Appendix 3: Landscape (Ecological) Analysis

Sam Veloz, Point Blue Conservation Science

Introduction

The restoration strategy and alternatives are designed to provide a mosaic of functional and resilient habitats in the Lower Sonoma and Tolay Creek watersheds. This section of the plan evaluates how well each of the alternatives succeeds at achieving this goal up to 2100 based on the designs of the alternatives and habitat evolution in response to sea level rise.

Methods

We are taking advantage of existing models of habitat and wildlife response to sea level rise to assess the performance of each of the alternatives. Stralberg et al. (2011) used a hybrid approach to marsh accretion modeling in which projections from a point-based accretion model were spatially interpolated across the San Francisco Estuary. Hayden et al. (2019) modified these models to incorporate more extreme sea level rise projections and to allow variation of timing of restoration within an evolving landscape. Here we applied these models to each of the alternatives developed for the project.

The Marsh98 accretion model applied in the study is briefly described here, although Stralberg et al. (2011) provides additional detail. Marsh98 models accretion (the vertical accumulation of organic material and inorganic sediment) as a function of the availability of suspended sediment, depth and periods of inundation by tides and the addition of organic material. For this analysis we used constant values of 150 mg/L of suspended sediment and 2 mm/year of contribution from organic material. The model does not include the effects of erosion that are likely to occur due to changes in tidal prism or from wind wave forces. We applied a "medium-high risk" sea level rise curve from the 2018 State of California sea level rise guidance which projects an increase of sea levels of 1.9 feet by 2050 and 6.9 feet by 2100 (California Ocean Protection Council 2018). The starting elevation of each model run was based on the SonomaVegMap 3-ft bare earth LiDAR-derived digital elevation model(DEM) (2013, http://sonomavegmap.org/data-downloads/) and the 3.3-ft OPC LiDAR-derived DEM for the Detjen and West End properties.

In all cases, the model begins accretion in 2010 for all areas that are currently open to tides and continues until 2100. To assess how the timing of restoration would affect results, we ran seven different runs of the accretion model in which potential restoration areas are restored in 2022, then in 5-year intervals from 2025 – 2050. For each model run, accretion begins at the specified restoration year and continues until 2100 in areas that are not currently open to full tidal exchange.

We used habitat classes from Takekawa et al. (2013) to categorize the marsh surface by habitat class and summed the acreage of each habitat class within each potential restoration area.

We used existing models of tidal marsh bird abundance (Veloz et al. 2013) to assess whether the habitat provided in each alternative could provide functional habitat for wildlife species. Observations of four species of tidal marsh birds were made from the entire San Francisco Estuary between 2000 and 2009: California black rail (*Laterallus jamaicensis,* CA state threatened), California Ridgway's rail (*Rallus obsoletus obsoletus*, federally endangered), saltmarsh common yellowthroat (*Geothlypis trichas*, state species of special concern) and marsh wren (*Cistothorus palustris*). These species were selected as they represent a range of conservation concern from endangered to common and each species utilizes different aspects of marsh habitat thus serving as indicators for a range of marsh species. We used a statistical machine learning approach to correlate the abundance of individuals of each species to a suite of environmental variables such as elevation-based habitat metrics, salinity, channel density and distance to the bay and levees. Additional details on modeling are provided in Veloz et al. (2013). We used these existing models to project the abundance of individuals of each species to the evolved landscape at 20-year intervals (2020-2100) from the Marsh98 model results. We summarized the number of each species within each property in the study area to assess the response to the management alternatives.

We used observations of the relative abundance of fish at mature marshes and restoring marshes in the North Bay to estimate how the fish community will respond to habitat evolution and the management alternatives. We acquired data only from monitoring studies in which sampling was conducted within mature or restored marshes, thus excluding data from channels and sloughs. We evaluated data collected within the Green Island Unit of the Napa Sonoma Marshes Wildlife Area and Fagan Slough Ecological Reserve (Fagan SER) from 2009 - 2011 (URS 2012). Fish were sampled at three restoration sites and one mature marsh. We also included fish monitoring data from the Sears Point restoration project (Keegan and Lee, 2018). In all cases, marsh sites were attributed with the maximum observed relative abundance of each species at a site. We were not able to include all observations over years or months as the environmental variables (marsh elevation) of interest do not vary substantially on such a short time scale.

As sampling locations within the reports we investigated only provided the location at the resolution of the site, we summarized the mean elevation of each site where sampling occurred. We visually inspected scatter plots of the relative abundance of each species vs the mean elevation of the sites. We characterized species into groups that preferred relatively deeper water habitats (sub-tidal and mudflat habitats) and those that preferred higher elevations (mudflat to mid-marsh habitats). We included only native California species in our assessment. We were able to estimate a correlation between relative abundance and elevation for: Bay Goby (*Lepidogobius lepidus*), California halibut (*Paralichthys californicus*), Central California Coast steelhead (*Oncorhynchus mykiss*), Pacific herring (*Clupea pallasii*), staghorn sculpin (*Leptocottus armatus*) and Threespine stickleback (*Gasterosteus aculeatus*). We could not detect any clear correlation between relative abundance and elevation for any other species.

Results

Marsh accretion models

There is a general pattern of accretion across all alternative and restoration starting year scenarios. While mid and low marsh habitats can increase in acreage between 2030 and 2070, as rates of sea level rise increase towards the end of the century, the models consistently predict that marshes will drown with the landscape dominated by mudflat habitat (**Figure 1**). Additionally, starting restoration later results in a greater proportion of high marsh habitat but less mid marsh habitat at 2050 than starting restoration early, because elevations are raised to high marsh elevation prior to breaching in the restoration design and are thus at a higher elevation than when restoration begins earlier.

There tends to be more low marsh habitat remaining in the landscape at 2090 when restoration is initiated in 2022 vs 2050. By 2100, almost all models project very little marsh habitat remaining in the landscape with the exception of close to 2500 acres of low marsh persisting at 2100 in Alternative 3 when restoration starts at 2050. However, the potential benefits of delaying restoration must be contrasted with the loss of any habitat prior to 2050 in which species could be building populations.

For the remainder of the results we focus on model runs where restoration is initiated in 2022. Alternative 3 results in the greatest range of habitats persisting consistently throughout the study period with substantially more subtidal habitat than the other two alternatives. In addition to starting with substantially more subtidal habitat than the other alternatives, Alternative 3 also begins with more high marsh and upland habitat than the other two (**Figure 2**).

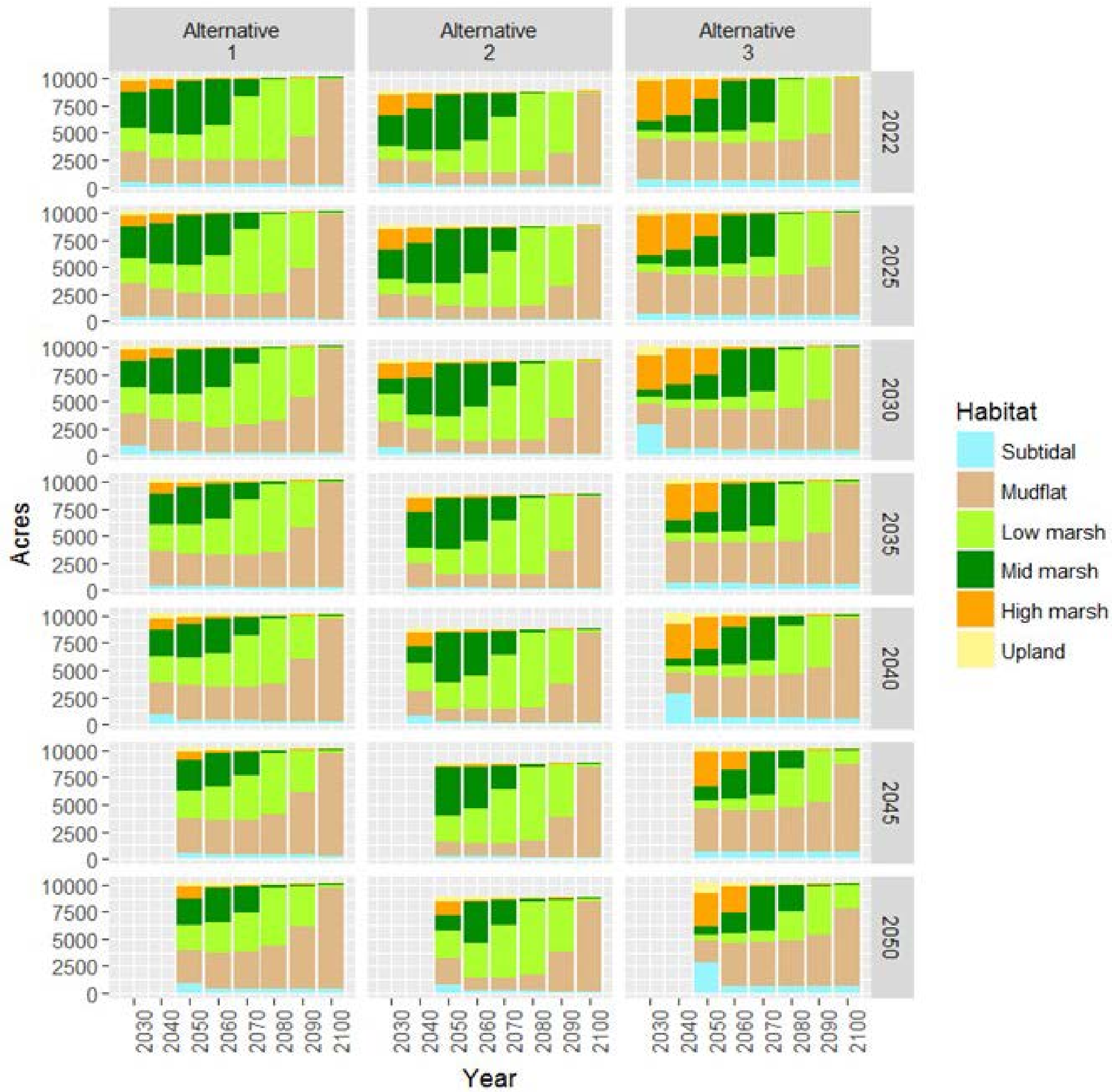

Figure 1. The acres of bayland habitats projected by the Marsh98 model in response to sea-level rise. The bars in each graph are colored by habitat type. The years along the x axis indicate the model year from the Marsh98 model. Each vertical panel represents the results from the management alternatives. Each horizontal panel indicates the year in which restoration was initiated in the model. Columns are left blank where the model year precedes the restoration year.

The high marsh habitat persists through 2050 in Alternative 3, whereas the high marsh habitat in Alternatives 1 & 2 is largely converted to mid-marsh by 2050 (**Figure 2**). Alternatives 1 & 2 achieve relatively more mid-marsh habitat than alternative 3 through 2050 but by 2060, Alternative 3 has more mid-marsh habitat than Alternatives 1 & 2. By 2080, very little mid-marsh habitat remains in any of the alternatives (**Figures 2 & 3**). Marsh98 projects that the amount of low marsh habitat substantially increases in 2070 in Alternatives 1 & 2 and by 2080 in Alternative 3, corresponding to decreases in the projections of mid-marsh habitat (Figure 2 & 3). Although there is less overall area restored in Alternative 2, Marsh98 projects similar acreage of low, mid, and high marsh habitat between Alternatives 1 & 2 (**Figure 2**).

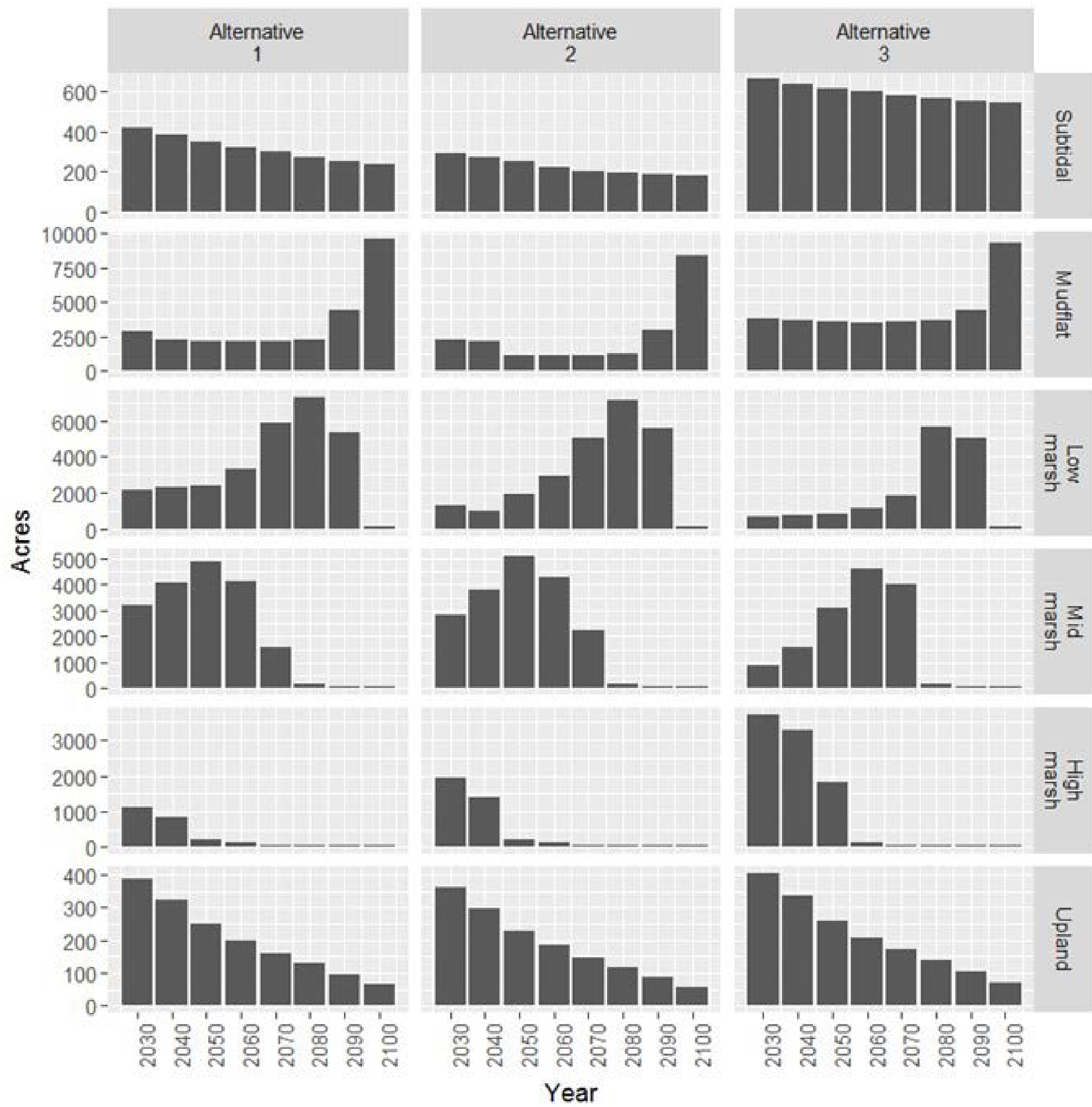

Figure 2. Acres of bayland habitat projected for each model year. Each vertical panel displays the results from each management alternative. Horizontal panels provide results by habitat classes. Restoration was initiated in 2022.

The design of each of the alternatives leads to varying spatial patterns in habitat availability across the alternatives. By 2080, Alternatives 1 & 2 result in large areas of low marsh habitat distributed fairly homogeneously across the landscape. In contrast, there is a mixture of habitats in many of the restored properties in Alternative 3, primarily mudflat and low marsh habitat by 2080 but also narrow patches of mid-marsh along the edges of properties (**Figure 3**). Detailed summaries of habitat present in each property for each alternative are available in Appendix 3A.

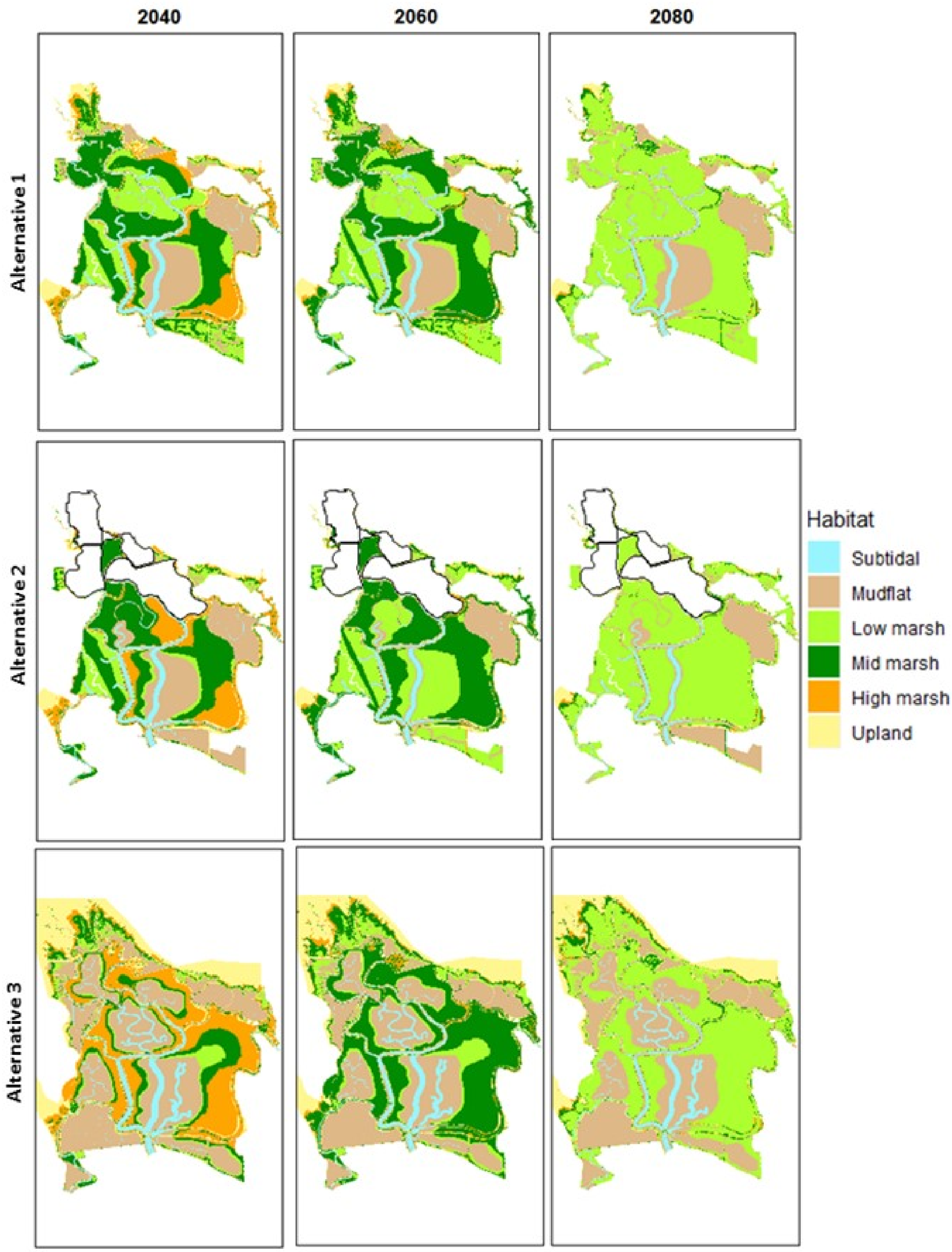

Figure 3. Maps of Marsh 98 model results. Colors indicate habitat classes. Columns indicate the model year. Rows indicate management alternatives.

Bird models
We found substantial differences in the projected abundance of each species within the study area across the three management alternatives. Which alternative resulted in the highest abundance of each species varied by when restoration was initiated and the species of interest. Across all species and models we found that birds respond fairly quickly to restoration as we project large increases in each species immediately following restoration (**Figure 4**). A peak in abundance for each species is projected around 2060 then declines in abundance as habitats begin to drown in the last half of the century. We also found a consistent pattern that starting restoration sooner results in greater numbers of each species, although this difference declines by 2080 as little marsh habitat remains irrespective of when restoration was initiated (**Figure 4**).

In general, we project decreased abundance of the four bird species in Alternative 3 versus Alternatives 1 & 2. The differences are likely due to the greater areas of non-tidal marsh habitat within Alternative 3. By 2080, where the landscapes become similar across the alternatives in terms of the amount of marsh habitat remaining (primarily low marsh, **Figure 1**), we project similar abundance of each species in each of the scenarios (Figure 4). The projected decline in abundance in each of the species between 2060 and 2080 is less pronounced in Alternative 3 versus Alternatives 1 & 2. As marshes drown by 2100, we project that all species will decline to near zero within the study properties within each of the alternatives (**Figure 4**).

The timing of restoration seems to have varying effects on the four tidal marsh species studied across management alternatives. When restoration is initiated in 2022, we almost always project greater numbers of each species in Alternative 1 versus Alternatives 2 & 3 (**Figure 4**). In contrast, when restoration is initiated in 2040, we project similar or higher abundance of each species in Alternative 2 versus Alternatives 1 & 3, with the greatest difference occurring at model year 2060.

Focusing on models in which restoration was initiated in 2022, we can see the upper limits of the abundance of each species across the alternatives. Restoration will result in dramatic increases in the numbers of each species within San Pablo Bay between 2040 and 2080 as compared to current populations. For example, we estimated approximately 300 Ridgway's rail occurred in San Pablo Bay in 2010 (Veloz et al. 2012), so restoration will result in a doubling or tripling of the 2010 population between 2040 and 2080, depending on which alternative is selected. We project similar population increases following restoration for the other three species as well (**Figure 5**). Although we project these population gains are essentially lost by 2100, the restoration can create habitat from which species can migrate to newly available habitats beyond the study region.

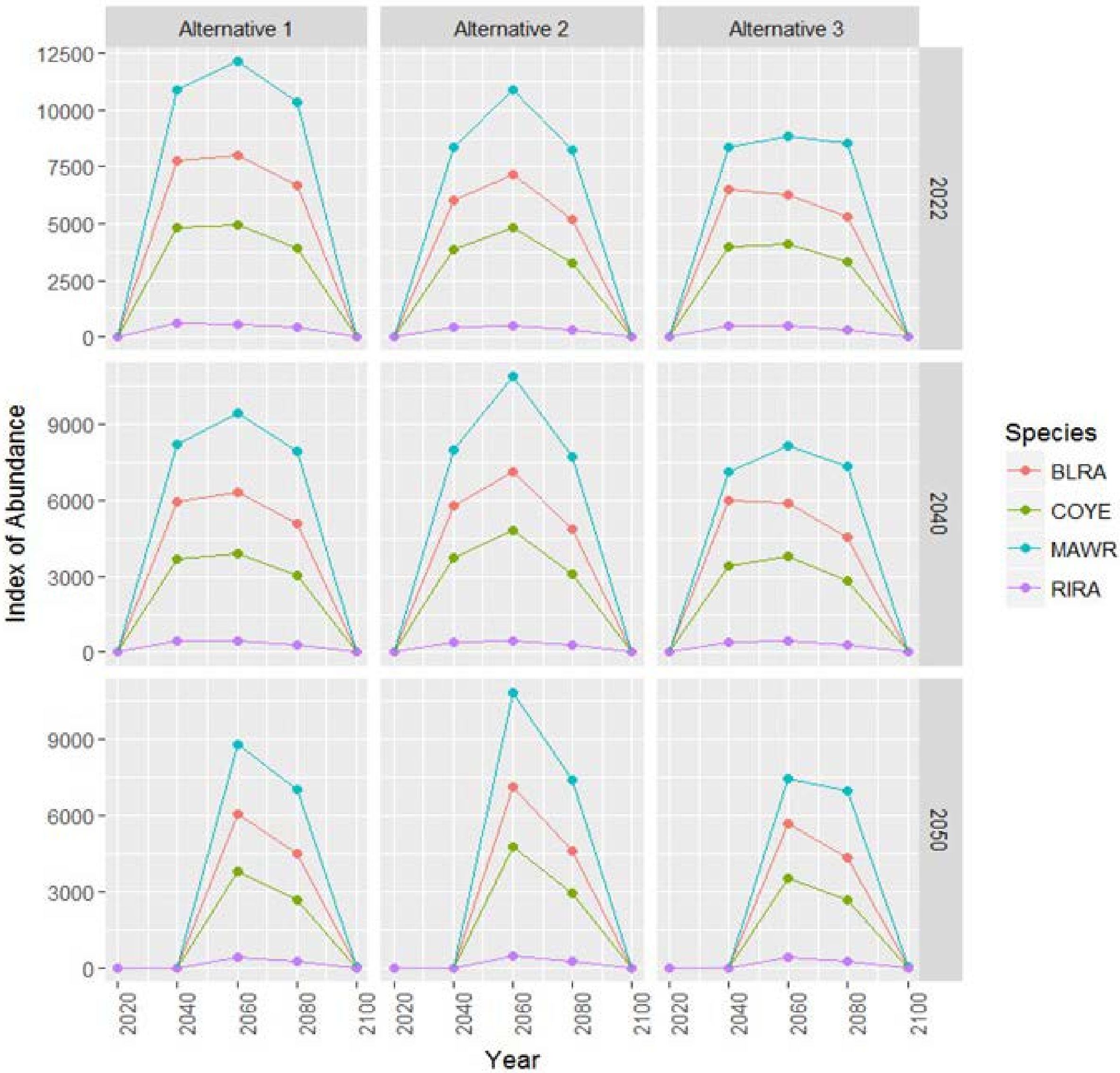

Figure 4. Index of the projected number of individuals of four species of tidal marsh birds; black rail (BLRA), common yellowthroat (COYE), marsh wren (MAWR) and Ridgway's rail (RIRA). The horizontal axis indicates the year of the model results. Each vertical panel represents a management alternative. Each horizontal row represents the year restoration was initiated in the model.

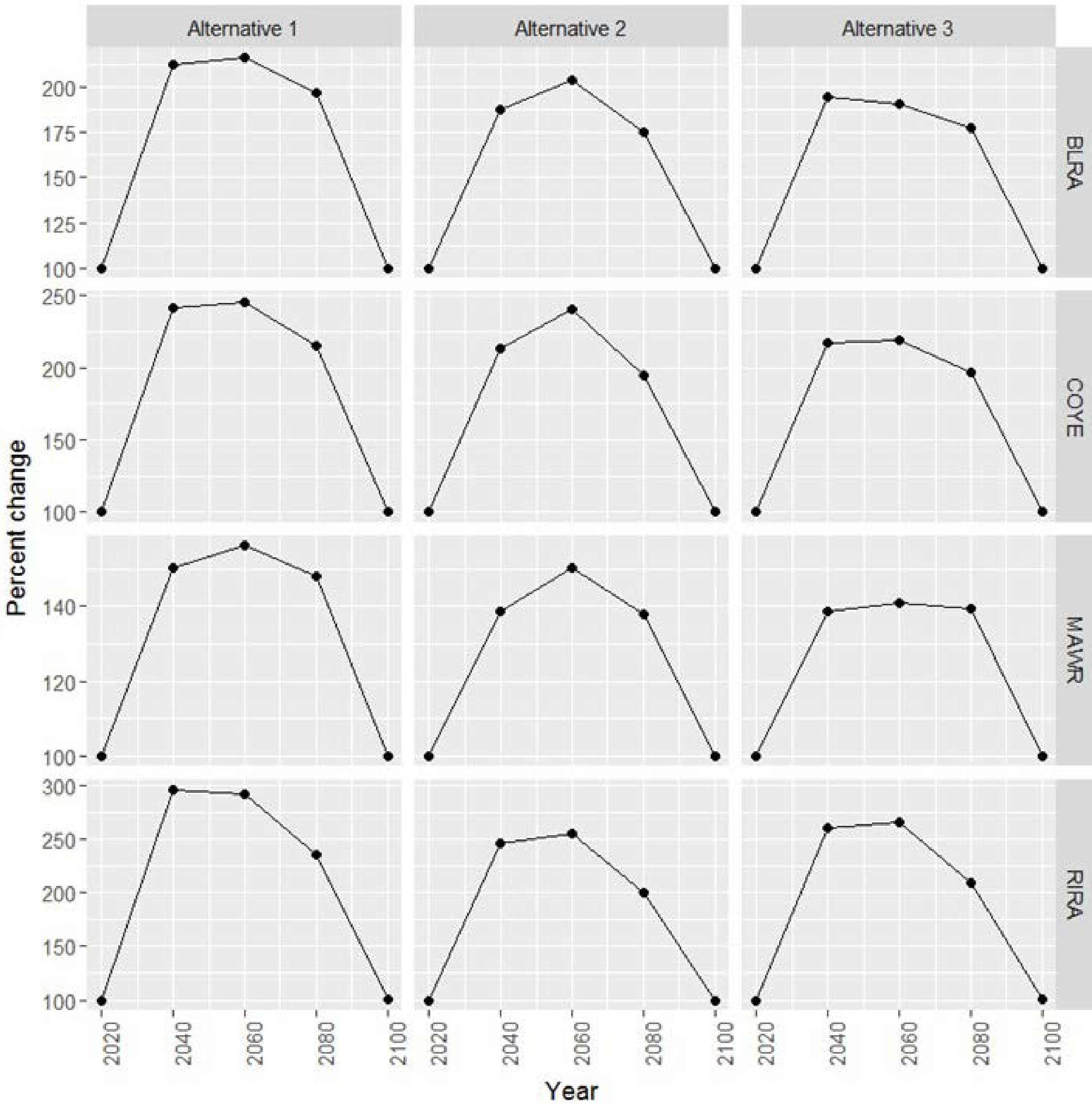

Figure 5. Percent change in the 2010 San Pablo Bay population for each of four species of tidal marsh birds; black rail (BLRA, 6,900), common yellowthroat (COYE, 3,400), marsh wren (MAWR, 21,700) and Ridgway's rail (RIRA, 300). Values following the acronym here are the 2010 population estimate in San Pablo Bay for each species from Veloz et al. (2012). Restoration was initiated in 2022 for these results.

Fish observations

With the limited observation data available for this assessment we were only able to coarsely characterize fish habitat into those that prefer deeper waters (subtidal - mudflat habitat) and those that prefer shallower habitats (mudflat - mid-marsh). Our assessment classified bay goby, California halibut and staghorn sculpin as species that prefer the deeper habitats within baylands with the highest relative abundance of these species found at sites with mean elevation < -0.6 m MHHW. Central California Coast steelhead, Pacific herring and threespine stickleback were all found at higher relative abundance at sites with mean elevation > -0.3 m MHHW.

Using these coarse classifications we can qualitatively ranking of the three management alternatives by how they affect fish species. Alternative 3 that results in the highest proportion of mudflat and subtidal habitat would provide the somewhat more preferred habitat. Similarly, as marshes lose elevation with increasing sea level rise, the increase of low elevation habitat should benefit the deeper habitat associated species. In contrast, the species more closely associated with lower marsh elevations will likely experience a decline in the quality of their habitats as the marshes drown with increasing sea level rise.
The assessment of fish habitat we provide here should be considered extremely preliminary as we had very limited data with which to estimate habitat preferences. Conducting surveys across more sites that better sample the range of marsh elevations would help enhance our assessment and allow quantitative predictions of fish response to restoration and marsh evolution.

Discussion

Our survey shows that restoration will substantially increase habitat that will result in increases in the populations of tidal marsh dependent species within the study area between 2020 and 2080. With high rates of sea level rise, we do project that by 2100 this habitat will largely be lost as marshes drown. However, with lower rates of sea level rise, previous surveys have shown that these habitat gains and subsequent population gains may be resilient beyond 2100 (Veloz et al. 2013). If rates of sea level rise are as high as assumed for this analysis, maintaining the population gains that follow restoration will require additional habitat restoration and space for marsh migration in currently upland areas.
The benefits of each of the alternatives relative to one another are assessed by focusing on the abundance of four representative tidal marsh species. However, there is no clear preferred alternative based on that metric alone as the results vary by when restoration is initiated and which species is used. Additionally, the other habitats not included in our assessment, subtidal and mudflat, will likely provide habitat for fish and wildlife such as shorebirds and waterfowl. It is possible that including a wider range of taxa in the assessment of benefits across alternatives would result in a different perspective of which alternative could provide the greatest benefits to biodiversity.

Creating higher habitat within restoration sites that provides migration space as sea levels rise seems to be the most resilient strategy for maintaining marsh habitat for the longest period of time. Starting elevations within alternative 3 are higher within some of the properties considered and these areas provide the most resilient habitat within the restoration areas. Additionally, we project that areas of fringing infill wetlands will develop in areas that are currently at upland elevations outside the planning area. If these areas were protected as open space, the habitat created through restoration in each of the alternatives could provide source populations in the future from which individuals could colonize newly evolving habitat outside the planning area.

References

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