SAN FRANCISCO BAY
BIRD OBSERVATORY

Establishing baseline conditions to inform adaptive management of South San Francisco Bay salt ponds: A comparison of waterbird abundance from the 1980s to the 2000s

Final Report

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16 October 2013

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INTRODUCTION

The 30,000 acres of wetlands within the Don Edwards San Francisco Bay National Wildlife Refuge (Refuge) provide critical habitat for over one million waterbirds annually (Page et al. 1999, Warnock et al. 2002). These wetlands consist largely of tidal marshes and open water ponds. Salt evaporator ponds have been in this landscape for over 150 years (Ver Planck 1958) and are heavily used by shorebirds, waterfowl and other wildlife species (Anderson 1970, Accurso 1992, Takekawa et al. 2001, Warnock et al. 2002). Salt ponds, and former salt ponds now managed as wildlife habitat, provide the majority of the roosting and (for some species) foraging habitat for waterbirds in the San Francisco Bay. The South Bay Salt Pond Restoration Project (Restoration Project), of which the Refuge and California Department of Fish and Wildlife's (CDFW, also CDFG) Eden Landing Ecological Reserve are a part, is implementing a large-scale plan to convert 15,100 acres of former salt ponds into tidal and managed wetland habitats (SBSPRP 2007).

While the restoration of former salt ponds to tidal marsh will increase habitat for species that depend on tidal marshes, it also will reduce the overall pond habitats available for waterbirds. However, through adaptive management, the Restoration Project is committed to maintaining "baseline" levels of waterbirds in this site of international importance along the Pacific Flyway (Ramsar Convention on Wetlands, 2013). The Restoration Project has committed to retaining between 10-50% of the 15,100 total Project acres as ponds that are managed largely for waterbirds, but information is needed to ensure that the habitat requirements of large numbers of waterbirds can be met with reduced pond acreage.

Monthly ground-based surveys, conducted in former and currently active salt ponds by the U.S. Geological Survey San Francisco Bay Estuary Field Station (USGS) and San Francisco Bay Bird Observatory (SFBBO) have been ongoing since 2002 and 2005, respectively, however, these surveys began after the Restoration Project started. Thus, baseline (i.e., historical) numbers remain largely unknown for many waterbird species prior to the initiation of the Restoration Project. However, in the 1980's, state and federal biologists conducted monthly aerial surveys of waterbirds on all of the salt ponds in the South Bay. These data were recently rediscovered and scanned through a cooperative effort with USGS.

In 2009, the USGS scanned these datasheets, and a Refuge intern began the process of entering data into a modified version of SFBBO's current waterbird survey database. In 2010, SFBBO and the Refuge received support from the USFWS Inventory & Monitoring Program, with the goal of completing entry of historical data and analyzing these data to compare historical and current waterbird numbers in Eden Landing Ecological Reserve and the Newark, Alviso, Mowry and Ravenswood salt pond complexes. A metadata report describing the datasets, collection methods, and potential caveats, was submitted previously by SFBBO (Demers & Tokatlian 2012).

In this report, we describe the methods we used to compare the current and baseline (historical) datasets and present our findings on the current and historical patterns of abundance and distribution for nine guilds and several individual species of interest to the Refuge, CDFW and Restoration Project. We also compare changes in community structure from the historical to the current data, focusing on changes in patterns of species richness and abundance. We also describe work conducted by researchers at the University of California, Davis, to develop a "conversion factor" that enabled current (ground-based) survey data to be compared with historical (aerial-based) survey data.

METHODS

Historical data collection, data entry and data proofing (taken in part from Demers & Tokatlian 2012)

In fall 2010, SFBBO received a single box from the Refuge containing data, maps, personal notes, summaries, and reports of the researchers. We examined, organized, and catalogued the contents of the box. We entered and proofed all data. We used the maps to determine the geographic locations referenced on the datasheet. We contacted and interviewed the USFWS and CDFG biologists involved in the original data collection in the 1980's. Current ground-based salt pond surveys occur during high tide windows, defined as a high tide at 4 feet or greater at Alameda Creek, and we used the website www.tides.mobilegeographics.com to generate high tide windows following the current criteria for historical survey days.

During our exploration of the data, we focused on documenting aerial salt pond surveys (hereafter historical salt pond surveys), and we paid particular attention to data collected in the 5 complexes where current ground-based waterbird surveys occur.

We found and entered data for 34 historical salt pond surveys occurring between February 1981 and January 1986. We contacted the biologists involved with the initial study design and data collection in the 1980's, and spoke directly with Roy Lowe and Paul Kelly and emailed Tom Harvey.

<u>Historical Salt Pond Survey Study Area</u>: We found a work plan outlining the initial goals of the 1980's salt pond study, which were to: 1) evaluate use of South San Francisco Bay salt ponds by breeding and migrant waterbirds, 2) determine the role of salt ponds in supporting regional populations of CA coastal waterbirds, and 3) determine conditions and characteristics of ponds that support waterbirds. The goal was to survey 90 ponds as well as open bay habitats for comparison. On each single survey day, Alviso, Eden Landing Ecological Reserve (formerly Baumberg), Newark (historically Plant 1; current names also include Fremont, Dumbarton, or Coyote Hills), Mowry (historically Plant 2), Ravenswood and Redwood City (the Ravenswood complex was formerly named Redwood), and Bair Island were surveyed. In addition, open bay habitats were regularly surveyed as were specific sewage treatment ponds, sloughs, and flood control channels. The biologists defined open bay as open water only, and therefore these surveys do not include mudflats.

Based on conversations with the 1980's biologists, it is likely that they surveyed all wetland units and habitats during their flight routes (see methods below); however, they only recorded data when birds were present and didn't record zeros when no birds were seen. Because of their survey methods, we assumed that all salt ponds were surveyed on each survey date, and therefore missing data within the 5 complexes of concern here, with the exceptions noted, were assumed to be true zeros.

Historical Salt Pond Survey Methods: Two experienced observers identified waterbirds and estimated numbers from either side of a CDFG Cessna 185. For all but one survey (3/12/1981), the same team of three observers (Paul Kelly of CDFG and Tom Harvey and Roy Lowe from USFWS) collected survey data throughout the study period. The biologists conducted training exercises using aerial photographs to estimate flock size, and calibrated count estimates against themselves (i.e., counting the same flocks independently and then comparing estimates). The plane flew at low altitudes (200 – 250 ft), following the same route for every survey. The biologists attempted to conduct surveys once per month, weather permitting. Surveys started at Hayward Airport, and all South Bay salt ponds south of the San Mateo Bridge were surveyed following a clockwise route around the South Bay. The biologists set up informal transects that bisected each pond, so both observers on either side of the plane could see the entire pond and the levees. The pilot flew these transects during each survey. Open bay surveys occurred after the salt pond surveys (after a lunch break at the San Carlos airport).

The biologists did not record start or end times of all surveys, but recall: 1) recording start and end times when they deviated from their normal schedule, and 2) generally starting surveys around 0900 and finishing up the salt pond portion around 1200 or 1300. The start times listed on the datasheet follow this general schedule. Generally, the salt pond surveys took 3-4 hours to complete. The biologists used a tape recorder to record survey data in the plane, and then transcribed the data onto datasheets. The biologists did not transcribe zeros (e.g., when a pond was surveyed and no birds were seen). The biologists report rarely missing a pond, and if they did, it was noted and recorded.

Waterbird Identification: During surveys, the biologists attempted to identify each bird to species, with the exception of Long-Billed and Short-Billed Dowitchers, which were identified as dowitchers; Greater and Lesser Scaup, which were identified as scaup; all gull species, with the exception of Bonaparte's Gulls, which were identified as gulls; and Eared Grebes and Horned Grebes, which were identified as small grebes during surveys. When identification to species was not possible, surveyors identified to taxonomic grouping (e.g., heron, egret, small shorebird, medium shorebird, large shorebird, dabbler, diver, teal, and phalarope). Biologists reported that any shorebird smaller than a dowitcher was difficult to identify and subsequently classified those birds as small shorebirds. Within the data, species like Dunlin and Least Sandpiper were never individually identified and only identified to this taxonomic grouping. They classified dowitchers, Killdeer, and Black-bellied Plovers as medium shorebirds, and Marbled Godwits, Long-billed Curlews, Willets, Yellowleg spp., American Avocets, and Black-necked Stilts as large shorebirds. Biologists identified Phalaropes separately and never categorized them into any of the shorebird designations. SFBBO also categorized each species into a foraging guild for analyses and presentation, based on their foraging methods and prey requirements (Appendix 1).

Current Salt Pond Waterbird Surveys

SFBBO and USGS have been surveying the currently active and former salt ponds since the early 2000's. For the analyses and maps described below, we used SFBBO and USGS monthly data from October 2005 through September 2012. SFBBO surveyed all ponds in the Newark and Mowry salt pond complexes, while USGS surveyed all ponds in the Alviso, Eden Landing and Ravenswood complexes (Figure 1). Although the Newark and Mowry ponds are owned by the Refuge, Cargill Salt retains mineral rights and regulates water flow for salt production. The Alviso and Ravenswood ponds are owned and managed by the Refuge; the Eden Landing ponds are owned and managed by CDFW, and are no longer actively managed for salt production. SFBBO and USGS conducted salt pond surveys using identical methods, described briefly below. Additional details on survey methods can be found in previous SFBBO reports (Donehower et al. 2012, Robinson-Nilsen & Bluso-Demers 2012, Robinson-Nilsen et al. 2009).

During each survey, birds were observed from the nearest drivable road or levee using spotting scopes and binoculars. Birds present on the ponds were counted and their locations recorded using aerial site photos superimposed with 250 m^2 individually labeled grids. For each grid-scale sighting of an individual bird or bird group of the same species, behavioral data (whether the bird(s) was foraging or roosting) were also recorded. For roosting birds only, whether the bird(s) was seen on a levee, island, or manmade/artificial structure (e.g., blind, fence post) was noted. We do not report here on the behavioral aspects of the data collected, but instead focus on the observed patterns of abundance and distribution.

Birds were identified to the species level whenever possible, with the exception of Long-Billed and Short-Billed Dowitchers (identified as dowitchers), and Greater and Lesser Scaup (identified as scaup). When species identification was not possible, birds were identified to genus or foraging guild (e.g., gulls, small shorebirds, medium shorebirds, phalaropes).

Comparing Historical and Current Data

Due to differences (and in some cases errors) in the way data were reported in the historical, SFBBO and USGS datasets, a significant amount of time was spent proofing the data and making minor modifications (e.g., standardizing pond names/labels, to reconcile pond names for those that were split or combined between historical and current surveys, etc.). In addition, to enhance our ability to accurately compare abundance estimates from aerial (historical) and ground (current) survey data, researchers Dr. Vanessa Tobias and Dr. Emilio Laca (University of California, Davis) used a set of matched aerial (U.S. FWS Mid-winter Waterfowl Surveys) and ground survey data (SFBBO and USGS salt pond surveys) conducted in the South Bay salt ponds during 2006-2010, and 2012, to develop a conversion factor that we could use to convert the historical aerial survey data to "ground count equivalents" for direct comparison with ground survey data. The methods used by Drs. Tobias and Laca are described in a later section (*Calculating a Conversion Factor)* of this report. We used their model to transform the aerial historical survey data to ground count equivalents, and, following these modifications we conducted the processing steps below.

Only ponds that were surveyed in both historical and current periods were included in these analyses, and only spring, winter and fall seasons were included, as the historical dataset lacked summer sampling. Individual ponds were the finest-scale sampling units used in our analysis. Abundance data collected during current ground surveys at the grid scale for a given guild or species were summed to generate totals at the pond scale. Each pond was completely surveyed within a single day (no pond survey was ever split between two days). In general, a pond was surveyed once per month; however, a few cases exist where a pond was surveyed twice in a month. These surveys are treated as independent sampling events (i.e., we assume that bird communities surveyed early in the month did not impact bird communities observed later in the month).

For a given guild or species, monthly survey data in each of four seasons were averaged across years for each pond for the historical and current datasets (e.g., average gull abundance in Mowry pond M2 in spring during the historical period; see Appendix 2 for the Access query details used to compute these averages). Survey dates were grouped into seasons as follows: Fall: Sept-Nov; Winter: Dec-Feb; Spring: Mar-May; Summer: Jun-Aug. Only data from surveys conducted during high tide windows were used, with this rule applied to both current and historical data for all guilds and species. We grouped species into the following guilds (Appendix 1): dabblers, divers, Eared Grebes, fisheaters, gulls, herons and egrets, phalaropes, terns and shorebirds. For the purposes of this report, shorebirds were grouped, irrespective of size. In addition, data were summarized for particular species of interest to Refuge management (C. Strong, *pers comm*): American Avocet, Northern Shoveler, and Ruddy Duck.

For a given guild or species, the average survey abundance was calculated for a given pond in a particular season by averaging the recorded abundances of that guild/species observed during monthly surveys conducted in that pond and season across all years (1981-1986 for historical data; 2005-2012 for current data). Abundance values at a given pond could not be totaled over an entire season, as the numbers of surveys conducted during a season varied from year to year, particularly in the historical dataset, and individual birds would undoubtedly be double counted. Thus, the abundance values presented in the results section are the average abundance values for a particular guild or species conducted within a given season. These pond-level averages were then summed to arrive at a total abundance index for each guild or species at the complex scale (e.g. all pond-scale, spring dabbler abundances for the current dataset were summed for all of the Alviso ponds to generate an abundance index for the Alviso complex, made up of X ponds). Similarly, to compute an index of abundance for a given guild or species across all three seasons sampled (fall, winter and spring), pond-level abundance values per guild/species were averaged across all surveys, and then pond averages were summed to generate a complex-scale abundance index for the year (exclusive of summer, which was not surveyed by the historical survey team).

For the purposes of this report, we mapped only the combined, 3-season survey abundance index values for a given guild/species at the complex scale. Data from each season has also been summarized, and indeed, maps for all guilds and selected species have been created for all seasons, but to keep the number of maps to a reasonable level, only combined, 3-season abundance indices are shown in our maps, though we do show all seasons in other Tables and Graphs provided here.

A coarse assessment of breeding bird abundance was also conducted at the request of Refuge staff (C. Strong, *pers comm*). Breeding birds that were incorporated into this assessment included American Avocet, Black-necked Stilt, Gulls (guild) and Terns (guild). We calculated an abundance index at the complex scale for each of these species/guilds by simply combining the pond-scale average abundance values, as described above. Because there is no high-tide historical data from summer months, we used counts from the spring season to represent breeding numbers. In order to preserve comparability with other spring summaries, we included March data in this analysis even though it includes non-breeding species as part of the Gull and Tern guilds. Most of the non-breeding species included as a result of this are from the Gull guild category (such as Bonaparte's Gull, Glaucous-winged Gull, Herring Gull, and Ring-billed Gull). Therefore any changes in these species between the historic and current dataset may artificially increase or decrease the differences between the current and historic breeding species values. However, it is worth noting that the number of California Gulls in the current dataset alone represents more than 50% of all records (current and historic combined) involved in this analysis. Therefore the majority of changes seen in the results are likely driven by the increase in the California Gull populations seen in the Bay Area over the past 30 years (Donehower et al. 2012), and non-breeding species likely have a minor effect on the results.

Generating scales for abundance indices: Maps were created using SFBBO's waterbird Access database and ArcGIS software. None of the standard GIS options for generating the scale for abundance index values (i.e., the number of abundance index levels displayed in different colors and the range of abundance index values for each level) were appropriate for these data. This is primarily because there were many individuals at some locations and very few individuals at others. Since the information at the lower end of the abundance scale is of considerable relevance to management and conservation of these guilds/species, and we did not want these data to be "lost" among the higher abundance data, we developed our own system for scaling these maps. Within a guild, we present maps with an identical scale for both the historical and current data, to facilitate direct visual comparison of patterns of abundance and distribution. Note that the scales used do not reflect any manipulation of the data, simply our best attempt to provide clear visual representation of the data.

Specifically, for the pond-scale analysis, there are many guilds/species with low levels of abundance; therefore, the scale needed to be weighted towards the lower values so that the resolution would not be lost. We used six levels, starting with zero (i.e., no birds observed). We used the following formula to identify the low and high values for each level:

$$\frac{n_{max}}{a^2}$$

where n_{max} = the maximum average number of birds seen at any pond (for a single guild in a single season) between the historical and current data; and where a = a constant value. We used a = 6.5, 4, 2.5, 1.5, and 1 to produce a smooth exponential curve from 0 to n_{max} . This method allows detail at the lower abundances to be seen, but also enables us to visualize the locations with truly high levels of abundance.

For the complex-scale analysis, the data were more evenly distributed, so we used a liner projection from 0 to n_{max} , with equal spacing between each of the six levels.

Calculating a Conversion Factor

To allow comparisons to be made between modern ground-based data and historical aerial data, V. Tobias and E. Laca developed a conversion factor using waterfowl abundance data from dates when ground and aerial surveys were conducted at the same ponds. Tobias and Laca undertook the following procedure:

1. <u>Detectability Index Development</u>

To account for the fact that detection probability for different guilds/species is unequal, we calculated an index of detectability for each species based on physical attributes (Table 1). The index was calculated as a weighted average of four criteria: (1) average body mass, as given in Sibley (2003); (2) a subjective score for plumage conspicuousness (species with highly contrasting plumage; e.g., Canvasback, received a higher score than species with less contrasting plumage; e.g., Gadwall); (3) a subjective score for behavior (3 = likely to flush; 2 = likely to remain on the water; and 1 = likely to dive); and (4) average flock size, as calculated from recent aerial survey data. Detection probability was assumed to be positively correlated with body size, plumage conspicuousness, the behavior score and average flock size. All criteria scores were rescaled from zero to one and weights were assigned to each of the criteria as follows: 0.4 for body mass, 0.2 for plumage conspicuousness, 0.1 for behavior and 0.3 for flock size. Weights were determined subjectively by consulting with aerial waterfowl survey experts. A single detectability score for each species/guild was then calculated as the weighted average of the four criteria.

2. <u>Data selection/pond & species matching for model development</u>

We used ground and aerial survey data where birds were counted in a given pond by both methods on the same day. We were unable to match surveys at finer temporal scales than the same day because the time each pond was observed was not recorded for aerial surveys prior to 2012. We did not aggregate counts spatially or temporally for the conversion factor analysis. Species included in model development were limited to waterfowl because other waterbirds were not counted from the air in the available dataset.

We found 60 instances of ponds that were counted by both ground and aerial surveys on the same day, resulting in 255 data points, consisting of paired ground and aerial counts. The species included in the matched counts were: AMWI, BUFF, CANV, COOT, GADW, GOLD, GWTE, MALL, PINT, REDH, RUDU, SCAU, and SHOV (see Table 1 and Appendix 1 for species names); however, not every species was present in every pond. All ground surveys included in the matched dataset were from ponds counted by the USGS. Although some aerial counts were very similar to (or the same as) their paired ground counts, there was a considerable amount of variation in the data (Figure 3).

We removed outliers to reduce the influence of data points where movement of birds was likely a factor in the difference between ground and aerial counts. (See the discussion of model assumptions and limitations for details on bird movement.) To accomplish this, we fit the final model and then removed observations where the observed ground count was outside the 95% confidence interval for each observation using the selected model. The 95% confidence interval was calculated by using a bootstrap approach (2000 iterations, quasipoisson distribution). A total of 18 observations were removed by this process. We then fit the model again without the outliers to produce parameter estimates for use in predicting ground counts from aerial counts.

3. Statistical Model Development

We developed a conversion factor for comparisons of ground-based vs. aerial waterfowl survey data using a generalized linear model framework. We used regression rather than ratio methods for developing a correction factor because regression estimators allow more flexibility. Ratio estimators are appropriate when the relationship between the aerial and ground surveys approximates a straight line that passes through the origin, but they are not appropriate for curved relationships or for small counts or small probabilities of detection (Collins 2007). Having no *a priori* reason to assume our data met the requirements for a ratio estimator, we chose to use a regression estimator. The abundance values were assumed to be distributed according to a Quasi-Poisson distribution. The Quasi-Poisson distribution was used rather than a Poisson distribution because the data were counts with a fair amount of overdispersion (i.e. the variance was larger than the mean). The Poisson distribution fits count data well when the mean and variance are equal; Quasipoisson fits count data where the mean and variance are unequal. The canonical log link prevents the model from predicting negative ground counts.

The data had many instances where no birds of a given guild/species were detected in either the ground or aerial survey at a given pond. In addition, the data had many instances where birds were identified on the ground survey, but not the aerial survey, and vice versa. Based on input from waterbird biologists, we assumed that the abundance values from ground counts were "true values," or at least that they were closer to true values than values from aerial counts. This is because observers on ground counts have more time to thoroughly scan and evaluate the birds on each pond, whereas aerial observers must make rapid assessments of species composition and abundance in just a few seconds as they fly over each pond. While they were conducted on the same day, paired ground and aerial counts were not simultaneous, which introduces an additional error component associated with the fact that birds could have moved between ponds or other habitats between surveys; i.e., the population was not closed at the pond (and other) level(s) (Figure 2). Potentially better models could be developed by considering the temporal and spatial correlations in bird numbers as a function of distance in space and time (or only time if we restrict ourselves to single pond counts). Ground and aerial counts should be considered imperfect observations of different true values that are potentially correlated.

We regressed observed ground counts (x_g) on aerial counts (x_a) and detectability index. The purpose was to estimate x_g given x_a; i.e., what would the equivalent ground count be for a given aerial count, not accounting for bird movements between the ground and aerial surveys? In cases where $x_a>0$ and $x_g=0$, we assumed that the birds moved between observations because the probability that the ground count was zero when birds were present is essentially zero. Thus, those observations were removed from the analysis.

Observations where $x_a>0$ and $x_g=0$ were omitted from the model for the following reasons. Based on a Mathematica model of the probability of detection for surveys where $x_a=0$, there was a significant chance that birds were missed by the aerial count (Wolfram Research, Inc. 2012); the probability of an aerial count recording a zero when the ground count recorded a number greater than zero was about 0.25 ($P[x_a=0|x_g>0] \sim 0.25$). This probability includes both bird movement and birds that were visible from the ground, but not from the air. In addition, cases where $x_g>0$ and $x_a=0$ could have been due to bird movements; thus including these observations in the model (i.e. using the observed $pdf(x_g|x_a=0)$) will tend to overestimate the number of birds actually missed by the aerial count.

4. Model Selection

We began with a hurdle model of the effects of aerial count and detectability index on ground count. Hurdle models such as this are regression models that contain two parts: a zero part and a non-zero part (see Zuur et al. 2009 for a discussion of two-part regression models). In this case, the non-zero part is a generalized linear model of the non-zero count data with a quasi-poisson distribution. This allowed the model to take into account different factors that may influence the distribution of ground counts when aerial counts are zero and non-zero, respectively. The non-zero (count) part of the model used the independent variables aerial count (third order polynomial of the log of aerial count) and detectability index (second order polynomial; see above for calculation methods for this variable). The zero portion used only the independent variable aerial count (third order polynomial of the log of aerial count).

A generalized linear model with the aerial count and visibility index as explanatory variables, without a zero component, was a better fit for the data. A generalized linear model including smoothed aerial counts, smoothed detectability index values, and an interaction between aerial counts and detectability index (bspline(aerial count, df=4) + bspline(detectability index, df=4) + interaction; deviance explained = 64.3%)explained approximately the same amount of variation in the ground counts as a similar, simpler model containing only aerial counts and species identity with no smoothing components (aerial count + species + interaction; deviance explained = 68.4%).

Within species identity in the simpler model, all species exhibited a similar relationship between aerial and ground counts except ruddy duck (aerial count + ruddy duck + interaction). We simplified the model further by reducing species identity to a binary variable where species were classified as RUDU or other species. This final model explained about the same amount of variation as the previous models (deviance explained = 67.0%). This model uses the number of birds of a particular species that are counted from the air to predict the number of birds counted on the ground. It allows separate slopes and intercepts for RUDU vs. all other species. After removing outliers (top 5%), this model explained 80% of the deviance. This model was used to convert all of the data collected during historic aerial counts to values that we believe best estimate what we would have observed should ground counts have been conducted during the historical period. For all of the maps, tables and analyses described below, we compare this converted historical data to the observed ground count data for the current period.

RESULTS AND DISCUSSION

Comparing patterns of avian abundance and distribution in historical and current data

After converting the historical aerial survey data as described above to facilitate comparison with current ground count data, we examined changes in abundance indices across each of the nine guilds, and for all guilds combined, for each season (fall, winter and spring) separately, and for all seasons combined. We calculated average survey abundance at the pond level by season and summed these values to reach an abundance index for each pond complex. For simplicity, here we present only data at the complex scale (Tables 2-7; Figures 5-14); however, pond-level data can be provided as needed for future analyses. The figures provided in Appendix 3 illustrate, for the current survey period, the amount of annual and seasonal variation in average survey abundances for each guild found at each complex.

<u>Fall</u>: In the fall (Tables 2, 6 and 7), in both the current and historical datasets, the abundance index for shorebirds was the highest of any guild, followed by dabblers, divers and gulls. Other guilds were far less abundant during this and other seasons. The abundance index across all complexes and all guilds was higher in the historical fall season (249,735) than it was in the current fall season (164,120; Table 2). The change in the abundance index from the historical to the current period was strongly negative for dabblers (-16,423; -33%), divers (-23,927; -62%) and shorebirds (-46,615; -36%) across all complexes during the fall season, with an average loss across all guilds and all complexes of -85,615 (-34%; Tables 6 & 7). Though less numerically abundant, Eared Grebes also experienced a decrease in the abundance index of 40% (-1610; Tables 6 & 7). Not all complexes exhibited similar changes, however. For example, while dabblers showed declines at Mowry, Newark and Ravenswood complexes, they showed increases of 19 and 29% at Alviso and Eden Landing, respectively (Table 7). Similarly, the gull abundance index increased by over 400% at Mowry, and also increased at Alviso, but gull numbers declined at the other complexes, and remained nearly the same across all complexes combined between the historical and current datasets. Percent change for each guild and complex observed during fall surveys is shown in Figure 16. Standard deviations for all average survey abundances reported in the Tables can be found in Appendix 4.

Winter: In the winter (Tables 3, 6 and 7) during the historical period, the abundance indices for divers and shorebirds were the highest of any guild, followed by dabblers, gulls and fisheaters. Other guilds were far less abundant during this season. In the current period, shorebird abundance was the highest, followed distantly by dabblers, divers and gulls. Unlike the fall season, the abundance index for all complexes and all guilds combined was higher in the current winter dataset (210,890) than it was in the historical winter dataset (182,139; Table 3). The change in the abundance index from the historical to the current period in the winter season was strongly positive for dabblers (22,044; 85%) and shorebirds (24,881; 41%), and negative for divers (-16,136, -26%) and fisheaters (-8011, -84%) across all complexes combined during the winter season, with an average increase in the abundance index across all guilds and all complexes of 28,751 (16%; Tables 6 & 7). The abundance index increased for Eared Grebes by 15%, increased for gulls by 28%, and increased for terns by 163%. Similar to the fall season, not all complexes exhibited parallel changes, however. Nonetheless, some guilds did show very similar patterns across complexes. For example, in winter, all complexes showed signs of declines in the abundance index for fisheaters, ranging from losses of 59-99%. Since abundance indices were highest for most guilds in winter, and hence that season had the largest impact on our overall findings, for a visual representation of changes in abundance over time, we show abundance indices at the complex scale for each guild using the current and historical survey data (Figure 15). Percent change for each guild and complex observed during winter surveys is shown in Figure 16. Standard deviations for all abundance indices reported in the Tables can be found in Appendix 4.

Spring: In the spring (Tables 4, 6 and 7) during the historical period, the abundance index for divers and shorebirds were the highest of any guild, followed by Eared Grebes, gulls and dabblers. Other guilds were far less abundant during this season. Similar to the fall season, the abundance index across all complexes and all guilds was higher in the current spring dataset (146,476) than it was in the historical spring dataset (113,193; Table 4). The change in the abundance index from the historical to the current period in the winter season was strongly positive for shorebirds (44,557; 124%). gulls (18,249; 265%) and dabblers (10,079; 152%), and negative for divers (-28,901; -64%) and Eared Grebes (-10,074; -66%), with an average increase in the abundance index across all guilds and all complexes of 33,284 (29%; Tables 6 & 7). As observed in the fall and winter seasons, not all complexes exhibited similar changes. Nonetheless, some guilds showed very similar patterns across complexes. For example, in spring, all complexes had declines in the diver abundance index (from -39-92%), the Eared Grebe abundance index (from -30-80%), and the tern abundance index (from -23-97%). The abundance index for gulls increased in in all complexes except Ravenswood. Percent change for each guild and complex observed during spring surveys is shown in Figure 16. Standard deviations for all abundance indices reported in the Tables can be found in Appendix 4.

Fall, winter and spring combined: When abundance indices were calculated using all three seasons (Tables 5- 7), for the historical period the abundance indices for shorebirds and divers were the highest of any guild, followed by dabblers, gulls, Eared Grebes and fisheaters (in that order). Other guilds were far less abundant. Overall, the abundance index for all complexes and all guilds combined was nearly the same in the current dataset (174,302) compared to the historical dataset (170,968, Table 5). Standard deviations for Table 5 are reported in Appendix 5. The change in the abundance index from the historical to the current period was strongly positive for shorebirds (15,937; 24%), gulls (8,749; 62%), and dabblers (9,043; 38%), and negative for divers (-24,063; -48%), Eared Grebes (-4,266; -50%), and fisheaters (-2,380; -44%). The abundance index across all guilds and all complexes combined was an average of 3,334 birds per survey (representing a 2% increase; Tables 6 & 7). As observed for each season individually, there was considerable variation across complexes. For select species, including American Avocet, Black-necked Stilt, Northern Shoveler, and Ruddy Duck, we also examined differences in the abundance index between historical and current periods (Table 9). We observed declines in the abundance index from historical to current surveys for Black-necked Stilt (from -34-85%) and for Ruddy Duck (-3-95%) across all complexes, and declines of American Avocet in all complexes except Eden Landing (Table 9). Northern Shoveler changes were highly variable, and ranged from increases of over 800% in the abundance index to decreases of nearly 90%, depending on the complex.

Statistical analysis of abundance

To evaluate the statistical significance of the differences observed between data collected during historical surveys and those from current surveys, and to evaluate differences in abundances across complexes, we conducted two-way ANOVAs for each guild and each season independently (Table 8 and Figure 16). Overall, we found that, as expected, there were considerable differences in waterbird patterns of abundance among complexes. In 20 of 27 analyses, complex p-values were below p=0.05, indicating significant differences in abundance indices between at least two complexes.

Fisheaters, Phalaropes, Shorebirds and Terns were the only guilds to have non-significant differences between complexes at a given time of year. Terns were only non-significant in winter, and Fisheaters, Phalaropes and Shorebirds were non-significant in two of three seasons. Dabblers, Divers, Eared Grebes, Gulls, and Herons/Egrets were significantly different between complexes in all seasons. Therefore, the first group showed greater flexibility in the types of habitat used in each season, whereas the second group was more restricted to certain types of habitats in each season. Phalaropes and Shorebirds require shallow water on the edges of ponds or islands for foraging habitat. This type of habitat can be found on nearly any pond. In contrast, Dabblers, Divers, Eared Grebes, and Herons/Egrets have a more restricted range of habitat (i.e. a certain optimal water depth) that can be found in only a subset of the ponds. Terns can forage in shallow or deep waters. The Fisheater guild includes a diverse set of species and foraging strategies, including small grebes, Double-crested Cormorants, Mergansers and Pelicans, and consequently shows up on most ponds.

Our statistical analysis indicated that abundance indices compared across times periods (i.e., historical vs. current surveys) were statistically significant in 10 out of 27 analyses, with significant differences for at least one season for each guild, with the exception of phalaropes. Eight of these ten cases (80%) showed significant *declines* in abundance over the past 30 years, including lower abundance indices for divers in all seasons, dabblers and shorebirds in the fall, Eared Grebes in the spring, fisheaters in the winter, and terns in the spring. In contrast, there were significantly higher abundance indices for gulls, herons and egrets in the spring for the current vs. historical period.

Species richness

We evaluated changes in species richness for the set of species that could be reliably differentiated at the species level (Tables 10 & 11; Figure 17). We found richness to vary among complexes ($p<0.001$) and when compared between historical and current periods ($p<0.001$). Current richness was significantly higher than historical richness. Across all complexes combined, there were a total of 6 new species observed in current surveys that were not reported in any historical survey.

Four “new” species were rare species that were potentially missed by the lower survey rate in the historical period: Black Brant, Blue-winged Teal, Long-tailed Duck, and Snow/Ross’s Goose. Of these, Blue-winged Teal and Long-tailed Duck may have been mistaken for other species and so may not represent species that have arrived at these sites since the early 1980s. However, Brant and Snow/Ross’s Geese would likely be easily identifiable in historical surveys, and are therefore probably authentic additions to the current assemblage of waterbirds. One species, the Greater White-fronted Goose, was uncommon in the current surveys and could have been extant but missed by the lower survey rates in the historical period. The number of surveys conducted during the historical period was far fewer than that in the current period, with often twice as many surveys conducted in a given year currently compared with the 1980’s (Table 10). Nonetheless, this species would be easily detected from the air, and unlikely to be confused with any other species since Canada Goose, the only other species with which it could be easily confused, was not documented in historical surveys either.

One new species, Canada Goose, was commonly observed in current surveys, but was not recorded in historical surveys. The historical aerial surveys would most likely have documented this species if it was present, so we believe that it has arrived in the South Bay since the early 1980s. In summary, there appear to be several authentic new arrivals – Canada Goose, Brant, Greater White-fronted Goose, and Snow/Ross’s Geese. However, some of the “new” species – namely Blue-winged Teal and Long-tailed Duck– may have been present during the historical period but missed due to low aerial survey rates. Given the large and easily identifiable nature of most of these species, misidentifications from the air were probably not an issue.

Gulls

In a separate 30+ year study, SFBBO has documented dramatic rates of increase in the number of breeding California Gull pairs during May breeding colony counts. To examine to what extent changes in California Gull numbers are driving observed changes in the gull guild presented earlier in this report, we evaluated changes in total gull numbers, California Gull abundance, and non-California Gull abundances at four ponds in the Alviso complex, where gull increases have been most prevalent in recent years, particularly in the spring season. At ponds A11, A14, A19 and A21 (Figure 18) we found that although in some cases total gull numbers are stable or declining in a given location, the percentage of those that are California Gulls is increasing. Notably, at A14, where SFBBO has observed rapid California Gull colony expansion, total gull numbers have increased dramatically in the past few years, but this is driven almost entirely by increases in California Gulls.

Calculating a Conversion Factor

In general, more birds were counted in ground surveys than in aerial surveys; however, many more RUDU were counted by ground surveys than by aerial surveys, especially for smaller groups of RUDU. For RUDU, aerial and ground counts were more similar for very small and very large numbers of RUDU in a pond. For other species, the ratio between aerial and ground counts was relatively constant throughout the range, and was close to a one-to-one correspondence for the majority of the range of observations. Confidence and prediction intervals for predicted ground counts became wider as the number of birds increased (Figure 4).

Modeled differences between ground and aerial counts

For an overwhelming number of the observations (~93% of the historical dataset), the predicted ground count was greater than the aerial count. For very large counts, however, the predicted ground counts were often smaller than the aerial counts. One possible explanation for this is that for very large numbers of birds, visual saturation is more pronounced for ground observers. That is, birds are more likely to be hidden by other birds if they are crowded into very dense flocks. This is less of an issue from the air because birds aren't likely to be underneath each other. Another possible reason for higher aerial counts than ground counts for very large flocks of birds could be biases in estimation of flock size from the air. Aerial observers have very little time to quickly estimate flock size, which could result in overestimates of the actual number of birds present.

Differences between RUDU and other species

The relatively large discrepancy between ground and aerial counts of RUDU can be attributed to a combination of their body size and behavior. RUDU are smaller than many other waterfowl in our study, so they are harder to see from the airplane. RUDU also tend to be more scattered across a pond, rather than in a tight flock. This makes estimating their numbers more difficult. People tend to underestimate counts when objects are in a diffuse pattern. In addition, RUDU often dive when approached by plane, which also increases difficulties with detection.

Caveats and Assumptions

We assumed that the aerial and ground counts were proportional to the actual number of birds in a pond at the time of counting (Figure 2). This essentially means that we assumed that the probability of detection is constant over time and space (Pollock et al. 2002). This assumption is probably only loosely met, if at all, because varying environmental conditions in different ponds and on different survey days likely change the probability of detection. This assumption is necessary, however, to make comparisons over space and time (Pollock et al. 2002). The error structure in the model assumed that ground and aerial surveys were conducted simultaneously, or that no bird movement in or out of ponds occurred in the time between surveys (Figure 2). This assumption was not realistic, but we lacked data on the amount of time that had passed between ground and aerial surveys on the same days that would have enabled us to more accurately model potential deviations from this assumption. Time between surveys allowed for some unknown movement of birds, which adds error to the correlation between the ground and aerial survey counts. Removing observations where bird movement was most likely to have occurred (as described in the previous two sections) reduces the difference between the observed error structure and the error structure assumed in our model and improves the correlation between the ground and aerial survey counts.

The temporal scale of matching is rather coarse because the recent aerial data did not have time stamps on observations. Given that there are likely few surveys that were actually undertaken simultaneously, it would have been ideal to introduce information about the number of hours between the two surveys, but the best temporal data available were for the date of each survey. The fact that ground and aerial surveys were not simultaneous introduces potential sources of errors. First, birds may have moved between the counts. Second, environmental conditions may have changed. For example, we have no way to know the tidal stage during the aerial surveys. This could change bird detectability and/or cause bird movement.

The current aerial surveys and historical aerial surveys did not use exactly the same protocols. This adds some unknown degree of uncertainty to comparison with calculated ground counts for the historical waterbird dataset.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

This analysis indicates that waterbird abundance varies substantially across seasons (as expected) and across the five major pond complexes in the South Bay. It also suggests that abundances have changed significantly for particular guilds, with some guilds increasing and others decreasing over this 30+ year period of time. Notable "winners" were gulls and shorebirds, and "losers" included divers and Eared Grebes, among others. Total abundance across all guilds and complexes combined has not changed much over this period, with only a 2% change observed. As a result, the data indicate strong shifts in community structure and patterns of relative abundance in some seasons, but little change in overall abundance.

The magnitude of the difference between historical and current surveys varied with season and complex. Some guilds showed a strong reduction in abundance relative to historical times in one season, but a positive change in another season. For example, our data indicate that gulls have increased since the historical period in the spring in nearly all complexes, but that they have declined in many complexes in other seasons (Table 7). In addition, we found many cases where declines were observed in one complex but not another. Therefore, the answer to the question "how have waterbird communities changed over time" is complex. We encourage further investigation that will help to explain "why" the observed changes over time occurred. For example, analysis of the relationship between patterns of guild abundance and observed water salinities and water depth would be very informative, particularly analyses that examine if and how these relationships have changed over time. In this report, we have focused on the "what" – what were the changes in bird communities over this time period? Based on the information we present, we make the following recommendations:

1. Manage ponds at a variety of water levels and salinities across the landscape – subtle changes in these factors can have big impacts on habitat use by waterbirds. For example, field observations and recent analysis focused on the current period (Robinson-Nilsen and Bluso Demers 2012) indicate that different species/guilds can have strong preferences for ponds with certain ranges of water salinity and depth. Dabblers are often found on shallower ponds, whereas divers are often found on deeper ponds. Eared Grebes seem to prefer higher salinity ponds, Northern Shovelers appear to tolerate high salinities but are also found on lower-salinity ponds, and American Wigeons seem to prefer the lower-salinity ponds. Managing for a variety of combinations of water depth and salinity will be necessary to ensure that adequate habitat is provided for each guild.

2. Continue to monitor the impacts of ongoing restoration and management practices on waterbirds, to provide information for future adaptive management.

3. Evaluate the data that we have presented here within the context of population change observed for these species across the Pacific Flyway. For example: are divers decreasing throughout the Pacific Flyway?

4. Provide roosting and foraging habitat in close proximity to one another to reduce travel distances needed and to attract a higher density of birds.

5. Develop plans for pond management and restoration/enhancement that favors guilds that we have shown to have experienced strong declines in abundance since the historical surveys were conducted, particularly divers, Eared Grebes and fisheaters.

6. Conduct research to better understand the likely impacts of increased gull populations on other waterbird species, and, as needed, manage gull populations to reduce their negative ecological impacts.

ACKNOWLEDGMENTS

SFBBO would like to thank Cheryl Strong and Eric Mruz at the Don Edwards San Francisco Bay National Wildlife Refuge and Orien Richmond with the Region 8 Refuge Inventory and Monitoring Initiative for their support of this work at all phases of development and implementation. Thanks to Pat Mapelli and others at Cargill Salt for facilitating the ongoing data collection at the actively managed Newark and Mowry salt ponds. We would like to acknowledge Stacy Moskal and her team at the U.S. Geological Survey for carrying out the current surveys at the Eden Landing, Ravenswood and Alviso complexes. Thanks also to Lacy Smith and John Takekawa for sharing these USGS data, without which this project would not have been possible. We are indebted to Caitlin Robinson-Nilsen for managing the SFBBO salt pond survey program throughout most of the study period, and for the many biologists and field assistants who have contributed to the data collection over the years. We thank those who initiated and completed the salt pond surveys in the 1980's, including Roger Johnson, Paul Kelly, Roy Lowe and Thomas Harvey. Thanks to Katie Rodriguez for data entry. Cheryl Strong, John Takekawa, Orien Richmond and Jill Demers provided valuable insights through project development and implementation – we greatly appreciate their time, thoughtful feedback, and willingness to collaborate. This project was funded by the USFWS Refuges Inventory and Monitoring Initiative.

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Table 1: Visibility index calculations for waterfowl species used in air-to-ground count model testing. Plumage conspicuousness (High=3, Med=2, Low=1); Behavior (3 = tends to flush; 2=tends to stay on surface; 1=tends to dive).

Symbol	Common name	Scientific name	Group	Guild	Length (in), Sibley 2003	Body mass (Sibley 2003)	mass (g)	MASS INDEX	Plumage conspicuousness	PLUMAGE INDEX	Behavior	FLUSH INDEX	Mean flock size (number of birds)	FLOCK SIZE INDEX	VISIBILITY INDEX
					Value weighting:			0.4		0.2		0.1		0.3	
AMWI	American Wigeon	*Anas americana*	WATER FOWL	DABBLER	20	720	720	0.24	3	1.00	3	1.00	69.6	0.35	0.50
BRAN	Brant	*Branta bernicla*	WATER FOWL	GOOSE	25	1400	1400	0.46	3	1.00	2	0.67	46.7	0.23	0.52
BUFF	Bufflehead	*Bucephala albeola*	WATER FOWL	DIVER	13.5	380	380	0.12	3	1.00	1	0.33	17.5	0.09	0.31
CAGO/ WCGO	Canada Goose	*Branta canadensis*	WATER FOWL	GOOSE	25-45	1600-4500	3050	1.00	3	1.00	2	0.67	29.8	0.15	0.71
CANV	Canvasback	*Aythya valisineria*	WATER FOWL	DIVER	21	1220	1220	0.40	3	1.00	2	0.67	159.1	0.79	0.66
CITE	Cinnamon Teal	*Anas cyanoptera*	WATER FOWL	DABBLER	16	400	400	0.13	2	0.67	2	0.67	22.5	0.11	0.29
COOT	American Coot	*Fulica americana*	WATER FOWL	COOT	15.5	650	650	0.21	3	1.00	2	0.67	119.5	0.59	0.53
GADW	Gadwall	*Anas strepera*	WATER FOWL	DABBLER	20	910	910	0.30	2	0.67	2	0.67	31.7	0.16	0.37
GOLD	Goldeneye (common and Barrow's)	*Bucephala clangula* *Bucephala islandica*	WATER FOWL	DIVER	18.5/18	850/ 950	900	0.30	3	1.00	1	0.33	12.7	0.06	0.37
GWTE	Green-winged Teal	*Anas crecca*	WATER FOWL	DABBLER	14	350	350	0.11	1	0.33	2	0.67	102.7	0.51	0.33
MALL	Mallard	*Anas platyrhynchos*	WATER FOWL	DABBLER	23	1100	1100	0.36	2	0.67	2	0.67	18.17	0.09	0.37

NOPI/ PINT	Northern Pintail	*Anas acuta*	WATER FOWL	DABBLER	21	800	800	0.26	3	1.00	3	1.00	187.7	0.93	0.68
NSHO	Northern Shoveler	*Anas clypeata*	WATER FOWL	DABBLER	19	610	610	0.20	3	1.00	2	0.67	148.6	0.74	0.57
REDH	Redhead	*Aythya americana*	WATER FOWL	DIVER	19	1050	1050	0.34	2	0.67	2	0.67	68.2	0.34	0.44
RUDU	Ruddy Duck	*Oxyura jamaicensis*	WATER FOWL	DIVER	15	560	560	0.18	2	0.67	1	0.33	134.8	0.67	0.44
SCAU	Scaup (lesser and greater)	*Aythya affinis* and *Aythya marila*	WATER FOWL	DIVER	16.5/18	830/ 1050	940	0.31	3	1.00	2	0.67	201.5	1.00	0.69
SCOT	Surf Scoter	*Melanitta perspicillata*	WATER FOWL	DIVER	20	950	950	0.31	2	0.67	2	0.67	32.0	0.16	0.37
TUSW	Tundra Swan	*Cygnus columbianus*	WATER FOWL	SWAN	60	10500		1.00	3	1.00	2	0.67	1.5	0.01	0.67
LTDU	Long-tailed Duck	*Clangula hyemalis*	WATER FOWL	DIVER	16.5	740	740	0.24	3	1.00	2	0.67			
ROGO	Ross's Goose	*Chen rossii*	WATER FOWL	GOOSE	23	1250	1250	0.41	1	0.33	2	0.67			
WODU	Wood Duck	*Aix sponsa*	WATER FOWL	DABBLER	18.5	600	600	0.20	3	1.00	2	0.67			
HARD	Harlequin Duck	*Histrionicus histrionicus*	WATER FOWL	DIVER	16.5	600	600	0.20	3	1.00	2	0.67			
SNGO	Snow Goose	*Chen caerulescens*	WATER FOWL	GOOSE	28	2420	2420	0.79	3	1.00	2	0.67			
BWTE/ BCTE	Blue-winged Teal	*Anas discors*	WATER FOWL	DABBLER	15.5	380	380	0.12	3	1.00	2	0.67			
SWAN	Unidentified swan		WATER FOWL	GOOSE											
WFGO	Greater White-fronted Goose	*Anser albifrons*	WATER FOWL	GOOSE	28	2200	2200	0.72	3	1.00	2	0.67			
GOOS	Snow Goose/Ross's Goose		WATER FOWL	GOOSE	28/23	2420/1 250	1835	0.60	3	1.00	2	0.67			
CACG	Cackling Goose	*Branta hutchinsii*	WATER FOWL	GOOSE	25-45	1600-4500	3050	1.00	1	0.33	2	0.67			

RNDU	Ring-necked Duck	*Aythya collaris*	WATER FOWL	DIVER	17	700	700	0.23	2	0.67	2	0.67			
MERG/ RBME	Red-breasted Merganser		WATER FOWL	FISHEAT	23	1060	1060	0.35	2	0.67	1	0.33			

Table 2. FALL survey abundance index for dabblers, divers, eared grebes, fish eaters, gulls, herons and egrets, phalaropes, shorebirds and terns, and for all guilds combined (ALL), calculated at the complex scale for the current and historical time periods. Values indicate the sum of pond-level average abundances across all ponds in each complex using data from fall surveys. See text for details on the data processing steps used to generate the values listed. Standard deviations are provided in Appendix 4, and statistical analysis in Table 8.

Period	Season	Complex	Dabblers	Divers	Eared Grebes	Fish eaters	Gulls	Herons and egrets	Phalaropes	Shorebirds	Terns	ALL guilds
Current	**Fall**	Alviso	25949	13814	1001	3840	9755	552	383	21338	684	77315
		Eden Landing	2525	484	53	1220	852	196	622	38261	441	44654
		Mowry	1464	55	824	224	7477	20	277	4905	28	15275
		Newark	3383	573	547	1066	1356	226	438	13197	238	21023
		Ravenswood	229	33	10	49	85	18	5	5424	0	5853
		ALL	33549	14958	2435	6399	19525	1012	1726	83126	1390	164120
Historical	**Fall**	Alviso	21801	15328	435	2449	7765	580	11	25819	243	74431
		Eden Landing	1959	13619	1	1534	3164	712	602	47354	1024	69969
		Mowry	5480	3719	3476	380	1397	26	93	17376	142	32089
		Newark	19761	5918	133	101	4805	11	141	18172	178	49219
		Ravenswood	971	301	0	1	1686	0	46	21020	0	24026
		ALL	49973	38885	4045	4465	18817	1328	894	129741	1588	249735

Table 3. WINTER survey abundance index for dabblers, divers, eared grebes, fish eaters, gulls, herons and egrets, phalaropes, shorebirds and terns, and for all guilds combined (ALL), calculated at the complex scale for the current and historical time periods. Values indicate the sum of pond-level average abundances across all ponds in each complex using data from winter surveys. See text for details on the data processing steps used to generate the values listed. Standard deviations are provided in Appendix 4, and statistical analysis in Table 8.

Period	Season	Complex	Dabblers	Divers	Eared Grebes	Fish eaters	Gulls	Herons and egrets	Phalaropes	Shorebirds	Terns	ALL guilds
Current	**Winter**	Alviso	37560	32191	1781	1162	14694	207	0	22562	105	110260
		Eden Landing	6258	8684	316	192	595	88	0	36047	54	52234
		Mowry	659	746	1551	64	6586	9	0	5251	19	14885
		Newark	3127	3438	1544	130	1849	57	1	12905	19	23070
		Ravenswood	295	718	31	6	121	9	0	9254	7	10441
		ALL	47898	45777	5223	1554	23846	370	2	86019	203	210890
Historical	**Winter**	Alviso	14574	23201	907	2820	7618	238	0	15156	7	64522
		Eden Landing	2529	21853	66	571	1212	229	0	11410	21	37890
		Mowry	715	2824	2414	4867	2561	0	0	1884	20	15284
		Newark	5672	9552	1104	1230	2232	2	2	17664	30	37490
		Ravenswood	2364	4483	39	76	4966	0	0	15024	0	26953
		ALL	25854	61913	4530	9565	18590	470	2	61138	77	182139

Table 4. SPRING survey abundance index for dabblers, divers, eared grebes, fish eaters, gulls, herons and egrets, phalaropes, shorebirds and terns, and for all guilds combined (ALL), calculated at the complex scale for the current and historical time periods. Values indicate the sum of pond-level average abundances across all ponds in each complex using data from spring surveys. See text for details on the data processing steps used to generate the values listed. Standard deviations are provided in Appendix 4, and statistical analysis in Table 8.

Period	Season	Complex	Dabblers	Divers	Eared Grebes	Fish eaters	Gulls	Herons and egrets	Phalaropes	Shorebirds	Terns	ALL guilds
Current	**Spring**	Alviso	11959	9784	927	897	12552	167	94	19882	519	56781
		Eden Landing	3601	4028	93	150	418	114	343	37603	180	46531
		Mowry	40	191	1700	7	7052	3	9	1064	4	10069
		Newark	1063	1384	2456	70	4812	20	361	8753	125	19043
		Ravenswood	66	542	20	8	304	9	23	13054	28	14053
		ALL	16729	15929	5195	1132	25138	312	829	80356	857	146476
Historical	**Spring**	Alviso	3602	16150	3476	401	2501	78	0	11104	723	38035
		Eden Landing	1126	13856	133	358	145	46	130	4642	301	20736
		Mowry	22	2536	6964	615	1838	0	0	1619	118	13713
		Newark	1774	8834	4599	311	1498	5	363	16716	162	34262
		Ravenswood	126	3454	98	1	907	0	100	1717	44	6446
		ALL	6650	44830	15269	1686	6889	129	593	35798	1348	113193

Table 5. COMBINED, 3-season abundance indices for dabblers, divers, eared grebes, fish eaters, gulls, herons and egrets, phalaropes, shorebirds and terns, and for all guilds combined (ALL), calculated at the complex scale for the current and historical datasets. Values indicate the sum of complex-level abundance indices using data from fall, winter and spring surveys. See text for details on the data processing steps used to generate the averages listed. Standard deviations are provided in Appendix 4, and statistical analysis in Table 8.

Period	Season	Complex	Dabblers	Divers	Eared Grebes	Fish eaters	Gulls	Herons and egrets	Phalaropes	Shorebirds	Terns	ALL guilds
Current	**Fall, winter, spring**	Alviso	25278	18681	1242	1943	12408	306	156	21144	433	81591
		Eden Landing	4171	4485	157	507	617	131	318	37364	220	47971
		Mowry	747	339	1355	103	6976	11	101	3800	17	13449
		Newark	2537	1846	1515	398	2701	97	266	11601	123	21085
		Ravenswood	195	441	21	21	172	12	9	9322	12	10206
		ALL	32928	25793	4289	2972	22875	557	850	83231	806	174302
Historical	**Fall, winter, spring**	Alviso	11964	18607	1786	1802	5660	255	3	16030	347	56454
		Eden Landing	1864	16789	78	709	1265	273	186	17167	360	38691
		Mowry	1548	2920	4409	2196	2015	6	21	5357	86	18558
		Newark	7327	8418	2229	615	2540	5	174	17450	116	38875
		Ravenswood	1182	3122	53	30	2648	0	49	11290	17	18391
		ALL	23885	49856	8555	5353	14127	540	433	67294	926	170968

Table 6. Change in abundance indices of dabblers, divers, eared grebes, fish eaters, gulls, herons and egrets, phalaropes, shorebirds and terns, and for all guilds combined (ALL), calculated at the complex scale for the current and historical datasets. Change in the abundance index was calculated as the current abundance index minus the historical abundance index. Positive values indicate that abundance increased, while negative values indicate that abundance decreased.

Season	Complex	Dabblers	Divers	Eared Grebes	Fish eaters	Gulls	Herons and egrets	Phalaropes	Shorebirds	Terns	ALL guilds
Fall	Alviso	4147	-1514	566	1391	1990	-28	372	-4481	440	2884
	Eden Landing	565	-13135	53	-314	-2312	-516	20	-9093	-583	-25315
	Mowry	-4016	-3664	-2652	-155	6080	-6	184	-12470	-115	-16815
	Newark	-16378	-5345	414	965	-3449	216	297	-4974	59	-28196
	Ravenswood	-741	-268	10	48	-1601	18	-41	-15597	0	-18173
	ALL	-16423	-23927	-1610	1934	708	-316	832	-46615	-198	-85615
Winter	Alviso	22985	8990	874	-1659	7076	-31	0	7405	98	45739
	Eden Landing	3729	-13170	250	-379	-617	-141	0	24637	33	14344
	Mowry	-56	-2078	-863	-4802	4025	9	0	3367	-1	-399
	Newark	-2546	-6114	440	-1100	-383	55	0	-4759	-12	-14420
	Ravenswood	-2070	-3765	-8	-70	-4845	9	0	-5770	7	-16512
	ALL	22044	-16136	693	-8011	5256	-101	0	24881	126	28751
Spring	Alviso	8357	-6366	-2549	496	10052	89	94	8777	-204	18746
	Eden Landing	2475	-9828	-39	-209	273	68	213	32962	-120	25795
	Mowry	19	-2345	-5264	-608	5213	2	9	-555	-115	-3644
	Newark	-711	-7450	-2143	-241	3314	15	-2	-7964	-37	-15219
	Ravenswood	-61	-2912	-78	7	-603	9	-77	11337	-15	7607
	ALL	10079	-28901	-10074	-554	18249	183	236	44557	-492	33284
Fall, winter, spring	Alviso	13314	74	-544	141	6748	51	154	5113	86	25138
	Eden Landing	2307	-12303	79	-202	-647	-141	131	20197	-140	9280
	Mowry	-801	-2581	-3054	-2093	4962	5	79	-1557	-69	-5109
	Newark	-4790	-6572	-714	-217	161	91	92	-5849	8	-17790
	Ravenswood	-987	-2681	-32	-10	-2476	12	-40	-1967	-5	-8184
	ALL	9043	-24063	-4266	-2380	8749	17	417	15937	-120	3334

Table 7. Percent change in abundance indices of dabblers, divers, eared grebes, fish eaters, gulls, herons and egrets, phalaropes, shorebirds and terns, and for all guilds combined (ALL), calculated at the complex scale for the current and historical datasets. Percent change in abundance index was calculated as (current abundance index – historical abundance index)/historical abundance index * 100.

Season	Complex	Dabblers	Divers	Eared Grebes	Fish eaters	Gulls	Herons and egrets	Phalaropes	Shorebirds	Terns	ALL guilds
Fall	Alviso	19	-10	130	57	26	-5	3309	-17	181	4
	Eden Landing	29	-96	6485	-20	-73	-72	3	-19	-57	-36
	Mowry	-73	-99	-76	-41	435	-22	198	-72	-81	-52
	Newark	-83	-90	311	955	-72	2022	211	-27	33	-57
	Ravenswood	-76	-89	N/A	3200	-95	N/A	-90	-74	N/A	-76
	ALL	-33	-62	-40	43	4	-24	93	-36	-12	-34
Winter	Alviso	158	39	96	-59	93	-13	N/A	49	1486	71
	Eden Landing	147	-60	377	-66	-51	-62	N/A	216	161	38
	Mowry	-8	-74	-36	-99	157	1753	N/A	179	-4	-3
	Newark	-45	-64	40	-89	-17	2237	-24	-27	-38	-38
	Ravenswood	-88	-84	-21	-92	-98	1767	N/A	-38	N/A	-61
	ALL	85	-26	15	-84	28	-21	-1	41	163	16
Spring	Alviso	232	-39	-73	124	402	115	N/A	79	-28	49
	Eden Landing	220	-71	-30	-58	188	147	164	710	-40	124
	Mowry	87	-92	-76	-99	284	435	N/A	-34	-97	-27
	Newark	-40	-84	-47	-77	221	317	-1	-48	-23	-44
	Ravenswood	-48	-84	-80	464	-66	N/A	-77	660	-35	118
	ALL	152	-64	-66	-33	265	142	40	124	-36	29
Fall, winter, spring	Alviso	111	0	-30	8	119	20	5936	32	25	45
	Eden Landing	124	-73	102	-29	-51	-52	70	118	-39	24
	Mowry	-52	-88	-69	-95	246	75	369	-29	-80	-28
	Newark	-65	-78	-32	-35	6	1712	53	-34	7	-46
	Ravenswood	-83	-86	-61	-31	-93	6179	-81	-17	-28	-45
	ALL	38	-48	-50	-44	62	3	96	24	-13	2

Table 8. Two-way ANOVA results to evaluate abundance index as a function of complex and time period (current vs. historical). The response variable was the abundance index within a season for each guild/species, the fixed factors were complex and time period (current vs. historical). An ANOVA model was fit for each guild and season combination separately.

Season	*Guild*	*Complex p-value*	*Period p-value*
Fall	Dabblers	**<0.001**	**0.004**
Winter		**<0.001**	0.208
Spring		**<0.001**	0.151
Fall	Divers	**<0.001**	**<0.001**
Winter		**<0.001**	**0.006**
Spring		**0.004**	**<0.001**
Fall	Eared Grebes	**0.022**	0.250
Winter		**0.010**	0.563
Spring		**0.005**	**0.031**
Fall	Fish Eaters	**<0.001**	0.102
Winter		0.113	**0.016**
Spring		0.570	0.072
Fall	Gull	**<0.001**	0.432
Winter		**0.002**	0.790
Spring		**<0.001**	**<0.001**
Fall	Heron	**<0.001**	0.892
Winter		**0.001**	0.404
Spring		**<0.001**	**0.002**
Fall	Phalarope	0.541	0.506
Winter		0.102	0.946
Spring		**0.052**	0.481
Fall	Shorebird	0.095	**<0.001**
Winter		0.128	0.803
Spring		**0.007**	0.109
Fall	Tern	**0.011**	0.415
Winter		0.353	0.136
Spring		**<0.001**	**0.020**

Table 9. For select species, current and historical abundance indices for fall, winter and spring data combined, the change in the abundance index from historical to current time periods (current – historical; positive values indicate an increase in abundance since historical surveys), and the percent change.

	Season	Complex	American Avocet	Black-necked Stilt	Northern Shoveler	Ruddy Duck
Average survey abundance – Current data	**Fall, winter, spring**	Alviso	2730	429	11020	12836
		Eden Landing	1907	623	2475	2769
		Mowry	655	139	722	156
		Newark	742	247	1892	979
		Ravenswood	256	128	121	45
Average survey abundance – Historical data	**Fall, winter, spring**	Alviso	3264	845	3576	13261
		Eden Landing	1404	942	263	12166
		Mowry	674	259	787	1866
		Newark	1489	1286	4345	5141
		Ravenswood	2024	865	1075	861
Change in abundance	**Fall, winter, spring**	Alviso	-534	-416	7444	-426
		Eden Landing	502	-319	2213	-9397
		Mowry	-20	-121	-66	-1709
		Newark	-746	-1039	-2453	-4162
		Ravenswood	-1768	-737	-954	-816
Percent change in abundance	**Fall, winter, spring**	Alviso	-16.4	-49.2	208.2	-3.2
		Eden Landing	35.8	-33.8	842.6	-77.2
		Mowry	-2.9	-46.5	-8.3	-91.6
		Newark	-50.1	-80.8	-56.5	-81.0
		Ravenswood	-87.4	-85.2	-88.8	-94.7

Table 10. Average species richness and standard deviation of waterfowl species in the historical versus the current dataset, calculated at the complex level.

Complex	**Current Richness** ($\pm$ SD)	**Historical Richness** ($\pm$ SD)
Alviso	16.8 $\pm$ 3.3	12.3 $\pm$ 3.1
Eden Landing	14.4 $\pm$ 3.3	12.5 $\pm$ 2.4
Mowry	9.5 $\pm$ 4.2	6.5 $\pm$ 2.5
Newark	12.6 $\pm$ 3.5	7.8 $\pm$ 2.5
Ravenswood	9.5 $\pm$ 2.8	5.3 $\pm$ 2.1

Sample size - number of pond surveys per complex during the current (2005-2012) sampling period

Cohort	**Alviso**	**Eden Landing**	**Mowry**	**Newark**	**Ravenswood**
2005-2006	169	139	48	114	42
2006-2007	212	185	53	132	54
2007-2008	208	189	54	122	55
2008-2009	211	186	54	130	54
2009-2010	210	187	54	130	54
2010-2011	207	180	43	128	54
2011-2012	211	184	54	132	52
2012-2013	24	21	6	14	6

Sample size - number of pond surveys per complex during the historical (1980-1984) sampling period

Cohort	**Alviso**	**Eden Landing**	**Mowry**	**Newark**	**Ravenswood**
1980-1981	31	36	10	22	7
1981-1982	132	118	35	74	33
1982-1983	45	39	11	25	11
1983-1984	69	54	18	37	18

Table 11. Species included in richness analysis (data presented in Table 10).

ID	SpeciesRecordedAs	SpeciesCode	SpeciesName
1	AMCO	AMCO	American Coot
2	AMWI	AMWI	American Widgeon
4	BLBR	BLBR	Black Brant
5	BUFF	BUFF	Bufflehead
6	BWTE	BWTE	Blue-winged Teal
7	CACG	CAGO	Canada Goose
8	CAGO	CAGO	Canada Goose
9	CANV	CANV	Canvasback
10	CITE	CITE	Cinnamon Teal
12	GADW	GADW	Gadwall
3	BAGO	GOLD	Barrow's or Common Goldeneye
11	COGO	GOLD	Barrow's or Common Goldeneye
13	GOLD	GOLD	Barrow's or Common Goldeneye
15	GWFG	GWFG	Greater White-fronted Goose
16	GWTE	GWTE	Green-winged Teal
17	HADU	HADU	Harlequin Duck
19	LTDU	LTDU	Long-tailed Duck
20	MALL	MALL	Mallard
21	NOPI	NOPI	Northern Pintail
22	NSHO	NSHO	Northern Shoveler
23	RBME	RBME	Red-breasted Merganser
24	REDH	REDH	Redhead
25	RNDU	RNDU	Ring-necked Duck
27	RUDU	RUDU	Ruddy Duck
14	GRSC	SCAU	Greater or Lesser Scaup
18	LESC	SCAU	Greater or Lesser Scaup
28	SCAU	SCAU	Greater or Lesser Scaup
26	ROGO	SNGO/ROGO	Snow or Ross's Goose
29	SNGO	SNGO/ROGO	Snow or Ross's Goose
30	SNGO/ROGO	SNGO/ROGO	Snow or Ross's Goose
31	SUSC	SUSC	Surf Scoter
32	SWAN	SWAN	Unidentified Swan
33	TUSW	SWAN	Unidentified Swan
34	WODU	WODU	Wood Duck

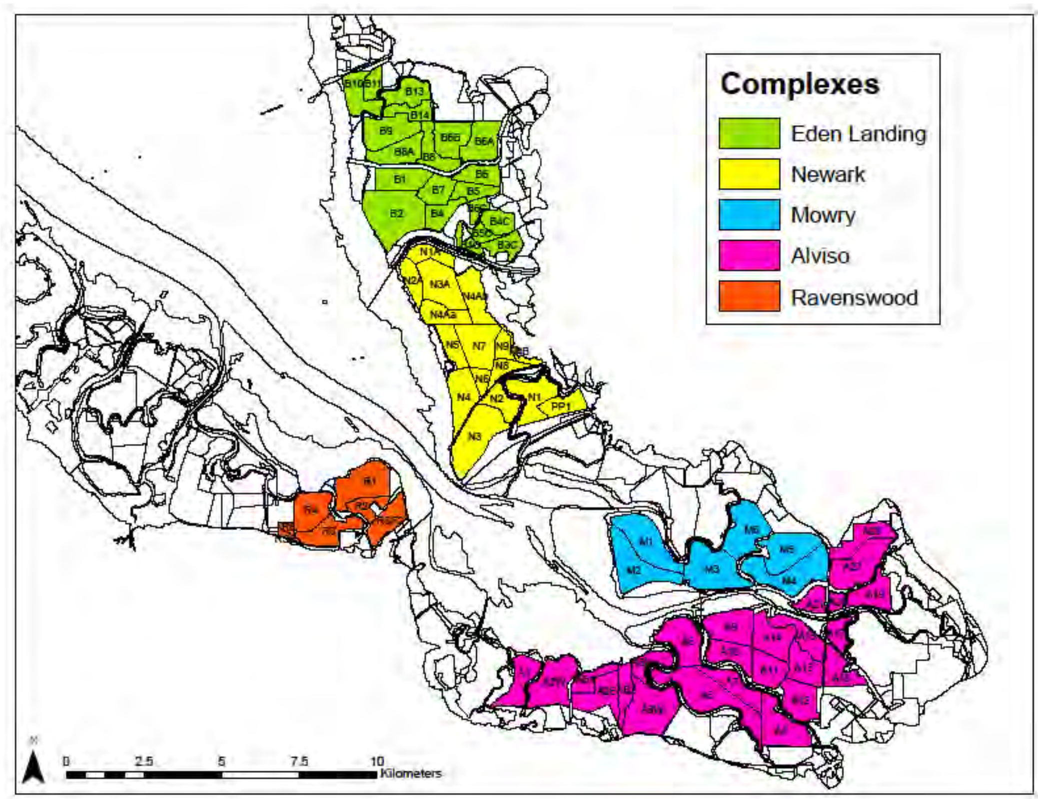


Figure 1. Former (Eden Landing, Alviso, and Ravenswood) and still active (Newark and Mowry) South San Francisco Bay salt ponds where ground-based waterbird surveys are conducted by the USGS and SFBBO.

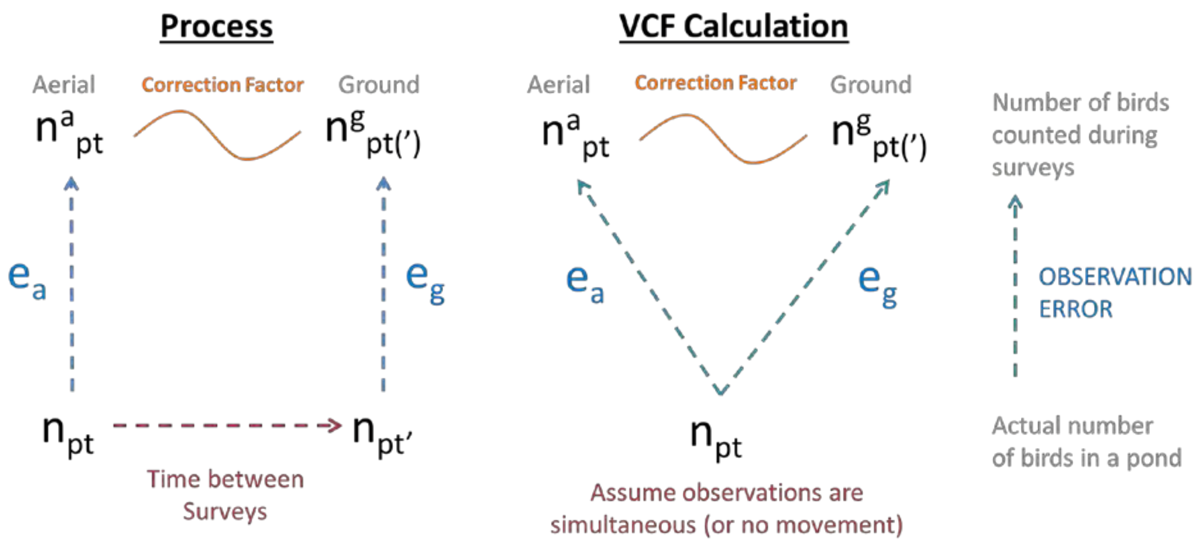


Figure 2. Conceptual models for the data collection process comparing aerial and ground count data and sources of error (left panel), and the conceptual model for the conversion factor calculation (right panel).

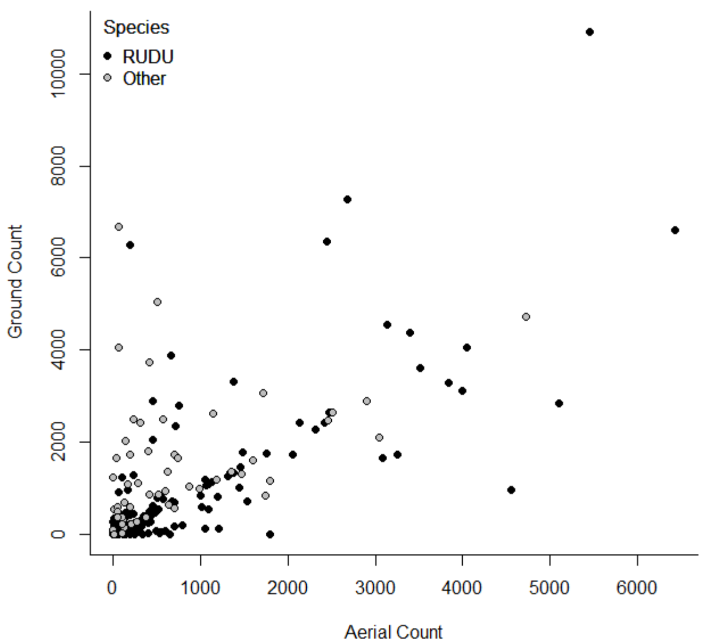


Figure 3: Paired aerial (MWS) and ground (USGS) counts of birds made in the same pond on the same day. Modeling efforts indicated that Ruddy Duck (RUDU) observations should be converted using a separate algorithm than all other species.

a) b)

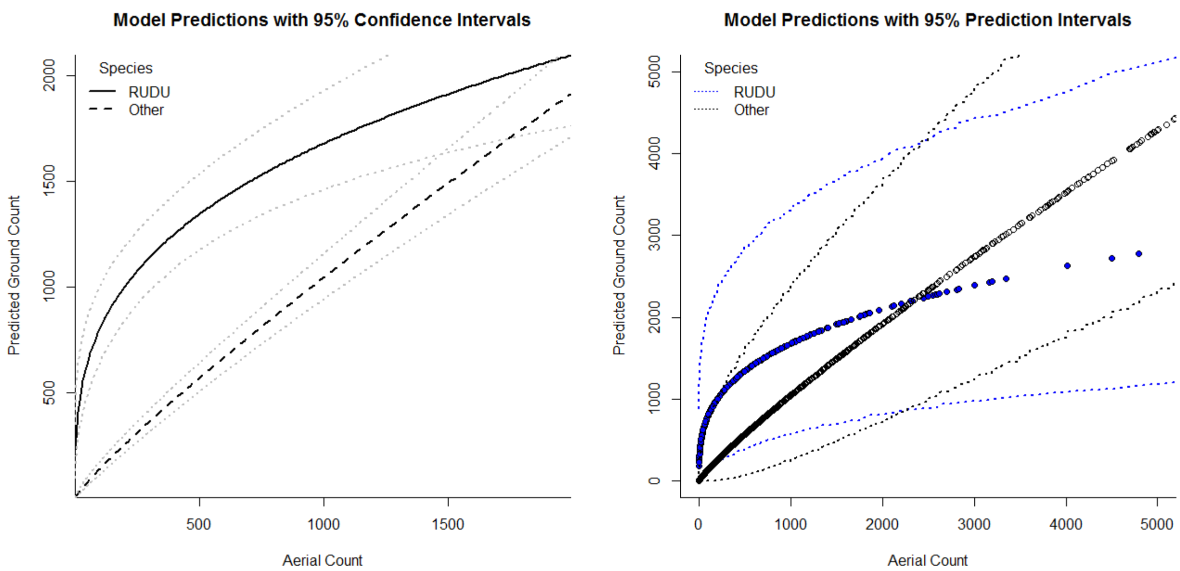
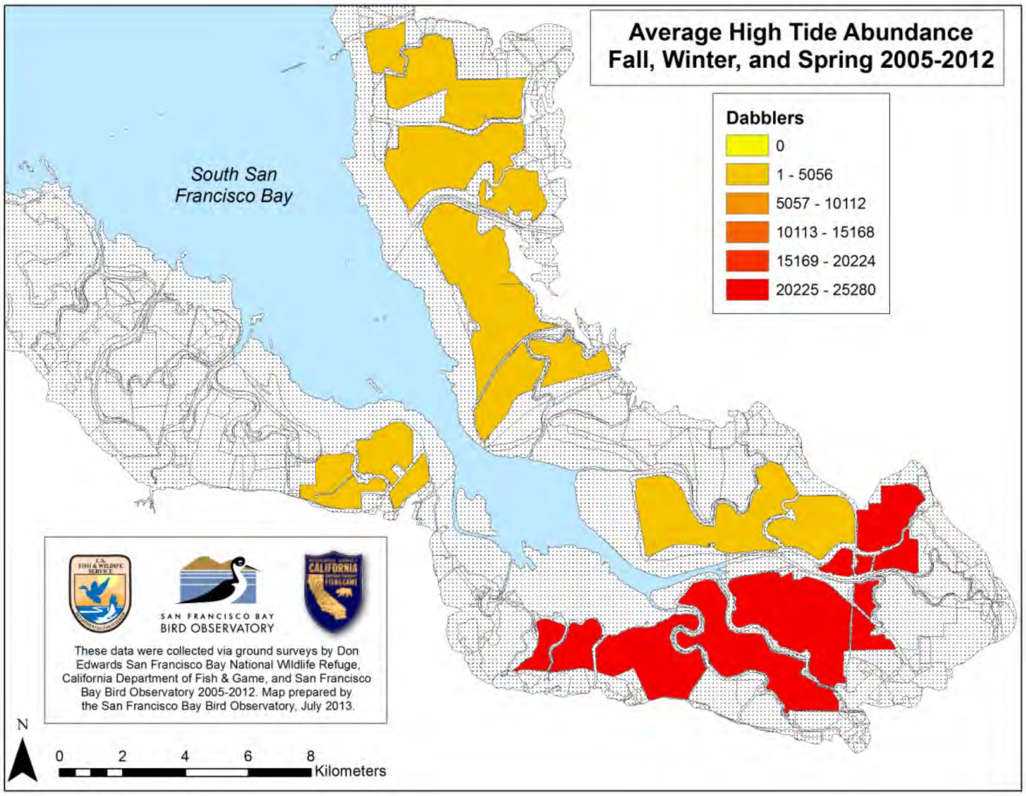


Figure 4: Modeled aerial count predictions based on converted values for observed ground counts with (a) 95% confidence intervals and (b) 95% prediction intervals. (a) was plotted with simulated data and (b) was plotted with data from the Historic Waterbird Dataset.



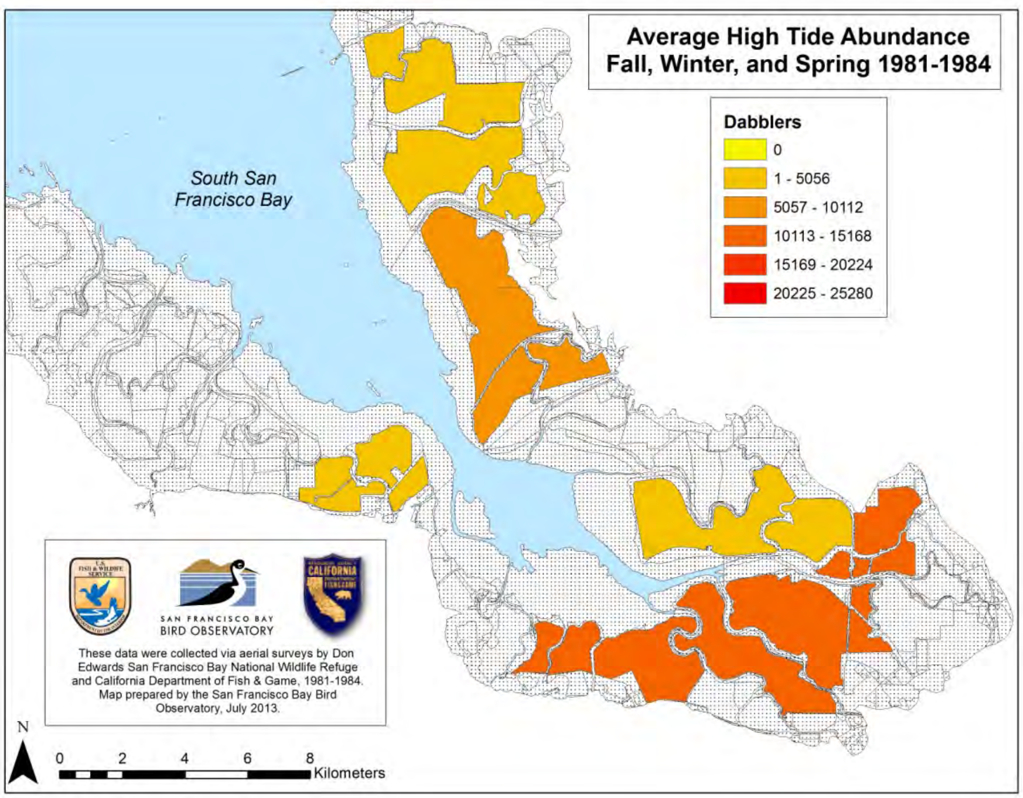


Figure 5. Average abundance index of dabblers during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundances indices based on historic aerial surveys.

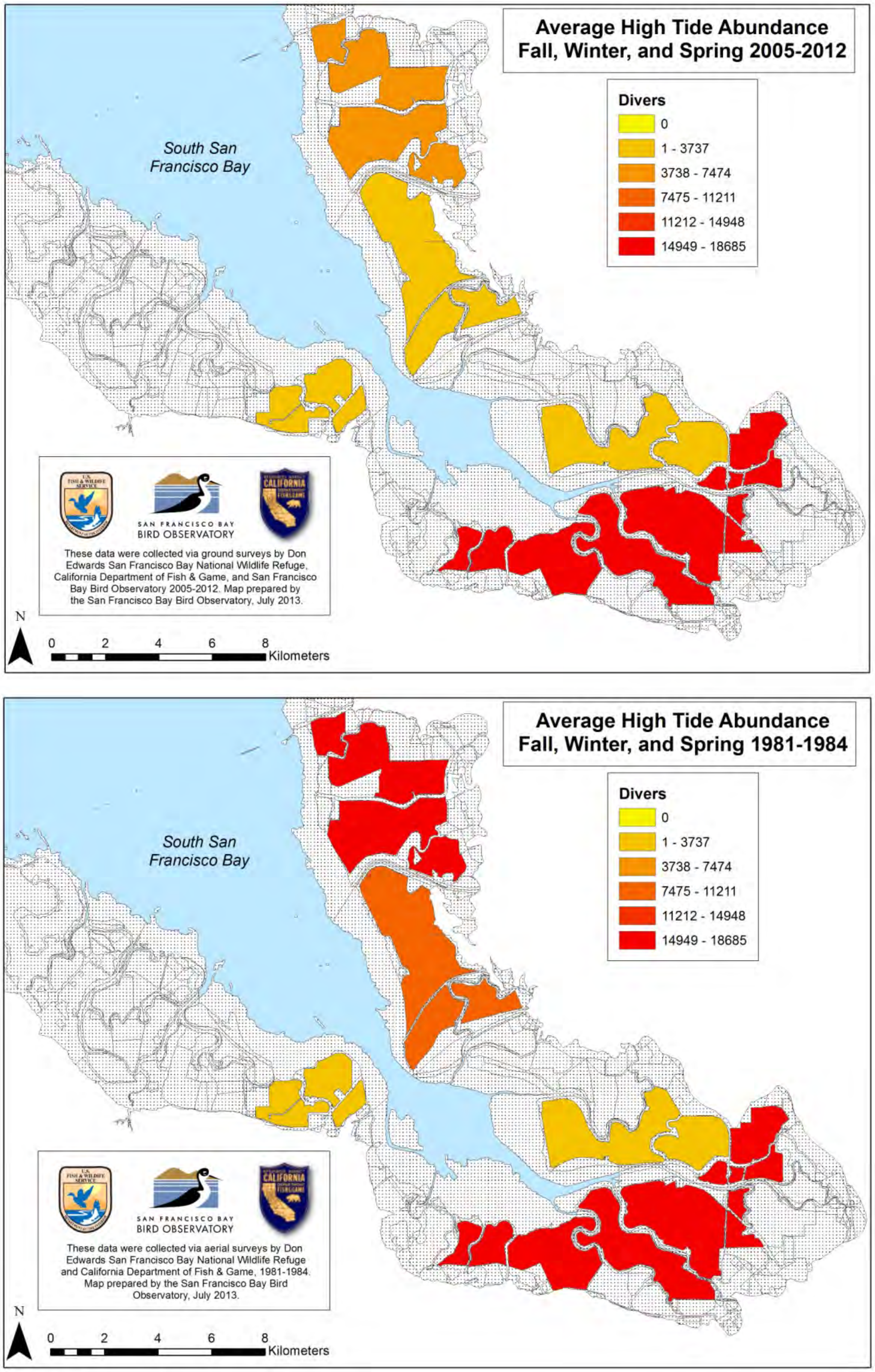
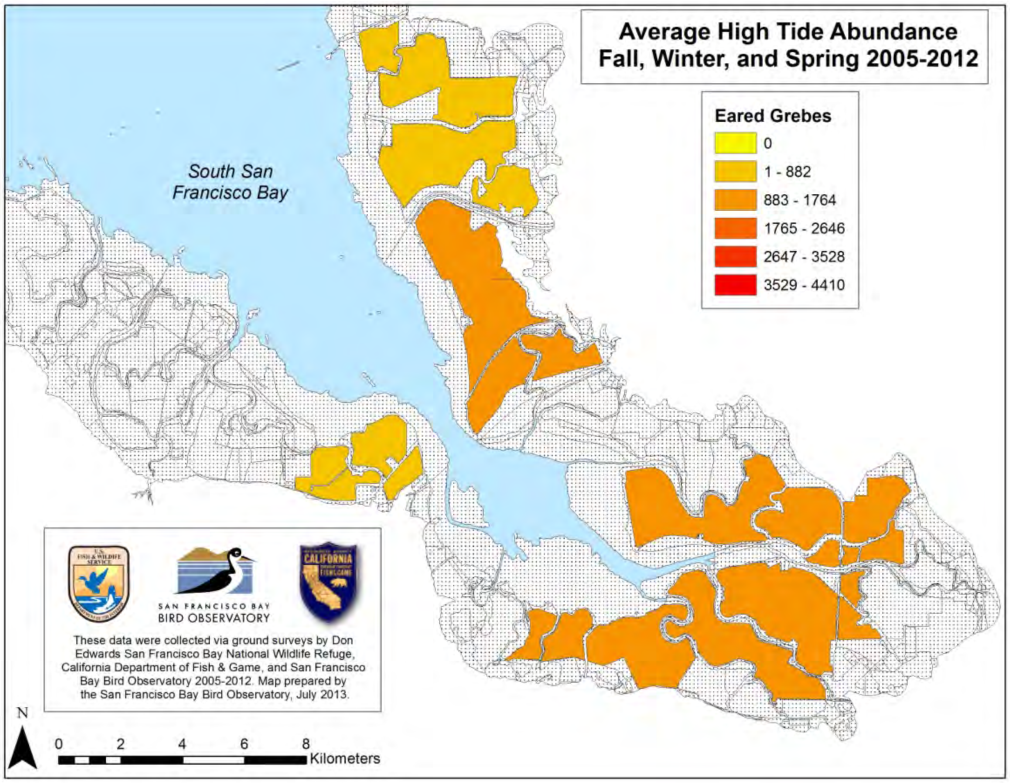


Figure 6. Average abundance index of divers during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.



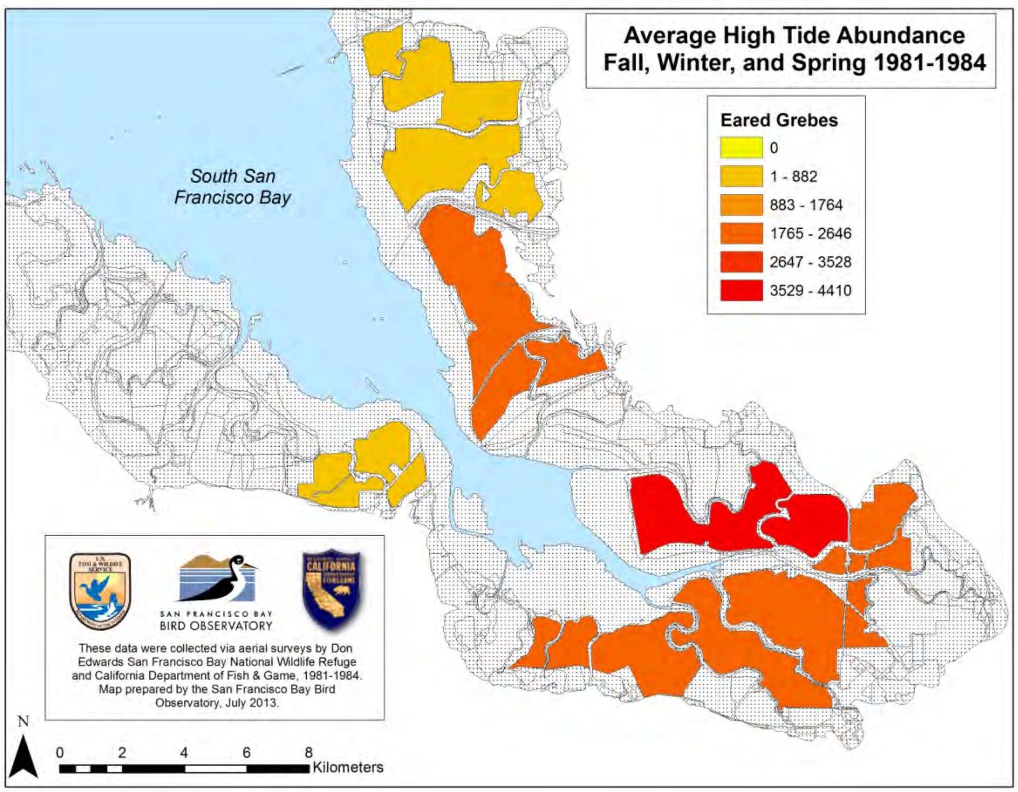
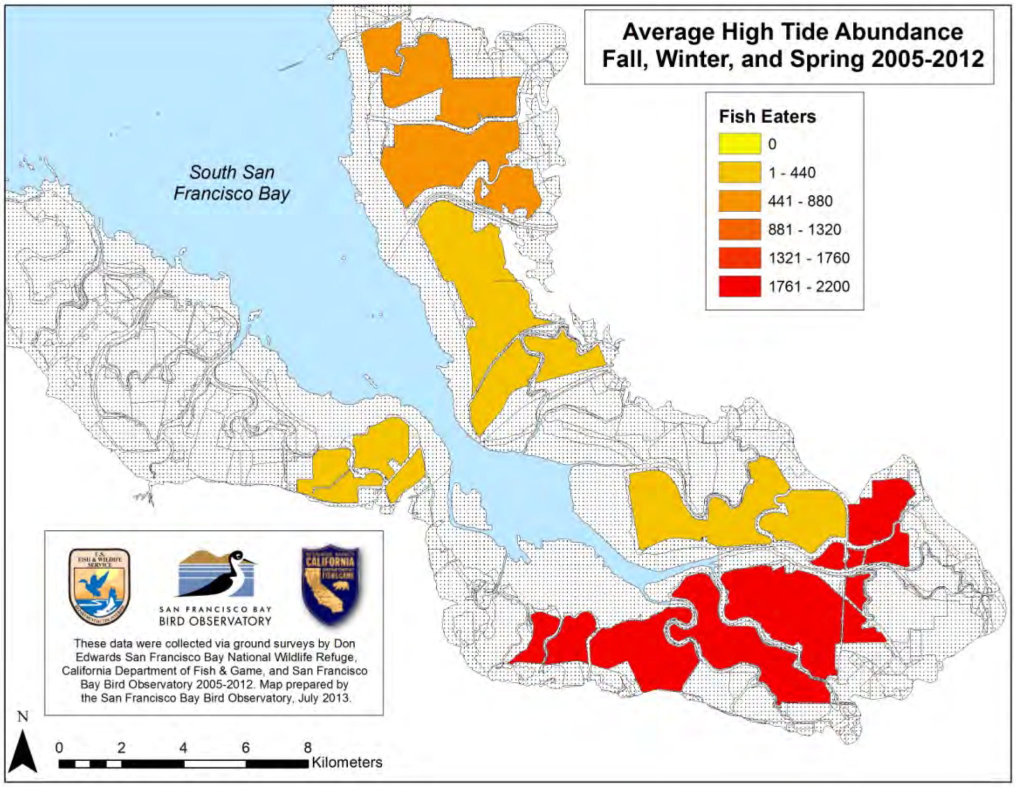


Figure 7. Average abundance index of Eared Grebes during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.



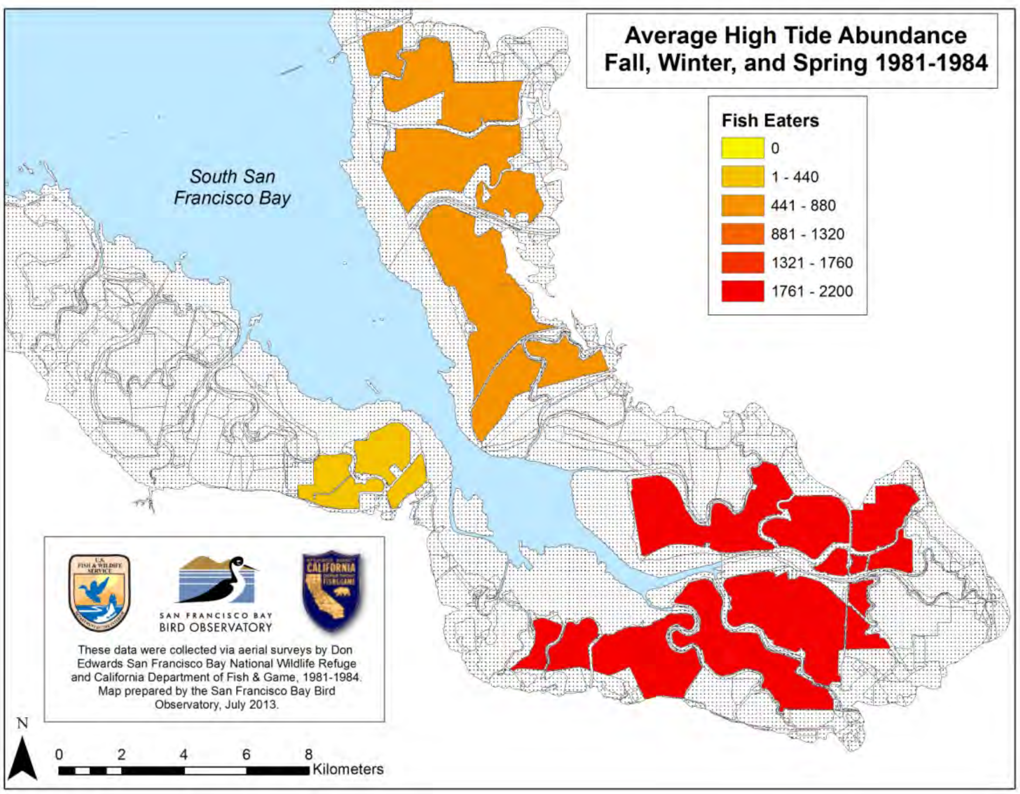
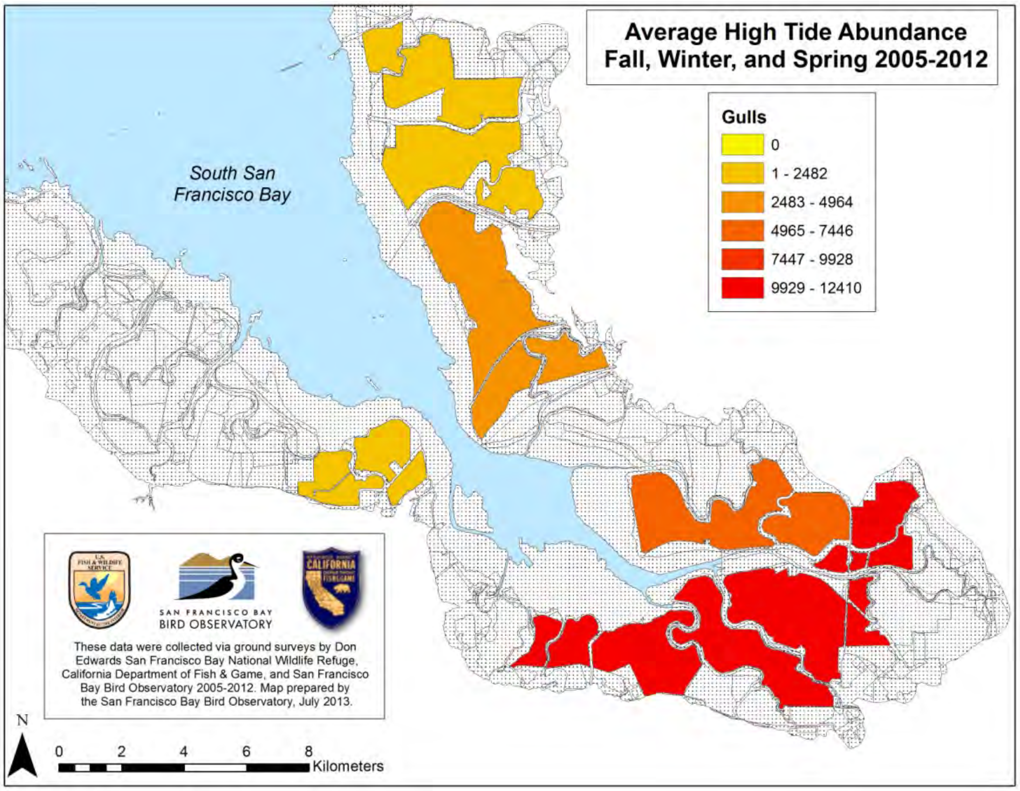


Figure 8. Average abundance index of fish eaters during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.



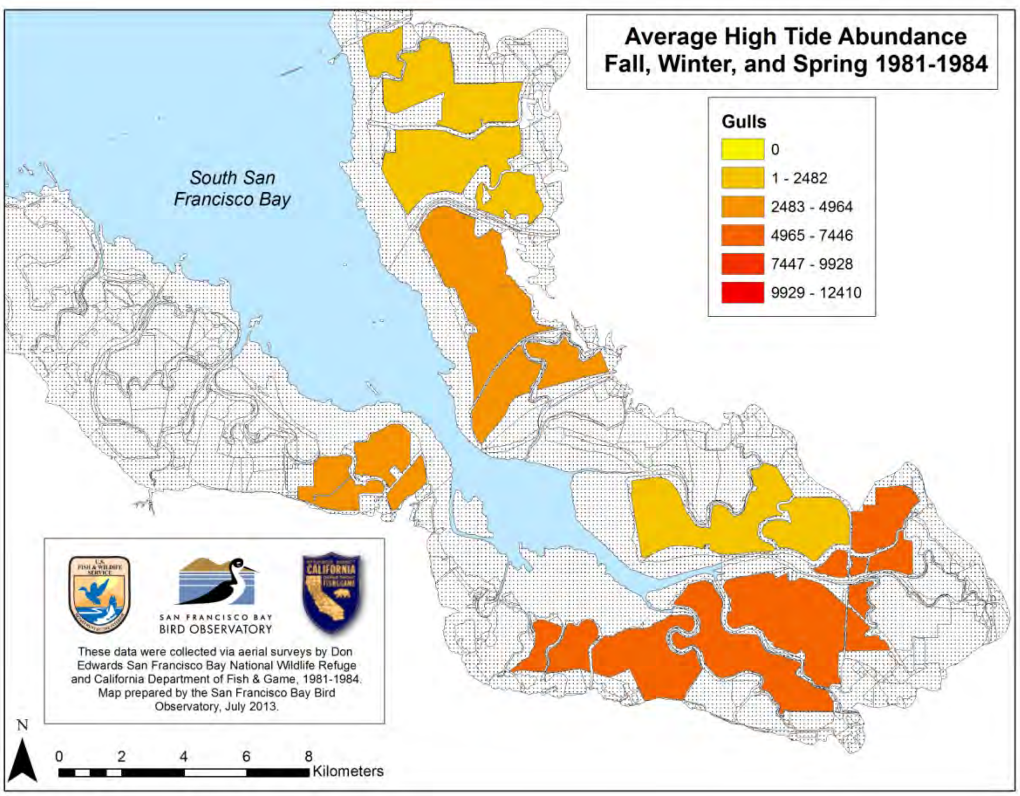
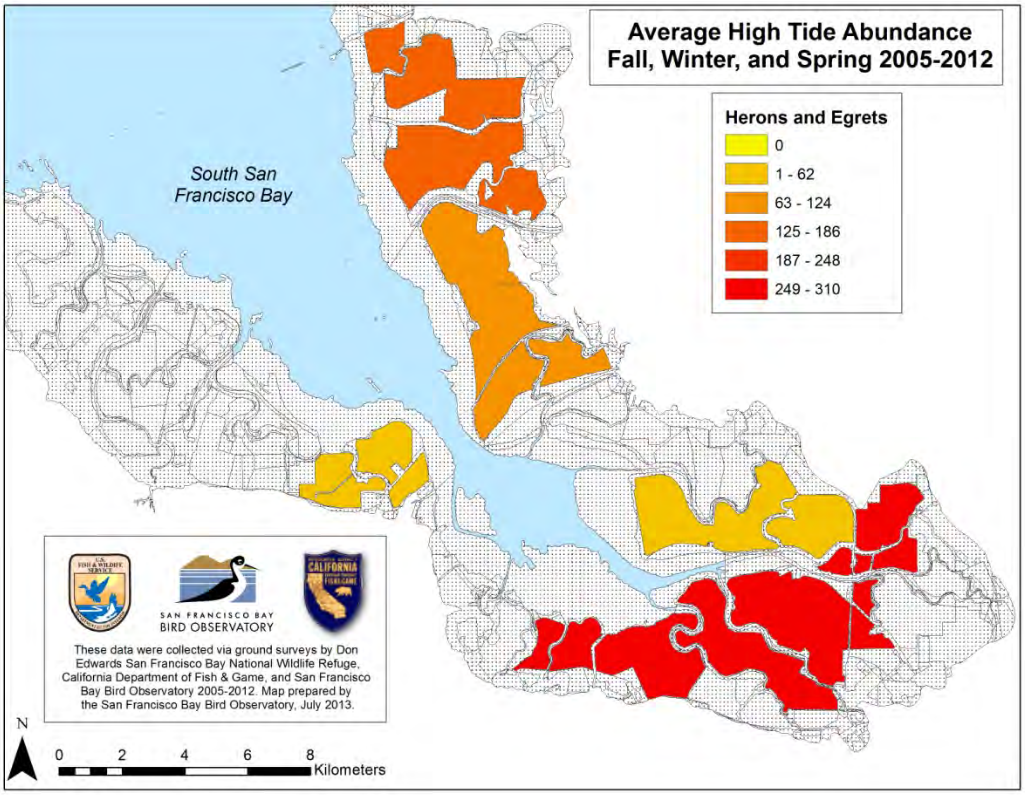


Figure 9. Average abundance index of gulls during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.



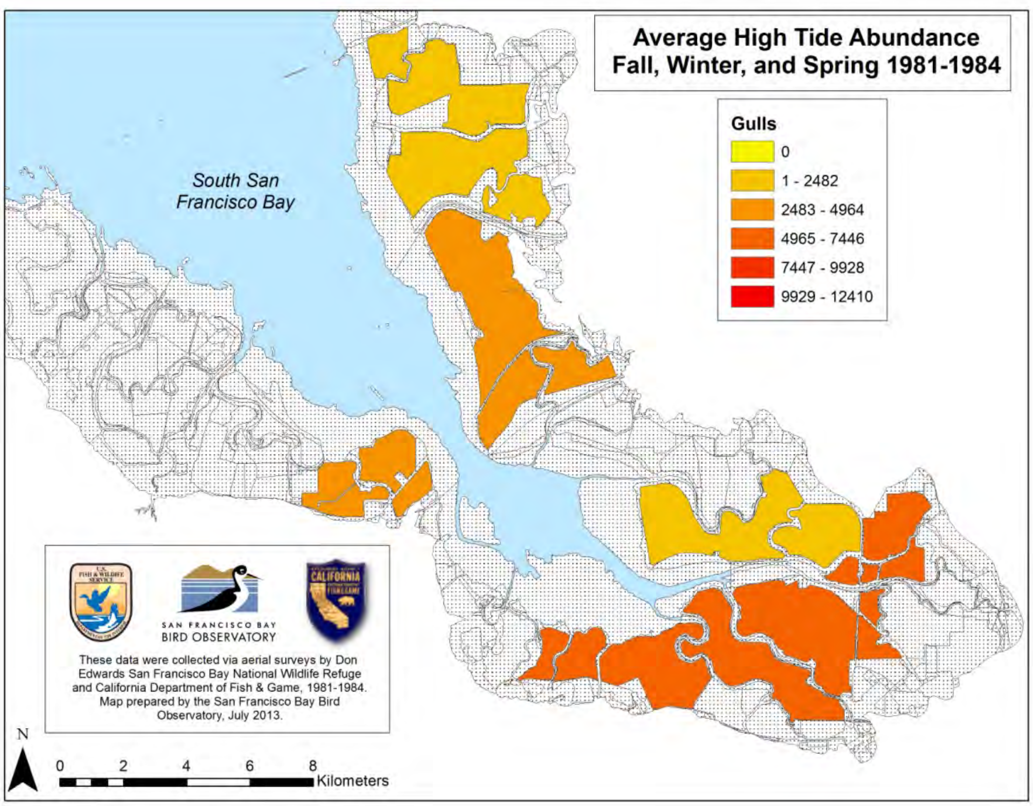
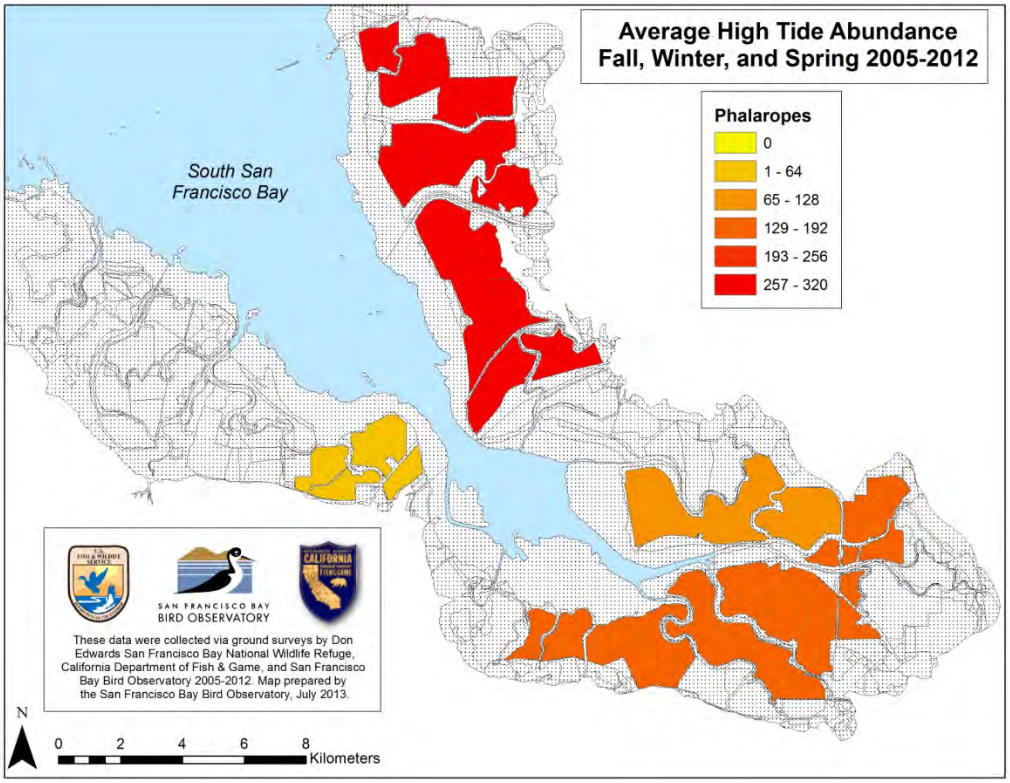


Figure 10. Average abundance index of herons and egrets during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.



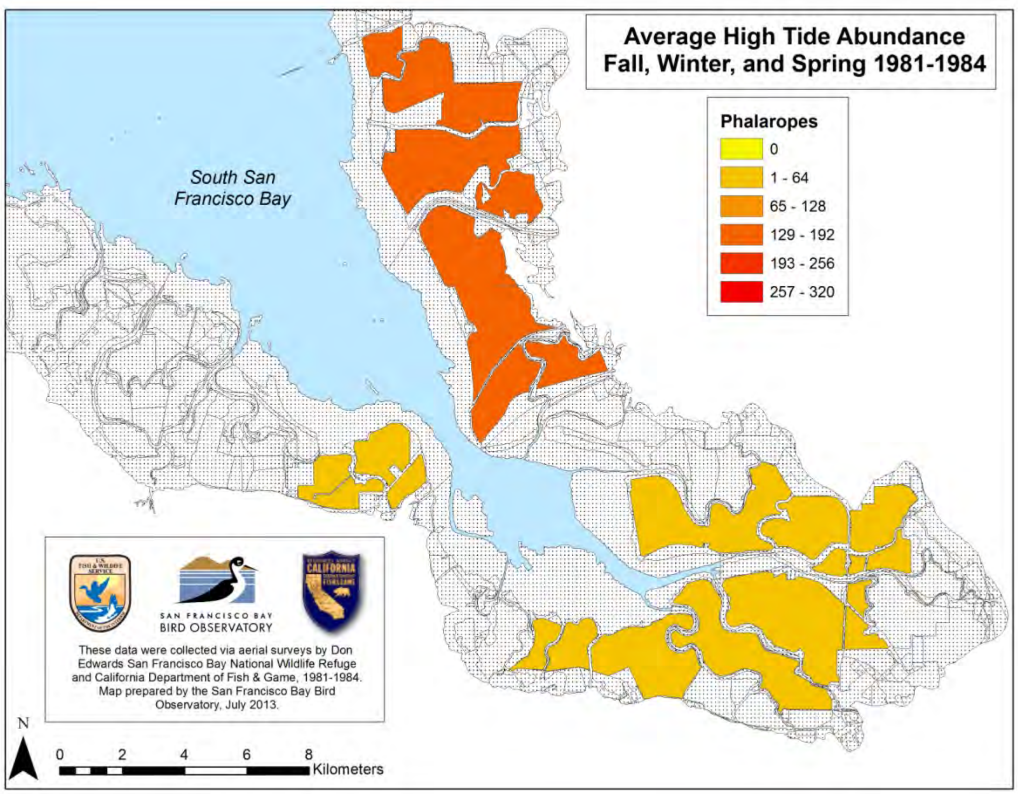


Figure 11. Average abundance index of phalaropes during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.

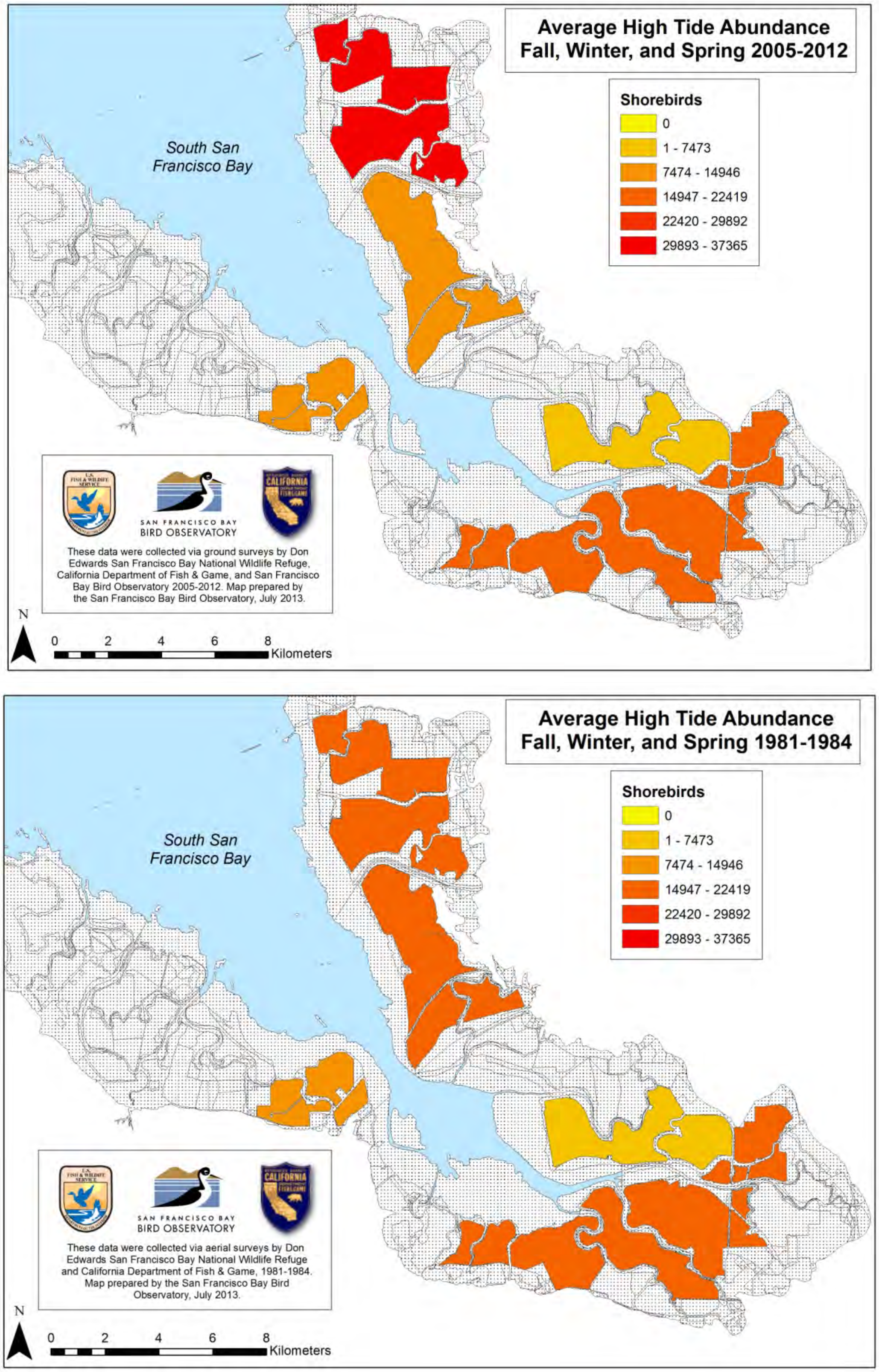
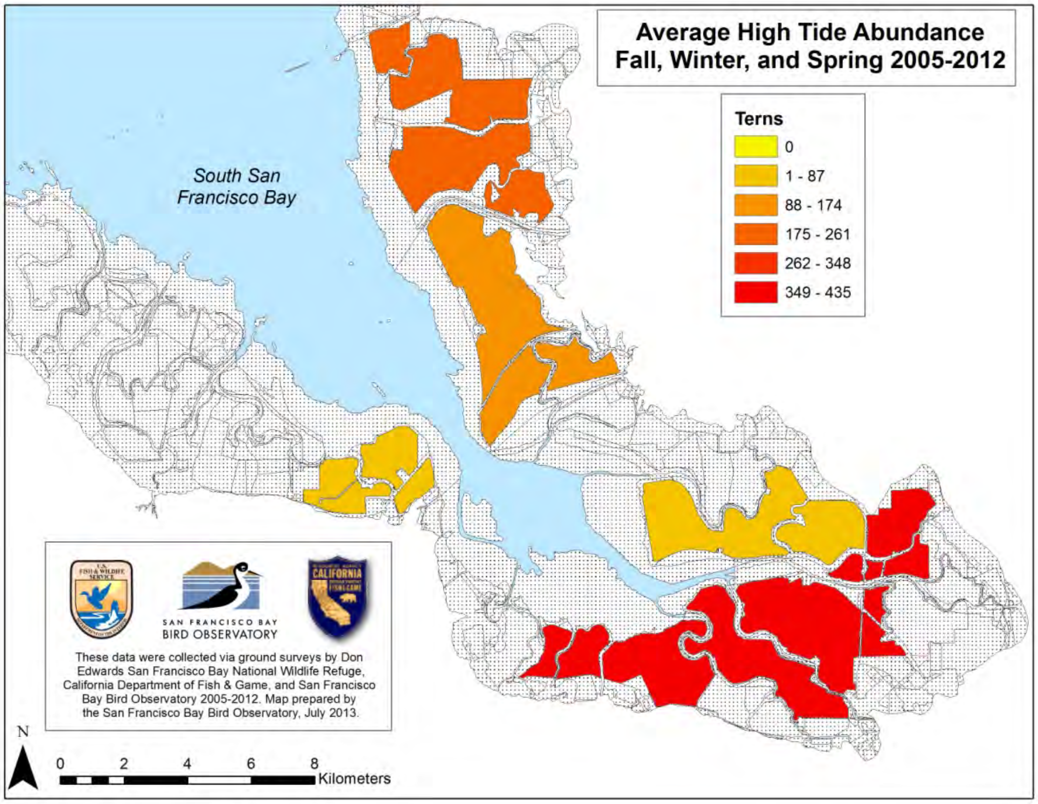


Figure 12. Average abundance index of shorebirds during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.



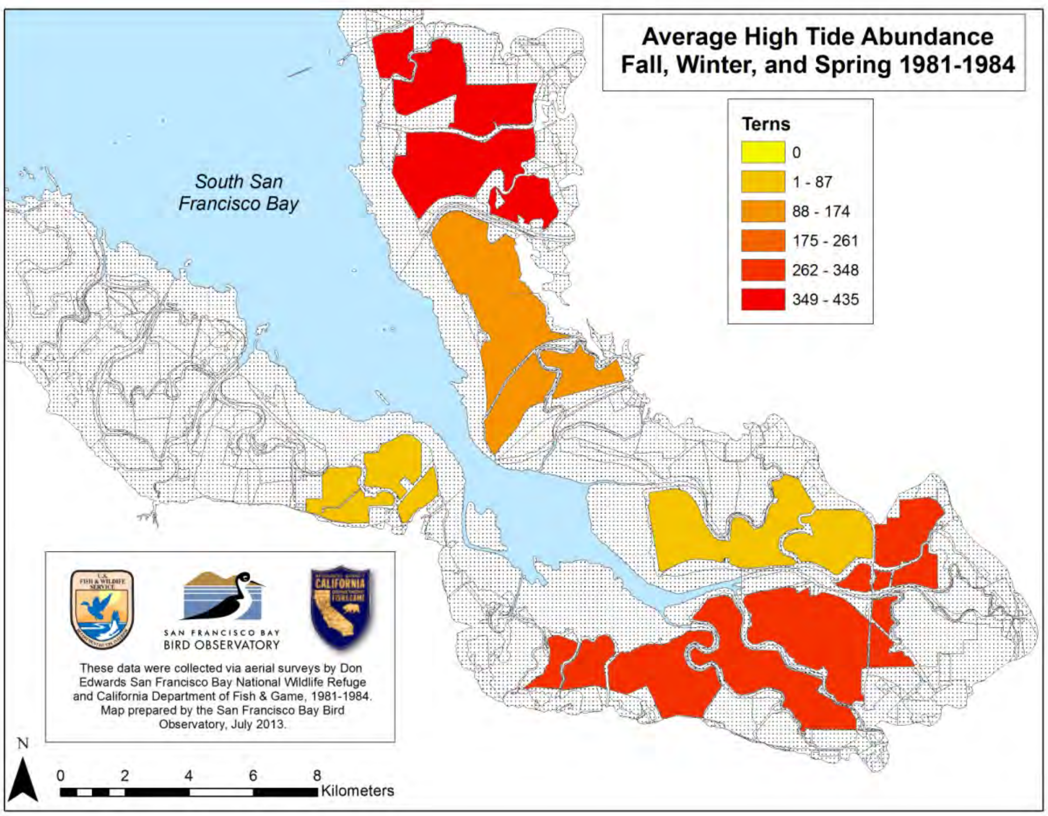
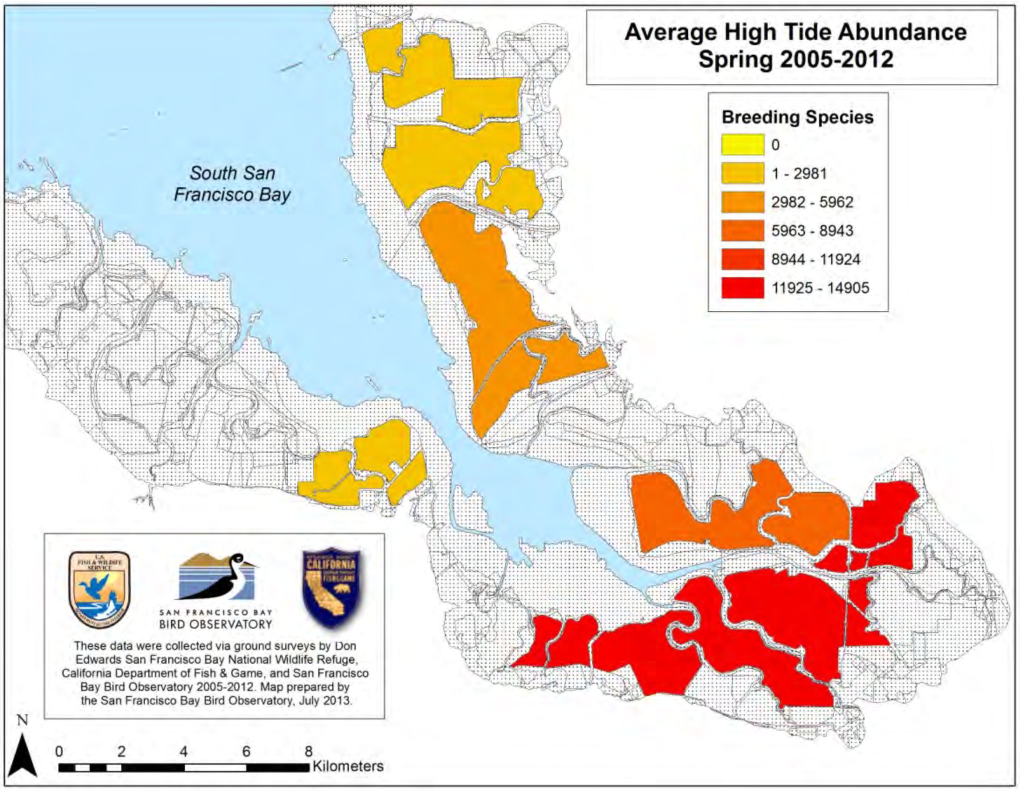


Figure 13. Average abundance index of terns during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.



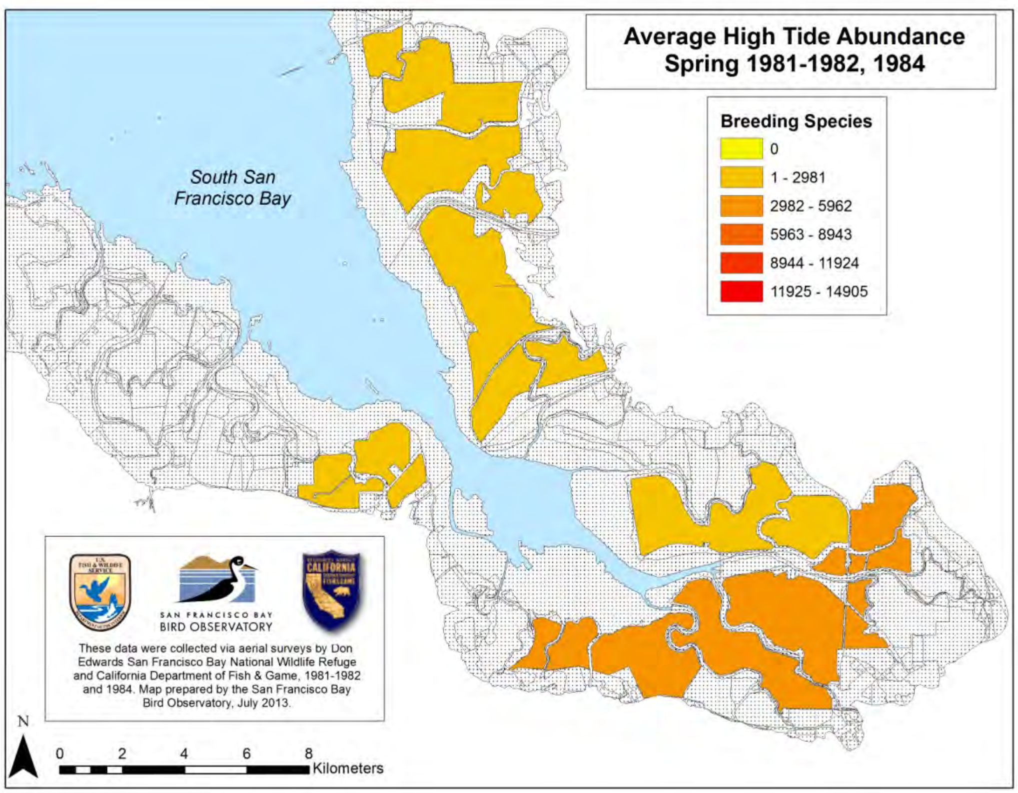


Figure 14. Average abundance index of breeding species (American Avocet, Black-necked Stilt, Gulls (guild) and Terns (guild)) during high tide surveys, calculated at the complex scale across all three seasons (fall, winter, spring). The top panel shows average survey abundance indices based on current ground surveys, and the bottom panel shows abundance indices based on historic aerial surveys.

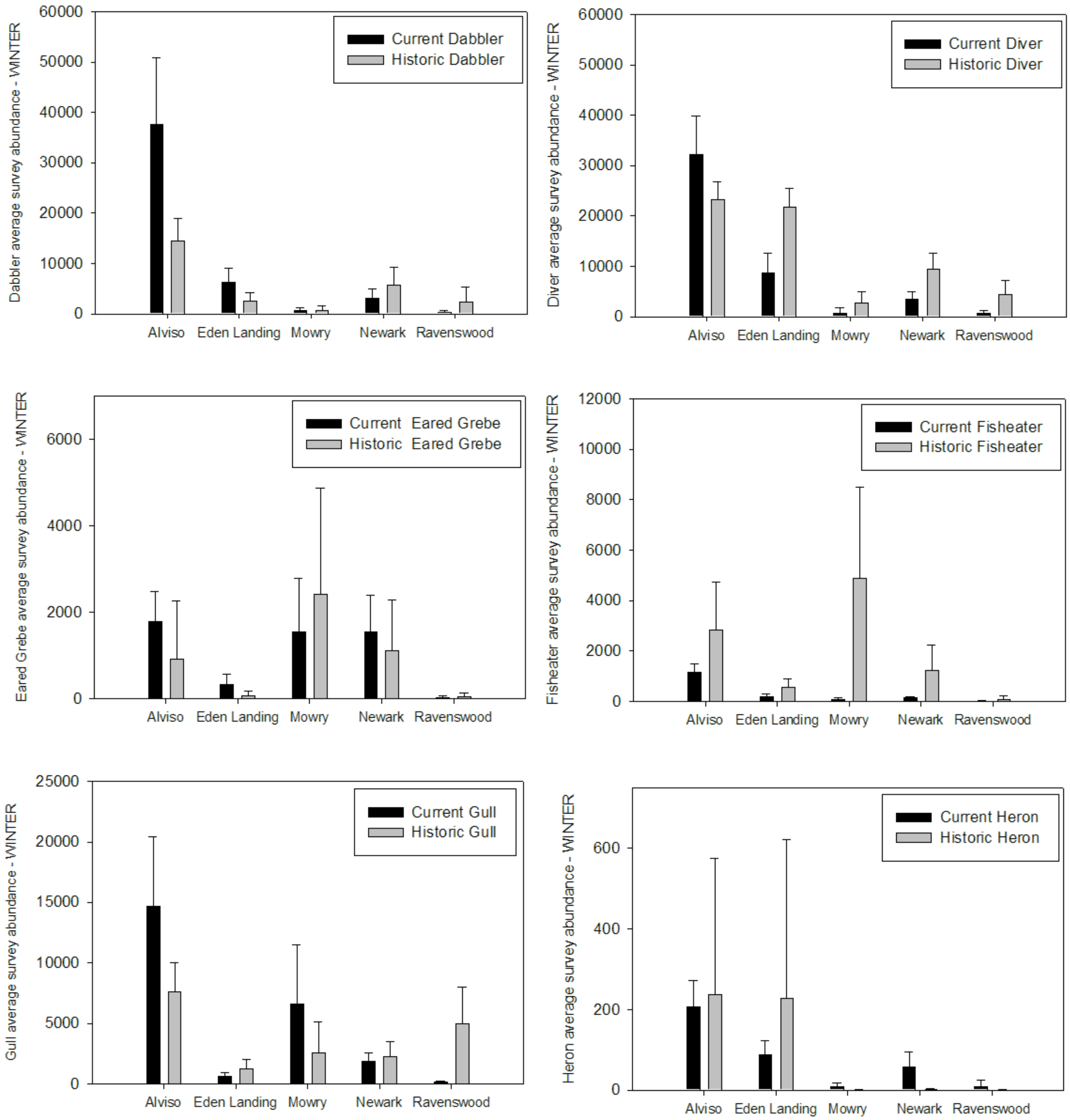
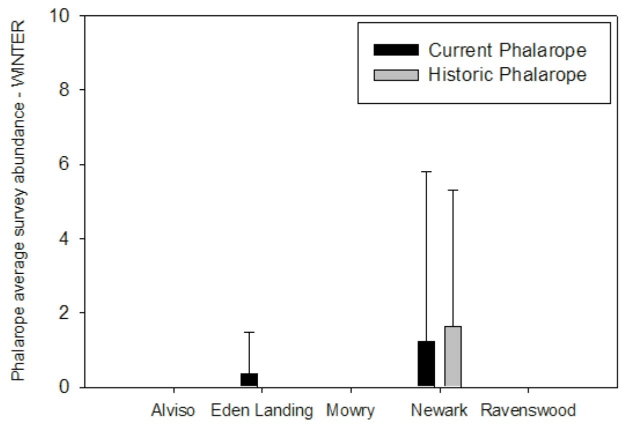
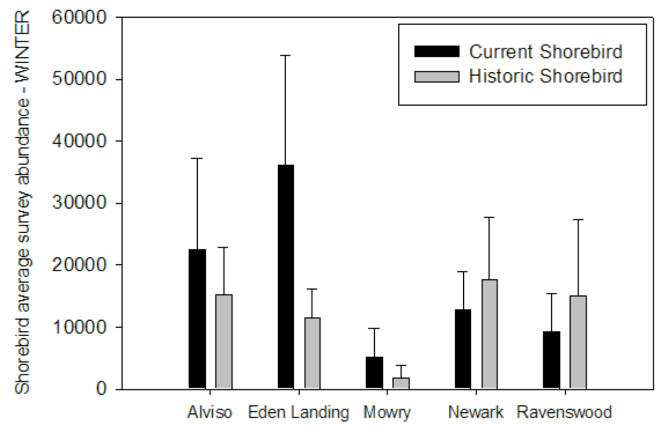
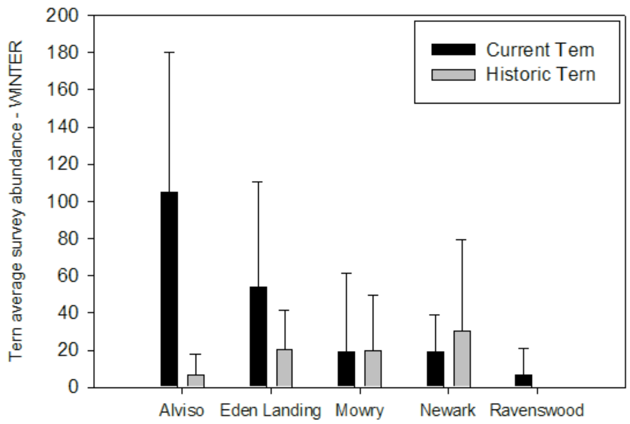


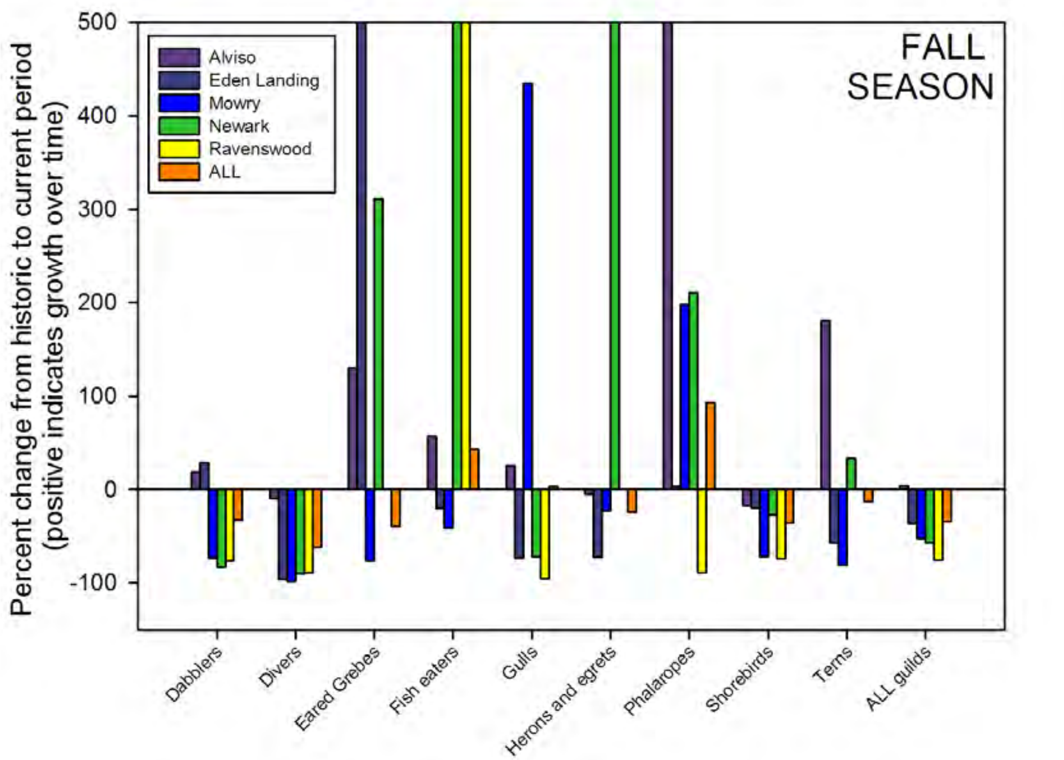
Figure 15. Differences in average survey abundance index (with standard deviations) for each guild during the WINTER season. Abundance indices from the current period are shown in black, and the historical period shown in grey. Data for other seasons, and all seasons combined, can be found in Tables 2-5, and results of statistical analysis in Table 8.

Figure 15, continued.









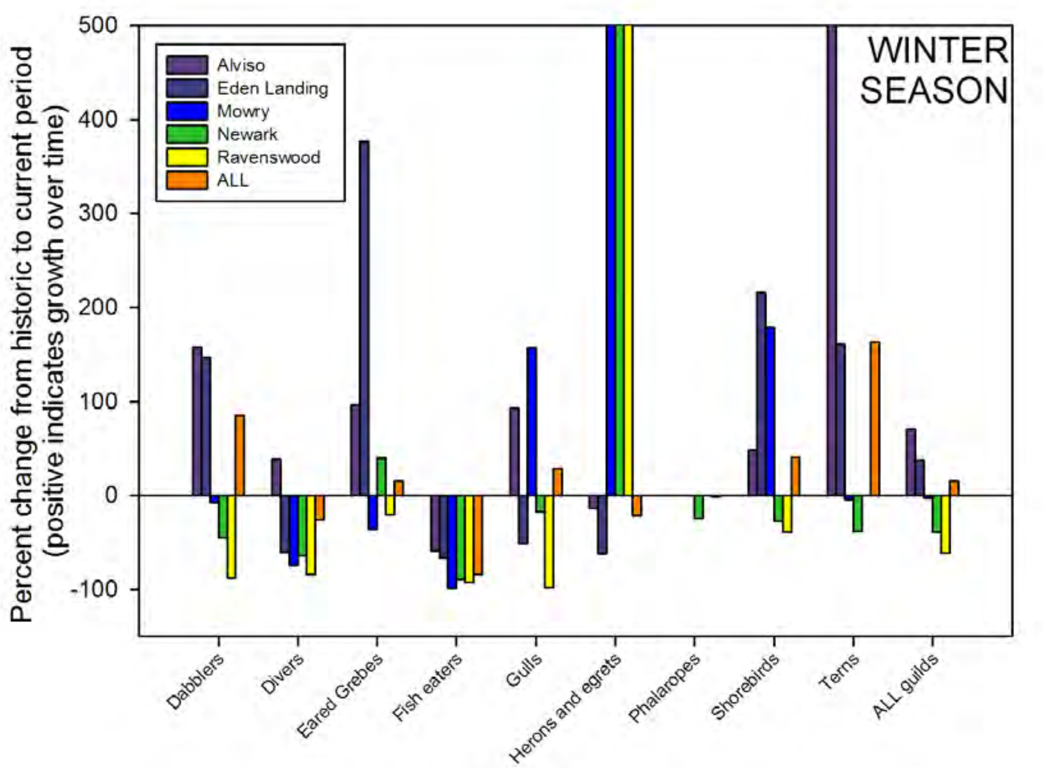
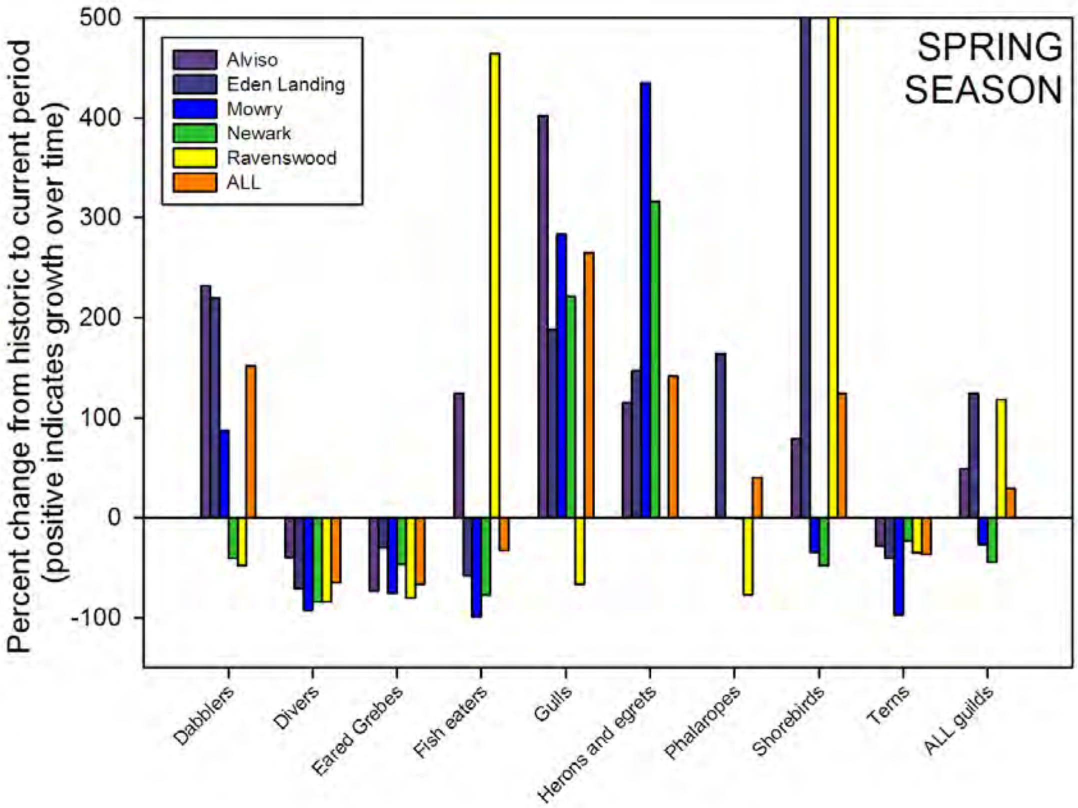
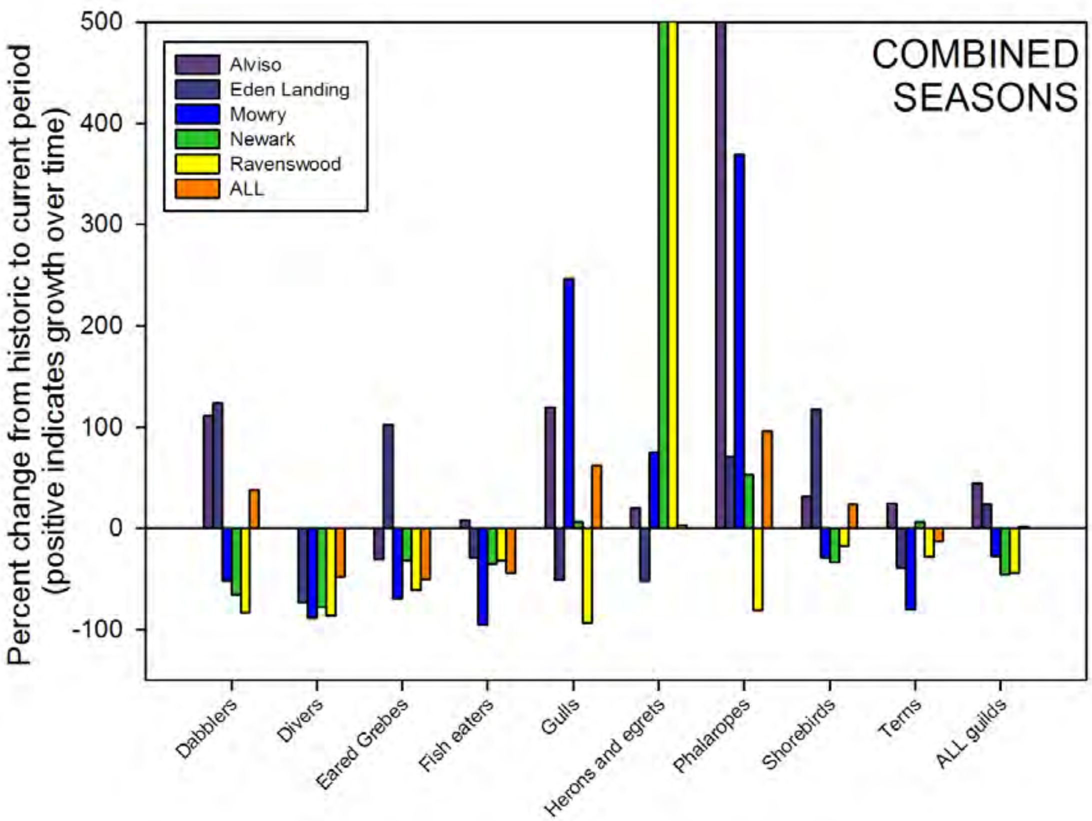


Figure 16. Percent change in average survey abundance index for each guild, calculated as (current abundance index – historic abundance index)/historic abundance index * 100. Percent change greater than 500% was observed for bars shown at the 500% level. "Combined" seasons represents average survey abundance index for fall, winter and spring surveys.

Figure 16, continued.





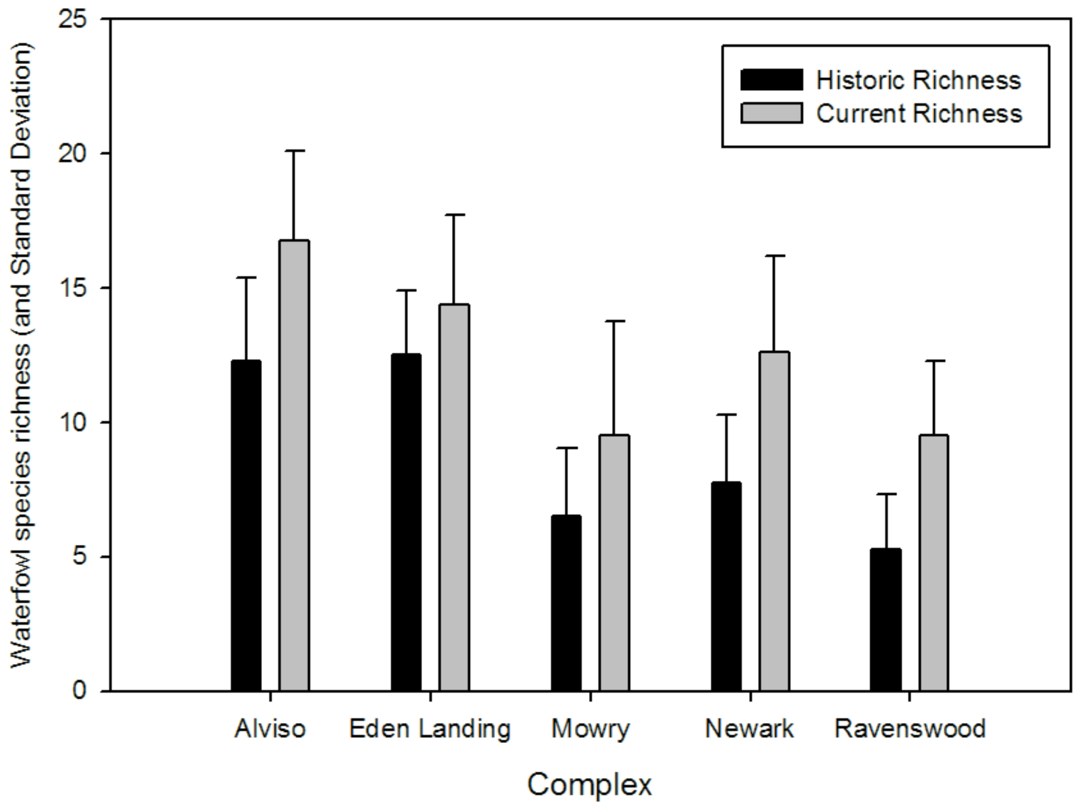


Figure 17. Waterfowl species richness (number of species) for the historic and current periods at each complex. See Tables 10 & 11 for species list and sample size information for this analysis. Two-way ANOVA (response variable = waterfowl species richness; fixed factors = complex, period (historical vs. current). Both factors significant at $p<0.001$.

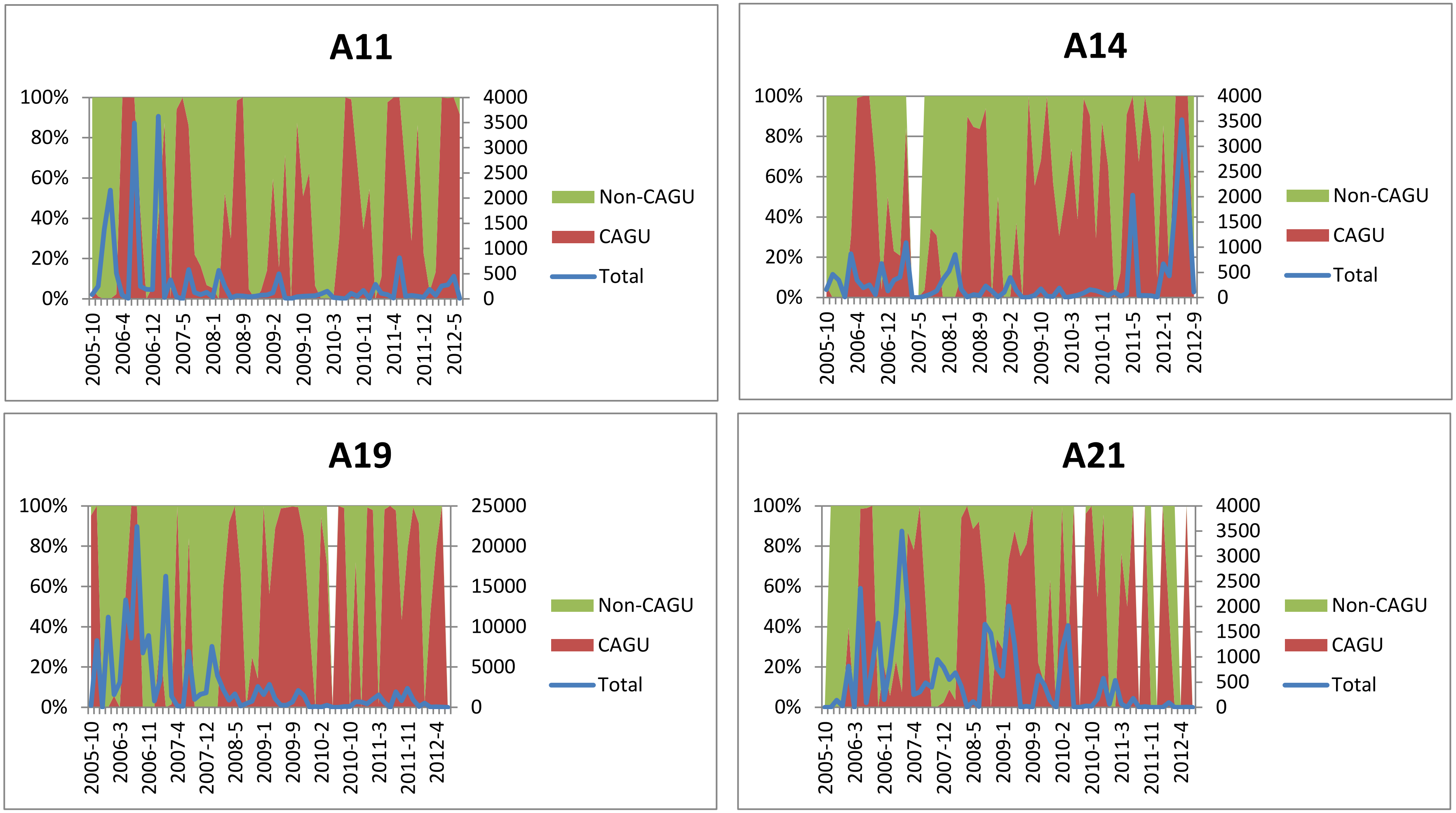


Figure 18. For ponds A11, A14, A19, and A21: total average survey abundance index (blue line) for all gulls surveyed during the current time period (year and month indicated on the x-axis). Red regions indicate the percentage of the abundance that is comprised of California Gulls (CAGU), and the green areas the percentage of the area comprised of other gull species.

Appendix 1. Bird species identified during aerial salt pond and seasonal wetland surveys in San Francisco Bay, CA, 1981-1986. In the air, biologists attempted to identify each bird to species, with the exceptions noted below. We categorized each species into a foraging guild based on their foraging methods and prey requirements.

Common Name	Species Code	Scientific Name	Guild	Notes
American Avocet	AMAV	*Recurvirostra americana*	LSHORE	
American Coot	AMCO	*Fulica americana*	DABBLER	
American Green-winged Teal	AGWT	*Anas crecca*	DABBLER	
American White Pelican	AWPE	*Pelecanus erythrorhynchos*	FISHEAT	
American Wigeon	AMWI	*Anas americana*	DABBLER	
Ashy Storm-Petrel	ASSP	*Oceanodroma homochroa*	FISHEAT	
Black-bellied Plover	BBPL	*Pluvialis squatarola*	MEDSHORE	
Black-crowned Night-Heron	BCNH	*Nycticorax nycticorax*	HERON	
Black-necked Stilt	BNST	*Himantopus mexicanus*	LSHORE	
Bonaparte's Gull	BOGU	*Larus philadelphia*	GULL	
Brown Pelican	BRPE	*Pelecanus occidentalis*	FISHEAT	
Bufflehead	BUFF	*Bucephala albeola*	DIVER	
California Gull	CAGU	*Larus californicus*	GULL	counted as GULL only
Canada Goose	CAGO	*Branta canadensis*	GOOSE	
Canvasback	CANV	*Aythya valisineria*	DIVER	
Caspian Tern	CATE	*Hydroprogne caspia*	TERN	
Cattle Egret	CAEG	*Bubulcus ibis*	HERON	
Chilean Flamingo	CHFL	*Phoenicopterus chilensis*	FLAMINGO	
Cinnamon Teal	CITE	*Anas cyanoptera*	DABBLER	
Clark's Grebe	CLGR	*Aechmophorus clarkii*	FISHEAT	counted as GREBE
Common Goldeneye	COGO	*Bucephala clangula*	DIVER	
Common Loon	COLO	*Gavia immer*	FISHEAT	
Double-crested Cormorant	DCCO	*Phalacrocorax auritus*	FISHEAT	
Dunlin	DUNL	*Calidris alpina*	SSHORE	ID-ed only as SSHORE
Eared Grebe	EAGR	*Podiceps nigricollis*	EAREDGR	ID-ed only as SGREBE
Elegant Tern	ELTE	*Sterna elegans*	TERN	
Flamingo	FLAM	*Phoenicopterus ruber*	FLAMINGO	

Appendix 1. Cont.

Common Name	Species Code	Scientific Name	Guild	Notes
Forster's Tern	FOTE	*Sterna forsteri*	TERN	
Gadwall	GADW	*Anas strepera*	DABBLER	
Glaucous Gull	GLGU	*Larus hyperboreus*	GULL	counted as GULL only
Glaucous-winged Gull	GWGU	*Larus glaucescens*	GULL	counted as GULL only
Great Blue Heron	GBHE	*Ardea herodias*	HERON	
Great Egret	GREG	*Ardea alba*	HERON	
Greater Scaup	GRSC	*Aythya marila*	DIVER	ID-ed as SCAUP only (unidentifed scaup)
Greater White-fronted Goose	GWFG	*Anser albifrons*	GOOSE	
Greater Yellowlegs	GRYE	*Tringa melanoleuca*	LSHORE	ID-ed as LSHORE only
Green-winged Teal	GWTE	*Anas crecca*	DABBLER	
Herring Gull	HERG	*Larus argentatus*	GULL	counted as GULL only
Horned Grebe	HOGR	*Podiceps auritus*	FISHEAT	Also could be in SGREBE, but uncommon in salt ponds
Killdeer	KILL	*Charadrius vociferus*	MEDSHORE	
Least Sandpiper	LESA	*Calidris minutilla*	SSHORE	Counted as SSHORE only
Least Tern	LETE	*Sterna antillarum browni*	TERN	
Lesser Scaup	LESC	*Aythya affinis*	DIVER	ID-ed as SCAUP only (unidentifed scaup)
Lesser Yellowlegs	LEYE	*Tringa flavipes*	LSHORE	ID-ed as LSHORE only
Little Blue Heron	LBHE	*Egretta caerulea*	HERON	
Long-billed Curlew	LBCU	*Numenius americanus*	LSHORE	
Long-billed Dowitcher	LBDO	*Limnodromus scolopaceus*	MEDSHORE	ID-ed as DOWI only
Long-tailed Duck	LTDU	*Clangula hyemalis*	DABBLER	
Mallard	MALL	*Anas platyrhynchos*	DABBLER	
Marbled Godwit	MAGO	*Limosa fedoa*	LSHORE	
Mew Gull	MEGU	*Larus canus*	GULL	counted as GULL only
Northern Harrier	NOHA	*Circus cyaneus*	RAPTOR	
Northern Pintail	NOPI	*Anas acuta*	DABBLER	
Northern Shoveler	NSHO	*Anas clypeata*	DABBLER	
Peregrine Falcon	PEFA	*Peregrine Falcon*	RAPTOR	
Pied-billed Grebe	PBGR	*Podilymbus podiceps*	FISHEAT	
Red Knot	REKN	*Calidris canutus*	MEDSHORE	

Appendix 1. Cont.

Common Name	Species Code	Scientific Name	Guild	Notes
Red Phalarope	REPH	*Phalaropus fulicaria*	PHAL	
Red-breasted Merganser	RBME	*Mergus serrator*	FISHEAT	
Redhead	REDH	*Aythya americana*	DIVER	
Red-necked Grebe	RNGR	*Podiceps grisegena*	FISHEAT	
Red-necked Phalarope	RNPH	*Phalaropus lobatus*	PHAL	
Ring-billed Gull	RBGU	*Larus delawarensis*	GULL	counted as GULL only
Ring-necked Duck	RNDU	*Aythya collaris*	DIVER	
Ruddy Duck	RUDU	*Oxyura jamaicensis*	DIVER	
Ruddy Turnstone	RUTU	*Arenaria interpres*	MEDSHORE	
Sanderling	SAND	*Calidris alba*	SSHORE	ID-ed as SSHORE only
Semipalmated Plover	SEPL	*Charadrius semipalmatus*	SSHORE	ID-ed as SSHORE only
Sharp-shinned Hawk	SSHA	*Accipiter striatus*	RAPTOR	
Short-billed Dowitcher	SBDO	*Limnodromus griseus*	SSHORE	ID-ed as DOWI only
Snow Goose	SNGO	*Chen caerulescens*	GOOSE	
Snow Goose/Ross's Goose	SNGO/ROGO	Snow Goose/Ross's Goose	GOOSE	
Snowy Egret	SNEG	*Egretta thula*	HERON	
Snowy Plover	SNPL	*Charadrius alexandrinus*	SSHORE	
Spotted Sandpiper	SPSA	*Actitis macularia*	SSHORE	
Surf Scoter	SUSC	*Melanitta perspicillata*	DIVER	
Tundra Swan	TUSW	*Cygnus columbianus*	GOOSE	
Unidentifed yellowlegs	YELL	Greater or Lesser yellowlegs	LSHORE	
Unidentified dabbling duck	DABB	dabbling duck spp.	DABBLER	
Unidentified diving duck	DIVE	diving duck spp.	DIVER	
Unidentified Dowitcher	DOWI	*Limnodromus* spp.	MEDSHORE	All medium shorebirds were ID-ed to species
Unidentified Duck	DUCK	*Duck* spp.	DUCK	
Unidentified Egret	EGRET	*Egret* spp.	HERON	
Unidentified goldeneye	GOLD	*Bucephala* spp.	DIVER	Mostly Common Goldeneye, Barrow's is uncommon
Unidentified grebe	GREBE	*Aechmophorus* spp.	FISHEAT	WEGR or CLGR only - no PBGR, HOGR, or EAGR
Unidentified gull	GULL	*Larus* spp.	GULL	all gull species except Bonaparte's Gull
Unidentified jaeger	JAEG	*Stercorarius* spp.	FISHEAT	

Appendix 1. Cont.

Common Name	**Species Code**	**Scientific Name**	**Guild**	**Notes**
Unidentified Large Shorebird	LSHORE	large shorebird spp.	LSHORE	
Unidentified Loon	LOON	*Gavia* spp.	FISHEAT	
Unidentified peeps	PEEP	*Calidris* spp.	SSHORE	
Unidentified phalarope	PHAL	*Phalaropus* spp.	PHAL	
Unidentified Plover	PLOV	Plover species	SSHORE	
Unidentified scaup	SCAU	*Aythya* spp.	DIVER	
Unidentified shorebird	SHOR	shorebird spp.	SHORE	
Unidentified Small Grebe Species	SGREBE	*Podiceps nigricollis*	EAREDGR	Mostly Eared Grebe ID-ed
Unidentified Small Shorebird	SSHORE	small shorebird spp.	SSHORE	
Unidentified swan	SWAN	*Cygnus* spp.	GOOSE	
Unidentified Teal	TEAL	Teal spp.	DABBLER	
Western Grebe	WEGR	*Aechmophorus occidentalis*	FISHEAT	
Western Gull	WEGU	*Larus occidentalis*	GULL	counted as GULL only
Western Sandpiper	WESA	*Calidris mauri*	SSHORE	
Whimbrel	WHIM	*Numenius phaeopus*	LSHORE	
White-winged scoter	WWSC	*Melanitta fusca*	DIVER	
Willet	WILL	*Catoptrophorus semipalmatus*	LSHORE	
Wilson's Phalarope	WIPH	*Phalaropus tricolor*	PHAL	

Appendix 2. Access database query steps to obtain average abundances presented in data tables and figures.

Data Processing and Summary

<u>Assumptions</u>

Date and Pond are the smallest sampling units in this analysis. Data at the grid-scale (from current methodology) were added together to provide totals at the pond-scale. The entirety of any given pond was surveyed within a single day (no pond-level survey was ever split between two days). In general, a pond was surveyed once per month. However, a few cases exist where a pond was surveyed twice in a month. These surveys are treated independently.

<u>Current Data</u>

Stored in Access database "Current Data USGS and SFBBO 2005 – 2012.accdb." Data from USGS were provided to SFBBO in a summarized format: totals for each species and guild were listed in columns for every pond and survey date. We formatted SFBBO data to match the USGS formatting, and combined the datasets. For the current-historic analysis, the provided summaries were processed using the following filters (the query which contains the filter is listed at the end of each description; each query is defined in the "metadataQueries" table stored in the database, however this summary provides a much clearer explanation of each step, and how each query works in conjunction with other queries):

Species and Guild Summary

1. Steps 2 – 6 provide averages at the pond level. Step 7 provides total averages at the Complex level. Step 8 provides the average for a given pond in a complex, at the complex scale.
2. Restrict the results to only include the species American Avocet, Black-necked Stilt, Northern Shoveler, and Ruddy Duck; and the guilds Dabbler, Diver, Eared Grebe, Fish Eater, Gull, Heron, Phalarope, Tern, and Shorebird (all sizes lumped together). Query AAA01.
    a. Note: since the original data were provided in a summarized format which already accounted for surveys where no birds were seen, it is appropriate to restrict the dataset to these species at this point.
3. Restrict the results to only include data from ponds that were surveyed in both the historic dataset and the current dataset. Query AAA01.
4. Restrict the results to only included data from ponds that were surveyed during a high tide window. Query AAA01.
5. Merge (sum) data from ponds that were surveyed as one unit in either the historic or current dataset. Query AAA02.
6. Average data for each season (Fall: Sep – Nov; Winter: Dec – Feb; Spring: Mar – May; Summer: Jun – Aug). Query AAA03.
    a. Note: because data were summarized by date, not by month, this step treats multiple surveys conducted in the same month as separate surveys. This method is preferable to summing the data by month and then averaging, because in some cases the same pond might be surveyed twice in the same month. However, we may want to omit multiples of surveys for a single month to standardize the survey methodology of one survey per pond per month.
    b. Note: This step factors in surveys where no birds were seen.
7. Now that we have the average number of each species / guild expected for each pond in a given season, we can sum the averages to get the average number of each species / guild when all ponds are combined at the Complex level. Query AAA04.
8. Additionally, we can average the averages from query AAA03 to provide an estimate of the number of birds expected for a given pond in a Complex, to allow for comparisons between Complexes. However, this is not a true density comparison, since each pond is a different area and area is not accounted for in this query, so the results from query AAA04 are more valuable for the report. Query AAA05.

Breeding Bird Summary

1. Breeding birds include the following groups: American Avocet, Black-necked Stilt, Gulls (guild) and Terns (guild).

2. To get the average number of all of these species on the Complex scale, data from query AAA04 for American Avocet, Black-necked Stilt, Gull (Guild), and Tern (Guild) were combined (summed) into one Breeding Species category. Query AAB01.

Guilds, Species, and Breeding Bird Summary for GIS Output

1. To get the combined list of individual species, guilds, and breeding birds into two tables (one for Pond-level scale, one for Complex-level scale; easier to manage in GIS), data from each corresponding query were combined. Species and Guilds were pulled from AAA03 and AAA04; breeding birds were pulled from AAE01 (but only for the Complex-level summary). Queries AAC01 (Pond-level scale) and AAC02 (Complex-level scale).

Standard Deviation – Species and Guild at the Pond Scale

1. Calculate the standard deviation of the species and guild averages at the pond scale. This query is equivalent to and pairs with the results from Query AAA03 (from step 6 in the Species and Guild Summary section, above), except instead of using the avg() function in Access, use the stdev() function. Query AAD01.

Standard Deviation – Species and Guild at the Complex Scale

1. Calculate the standard deviation of the species and guild averages at the complex scale. This query is equivalent to and pairs with the results from Query AAA04 (from step 7 in the Species and Guild Summary section, above). This query performs the following calculation based on the standard deviations calculated in Query AAD01:

$$StDev_{complex} = \sqrt{\sum StDev_{pond}{}^{2}}$$

Where $StDev_{complex}$ = the standard deviation at the complex scale and $StDev_{pond}$ = the standard deviation at the pond scale. Square the standard deviation for each pond, which results in the variance for that pond. Sum the variance across ponds to get the total variance at the complex scale. Take the square root of the complex-scale variance to get the standard deviation at the complex scale. Query AAD02.

   a. Note: we assume here that our variables are independent and that our data are normally distributed, such that a linear combination of variance is valid.

Standard Deviation – Breeding Species

1. Calculate the standard deviation of the breeding species averages at the complex scale. This query is equivalent to and pairs with the results from Query AAB01 (from step 2 in the Breeding Bird Summary section, above). This query performs the following calculation based on the standard deviations calculated in Query AAM02 and Query AAN02:

$$StDev_{breeders} = \sqrt{\sum StDev_{complex}{}^{2}}$$

Where $StDev_{breeders}$ = the standard deviation of the sum of the breeding species at the complex scale and $StDev_{complex}$ = the standard deviation of each individual species or guild at the complex scale. Square the standard deviation for each species/guild, which results in the variance for that species/guild. Sum the variance across species/guilds to get the total variance of breeding species at the complex scale. Take the square root of the complex-scale variance to get the standard deviation of the breeding species at the complex scale. Query AAE01.

   a. Note: we assume here that our variables are independent and that our data are normally distributed, such that a linear combination of variance is valid.

Standard Deviation - Guilds, Species, and Breeding Bird Summary for GIS Output

1. To get the combined list of standard deviations for individual species, guilds, and breeding birds into two tables (one for Pond-level scale, one for Complex-level scale; easier to manage in GIS), data from each corresponding query were combined. Species and Guilds were pulled from AAD01 and AAD02; breeding birds were pulled from AAE01 (but only for the Complex-level summary). Queries AAF01 (Pond-level scale) and AAF02 (Complex-level scale).

Historic Data (uncorrected)

Stored in Access database "Historic Data USGS 1981 – 1986.accdb." Data from USGS were provided in the raw survey format, therefore guilds and individual species needed to be summarized separately. For the current-historic analysis, data were processed using the following filters (the query which contains the filter is listed at the end of each description):

Guild Summary

1. Steps 2 – 6 provide averages at the pond level. Step 7 provides total averages at the Complex level. Step 8 provides the average for a given pond in a complex, at the complex scale.
2. Restrict the results to only include the guilds Dabbler, Diver, Eared Grebe, Fish Eater, Gull, Heron, Phalarope, Tern, and Shorebird (all sizes lumped together); individual species will be handled in a separate query, below. Query AAB01.
    a. Note: for final report, added guild "None" to Query AAB01 to include surveys with no birds seen in the final average.
3. Restrict the results to only include data from ponds that were surveyed in both the historic dataset and the current dataset. Query AAB01.
4. Restrict the results to only include data from ponds that were surveyed during a high tide window. Query AAB01.
5. Sum each guild by survey date and pond to provide the total number of birds in each guild seen on a given date and pond (important distinction – the same pond surveyed on a different date (even within the same month) will be treated independently and not combined in this step). Query AAB01.
6. Transform the data from AAB01 into a crosstab format, where each survey date is a single row, and the totals for each guilds are in separate columns. This step preserves survey dates where no birds were seen. Query AAB02.
    a. Note: this step was skipped in the first draft of the report, leading to artificially inflated abundances for historic data.
    b. Note: as of 6/21/2013, results are 1 survey short of the 874 pond surveys conducted.
7. Average the total number of birds in each guild by pond and season. Results from this query are equivalent to the results from query AAA03 in the Current data, above. Query AAB03.
8. Now that we have the average number of each guild expected for each pond in a given season, we can sum the averages to get the average number of each guild when all ponds are combined at the Complex level. Results from this query are equivalent to the results from query AAA04 in the Current data, above. Query AAB04.
9. Additionally, we can average the averages from query AAB03 to provide an estimate of the number of birds expected for a given pond in a Complex, to allow for comparisons between Complexes. However, this is not a true density comparison, since each pond is a different area and area is not accounted for in this query, so the results from query AAB04 are more valuable for the report. Results from this query are equivalent to the results from query AAA05 in the Current data, above. Query AAB05.

Species Summary

1. Steps 2 – 6 provide averages at the pond level. Step 7 provides total averages at the Complex level. Step 8 provides the average for a given pond in a complex, at the complex scale.
2. Restrict the results to only include the species American Avocet, Black-necked Stilt, Northern Shoveler, and Ruddy Duck. Query AAD01.

    a. Note: for final report, added guild "None" to Query AAB01 to include surveys with no birds seen in the final average.
    b. Note: this exclusion was incorrectly applied here for the draft report. This step should happen as part of AAD03, during step 7. By excluding all other species in this step, we removed surveys where other species were seen but no AMAV, BNST, NSHO, and RUDU were seen. Therefore, zero-values were removed from the averages, and the results are artificially inflated.
3. Restrict the results to only include data from ponds that were surveyed in both the historic dataset and the current dataset. Query AAD01.
4. Restrict the results to only include data from ponds that were surveyed during a high tide window. Query AAD01.
5. Sum each species by survey date and pond to provide the total number of birds of each species seen on a given date and pond (important distinction – the same pond surveyed on a different date (even within the same month) will be treated independently and not combined in this step). Query AAD01.
6. Transform the data from AAD01 into a crosstab format, where each survey date is a single row, and the totals for each guilds are in separate columns. This step preserves survey dates where no birds were seen. Query AAD02.
    a. Note: this step was skipped in the first draft of the report, leading to artificially inflated abundances for historic data.
    b. Note: as of 6/21/2013, results are 203 surveys short of the 874 pond surveys conducted.
7. Average the total number of birds of each species by pond and season. Results from this query are equivalent to the results from query AAA03 in the Current data, above. Query AAD03.
8. Now that we have the average number of each species expected for each pond in a given season, we can sum the averages to get the average number of each species when all ponds are combined at the Complex level. Results from this query are equivalent to the results from query AAA04 in the Current data, above. Query AAD04.
9. Additionally, we can average the averages from query AAD03 to provide an estimate of the number of birds expected for a given pond in a Complex, to allow for comparisons between Complexes. However, this is not a true density comparison, since each pond is a different area and area is not accounted for in this query, so the results from query AAD04 are more valuable for the report. Results from this query are equivalent to the results from query AAA05 in the Current data, above. Query AAD05.

Breeding Bird Summary

1. Breeding birds include the following groups: American Avocet, Black-necked Stilt, Gulls (guild) and Terns (guild).
2. To get the average number of all of these species on the Complex scale, data from the previous two query groups were combined (summed) into one Breeding Species category. American Avocet and Black-necked Stilt averages were pulled from query AAD04, and Gull and Tern averages were pulled from AAB04. Query AAE01.

Guilds, Species, and Breeding Bird Summary for GIS Output

1. To get the combined list of individual species, guilds, and breeding birds into two tables (one for Pond-level scale, one for Complex-level scale; easier to manage in GIS), data from each corresponding query were combined. Individual species were pulled from AAD02 and AAD03; guilds were pulled from AAB02 and AAB03; breeding birds were pulled from AAE01 (but only for the Complex-level summary). Queries AAF01 (Pond-level scale) and AAF02 (Complex-level scale).

<u>Historic Data (corrected)</u>

Stored in Access database "Historic Data USGS 1981 – 1986.accdb." Data from USGS were processed through a model developed by Vanessa Tobias, University of California at Davis, which corrected air survey data for discrepancies between air and ground counts. Data were provided in the raw survey format, therefore guilds and individual species needed to be summarized separately. For the current-historic analysis, data were processed using the following filters (the query which contains the filter is listed at the end of each description):

Model Correction

1. Restrict the results to exclude guilds "Raptor," "Goose," and "Flamingo." Query AAG01.
    a. Note: There is no instance in the historic data where Raptor, Goose, and/or Flamingo were the only guilds found on a pond during a survey; therefore, we can remove these guilds now and retain all pond surveys for accurate averaging later.
2. Restrict the results to only include data from ponds that were surveyed in both the historic dataset and the current dataset. Query AAG01.
3. Restrict the results to only include data from ponds that were surveyed during a high tide window. Query AAG01.
4. Save data as "air.data.csv" in this folder, and follow the rest of the steps in the "Corrected Model Metadata.docx" file in the same folder.
5. Import the "air.data.output" back into Access, into table "dataBirdSurveysCorrected." The following data summaries are based on this table.

Guild Summary

1. Data summarized from table "dataBirdSurveysCorrected," which is based on query AAG01. See "Model Correction" section, above, for data restrictions.
2. Steps 3 – 5 provide averages at the pond level. Step 6 provides total averages at the Complex level. Step 7 provides the average for a given pond in a complex, at the complex scale.
3. Sum each guild by survey date and pond to provide the total number of birds in each guild seen on a given date and pond (important distinction – the same pond surveyed on a different date (even within the same month) will be treated independently and not combined in this step). Query AAH01.
4. Transform the data from AAH01 into a crosstab format, where each survey date is a single row, and the totals for each guilds are in separate columns. This step preserves survey dates where no birds were seen. Query AAH02.
    a. Note: all 874 pond surveys are accounted for here.
5. Average the total number of birds in each guild by pond and season. Results from this query are equivalent to the results from query AAA03 in the Current Data section, above. Query AAH03.
    a. Note: we assume here that our variables are independent and that our data are normally distributed, such that a linear combination of averages is valid.
6. Now that we have the average number of each guild expected for each pond in a given season, we can sum the averages to get the average number of each guild when all ponds are combined at the Complex level. Results from this query are equivalent to the results from query AAA04 in the Current data, above. Query AAH04.
7. Additionally, we can average the averages from query AAH03 to provide an estimate of the number of birds expected for a given pond in a Complex, to allow for comparisons between Complexes. However, this is not a true density comparison, since each pond is a different area and area is not accounted for in this query, so the results from query AAH04 are more valuable for the report. Results from this query are equivalent to the results from query AAA05 in the Current data, above. Query AAH05.

Species Summary

1. Data summarized from table "dataBirdSurveysCorrected," which is based on query AAG01. See "Model Correction" section, above, for data restrictions.
2. Steps 3 – 6 provide averages at the pond level. Step 7 provides total averages at the Complex level. Step 8 provides the average for a given pond in a complex, at the complex scale.
3. Sum each species by survey date and pond to provide the total number of birds of each species seen on a given date and pond (important distinction – the same pond surveyed on a different date (even within the same month) will be treated independently and not combined in this step). Query AAI01.

4. Transform the data from AAI01 into a crosstab format, where each survey date is a single row, and the totals for each guilds are in separate columns. This step preserves survey dates where no birds were seen. Query AAI02.
    a. Note: all 874 pond surveys are accounted for here.
5. Restrict the results to only include the species American Avocet, Black-necked Stilt, Northern Shoveler, and Ruddy Duck. Query AAI03.
    a. Note: do this step here, so that all surveys are accounted for up to this point (including NONE results). If a survey only detected species that end up being removed, then the survey would not make it into the average, and artificially inflate the results.
6. Average the total number of birds of each species by pond and season. Results from this query are equivalent to the results from query AAA03 in the Current data, above. Query AAI03.
    a. Note: we assume here that our variables are independent and that our data are normally distributed, such that a linear combination of averages is valid.
7. Now that we have the average number of each species expected for each pond in a given season, we can sum the averages to get the average number of each species when all ponds are combined at the Complex level. Results from this query are equivalent to the results from query AAA04 in the Current data, above. Query AAI04.
8. Additionally, we can average the averages from query AAI03 to provide an estimate of the number of birds expected for a given pond in a Complex, to allow for comparisons between Complexes. However, this is not a true density comparison, since each pond is a different area and area is not accounted for in this query, so the results from query AAI04 are more valuable for the report. Results from this query are equivalent to the results from query AAA05 in the Current data, above. Query AAI05.

Breeding Bird Summary

1. Breeding birds include the following groups: American Avocet, Black-necked Stilt, Gulls (guild) and Terns (guild).
2. To get the average number of all of these species on the Complex scale, data from the previous two query groups were combined (summed) into one BreedingSpecies category. American Avocet and Black-necked Stilt averages were pulled from query AAI04, and Gull and Tern averages were pulled from AAH04. Query AAJ01.

Guilds, Species, and Breeding Bird Summary for GIS Output

1. To get the combined list of individual species, guilds, and breeding birds into two tables (one for Pond-level scale, one for Complex-level scale; easier to manage in GIS), data from each corresponding query were combined. Individual species were pulled from AAI03 and AAI04; guilds were pulled from AAH03 and AAH04; breeding birds were pulled from AAJ01 (but only for the Complex-level summary). Queries AAK01 (Pond-level scale) and AAK02 (Complex-level scale).

Standard Deviation – Guild and Pond Scale

2. Calculate the standard deviation of the guild averages at the pond scale. This query is equivalent to and pairs with the results from Query AAH03 (from step 5 in the Guild Summary section, above), except instead of using the avg() function in Access, use the stdev() function. Query AAM01.

Standard Deviation – Guild and Complex Scale

Calculate the standard deviation of the guild averages at the complex scale. This query is equivalent to and pairs with the results from Query AAH04 (from step 6 in the Guild Summary section, above). This query performs the following calculation based on the standard deviations calculated in Query AAM01:

$$StDev_{complex} = \sqrt{\sum StDev_{pond}^{2}}$$

Where $StDev_{complex}$ = the standard deviation at the complex scale and $StDev_{pond}$ = the standard deviation at the pond scale. Square the standard deviation for each pond, which results in the variance for that pond. Sum the variance across ponds to get the total variance at the complex scale. Take the square root of the complex-scale variance to get the standard deviation at the complex scale. Query AAM02.

a. Note: we assume here that our variables are independent and that our data are normally distributed, such that a linear combination of variance is valid.

Standard Deviation – Species and Pond Scale

1. Calculate the standard deviation of the species averages at the pond scale. This query is equivalent to and pairs with the results from Query AAI03 (from step 6 in the Species Summary section, above), except instead of using the avg() function in Access, use the stdev() function. Query AAN01.

Standard Deviation – Species and Complex Scale

1. Calculate the standard deviation of the species averages at the complex scale. This query is equivalent to and pairs with the results from Query AAI04 (from step 7 in the Species Summary section, above). This query performs the following calculation based on the standard deviations calculated in Query AAN01:

$$StDev_{complex} = \sqrt{\sum StDev_{pond}{}^2}$$

Where $StDev_{complex}$ = the standard deviation at the complex scale and $StDev_{pond}$ = the standard deviation at the pond scale. Square the standard deviation for each pond, which results in the variance for that pond. Sum the variance across ponds to get the total variance at the complex scale. Take the square root of the complex-scale variance to get the standard deviation at the complex scale. Query AAN02.

a. Note: we assume here that our variables are independent and that our data are normally distributed, such that a linear combination of variance is valid.

Standard Deviation – Breeding Species

2. Calculate the standard deviation of the breeding species averages at the complex scale. This query is equivalent to and pairs with the results from Query AAJ01 (from step 2 in the Breeding Bird Summary section, above). This query performs the following calculation based on the standard deviations calculated in Query AAM02 and Query AAN02:

$$StDev_{breeders} = \sqrt{\sum StDev_{complex}{}^2}$$

Where $StDev_{breeders}$ = the standard deviation of the sum of the breeding species at the complex scale and $StDev_{complex}$ = the standard deviation of each individual species or guild at the complex scale. Square the standard deviation for each species/guild, which results in the variance for that species/guild. Sum the variance across species/guilds to get the total variance of breeding species at the complex scale. Take the square root of the complex-scale variance to get the standard deviation of the breeding species at the complex scale. Query AAO01.

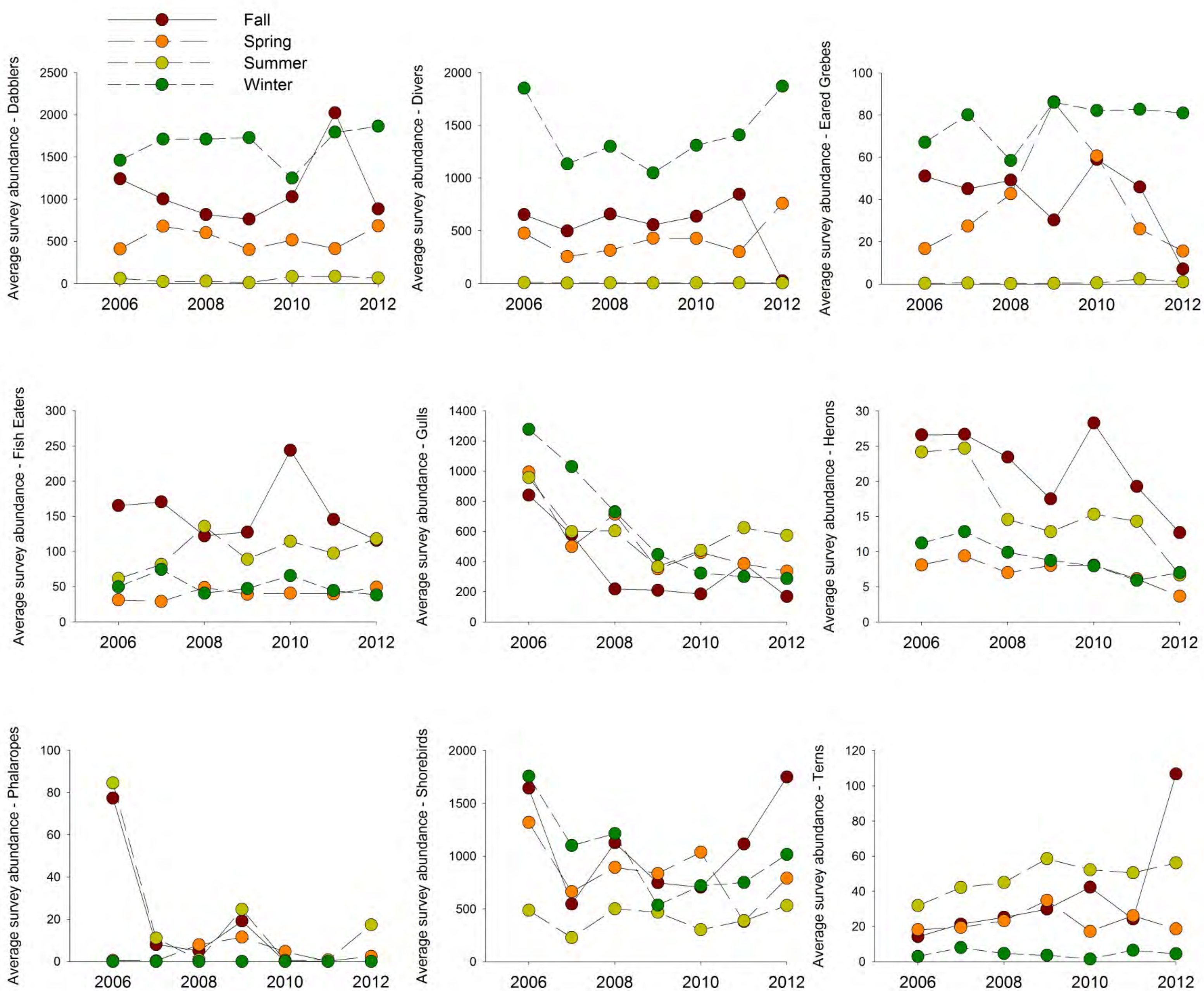
a. Note: we assume here that our variables are independent and that our data are normally distributed, such that a linear combination of variance is valid.

Standard Deviation - Guilds, Species, and Breeding Bird Summary for GIS Output

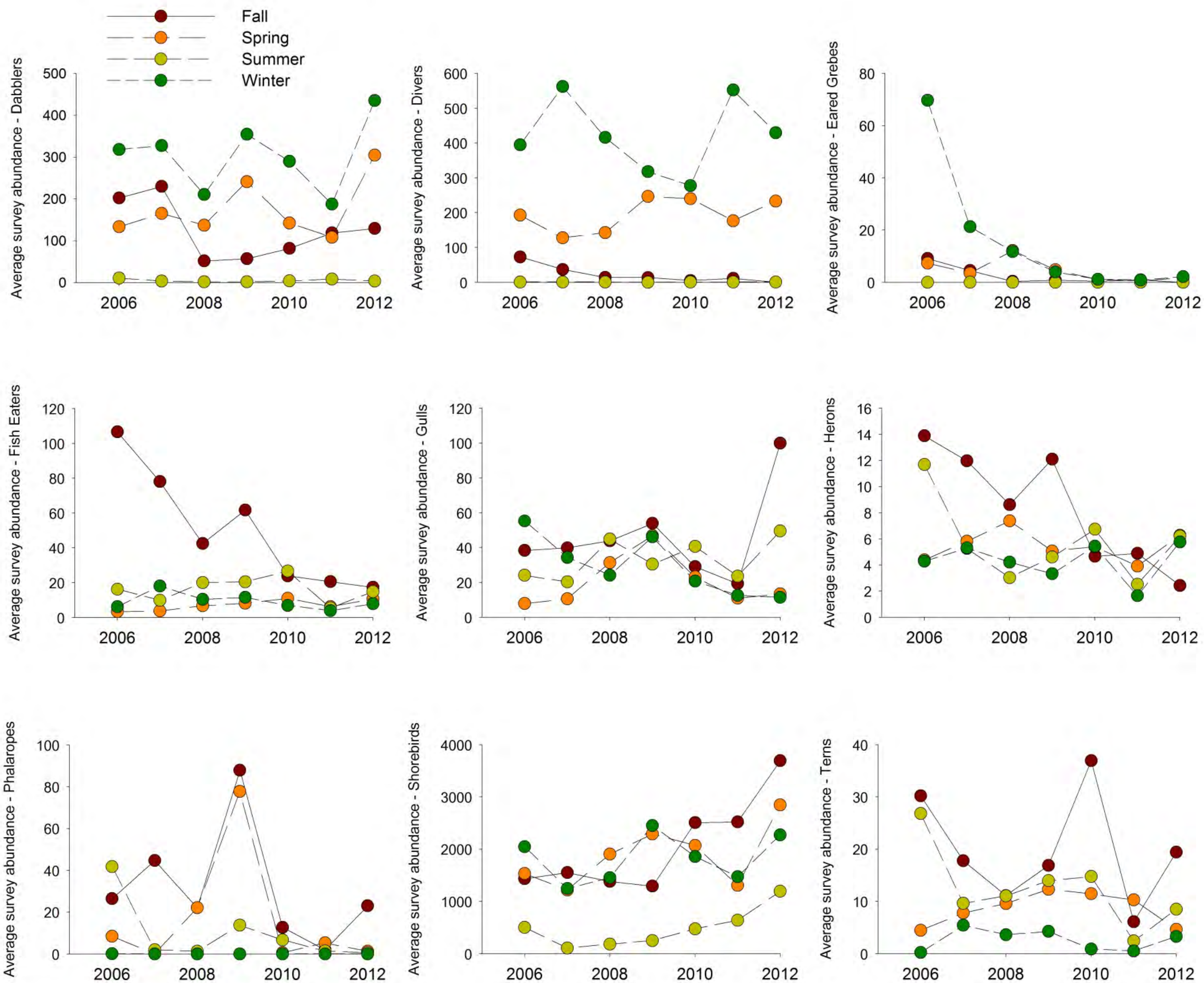
1. To get the combined list of standard deviations for individual species, guilds, and breeding birds into two tables (one for Pond-level scale, one for Complex-level scale; easier to manage in GIS), data from each corresponding query were combined. Individual species were pulled from AAN01 and AAN02; guilds were pulled from AAM01 and AAM02; breeding birds were pulled from AAO01 (but only for the Complex-level summary). Queries AAP01 (Pond-level scale) and AAP02 (Complex-level scale).

Appendix 3. Change in abundance over time during the current survey period, for each guild and season at each complex.

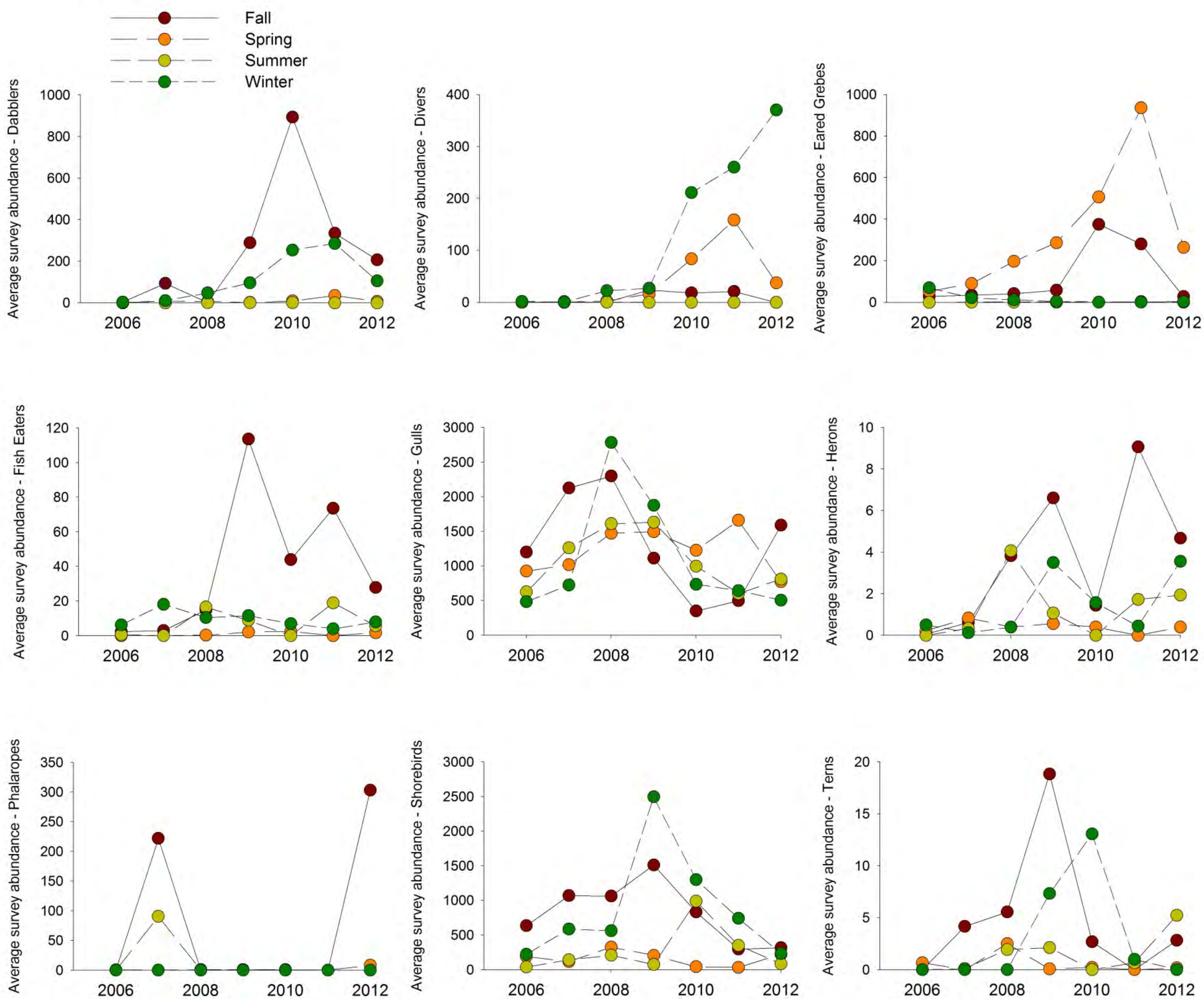
ALVISO



EDEN LANDING

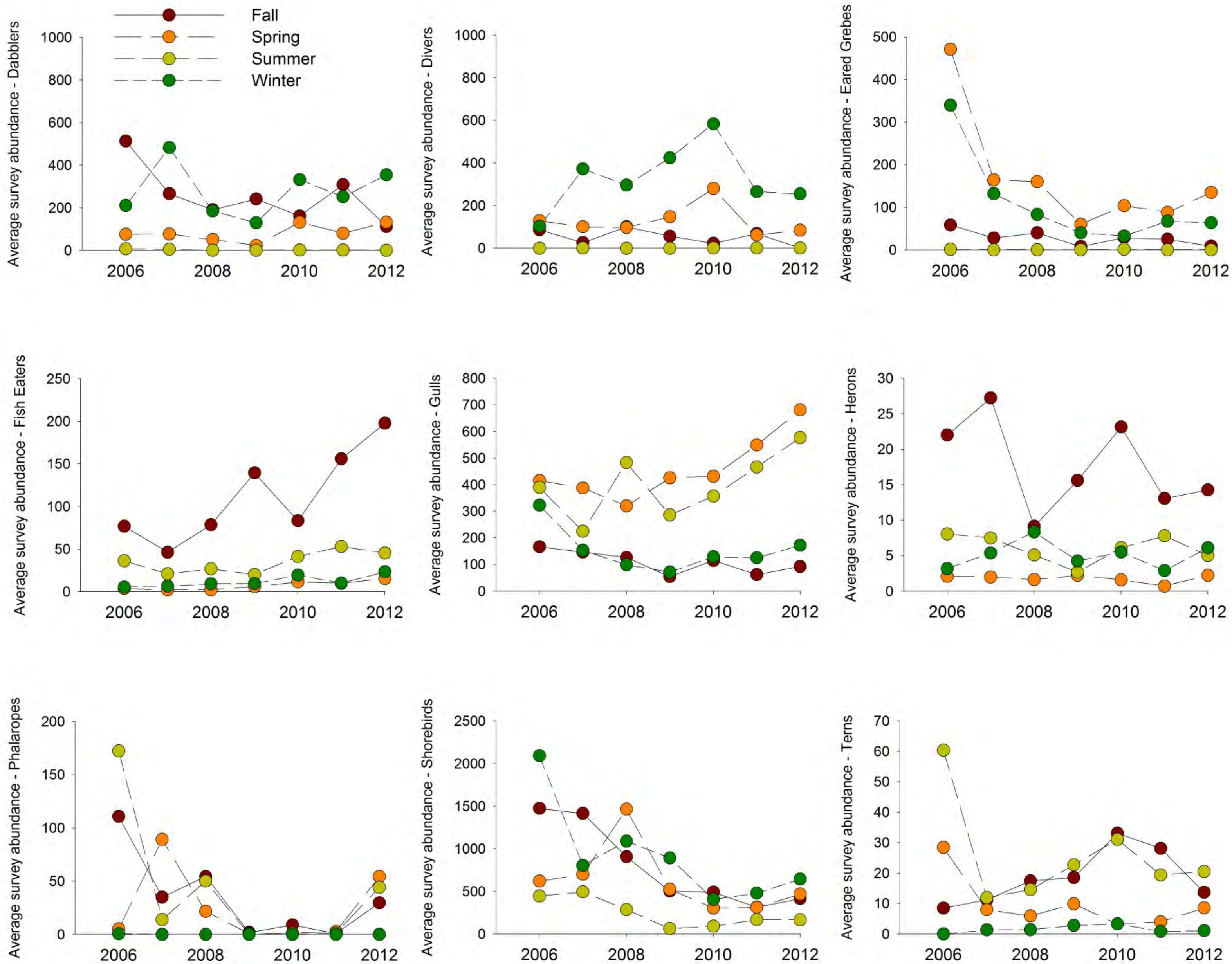


MOWRY



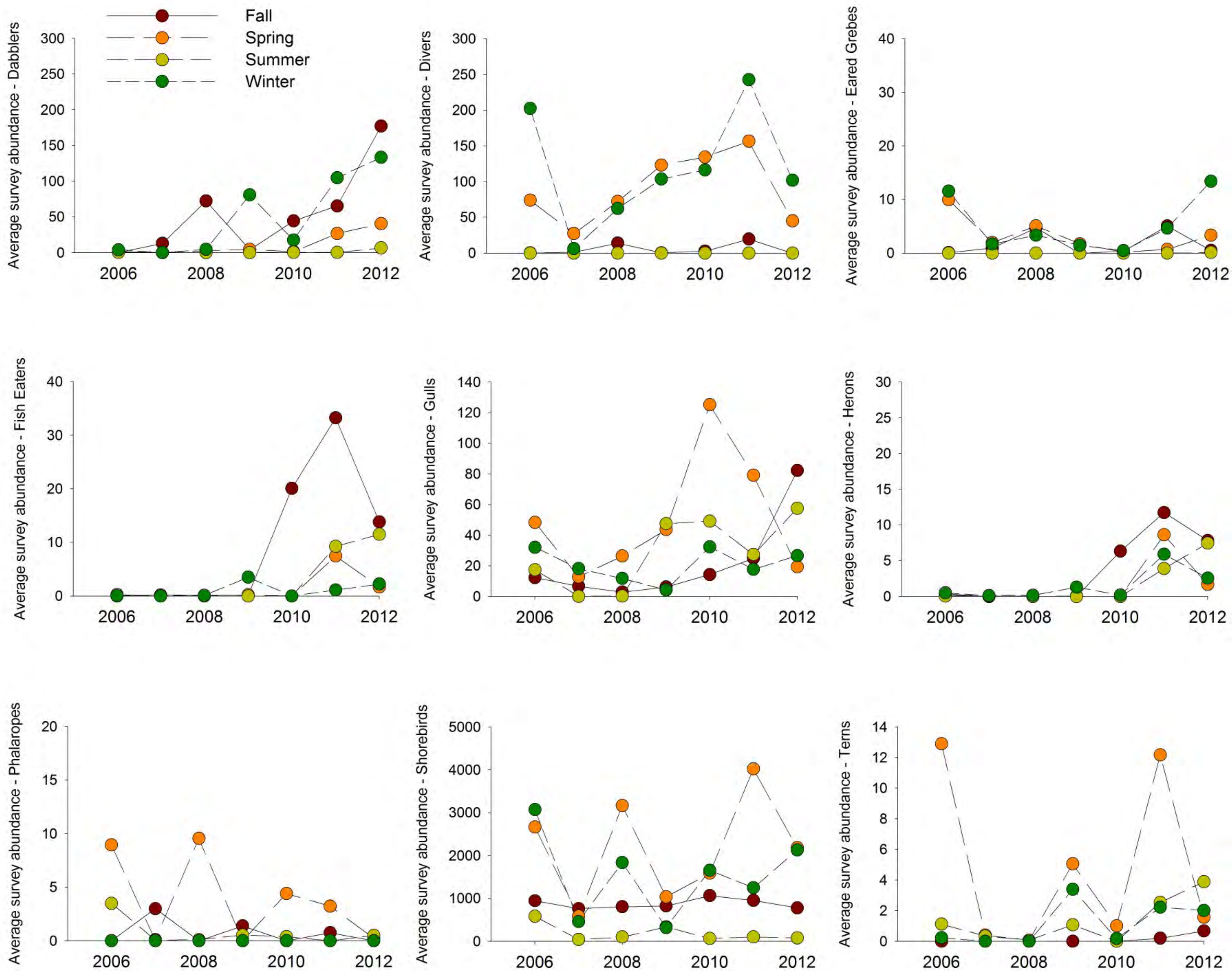
Fall
Spring
Summer
Winter
Average survey abundance - Dabblers
1000
800
600
400
200
0
2006
2008
2010
2012
Average survey abundance - Divers
400
300
200
100
0
Average survey abundance - Eared Grebes
Average survey abundance - Fish Eaters
120
100
80
60
40
20
Average survey abundance - Gulls
3000
2500
2000
1500
1000
500
Average survey abundance - Herons
10
8
6
4
2
Average survey abundance - Phalaropes
350
300
250
200
150
100
50
Average survey abundance - Shorebirds
Average survey abundance - Terns
20
15
10
5

NEWARK



Fall
Spring
Summer
Winter
Average survey abundance - Dabblers
Average survey abundance - Divers
Average survey abundance - Eared Grebes
Average survey abundance - Fish Eaters
Average survey abundance - Gulls
Average survey abundance - Herons
Average survey abundance - Phalaropes
Average survey abundance - Shorebirds
Average survey abundance - Terns
2006
2008
2010
2012

RAVENSWOOD



Fall
Spring
Summer
Winter
Average survey abundance - Dabblers
Average survey abundance - Divers
Average survey abundance - Eared Grebes
Average survey abundance - Fish Eaters
Average survey abundance - Gulls
Average survey abundance - Herons
Average survey abundance - Phalaropes
Average survey abundance - Shorebirds
Average survey abundance - Terns
2006
2008
2010
2012

Appendix 4. Standard deviations for survey abundances calculated by period, season and complex for each guild. Averages are listed in Tables 2-4.

Period	Season	Complex	Dabblers	Divers	Eared Grebes	Fisheaters	Gulls	Herons	Phalaropes	Shorebirds	Terns
Historic	Fall	Alviso	10021	3038	432	1456	2619	401	19	9726	307
Historic	Fall	Eden Landing	1171	4063	1	628	1902	515	755	20084	933
Historic	Fall	Mowry	5686	3036	2736	358	719	43	158	8929	173
Historic	Fall	Newark	7860	2599	167	122	2025	15	155	5639	117
Historic	Fall	Ravenswood	635	499	0	3	1397	0	80	11664	0
Historic	Winter	Alviso	4388	3570	1348	1908	2396	337	0	7790	11
Historic	Winter	Eden Landing	1619	3720	113	331	779	393	0	4782	21
Historic	Winter	Mowry	896	2074	2457	3642	2553	1	0	1914	30
Historic	Winter	Newark	3608	2985	1178	1010	1271	3	4	10111	49
Historic	Winter	Ravenswood	3047	2805	88	162	3043	1	0	12341	0
Historic	Spring	Alviso	2893	3902	2332	576	1647	61	0	5905	386
Historic	Spring	Eden Landing	662	2796	123	419	97	30	140	2338	232
Historic	Spring	Mowry	34	2106	4474	909	1435	1	0	1842	122
Historic	Spring	Newark	2615	3257	3704	434	953	4	356	10917	109
Historic	Spring	Ravenswood	129	1730	108	2	714	0	102	1621	69
Current	Fall	Alviso	10866	5015	562	1217	5244	193	1165	12072	403
Current	Fall	Eden Landing	1424	770	81	878	492	108	880	17163	378
Current	Fall	Mowry	2151	82	955	304	4515	32	708	3676	46
Current	Fall	Newark	2037	588	353	540	879	135	798	6193	181
Current	Fall	Ravenswood	342	72	21	105	111	34	13	3348	1
Current	Winter	Alviso	13340	7732	697	335	5723	66	0	14605	75
Current	Winter	Eden Landing	2749	4015	246	105	320	35	1	17708	57
Current	Winter	Mowry	679	1049	1229	94	4886	9	0	4486	43
Current	Winter	Newark	1891	1537	843	70	732	37	5	6089	20
Current	Winter	Ravenswood	439	471	36	15	99	16	0	6100	14
Current	Spring	Alviso	5160	3355	591	264	5732	49	205	15375	270
Current	Spring	Eden Landing	2151	1862	97	77	292	49	786	15941	98
Current	Spring	Mowry	62	360	1720	6	1818	4	26	1219	11
Current	Spring	Newark	1078	1042	1654	45	1566	9	720	4978	105
Current	Spring	Ravenswood	164	588	24	16	302	20	45	9880	44

Appendix 5. Standard deviations for combined, 3-season survey abundances calculated by period and complex for each guild. Averages are listed in Table 5.

Period	Complex	Dabblers	Divers	Eared Grebes	Fisheaters	Gulls	Herons	Phalaropes	Shorebirds	Terns
Historic	Alviso	1968	983	382	322	513	62	2	2261	69
Historic	Eden Landing	284	1011	23	114	241	83	84	2716	109
Historic	Mowry	1171	922	1494	1204	812	9	31	2294	47
Historic	Newark	1609	938	720	200	392	2	64	2892	29
Historic	Ravenswood	905	912	36	41	1000	0	30	4112	18
Current	Alviso	2522	1593	155	188	1496	30	140	3207	68
Current	Eden Landing	540	733	37	142	91	18	151	4225	57
Current	Mowry	573	286	605	80	1947	9	169	1500	16
Current	Newark	549	455	340	119	500	28	167	1765	38
Current	Ravenswood	143	202	13	27	83	11	11	3144	11