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Floodplains Reimagined:
Shorebird bioenergetics under baseline conditions

Prepared for the Floodplains Reimagined Steering Committee
February 2024
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Introduction

The vision of the Floodplains Reimagined program is to improve floodplain function in the Mid-Sacramento River Valley region, reconnecting rivers to their historical floodplains in the Butte, Colusa, and Sutter subregions, through voluntary collaborative partnerships with private landowners, sovereign tribal entities, government, and non-government representatives. By improving floodplain connectivity, these actions are intended to improve habitat for fish and birds among many other priorities, such as recreation, economic prosperity, and indigenous cultural values.

California's Central Valley provides valuable habitat to a diverse community of birds, including at least half a million shorebirds that rely on flooded habitat in the region each year during the non-breeding season (Shuford et al. 1998), despite the loss of more than 90% of its historical wetlands (Frayer et al. 1989; Reid et al. 2018). Consequently, the number of shorebirds in the Central Valley is thought to be much smaller than it was historically, and is expected to be limited by the availability of suitable habitat, particularly areas of shallow open water (up to 4 inches deep) that provide food in the form of benthic invertebrates (Dybala et al. 2017; CVJV 2020). In addition, because habitat during the non-breeding season can have important effects on migratory shorebird population dynamics (Aharon-Rotman et al. 2016), such as through effects on body condition, survival, and subsequent reproductive success (Yohannes et al. 2010; Swift et al. 2020), the quality and quantity of shorebird habitat provided in the Central Valley may have significant impacts on shorebird population dynamics well beyond the boundaries of the Central Valley.

To estimate the extent of shorebird habitat currently in the program area, among other priority taxa, the Floodplains Reimagined applied habitat suitability criteria to estimate the weighted usable area (WUA) in each subregion in each of 5 water years analyzed, presented in a separate Appendix (Dybala 2024). However, where foraging habitat is the major limiting factor for a population of interest, and the amount of foraging habitat is highly variable over time, bioenergetics models can offer additional perspective on the population-level impacts of variation in WUA. Bioenergetics models estimate the total food energy supply available in the landscape in each time-step relative to the energy needs of the entire population of birds in the area, while also tracking changes in how much of the food supply is becoming available or being consumed. Bioenergetics models have been developed for waterfowl and shorebirds during the non-breeding season, and they form the cornerstone of conservation objectives established by the Central Valley Joint Venture (Petrie et al. 2016; Dybala et al. 2017; CVJV 2020).

Recommended Citation: Dybala KE, Jongsomjit D (2024) Floodplains Reimagined: Shorebird bioenergetics under baseline conditions. Petaluma, CA: Point Blue Conservation Science. 17pp.

Previous applications of the shorebird bioenergetics model have identified significant shortfalls in the supply of food energy available to shorebirds in the Central Valley, particularly during the early non-breeding season (July–September), when the shallow open water habitat they require is scarce throughout the region (Dybala et al. 2017; Golet et al. 2022). Shortfalls in the supply of food energy also emerge late in the non-breeding season (especially mid-March–late-April), after many winter-flooded wetlands and rice fields have been drawn down and shorebird energy needs are simultaneously expected to rise as they prepare for spring migration. Thus, Central Valley habitat objectives include increasing the extent of shallow (<4") open water habitat during these two critical shortfall periods (CVJV 2020). Actions to increase floodplain connectivity in the Floodplains Reimagined program area could provide valuable shorebird foraging habitat that contributes to these objectives. However, an increase in flooding depths could reduce the total area of foraging habitat that is accessible to shorebirds.

Here, we document and describe the application of the shorebird bioenergetics model in Phase I of the Floodplains Reimagined program and summarize the results under baseline conditions. We also discuss the assumptions of the bioenergetics model and recommendations for future phases of the Floodplains Reimagined program.

Bioenergetics Model Methodology

We applied the bioenergetics model that was originally developed for the CVJV for defining Central Valley conservation objectives for shorebirds during the non-breeding season (Dybala 2016; Dybala et al. 2017). The model estimates the daily food energy available from benthic invertebrates across all suitable land cover classes in comparison to the estimated daily energy needs of the shorebird community. It also accounts for dynamic changes in the extent and depth of flooding on the landscape and variation in the size and species composition of the shorebird community over the course of the non-breeding season. The model's structure and parameterization were described in detail by Dybala et al. (2017), but we provide a brief overview here and note where data from Floodplains Reimagined were incorporated.

Estimating daily food supply

To estimate the daily supply of food energy available to shorebirds, we drew on the hydrodynamic models developed for each subregion of the Floodplains Reimagined program area to estimate the daily change in the extent of suitable flooded habitat. In alignment with the CVJV and the Habitat Suitability Criteria for shorebirds developed for the Floodplains Reimagined program, we considered several land cover classes to be compatible with providing the shallow open water foraging habitat required by shorebirds during the non-breeding season. These land cover classes include wetlands, rice, corn, and other field and row crops that may provide suitable open-water habitat when flooded post-harvest (Dybala et al. 2017; Dybala 2023).

The CVJV commonly specifies "managed wetlands" as suitable habitat for shorebirds, referring to the wildlife refuges and privately-managed wetlands that make up the vast majority of reliably-flooded wetland habitat in the Central Valley today. However, in the context of Floodplains Reimagined, "managed" in the hydrodynamic models specifically refers to wetlands or rice fields where water is modeled as intentionally applied according to specific management goals, separate from any flooding that may naturally occur. Thus, in the shorebird bioenergetics model, we also included "unmanaged" rice and wetlands as suitable land cover classes, in the sense that water may not be intentionally applied every year, but they may still provide suitable habitat when flooded. Importantly, we note for comparison that the waterfowl bioenergetics model, for which results are presented in a separate Appendix (Ducks Unlimited 2023), included only "managed" seasonal wetlands and "managed" rice as suitable land cover classes.

When flooded, these land cover classes produce benthic invertebrates that provide much of the food supply for shorebirds during the non-breeding season. These include small aquatic animals and the aquatic larval stages of insects that live either on top of or burrowed into the muddy bottom of a water body, which shorebirds reach by probing into the mud. Benthic invertebrates are distinct from aquatic invertebrates living in the water column or on the water's surface, which form an important food supply for fish. Based on prior analyses adopted for the CVJV, managed wetlands are estimated to provide an average of 186.60 MJ/ha of food energy from benthic invertebrates, while flooded rice and other agricultural fields are estimated to provide an average of 104.95 MJ/ha (Dybala et al. 2017). We assumed these values applied to each subregion of the Floodplains Reimagined program area. In addition, due to a scarcity of information about temporal variation in benthic invertebrate in these systems, the shorebird bioenergetics model assumes that the full value of the food supply becomes available as soon as suitable land covers are flooded, does not grow or decay, and may be consumed by the shorebird population until it is reduced to zero or is no longer flooded. These assumptions could overestimate food availability on initial flooding and underestimate food availability in areas that remain flooded for many weeks. With additional research on benthic invertebrates, further development of the shorebird bioenergetics model could include estimates of any delay in the availability of the food supply after the onset of flooding, how long food remains available in wet mud after flooding, rates of growth or decomposition related to environmental conditions, and regional or annual variations in any of these model parameters.

Although benthic invertebrates may be available throughout all flooded portions of the suitable land cover classes, only a subset of the total food supply may be accessible to foraging shorebirds each day, depending on the depth of flooding. Shorebirds vary in body size and leg length, but in alignment with the CVJV and the Habitat Suitability Criteria for shorebirds developed for the Floodplains Reimagined program, we considered 4 inches (or 10 cm) to represent the upper limit of optimal depths (Dybala et al. 2017; CVJV 2020; Dybala 2023). Thus, estimating the daily supply of food energy available to shorebirds requires estimating the daily change in the flooded area of each suitable land cover class, as well as the daily proportion of the flooded area that has a suitable depth.

Estimating daily energy need

We adopted daily energy need estimates originally developed for the CVJV's long-term shorebird population objectives (Dybala et al. 2017), which represent a doubling of the baseline population sizes estimated from surveys conducted from 1992 to 1995 (Shuford et al. 1998). To support these population objectives, the daily energy needs of the shorebird community were estimated using allometric equations that relate energy intake to body mass (Kersten and Piersma 1987; Brand et al. 2013). The baseline shorebird surveys provided data on changes in the relative abundance of each species in the community throughout the non-breeding season, which was used to estimate the changing mean body mass for an average individual shorebird. Additional adjustments to the daily energy needs accounted for imperfect assimilation efficiency and an assumed increase in metabolic rate as birds prepare for spring migration (Castro et al. 1989; CVJV 2006). Thus, the daily energy needs of the entire Central Valley shorebird population vary over the course of the non-breeding season in response to the changing abundance, species composition, and body sizes of individuals in the community, as well as timing relative to spring migration (**Figure 1**).

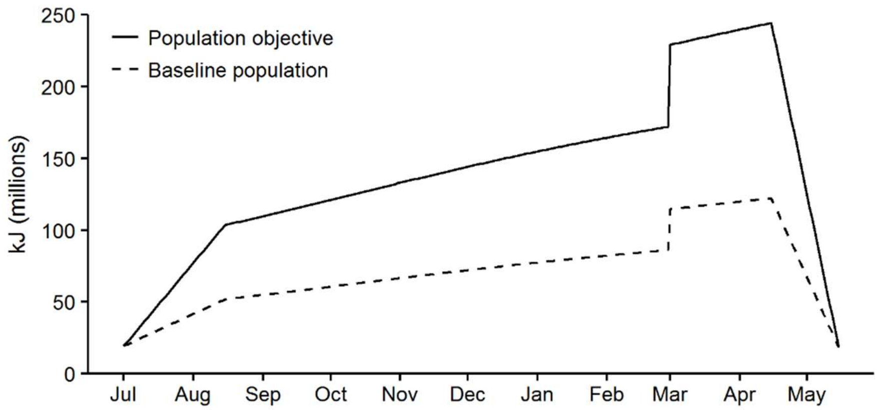


Figure 1. Estimated daily energy needs to meet population objectives for Central Valley shorebirds.

We did not attempt to assign a proportion of these energy needs to each of the subregions within the Floodplains Reimagined program. The relative abundance of individual shorebird species varies temporally and spatially, and shorebirds are known to travel widely throughout the Central Valley in response to changing habitat availability (Barbaree et al. 2018). Thus, we did not find it ecologically realistic to assume each subregion would support a consistent proportion of the energy needs throughout the non-breeding season, nor did we have a scientifically defensible method for assigning such a proportion. Instead, we consider these daily energy needs to represent the upper limit of the daily energy that could be consumed in each subregion.

Model structure

The model is applied to a defined study area with several land cover classes that may provide suitable habitat when flooded. At the start of each daily time-step, the energy supply (*ES*) available in each suitable land cover class is estimated from any energy supply that may be remaining at the end of the previous day plus any new energy supply contributed by newly added areas of open water in that land cover class. As described above, the full food energy supply is assumed to be available in any newly-added open water area. From *ES*, the energy accessible (*EA*) in each land cover class is then estimated as the proportion of *ES* that is less than 4 inches (10 cm) deep.

Shorebirds then consume energy according to their estimated daily energy requirement (*DER*) and the model assumes energy is consumed in each land cover class in proportion to the *EA* in each land cover class. However, if the *DER* is higher than the total *EA* across all land cover classes, the magnitude of the shortfall in energy supply during this time step is also estimated. At the end of each daily time step, the total energy remaining in the flooded area of each land cover class, regardless of depth, is then estimated as *ES* minus energy consumed that day. In addition, the model accounts for any additional energy that may be lost in any flooded area that will go dry before the next time step. Effectively, estimates of the energy (and benthic invertebrates) remaining in each land cover class are allowed to redistribute evenly within that class, allowing additional energy to become accessible in the shallow areas of that class.

The model is designed to run iteratively for each daily time step within one shorebird non-breeding season, from July 1 (set as t = 1) through the following May 15 (t = 319). The model is represented by a set of equations implemented in the R package “bioenergmod” (Dybala 2016).

Application to Floodplains Reimagined

We applied this shorebird bioenergetics model to the Floodplains Reimagined area by fitting the model to each subregion (Colusa, Butte, and Sutter) under the hydrological conditions in each of 5 distinct water years (WY) analyzed, chosen to represent a range of the volume and timing of water flow (2003, 2011, 2013, 2015, 2019). However, water management was assumed constant across all water years, such as in wetlands or postharvest-flooded rice fields, rather than allowed to vary in response to hydrological conditions.

For each water year and subregion, we worked with cbec to extract many of the necessary model inputs from the hydrodynamic models developed for Floodplains Reimagined. These included: (1) the total area of each suitable land cover class, (2) the daily area of each land cover class that was flooded, (3) the daily area of each land cover class that was newly flooded that day, (4) the daily area of each land cover class that is flooded but would go dry before the start of the next day, and (5) the daily proportion of the flooded area in each land cover class that was less than 4 inches (10 cm) deep. These model inputs capture the variability in the daily supply of habitat, and thus food energy, available to shorebirds during the non-breeding season. However, we note that the hydrodynamic models start from October 1 (day = 93), and thus we could not model or evaluate habitat and food supply during the late summer and early fall period of the shorebird non-breeding season (July 1 – September 30). We treated any habitat that was already flooded on the first day of the hydrodynamic model as though it was newly-added that day and contained the full food supply value.

We applied the daily energy requirements of the CVJV population objectives against the variable habitat and energy supply available to shorebirds in each subregion and water year as a means of estimating the maximum number of bird-days that could be supported by each subregion in each water year. We defined one shorebird-day as the energy required to support one shorebird for one day, and we calculated this quantity as the daily energy requirement divided by the daily number of individuals in the CVJV population objectives. This approach represents a distinct use-case for the shorebird bioenergetics model, estimating the impacts of habitat change on a smaller regional scale in terms of bird-days. While previous applications of the shorebird bioenergetics model have required incorporating estimates of habitat availability throughout the entire Central Valley landscape to identify the timing and magnitude of landscape-scale energy shortfalls (e.g., Golet et al. 2022), this approach offers a more localized perspective that can be helpful for evaluating the impacts of local actions.

We fit the shorebird bioenergetics model for each subregion and water year in R using the R package "bioenergmod" (Dybala 2016; R Core Team 2023) . For each subregion and water year, we calculated the total number of bird-days supported and the proportion of the CVJV population objectives supported over (1) the entire water year modeled (October 1 – May 15; days 93–319) and (2) during the spring critical shortfall period (mid-March – late-April; days 256–297), when additional shorebird habitat has been identified as a conservation need by the CVJV.

Baseline Results

Bird-days supported

We estimated that all three subregions provided foraging habitat for shorebirds under the baseline conditions in all five water years evaluated, but the maximum number of bird-days that could be supported by each subregion varied. In terms of the total number of bird-days over the entire the modeled portion of the water year (October 1 – May 15; days 93–319), mean values across the five water-years ranged from a low of 3.7 million bird-days in the Sutter subregion to a high of 32.5 million for Butte (**Figure 2**). In terms of the number of bird-days supported within the spring critical shortfall period (mid-March – late-April; days 256–297), the pattern was similar, with mean values ranging from 0.6 million in the Sutter subregion to a high of 6.4 million for Butte. For both metrics, the mean number of bird-days supported by the Colusa subregion fell between the other two subregions, but also had the highest variability across water years relative to the mean (**Table 1**).

Figure 2. Bird-days supported by subregion across water years. (**A**) Total bird-days over the entire modeled water year. (**B**) Bird-days within the spring critical shortfall period. Boxplots illustrate the mean (horizontal line) and middle 50% (box) for the number of bird-days supported across all five water years evaluated (mean values are also provided in Table 1). Points display the values for each individual water year (also provided in Table 2).

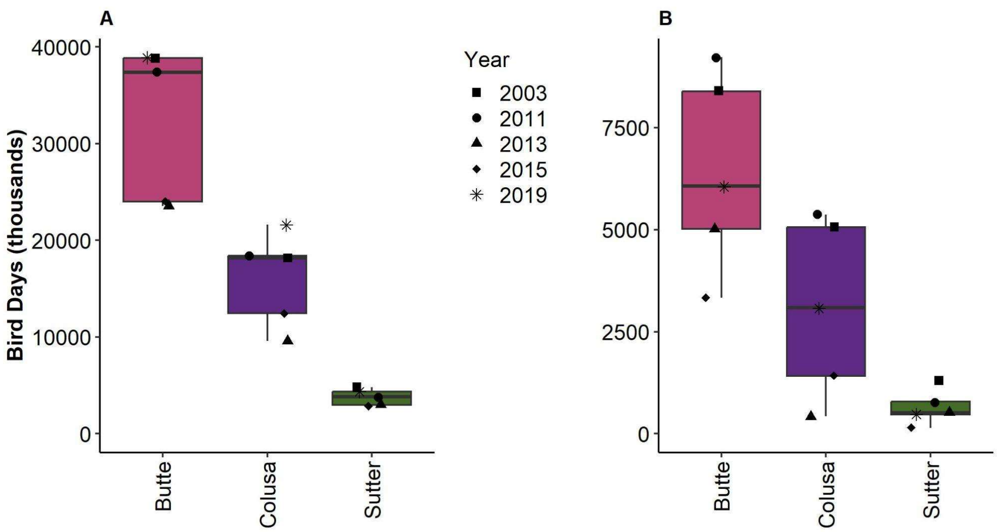


Table 1. Summary statistics for bird-days supported by subregion across water years. Mean, median, and coefficient of variation are shown for each subregion across five water years for the estimated total bird-days over the entire modeled water year (October 1–May 15; days 93–319) and during the critical shortfall period (mid-March–late-April; days 256–297).

	Total			Critical Shortfall Period		
Subregion	**Mean**	**Median**	**CV**	**Mean**	**Median**	**CV**
Butte	32,529,022	37,362,567	0.247	6,406,769	6,063,041	0.377
Colusa	16,048,813	18,182,816	0.304	3,071,803	3,084,767	0.709
Sutter	3,765,888	3,808,961	0.225	645,396	513,346	0.676

To put these estimates in context, we calculated the total number of bird-days required by the CVJV population objectives during the modeled portion of the water year as 109.5 million bird-days, and the total number during the spring critical shortfall period as 26.3 million bird-days. We estimated the proportion of the CVJV population objectives each subregion could support in each water year, and found that within each subregion, the proportions and their relative values across water years were largely similar whether calculated for the entire water year or the critical shortfall period (**Figure 3**). For example, we found that the hydrological conditions in the 2013 and 2015 water years both resulted in the lowest estimates for both metrics in the Butte and Colusa subregions as well as relatively low estimates in the Sutter subregion (**Table 2**). However, we also found a reduced value in 2019 in the Sutter subregion during the critical shortfall period that did not correspond to a reduced value for the total number of bird-days supported. Similarly, 2019 estimates in the Butte and Colusa subregions supported a relatively high number of bird-days over the entire water year but only moderate numbers during the critical shortfall period, suggesting important differences in the timing of habitat availability for shorebirds in 2019 relative to the other water years.

Figure 3. Proportion of CVJV objectives supported by subregion and water year. (**Left**) Total bird-days over the entire modeled water year (October 1 – May 15; days 93–319). (**Right**) Bird-days within the critical shortfall period (mid-March – late-April; days 256–297).

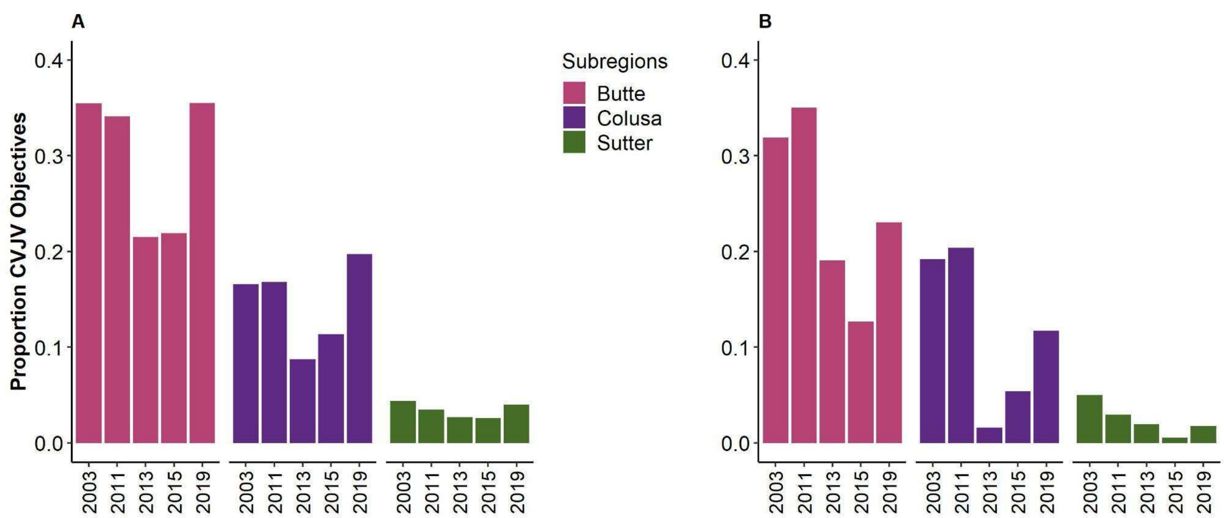


Table 2. Bird-days supported by subregion and water-year. (**A**) Total bird-days over the entire modeled water year (October 1 – May 15; days 93–319). (**B**) Bird-days within the critical shortfall period (mid-March – late-April; days 256–297). Each value is also shown as a proportion of the number required by the CVJV population objectives.

	Butte		Colusa		Sutter	
Year	Value	Proportion	Value	Proportion	Value	Proportion
A. Total						
2003	38,827,768	0.36	18,182,816	0.17	4,810,369	0.04
2011	37,362,567	0.34	18,399,669	0.17	3,808,961	0.03
2013	23,550,239	0.22	9,589,939	0.09	2,980,319	0.03
2015	23,993,959	0.22	12,467,528	0.11	2,864,274	0.03
2019	38,910,579	0.36	21,604,112	0.20	4,365,519	0.04
B. Critical shortfall period						
2003	8,394,062	0.32	5,058,560	0.19	1,313,130	0.05
2011	9,222,229	0.35	5,369,839	0.20	784,271	0.03
2013	5,018,941	0.19	427,230	0.02	513,346	0.02
2015	3,335,574	0.13	1,418,616	0.05	146,352	0.01
2019	6,063,041	0.23	3,084,767	0.12	469,882	0.02

Habitat availability

Contributing to the variation in the number of bird-days they can support, the three subregions varied in the total area of suitable land cover classes, ranging from the relatively small Sutter subregion containing 6,202 ha of suitable land cover to the 57,295 ha in the Butte subregion, more than nine times larger (**Table 3**). In all three subregions, rice was the most common of the suitable land cover classes, but each subregion also contained substantial amounts of suitable row and field crops and seasonal wetlands. Both Butte and Colusa also included a small amount of permanent/semi-permanent wetlands, and Butte had 1,316 ha of corn.

Table 3. Total area (ha) of suitable land cover classes by subregion.

Land Cover Class	Butte	Colusa	Sutter	Total
Seasonal wetlands	16,119	7,389	1,332	23,508
Permanent/semi-permanent wetlands	106	68	0	175
Rice	33,500	17,961	3,342	54,802
Corn	1,316	0	0	1,316
Other suitable agriculture	6,254	17,092	1,528	24,874
Total	57,295	42,509	6,202	106,006

In addition to their variation in size, the three subregions varied in the temporal dynamics of the total area of open water in suitable land covers and the total area that was sufficiently shallow (< 4 in or 10 cm) to be accessible to foraging shorebirds (**Figures 4–6**). In both the Butte and Colusa subregions, there was a clear signal of managed winter flooding in wetlands and rice, a pattern seen throughout the Central Valley, with a consistent increase in the area of open water in mid-October across all water years, corresponding to a brief rise in the area accessible to foraging shorebirds followed by a long period (November–January) when very little habitat is accessible. In both subregions, there was also a consistent rapid decline in the area of open water in rice in early February across all water years as winter-flooded rice is drawn down in preparation for spring planting, again corresponding to a brief pulse of accessible habitat for shorebirds in rice. The drawdown in managed wetlands was more gradual and occurred later in March and April, resulting in a more gradual and longer-lasting pulse of accessible habitat that overlapped with the spring critical shortfall period (mid-March—late-April).

Figure 4. Variation in habitat availability for shorebirds in the Butte subregion across water years (ha, thousands). (**A**) Total open water. (**B**) Accessible open water <4 in (10 cm). Note the different scales in each panel. Each plot also illustrates the relative contribution of each suitable land cover class to the total habitat available, including rice, corn, other suitable field & row crops ("other"), and permanent and seasonal managed wetlands.

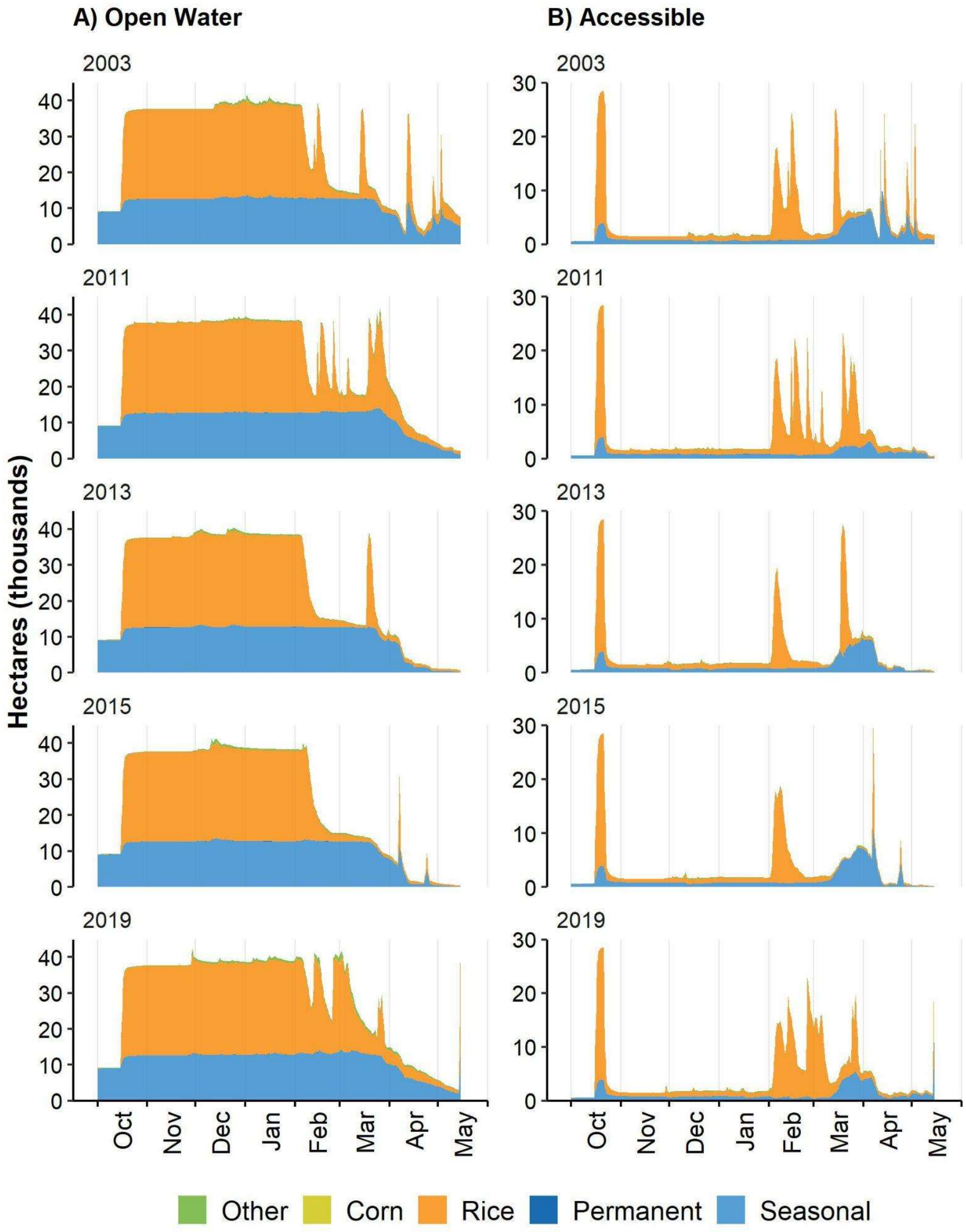


Figure 5. Variation in habitat availability for shorebirds in the Colusa subregion across water years, ha (thousands). (**A**) Total open water. (**B**) Accessible open water < 4 in (10 cm). Note the different scales in each panel. Each plot also illustrates the relative contribution of each suitable land cover class to the total habitat available, including rice, other suitable field & row crops ("other"), and permanent and seasonal managed wetlands.

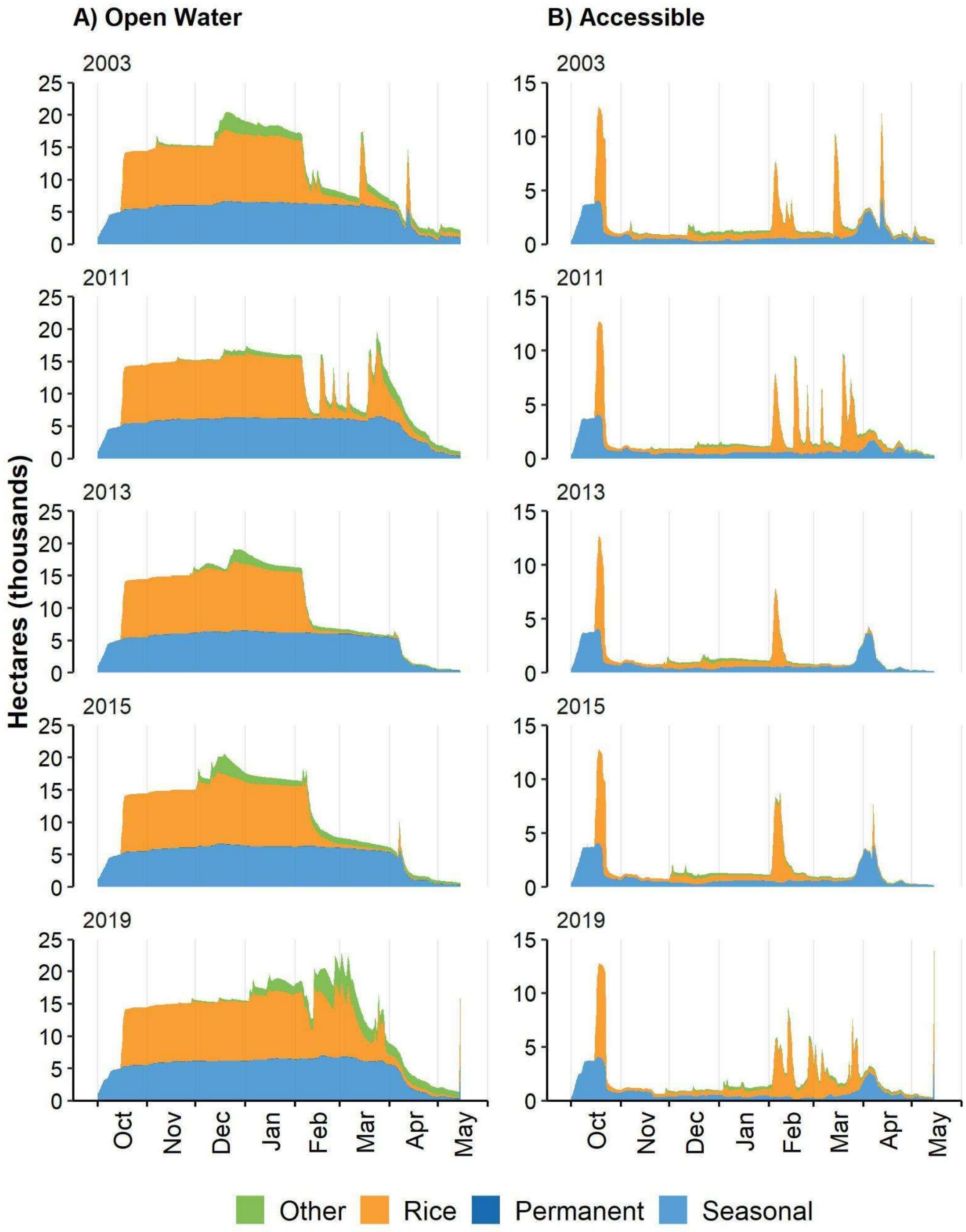
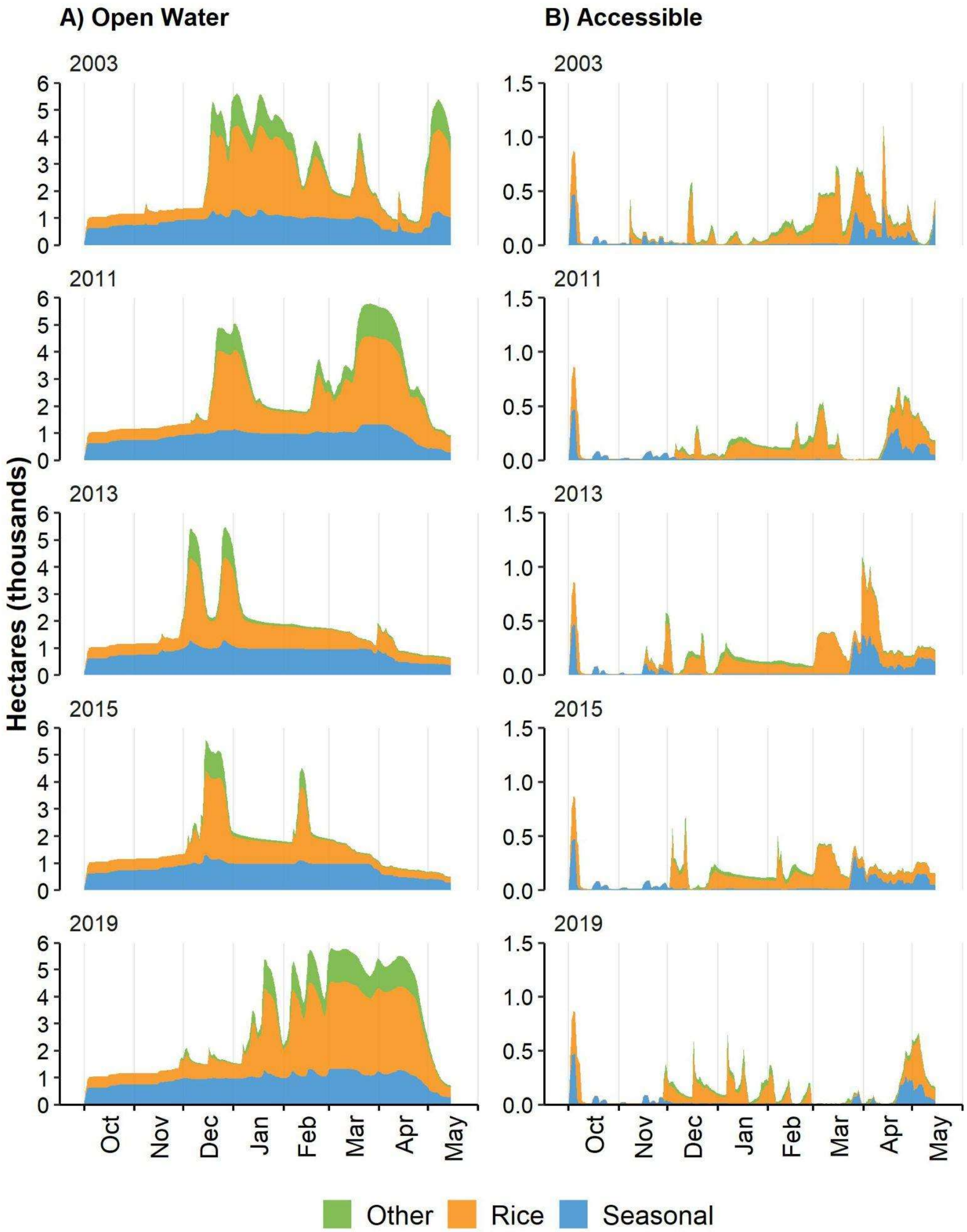


Figure 6. Variation in habitat availability for shorebirds in the Sutter subregion across water years (ha, thousands). (**A**) Total open water. (**B**) Accessible open water < 4 in (10 cm). Note the different scales in each panel. Each plot also illustrates the relative contribution of each suitable land cover class to the total habitat available, including rice, other suitable field & row crops ("other"), and seasonal managed wetlands.



On top of this general pattern of managed winter flooding in the Butte and Colusa subregions, there were also brief pulses of total open water and corresponding accessible open water habitat corresponding to flooding events in each subregion (**Figures 4-5**). These pulses were primarily detectable in February–April, and they are likely the primary sources of variation among water years in the number of bird-days supported, both the total over the entire water year and the number during the critical shortfall period. For example, under the hydrological conditions of 2013 and 2015, there was little additional open water habitat in each of these regions beyond that expected from managed wetlands and winter-flooded rice, contributing to a reduced number of bird-days supported in these years (**Figure 3**). In comparison, under the hydrological conditions of 2003 and 2011, numerous pulses of spring flooding contributed to a larger number of bird-days supported. In 2019, there was a more substantial, longer-duration pulse of flooding in late-February–early-March in both basins that was not seen in other water years, but because it occurred before the critical shortfall period it contributed to the relatively high total number of bird-days and moderate number during the critical shortfall period, as noted above.

In contrast, while the availability of habitat in the Sutter subregion had a similar pattern across water years to the Butte and Colusa subregions in terms of reduced bird-days in 2013 and 2015 (**Figure 3**), it did not follow the same seasonal patterns (**Figure 4**). The extent of open water in managed wetlands was relatively constant throughout the non-breeding season, and there was more variability across water years in timing of peaks in open water in rice and other suitable field and row crops. Compared to the Butte and Colusa subregions, these pulses of flooding were distributed throughout the non-breeding season, lasted longer, and became fairly deep, thereby contributing to corresponding periods of reduced accessible habitat until the flood pulses receded.

Discussion

By applying the shorebird bioenergetics model to each subregion of the Floodplains Reimagined program area, we were able to estimate the total number of bird-days each subregion could support across each of five water-years under baseline conditions. With more than 106,000 ha of suitable land cover in the Floodplains Reimagined program area (**Table 3**), we estimated the Butte and Colusa subregions could each support substantial proportions of the CVJV population objectives in most of the water years modeled (22-36% and 9-20%, respectively), while the much smaller Sutter subregion was still capable of supporting up to 3-4% of the CVJV population objectives (**Table 2**). While these numbers represent an upper limit, based on an assumption that all shorebirds can immediately access habitat when it becomes available and that the food energy supply in the form of benthic invertebrates is also immediately available, our results indicate the value of the Floodplains Reimagined area to shorebird conservation in the Central Valley under baseline conditions.

Our results also demonstrate that the interplay between the total area, available habitat types, floodplain connectivity, and management practices in each subregion have a large impact on the amount and variability in available habitat within each subregion. Shorebird habitat in the Butte and Colusa subregions was reliably provided by a core of managed wetlands and winter-flooded rice that contributed large pulses of accessible habitat during flood-up and draw-down, while the variability among water years in the number of bird-days supported was primarily driven by intermittent pulses of flooding, especially during February–April (**Figures 4–5**). In comparison to Butte and Colusa, shorebird habitat in the Sutter subregion was reliably available across the hydrological conditions in each water year, but the timing of habitat availability was distributed throughout the non-breeding season and more variable across water years (**Figure 6**).

These results provide baseline metrics against which future scenarios can be compared, to evaluate the impacts of proposed actions in the program area on shorebird bioenergetics and the contributions of each subregion to CVJV conservation objectives for shorebirds. Considering the variation in support for bird-days we found across subregions and water years under just the baseline conditions, our results demonstrate the substantial impacts to shorebird habitat of varying the timing, extent, and depth of flooding on the total number of bird-days supported and the number of bird-days within the critical shortfall period. Pulses of shallow flooding can already provide substantial habitat value for foraging shorebirds, and actions that increase floodplain connectivity may further increase this habitat value, particularly if flooding occurs during the critical shortfall period. Given the variation in the results across water years, we recommend that future phases of Floodplains Reimagined evaluate scenarios by estimating the net change compared to these baseline results in the number of bird-days supported both by individual water year and in summary statistics across the set of water years. The net change for an individual water year will provide insights into impacts of a proposed action under a particular hydrological condition, while the net change in the mean across water years can provide insights into any impacts on the reliability and resilience of shorebird habitat across a range of hydrological conditions.

We also recommend future phases of Floodplains Reimagined continue to evaluate both the total number of bird-days supported and the number within the spring critical shortfall period. With the extensive loss of historical wetlands, shorebird populations are presumed to have declined substantially from historical levels, and any habitat support for bird-days during the nonbreeding season is expected to contribute to shorebird conservation on the Pacific Flyway. However, habitat during the fall and spring critical shortfall periods is particularly limited, and thus we expect any change in habitat support for bird-days during these periods to be particularly important. If future hydrodynamic modeling allows, we also recommend evaluating the fall critical shortfall period (late July–September; days 28-90), which has been identified as an even more persistent need and factor limiting shorebird populations (Dybala et al. 2017; Golet et al. 2022).

Assumptions

Here, we note several assumptions of our modeling approach should be considered in interpreting the results of future scenario evaluations. First, the estimated number of bird-days supported should be considered an index for use in estimating the direction of change between water-years or scenarios, rather than an actual value, and the numbers estimated for each subregion should not be summed together to estimate their combined impact. Our modeling approach allowed the entire Central Valley shorebird population objectives to access the habitat available in each subregion on each day, such that the results reflect the maximum number of bird-days that could be supported if all shorebirds were able to locate habitat as soon as it became available. A combined model with all three subregions would allow the population to distribute across the subregions each day, impacting the daily estimates of consumption and carry-over of energy to subsequent days, while a model including other areas of the Central Valley would allow the population to distribute farther across the landscape.

Second, the original shorebird bioenergetics model was developed for use on a larger spatial scale, incorporating open water habitat throughout the Central Valley, and using remotely-sensed surface water data that was available only on a less frequent time step (Reiter et al. 2018). Thus, the original model and data sets used to develop it did not allow (or account) for frequent short pulses of flooding, as seen in the hydrodynamic models developed for Floodplains Reimagined. When these brief pulses of flooding create newly-flooded areas, they are immediately assigned the full food value in the shorebird bioenergetics model, and can be immediately consumed by the entire Central Valley shorebird population, likely overestimating the actual number of bird-days that can be supported. Any additional information on the rate of increase in the benthic invertebrate food supply from the onset of flooding would improve model results.

Finally, we assigned the food energy supply to each newly-flooded area by land cover class, based on mean values previously estimated for the CVJV for managed wetlands and rice, with values for rice also assumed to apply to corn and other field and row crops. Therefore, future scenarios including changes in land cover class may have a substantial impact on the results of the shorebird bioenergetics model, particularly changes to or from a suitable land cover class. In addition, we recognize that the food supply available to shorebirds in each parcel is likely to vary, by factors including vegetation cover, water supply, and other environmental conditions. Data on the spatial and temporal distribution of benthic invertebrates is sparse in the Central Valley, and future research to further develop our understanding of the factors and management practices that promote the food energy supply for shorebirds would greatly improve the shorebird bioenergetics model and our ability to conserve shorebird populations.

Next Steps and Recommendations

- We recommend that future phases of Floodplains Reimagined evaluate scenarios incorporating future proposed actions both by individual water year and across the set of 5 water years, to examine the impact of proposed actions on the reliability and resilience of the habitat provided across a range of hydrological conditions.

- We recommend future phases of Floodplains Reimagined continue to evaluate both the total number of bird-days supported and the number within the spring critical shortfall period, which has been identified as a need for shorebirds in the Central Valley. If future hydrodynamic modeling allows, we also recommend evaluating the fall critical shortfall period (late July–September; days 28-90), which has been identified as an even more persistent need and factor limiting shorebird populations (Dybala et al. 2017; Golet et al. 2022).

- We recommend additional research on the abundance and composition of benthic invertebrates in different land covers the Floodplains Reimagined program area, how quickly they become available following flooding, as well as research to identify the environmental factors and management practices that promote the food energy supply for shorebirds.

Acknowledgements

Thanks to Dan Smith and Jesse Rowles for their review and comments on earlier drafts of this report.

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