Phalarope Migration Surveys
June – September 2023

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Contents

List of Tables

List of Figures

Executive Summary

The South Bay Salt Pond Restoration Project (SBSPRP) is restoring over 15,000 acres of former salt evaporation ponds to a mix of tidal marsh and ponded wetland habitats. These wetlands provide habitat for many waterbirds, including migrating Red-necked Phalarope (*Phalaropus lobatus*) and Wilson's Phalarope (*P. tricolor*). Sustaining baseline population goals for wildlife populations requires understanding how species are responding to restoration actions over time. While many waterbird guilds have increased in abundance from pre-restoration baselines, phalarope numbers have declined >50% below baseline numbers. The purpose of this ongoing study is to understand observed declines in phalarope numbers within the SBSPRP area and their relationship with broader population trends and phalarope movements. This report serves as a data summary and coarse-scale assessment of phalarope monitoring efforts in the South San Francisco Bay during the 2023 migration.

From June 19, 2023 to September 26, 2023, we conducted phalarope migration surveys at 31 sites (**7** Cargill-managed salt production ponds, 17 SBSPRP managed ponds, and **7** sites outside of these areas). We also sampled water quality at all sites twice between July 4, 2023 and October 12, 2023.

The surveys found that counts of Wilson's Phalaropes peaked at 1056 on 07/17 and counts of Red-necked Phalaropes peaked at 6,616 on 08/28. Across all sites, a total of 17,233 phalaropes were counted throughout the summer (1,671 Wilson's, 14,613 red-necked, and 949 that could not be identified to species). Looking only at the 24 sites within SBSPRP area, a total of 14,406 phalaropes were counted throughout the survey season (1,348 Wilson's, 12,171 red-necked, and 887 that could not be identified to species).

Peak counts for Wilson's Phalarope have been steady since 2020, but increased by 44% this year. Red-necked Phalarope numbers increased by 52% compared to 2022, bringing the count back to the same level it was in 2021. The proportion of unidentified phalaropes relative to total observations decreased slightly from 2022 and continues to be a complicating factor in species-level analysis, but taking the measure of assigning them to the most likely based on survey date does not change the peak counts/dates or the direction of the trends for season totals for either species. Calculations to compare the current year's survey data against the revised July–September NEPA/CEQA baseline by 62%, and therefore remain below the management trigger of more than 50% below baseline values.

We reanalyzed the historical salt pond survey data using the new recommended windows of July–September for both total phalaropes and Red-necked Phalarope and Wilson's Phalarope separately. The resulting trendline shows an even steeper decline in phalaropes between 2004–2011, though with large variability in annual counts. Species-specific trends showed that Red-necked Phalaropes and Wilson's Phalaropes both declined concurrently, though because Red-necked Phalaropes were more abundant overall, this species contributed more to the trends in total phalarope counts. This disproves the hypothesis that declines were driven by loss of Wilson's Phalaropes while Red-necked Phalaropes persisted because the former are believed to be more specialized on hypersaline habitats than the latter. However, there is still evidence that Red-necked Phalaropes have responded better to the changes in pond management under the SBSPRP than Wilson's Phalaropes have. By the early 2010s, Red-necked Phalaropes were almost entirely extirpated from salt production ponds while they persisted in SBSPRP ponds, while Wilson's Phalaropes had been almost wholly extirpated from SBSPRP ponds but persisted in salt production ponds.

We modeled how changes in phalarope abundances within each pond related to habitat characteristics and annual climate, but sample sizes were too low to fit a statistically robust model and these results should be viewed as very preliminary. The top model for all phalaropes and Red-necked Phalaropes showed that populations increased as the percent of the pond that was flooded with open water increased, and decreased as ponds were dried out. For all phalaropes only, the top model showed increasing abundance was positively related to increasing pond pH. Wilson's Phalaropes showed a strong negative relationship with precipitation, with populations declining in response to greater precipitation in the previous three years.

At the pond-level, phalarope abundance continues to not align with expectations around their preference for high-salinity ponds. During the current and previous year the majority of phalaropes, 85% and 96% respectively, were found in medium- and low-salinity sites, suggesting that they may be using different selection criteria.

As the SBSPRP progresses, we recommend a precautionary approach to waterbird habitat management and tidal marsh restoration. Enough ponds within the project area should be maintained to provide a variety of salinity and water levels suitable for many different guilds. Special consideration should be given to understanding what influences phalarope site selection and preserving ponds with those characteristics. Continued dedicated monitoring of phalaropes and analysis of external datasets will be valuable in assessing the decline in survey counts since pre-restoration baselines. Future phalarope migration surveys are needed to estimate inter-year changes in abundance that could be used to assess the relative importance of broader-scale climatic drivers (or breeding ground conditions) versus local management and habitat characteristics on the observed declines. Other research groups have begun capturing and fitting phalaropes with tracking tags, and future tudy of movement data when it is available will aid in estimating population sizes and understanding phalarope migration between stopover sites.Introduction

In 2003, the U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Wildlife (CDFW, formerly California Department of Fish and Game) entered into an historic agreement with Cargill Salt to acquire 15,100 acres of salt evaporator ponds in the South San Francisco Bay. The South Bay Salt Pond Restoration Project (SBSPRP) has begun to restore the area to a mix of tidal and ponded habitats while continuing to provide flood protection and improved public access to many sites.

Salt ponds have been present in the San Francisco Bay for over 150 years (Ver Planck 1958) and have significant wildlife value (Anderson 1970, Accurso 1992, Takekawa et al. 2001, Warnock et al. 2002). Due to the loss of wetlands elsewhere, the ponds now provide important foraging and roosting areas for many waterbirds. As a major migratory and wintering location along the Pacific Flyway, the San Francisco Bay supports more than a million birds throughout the year (Page et al. 1999, Warnock et al. 2002). The SBSPRP has committed to restoring some ponds to tidal marsh, while retaining some pond habitat (as managed ponds) within the project area for waterbirds. Today phalaropes during migration use an area which includes a mix of SBSPRP-managed ponds SBSPRP-restored tidal marsh, ponds still operated for salt production by Cargill Salt, and other wetland habitats within South San Francisco Bay.

More than a decade of waterbird counts show that many waterbird guilds increased in abundance relative to the SBSPRP's NEPA/CEQA baselines, which were established prior to implementation of project restoration and enhancement actions (Tarjan 2019a). However, combined counts of two phalarope species, Red-necked Phalarope (*Phalaropus lobatus*) and Wilson's Phalarope (*P. tricolor*) showed a decline of 78% from prior to the start of restoration project activities by 2017 (Tarjan 2019a). Less frequent summer salt pond surveys during phalarope migration impeded our ability to capture phalarope use of the South Bay area. NEPA/CEQA significance thresholds require that a decline is attributed to restoration activities (South Bay Salt Pond Restoration Project, 2007). Understanding phalarope trends within the SBSPRP and how they relate to broader population trends requires targeted surveys during the peak phalarope season, supplemented with evaluation of external datasets that may offer insight into broader regional trends and explanatory factors such as habitat quality and SBSPRP management changes.

Through an analysis of the existing dataset and eBird observations (Tarjan 2019b), we found that Wilson's Phalarope exhibited one peak that clustered in late summer, whereas Red-necked Phalarope showed one peak in spring and were present for a more prolonged period in late summer to early fall. Both species showed similar preferences for select sites, suggesting that surveys could target specific areas. Based on these results, SFBBO made the following recommendations: 1) Capturing the peak migration for the two common phalarope species in San Francisco Bay requires conducting two sets of surveys, one set centered around July 17 for Wilson's Phalarope and one set centered around August 24 for Red-necked Phalarope; and 2) Surveys of 24 SBSPRP and Cargill-managed ponds are likely to capture >95% of phalaropes on SBSPRP ponds; eBird sightings suggest adding 7 sites outside the traditional SBSPRP survey area to the phalarope surveys.

In accordance with these recommendations, SFBBO piloted two surveys during peak phalarope migration in 2019. In 2020, due Covid-19 safety requirements, we conducted surveys across the full range of seven dates at only a subset of sites. We conducted surveys at all sites on all dates during years 2021-2023. This report summarizes the results of SFBBO's phalarope surveys in the South San Francisco Bay from 2019 through 2023.

To shed light on historical trends, we also reanalyzed data from the historical salt pond surveys to model species-specific trendlines and thresholds using the new recommended July–September survey window (Burns & Van Schmidt 2023). We hypothesized that the unexpected results that phalaropes appear to be selecting low- to medium-salinity sites (Burns et al. 2023, Van Schmidt & Parsons 2023) would be explained by Red-necked Phalaropes, which are less specialized on saline habitats, faring better post-restoration while most declines would be in Wilson's Phalaropes, which are generally regarded as saline specialists (LaBarbera et al. 2023). Lastly, we applied the habitat trend model of Van Schmidt & Parsons (2023) to the phalarope migration survey dataset to analyze whether site-scale habitat characteristics or annual climate could explain observed changes in phalarope population sizes.

Methods

Study Area

The study area for SFBBO's annual waterbird monitoring for the SBSPRP includes 82 current and former salt ponds in the Santa Clara, Alameda and San Mateo counties of California. The Coyote Hills, Dumbarton, and Mowry salt ponds are owned by Don Edwards San Francisco Bay National Wildlife Refuge and managed for salt production by Cargill Salt and theAlviso and Ravenswood complexes are owned and managed by Don Edwards San Francisco Bay National Wildlife Refuge. The Eden Landing Ecological Reserve (Eden Landing) ponds are owned and managed by California Department of Fish and Wildlife (CDFW). Sites outside of the SBSPRP footprint are owned by various other entities, including City of Sunnyvale (Sunnyvale Water Pollution Control Plant ponds) and East Bay Regional Parks District (Coyote Hills Park).

Phalarope migration surveys were conducted at a subset of these ponds as well as additional sites outside of the SBSPRP footprint (Figure 1). The SBSPRP ponds surveyed include 4 ponds in the Alviso complex, 1 pond in the Coyote Hills complex, 3 ponds in the Dumbarton complex, 10 ponds in the Eden Landing complex, 3 ponds in the Mowry complex, and 3 ponds in the Ravenswood complex. Seven sites outside of the project were surveyed: Coyote Hills Regional Park, Crittenden Marsh, Northeast of N1, New Chicago Marsh, Spreckles Marsh, Alviso Marina, and the Sunnyvale Water Pollution Control Plant.

Phalarope Migration Surveys

We conducted 8 surveys in 2023 during the season of peak phalarope migration. Surveys occurred every two weeks with the following target dates: 06/20, 07/04, 07/18, 08/01, 08/15, 08/29, 09/12, 09/26 (Table 1). Most surveys were done on a single day, but a few were completed 1-2 days before or after. Counts were collected by a combination of SFBBO staff and trained community scientist volunteers to allow all sites to be surveyed synchronously or near synchronously. Surveyors were trained to identify Red-necked Phalaropes, Wilson's Phalaropes, and Red Phalaropes (*P. fulicarius*). However, the Red Phalaropes are rare in South San Francisco Bay and were not observed, and therefore are not covered by this report.

During each survey period, all sites were surveyed as close in time as possible, with most being surveyed simultaneously between 8:00 AM and 12:00 PM. Surveyors identified and counted phalaropes at each site from the nearest drivable levee using spotting scopes. Data included species counts, date, survey start time, survey end time, an estimate of the percent of the site that was visible to the observer, and an estimate of the percent of the site that was covered in water.

In order to ensure we do not miss sites that are newly colonized by phalaropes as habitats change, we also encouraged surveyors to scan other nearby ponds for phalaropes and collected observations from agency staff. We report significant incidental sightings in this report, but excluded them from counts to allow for comparison with previous years and because these ponds were not surveyed in all time periods.

Water Quality Sampling

For the first time this summer, we sampled water quality at all 31 of the survey sites (including sites outside of the SBSPRP and Cargill ponds) during summer (July 4–July 10) and in early fall

2022 (September 1–October 12). The water sampling did not necessarily occur on the same day as the phalarope counts, however we do not expect pond salinity to vary widely over a matter of a few days or weeks. We recorded dissolved oxygen, salinity, conductivity, pH, and temperature at one sampling location at each site using a Hydrolab Minisonde (Hydrolab-Hach Company, Loveland, CO). When salinities exceeded approximately 72 ppt (the maximum value registered by the Hydrolab Minisonde), we calculated salinity using a hydrometer (Ertco, West Paterson, NJ) to measure specific gravity in combination with a temperature reading from the water sample. We calibrated all Hydrolab Minisonde sensors before the start of each sampling day. We followed water quality monitoring methods outlined by Murphy et al. (2007). Sites were classified as low (0-60 ppt), moderate (61-120 ppt), or high (>120 ppt) salinity.

Data Summary

We calculated the total counts and peak counts for each species, and both species combined. Counts were summarized across the entire study area, SBSPRP project footprint only, site-specific, and in each of the three salinity bins. We visualized phalarope trends using the ggplot2 package (Wickham 2016) in R version 4.3.1 (R Development Core Team 2018).

We also reassessed trends from historical salt pond survey data (described in Tarjan 2019a) for the revised July-September window recommended by Burns and Van Schmidt (2023). Following the methods of Tarjan (2019a), we used Loess regression curves to model change in abundance over time. We also fit separate models for both Red-necked Phalaropes and Wilson's Phalaropes in order to determine whether historical declines in total counts were more strongly driven by one of these two species. For total phalarope counts, we compared it to the new recommended baseline of 5,324 (Burns and Van Schmidt 2023). For the species-specific counts, we calculated a comparable new baseline as the mean July-September total counts across all salt pond sites for each species from 2005-2007. These new recommended baselines for comparison to the new survey methodology do not replace the regulatory NEPA/CEQA baselines, but provide an improved method for analyzing and understanding trends.

Habitat Trend Model

We modeled whether pond characteristics, water quality changes, and climate drove observed inter-annual changes in seasonal population size within ponds for three groups: (1) all phalaropes (total count), (2) Red-Necked Phalarope, and (3) Wilson's Phalarope. Our modeling approach followed that of Van Schmidt and Parsons (2023). Briefly, we used linear models (package *stats*) in R v4.1.3 and v4.3.1. For each species, and both combined, we calculated abundance during the summer migration as the sum count at each pond across all surveys during that season. We used the sum of counts rather than the average because of the addition of June surveys in 2022, which largely consisted of zero counts and would therefore artificially pull down the averages. We then calculated the dependent variable as:

$$\%\ Change\ in\ Abundance = \mathrm{Ln}(1 + ((Abundance_t - Abundance_{t-1}) / (Abundance_{t-1} + 1)))$$

Zero change could indicate either a stable population, or no population (Abundance = 0 in both year t and year t-1). The latter represents a different process and likely conflates large amounts of habitat that may be wholly unsuitable. Unlike previous studies (e.g., De La Cruz et al. 2018), we sought explicitly to model drivers of observed changes in populations, not abundance or habitat selection. We therefore removed all ponds that had zero phalarope sightings during both years from the dataset. It is important to keep in mind when interpreting our results that factors which might be very important in rendering a habitat suitable or unsuitable overall were by design excluded from the scope of our assessment.

Table 2 shows the resulting number of ponds with phalarope counts, water quality samples, and complete cases in each year. Note that for a pond to have a "complete case" it needed to have detections in both the current and previous year, and a full set of water quality measurements. Because surveys only began in 2019, and water quality information was not collected in year 2020 due to the COVID-19 pandemic, only 2021 to 2022 and 2022 to 2023 had complete cases that could be included in the analysis. As a result, the final sample sizes were small (n = 40 for all phalaropes and Red-necked Phalarope, and n = 12 for Wilson's Phalarope).

A full list of variables we assessed is in Table 3; see Van Schmidt and Parsons (2023) for descriptions of how each variable was measured. Water quality, water elevation, and percent open water measures were averaged from all observations the first set of salt pond surveys in the fall (September 1–October 14) and, for 2023, our new summer surveys in July.

We carried out a model selection exercise based on corrected Akaike's Information Criterion (AICc; calculated in package *AICcmodavg*). Due to the small sample sizes, we had to modify the model selection procedure of the previous study. As a rule of thumb, statisticians recommend 10 observations per covariate. Our set of candidate models therefore only included all combinations of up to four covariates for all phalaropes and Red-necked Phalarope, and up to two covariates for Wilson's Phalarope. Unlike the previous study, because of the limited number of covariates we could include, we did not bundle change measures and raw measures in candidate models (e.g., we allowed "Salinity_AC" without "Salinity"). We first estimated a "base" model of static pond characteristics (Table 2, "base" in column *Stage*). We selected the top model from this assessment to carry forward as the base model. The base model selection tables are in Appendix I. Model selection on the remaining variables was the main focus of our study. The full modelset was all permutations of column variables in the "main" category, appended to a single (static) "base" model that was unique to each of the three taxa groups. LDO_mgL and LDO_mgL_AC, and LandfillDist_km and OpenHunting_pct, could not be included in the same candidate models because their correlation was >0.7. For Wilson's Phalarope, multicollinearity was a worse issue because of small sample sizes (n = 12 complete cases), so we also had to drop any candidate models that included both Salinity_AC and Temp_C, Temp_C and Temp_C_AC, and any combination of the three precipitation measures (PPT0, PPT1, and PPT3).

Results

Total Counts

Across all 31 targeted sites and 8 surveys in 2023 we counted a total of 14,063 Red-necked Phalarope, 1,638 Wilson's Phalarope, and 949 phalarope of unidentified species (Figure 2). Red-necked Phalarope were most abundant at A9, Sunnyvale WPCP, and E6. Wilson's Phalarope were most abundant at A9, New Chicago Marsh, and Spreckles Marsh (Figures 3, 4). Excluding the seven sites outside of the SBSPRP and Cargill areas, we observed a total of 11,621 Red-necked Phalarope, 1,315 Wilson's Phalarope, and 887 phalarope of unidentified species, for a grand total of 13,823 birds. Within the SBSPRP footprint, Red-necked Phalaropes were most abundant in ponds A9, E6, and E13 and Wilson's Phalarope were most abundant in ponds A9, E4, and E5. The July–September 2023 survey round mean counts are 62% below the revised baseline of 5,324, meaning that counts remain below the trigger threshold for phalaropes.

Surveyors and agency staff reported phalaropes at four sites that were not currently part of our survey effort. These were E5C (2,880 Red-Necked Phalaropes, 3 Wilson's Phalaropes), AB2 (45 Red-necked Phalaropes, 2 Wilson's Phalaropes), E14B (21 Red-necked Phalaropes), Hayward Regional Shoreline (4 Red-necked Phalaropes, 21 Wilson's Phalaropes), and Lockheed Pond (10 Wilson's Phalaropes). This means that our surveys represented 83% of known Red-necked Phalarope sightings and 98% of known Wilson's Phalaropes sightings. With the addition of E5C to the surveys, we would have captured 99% of Red-necked Phalarope sightings. However, not all of these detections were during survey window weeks, further complicating interpretations. This makes it unclear whether these observations were double-counting birds, and including them in the formal numbers reported makes it problematic to calculate a peak count because the set of sites is inconsistent across the different survey windows. Therefore, they have not been included in the totals for this report. Including these counts does not change whether the current survey round mean is below the revised baseline.

Peak Counts

Across all sites, counts of Wilson's Phalaropes peaked at 1,035 birds during the survey beginning on 07/17 and counts of Red-necked Phalaropes peaked at 6,616 birds during the survey beginning on 08/28. Within just the SBSPRP footprint, counts of Wilson's Phalaropes peaked at 1,030 birds during the survey beginning on 07/18 and counts of Red-necked Phalaropes peaked at 2,971 birds during the survey beginning on 09/01. These peaks indicate that the current survey schedule largely spans the period when phalaropes are present in the area (Figure 2). When taken with data from past years, they indicate a level of variability in migration timing that suggests we should continue our broad range of survey dates, including the new date in late June.

Unidentified Phalaropes

Observations of unidentified phalarope present a particular challenge when analyzing data to understand species-specific trends. In 2023, unidentified species represented 5.5% of the total observations, versus 7.0% in 2022 and 8.0% in 2021. Handling of unidentified observations is a challenge for phalarope studies across their migration range and there is no agreed upon best practice for whether or how to include them in analysis (Carle et al. 2022). One estimation method is to assign all unidentified individuals to species based on which migration peak they were observed in (e.g. unidentified phalarope in July would be cast as Wilson's). When applying this method to 2023 numbers, the peak count nor date changed for either species. The majority (888 of 949) of unidentified phalaropes were observed during the Red-necked Phalarope migration window.

Trends Across Years

The total counts for phalaropes were higher this year than in the past two years, however the data does not show a consistent up or down trend. Counts of Wilson's Phalarope were similar in 2021 and 2022, but increased by 44% this year in comparison with last year. However, Wilson's Phalarope numbers are lower than 2020 counts, during which fewer sites were surveyed due to

Covid-19 restrictions. Red-necked Phalarope also increased this year in comparison to last year by 52%, resulting in the highest count since targeted phalarope migration surveys began. Unidentified phalarope counts from this year were similar to 2022 counts.

In 2019, coordinated monitoring of phalarope staging sites in western North America began (Carle et al. 2022). Between 2019 and 2022 there was an overall decrease in the range-wide peak counts for both Wilson's and (to a lesser extent) Red-Necked Phalarope (Carle et al. 2023), but 2023 numbers showed strong increases at almost all staging sites, in agreement with our results. Region-wide, phalaropes had a very strong year, with increases of >20,000 birds in overall phalarope numbers at Lake Abert and Owens Lake, and the highest count at GSL of any survey since they began in 2019. At Mono Lake, Red-necked Phalaropes also had their highest year since 2019, though Wilson's Phalarope decreased by half their 2022 levels (Carle et al. 2024). Notably, these increases followed an extremely wet winter that greatly increased water levels at Great Salt Lake, Lake Abert, Mono Lake, and Owens Lake (Carle et al. 2024). This suggests that region-wide trends were likely responsible for the increases in phalaropes observed in the South Bay study area this year.

Historical Trends in Salt Pond Surveys

We reanalyzed the historical salt pond survey data using the new recommended windows of July-September for both total phalaropes and Red-necked Phalarope and Wilson's Phalarope separately (Figure 5). The resulting trendline shows an even steeper decline in phalaropes between 2004-2011, though with large variability in annual counts. Declines are strongly driven by six observations of over 5,000 average monthly counts, which were never observed after the Project's first decade.

Species-specific trends showed that Red-necked Phalaropes and Wilson's Phalaropes both declined concurrently, though because Red-necked Phalaropes were more abundant overall, this species contributed more to the trends in total phalarope counts (Figure 5). This disproves the hypothesis that declines were driven by loss of Wilson's Phalaropes while Red-necked Phalaropes persisted because the former are believed to be more specialized on hypersaline habitats than the latter (LaBarbera et al. 2023, Burns et al. 2023). However, there is still evidence that Red-necked Phalaropes have adapted better to the changes in pond management under the SBSPRP than Wilson's Phalaropes have. Red-necked Phalaropes showed rapid decline in both SBSPRP ponds and salt production ponds in the 2000s, but were almost entirely extirpated from salt production ponds while they persisted in SBSPRP ponds (Figure 5). In contrast, Wilson's Phalaropes had been almost wholly extirpated from SBSPRP ponds by the 2010s, while they persisted in salt production ponds. Both species saw a brief resurgence in abundance in salt production ponds from 2012-2015.

Drivers of Abundance Changes

We modeled how changes in phalarope abundances within each pond related to habitat characteristics and annual climate. As in Van Schmidt and Parsons (2023), no static pond characteristics or pond location characteristics were supported in model selection (Appendix 1; Tables A1.1-A1.3). Model power was low due to the small sample sizes, with only two years of turnover able to be modeled due to missing water quality samples.

The top model for all phalaropes showed that populations increased as the percent of the pond that was flooded with open water increased, and decreased as ponds were dried out (Figure 6). We also found evidence that as pond pH increased, so too did its abundance (and vice versa). This was unexpected, as this relationship was not observed in the historical salt pond survey dataset, while negative relationships with salinity, dissolved oxygen, water depth, and minimum air temperature were. There was some support for these relationships (most notably a negative relationship with salinity) in model selection (Table 4), but these covariates did not enter into the top model. However, our statistical power to detect relationships was weak, with confidence intervals for all modeled relationships overlapping zero.

Because most phalaropes observed were Red-Necked Phalaropes (Table 1), the modeled relationships for “all phalaropes” were similar to this group, and should be interpreted as being primarily the result of its habitat preferences. Nevertheless, our results for Red-necked Phalaropes did differ somewhat from those for all phalaropes. The top model for Red-Necked Phalarope only had one covariate, which showed abundance increasing as the percent of the pond that was covered with water increased (and vice versa; Figure 6). Confidence intervals for this relationship did not overlap zero, indicating a strong result. Model selection tables showed some support for the other relationships observed for all phalaropes, including a weak negative relationship with changes in salinity (Table 5).

Wilson’s Phalaropes showed a strong negative relationship with precipitation, with populations declining in response to greater precipitation in the previous three years (Figure 6); an alternative model based on precipitation in just the current year showed nearly equal support (Table 6). While this could be interpreted to suggest that current population trends are primarily driven by precipitation, we caution that this model is very preliminary. With a sample size of only 12, only two covariates could be included at a time, and many covariates could not be included together in the same model at all due to high collinearity. The next top model was one that had positive effects of minimum temperature and negative effects of maximum temperature, which had very large standard errors indicating model convergence problems and unreliable results.

Nevertheless, this result aligns with observations at other staging sites which suggest that phalaropes to some degree shift staging site use based on annual weather. Lake Abert’s peak phalarope count has doubled in years when the lake has water compared to when it is dry, and phalarope counts at Mono Lake increased by 40,000 in 2021 when Lake Abert drying altogether (Carle et al. 2024). Following exceptional rains last winter, Owen’s Lake was significantly more flooded than it has been in past years and saw a corresponding increases in both phalarope species from <3000 to ≥30,000 birds. Furthermore, increases in counts there from one survey period to the next were directly proportional to decreases in counts at Mono Lake. Taken together, these trends suggest phalaropes may be tracking favorable conditions at staging site (Carle et al. 2024). Historic eBird observations of phalaropes in San Francisco Bay show some exceptional peaks (LaBarbera et al. 2023), which might also correspond to dry periods. Future analyses could test this hypothesis by fitting covariates to historical eBird data as well. These exceptionally high counts have not been seen in San Francisco Bay since the 1990s, despite both very wet and very dry years after 2000. This suggests that if San Francisco Bay once offered an alternative staging site in very dry years, in recent years it may not have had the carrying capacity to support such a large influx of migrants.

Phalaropes traditionally exhibit preference for high-salinity environments, such as saline lakes (Jehl 1988). As such, we would expect them to be more abundant in the remaining medium to high-salinity salt ponds surveyed compared to low-salinity ponds. This assumption is not strongly supported by the data from 2021 through 2023. Our model showed some weak support that decreasing salinity increased phalarope abundance at the site-scale, and analysis of the historic salt pond surveys showed strong support for this relationship (Van Schmidt & Parsons 2023). The most abundant sites during 2021 surveys were ones that are predominantly low-salinity, with the exception of A13, which was classified as medium-salinity. In 2022 and 2023, phalarope sightings primarily occurred in low- or medium-salinity ponds, accounting for 96% and 85% of all observations, respectively. One point of note is that in 2021, E6 was classified as a high-salinity pond and had no reported phalaropes. In 2022 and 2023, the water quality readings made it a medium-salinity pond and it was among the ponds with the greatest total abundances during both seasons.

Discussion: Recommendations for Management and Future Research

Phalarope Surveys

We suggest the continuation of these Phalarope Migration Surveys in 2024 and future years at intervals of no less than every two weeks during the peak migration period for each phalarope species. Annual surveys allow for estimation of year-to-year changes in phalarope abundance that can be compared to changes in other regions to test whether declines are driven by broad-scale annual climatic conditions or local-scale habitat conditions (Coates et al. 2020). Comparisons could also be made between rates of decline within salt ponds and non-salt pond sites. This can provide a robust approach to determining whether management actions within the SBSPRP are a significant factor in the observed ongoing declines, but requires an annual estimate of lambda to account for the high inter-annual variability in population counts, with the statistical power of this method increasing when exceptional declines are observed in multiple consecutive years.

For guilds that migrate through the area over a short timespan, such as phalaropes, frequent sampling is required during phalarope migration to understand their use of the SBSPRP area and surrounding areas in south SF Bay. Robinson-Nilsen and Demers (2012) suggested intervals of 2-3 days during the latter part of summer, so a two-week window is likely already liberal. The cessation of summer salt pond surveys in 2019 makes alternative approaches to monitoring for these declining species particularly important. We now have three complete years of data (2021–2023) and two partial years (2019–2020). Though we observed few birds in the new mid-June survey, inter-annual variability in migration timing is high and we recommend continuing it for the time being to ensure we are capturing the full range of migration of the rarer Wilson's Phalarope.

We recommend updating the set of sites surveyed to include E5C, which had a significant sighting of Red-necked Phalaropes this year (16% of all counted birds). Based on the original goal of our set of survey sites capturing 95% of likely phalarope sightings within South San Francisco Bay, adding E5C would meet this goal. These sightings highlight the importance of continuing to periodically survey for birds outside of the core set of sites, to ensure we are not undercounting phalaropes. This will be especially important as habitats continue to change as restoration proceeds because birds may shift to new sites.

Habitat Associations

Efforts should be made to understand what factors influence phalarope site preference within the salt pond project area in order to inform management decisions. At the site level, phalarope abundance in 2021 through 2023 largely did not support our assumptions that numbers would be greater in ponds with higher salinity. Results from our population change model indicate that phalarope increases have occurred where salinity has fallen (and vice versa), contrary to expectations for this saline habitat specialist (Van Schmidt and Parsons 2023). These observations have significant management implications and merit further investigation.

We conducted a preliminary model of the relationship between site-scale inter-annual population trends and habitat and climate variables (Figure 6). However, it is important to note that due to the very small sample sizes of complete observations of both phalarope population sizes and water quality variables ($n = 40$ for Red-Necked Phalarope and all phalaropes, and $n = 12$ for Wilson's Phalarope), results from this model should be interpreted very cautiously. Statisticians recommended sample sizes have at least 10 observations per covariate assessed, so we do not yet have adequate sample sizes to conduct a full model. Data from 2019–2021 was largely unusable (except for calculating changes from 2021 to 2022) because water quality samples were not collected during late spring/early fall waterbird surveys in 2020 due to the COVID-19 pandemic. This highlights the critical importance of maintaining annual surveys: a single missed year of either water quality sampling or waterbird counts renders not only the data in that year unusable for modeling drivers of changes in abundance, but also data in the previous and subsequent year.

This year, we began taking a single round of water quality samples during July to ensure we had at least one data point for each site near the start and the end of surveys. Assuming we continue this concerted effort to conduct water quality sampling at all sites going forward, we would expect at least 20 additional usable observations of population change each year. In this case, a model properly assessing all six of the "change in water quality" variables could be possible after one more year of surveys, a model assessing all of these and the five climate variables in four more years, and a model assessing these and the raw water quality parameters (i.e., "Salinity" instead of "change in salinity") and their interactions in over a decade. Surveying additional ponds (such E3C which was not included in the original set of 31 ponds but which had significant observations) would improve the rate of annual sample collection to hasten this process, though it is fundamentally limited by the rarity of phalaropes in South San Francisco Bay and the relatively small subset of ponds used by them. Improved statistical power could be achieved more quickly by developing a data fusion model that includes both historic waterbird counts (Van Schmidt & Parsons 2023) and contemporary migration surveys. Due to differences in survey protocols, this would require a more complex state-space model that could directly estimate the underlying abundances that underlie the raw counts via linking a "process model" and an "observation model" in a Bayesian statistical framework (Auger-Méthé et al. 2021).

Alternatively, investigation into other site characteristics, especially prey abundance, could more directly identify phalarope habitat needs. These might more directly correlate with phalarope site selection than salinity, dissolved oxygen, pH, water temperature, and water depth, which are likely underlying factors that drive phalarope population trends because they support prey abundance. It could also be informative to compare our data with water quality characteristics of other major stopover sites such as Mono Lake and Great Salt Lake, and examine how these relate to prey abundance at those sites as well.

Movement Ecology

Additional study would be useful to investigate the stopover time of phalaropes in the Bay Area during migration. This would make it possible to estimate the likelihood of counting the same individuals across multiple surveys, enabling the instantaneous counts produced by the surveys to be better converted to true population size estimates. There is some evidence that suggests birds may switch from using one site to another during years when conditions are less favorable (Carle et al. 2022), but research has yet to confirm the frequency or scope of this behavior.

One avenue of investigation would be to analyze data from Motus towers that have recently been or are currently being installed around the Bay Area. Motus tags were successfully deployed by researchers on phalaropes for the first time this summer (Tarr & Carle 2023). Their success suggests that boat captures and spotlighting at night may be effective. In a separate effort, two Wilson’s Phalaropes fitted with satellite tags by researchers in Tule Lake this summer were detected migrating through South San Francisco Bay though it is unclear whether they used it as a stopover point (Tarr & Carle 2023). These birds continued on to Baja California, with a distinctly different migratory pathway than other phalaropes tagged in Tule Lake that continued inland via Mono Lake to central Mexico. SFBBO has installed one Motus tower near the Alviso ponds and is currently working to install two others at sites in the South Bay. If some of the tagged birds migrate through the Bay Area and are detected by one of the new Motus towers, it will give us insight into their stopover time. Because of the now low number of Wilson’s Phalarope in San Francisco Bay compared to Mono Lake, relying on birds tagged elsewhere to elucidate movement between these two potentials paths is unlikely to be fruitful. Tagging phalaropes in San Francisco Bay will likely be much more effective at determining how (and how frequently) phalaropes move between San Francisco Bay and other stopover sites (e.g. Mono Lake) within and between migrations.

Management Recommendations for the South Bay

After controlling for protocol differences between these surveys and those used to compute the NEPA/CEQA baseline, the 2023 counts are 62% below the revised baseline of 5,324, which is below the trigger value of 50% below baseline (LaBarbera et al. 2023). A link between SBSPRP management actions and ongoing declines has not been scientifically proven, but the precautionary principle suggests conservative management to prevent further declines until such a statistical test has been conducted. Significant work has been completed in recent years to contextualize the declines within South San Francisco Bay with historical trends throughout California (Tarjan 2019a, LaBarbera et al. 2023) and to develop a model that can relate the observed decline in the early years of the SBSPRP to habitat and climate covariates (Van Schmidt & Parsons 2023). We have here extended these models to be species-specific and assess the Phalarope Migration Survey data. These efforts have continued to highlight confounding results around the relationship between phalarope abundance and salinity (and changes in salinity).

Until these relationships can be thoroughly interrogated with additional analyses (i.e., predictive models or decomposing the relative contribution of each variable to observed trends), we recommend being cautious with changes to phalarope habitats. In order for the South Bay to retain its current bird numbers, we recommend that the SBSPRP's Project Management Team, the Refuge, and Eden Landing Ecological Reserve consider managing ponds to support use by phalaropes in order to address declines at SBSPRP sites. Special consideration should be given to ponds that have hosted large numbers of phalaropes in recent years (e.g., A13, E6, and M2) when making management decisions such as seasonal adjustments to water level. Due to the substantial uncertainty in phalarope habitat selection, we suggest avoiding changes to these ponds whenever possible, and generally managing for conditions in each pond so that they reflect conditions in the years where its count was highest. Leaving sufficient suitable habitat for phalaropes should also be a consideration when making plans around which sites will be maintained as managed ponds or converted for tidal marsh restoration.

Acknowledgements

Thank you to the California Wildlife Foundation, the U.S. Fish & Wildlife Service, the California State Coastal Conservancy, and the Santa Clara Valley Water District (Valley Water) for coordinating and funding this work. We would like to thank Rachel Tertes at the Refuge for help with coordinating site access. We would like to acknowledge the South Bay Salt Pond Restoration's Pond Management Working Group that has recommended and implemented many management changes over the years as they relate to specific pond systems. Thank you to Dave Halsing of the South Bay Salt Pond Restoration Project, John Krause and Carly White with the CDFW Eden Landing Ecological Reserve. We could not have done this work without our dedicated field crew of SFBBO staff and volunteers: Byron Ryono, Chris Overington, Christopher Wilson, Dan Wenny, Jeff Englander, Jeremy Reinhard, Jesse Wentworth, Josh Scullen, Katie LaBarbera, Maddy Schwarz, Maureen Lahiff, Mike Mammoser, Neela Srinivasan, Parker Kaye, Pete Dunten, Phil Cotty, Rasia Holzman Smith, and Sirena Lao. We also thank Gabbie Burns, Max Tarjan, and Katie LaBarbera for their work on earlier versions of this report.

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Tables

Table 1. Schedule for phalarope migration surveys. Sites = the number of sites visited during each survey, where each site was visited once between the start and end dates. RNPH = number of Red-necked Phalaropes; WIPH = number of Wilson's Phalaropes; PHAL = number of phalaropes that could not be identified to species. No Red Phalaropes were observed.

Survey ID	Survey block	Year	Start	End	Sites	RNPH	WIPH	PHAL	Total
1	Mid Aug.	2019	08/15	08/20	30	1447	251	2	1700
2	Late Aug.	2019	08/26	09/01	34	1063	114	1	1178
3	Early July	2020	07/06	07/09	15	1	548	0	549
4	Mid July	2020	07/20	07/23	17	182	767	140	1089
5	Early Aug.	2020	08/04	08/06	15	758	446	5	1209
6	Mid Aug.	2020	08/18	08/20	15	904	162	0	1066
7	Late Aug.	2020	08/31	09/01	14	1700	110	0	1810
8	Mid Sept.	2020	09/15	09/16	13	935	0	32	967
9	Late Sept.	2020	09/29	09/29	14	40	1	0	41
10	Early July	2021	07/06	07/07	31	35	738	16	789
11	Mid July	2021	07/19	07/20	31	313	12	414	739
12	Early Aug.	2021	08/02	08/03	31	370	240	84	694
13	Mid Aug.	2021	08/16	08/17	30	1196	24	3	1223
14	Late Aug.	2021	08/30	08/31	31	2992	33	792	3817
15	Mid Sept.	2021	09/13	09/14	31	6767	0	0	6767
16	Late Sept.	2021	09/28	09/30	30	811	0	0	811
17	Late June	2022	06/20	06/21	29	0	18	0	18
18	Early July	2022	07/05	07/06	29	0	83	2	85
19	Mid July	2022	07/18	07/19	29	186	735	0	921
20	Early Aug.	2022	08/01	08/02	29	87	10	0	97
21	Mid Aug.	2022	08/15	08/16	31	1557	19	30	1606
22	Late Aug.	2022	08/29	08/30	31	4357	220	0	4577
23	Mid Sept.	2022	09/12	09/13	31	2882	15	875	3772
24	Late Sept.	2022	09/27	09/27	30	1963	0	0	1963
25	Late June	2023	06/19	06/20	31	0	0	0	0
26	Early July	2023	07/03	07/05	29	0	177	0	177
27	Mid July	2023	07/17	07/19	30	157	1035	2	1194
28	Early Aug.	2023	07/31	08/03	33	774	146	59	979
29	Mid Aug.	2023	08/14	08/16	32	1669	136	200	2005
30	Late Aug.	2023	08/28	09/01	33	6554	100	334	6988
31	Mid Sept.	2023	09/11	09/12	33	3344	43	301	3688
32	Late Sept.	2023	09/25	09/26	32	1565	1	53	1619

Table 2. Number of ponds that had phalarope counts, water quality samples, and complete cases for a change in abundance model (both phalarope counts and water quality samples in the focal year and previous year, and phalaropes present in one of those two years).

Year	Waterbird Counts	Water Samples	Complete Cases
2019	22	24	0
2020	17	0	0
2021	31	24	0
2022	31	24	20
2023	31	29	20

Table 3. Predictor variables used to predict change in seasonal mean waterbird abundance within 85 current and former salt ponds of the South San Francisco Bay. "Base" stage indicates the variable were included in all models significant for a species/guild in De La Cruz et al. (2018), while "Main" indicates AICc model selection was carried on out on the variable. *Change model* column indicates whether the variable varied was static across years, varied annually, or was modeled as the annual change in this variable from its value in the previous year ("Change", with name suffix "_AC"). Three variables were excluded from consideration: specific conductivity, because it was highly correlated with salinity, percent open water, because it was not collected during the first half of the study period, and distance to urban area, because an earlier study found it did not significantly affect any guild (De La Cruz et al. 2018).

Stage	Class	Name	Description	Units	Change model
Base	Pond characteristics	Area_km2	Pond area	km^2	Static
Base		Islands_num	Number of islands	count	Static
Base		OpenPublic_pct	Maximum % of levees open to public across all years	%	Static
Base		OpenHunting_pct	Maximum % of levees open for hunting across all years	%	Static
Base	Pond location	BayDist_km	Distance to San Francisco Bay	km	Static
Base		CreekDist_km	Distance to creek/slough	km	Static
Base		LandfillDist_km	Distance to Tri-cities Landfill	km	Static
Main	Hydrology	BreachOrGate	Breached to tidal action or gated culvert (semi-tidal)	Binary 1 / 0	Annual
Main		WaterElev_m	Mean water depth	cm	Change
Main	Water quality	Salinity	Mean salinity	ppt	Annual + Change
Main		pH	Mean pH	pH scale	Annual + Change
Main		LDO_mgL	Mean dissolved oxygen	mg/L	Annual + Change
Main		Temp_C	Mean water temperature	°C	Annual + Change
Main	Climate	PPT0	Cumulative annual precipitation – year-to-date	mm	Annual
Main		PPT1	Cumulative annual precipitation – last year's only	mm	Annual

Main	PPT3	Cumulative annual precipitation – last three years	mm	Annual
Main	TMX	Mean daily maximum temperature for the season	°C	Annual
Main	TMN	Mean daily minimum temperature for the season	°C	Annual

Table 4. Model selection table for interannual change in abundance of all phalaropes during summer migration (mid June - late September) in current and former salt ponds in South San Francisco Bay, California, 2021–2023. All models were linear regression models with fixed effects representing water quality and climate covariates; site characteristics were subject to model selection in an earlier step but not supported as important (Appendix I). Model selection was carried out based on corrected Akaike Information Criterion (AICc); only models with AICc weight ≥0.01 are shown.

Formula	K	dAICc	AICc	-2LogLike	wi
Abun_PC ~ OpenWater_pct_AC + pH_AC	4	0.00	222.35	-106.60	0.01
Abun_PC ~ OpenWater_pct_AC	3	0.13	222.47	-107.90	0.01
Abun_PC ~ OpenWater_pct_AC + Salinity_AC	4	0.19	222.54	-106.70	0.01
Abun_PC ~ OpenWater_pct_AC + pH_AC + Salinity_AC	5	1.08	223.43	-105.83	0.01
Abun_PC ~ OpenWater_pct_AC + pH_AC + Temp_C	5	1.41	223.76	-106.00	0.01
Abun_PC ~ OpenWater_pct_AC + pH	4	1.53	223.88	-107.37	0.01
Abun_PC ~ OpenWater_pct_AC + WaterElev_m_AC	4	1.55	223.90	-107.38	0.01

Table 5. Model selection table for interannual change in abundance of Red-necked Phalarope during summer migration (mid June - late September) in current and former salt ponds in South San Francisco Bay, California, 2021–2023. All models were linear regression models with fixed effects representing water quality and climate covariates; site characteristics were subject to model selection in an earlier step but not supported as important (Appendix I). Model selection was carried out based on corrected Akaike Information Criterion (AICc); only models with AICc weight ≥0.01 are shown.

Formula	**K**	**dAICc**	**AICc**	**-2LogLike**	**wi**
Abun_PC ~ OpenWater_pct_AC	3	0.00	223.79	-108.56	0.01
Abun_PC ~ OpenWater_pct_AC + Salinity_AC	4	0.51	224.30	-107.58	0.01
Abun_PC ~ OpenWater_pct_AC + pH_AC	4	0.85	224.63	-107.75	0.01
Abun_PC ~ OpenWater_pct_AC + WaterElev_m_AC	4	1.50	225.29	-108.07	0.01
Abun_PC ~ OpenWater_pct_AC + pH	4	1.60	225.39	-108.12	0.01

Table 6. Model selection table for interannual change in abundance of Wilson's Phalarope during summer migration (mid June - late September) in current and former salt ponds in South San Francisco Bay, California, 2021–2023. All models were linear regression models with fixed effects representing water quality and climate covariates; site characteristics were subject to model selection in an earlier step but not supported as important (Appendix I). Model selection was carried out based on corrected Akaike Information Criterion (AICc); only models with AICc weight ≥0.01 are shown.

Formula	K	dAICc	AICc	-2LogLike	wi
Abun_PC ~ PPT3	3	0.00	59.99	-25.50	0.13
Abun_PC ~ PPT0	3	1.62	61.61	-26.31	0.06
Abun_PC ~ TMN + TMX	4	2.11	62.10	-24.19	0.05
Abun_PC ~ PPT3 + TMN	4	2.57	62.56	-24.42	0.04
Abun_PC ~ PPT0 + TMN	4	2.69	62.69	-24.49	0.03
Abun_PC ~ PPT3 + Salinity	4	2.86	62.85	-24.57	0.03
Abun_PC ~ TMN	3	3.00	62.99	-27.00	0.03
Abun_PC ~ 1	2	3.01	63.00	-28.83	0.03
Abun_PC ~ PPT1	3	3.04	63.04	-27.02	0.03
Abun_PC ~ Salinity	3	3.28	63.28	-27.14	0.03
Abun_PC ~ OpenWater_pct + PPT3	4	3.32	63.31	-24.80	0.03
Abun_PC ~ Salinity_AC + TMN	4	3.34	63.34	-24.81	0.03
Abun_PC ~ pH_AC + TMN	4	3.78	63.78	-25.03	0.02
Abun_PC ~ Salinity_AC	3	3.86	63.85	-27.43	0.02
Abun_PC ~ Salinity + TMN	4	3.87	63.86	-25.07	0.02
Abun_PC ~ OpenWater_pct_AC + PPT3	4	3.96	63.95	-25.12	0.02
Abun_PC ~ PPT1 + TMN	4	3.98	63.98	-25.13	0.02
Abun_PC ~ PPT3 + Salinity_AC	4	4.00	63.99	-25.14	0.02
Abun_PC ~ pH_AC + PPT3	4	4.07	64.06	-25.17	0.02
Abun_PC ~ TMX	3	4.14	64.13	-27.57	0.02
Abun_PC ~ Salinity + Salinity_AC	4	4.50	64.50	-25.39	0.01
Abun_PC ~ Salinity_AC + Temp_C_AC	4	4.51	64.50	-25.39	0.01
Abun_PC ~ LDO_mgL_AC + PPT3	4	4.55	64.54	-25.41	0.01
Abun_PC ~ PPT3 + TMX	4	4.67	64.66	-25.47	0.01
Abun_PC ~ BreachOrGate + PPT3	4	4.70	64.69	-25.49	0.01
Abun_PC ~ PPT3 + WaterElev_m_AC	4	4.71	64.70	-25.49	0.01
Abun_PC ~ PPT3 + Temp_C_AC	4	4.71	64.71	-25.50	0.01
Abun_PC ~ OpenWater_pct + PPT0	4	4.82	64.81	-25.55	0.01
Abun_PC ~ PPT0 + Salinity	4	5.11	65.11	-25.70	0.01
Abun_PC ~ PPT0 + Salinity_AC	4	5.41	65.40	-25.84	0.01

Formula	K	dAICc	AICc	-2LogLike	wi
Abun_PC ~ pH_AC	3	5.51	65.51	-28.25	0.01
Abun_PC ~ pH_AC + PPT0	4	5.62	65.62	-25.95	0.01
Abun_PC ~ OpenWater_pct_AC + PPT0	4	5.77	65.76	-26.02	0.01
Abun_PC ~ LDO_mgL_AC	3	5.82	65.81	-28.41	0.01
Abun_PC ~ LDO_mgL_AC + PPT0	4	5.95	65.94	-26.11	0.01
Abun_PC ~ PPT1 + Salinity	4	5.96	65.96	-26.12	0.01
Abun_PC ~ PPT0 + TMX	4	6.01	66.01	-26.15	0.01
Abun_PC ~ BreachOrGate	3	6.13	66.12	-28.56	0.01
Abun_PC ~ PPT0 + Temp_C_AC	4	6.25	66.24	-26.26	0.01
Abun_PC ~ PPT0 + WaterElev_m_AC	4	6.30	66.29	-26.29	0.01
Abun_PC ~ pH_AC + Salinity	4	6.30	66.30	-26.29	0.01
Abun_PC ~ BreachOrGate + PPT0	4	6.32	66.32	-26.30	0.01
Abun_PC ~ Temp_C_AC + TMN	4	6.35	66.35	-26.32	0.01
Abun_PC ~ WaterElev_m_AC	3	6.51	66.50	-28.75	0.01

Figures

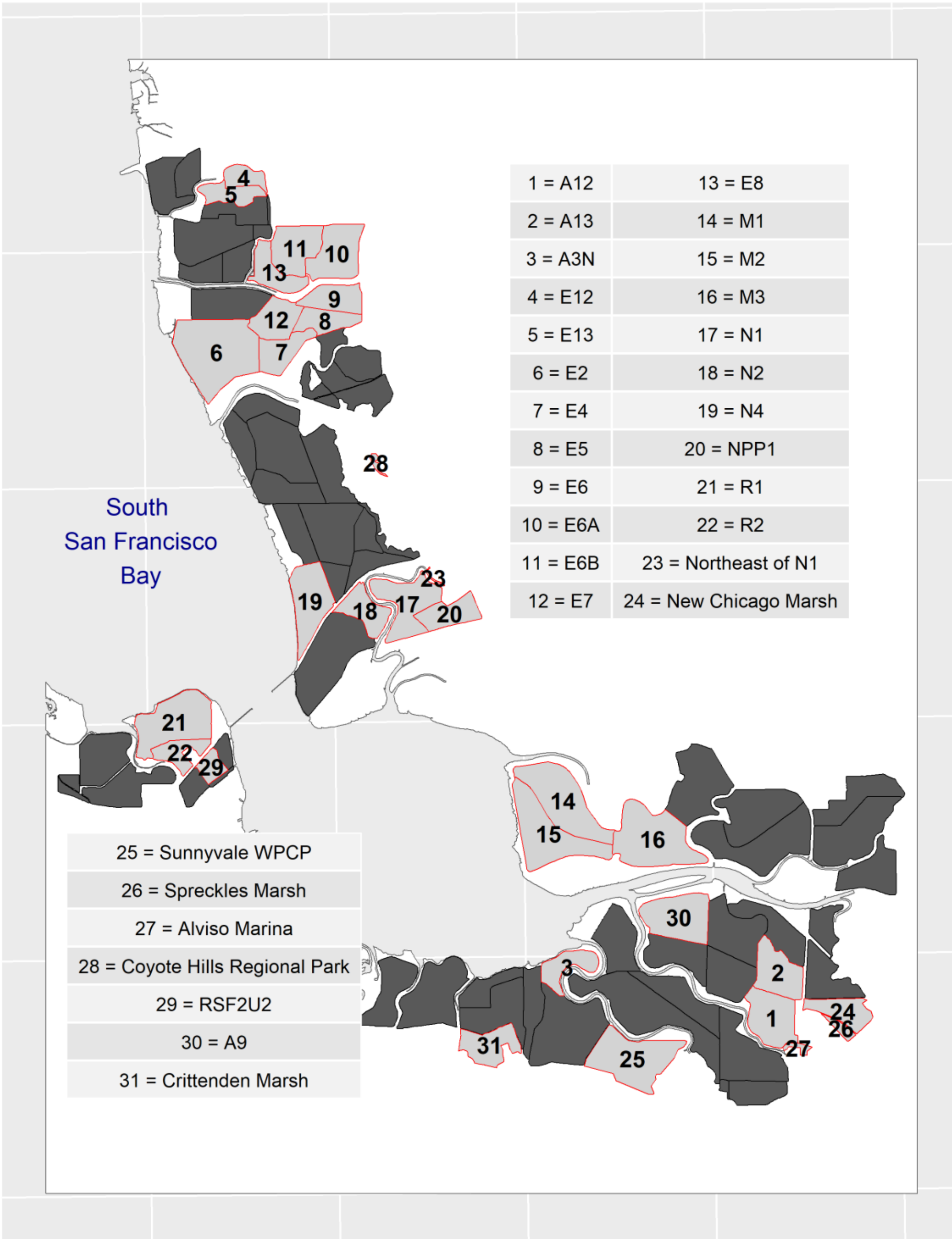

Figure 1. Map of target sites for Phalarope Migration Surveys.

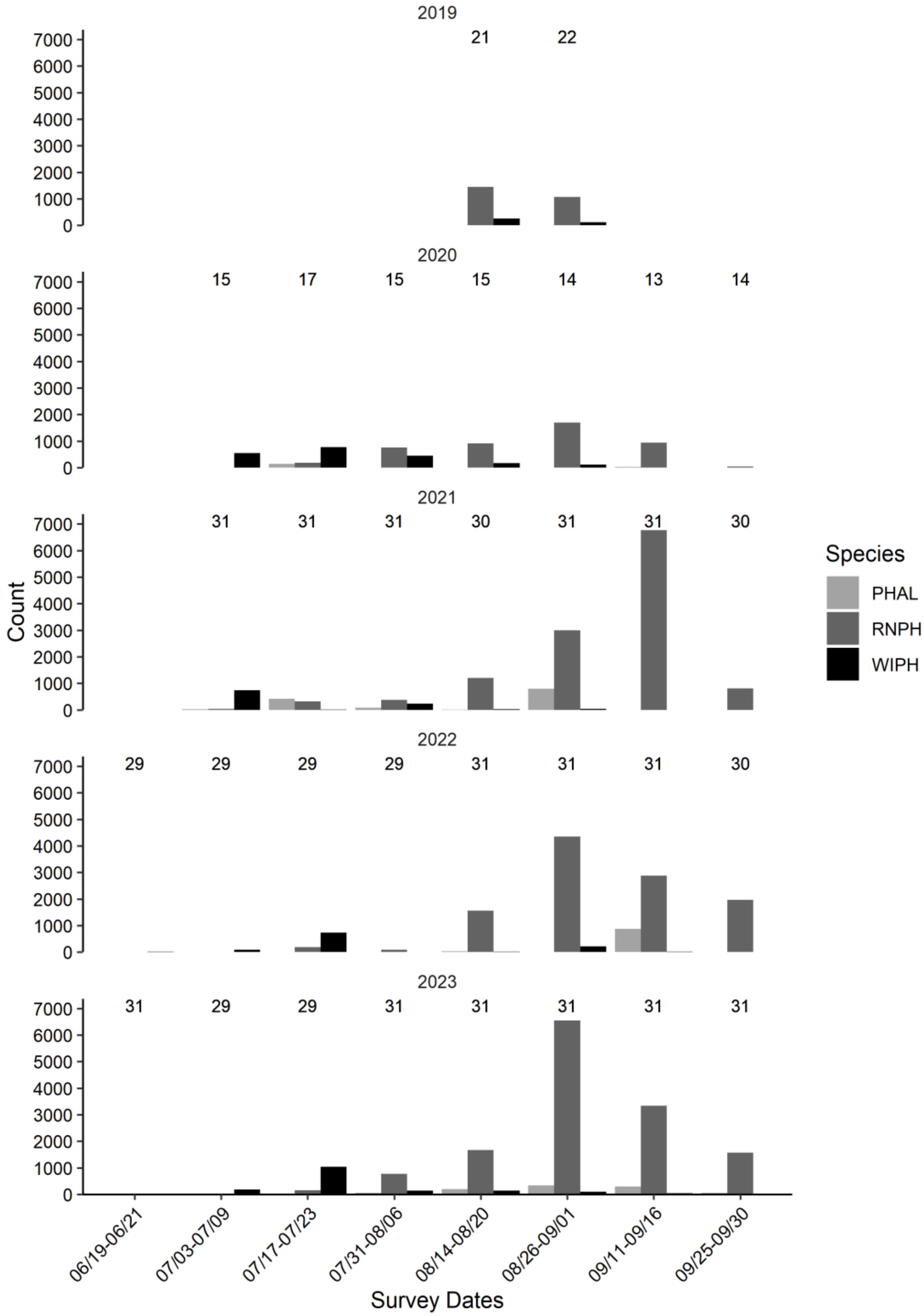

Figure 2. Counts of phalarope species observed during the phalarope migration surveys in 2019–2022. PHAL = phalaropes of unidentified species; RNPH = Red-necked Phalarope; WIPH = Wilson's Phalarope. No Red Phalaropes were observed. Counts are summed across sites visited during each survey. Number above each date is the number of sites surveyed during that round.

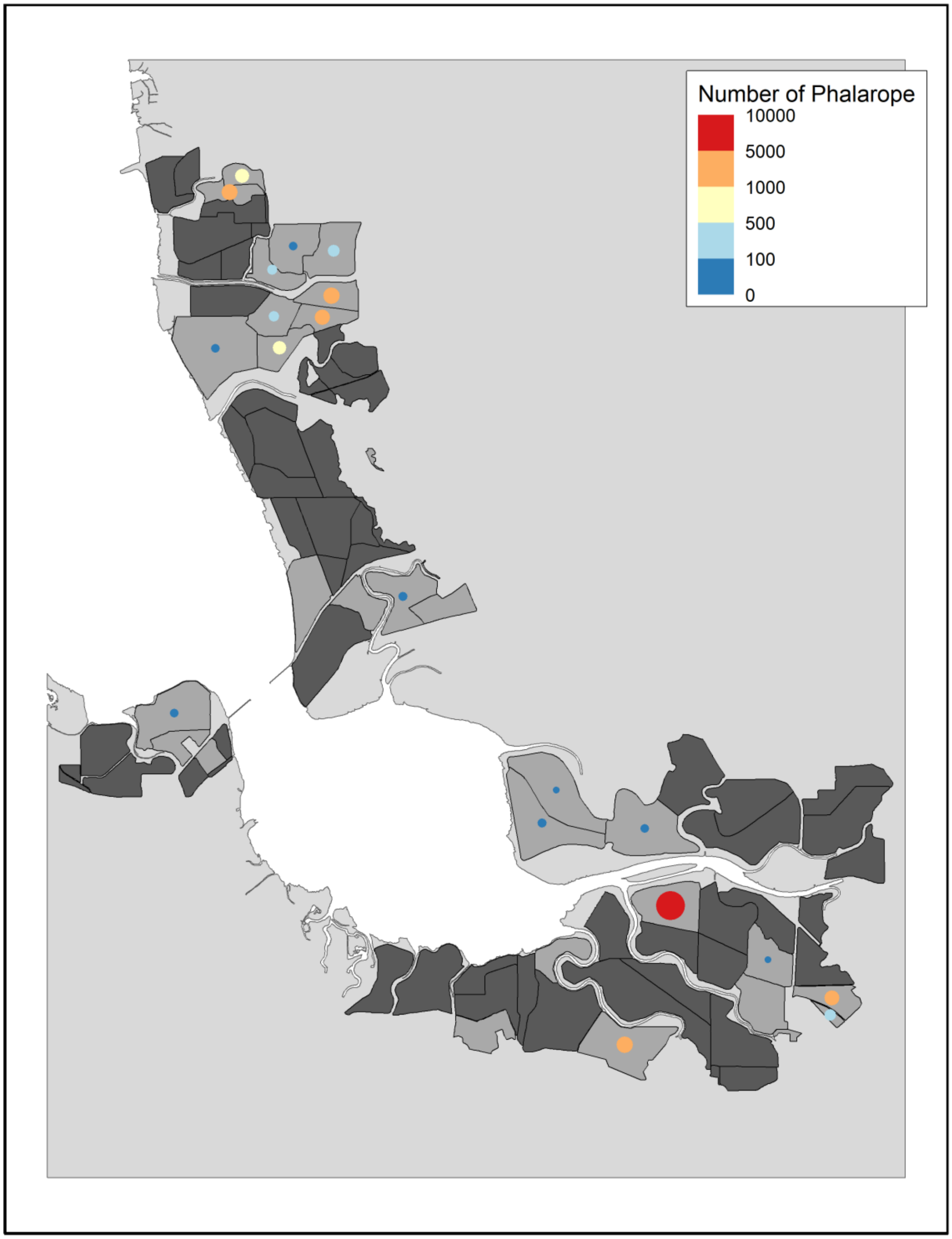

Figure 3. Map with counts of the total number of phalaropes observed during the phalarope migration surveys in 2023. Dots are scaled to represent the relative number of phalaropes observed. Ponds with no dot had zero phalarope observations during 2023 surveys.

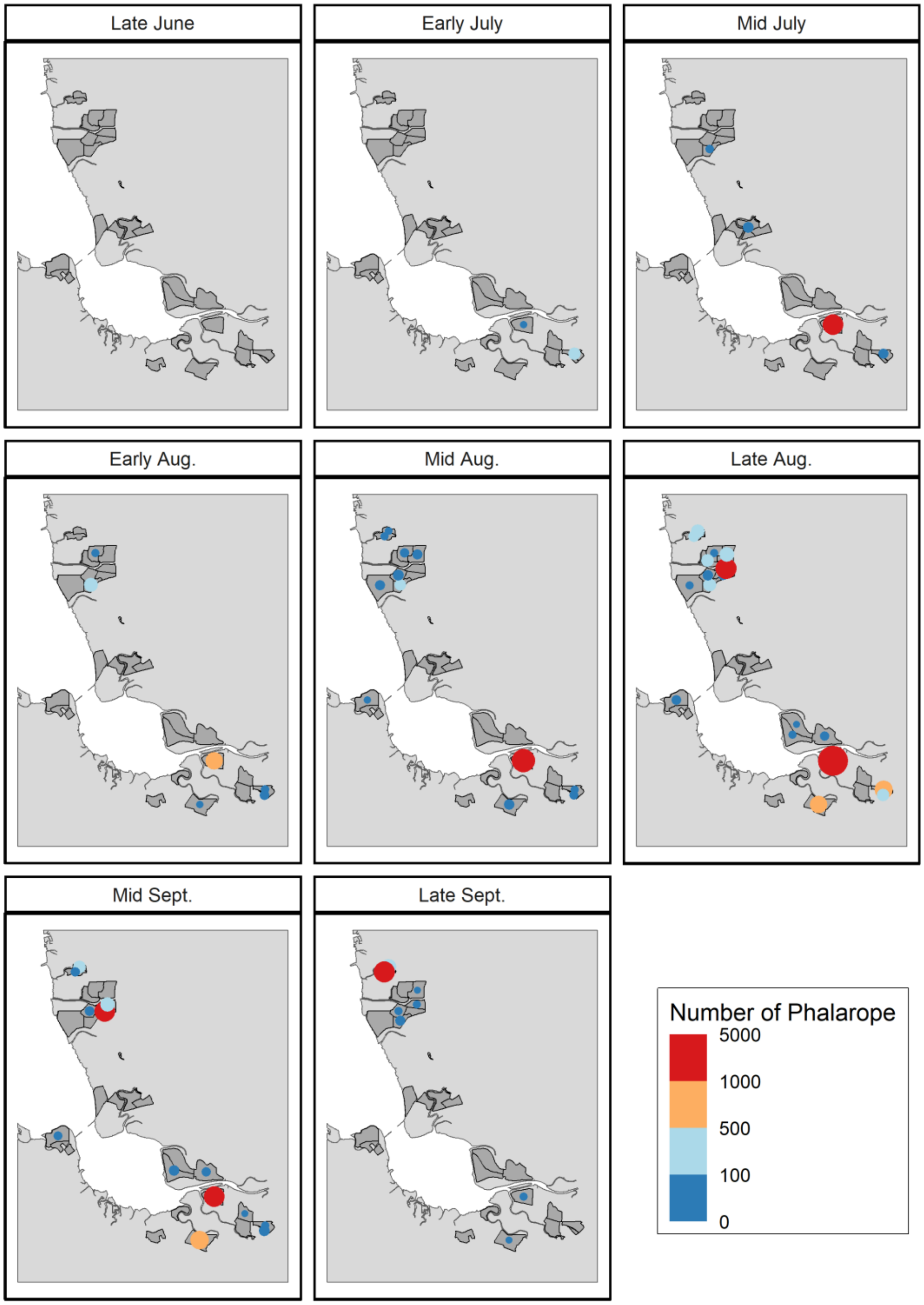

Figure 4. Map with counts of the total number of phalaropes observed during each phalarope migration survey in 2023. Survey block is indicated at the top of each map. Dots are scaled to represent the relative number of phalaropes observed. Ponds with no dot had zero phalarope observations during 2023 surveys.

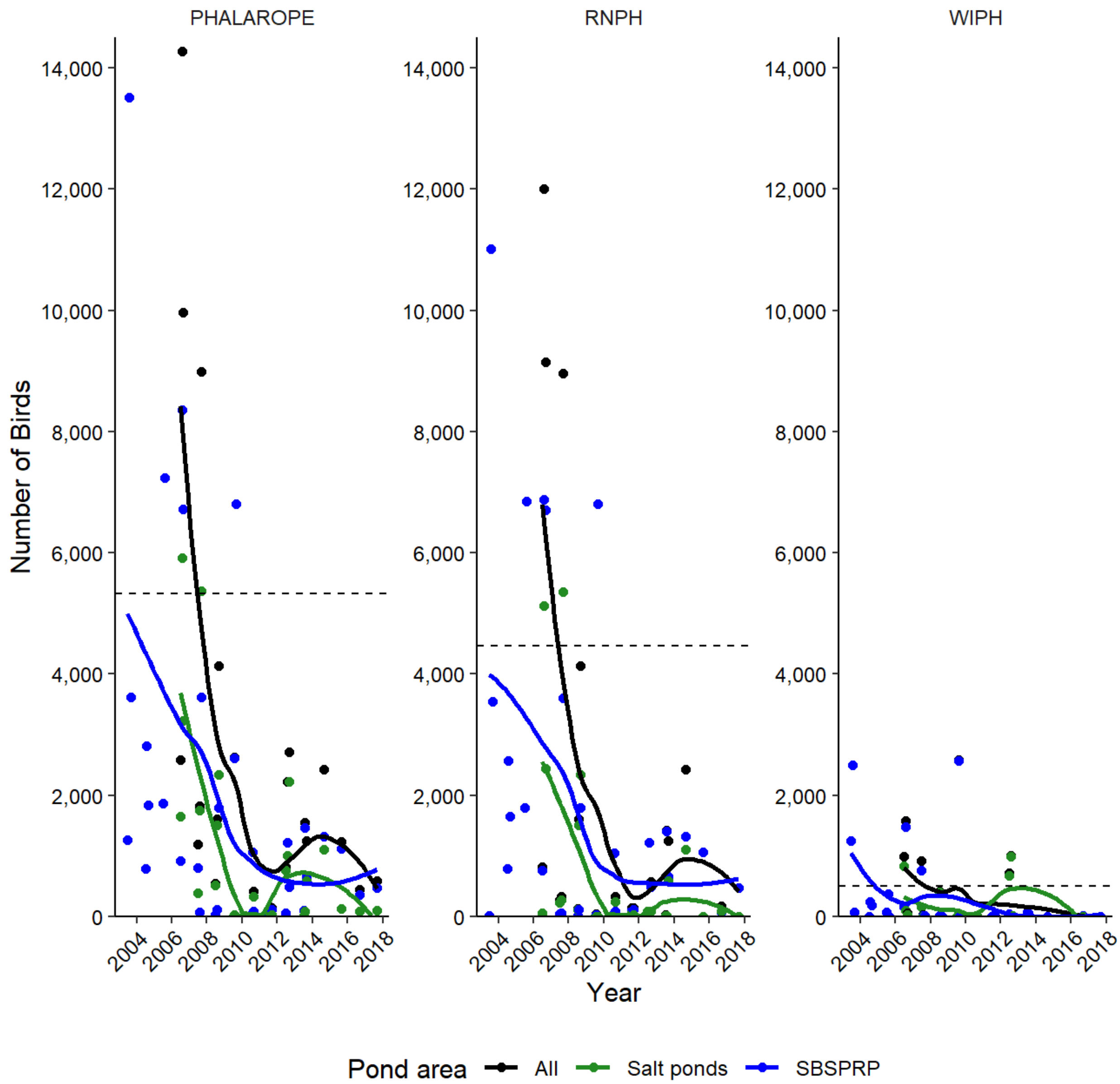

Figure 5. Counts of total phalaropes, Red-necked Phalarope, and Wilson's Phalarope during summer migration (Jul-Sept) within the South Bay Salt Pond Restoration Project (SBSPRP) and salt production ponds. Lines represent LOESS curves and the dashed lines denote recommended new SBSPRP targets based on recalculated baseline values (average counts from 2005–2007; see text and Burns & Van Schmidt 2023).

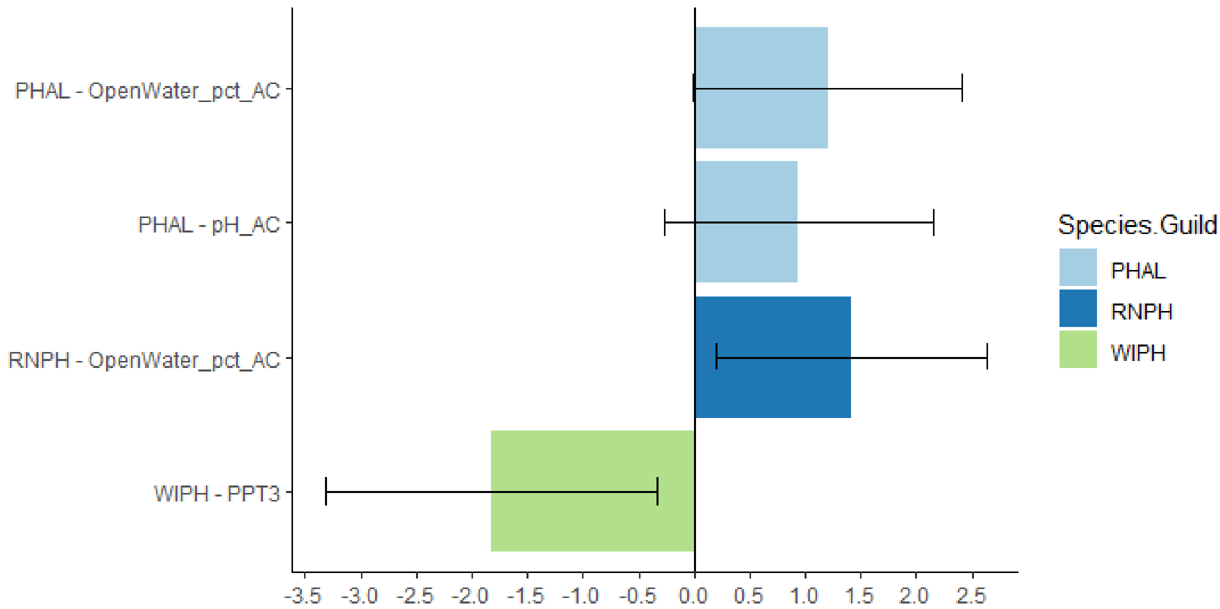

Figure 6. Parameter coefficients (effect sizes) from the top linear regression models for inter-annual change in abundance of three groupings of phalaropes during summer migration (July–September) in current and former salt ponds in South San Francisco Bay, California, 2021–2023. Bars represented 95% confidence intervals. Colors represent three different models fit to data from the three different species groupings. PHAL = all phalaropes (*n* = 40); RNPH = Red-Necked Phalarope (*n* = 40); WIPH = Wilson's Phalarope (*n* = 12).

Appendix 1

Table A1.1. Model selection table for base linear regression model of pond characteristics related to inter-annual change in abundance of total phalaropes during summer migration (Jun-Aug) in current and former salt ponds in South San Francisco Bay, California, 2019-2023. Model selection was carried out based on corrected Akaike Information Criterion (AICc); only models with AICc weight ≥0.01 are shown. -2LL = -2 * Log Likelihood.

Formula	K	dAICc	AICc	-2LL	wi
Abun_PC ~ 1	3	0.00	382.51	-188.07	0.11
Abun_PC ~ OpenHunting_pct	4	0.57	383.08	-187.24	0.09
Abun_PC ~ LandfillDist_km	4	0.66	383.16	-187.28	0.08
Abun_PC ~ CreekDist_km	4	1.45	383.95	-187.67	0.06
Abun_PC ~ OpenPublic_pct	4	1.68	384.19	-187.79	0.05
Abun_PC ~ Area_km2	4	2.15	384.66	-188.03	0.04
Abun_PC ~ BayDist_km	4	2.25	384.75	-188.07	0.04
Abun_PC ~ CreekDist_km + OpenHunting_pct	5	2.26	384.77	-186.92	0.04
Abun_PC ~ CreekDist_km + LandfillDist_km	5	2.48	384.98	-187.03	0.03
Abun_PC ~ Area_km2 + LandfillDist_km	5	2.67	385.17	-187.13	0.03
Abun_PC ~ Area_km2 + OpenHunting_pct	5	2.69	385.20	-187.14	0.03
Abun_PC ~ BayDist_km + OpenHunting_pct	5	2.73	385.23	-187.15	0.03
Abun_PC ~ OpenHunting_pct + OpenPublic_pct	5	2.88	385.39	-187.23	0.03
Abun_PC ~ BayDist_km + LandfillDist_km	5	2.91	385.41	-187.25	0.03
Abun_PC ~ LandfillDist_km + OpenPublic_pct	5	2.95	385.45	-187.27	0.03
Abun_PC ~ CreekDist_km + OpenPublic_pct	5	3.28	385.79	-187.43	0.02
Abun_PC ~ Area_km2 + CreekDist_km	5	3.44	385.94	-187.51	0.02
Abun_PC ~ BayDist_km + CreekDist_km	5	3.53	386.04	-187.56	0.02
Abun_PC ~ BayDist_km + OpenPublic_pct	5	3.76	386.27	-187.67	0.02
Abun_PC ~ Area_km2 + OpenPublic_pct	5	4.00	386.51	-187.79	0.02
Abun_PC ~ Area_km2 + CreekDist_km + OpenHunting_pct	6	4.20	386.71	-186.70	0.01
Abun_PC ~ Area_km2 + CreekDist_km + LandfillDist_km	6	4.30	386.81	-186.75	0.01
Abun_PC ~ Area_km2 + BayDist_km	5	4.44	386.95	-188.01	0.01
Abun_PC ~ Area_km2 + BayDist_km + OpenHunting_pct	6	4.46	386.96	-186.83	0.01
Abun_PC ~ Area_km2 + BayDist_km + LandfillDist_km	6	4.57	387.08	-186.88	0.01
Abun_PC ~ CreekDist_km + OpenHunting_pct + OpenPublic_pct	6	4.64	387.15	-186.92	0.01

Formula	K	dAICc	AICc	-2LL	wi
Abun_PC ~ BayDist_km + CreekDist_km + OpenHunting_pct	6	4.65	387.16	-186.92	0.01
Abun_PC ~ CreekDist_km + LandfillDist_km + OpenPublic_pct	6	4.84	387.34	-187.02	0.01
Abun_PC ~ BayDist_km + CreekDist_km + LandfillDist_km	6	4.85	387.36	-187.02	0.01
Abun_PC ~ Area_km2 + OpenHunting_pct + OpenPublic_pct	6	4.92	387.43	-187.06	0.01
Abun_PC ~ Area_km2 + LandfillDist_km + OpenPublic_pct	6	5.03	387.54	-187.11	0.01
Abun_PC ~ BayDist_km + OpenHunting_pct + OpenPublic_pct	6	5.10	387.60	-187.15	0.01
Abun_PC ~ BayDist_km + LandfillDist_km + OpenPublic_pct	6	5.17	387.68	-187.18	0.01
Abun_PC ~ Area_km2 + CreekDist_km + OpenPublic_pct	6	5.57	388.08	-187.38	0.01
Abun_PC ~ BayDist_km + CreekDist_km + OpenPublic_pct	6	5.67	388.17	-187.43	0.01
Abun_PC ~ Area_km2 + BayDist_km + CreekDist_km	6	5.76	388.27	-187.48	0.01
Abun_PC ~ Area_km2 + BayDist_km + OpenPublic_pct	6	6.09	388.60	-187.64	0.01

Table A1.2. Model selection table for base linear regression model of pond characteristics related to inter-annual change in abundance of Red-necked Phalarope during summer migration (Jun-Aug) in current and former salt ponds in South San Francisco Bay, California, 2019-2023. Model selection was carried out based on corrected Akaike Information Criterion (AICc); only models with AICc weight ≥0.01 are shown. -2LL = -2 * Log Likelihood.

Formula	K	dAICc	AICc	-2LL	wi
Abun_PC ~ 1	3	0.00	367.34	-180.48	0.14
Abun_PC ~ OpenHunting_pct	4	1.35	368.69	-180.02	0.07
Abun_PC ~ CreekDist_km	4	1.36	368.69	-180.02	0.07
Abun_PC ~ LandfillDist_km	4	1.43	368.76	-180.06	0.07
Abun_PC ~ OpenPublic_pct	4	1.82	369.16	-180.26	0.05
Abun_PC ~ Area_km2	4	2.03	369.37	-180.36	0.05
Abun_PC ~ BayDist_km	4	2.25	369.59	-180.47	0.04
Abun_PC ~ CreekDist_km + OpenHunting_pct	5	2.94	370.28	-179.65	0.03
Abun_PC ~ CreekDist_km + LandfillDist_km	5	3.09	370.43	-179.72	0.03
Abun_PC ~ Area_km2 + CreekDist_km	5	3.16	370.49	-179.76	0.03
Abun_PC ~ Area_km2 + OpenHunting_pct	5	3.26	370.59	-179.81	0.03
Abun_PC ~ Area_km2 + LandfillDist_km	5	3.28	370.61	-179.81	0.03
Abun_PC ~ CreekDist_km + OpenPublic_pct	5	3.38	370.72	-179.87	0.02
Abun_PC ~ BayDist_km + OpenHunting_pct	5	3.51	370.85	-179.93	0.02
Abun_PC ~ BayDist_km + CreekDist_km	5	3.57	370.90	-179.96	0.02
Abun_PC ~ BayDist_km + LandfillDist_km	5	3.67	371.01	-180.01	0.02
Abun_PC ~ OpenHunting_pct + OpenPublic_pct	5	3.68	371.02	-180.02	0.02
Abun_PC ~ LandfillDist_km + OpenPublic_pct	5	3.71	371.05	-180.03	0.02
Abun_PC ~ BayDist_km + OpenPublic_pct	5	3.72	371.06	-180.04	0.02
Abun_PC ~ Area_km2 + OpenPublic_pct	5	4.08	371.41	-180.21	0.02
Abun_PC ~ Area_km2 + BayDist_km	5	4.20	371.54	-180.28	0.02
Abun_PC ~ Area_km2 + CreekDist_km + OpenHunting_pct	6	4.60	371.94	-179.27	0.01
Abun_PC ~ Area_km2 + BayDist_km + OpenHunting_pct	6	4.66	371.99	-179.30	0.01
Abun_PC ~ Area_km2 + CreekDist_km + LandfillDist_km	6	4.73	372.06	-179.33	0.01
Abun_PC ~ Area_km2 + BayDist_km + LandfillDist_km	6	4.97	372.31	-179.45	0.01
Abun_PC ~ CreekDist_km + OpenHunting_pct + OpenPublic_pct	6	5.35	372.69	-179.65	0.01
Abun_PC ~ BayDist_km + CreekDist_km + OpenHunting_pct	6	5.36	372.69	-179.65	0.01

Formula	**K**	**dAICc**	**AICc**	**-2LL**	**wi**
Abun_PC ~ CreekDist_km + LandfillDist_km + OpenPublic_pct	6	5.47	372.80	-179.70	0.01
Abun_PC ~ Area_km2 + CreekDist_km + OpenPublic_pct	6	5.47	372.80	-179.70	0.01
Abun_PC ~ BayDist_km + CreekDist_km + LandfillDist_km	6	5.50	372.83	-179.72	0.01
Abun_PC ~ Area_km2 + BayDist_km + CreekDist_km	6	5.57	372.91	-179.76	0.01
Abun_PC ~ Area_km2 + OpenHunting_pct + OpenPublic_pct	6	5.59	372.93	-179.76	0.01
Abun_PC ~ Area_km2 + LandfillDist_km + OpenPublic_pct	6	5.67	373.01	-179.80	0.01
Abun_PC ~ BayDist_km + OpenHunting_pct + OpenPublic_pct	6	5.72	373.06	-179.83	0.01
Abun_PC ~ Area_km2 + BayDist_km + OpenPublic_pct	6	5.74	373.08	-179.84	0.01
Abun_PC ~ BayDist_km + CreekDist_km + OpenPublic_pct	6	5.79	373.13	-179.86	0.01
Abun_PC ~ BayDist_km + LandfillDist_km + OpenPublic_pct	6	5.79	373.13	-179.86	0.01

Table A1.3. Model selection table for base linear regression model of pond characteristics related to inter-annual change in abundance of Wilson's Phalarope during summer migration (Jun-Aug) in current and former salt ponds in South San Francisco Bay, California, 2019-2023. Model selection was carried out based on corrected Akaike Information Criterion (AICc); only models with AICc weight ≥0.01 are shown. -2LL = -2 * Log Likelihood.

Formula	K	dAICc	AICc	-2LL	wi
Abun_PC ~ 1	3	0.00	164.50	-78.82	0.26
Abun_PC ~ CreekDist_km	4	2.25	166.75	-78.63	0.08
Abun_PC ~ OpenPublic_pct	4	2.37	166.87	-78.69	0.08
Abun_PC ~ BayDist_km	4	2.48	166.98	-78.75	0.07
Abun_PC ~ LandfillDist_km	4	2.60	167.10	-78.81	0.07
Abun_PC ~ Area_km2	4	2.61	167.11	-78.81	0.07
Abun_PC ~ OpenHunting_pct	4	2.62	167.12	-78.82	0.07
Abun_PC ~ BayDist_km + OpenPublic_pct	5	4.18	168.68	-78.19	0.03
Abun_PC ~ CreekDist_km + OpenPublic_pct	5	4.63	169.13	-78.41	0.03
Abun_PC ~ CreekDist_km + LandfillDist_km	5	4.82	169.32	-78.50	0.02
Abun_PC ~ OpenHunting_pct + OpenPublic_pct	5	4.89	169.39	-78.54	0.02
Abun_PC ~ Area_km2 + OpenPublic_pct	5	4.96	169.46	-78.57	0.02
Abun_PC ~ CreekDist_km + OpenHunting_pct	5	5.02	169.52	-78.61	0.02
Abun_PC ~ BayDist_km + CreekDist_km	5	5.07	169.57	-78.63	0.02
Abun_PC ~ Area_km2 + CreekDist_km	5	5.07	169.57	-78.63	0.02
Abun_PC ~ BayDist_km + LandfillDist_km	5	5.10	169.60	-78.64	0.02
Abun_PC ~ LandfillDist_km + OpenPublic_pct	5	5.17	169.67	-78.68	0.02
Abun_PC ~ BayDist_km + OpenHunting_pct	5	5.30	169.79	-78.74	0.02
Abun_PC ~ Area_km2 + BayDist_km	5	5.30	169.80	-78.75	0.02
Abun_PC ~ Area_km2 + LandfillDist_km	5	5.41	169.91	-78.80	0.02
Abun_PC ~ Area_km2 + OpenHunting_pct	5	5.43	169.93	-78.81	0.02

Table A1.4. Top linear regression model for inter-annual site-scale percent change in abundance of all phalaropes in relation to climate and water quality characteristics in current and former salt ponds in South San Francisco Bay, California, during summer migration (Jun-Aug) from 2021–2023.

Coefficient	Estimate	SE	t-value	Lower 95% CI	Upper 95% CI
(Intercept)	0.6265	0.5716	1.0960	-0.5317	1.7846
OpenWater_pct_AC	1.2023	0.5963	2.0162	-0.0059	2.4105
pH_AC	0.9405	0.5963	1.5771	-0.2678	2.1487

Table A1.5. Top linear regression model for inter-annual site-scale percent change in abundance of Red-necked Phalarope in relation to climate and water quality characteristics in current and former salt ponds in South San Francisco Bay, California, during summer migration (Jun-Aug) from 2021–2023.

Coefficient	Estimate	SE	t-value	Lower 95% CI	Upper 95% CI
(Intercept)	0.6710	0.5923	1.1328	-0.5281	1.8701
OpenWater_pct_AC	1.4145	0.5999	2.3580	0.2001	2.6289

Table A1.6. Top linear regression model for inter-annual site-scale percent change in abundance of Wilson's Phalarope in relation to climate and water quality characteristics in current and former salt ponds in South San Francisco Bay, California, during summer migration (Jun-Aug) from 2021–2023.

Coefficient	Estimate	SE	t-value	Lower 95% CI	Upper 95% CI
(Intercept)	0.7737	0.6405	1.2080	-0.6534	2.2009
PPT3	-1.8248	0.6690	-2.7277	-3.3154	-0.3342