San Francisco Estuary Watershed Indicators
Avian Indicators
N. Nur and J. Kelly, 12 January 2011

Calculation and Evaluation of Selected Indicators [Watershed Assessment Framework, Task 4]

Biotic Condition 1. Tidal Marsh Bird Population Indicator

Background and Rationale:
San Francisco Estuary tidal marsh habitat has been dramatically altered in the past one hundred and sixty years. Approximately 85% of the original tidal marsh habitat in the region has been lost due to creation of salt ponds, conversion to agricultural and industrial/urban use, and water diversion and management (Marshall & Dedrick 1994, Goals Project 1999). The reduction in area, fragmentation of remaining habitat, degradation in habitat quality, and spread of invasive species have all contributed to reductions in the population size and viability of tidal marsh obligate species (Takekawa et al. 2006). For these reasons, many of the species that depend on tidal marsh habitat are currently listed as Federally- or State- threatened or endangered, in particular Clapper Rail and Black Rail, or are of conservation concern (e.g., California Species of Special Concern, Shuford & Gardali 2008). It is for these reasons that the first-listed "Aquatic Resources Goal" of the CCMP is

- "Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction."

The indicator presented here, **Tidal Marsh Bird Population Indicator**, assesses abundance of target species of concern and provides information on health of these populations by determining changes in abundance metrics. This indicator also provides information regarding progress towards the second and third stated goals for Aquatic Resources, i.e.,

- "Restore healthy estuarine habitat to the Bay-Delta" and
- "Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline."

This indicator does not assess healthy estuarine **habitat** directly, but instead allows for inference to be made, based on bird populations that depend on healthy estuarine habitat. The indicator also allows assessment of progress made with respect to the recovery of threatened and endangered species, as well as additional species that are known or presumed to have reduced abundance compared with earlier time periods, especially the period before 1800.

The proposed indicator draws primarily on PRBO's tidal marsh bird monitoring project begun in 1996 (Nur et al. 1997, Spautz et al. 2006). This program has been studying tidal marsh-dependent species throughout the San Francisco Estuary, utilizing an extensive array of breeding-season point count surveys (about 10 point count locations per mash), conducted twice per breeding season, between 1996 and 2010. Until 2007, surveys were conducted at about 20 to

40 marshes per year; from 2008 to the present, surveys have been conducted at about 8 marshes per year. The indicator is calculated for three identified regions: Suisun Bay, San Pablo Bay, and San Francisco Bay. The San Francisco Bay region includes both Central and South San Francisco Bay, combined.

Four species are included in this indicator. Each is year-round resident (or primarily resident) and **is dependent on, or strongly associated with, tidal marsh habitat** (Goals Project 2000). Two species are rails, **Clapper Rail** and **Black Rail** (family Rallidae); the indicator is restricted to the California Clapper Rail subspecies (*Rallus longirostris obsoletus*) and the California Black Rail subspecies (*Laterallus jamaicensis coturniculus*). The other two species are songbirds, **Song Sparrow** (*Melospiza melodia*) and **Common Yellowthroat** (*Geothlypis trichas*, a North American warbler). The proposed indicator (and data available) are specific to the tidal marsh-dependent subspecies of the Song Sparrow and Common Yellowthroat (Marshall and Dedrick 1994, Nur et al. 1997).

Data Source:
For Black Rails, Song Sparrows, and Common Yellowthroats, data are from PRBO tidal marsh bird project (www.prbo.org/cms/135; Nur et al. 1997, Spautz et al. 2006). Survey results for these three species are available for 1996 to 2008, and presented here. Information from 2009 and 2010 will soon be available for inclusion in the next iteration of the indicator (in early 2011).

Survey results for Clapper Rail are only available for 2005 to the present, though there is partial information, at the regional scale, for the 1990's (Albertson and Evens 2000). Clapper Rail data are from a consortium of organizations studying this species, led by PRBO (Liu et al. 2009; www.prbo.org/cms/135). For this species, only data from 2005 through 2008 have been analyzed (see Liu et al. 2009). For 2009 and 2010, data have been compiled and will be used to update the indicator in early 2011. However, with Clapper Rail data currently available only from 2005 to 2008, we have not subjected these data to the quantitative analysis presented for the other three species. We maintain that at least a five-year span is required for an informative analysis of trends for any bird species of the San Francisco Estuary. In early 2011, data from the requisite time period will be available for the appropriate analysis.

Methods and Calculations:
Abundance data were collected regarding Black Rails, Song Sparrows, and Common Yellowthroats, using point count surveys conducted at multiple marshes per region per year (usually 5 to 8 marshes per region per year) during the breeding season (March to end of May). Generally, 6 to 10 point count stations were established per marsh survey (Liu et al. 2007). For each species and each region, we estimated mean number of individuals detected per hectare of surveyed marsh per survey (usually, two surveys per year per marsh). These surveys did not use tape playback. Statistical analysis was conducted on densities per marsh per year, averaged over the number of survey visits. "Density" for this indicator refers to the number of birds detected per hectare surveyed, and is more properly termed "apparent density" since we did not correct for detectability (but see Nur et al. 1997; Thomas et al. 2010). All analyses were conducted on log-transformed values (with a constant added so that all densities were > 0; Nur et al. 1999).

Between 1996 and 2008, many marsh sites were surveyed, but the same sites were not surveyed in each year. To control for site-to-site differences in abundance, "site" was included as a categorical variable in the analyses. The statistical analysis was carried out separately for each region (SF Bay, San Pablo Bay, Suisun Bay), and for each species. Finally, a multiple-species metric was calculated based on the single species densities, while controlling for site differences. The multiple-species metric was calculated on log-densities, controlling for differences in apparent density among the three species. Note: (1) The statistical control for site effects was carried out separately for each species. (2) Black Rail density was not estimated for SF Bay region, due to lack of detections of individuals in that region (see Evens and Nur 2002).

In addition to presenting year-by-year results for 1996 to 2008, we calculated trends for two time periods: 1996 to 2008 (i.e., the most recent 13 years of survey data), and 2004 to 2008 (i.e., the most recent 5 years). We also compare the most recent three year-mean values (for 2006-2008) to the benchmark 5-year values (for 1996-2000). Trends were calculated for each of the three species and for all species combined in a multi-species statistical model that fit a single slope, common to the three species, but allowed species log(density) to differ among the three species. See Pyle et al. (1994) for similar example. Because these analyses were conducted on log-densities, the coefficients obtained (i.e., slopes) represent the constant proportional increase or decrease for each species or for the three combined species (Nur et al. 1999).

Clapper Rail density for 2005-2008 was estimated by Liu et al. (2009), for each year and for each region of the SF Estuary. We will present and evaluate this metric for the period 2005-2010 when additional data are available in early 2011 (see above).

Goals, Targets, and Reference Conditions:
There are no agreed upon, explicitly stated goals, targets or reference conditions for any of the four main focal species (Black Rail, Song Sparrow, Common Yellowthroat, and Clapper Rail). Because of loss of habitat, population size has been reduced from historical levels (e.g., since c. 1800). Therefore, one means of assessment is to evaluate trends since 1996 (the earliest year for which annual survey data are available for Black Rail, Song Sparrow, and Common Yellowthroat). To assist in evaluation of the "longer-term" trends (in this case, 1996 to 2008), we also consider more recent "short-term" trends (in this case from 2004 to 2008). Finally, we compare mean densities observed in 1996 to 2000 (best available 5-year benchmark) to the period 2006 to 2008 (most recent 3 years of data).

The goal (target) is for trends to be positive (indicating recovery of tidal marsh species), or at least to be non-negative. For all species considered, evaluations are carried out for each region within the Estuary.

Results:
For this indicator, results differed strikingly from one region of the SF Estuary to another. In addition, each species displayed a distinctive pattern.

For **Black Rail**, the trend in both San Pablo Bay and Suisun Bay has been positive (Figure T1 A, B). In San Pablo Bay the positive trend is exemplified in the longer-term (since 1996) and shorter-term (Table T1). In Suisun Bay, the positive trend is only evident in the last 5 years; in fact, the highest density values for Black Rails are all in the most recent 5 years of surveys (2004-2008; Table T1). The overall increase in density of Black Rails for San Pablo and Suisun is confirmed when one compares the most recent 3-year period with the earlier 5-year benchmark period (Table T2).

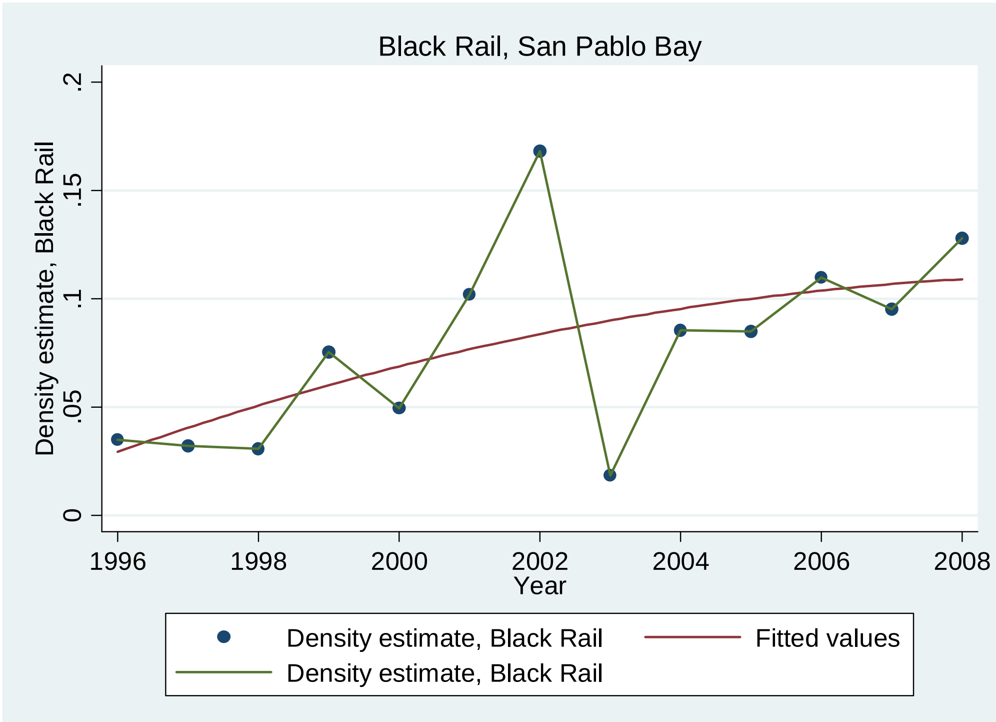
For **Common Yellowthroat**, there has been little increase in San Francisco Bay over the 13-year period, except that the most recent 10 years have higher densities than the first three years (Figure T1C). Nevertheless, the overall trends for the longer-time period and the shorter-time period are non-significant, nor does the most recent three-year period differ significantly from the five-year benchmark period (Table T1, T2). In contrast, in both San Pablo Bay and Suisun Bay, there have been significant increases over the long-term, but this trend has abated in recent years in San Pablo Bay (Figure T1 D, E). In Suisun Bay, it is less clear whether the increasing trend is evident, but the overall pattern is of higher densities in recent years compared to earlier years. Note that the density index for Suisun Bay Common Yellowthroats has remained about 10-fold greater than the comparable density index for San Francisco Bay or San Pablo Bay Common Yellowthroats (Figure T1 C, D, E). This consistent regional difference is likely due to habitat affinities: Common Yellowthroats prefer brackish marsh to saline marsh (Spautz et al. 2006, Stralberg et al. 2010).

For **Song Sparrows**, only the San Francisco Bay region shows an increase, and even then the increase has reversed, i.e., this region demonstrates a recent decline (Figure T1 F, Table T1). In contrast to the overall-increase for the San Francisco Bay region, Suisun and San Pablo Bay regions show overall decreases (Figure T1 G, H; Table T1). Moreover, all three regions demonstrate recent, short-term declines. As a result of these divergent trends, San Francisco Bay Song Sparrows no longer demonstrate the lowest density of the three regions, instead Suisun Song Sparrows evidence the lowest density, and San Francisco Bay Song Sparrows the middle level of density. For this species, there are no significant differences between the 3 most recent years and the 5-year benchmark period for any of the three regions (Table T2).

The **combined species** analysis demonstrates a different pattern for each region, though the overall-result is a net increase. In San Francisco Bay, the increase is evident earlier in the period but more recently demonstrates a decrease (Figure T1 I). In San Pablo Bay, the overall increase in density is evident during the entire period (Figure T1 J). In Suisun, an initial decrease has been followed by a more recent increase in density (Figure T1 K).

Figure T1. Population Trends for Three Tidal Marsh Species (Black Rail, Common Yellowthroat, and Song Sparrow) and Combined Trend for all 3 species. Shown is density index (birds detected per hectare per survey) by SF Estuary region, controlling for site-to-site differences in density within a region. Note: There are no breeding Black Rails in San Francisco Bay. Combined species trend depicts geometric mean across the three species (see text). Each species-region graph shows the best linear fit (Figures T1-E and T1-G) or quadratic fit (Figures T1-A to T1-D, T1-F, and T1-H to T1-K) as appropriate; choice of fit (linear vs. quadratic) determined by maximization of adjusted R^2 (Nur et al. 1999).

A)


Black Rail, San Pablo Bay
Density estimate, Black Rail
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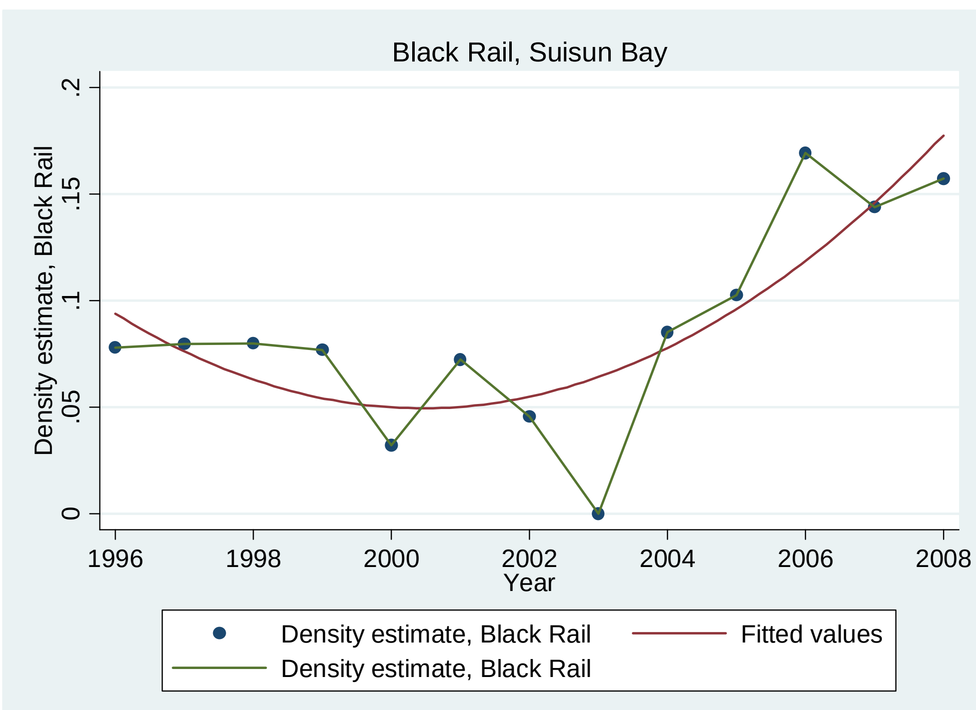
Density estimate, Black Rail

B)


Black Rail, Suisun Bay
Density estimate, Black Rail
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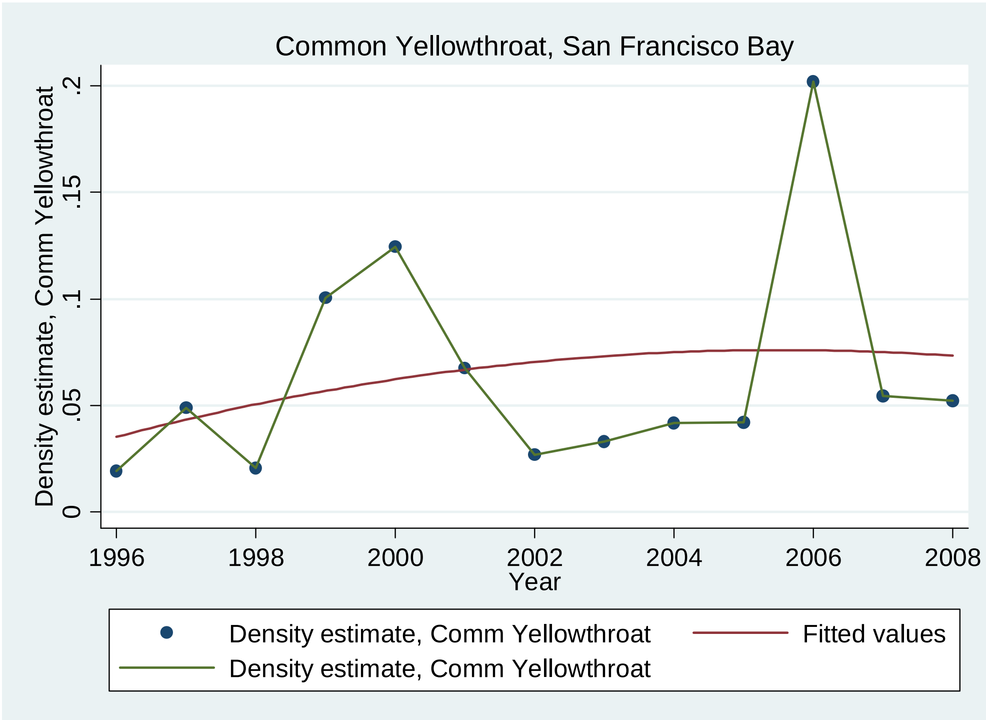
Density estimate, Black Rail

C)


Common Yellowthroat, San Francisco Bay
Density estimate, Comm Yellowthroat
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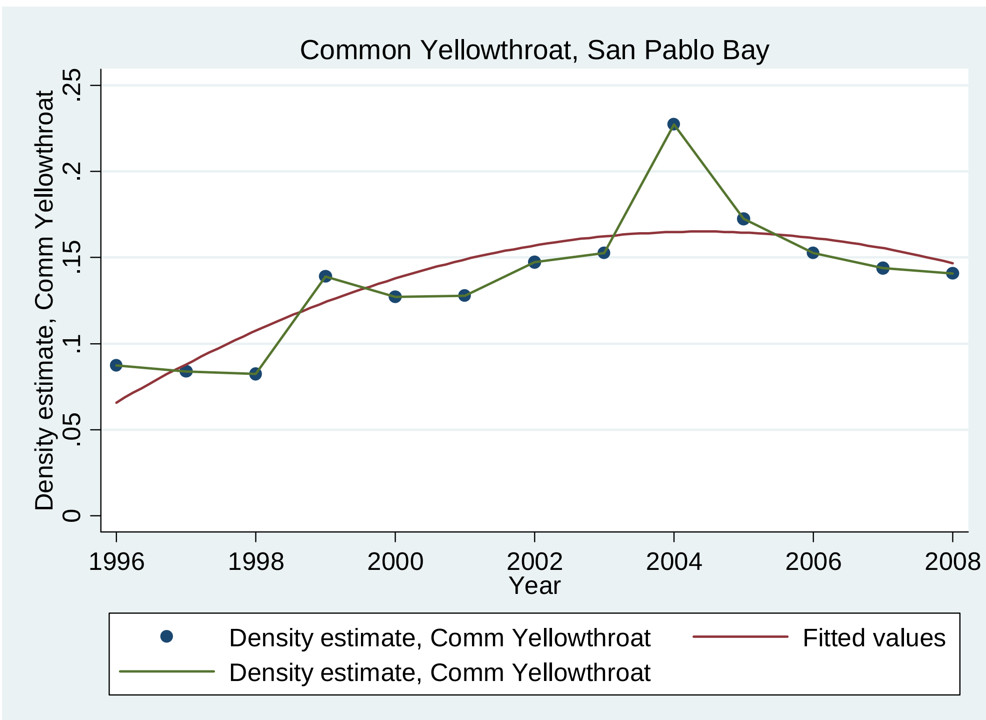
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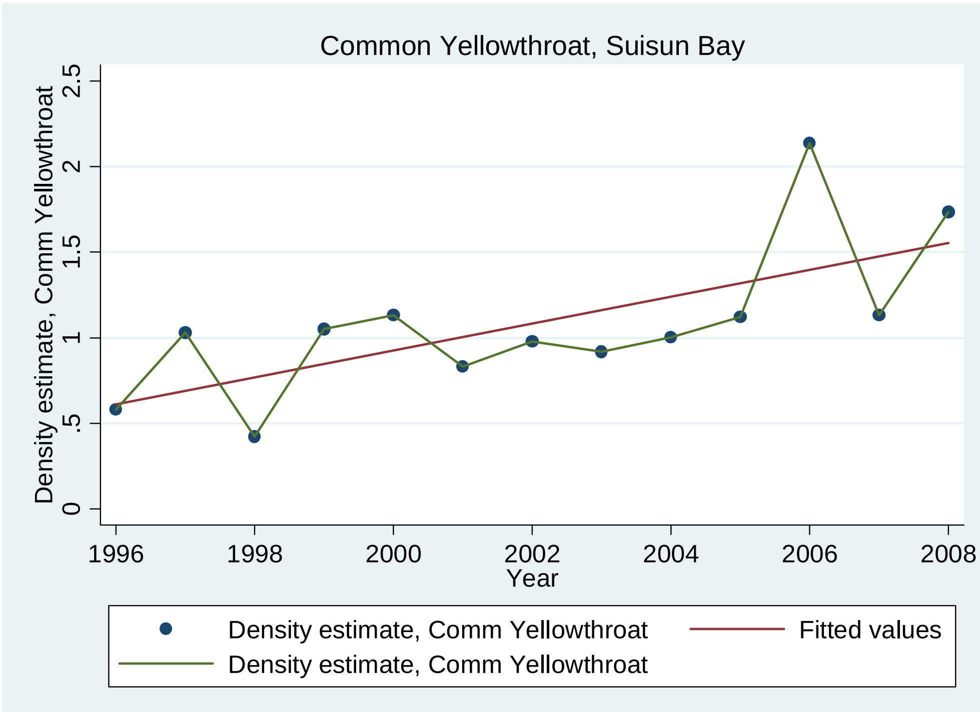
E)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Density estimate, Comm Yellowthroat
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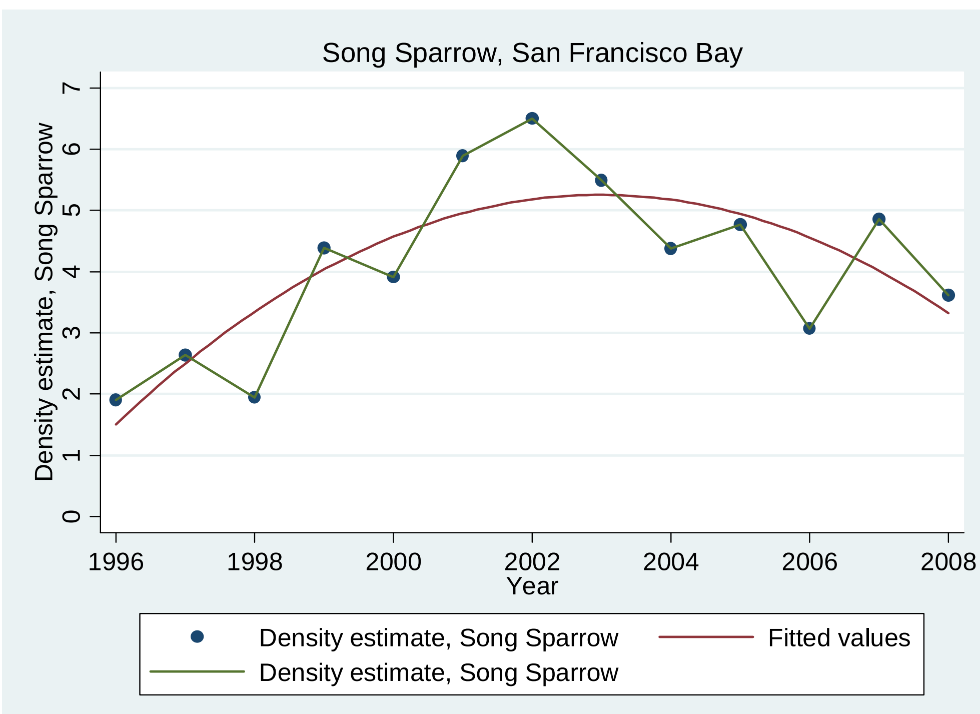
Density estimate, Comm Yellowthroat

F)


Song Sparrow, San Francisco Bay
Density estimate, Song Sparrow
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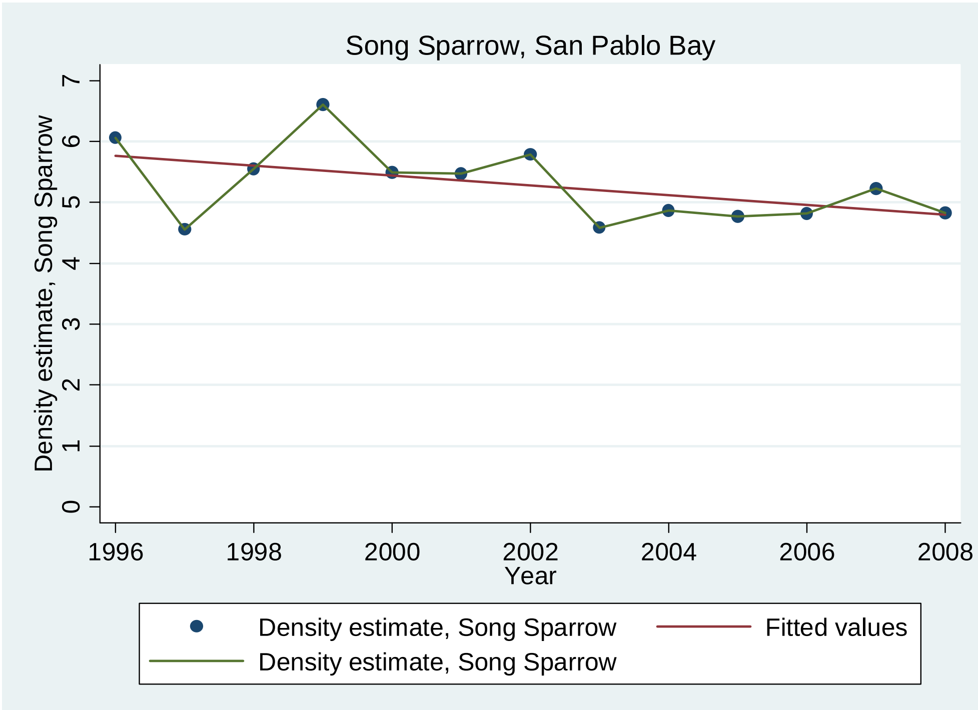
Density estimate, Song Sparrow

G)


Song Sparrow, San Pablo Bay
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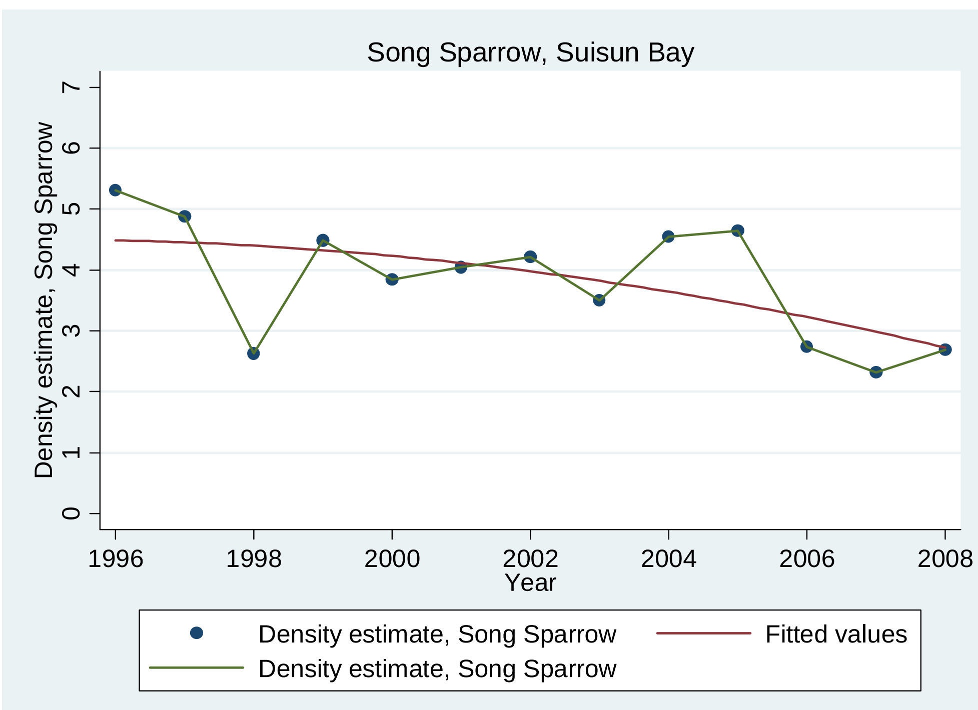
H)


Song Sparrow, Suisun Bay
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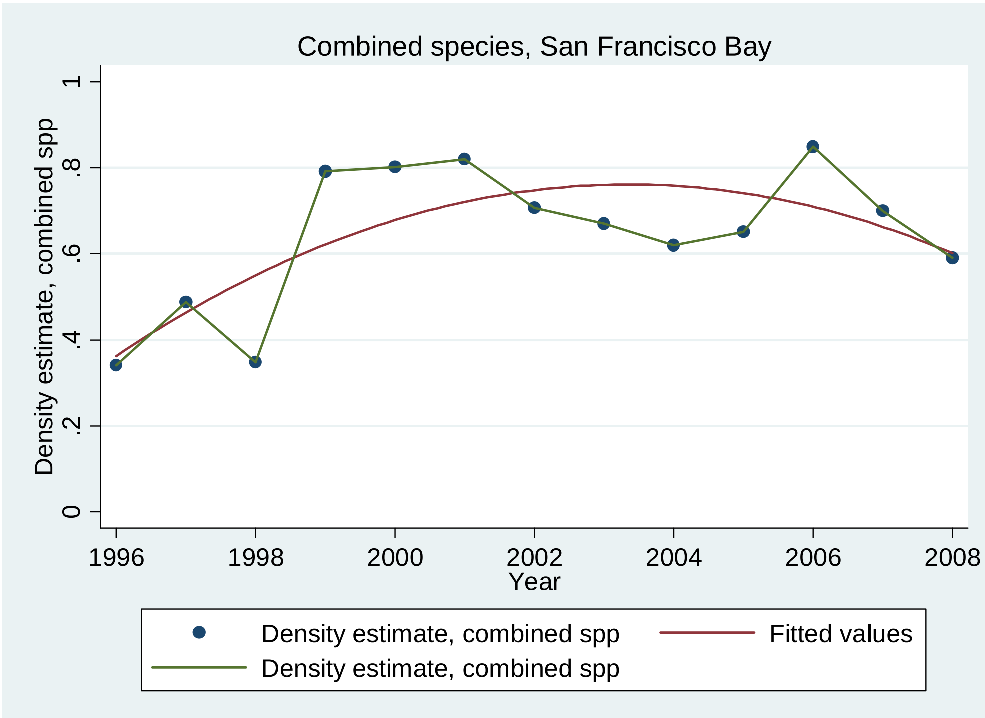
Density estimate, Song Sparrow
Fitted values
Density estimate, Song Sparrow

I)


Combined species, San Francisco Bay
Density estimate, combined spp
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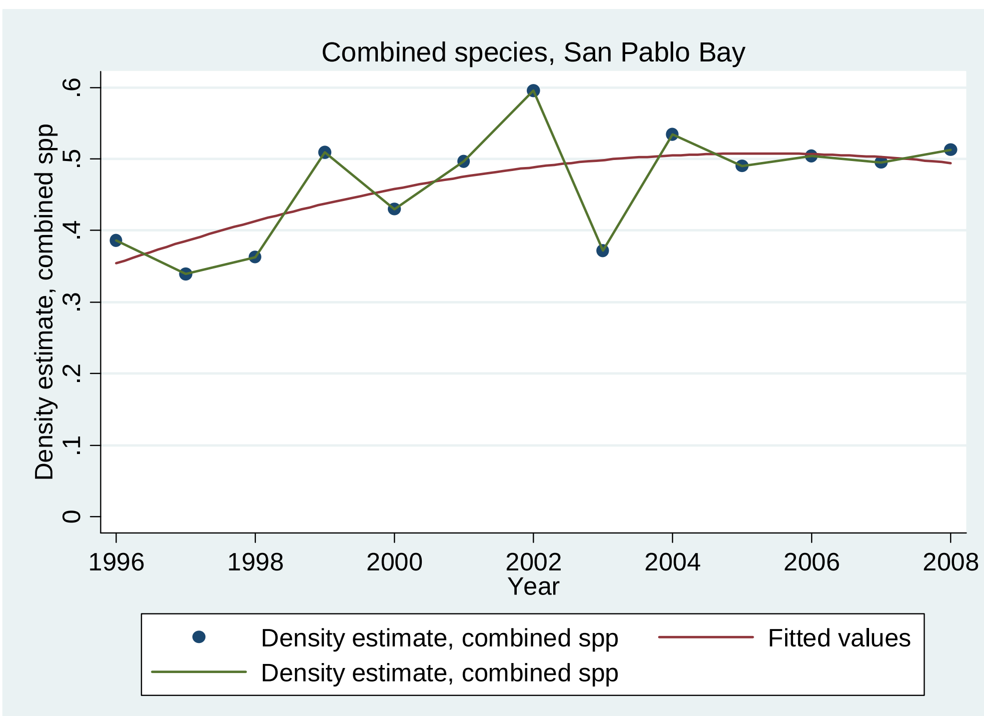
Density estimate, combined spp
Fitted values
Density estimate, combined spp

J)


Combined species, San Pablo Bay
Density estimate, combined spp
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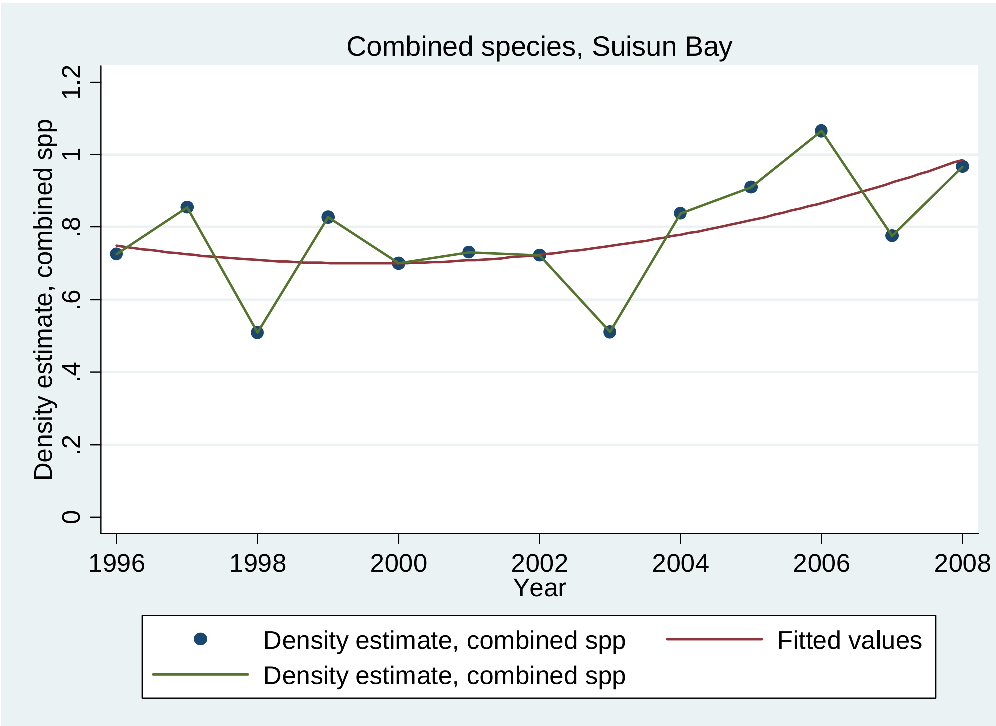
Density estimate, combined spp
Fitted values
Density estimate, combined spp

K)


Combined species, Suisun Bay
Density estimate, combined spp
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Year
Density estimate, combined spp
Fitted values
Density estimate, combined spp

Table T1.

Long-term (1996 to 2008) and Short-term (2004 to 2008) trends for tidal marsh bird species

Shown are estimated annual percent changes per year in density index. Highlighting indicates significant (P < 0.05) differences (bright yellow) or marginally significant (0.05 ≤ P < 0.10)

	San Francisco B		San Pablo B		Suisun & W. Delta	
Song Sparrow	Ann Pct	P-val	Ann Pct	P-val	Ann Pct	P-val
Long-term	5.77%	P = 0.008	-1.54%	P = 0.16	-2.63%	P > 0.2
Short-term	-0.67%	P > 0.9	-2.81%	P > 0.3	-14.7%	P = 0.19
Common Yellowthroat						
Long-term	-0.45%	P > 0.8	4.33%	P = 0.019	7.10%	P = 0.019
Short-term	1.37%	P > 0.8	-10.3%	P = 0.083	14.7%	P > 0.3
Black Rail						
Long-term	ND		4.08%	P = 0.034	2.18%	P > 0.4
Short-term	ND		5.19%	P > 0.5	7.37%	P > 0.4
Combined species						
Long-term	2.61%	P = 0.14	2.26%	P = 0.018	2.14%	P = 0.15
Short-term	0.34%	P > 0.9	-2.83%	P > 0.4	1.65%	P > 0.8

Table T2.

Comparison of 3-year Current (2006-2008) vs. 5-year Benchmark (1996 to 2000)

Shown are estimated percent differences in density index for two time periods. Highlighting indicates significant (P < 0.05) differences (bright yellow) or marginally significant (0.05 ≤ P < 0.10)

	San Francisco Bay		San Pablo Bay		Suisun Bay	
	Percent	P-val	Percent	P-val	Percent	P-val
Song Sparrow						
Comparison	2.70%	P > 0.9	-11.7%	P > 0.2	-33.8%	P = 0.18
Common Yellowthroat						
Comparison	20.0%	P > 0.4	38.7%	P = 0.073	74.3%	P = 0.15
Black Rail						
Comparison	ND		49.5%	P = 0.034	83.0%	P = 0.041
Combined species						
Comparison	11.0%	P > 0.5	22.3%	P = 0.033	28.3%	P = 0.19

In addition, we note that Clapper Rail population trends will be added to this indicator once the 2009 and 2010 data are available in early 2011. We feel that a minimum of 5 years of indicator data are required and as of now only four years (2005-2008) are available.

We conclude that the tidal marsh bird population indicator reveals a mixed picture: The combined species index shows overall increases in marsh bird population density since 1996, which **indicates some success in meeting the CCMP's first stated Aquatic Resources goal**: "Stem and reverse the decline in the health and abundance of estuarine biota." In San Pablo and San Francisco Bay regions, the increase for the combined species index is evident comparing 1999-2008 with 1996-1998, but recent years have not demonstrated further increases. For Suisun, the increase is evident comparing 2004-2008 to earlier years. Black Rails, a State-threatened species, clearly show a population-level increase which suggest that progress is also being made with regard to the third stated Aquatic Resources goal: "Ensure the survival and recovery of listed (and candidate) threatened and endangered species...." Song Sparrows reveal the other side of the story: this species demonstrates declines in density in San Pablo and Suisun Bays. Song Sparrows in San Francisco Bay show a recent decline (2002 to 2008) which partly counteracts the early improvements seen, from 1996 to 2002. The declines observed for this species are a cause for concern.

The overall declines in the Song Sparrow population index is consistent with the low levels of reproductive success that are apparent (see Biotic Indicator 4, *Marsh bird reproductive success*, below). The increase in density seen since 1996 reflects an improvement in habitat quality, at minimum increased habitat quality in restored tidal marshes. It is less clear whether mature marshes (those over 100 years of age) are showing increases in habitat quality.

Biotic Condition 2. Heron and Egret Nest Density Indicator

Background and Rationale:
Audubon Canyon Ranch has monitored Great Blue Heron and Great Egret nest abundance at all known nesting colonies (40-50 sites) in the northern San Francisco Estuary, annually, since 1991. The conspicuousness of heron and egret nesting colonies facilitates the use of nest abundance as an effective index of breeding population abundance and distribution. Heron and egret nest abundance is recognized as a valuable metric for assessing biotic condition in estuarine and wetland ecosystems (Fasola et al. 2010, Kelly et al. 2008, Erwin and Custer 2000). Energetic limits on the foraging ranges of these species are associated with interannual shifts among nesting colony sites that in turn lead to dynamic variation in nest density which reflects suitability of surrounding feeding areas (Gibbs 1991, Wittenberger and Hunt 1985, Kelly et al. 2008). The two target species are used to indicate population responses to different habitat conditions: Great Egrets preferentially forage in small ponds in emergent wetlands and in areas with shallow, fluctuating water depths for foraging. In contrast, Great Blue Herons forage along the edges of larger bodies of water and creeks and are less sensitive to water depth (Custer and Galli 2002, Gawlik 2002). This indicator is sensitive to changes in land-use, hydrology (especially water circulation and depth), geomorphology, environmental contamination, vegetation characteristics, and the availability of suitable prey (Kushlan 2000).

Differences in breeding abundance reflect responses to habitat conditions within 30-300 km^2 (Custer et al. 2004, Kelly et al. 2008) and can be used to evaluate differences in habitat use between or across years at multiple spatial scales (colony sites, major wetland subregions, region-wide). Linkage between nest abundance and the landscape distribution of wetland habitat types is well-documented in the San Francisco Estuary (Kelly et al 2008) and in the Sacramento Valley (Elphick 2008). At the local scale of colony sites and adjacent marshes, changes in heron and egret nest abundance reflect variation in other factors, such as disease, nest predation, especially by human commensal species such as raccoons or ravens, and direct human disturbance to colony sites (Kelly et al. 2007).

Herons and egrets are frequently used as symbols of wetland conservation (Parnell et al. 1988, Kushlan and Hancock 2005) and are widely recognized as indicators of wetland health (Kushlan 1993, Erwin and Custer 2000). These values lead to compelling interest by policy makers, resource managers, and the public, in metrics related to the ecological status of herons and egrets.

Data Source:
The Heron and Egret Nest Density Indicator was calculated using data from ongoing regional heron and egret studies by Audubon Canyon Ranch (Kelly et al. 1993, 2007). The data, which reflect repeated annual nest counts at all known colony sites, provide intensive and extensive measurements of nest abundance and an effective index of regional breeding population sizes. Additional data on nest abundances in the southern San Francisco Bay (not presented here) are available from partners at the San Francisco Bay Bird Observatory.

Methods and Calculations:
The Heron and Egret Nest Density Indicator includes metrics calculated for Great Egrets and Great Blue Herons. Results are provided for each year (1991-2008; updated results to 2010 are pending), for each colony within each of three northern subregions (Central San Francisco Bay, San Pablo Bay, and Suisun Bay). Nest density estimates are based on the peak number of active nests among four (monthly) visits to at each colony site (40-50 sites) within foraging range (10 km) of the historic tidal wetland boundary (ca.1770–1820; San Francisco Estuary Institute 1999; Figure H1), summed annually within and across subregions. Density is calculated based on the estimated peak nest abundance within 10 km of the historic tidal-marsh boundary of Suisun Bay, San Pablo Bay, and Central San Francisco Bay, and within the combined area of the three subregions, excluding the extensive open water areas of the San Francisco Estuary (Figure H1). The detection of new colony sites is achieved through ongoing communications with state, regional and local natural resource managers, county breeding bird atlas efforts, local birding networks, and occasional ground-based and aerial searches of the region. The Nest Density Indicator is calculated as the geometric mean percent change in nest density for the two species, in comparison to the 1991-1995 average (Great Blue Heron: 181±15 nests [S. E.], 5.1±0.43 100 km^{-2}; Great Egret: 535±47 nests, 15.1±1.33 100 km^{-2}). That is, the proportional change was calculated for each species for the specified time period and then the geometric mean was calculated; finally, the mean proportional change was converted to percent change.

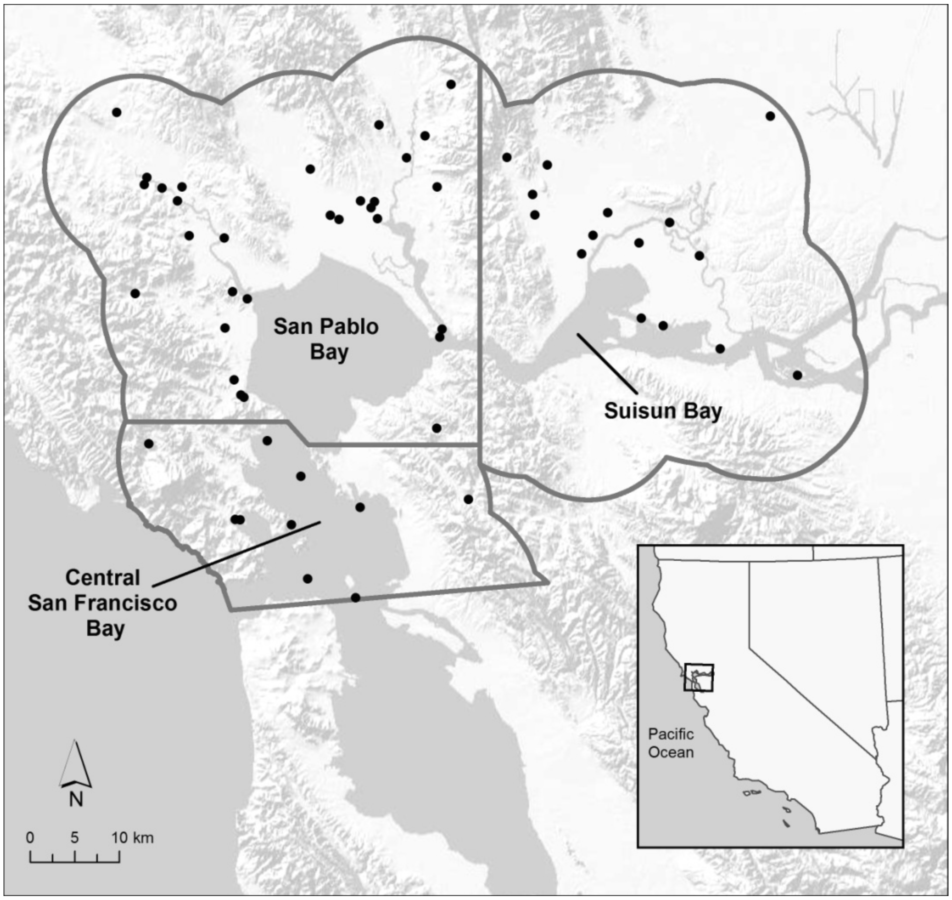


Figure H1. Heron and egret nesting colonies within 10 km of historic tidal wetlands in northern San Francisco Estuary, 1991-2008. Areas indicated by boundary lines, excluding the open waters of Suisun Bay, San Pablo Bay, and the Central Bay, were used to determine heron and egret nest density.

Goals, Targets and Reference Conditions:

CCMP goals to "restore" and "enhance" the ecological productivity and habitat values of wetlands are non-quantitative in nature. However, the use of time series back to 1991 allows the specification of appropriate quantitative reference conditions. Differences or trends in nest density can be quantified and used for assessment.

Maintenance of current regional or subregional breeding densities

- Target: current 5-year trend (linear) ≥ 0, i.e., stable or increasing
- Target: current 15-year trend ≥ 0, i.e., stable or increasing
- Target: current 3-year mean ≥ 5-year reference mean (1991-1995), i.e., current levels equal to or greater than reference.

Enhancement of regional or subregional breeding densities with wetland restoration

- Target: current 5-year trend (linear) ≥ current 15-year reference trend
- Target: current 3-year mean ≥ highest 5-year *subregional* reference mean (1991-1995)

Results: Annual results of the Heron and Egret Nest Density Indicator are shown in Figure H2.

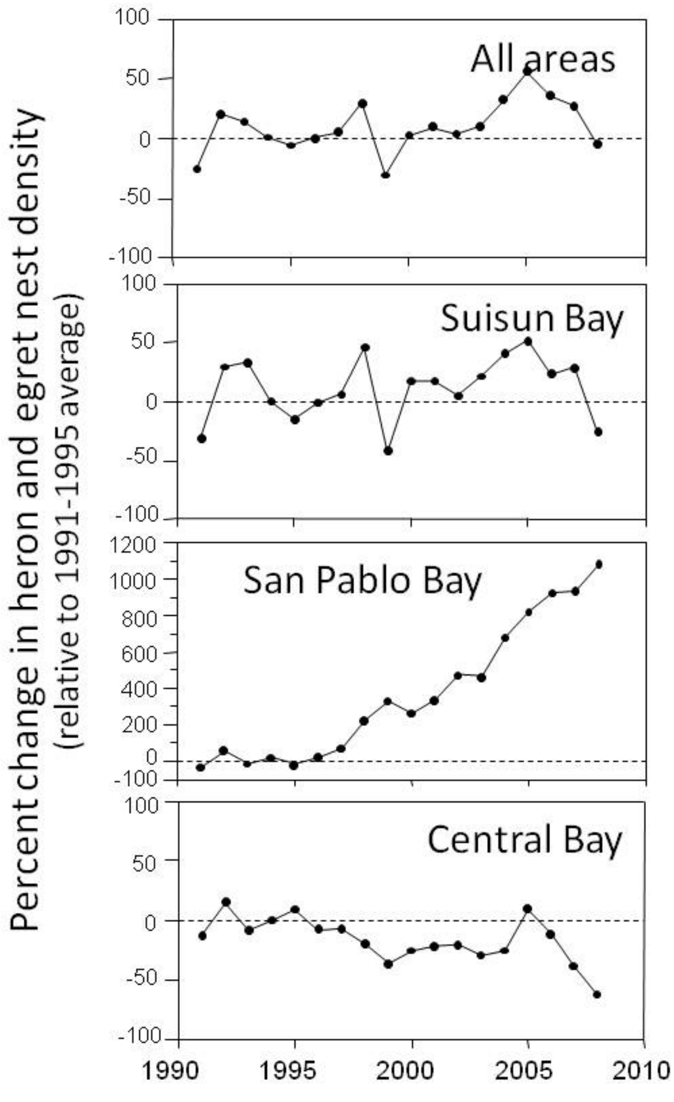


Figure H2. Annual percent change in heron and egret nest density, 1991-2008, relative to the average nest density (dashed line), 1991-1995, in the northern San Francisco Estuary.

Regional nest densities are stable for both species but 5-year trends provide evidence suggesting recent declines.

Recent (2006-2008), regional nest densities of herons and egrets did not differ significantly over 1991-1995 reference levels (t-tests, $P > 0.05$). Recent 15-year (1994-2008) linear trends in percent change in (log-transformed) nest density are > 0, but are marginally or not statistically significant for the combined species index (Indicator: $F_{1,13} = 3.3$, $P < 0.10$) and for individual species (Great Blue Heron: $P < 0.08$; Great Egret: $P < 0.18$). In contrast, the recent 5-year regional trends (2004-2008) are declining, although not significantly ($P > 0.05$), for both species, and trends are significantly less than the *current* 15-year trends, for the Indicator ($t_{18} = 4.2$, $P < 0.001$, Figure H2) and for each species (Great Blue Heron: $P = 0.02$; Great Egret: $P < 0.01$). This suggests recent, relative regional declines in breeding densities. Trends within subregions were similar to regional trends, with one exception: trends in San Pablo Bay were dominated by a small but dramatic increase in Great Egrets nest abundance, from less than 5 nests, in the early 1990s, to 163 in 2008 (Figure H2).

Nest densities were lower in San Pablo Bay than in other subregions, with some evidence of relative increases and a reduced variation among subregions.
During the reference period (1991-1995), Great Egret nest density was significantly lower in San Pablo Bay than in both other subregions, for Great Egret and, marginally, for Great Blue Heron (multiple comparisons, $P < 0.001$ and $P \leq 0.08$, respectively). The nest density indicator revealed a dramatic percent increase in San Pablo Bay in recent years (2006-2008) relative to the reference period (981±51%), that which was significantly greater than in other subregions (multiple comparisons, $P = 0.001$). As a result, Great Egret nest density in San Pablo Bay during the response period (2006-2008) was significantly lower only in comparison with Suisun Bay (multiple comparisons, $P < 0.05$), and Great Blue Heron density did not differ significantly among subregions ($F_{4,4} = 2.4$, $P = 0.21$).

Based on nest densities of Great Blue Herons and Great Egrets, CCMP goals of restoring or enhancing wetland productivity and associated wetland habitat values have not been generally met, but possible responses to habitat enhancement are suggested.
Nest densities in most of northern San Francisco Bay are stable, with some suggestion of gradual, long-term, subregional increases in San Pablo Bay wetlands. In that subregion, evidence of increasing nest density, especially for Great Egrets, suggests possible responses to continuing habitat restoration and enhancement. However, regional trends in recent years provide evidence of possible declines across northern San Francisco Bay.

Biotic Condition 3. Wintering Waterfowl Population Indicator

Background and Rationale:

San Francisco Estuary provides important wintering habitat for waterfowl (Goals Project 2000, Steere & Schaefer 2001), one of the most important such areas in North America. For some species, during the winter, San Francisco Estuary hosts a majority of the entire Pacific Flyway population (Steere & Schaefer 2001). This is in addition to the estuary's value to waterfowl during the breeding season (especially in Suisun Bay region) and during the spring and fall migratory periods. More than 30 species of waterfowl are commonly observed in the San Francisco Bay region (Goals Project 2000).

The importance of the estuary for waterfowl has long been recognized. The San Francisco Bay region is identified as a waterfowl habitat area of major concern in the North American Waterfowl Management Plan (NAWMP; U.S. Fish and Wildlife Service 1998). NAWMP is implemented and financed through joint venture partnerships involving federal and state agencies, along with non-government organizations, and the private sector. The San Francisco Bay Joint Venture is one such partnership, playing an active role in conservation throughout the Bay area (Steere and Schaefer 2001).

Because of the long-recognized importance of waterfowl to the mission of the U. S. Fish and Wildlife Service, the “Mid-Winter Waterfowl Surveys” have been conducted by this agency, throughout the United States since 1955, in cooperation with state agencies (Eggeman and Johnson 1989). The biotic indicator used here for the San Francisco Estuary, therefore, is just a subset of the nation-wide effort. The survey attempts to enumerate all waterfowl, by species, for the entire estuary. Survey efforts target three habitats or areas: open bay throughout the estuary; salt ponds in the estuary (San Pablo Bay and South San Francisco Bay); and Suisun Marsh (including Grizzly Island Wildlife Area). The principal objective of the MWW Surveys is to provide information on population trends.

Waterfowl include **dabbling ducks**, which feed at the surface or in shallow water, **diving ducks**, which forage underwater, **swans**, and **geese**, which feed on plants in wetlands and fields. For the “winter waterfowl population indicator” we focus just on the two most abundant (and species-rich) groups of waterfowl, **dabbling ducks** and **diving ducks**. Swans and geese are not currently a primary component of San Francisco Bay waterfowl, with the exception of the Canada Goose which has become a pest species recently. In addition to the four waterfowl groups listed above (dabbling ducks, diving ducks, swans, and geese) the Mid-Winter Waterfowl surveys identify a fifth group: **sea ducks**. We have chosen not to include in this indicator the sea ducks, which are considered a distinct group of waterfowl and have their own joint venture (www.seaduckjv.org). Sea ducks are most commonly found in coastal and off-shore areas of the Bay region. In San Francisco Bay, sea ducks are almost entirely represented by scoters (*Melanitta* spp.; Surf Scoter, Black Scoter, and White-winged Scoter). However, this indicator could be re-calculated to include scoter species as well.

Data Source:

USFWS and CDFG jointly conduct surveys in the San Francisco Estuary in January of each year. Joelle Buffa (USFWS) and Michael Wolder (USWFS) kindly provided the data used here. Data are summarized by survey area and then compiled into regional summaries.

Methods and Calculations:

Surveys are conducted on a single day per survey area per year; sometimes several areas are surveyed in a single day. Surveys are conducted mainly from fixed-wing aircraft, but sometimes from the ground or by boat. Open bay and salt ponds are the target of surveys by USFWS observers throughout the estuary. Survey numbers are summarized by bay region: Suisun Bay, North Bay (San Pablo Bay and the northern portion of San Francisco Bay), Central San Francisco Bay, and South San Francisco Bay. Suisun marsh, including Grizzly Island Wildlife Area, is the target of surveys by CDFG, which also surveys the Delta. Thus, Bayland habitat in the estuary, other than the Suisun region, is not adequately surveyed in the Mid-Winter Waterfowl Survey (Takekawa 2002).

As noted on the USFWS website for Mid-Winter Waterfowl Surveys, "[S]pecific sampling procedures are not defined. Instead, an aerial crew determines the best and most practical means to conduct a complete count of all waterfowl within a predefined unit area." Surveys are not standardized with respect to tide. Weather and other physical conditions during the survey period are noted but analyses do not statistically adjust for weather conditions. Survey effort may be noted, but numbers are not adjusted by effort. In theory, one could convert counts into densities by dividing by the area surveyed, but this has not yet been implemented.

The analysis presented here uses the regional totals in each year, broken out by species, where region is Suisun Bay, North Bay, Central San Francisco Bay, and South San Francisco Bay. Here "Suisun Bay" refers to the open water of the bay. Suisun Marsh is not currently included, but we are working to include these counts in the metric as well. The indicator will be re-analyzed when such data are available. We analyzed changes in the natural log-transformed counts per region and per species in a linear model that included species main effects, similar to the analysis used for combined species Tidal Marsh Bird Population indicator. Dabbling and diving duck species were excluded if the majority of years had zero counts for that species. This left twelve species for analysis: six species of dabblers (American Wigeon, Gadwall, Green-winged Teal, Mallard, Northern Pintail, Northern Shoveler) and six species of diving ducks (Bufflehead, Canvasback, Goldeneye, Redhead, Ruddy Duck, Scaup). The analyses of change over time were carried out separately for dabbling ducks and for diving ducks. The result was an overall estimate of change over time for each waterfowl group (dabblers and divers), while adjusting for differences in abundance among species within a group. The approach used was similar to that used for the "combined-species" index of tidal marsh bird populations (described above, Biotic Condition 1).

We used three methods to evaluate change over time: (1) long-term trends over time, for the period 1989 to 2006 (except 1988 to 2006 for South San Francisco Bay), (2) short-term trends over time, for the most recent 5-year period, which was 2002-2006 (except 2001-2006 for Suisun because surveys were not conducted there in 2005), and (3) comparison of the period 2004-2006 with the 5-year benchmark period, 1989 to 1993 (except 1988 to 1992 for South San Francisco Bay; only South San Francisco Bay had data available for 1988).

Goals, Targets, and Reference Conditions:

The San Francisco Bay Joint Venture (Steere and Schaefer 2001) has determined that values for estimated waterfowl abundance in the period 1988 to 1990 should be used as a baseline for comparison, and furthermore these estimated abundances should also provide goals for individual species. Table W1 provides estimates of the "long-term trends" by waterfowl group since 1988 or 1989, which facilitates evaluation. In addition, survey estimates of current numbers can be compared directly with the earlier period. Because of the high year to year variation in number, primarily due to the fact that the survey is conducted only on a single day, and that some important influences on counts are not statistically controlled for, we feel it most appropriate to use the most recent three-year period (2002-2006) for assessing "current" numbers and the five-year period that includes 1988 to 1990 as the benchmark value.

Results:

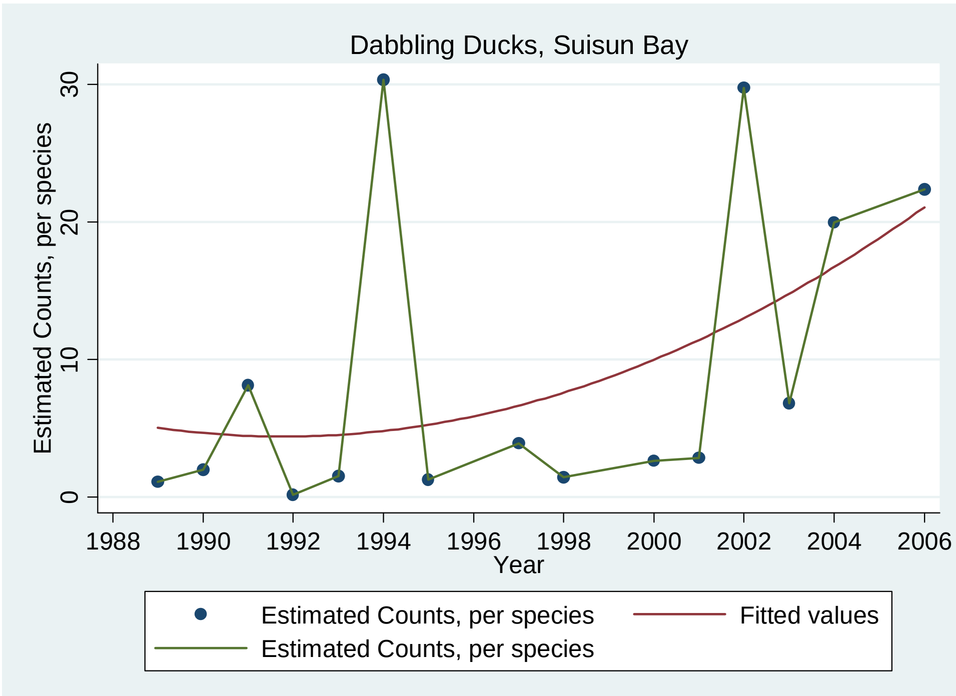
In **Suisun Bay**, dabbling ducks demonstrate an increase, but only in recent years (since 2001; Figure W1 A; Table W1). As a result, their numbers show a significant increase in recent years, compared with the 5-year benchmark period (Table W2). Diving ducks in Suisun Bay demonstrate a weak (non-significant) decline, with an estimated decline of 18.4%/year in the most recent 5 years (Figure W1 B; Table W1). Note that these population changes only refer to numbers as assessed in open water of the Bay. Suisun Marsh data will be added at a later time.

In the **North Bay**, dabbling ducks also demonstrate an increase, over a sustained period of time, 1995 to 2006 (Figure W1 C). However, the most recent 5-year period evidences a decrease, not an increase, for this group. Nevertheless, the result, when comparing the most recent 3-years with the 5-year benchmark is a significant increase (Table W2). Diving ducks, in contrast, have shown an overall decrease, and in the most recent years, this decline is significant (Figure W1 D, Table W1). The result is that counts for the most recent 3-year period are significantly lower for diving ducks in the North Bay compared to the 5-year benchmark period (Table W2).

In the **Central San Francisco Bay**, dabbling duck numbers have been low in every year except 1999. As a result, there are no significant trends or differences for this group, though the tendency has been for decreases in number (Figure W1 E, Tables W1 and W2). Compared to historical numbers, there is likely cause for concern. Diving ducks in this region have demonstrated no significant trends for the long-term or short-term, though since 1999 the trend has clearly been negative (Figure W1 F). That is, a decrease from 1989 to 1997 was followed by an increase from 1997 to 2001, followed by another drop.

In **South San Francisco Bay**, dabbling ducks demonstrate a slight increase overall (Figure W1 G). Numbers in the most recent 3-year period are greater than they were in 1992-1995, and marginally significantly greater in the most recent 3 years compared to the 5-year benchmark period ($P = 0.096$, Table W2). Diving ducks show an increase from 1988 to 2001, resulting in a significant increase over the long-term (Figure W1 H), with a non-significantly higher numbers in the most recent 3 years compared to the benchmark period (Table W2). However, since the peak in 2001-2002, there has been an overall decline, which in the last 5 years is marginally significant ($P = 0.083$).

Figure W1. Population Trends for Waterfowl in San Francisco Estuary, 1988 to 2006. Results are from USFWS Midwinter Waterfowl Surveys. Shown are mean counts per species per year for two groups of waterfowl: Dabbling Ducks (6 species included: American Wigeon, Gadwall, Green-winged Teal, Mallard, Northern Pintail, Northern Shoveler) and Diving Ducks (6 species included: Bufflehead, Canvasback, Goldeneye, Redhead, Ruddy Duck, Scaup). Results shown for Suisun Bay, North Bay, Central San Francisco Bay, and South San Francisco Bay. Analyses controlled for species differences in log-transformed counts. Trend lines are shown as quadratic fits (Figure W1-A) or linear fits (Figure W1-B to W1-H); choice of fit (linear vs. quadratic) determined by maximization of adjusted R^2 (Nur et al. 1999).A)



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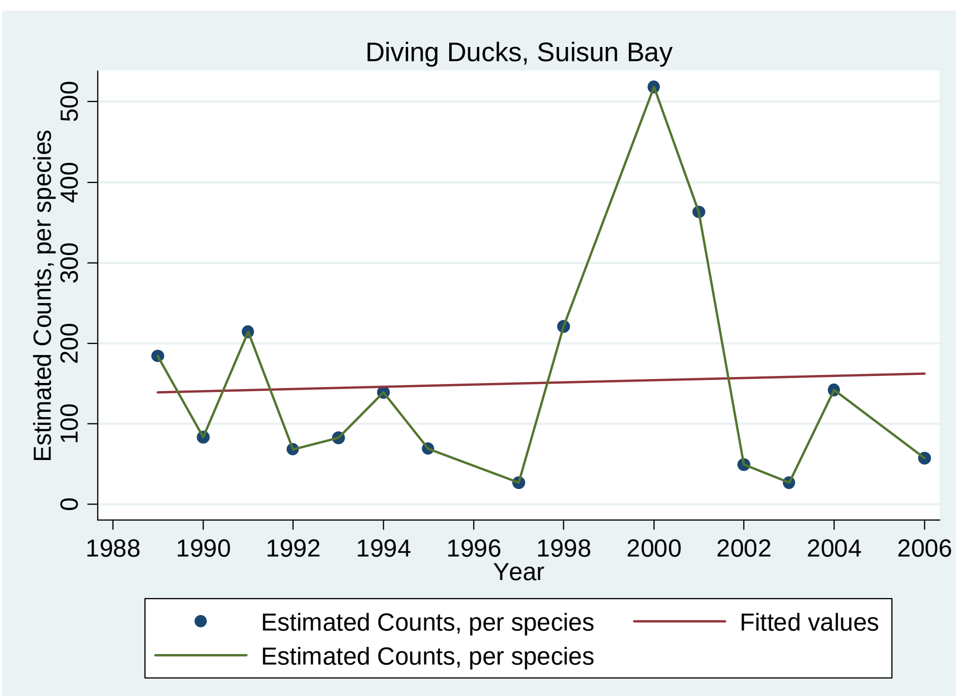
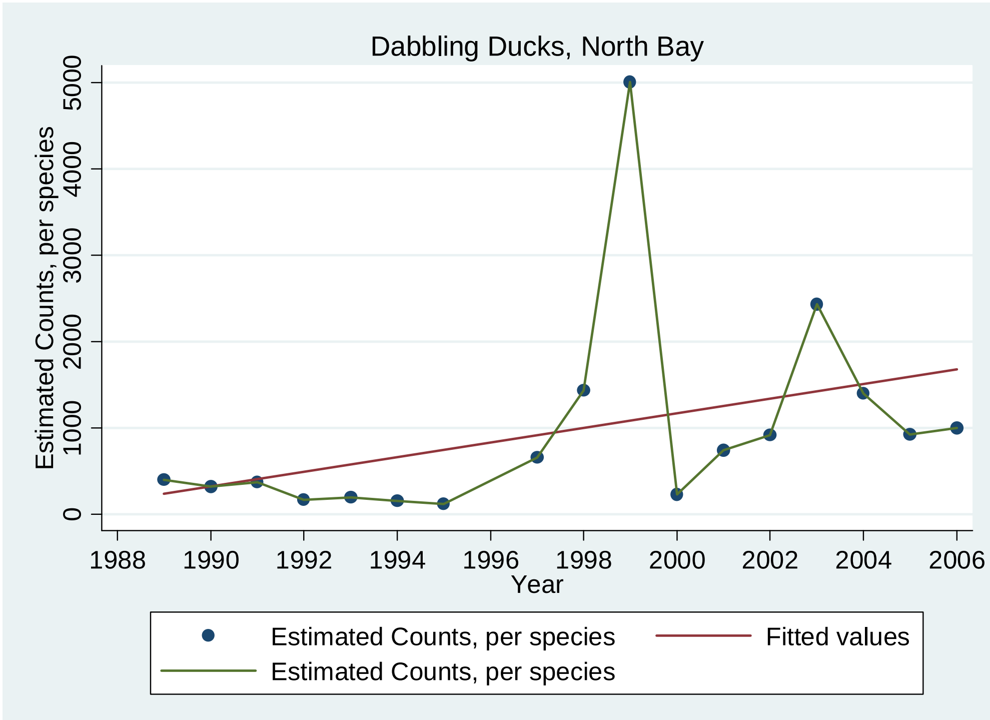
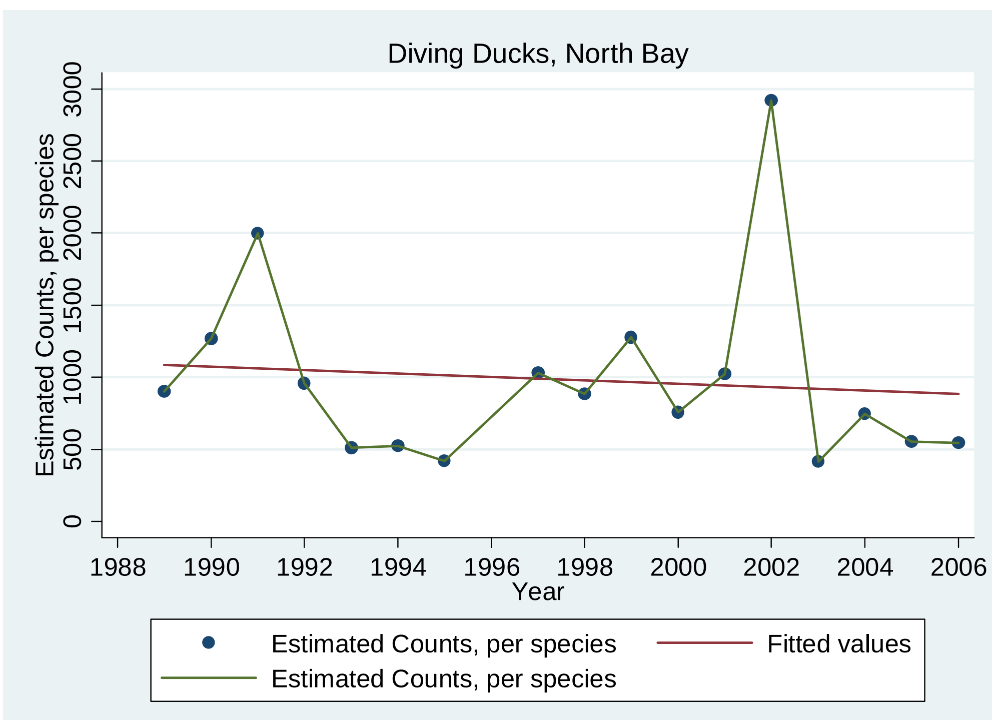


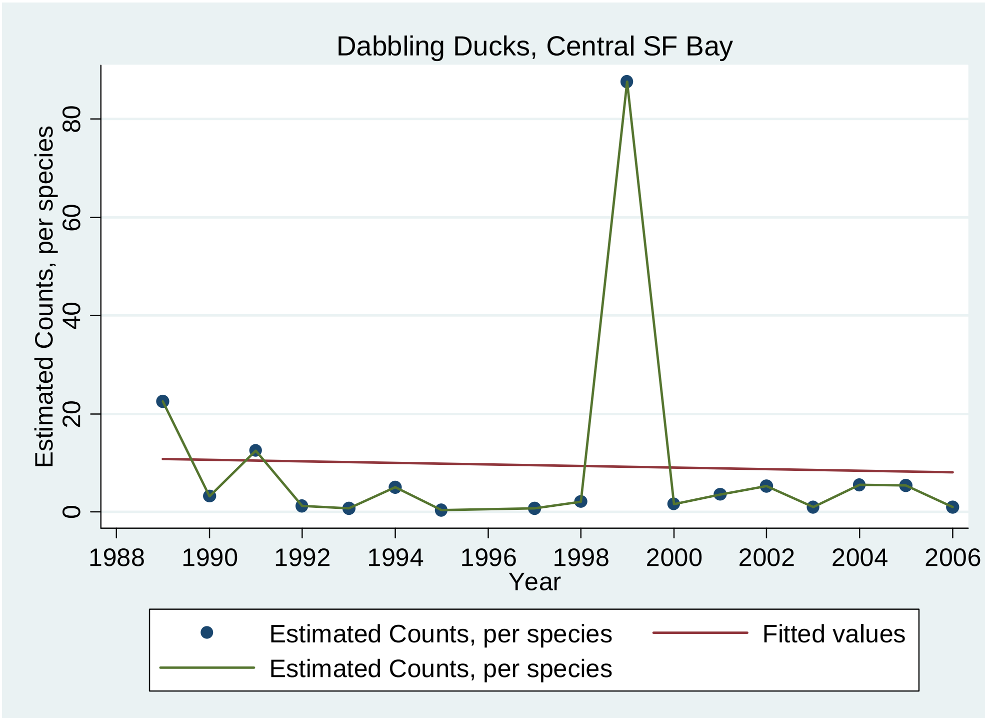
C)


Dabbling Ducks, North Bay
Estimated Counts, per species
0
1000
2000
3000
4000
5000
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

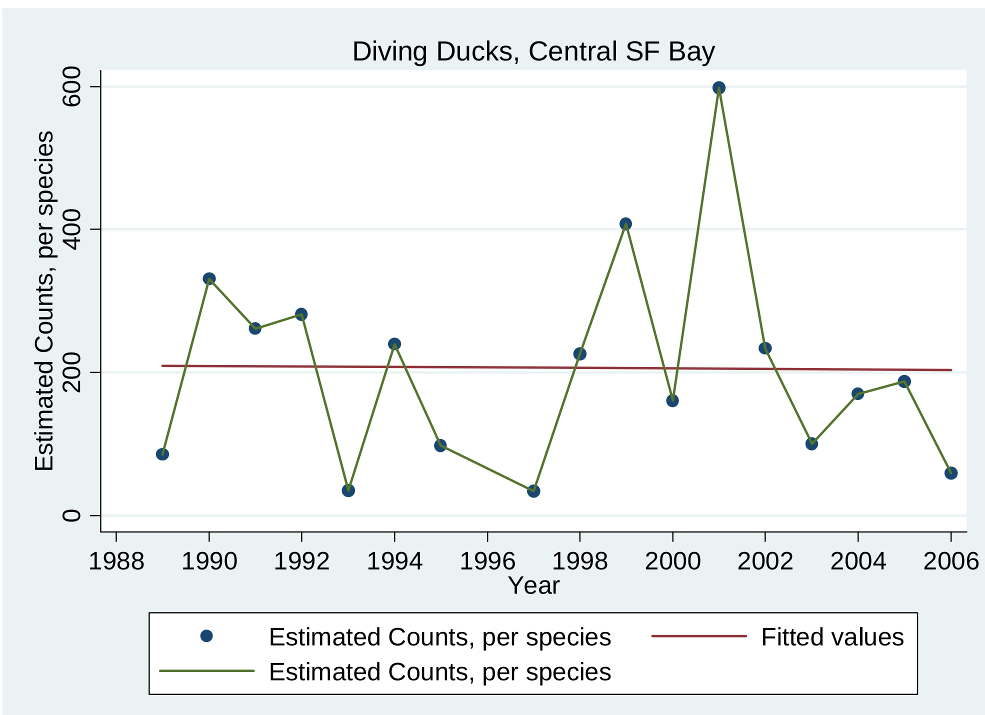
D)


Diving Ducks, North Bay
Estimated Counts, per species
0
500
1000
1500
2000
2500
3000
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

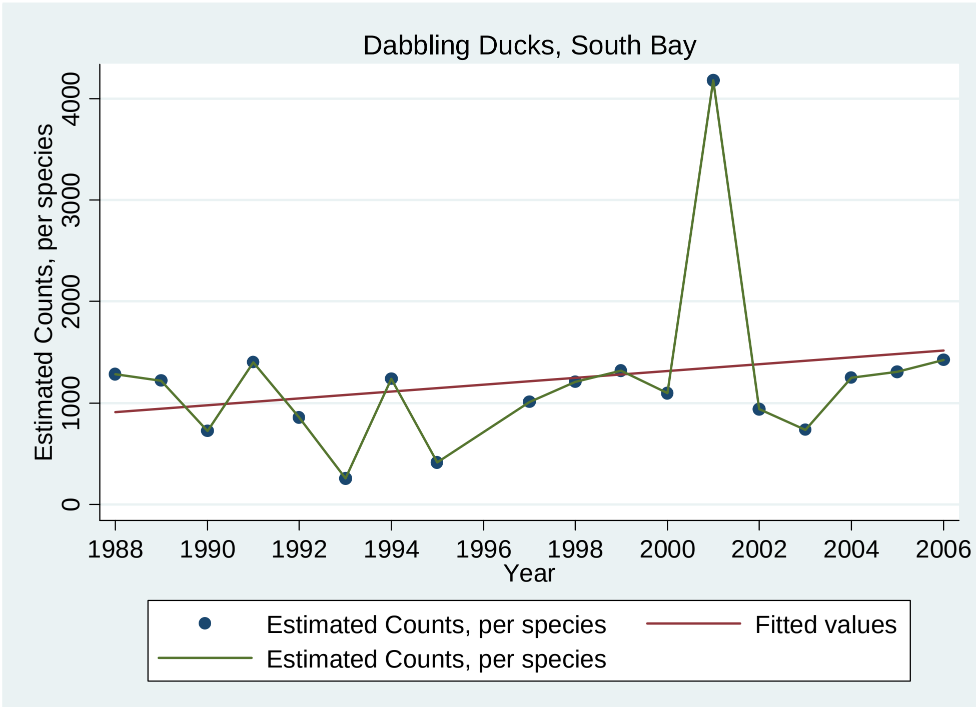
E)


Dabbling Ducks, Central SF Bay
Estimated Counts, per species
0
20
40
60
80
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

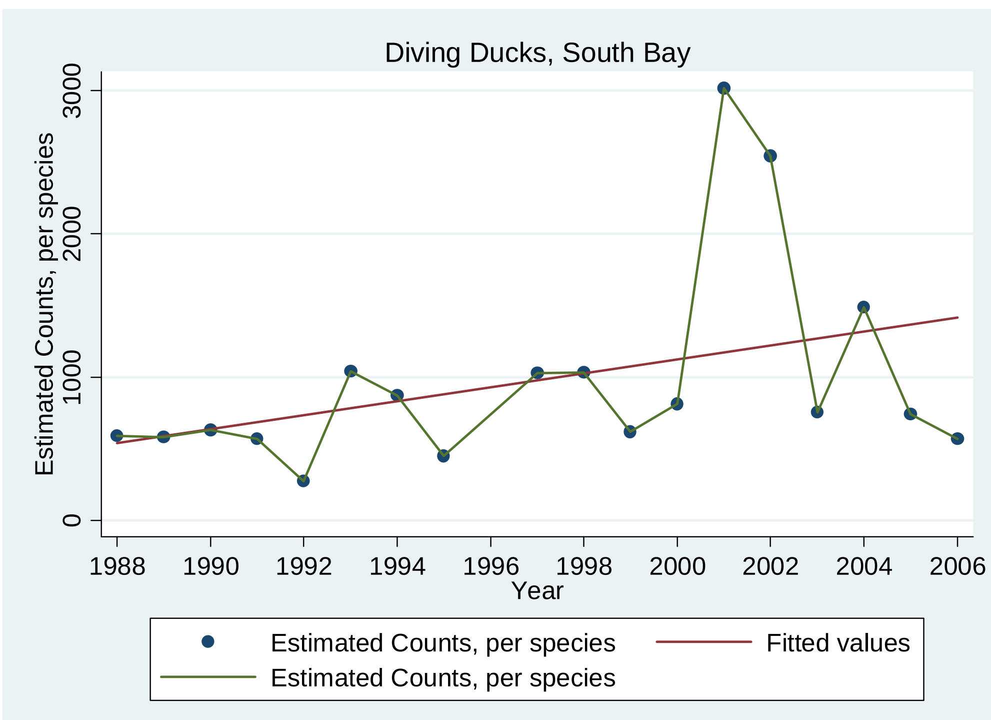
F)


Diving Ducks, Central SF Bay
Estimated Counts, per species
0
200
400
600
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

G)


Dabbling Ducks, South Bay
Estimated Counts, per species
0
1000
2000
3000
4000
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

H)


Diving Ducks, South Bay
Estimated Counts, per species
0
1000
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3000
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

Table W1. San Francisco Estuary Waterfowl: Long-term (1988 or 1989 to 2006) and Short-term (2002 to 2006) trends for two groups of waterfowl. Shown are estimated annual percent changes per year in population index. (Mid-winter waterfowl surveys, USFWS).

		Dabbling Ducks		Diving Ducks	
	number of years	Ann Pct	P-val	Ann Pct	P-val
Suisun Bay					
Long-term	15	11.5%	P = 0.001	-2.04%	P > 0.5
Short-term	5	29.0%	P = 0.19	-18.4%	P > 0.3
North Bay					
Long-term	18	12.5%	P < 0.001	-1.91%	P > 0.3
Short-term	5	-7.63%	P > 0.5	-26.5%	P = 0.033
Central SF Bay					
Long-term	18	-2.44%	P > 0.4	-0.09%	P > 0.9
Short-term	5	-10.3%	P > 0.5	-18.8%	P > 0.2
South SF Bay					
Long-term	19	2.70%	P = 0.14	4.54%	P = 0.037
Short-term	5	15.1%	P > 0.2	-26.0%	P = 0.083

Highlighting indicates significant (P < 0.05) differences (bright yellow) or marginally significant (light yellow; 0.05 ≤ P < 0.10)

Note: Suisun, North Bay, Central SF Bay long-term is for 1989 to 2006; South Bay long-term is for 1988 to 2006. Short-term is 2002 to 2006, except for Suisun Bay, which is 2001 to 2006 (no survey data in 2005)

Table W2. San Francisco Estuary Waterfowl: Comparison of 3-year Current (2004-2006) vs. 5-year Benchmark (1989 to 1993). Shown are percent differences in standardized count index for the two time periods (Mid-winter waterfowl surveys, USFWS).

	Dabbling Ducks		Diving Ducks	
	Percent	P-val	Percent	P-val
Suisun				
Comparison	683%	P < 0.001	-20%	P > 0.5
North Bay				
Comparison	295%	P < 0.001	-41%	P = 0.021
Central SF Bay				
Comparison	-21%	P > 0.6	-17%	P > 0.6
South SF Bay				
Comparison	58%	P = 0.096	49%	P = 0.17

Highlighting indicates significant (P < 0.05) differences (bright yellow) or marginally significant (light yellow; 0.05 ≤ P < 0.10)

Note: South SF Bay benchmark is for 1988 to 1992

Scoters, since they are usually considered sea ducks were not included, but it is interesting to compare their trends to dabblers and divers. There were no significant (P > 0.1) long-term or short-term trends evident for scoters in any region. However, numbers in the most recent 3-year period were lower in the North Bay than they were in the 5-year benchmark period (P = 0.072).

To summarize, the patterns are very different comparing dabbling ducks to diving ducks: Dabbling ducks have increased in Suisun and the North Bay, and there is the suggestion of an increase in the South Bay, too. Diving ducks have decreased in the North Bay and they demonstrate recent, short-term declines in all bay regions, though the declines are not significant in every case. Still, the magnitude of decline for diving ducks is of concern: for each bay region, recent declines exceeded 18% per year between 2002 and 2006. Thus, **CCMP Aquatic Resources Goal 1, to stem and reverse the decline in abundance of estuarine biota, has not been met for diving ducks, but the situation is encouraging for dabbling ducks.** Furthermore, current tidal marsh habitat restoration efforts are likely benefitting dabbling ducks, but not diving ducks, since the former utilize the shallow water habitat found in tidal marshes, but the latter group does not (Stralberg et al. 2009). The discrepancy for the two groups of waterfowl will only be enhanced in the future as more restoration projects come to fruition.

Biotic Condition 4. Marsh Bird Reproductive Success

Background and Rationale:

San Francisco Estuary tidal marsh habitat has been dramatically altered in the past one hundred and sixty years. Approximately 85% of the original tidal marsh habitat in the region has been lost due to creation of salt ponds, conversion to agricultural and industrial/urban use, and water diversion and management (Marshall & Dedrick 1994). The reduction in area, fragmentation of remaining habitat, degradation in habitat quality, and spread of invasive species have all contributed to reductions in the population size and viability of tidal marsh obligate species. Future threats such as climate change will also alter the area and distribution of marshes and may lead to increased risk of mortality due to flooding, as a result of sea level rise and increased frequency of storm surges (Takekawa et al. 2006). For these reasons, many of the species that depend on tidal marsh habitat are currently listed as Federally- or State- threatened or endangered, in particular Clapper Rail and Black Rail, or are of conservation concern (e.g., California Species of Special Concern, Shuford & Gardali 2008). It is for these reasons that the first-listed "Aquatic Resources Goal" of the CCMP is

- "Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction."

The indicator presented here, **Marsh Bird Reproductive Success**, provides for informative assessment of progress in meeting this goal, as well as providing information regarding progress towards the second and third stated goals for Aquatic Resources, i.e.,

- "Restore healthy estuarine habitat to the Bay-Delta" and
- "Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline."

Successful reproduction involves several components, for which we focus on one, **nest survival**. Other components of reproductive success include number of young reared per successful breeding attempt and number of breeding attempts per breeding pair (Chase et al. 2005). Nest survival in avian species is a parameter that is monitored and evaluated on the national and international levels (Greenberg et al. 2006, Jones and Geupel 2007).

Nest survival refers to the probability that a nesting attempt survives to fledge one or more young. Nest survival of tidal marsh **Song Sparrows** reflects two principal mortality pressures: predation on nests and flooding of nests (Greenberg et al. 2006, Nordby et al. 2008). For tidal marsh Song Sparrows, this indicator reflects primarily nest-predation (either predation on eggs or nestlings). Principal predators are birds (especially corvids), mammals (especially raccoons), and snakes. Secondarily, the indicator reflects inundation, and thus flooding due to high tides. Flooding is the second-leading cause of nest failure for tidal marsh Song Sparrows (Greenberg et al. 2006, Nordby et al. 2009).

Between 1996 and 2006, PRBO conducted systematic nest monitoring at up to five sites per year for two regions: San Pablo Bay and Suisun Bay. In addition, there is partial information from San Francisco Bay for 2002 and 2003 (Nordby et al. 2009).

Data Source:

PRBO biologists conducted nest-monitoring in tidal marsh habitat for Song Sparrows at three to five sites in each year, distributed between San Pablo and Suisun Bays, between 1996 and 2006. In 9 out of 11 years, there were at least two sites monitored per bay per year.

Methods and Calculations:

Nest monitoring was conducted following methods outlined in Martin and Geupel (1993) and Liu et al. (2007). At each site, two to four study plots were established. For each breeding pair, nests were intensively searched for and then monitored, from nest discovery to the fledging or failure of a nesting attempt. Nests were usually visited every 2-4 days in order to accurately estimate dates of nest failure, dates of egg laying, hatching of eggs, and fledging of young. The ultimate outcome of each nest (success or failure) was determined based on nest condition and behavior of the breeding pair (Martin and Geupel 1993). For each breeding season, we calculated daily nest survival of a specific site using the Mayfield method (Mayfield 1975). We then converted daily nest survival (calculated separately for each stage of the nesting cycle) into overall survival, from laying of the first egg until fledging following Nur et al. (1999).

Not every site was monitored in every year. Therefore, in order to adjust for site-specific differences in nest survival, which may confound differences among years, we included “site” as a categorical variable to be controlled for, when analyzing sites and years. This “standardization” of nest survival was carried out separately for each region, i.e., for San Pablo Bay sites and Suisun Bay sites. The statistical analysis was similar to that presented for the Tidal Marsh Bird Population Indicator (above). Note: no PRBO monitoring was carried out in Central or South San Francisco Bay (but see Nordby et al. 2009 for two years of results for that region).

Goals, Targets, and Reference Conditions:

This indicator focuses on a single species, the Song Sparrow; specifically, the subspecies that are endemic to tidal marsh habitat (Spautz and Nur 2008a, 2008b). For this indicator, it is possible and desirable to identify an absolute benchmark that will provide insight regarding success at meeting the first stated goal, “restoring healthy natural reproduction” for this species. On the basis of demographic modeling of this species, drawing on PRBO studies and the literature, it appears that a stable population of tidal marsh Song Sparrows requires nest survival probability of 20% or greater, and more likely 25% or greater, to achieve “source” status rather than “sink” status (Nur et al. 2007), where “source” refers to a population which can sustain itself without net immigration (Nur and Sydeman 1999). There is some uncertainty here, due to uncertainty with regard to other demographic parameter value. Our best estimate is 22 to 25%, but, we recognize that values as low as 20% may be sufficient.

Results:

Nest survival probabilities, standardized for site-to-site variation are shown for San Pablo Bay and Suisun Song Sparrows (Fig T-2). In 7 years out of 11, Suisun values were below 15%. This is a serious concern, given that at least 20% survival probability is needed for sustainability of the population. For San Pablo, the situation is less grave: only 3 out of 10 years were below 15%, but, nevertheless, in 7 years out of 11, nest survival was below 20%. A key point of this analysis is that absolute values are meaningful and not just the trend. The longer-term trend (1996 to 2006) is for nest survival to demonstrate a weak negative trend (5.5% decline per year, P = 0.093) for San Pablo Song Sparrows, and a slight increase (6.6% per year, P > 0.1) for Suisun Song Sparrows.

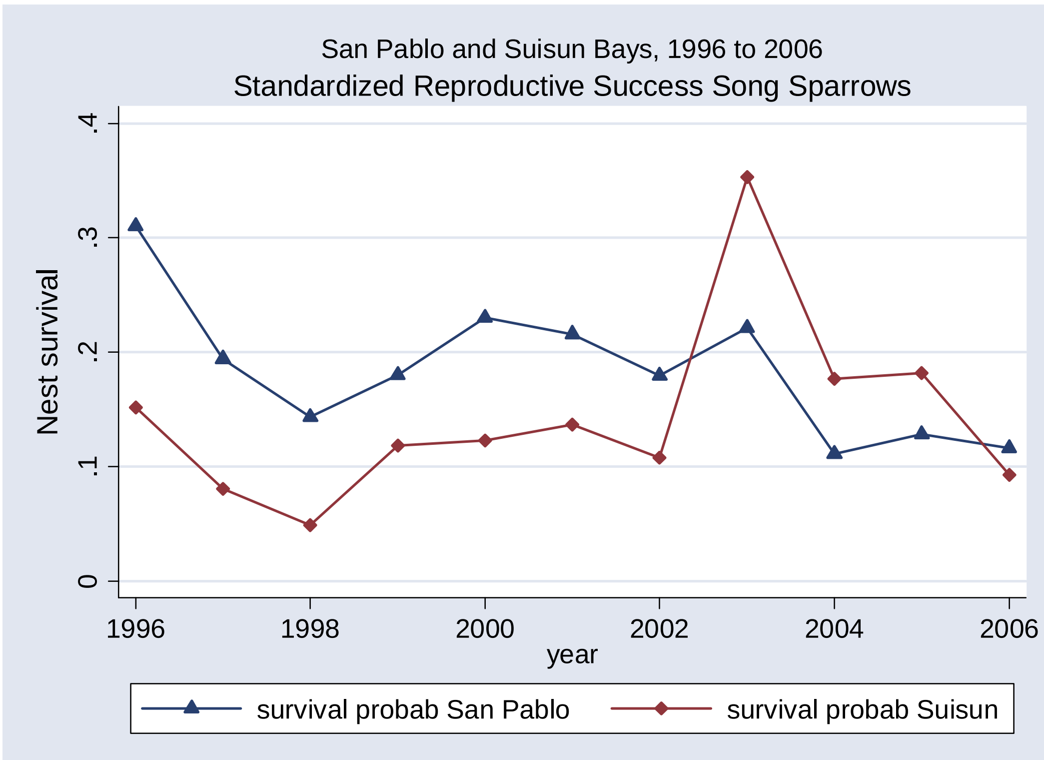

Figure T-2. Nest survival (standardized, see text) for San Pablo and Suisun Song Sparrows (based on PRBO unpublished studies; Liu et al. 2007).

Reproductive Success in tidal marsh songbirds appears to be insufficient to maintain population levels. Substantial improvement is needed to meet the goal of "restoring healthy natural reproduction." Suisun Song Sparrows have shown a slight increase in nest survival, between 1996 and 2006, but nevertheless in every year except one, nest survival was below the 20% threshold. Low reproductive success may account for the decline in Suisun Song Sparrow population density observed since 2000 (see Biotic Condition 1, above). San Pablo Song Sparrow nest survival rates are closer to meeting the minimum threshold of 20%, but at the same time this subspecies has demonstrated an apparent decline in nest survival, especially since 2000.

The Alameda subspecies of tidal-marsh Song Sparrow appears to have low nest survival rates as well (Nordby et al. 2009), though no trend information is available.

The causes of low nest survival probability are likely two-fold: high levels of predation on nests and nest failure due to flooding (i.e., tidal inundation; Greenberg et al. 2006, Nordby et al. 2009). Nest-predators are not well identified for tidal marsh Song Sparrows (Spautz and Nur 2008a, Spautz and Nur 2008b), but certainly include non-native predators, such as feral cats (*Felix catus*), red fox (*Vulpes fulva*), and Norway rats (*Rattus norvegicus*), as well as native predators, such as corvids (American Crow [*Corvus brachyrynchos*] and Common Raven [*Corvus corax*]) that thrive in proximity to humans.

Nordby et al. (2009) also identified a specific threat associated with the invasive cordgrass, *Spartina alterniflora* and its hybrids: nests in this type of plant were more likely to fail due to flooding, possibly because of the low elevation of the invasive *Spartina*, relative to high tides.

Biotic Condition 5. Heron and Egret Nest Survival Indicator

Background and Rationale:
Audubon Canyon Ranch has monitored the survival of focal Great Blue Heron and Great Egret nests (proportion of nests that fledge at least one young) across nesting colonies throughout the northern San Francisco Estuary, annually, since 1994 (Kelly et al. 2007). (Here we use "nest survival" as a term that also encompasses "nest survivorship"; the latter refers to the proportion of nests that survive from initiation to a specified point in time, whereas the former can refer to the probability of survival during any relevant time period. An extensive literature has developed regarding nest survival and its analysis, see Jones and Geupel 2007.)
The conspicuousness of heron and egret nesting colonies and the visibility of nests facilitates the monitoring of nesting activity and the use of nest survival as an effective index of overall nest success. This indicator is sensitive to nest predation and colony disturbance by native and introduced nest predators (especially by human commensal species such as raccoons and ravens), land development and human activity near heronries, and severe weather (Pratt and Winkler 1985, Frederick and Spalding 1994, Kelly et al. 2005 and 2007). Such ecological processes can vary over space and time in response to landscape patterns of habitat change, dynamics of predator populations, and changes in human land use, and are therefore likely to differentially affect nesting colonies of herons and egrets. Note that heron and egret nest survival is not a particularly strong indicator of food availability. Rather, food availability (and more generally, the food web) for piscivorous birds is reflected in the "Heron and Egret Brood Size Indicator", see Ecological Processes Indicator 1, below.

Data Source:
The Heron and Egret Nest Survival Indicator was calculated using data from ongoing regional heron and egret studies by Audubon Canyon Ranch (Kelly 1993, 2007). The data, which reflect the survival of focal nests followed through the entire nesting cycle on repeated visits to colony sites throughout the northern San Francisco Estuary, provide an effective index of regional and subregional nest success.

Methods and Calculations:

The Heron and Egret Nest Survival Indicator, calculated as the apparent nest success of Great Egrets and Great Blue Herons, is based on the proportion of focal nests that remain active through the nesting cycle, from nest initiation or early in the incubation period, at 40-50 colony sites within 10 km of the historic tidal wetland boundary (ca.1770–1820; San Francisco Estuary Institute 1999; Figure H1). Great Egret and Great Blue Heron nests are considered successful if at least one young survives to minimum fledging age of seven or eight weeks, respectively (Pratt 1970, Pratt and Winkler 1985). Nest are sampled I approximate proportion to colony size. In colonies with fewer than 15 active nests, all nests initiated before the colony reaches peak nest abundance are treated as focal nests. At larger colonies, random samples of at least 10-15 focal nests are selected. Nest survival is calculated as the geometric mean, between species, of percent deviation of the proportion of focal nests that are successful from average nest survival during a five year reference period (1995-1998).

Goals, Targets and Reference Conditions:

CCMP goals to "restore" and "enhance" the ecological productivity and habitat values of wetlands are non-quantitative. However, the use of time series back to 1994, allows the specification of appropriate quantitative reference conditions. Differences or trends in nest survival can be quantified and used for assessment.

Maintenance of current resource levels

- Target: current 3-year mean (2006-2008) ≥ 5-year reference mean (1994-1998)

Enhancement of resources with wetland restoration

- Target: *current* 3-year mean (2006-2008) ≥ highest 5-year *subregional* reference mean (1994-1998).

Results: Results of the Heron and Egret Nest Survival are shown in Figure H3.

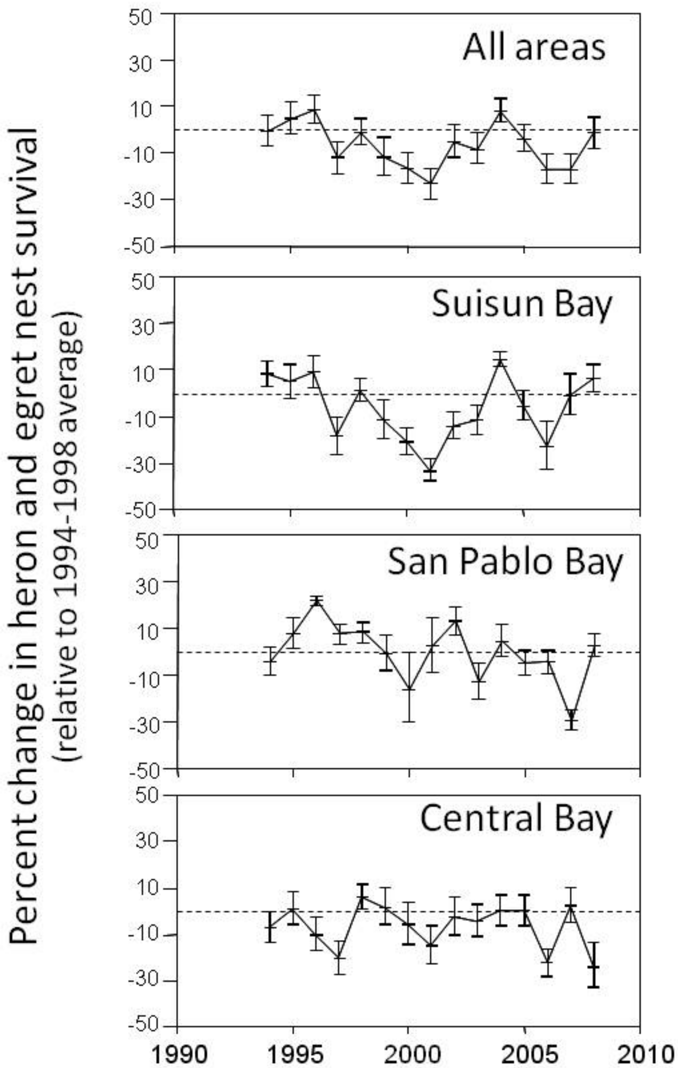

Figure H3. Annual percent change in heron and egret nest survival, 1994-2008, relative to the average nest survival (dashed line), 1994-1998, in the northern San Francisco Estuary.

Recent rates of nest survival (2006-2008) were generally lower than reference levels (1994-1998).

A marginally significant regional decline in nest survival (12.7%, $t_{272} = 1.97$, $P = 0.05$) reflected primarily a 16.8% decline in the survival of Great Egret nests. Within subregions, overall nest survival was significantly lower than the 1994-1998 regional level only in San Pablo Bay, which was lower, primarily because of an 18.1% decline in the survival in Great Egret nests ($t_{445} = 2.3$, $P < 0.02$; Figure H3). However, in the Central Bay, Great Blue Heron nest survival was 21.6%

lower ($t_{75} = 2.6$, $P < 0.05$) than in reference period and, in Suisun Bay, survival of Great Egret nests was 27.5% lower ($t_{146} = 4.1$, $P < 0.001$). Reference nest success rates (1994-1998) are 80.5% for Great Blue Heron and 81.8% for Great Egret.

Nest Survival differs among subregions, with differential ranking between species.
The Nest Survival Indicator differed significantly among subregions ($F_{2, 817} = 3.6$, $P < 0.05$). Suisun Bay exhibited significantly higher Great Blue Heron nest survival (10.0% increase over the regional reference level) and significantly lower Great Egret nest survival (32.0% decline) than other subregions (multiple comparisons, $P < 0.05$).

Based on the survival of Great Blue Heron and Great Egret nests, CCMP goals of restoring or enhancing wetland productivity and associated wetland habitat values have not been met in the region, although evidence suggests some subregional enhancement in nest survival.
Recent survival rates of Great Blue Heron and Great Egret nests are generally lower than rates measured during the 1994-1998 reference period. However, possible enhancement of Great Blue Heron nest success was suggested by the results for Suisun Bay. Differences in the survival of heron and egret nests among the subregions suggest that breeding performance in these species may contribute to informed comparisons of biotic condition among regions within the San Francisco Estuary.

Ecological Processes 1. Heron and Egret Brood Size

Background and Rationale:
Audubon Canyon Ranch has monitored brood size, prior to fledging, in Great Blue Heron and Great Egret nests across all known nesting colonies (40-50 sites) in the northern San Francisco Estuary, annually, since 1991. The number of young produced in successful heron and egret nests depends on the number of young hatched in the nest and the extent of subsequent brood reduction (i.e., mortality of nestlings during the brood-rearing period). Both parameters (young hatched per nest and survival of those young), reflect the amount of suitable foraging habitat, or supply or availability of prey, in surrounding wetlands, especially that which is needed to provision nestlings with food (Frederick 2002, Kushlan and Hancock 2005). The Heron and Egret Brood Size Indicator is sensitive to changes in the extent and quality of foraging habitat, and is likely to be influenced by changes in land-use, hydrology (especially water circulation and depth), geomorphology, environmental contamination, vegetation characteristics, and the availability of suitable prey (Kushlan 2000). The two target species reflect differences in feeding habitat preference: Great Egrets preferentially forage in small ponds in emergent wetlands and areas with shallow, fluctuating water depths for foraging. In contrast, Great Blue Herons forage along the edges of larger bodies of water and creeks and are less sensitive to water depth (Custer and Galli 2002, Gawlik 2002). Previous work in the northern San Francisco Estuary demonstrated that prefledging brood size in herons and egrets is influenced by the extent of wetland habitat types as far as 10 km from nest sites (Kelly et al. 2008). Thus, this indicator reflects wetland condition over large spatial scales. The conspicuousness of heron and egret nesting colonies and the visibility of nests and broods—especially when nestlings are too young

to leave the nests but old enough to have survived the period when most brood size reduction occurs—facilitates the use of brood size as an effective index of breeding productivity.

Data Source:
The Heron and Egret Brood Size Indicator was calculated using data from ongoing regional heron and egret studies by Audubon Canyon Ranch (Kelly et al. 1993, 2007). The data, which reflect brood size in successful nests at all known colony sites, provide an effective index of regional and subregional heron and egret productivity.

Methods and Calculations:
The Heron and Egret Brood Size Indicator includes metrics calculated for Great Egrets and Great Blue Herons. It is based on the number of young in completely visible nests when Great Blue Heron nestlings are known to be 5-8 weeks old and Great Egrets are known to be 5-7 weeks old (Pratt 1970, Pratt and Winkler 1985). The indicator measures changes or differences in brood size prior to fledging among nests that successfully fledge one or more young. Brood size counts are sampled in approximate proportion to colony size and averaged annually (1991-2008) among nests within and across the three major subregions of northern San Francisco Bay (Central San Francisco Bay, San Pablo Bay, and Suisun Bay). Brood size estimates are based on observations at most of the 40-50 colony sites within foraging range (i.e., 10 km) of the historic tidal wetland boundary (ca.1770–1820; San Francisco Estuary Institute 1999; Figure H1). The Brood Size Indicator is calculated as the geometric mean, calculated between species, of percent deviation of prefledging brood size (number of young produced in successful nests), when compared with the 1991-1995 average (Great Blue Heron: 2.01±0.088 young; Great Egret: 2.26±0.107 young, weighted equally across years).

Goals, Targets and Reference Conditions:
CCMP goals to "restore" and "enhance" the ecological productivity and habitat values of wetlands are non-quantitative. However, the use of time series back to 1991 allows the specification of appropriate quantitative reference conditions. Differences or trends in nest density can be quantified and used for assessment.

<u>Maintenance of current resource levels</u>
- Target: current 3-year mean (2006-2008) ≥ 5-year reference mean (1991-1995).

<u>Enhancement of resources with wetland restoration</u>
- Target: current 3-year mean (2006-2008) ≥ highest 5-year *subregional* reference mean (1991-1995)

Results:
Results of the Heron and Egret Brood Size Indicator are shown in Figure H4.

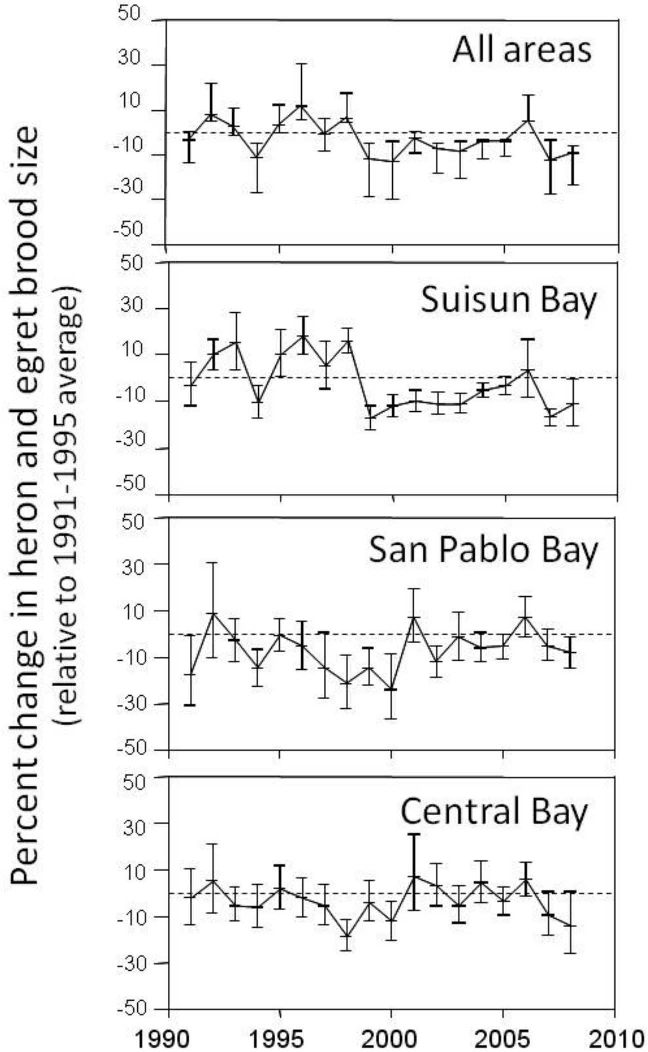

Figure H4. Annual percent change in heron and egret brood size, 1991-2008, relative to the average brood size (dashed line), 1991-1995, in the northern San Francisco Estuary.

Current brood sizes (2006-2008) declined from reference levels (1991-1995).

Brood sizes in the northern San Francisco Estuary declined significantly in 2006-2008, relative to 1991-1995 reference levels (t_{745} = -9.9, $P < 0.001$; Figure H4), with 8.4% and 17.1% fewer young produced in successful Great Blue Heron and Great Egret nests, respectively. Therefore, the proposed target associated with overall resource enhancement was also not achieved: regional productivity per nest was significantly less (t_{570} = 5.1, $P < 0.001$) than the highest subregional 1991-1995 level (Suisun Bay, 4.6% above regional reference value).

Changes in brood size differ among subregions.
During the 1991-1995 reference period, brood sizes were significantly smaller in San Pablo Bay than in other subregions (multiple comparisons, $P < 0.001$). In recent years (2006-2008), the Brood Size Indicator revealed significantly smaller broods in Suisun Bay than in other subregions ($P < 0.02$), suggesting a shift in relative per capita productivity among subregions (Figure H4). In addition, brood sizes in Suisun Bay in 2006-2008 were significantly smaller than the regional 1991-1995 average ($t_{353} = -8.3$, $P < 0.001$), with nests producing 14% fewer Great Blue Heron young and 19% fewer Great Egret young. The productivity of nests in San Pablo Bay in the recent years was also significantly lower than in the reference period ($t_{273} = -3.7$, $P < 0.001$), with average declines of 5.2% in Great Blue Herons and 10.5% in Great Egrets. In the Central Bay, the productivity of Great Egret nests declined by 13.8% ($t_{56} = 3.8$, $P < 0.001$) relative to reference levels, but the productivity in Great Blue Heron nests was apparently stable ($P > 0.05$).

Based on brood size estimates for Great Blue Heron and Great Egret, CCMP goals of restoring or enhancing wetland productivity and associated wetland habitat values have not been met in the region or within any subregion.
Recent productivity in successful nests of both species declined by 8-17% relative to the 1991-1995 reference period, with declines generally observed across the subregions. Subregional differences in productivity suggest opportunities for habitat restoration or enhancement, especially in Suisun Bay.

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