Kremen and Miles 2012, Ando and Mallory 2012, Garnache 2015, Suddeth and Lund 2016, Dang et al. 2019, Liu et al. 2020b), but that was beyond the scope of our current project. As a first step toward visualizing these trade-offs, we qualitatively developed radar diagrams (e.g., Kremen and Merenlender 2018) that illustrate how different rice management actions (timing of winter flood-up, depth of water, proximity of wetlands, presence of uplands, post-harvest straw management, and connection to a main river channel) may affect each species group (Figure 7.3). In a multi-purpose optimization (e.g., Suddeth and Lund 2016), the ecological value of each practice would be formally quantified, weighted for each species, and then used in a trade-of optimization analysis. Here, we instead qualitatively use these radar plots as a heuristic to both illustrate the commonalities among species as well as highlight management actions that are specific to a given group or might conflict with the needs of other groups. These radar plots offer three key take-home messages:

1. Several management practices have strong conservation value for almost all species: winter-flooding, early fall flooding, presence of adjacent wetlands and uplands, and straw management that does not reduce the availability or access to residual rice grain.
2. Trade-offs among species and agronomic practices are mostly over water depth and timing of winter flood-up.
3. The 'kaleidoscopic' nature of the composite plot (Figure 7.3, bottom) illustrates the diversity of requirements and emphasizes that no single management action will suffice for all species. An effective rice conservation footprint will require a mosaic of acres employing a mixture of management actions.

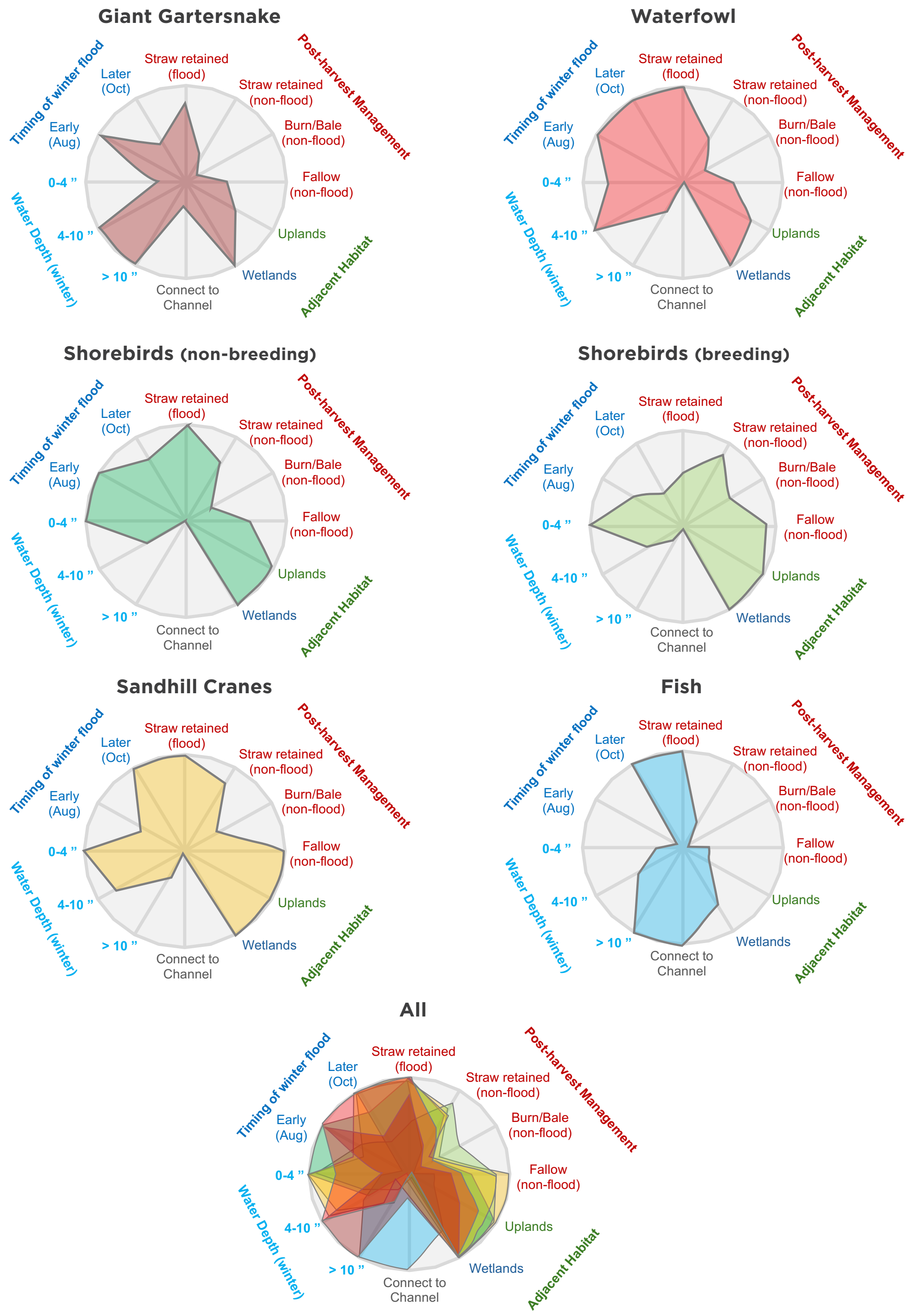

Figure 7.3. Radar diagrams illustrating how different rice management actions (timing of winter flood-up, depth of water, presence of wetlands and uplands, post-harvest straw management, and connection to a main river channel) may affect each group of species. Each axis is graded on a scale of 0–10 from the center origin (relatively little value/importance) to the outer edge (relatively high value/importance). Individual scores will vary depending on the spatial or temporal context and require further refinement. The values shown here are for illustration of the variation among species. The "All" diagram illustrates the potential overlap among all groups.

Compatibility of Locations

Our second objective was to assess priority rice locations for each species. In each of the taxa-specific sections, we employed a variety of modeling and analytical approaches to determine the most important rice regions for each species group. To do so, we first generated a common map for all rice fields, other crops, wetlands, and other habitats for four recent years (2020–2024), representing a range of conditions from dry to wet years. We also considered the frequency of rice rotation and risk of conversion to other crops. Based on these analyses, we identified areas of rice agriculture with high, medium, or low conservation value for each species. To identify priority rice locations for conservation across multiple species, we created spatial prioritization maps for ducks, cranes, Giant Gartersnakes (GGS), and shorebirds. These maps (Figure 7.4) highlight high-priority spatial footprints for each taxon, built using criteria outlined in their respective sections. Two adjustments were made for consistency: the GGS spatial footprint was refined by reducing the distance threshold between rice and wetland habitats from 5 miles to 1 mile, and the shorebird prioritization was scaled up from a fine landscape level to agricultural field units, with field units counted as high priority if, in either the breeding or non-breeding season, they either had >15 acres of “High Priority” area or >80% of the patch was “High Priority.”

The combined maps (Figures 7.5 and 7.6) aggregate these taxa-specific priorities, displaying the number of species for which each rice patch is classified as high priority. This synthesis offers an overview of multi-taxa overlaps and potential opportunities for joint management. As such, the maps could be useful in:

1. **Identifying conservation hubs:** Areas near wetland complexes and wildlife refuges emerged as high-priority zones for multiple species, emphasizing their importance as conservation hubs.
2. **Highlighting multi-taxa opportunities:** Patches classified as high priority for three or more species indicated areas where joint management strategies may maximize conservation benefits.
3. **Assessing spatial trends:** Regions such as the Sutter and Yolo Bypasses emerged as critical for fishes and other taxa, showcasing the need for tailored management in these areas.

On the other hand, the maps should NOT be used:

1. **As an indicator comprehensive conservation value:** These maps are not weighted rankings of conservation value. High-priority areas for multiple taxa are not necessarily of greater overall value than areas critical for a single species.
2. **To guide field-level management:** The maps do not prescribe specific management actions for individual patches. They lack fine-scale details on habitat quality and current management practices that may influence suitability.
3. **To identify areas of low importance:** Areas not classified as high priority may still hold significant conservation value, particularly for species or ecosystem services not included in this analysis.

With these caveats, the maps we present would best be used as tools to inform strategic planning and guide conservation discussions. They highlight broad spatial trends and provide a starting point for identifying areas of focus for multi-taxa conservation. For instance, high-priority patches for multiple taxa can indicate areas where joint management might be effective. They also suggest regions that may require more nuanced strategies given potential trade-offs (e.g., deeper water requirements for fish versus shallow water needs for shorebirds). The combined maps also underscore the importance of aligning conservation actions with species-specific needs. For example, while wetlands are critical for all taxa, the water depths required by ducks, cranes, and GGS differ significantly, necessitating tailored water management strategies. Similarly, fish habitat in the bypasses may require careful consideration of water flow, safe and timely passage, flooding duration, and agricultural compatibility.

To improve these prioritization efforts, future work should:

1. Incorporate multi-objective decision analyses to assign relative conservation values, factoring in the feasibility and cost of management actions.
2. Enhance data integration with additional hydrological modeling and fish habitat data to better understand trade-offs.
3. Engage stakeholders in priority areas, including landowners and managers, to translate spatial trends into actionable strategies.

By interpreting these maps within the context of their strengths and limitations, stakeholders can make informed decisions about where and how to focus conservation efforts for maximum impact.

Overall, the mapping effort revealed a high degree of complementarity in priority locations among species. For nearly all species groups, rice acreage in Colusa and Sutter basins, especially near wetlands and wildlife refuges, were often ranked as highest priority (Figure 7.4 and 7.5). Rice fields in the Sutter basin and the upper American basin were also high priority for several groups. The Yolo Basin, the Consumnes-Mokelumne Rivers region, and parts of the Delta were important for shorebirds and Sandhill Cranes. The entire Yolo and Sutter Bypasses represent critical areas for fishes in rice fields. Additional rice acres (as yet unspecified) further up the valley could be a priority for fish food programs. The rice footprint, in terms of locations, thus appears complementary among the species groups considered. How those acres are managed, however, is an important determinant of ultimate conservation value.

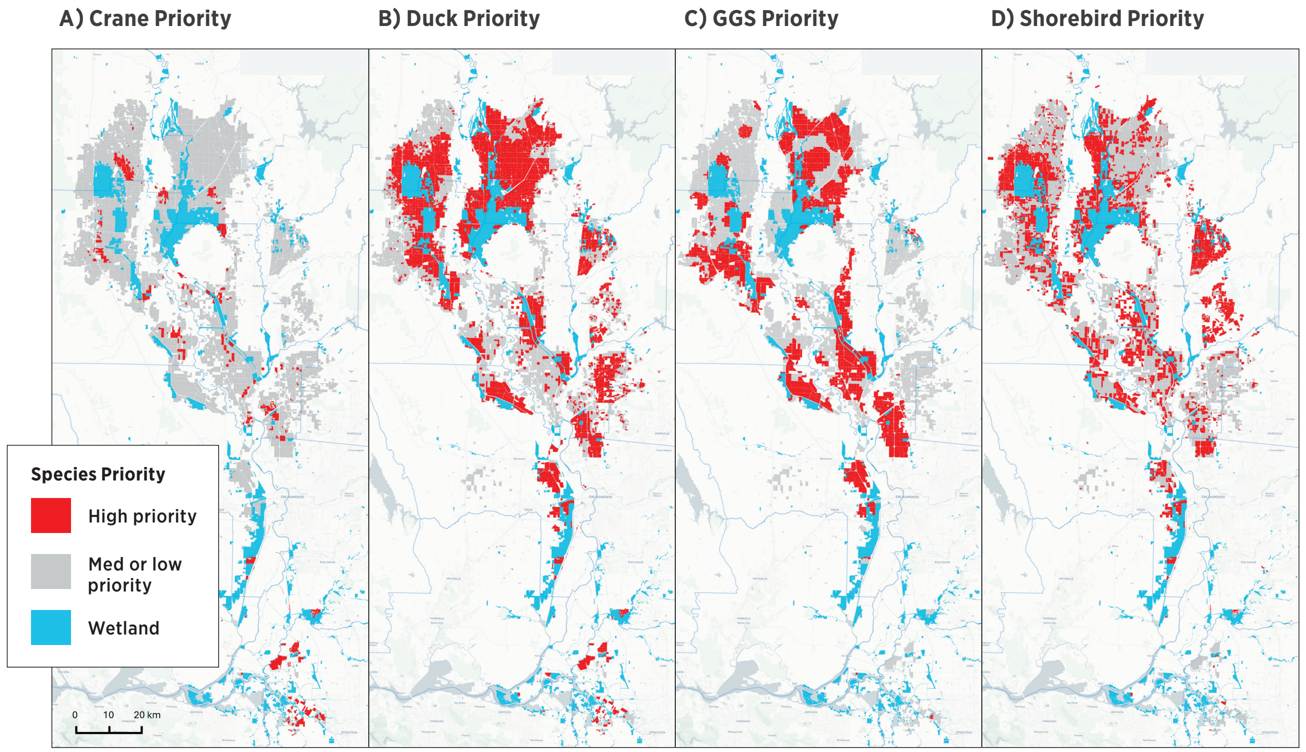

Figure 7.4. Spatial prioritization maps for four taxa groups: (A) Sandhill Cranes, (B) Ducks, (C) Giant Gartersnakes (GGS), and (D) Shorebirds/Black Terns. High-priority rice fields are shown in red, medium or low priority fields in grey, and wetlands in aqua. Each taxon-specific map reflects unique criteria for high-priority designation, as described in the report. Adjustments to the priority maps for GGS and Shorebirds, based on additional proximity and landscape-scale criteria, are detailed in the text. These maps provide essential guidance for habitat management strategies tailored to the needs of each species group.

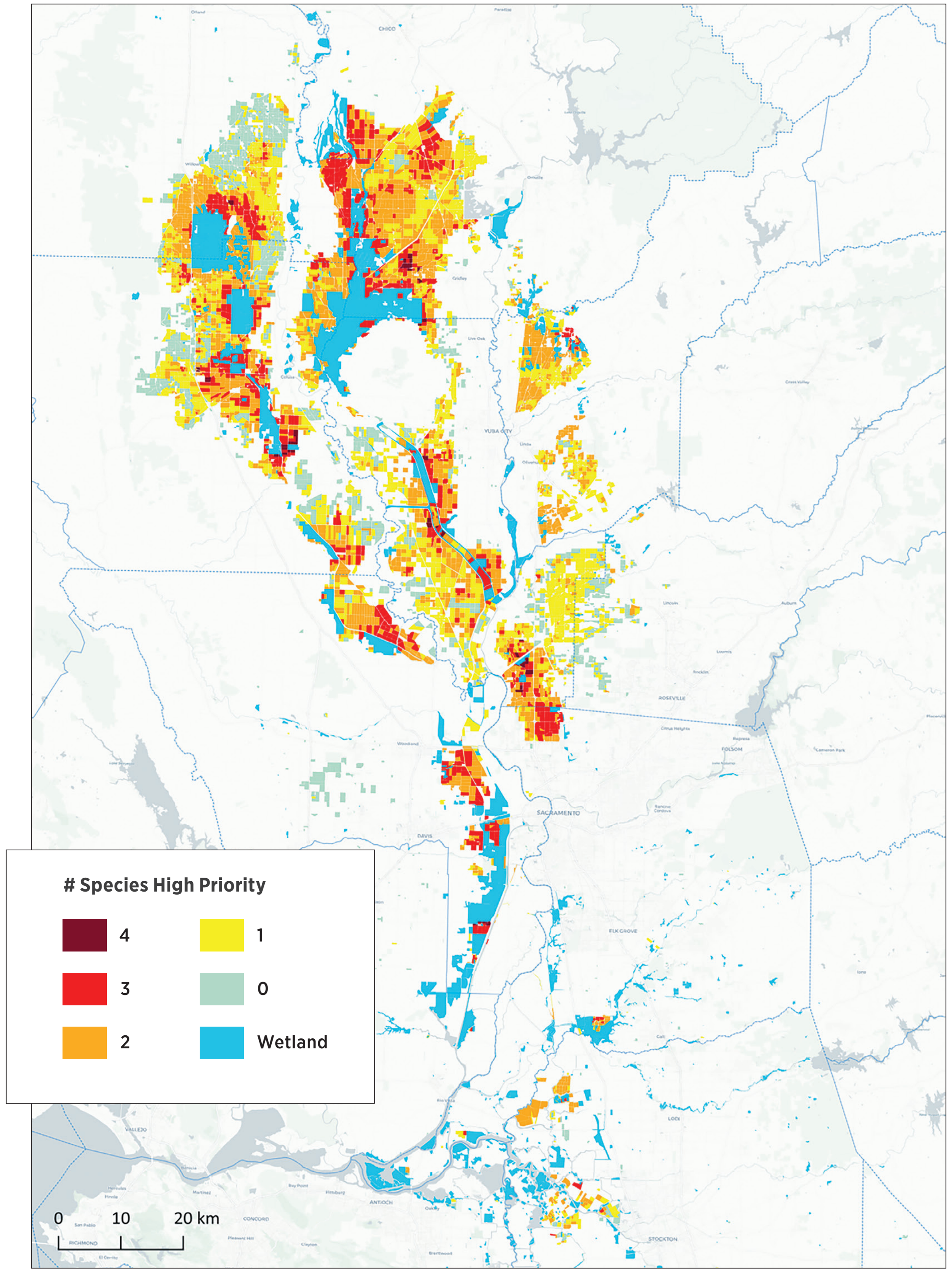

Figure 7.5. Combined priority map for rice fields based on high-priority classifications for four taxa: ducks, Sandhill Cranes, Giant Gartersnakes (GGS), and shorebirds/black terns. Rice fields are colored by the number of taxa for which the patch is considered high priority, with darker/redder colors indicating higher overlap among taxa (dark red = 4 species, red = 3, orange = 2, yellow = 1, green = 0, aqua = wetlands). This map highlights areas where joint management opportunities exist or where trade-offs between taxa may need to be carefully balanced. It provides a spatial framework for considering multi-species conservation efforts but does not assess the relative conservation value of individual patches.

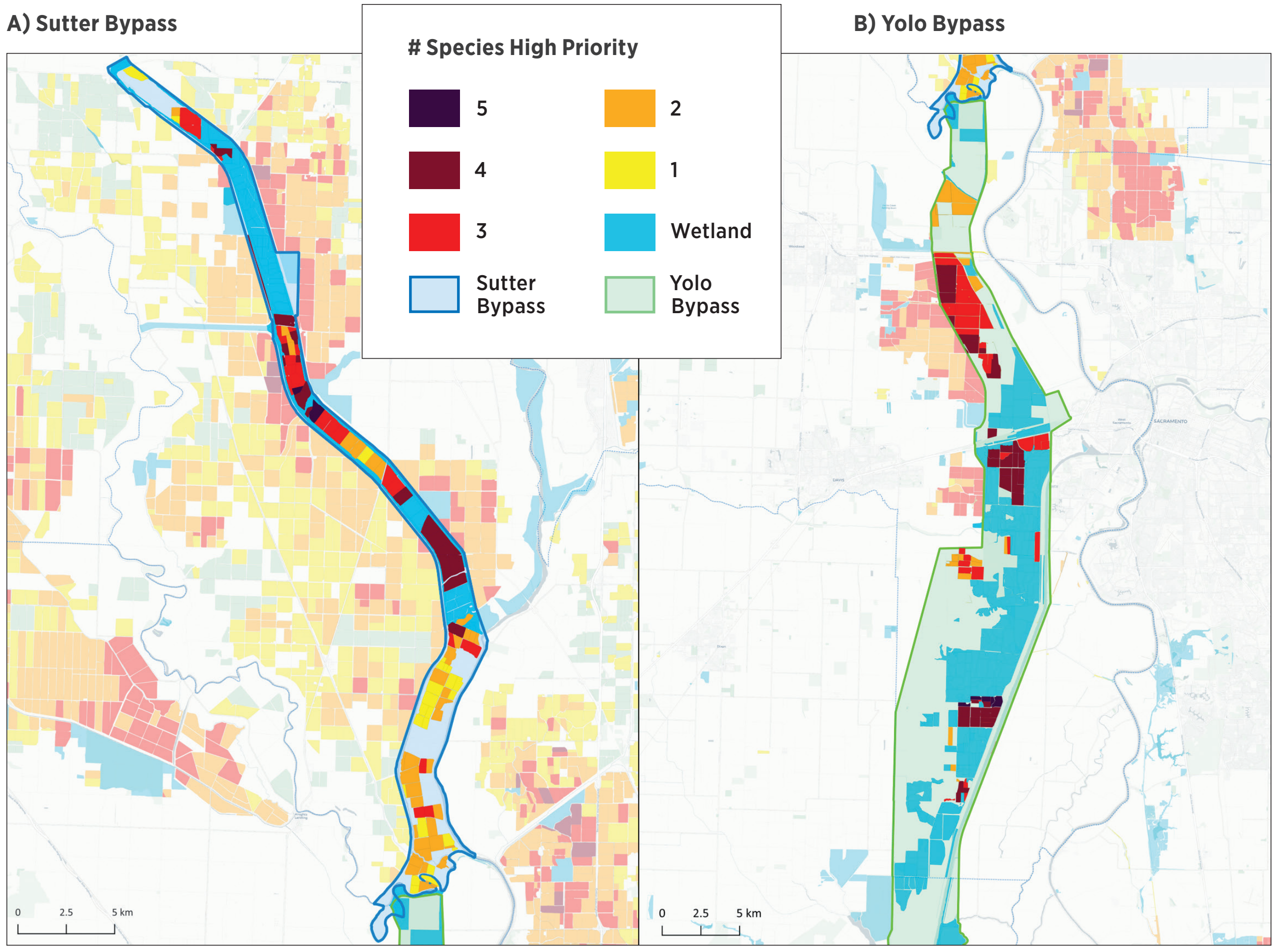

Figure 7.6. Combined priority map for rice fields in A) Sutter Bypass and B) Yolo Bypass, showing multi-taxa conservation priorities. Colors represent the number of species for which the patch is considered high priority, with darker colors indicating more species overlap (dark purple = 5 species, dark red = 4, red = 3, orange = 2, yellow = 1, green = 0, aqua = wetlands). Rice fields within the bypass boundaries receive an additional species priority count due to their inclusion as critical habitat for fishes, as identified in Section 5. The bypasses require careful management to balance water level needs for fishes with the habitat needs of other taxa, such as ducks, cranes, Giant Gartersnakes (GGS), and shorebirds.

For nearly all species groups, rice acreage in Colusa and Sutter basins, **especially near wetlands and wildlife refuges**, were often ranked as highest priority.

	Key Priorities	Locations
Giant Gartersnake	• fields that have cultivated rice consistently each year • closer to wetland habitat • basins that support Giant Gartersnake populations but where rice has been idled in recent droughts (e.g., south of the Sutter Buttes) • recovery plan target (539-acre wetland paired with 1,578 acres of rice, separated by no more than 5 miles)	High priority acres in Butte, Colusa, Sutter and American Basins; some in Glenn, Yolo, and the Delta
Non-breeding Waterfowl	• high quality winter-flooded foraging sites • proximity to roosts; roosts serve as ecological hubs due to their proximity to both foraging and resting sites • areas around refuges • lower-priority patches are typically located on basin peripheries	Critical areas in Colusa and Butte basins near the major wildlife areas, smaller priority areas in Glenn County, upper American Basin, Yolo Basin, Cosumnes River
Shorebirds and Black Terns	• during the breeding season, maintain consistent water levels and suitable nest sites • during the nonbreeding season, flooded rice or fallow fields, without dense vegetation, and ideally <4 in • management practices that incorporate rice straw and stubble into the soil may increase invertebrate densities • high priority areas represent only 20% of the rice footprint in 2020–2024, while at least 81% is needed to support Black Tern conservation objectives; all the high and moderate priority areas and a large proportion of the low priority areas are important to these species	Breeding densities highest in Yolo-Delta region for Stilt and Avocet; Black Tern densities were highest in the Sacramento region, especially Glenn and Yuba counties. During the nonbreeding season, high priority areas were more dispersed throughout including Colusa, Butte basins near the major wildlife areas, Sutter, upper American Basin, Yolo Bypass, Cosumnes
Sandhill Cranes	• combination of wetlands, non-rice agriculture, and rice; flooded wetland habitat alone is insufficient to support crane roosts at recommended densities • The Yolo-Delta Region has hotspots of high crane roost suitability; 68.9% of the highest-rated potential roost fields were from this Region	Yolo-Delta Region, southeast of Willows, and West of Live Oak
Fishes	• every acre of bypass fields enrolled in the practice standard is needed to maximally boost salmon populations • flooding of natural habitats (non-rice areas) would boost this number more, but there are not enough bypass rice acres to approach full replacement • basins south of the Sutter Buttes • 59,600 acres of fish food fields (currently enrolled) • up to 200,000–300,000 acres potentially on dry side for fish food production	Yolo and Sutter bypass, basins south of the Sutter Buttes. Additional acres enrolled in fish food program

Table 7.2. Summary of key priorities and locations of rice acreage to support multiple wildlife species.

Risk of Loss of Rice Acreage or Conversion

We considered the potential loss of rice acreage, either through rice rotations or conversion to other crops, that could significantly reduce the conservation footprint (Figure 7.6a). The primary rice growing counties of Colusa, Glenn and Butte had very little crop rotation, whereas crop rotation occurred primarily in the southern portion of the Sacramento Valley (mostly in Sutter and Yolo counties). Rotations occurred on only certain types of soil, suggesting only 11% of the continuous rice acreage could potentially support rotations with other crops (Figure 7.6a A for details). The conversion of rice to perennial crop systems (i.e., orchards, such as almonds and walnuts) represents a more permanent and long-term change and a greater loss of conservation value. Most replacement of rice with orchard crops has occurred on the periphery of the rice area, although walnuts did replace rice along some of the areas adjacent to the rivers (Figure 7.6a B). Heavy clay soils that make up much of the rice area will likely limit further replacement (Figure 7.6a C). Thus, under current economic conditions, the baseline rice acreage is unlikely to fall below 450,000 acres. This is reinforced by high water demands of permanent crops and the recent projections of challenging economic outlooks for tree fruits and nuts. However, during severe drought in 2022, many rice fields were fallowed, causing the planted acres to drop as low as 256,000 acres. Hence, drought, water availability, and water costs, driven by climate variability, will pose the greatest threats to rice habitat for wildlife and will require a footprint that provides some buffer against these uncertainties.

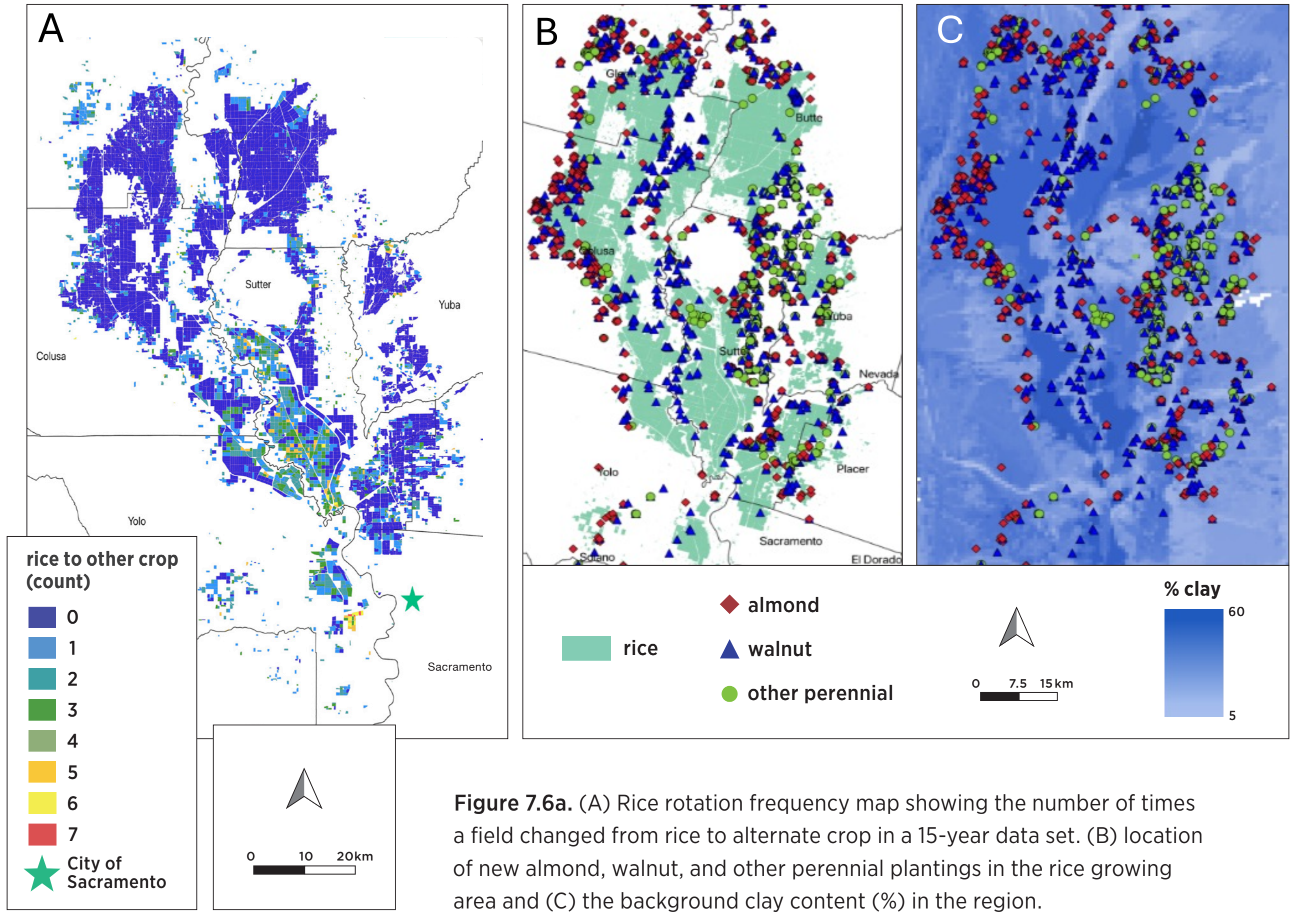

Figure 7.6a. (A) Rice rotation frequency map showing the number of times a field changed from rice to alternate crop in a 15-year data set. (B) location of new almond, walnut, and other perennial plantings in the rice growing area and (C) the background clay content (%) in the region.

The Conservation Footprint: Do We Have Enough Rice in California's Central Valley to Support Multiple Species of Wildlife?

Our final objective was to estimate the footprint of rice acreage needed to sustain wildlife species and populations within a viable rice production industry. We caution that this is a rough, or "muddy", footprint as we have not undertaken a formal multi-optimization analysis. Our task instead was to consolidate existing information for several key wildlife species groups, identify critical species needs, their response to rice management practices, and pinpoint locations of rice acreages that would have the greatest conservation value. Having done so, we summarize the acreages needed for each species as follows:

Giant Gartersnake: 83,634 acres of planted rice is needed to satisfy the recovery plan target habitat objectives. There are 158,110 acres that would satisfy these requirements even in a drought year. However, a population viability analysis (PVA) has not yet been completed, and additional acreage may actually be needed, including corridors, uplands, adjacent wetlands, and irrigation canals. Thus, while the current acreage of rice appears sufficient to satisfy recovery plan targets, more research is needed to determine the long-term ability of ricelands to support Giant Gartersnakes. Moreover, how rice is managed as well as the distribution of rice fields within a mosaic of habitats, are critical to consider.

Non-breeding Ducks: ~500,000 planted acres of rice, of which 257,727 acres are winter-flooded, is necessary to ensure resilience under high-competition (HARD) conditions. Alternatively, if competition is assumed to be lower (EASY), then habitat sufficiency could be achieved at 375,000 acres of planted rice, with 212,002 acres that are winter-flooded.

Shorebirds & Terns: 472,794 acres of planted rice is needed to meet existing conservation objectives for breeding Black Terns, which would also help maintain breeding shorebird populations. Below 472,294 acres there is a high risk of the Black Tern breeding population falling below 1,000 individuals, with increased risk of local extirpation and loss of genetic diversity. The rice footprint needed to support nonbreeding shorebirds depends on the extent that is winter-flooded and can include winter-flooded fallow rice fields. A midwinter peak of flooded rice and fallowed rice of at least 373,540 acres (is needed to maintain support for non-breeding shorebirds). A larger winter-flooded rice footprint above this minimum would contribute to nonbreeding shorebird conservation objectives in the CVJV implementation plan, while footprints below this threshold would increase pressure on managed wetlands. Ultimately, many shorebird populations are 'at-risk', and every additional rice acre would benefit shorebirds.

Cranes: Sandhill Cranes need 43,139 acres (of flooded acres, which is more than satisfied under current rice acreage). 56,759 acres would be needed if no other roosting habitat was available (which is also currently satisfied). However, there are periods in October when not enough rice is flooded.

Fishes: All the Yolo and Sutter bypass acres are needed (i.e., 74,000 acres, of which ~30,000 acres are rice). Managing all this acreage for fish would nearly double the Feather River population cohort replacement rate (CRR) from 22% to 38%. Rice alone cannot provide enough habitat for stable populations of fishes, but it can help. Ultimately, we are constrained by the areas of the bypasses for the current practice standard. 54,000 acres of fish food fields (as currently enrolled) could increase the CRR by an additional 6.8%, even with a much-reduced efficacy of the fish food practice relative to the bypass practice. If efficacy is closer to 50%, the CRR jumps to 34%, with no increase in enrolled acreage. These numbers increase substantially as enrolled acreage expands. Future research quantifying the impact of the fish food practice on CRR will be very useful.

If we were to establish the minimum rice footprint to meet the needs of all species, it could be determined as that which satisfies the minimum needs of the species with the largest acreage requirement — any reduction of rice below that target would impact at least that one species. Under this premise, waterfowl (500,000 planted acres) and shorebirds (472,794 planted acres) have the greatest needs and so a minimum footprint of ~470,000–500,000 acres would define the conservation footprint. Adding in the acreage of rice in the Yolo and Sutter Bypass for fishes (30,000 ac.), the total estimate would be 500,000– 530,000 acres.

However, there are several caveats to this approach. First, these acres represent the optimum to ensure that wildlife are buffered against unpredictable conditions (e.g. dry years, increased competition by geese, etc.). For both waterfowl and shorebirds, we also determined the minimum number of acres that would represent a lower threshold, below which significant population impacts would occur under all environmental conditions. These values are 10–25% lower (375,000 acres of planted rice for waterfowl, 426,043 acres for shorebirds). Between these two extremes is a region which is less than ideal and subject to impact of harsh conditions, but not necessarily catastrophic. We can envision these as zones of high risk (red) — where the amount of rice habitat is inadequate under all conditions, insufficient (yellow) — where there is risk of not meeting population objectives, especially when conditions are poor, and sufficient (green) — where there is enough rice habitat to buffer populations under almost all conditions. We present examples for waterfowl as well as shorebirds and Black Terns. This may be a more realistic approach to setting footprint goals, since environmental conditions always vary, and the ability to consistently meet goals that reach or exceed optimum levels of sufficiency (green) may be difficult.

Second, while we refer to the footprint as planted rice acres, for most of the species considered it is the number of flooded acres that matters most. 500,000 acres of rice will provide limited conservation value to most species if left dry in fall and winter. Accordingly, the threshold values for waterfowl would be 212,002 acres (red) to 255,727 (green) of winter-flooded rice while the threshold for shorebirds would be 373,540 acres of winter-flooded fields (be it flooded rice fields or flooded fallows). Ensuring the ability to provide winter-flooding will be essential to maintaining a viable conservation footprint for wildlife in the Central Valley.

Waterfowl and shorebirds have the greatest needs and so a minimum footprint of ~470,000–500,000 acres would define the conservation footprint.

Third, even though rice acreage currently appears to be adequate for the Giant Gartersnake and Sandhill Cranes, the availability, proximity, and quality of adjacent habitats will influence the conservation value of existing rice acreage significantly. We did not consider changes in the availability or quality of other important wildlife habitat (e.g. wetlands and uplands) but this clearly needs to be addressed. Equally important are the rice management practices on rice acres, especially the timing of flooding and water depths. Currently, we lack spatially-explicit data on the management actions for each rice field, but a future footprint should incorporate this variation.

Finally, our analysis of the needs of fishes in rice fields focused primarily on the bypasses, which also has conservation value for Giant Gartersnakes, shorebirds, ducks, and cranes (Figure 7.4). We simply treated all those rice acres as part of the conservation footprint, but we did not evaluate the trade-offs of management practices on those acres (e.g. timing and depth of flooding). This is a topic of considerable discussion (Sommer et al. 2001, 2001, 2020, Petrik et al. 2012, Howitt 2013, Suddeth and Lund 2016) and we defer to those analyses. It is worth noting, though, that the same trade-offs considered in the Yolo Bypass will ultimately need to be assessed for other rice acreage elsewhere in the valley as programs such as Floodplains Reimagined (https://floodplainsreimagined.org) or Fish Food Program (https://calricewaterbirds.org/fish-food/) develop.

The Agronomics and Economics of Conservation Efforts for Multiple Species

It is one task to prescribe the desired number of rice acres to support wildlife conservation in the Central Valley. It is an entirely more challenging task to evaluate the social and economic capital necessary to support these ricelands and wildlife-friendly management practices. How do farmers, conservationists, and the public value wildlife conservation on ricelands, and most importantly, is the broader public also willing to support these efforts financially and politically? To provide some perspective, we used several methods to project alternative measures of the perceived benefits of improved and expanded habitats for critical species: (i) willingness to pay for improved habitat for wildlife species, (ii) willingness to pay associated with use values rather than simply existence value, (iii) wildlife values associated with government payment programs, and (iv) wildlife-friendly label on rice packaging. Some key results were:

- Willingness to pay (WTP) estimates for individual species ranged from $572 per household for charismatic species to $106 per household for non-charismatic species.
- Regional estimates of WTP ranged between $0.08 and $0.18 per household for a one-year population increase of 1000 fish for Oregon Coast Coho Salmon, and $28.46 per US household to improve habitat for Northern Pintail.
- 89% of rice farmers and landowners allowed waterfowl hunting on their property, with 27% of the respondents collecting payment from hunting leases. 15% of hunter survey respondents donated between $250–$999, and 5% donated $1000 or more. 4% of birdwatchers donated $250–$999, and 1% donated $1000 or more.
- Some government programs pay $15–30 per acre for continuous flooding programs with specific conditions to support wildlife (California Winter Rice Habitat Incentive Program). The Fish Food program pays rice producers to flood their fields to support juvenile Chinook Salmon. BirdReturns generated over $2 million in farm payments and facilitated over 60,000 acres of bird habitat since 2014 (The Nature Conservancy, 2024a), averaging to about $33 per acre.
- Finally, wildlife-friendly label on rice packaging may elicit price premiums and changes in consumer purchasing behavior. The dolphin-safe label on tuna consumer increased the market share, with an annual effect ranging from $6–15 million.

With this background, we performed a series of illustrative valuation calculations for wildlife in California rice fields. Applying the estimate of $28.46 per household for Northern Pintails to 13 million California households results in a value of $369.98 million. Assuming rice comprises 60% of waterfowl food sources, rice fields contribute $221.99 million yielding approximately $554.98 per acre for permanent access to rice fields. Replacing the food base for waterfowl provided by winter-flooded rice would require an additional 255,000 acres of managed wetlands at a cost of nearly $2.8 billion in 2010 dollars (Petrie and Petrik 2010).

For Giant Gartersnakes, a one-time payment of $106 per household for non-charismatic species for the approximately 13 million households in California would result in a total value for the species of about $1.4 billion or $3,500 per acre of relevant riceland. In a related context, California voters strongly supported improved "habitat" of farm housing for mother sows that will cost Californians about $300 million per year in higher food prices (Lee, Sexton and Sumner, 2023). That amount applied to riceland could add $750 per acre per year for 400,000 acres of rice that committed to provide appropriate habitat along with growing rice.

These evaluations indicate a strong expressed and sometimes actual willingness to pay to support wildlife conservation in ricelands. To be effective, however, the ecological results must demonstrate the clear link between rice acreage above what would have been planted anyway and how this additional acreage would benefit the species' wellbeing. Quantifying economic and ecological alternatives for land, water and other resources used for rice must be part of the broader considerations for future analysis.

Next Steps

In each of our taxa-specific sections, we identified key uncertainties and important research needs for each species group, and we refer readers to those sections for details. Across all species, several cross-cutting research needs and next steps emerged:

1. Despite our focus on several well-known species of conservation and management concern, there is still a dearth of important science/natural history information for several species and/or for portions of their life history. The knowledge base is far more developed for some than others (e.g. waterfowl compared to Giant Gartersnake), in part a legacy of past state and federal focus and, in part, due to differences in the ability to survey, monitor, and follow populations. Additionally, there are many other species that use rice fields but were not included in this analysis (e.g., breeding waterfowl, wading birds, rails, wetland associated passerines, mammals, amphibians, other reptiles, and invertebrates), all of which might benefit from or be impacted by the rice footprint.
2. A focus of our analysis was to explore the compatibility of ecological needs among the species and the impacts of different rice management practices, yet there is much more that could be done to better understand the compatibility of rice acres among groups. For example, the different water depths required for each species was a key factor that conflicted most among groups, yet all rice mapping assumed either status quo (i.e., the current range of depths in rice fields) or that water depths would be sufficient. This is clearly not the case. Future analyses will require detailed water depth maps for flooded acres, including spatial and seasonal variation. Admittedly, this is a huge challenge although efforts are underway. Doing so would not only provide far more precise assessments of compatibility of locations but given the mosaic of habitats and depths needed to accommodate all species, we suspect that the conservation footprint would only be larger.
3. Our analysis, by design, provides a "muddy" footprint. We were successful in establishing management practices that support (or limit) wildlife use, identifying locations of high priority ricelands, and providing an estimate of minimum and optimum rice acreage needed to support the wildlife groups we considered. We recommend formal multi-objective decision making and/or multi-purpose optimization analyses as a next step. Doing so would enable a quantitative evaluation of the trade-offs of alternative conservation and management actions for rice fields in the Central Valley. Our analyses provide a solid starting point for such an approach.
4. Finally, we show that there is much potential support and a willingness to pay (WTP) for wildlife conservation in California rice. To move forward, in-depth surveys and analysis of economic outcomes, impacts, and WTP are needed, along with policy development and multi-stakeholder programs to support and enhance the conservation rice footprint.

References

Ando, A. W., and M. L. Mallory. 2012. Optimal portfolio design to reduce climate-related conservation uncertainty in the Prairie Pothole Region. Proceedings of the National Academy of Sciences 109:6484–6489.

Behney, A. C. 2020. The influence of water depth on energy availability for ducks. The Journal of Wildlife Management 84:436–447.

Colwell, M. A., and O. W. Taft. 2000. Waterbird communities in managed wetlands of varying water depth. Waterbirds 23:45–55.

Conlisk, E. E., G. H. Golet, M. Reynolds, N. Elliott, and M. E. Reiter. 2024. Factors influencing shorebird use of post-harvest flooded rice fields in California's Sacramento Valley. The Journal of Wildlife Management 88:e22661.

Dang, K. B., W. Windhorst, B. Burkhard, and F. Müller. 2019. A Bayesian belief network – based approach to link ecosystem functions with rice provisioning ecosystem services. Ecological Indicators 100:30–44.

Elphick, C. S., and L. W. Oring. 1998. Winter management of Californian rice fields for waterbirds. Journal of Applied Ecology 35:95–108.

Elphick, C., O. Taft, and P. M. Loureno. 2010. Management of rice fields for birds during the non-growing season. Waterbirds 33:181–192.

Garnache, C. 2015. Fish, farmers, and floods: Coordinating institutions to optimize the provision of ecosystem services. Journal of the Association of Environmental and Resource Economists 2:367–399.

Golet, G. H., K. E. Dybala, M. E. Reiter, K. A. Sesser, M. Reynolds, and R. Kelsey. 2022. Shorebird food energy shortfalls and the effectiveness of habitat incentive programs in record wet, dry, and warm years. Ecological Monographs 92:e1541.

Hallmann, C. A., R. P. B. Foppen, C. A. M. van Turnhout, H. de Kroon, and E. Jongejans. 2014. Declines in insectivorous birds are associated with high neonicotinoid concentrations. Nature 511:341–343.

Halstead, B. J., G. D. Wylie, and M. L. Casazza. 2010. Habitat suitability and conservation of the giant gartersnake (thamnophis gigas) in the Sacramento valley of california. Copeia:591–599.

Howitt, R. 2013. Agricultural and Economic Impacts of Yolo Bypass Fish Habitat Proposals.

Iverson, S. A., C. Hickey, and K. Sesser. 2024. Rice fallowing and wildlife: Minimizing impacts and increasing opportunity for wildlife due to rice fallowing and rotation in the Sacramento Valley. Point Blue Conservation Science, Petaluma, CA.

Köhler, H.-R., and R. Triebskorn. 2013. Wildlife Ecotoxicology of Pesticides: Can We Track Effects to the Population Level and Beyond? Science 341:759–765.

Kremen, C., and A. M. Merenlender. 2018. Landscapes that work for biodiversity and people. Science 362:eaau6020.

Kremen, C., and A. Miles. 2012. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecology and Society 17:40.

Li, Y., R. Miao, and M. Khanna. 2020. Neonicotinoids and decline in bird biodiversity in the United States. Nature Sustainability 3:1027–1035.

Liu, X., B. R. Bakshi, B. Rugani, D. M. de Souza, J. Bare, J. M. Johnston, A. Laurent, and F. Verones. 2020. Quantification and valuation of ecosystem services in life cycle assessment: Application of the cascade framework to rice farming systems. Science of the Total Environment 747:141278.

Migratory Bird Conservation Partnership. 2014. Waterbird Habitat Enhancement Program: California Rice Commission.

Molenaar, E., W. Viechtbauer, J. van de Crommenacker, and S. A. Kingma. 2024. Neonicotinoids Impact All Aspects of Bird Life: A Meta-Analysis. Ecology Letters 27:e14534.

Petrie, M. J., and K. L. Petrik. 2010. Assessing waterbird benefits from water use in California Ricelands:12.

Petrik, K., M. Petrie, A. Will, J. McCreary, and F. E. P. Team. 2012. Waterfowl Impacts of the Proposed Conservation Measure 2 for the Yolo Bypass–An effects analysis tool.

Rigal, S., V. Dakos, H. Alonso, A. Auniņš, Z. Benkő, L. Brotons, T. Chodkiewicz, P. Chylarecki, E. de Carli, J. C. del Moral, C. Domşa, V. Escandell, B. Fontaine, R. Foppen, R. Gregory, S. Harris, S. Herrando, M. Husby, C. Ieronymidou, F. Jiguet, J. Kennedy, A. Klvaňová, P. Kmecl, L. Kuczyński, P. Kurlavičius, J. A. Kålås, A. Lehikoinen, Å. Lindström, R. Lorrillière, C. Moshøj, R. Nellis, D. Noble, D. P. Eskildsen, J.-Y. Paquet, M. Pélissié, C. Pladevall, D. Portolou, J. Reif, H. Schmid, B. Seaman, Z. D. Szabo, T. Szép, G. T. Florenzano, N. Teufelbauer, S. Trautmann, C. van Turnhout, Z. Vermouzek, T. Vikstrøm, P. Voříšek, A. Weiserbs, and V. Devictor. 2023. Farmland practices are driving bird population decline across Europe. Proceedings of the National Academy of Sciences 120:e2216573120.

Sesser, K. A., M. Iglecia, M. E. Reiter, K. M. Strum, C. M. Hickey, R. Kelsey, and D. A. Skalos. 2018. Waterbird response to variable-timing of drawdown in rice fields after winter-flooding. PLOS ONE 13:e0204800.

Sommer, T., B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001. California's Yolo Bypass: Evidence that flood control Can Be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26:6–16.

Sommer, T., B. Schreier, J. L. Conrad, L. Takata, B. Serup, R. Titus, C. Jefres, E. Holmes, and J. Katz. 2020. Farm to fish: Lessons from a multi-year study on agricultural floodplain habitat. San Francisco Estuary and Watershed Science 18:1–20.

Strum, K. M., M. E. Reiter, C. A. Hartman, M. N. Iglecia, T. R. Kelsey, and C. M. Hickey. 2013. Winter management of California's rice fields to maximize waterbird habitat and minimize water use. Agriculture, Ecosystems & Environment 179:116–124.

Suddeth, R., and J. Lund. 2016. Multi-Purpose Optimization for Reconciliation Ecology on an Engineered Floodplain—Yolo Bypass, California, USA. San Francisco Estuary and Watershed Science 14.

California Rice

It's in our Nature

California Rice Commission

calrice.org