California Clapper Rail (*Rallus longirostris obsoletus*) Population monitoring: 2005-2011

Final Technical Report

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Executive Summary

- In 2005, PRBO Conservation Science led a multi-partner effort to develop standardized survey protocols and determine population size and trends for the endangered California Clapper Rail in the San Francisco Bay Estuary. Partners contributing to the standardized protocol dataset included the U. S. Fish and Wildlife Service, California Department of Fish and Game, California Coastal Conservancy's San Francisco Estuary Invasive *Spartina* Project, Avocet Research Associates, and East Bay Regional Park District.

- Data were collected from 212 marsh sites throughout the San Francisco Bay Estuary from 2005 through 2011 using standardized point count protocols to assess abundance and distribution and the relationship to habitat and landscape features.

- Data were analyzed using imperfect detection models or "zero-inflated models" that assume that some visits with no detections are in fact false zeroes meaning an individual was present but not detected. Failure to account for excess zeroes in the dataset can result in underestimates of true abundance. By correcting for imperfect detection, the statistical models can overcome an important bias affecting estimates of rail abundance.

- The California Clapper Rail population was relatively stable in 2005-2007, declined significantly in 2008 (51%), which was followed by low but relatively stable densities in 2009-2011. The decline in the South Bay (south of the San Francisco-Oakland Bay Bridge) was steeper and densities lower than in the North Bay during the period 2008-2011.

- The California Clapper Rail range-wide population size was estimated at 1,167 individuals (range 954 to 1426) during 2009–2011. This estimate was developed by combining the site-specific densities from surveyed sites with predicted densities from unsurveyed areas using a statistical model that incorporated 15 key physical predictor variables that characterized marsh habitat and landscape condition in relation to Clapper Rail density. By accounting for fine-scale variation in habitat conditions relevant to Clapper Rails, this method represents a significant improvement over previous population estimates that simply applied average densities to total marsh area.

- Marsh complexes with the highest densities identified by our models were found along the western shores of San Pablo Bay from China Camp to Petaluma River and Corte Madera area. Marsh complexes in the South Bay with relatively high densities included East Palo Alto-Guadalupe Slough and Bair-Greco-Ravenswood.

- Time of season and time of day were the most important factors affecting Clapper Rail probability of detection. The effect of Julian day on probability of detection was quadratic with detectability peaking mid-February. Clapper Rail probability of detection peaked about 25 minutes before sunrise and 25 minutes after sunset; the peaks are within the survey protocol window of 1 hour before and 1 hour after sunrise or sunset.

- Salinity and Invasive *Spartina* cover (up to 14%) had significant positive effects on density.

- Larger and more compact (i.e., low perimeter-area ratios) marshes supported higher densities of Clapper Rails, with rapid increases in density up to about 50 ha and little increase beyond 100 ha. All else being equal, acquisition choices and restoration design should strive for more compact marshes over those with high perimeter-area ratios such as linear strips of marsh.

- Clapper Rail density increased dramatically in response to tidal marsh restoration (e.g., levee breaching to restore tidal flows) but the increase typically began only after 17-20 years on average post breaching.

- At the landscape level, channel density was the most important feature favoring high Clapper Rail density and demonstrated a peak at around 75 m of channel length (excludes first order and small channels) per hectare of marsh.

- Managing for a mixture of elevation-based marsh types (low-, mid-, and high-marsh) will benefit Clapper Rail whose densities peaked at sites with 5-10% low-marsh, 30-60% mid-marsh and 5-10% high marsh.

- We recommend:

    - Annual monitoring, using the standard Type A protocol to continue at a minimum of 45 to 60 sites per year in order to analyze effects of changes in vegetation (such as invasive *Spartina* control) on Clapper Rails, determine rate of changes in occupancy (local extirpation and re-colonization), and to evaluate marsh restoration outcomes.

    - Implementing a Clapper Rail nest monitoring program to determine population health and how best to increase and maintain it. PRBO results show that population viability is sensitive to differences in nest survival.

    - Developing a more effective Clapper Rail monitoring program by continuing to test the National Marshbird Survey protocol (www.waterbirdconservation.org/marshmonitoring.html). The National protocol is similar to the SF Bay protocol but involves consistent broadcast of vocalizations for multiple rail species at each point. Before adopting the National protocol, an additional two years of testing is necessary to compare abundance estimates from the SF Bay protocol with the National protocol. Rigorous and thorough testing is needed to ensure the 8-year SF Bay protocol dataset can be used in conjunction with the data from the National protocol to assess long-term population trends and the effects of important landscape changes affecting rails (e.g., invasive *Spartina* control and restoration).

Introduction

The California Clapper Rail (*Rallus longirostris obsoletus*) is one of three subspecies of Clapper Rail recognized by the American Ornithologist's Union (AOU 1957) and is state- and federally-listed as an endangered species. It occurs solely in tidal marsh habitat and previously was found in California coastal estuaries from Humboldt Bay to Morro Bay, but presently is restricted to the San Francisco Bay Estuary (hereafter Estuary; Goals Project 2000). Historically, the California Clapper Rail, hereafter Clapper Rail or CCR, is thought to have been abundant in the Estuary, as "thousands" were reported to have been killed in a single day in 1859 for consumption in San Francisco and Sierra goldfields (Wilbur and Tomlinson 1976). Market hunting was arrested in 1913 and Clapper Rails began re-colonizing marshes in the first half of the 20th century but were found only in San Pablo Bay and San Francisco Bay (Grinnell and Miller 1944).

Tidal marsh in the Estuary has decreased 79% from its historical extent, due to widespread conversion to managed marsh, agriculture, and salt ponds between the mid-1800s and the curtailment of bay filling in the 1970s (Goals Project 1999). The Bay marsh habitat loss and sustained hunting took a severe toll on CCR populations. At the time of the federal listing of the Clapper Rail as an endangered species in 1970, the total Clapper Rail population in the Estuary was estimated at 4,200-6,000 birds (Gill 1979, Collins et al. 1994). Based on surveys from the mid-80s, the total population was placed at 1,200 to 1,500 individuals (cited in Albertson and Evens 2000). Predation by introduced red foxes (*Vulpes vulpes*) was suspected as the cause for the precipitous population decline in the late 1980s and in 1988 the total population was estimated to be only 700 individuals and in 1990-91 the total estimate dropped further to 300-500 (cited in Albertson and Evens 2000). Ongoing red fox control since then has been credited with the reversal of the population decline and limited rebound (Harding et al. 2001); in the mid- to late-90s the population was estimated to have increased to 1,040 to 1,264 individuals (Albertson and Evens 2000). It is not clear how much certainty can be placed on any of these estimates, as the methodologies differ greatly. Nevertheless, the estimates and opinion of the researchers associated with these studies point to a strong decline in the late 80's with some recovery thereafter.

Invasion by the non-native smooth cordgrass (*Spartina alterniflora*) and the subsequent proliferation of the invasive cordgrass hybrid (*Spartina foliosa x alterniflora*), hereafter invasive *Spartina*, may also have contributed to an increase in Clapper Rail population (Evens et al. 2010). The invasive *Spartina*, at least in its early stages of invasion of a marsh, may provide nest substrate and/or increased cover from predators for the rail, especially in habitat that is otherwise of poor quality for Clapper Rail.

Despite endangered species listing, the Clapper Rail is still negatively impacted by ongoing threats such as pollutants, human disturbance, and predation by non-native and human-associated predators (Schwarzbach et al. 2006, Nur et al. 2012). However, to date the effect of these impacts on rail populations has not been well studied. Habitat alteration, such as the spread and subsequent efforts to control invasive *Spartina*, is also thought to affect the rail's Estuary-wide population.

Climate change is expected to have a multitude of impacts on habitats and wildlife in the next 100 years (Stenseth and Mysterud 2002), particularly affecting coastal and estuarine wetlands due to sea-level rise and the potential for increases in the frequency and severity of storm surges and similar events (Michener et al. 1997, Day et al. 2008, Vermeer and Rahmstorf 2009). In addition, salinity, precipitation and run-off are expected to change in the foreseeable future (Knowles et al. 2006, Day et al. 2008), altering plant species composition in CCR habitats, in particular the availability of food, nesting vegetation and shelter from predators. Thus, climate change impacts can exacerbate challenges already faced by CCR and such impacts can mean the difference between the sustainability of populations, on the one hand, and extirpation and loss of ecological function by this ecosystem, on the other. A single, severe storm or flooding event during the breeding season can cripple that year's reproduction (van de Pol et al. 2010, Bayard and Elphick 2011). Similarly, during the winter, an especially high tide will lead to flooding of key roosting or foraging habitat of tidal marsh species, making them vulnerable to predators (e.g., herons and egrets) unless high-tide refugia are available (Evens and Page 1986).

Our limited understanding of the nature and magnitude of the effect of these factors, and the small population size, characterized by apparently high annual variation (Liu et al. 2009), dictates extensive monitoring of CCR populations to ensure timely actions can be taken to preserve and restore the species. Detailed studies are urgently needed to understand and assess current threats, in order to aid effectively in the recovery of the species in the short term. Long-term recovery plans will need to consider the negative effects of sea-level rise on the salt marshes in the Bay (Stralberg et al. 2011; Parker et al. 2011; Galbraith et al. 2002, Veloz et al. 2012), which eventually may translate into further habitat loss for the species.

Assessing the population status of Clapper Rails is made difficult by their secretive behavior and variable vocalizations. Their secrecy, as with many marsh birds, results in a low probability of detection (Conway and Gibbs 2011). In some cases no detections means an absence of rails, but in other cases, rails may be present but were not detected (e.g., because they did not vocalize). If improperly accounted for, these false zeroes may be incorrectly considered as rail absences, thereby biasing population estimates. This has led to the proposal, development and use of various non-standard methods to survey CCR. Thus, to date CCR surveys have been conducted using distinct methodologies. As a consequence, summarizing decades of surveys and quantitatively assessing long-term trends is difficult due to the spatial and temporal variation in survey effort and variation in the methods used to collect and store data. Therefore one objective of this study is to compare, as much as possible, population estimates during the 1990's with the most recent survey efforts.

In 2005 PRBO initiated a multi-partner CCR monitoring program for the entire Estuary and established standardized marsh bird survey protocols. From surveys conducted in 2005 to 2008, we obtained the first statistically rigorous population estimate for the 79 sites surveyed throughout the Estuary. The estimated average number of Clapper Rails at surveyed sites in the period 2005-2008 was 1,425 individuals, with a significant decline indicated between 2007 and 2008 (Liu et al. 2009).

The goals of this study were to:

- Assess the current population size and trends of the Clapper Rail from 2005 to 2011 within the Estuary and regionally;
- Compare current distribution and abundance with 1992-1993 surveys to identify populations trends within and among marshes as well as regionally
- Examine and better understand the annual and spatial variability in abundance estimates;
- Identify habitat and landscape predictors of rail presence and abundance; and
- Provide recommendations for implementation of long-term monitoring.

The CCR data analyzed in this report were collected under standardized protocols from 2005 to 2011 by PRBO Conservation Science (PRBO) and California Department of Fish and Game (CDFG), in collaboration with Avocet Research Associates (ARA), the California Coastal Conservancy's San Francisco Estuary Invasive *Spartina* Project (ISP), U.S. Fish and Wildlife Service (USFWS), and East Bay Regional Park District (EBRPD).

Our study is particularly important at this juncture for at least three reasons. First, invasive *Spartina* has spread widely to marshes in the Bay (Ayres et al 2010; Hogle 2011). Although at the initial stages of the invasion the invasive *Spartina* may have created habitat favorable to the CCR, the overall long-term impact on rail populations is unknown and a reason for concern, and it poses a threat to other marsh plants and wildlife (Stralberg et al 2010, Evens et al 2010, Christiansen et al 2010, Nordby et al. 2009). An invasive *Spartina* removal program was begun in 2004 which itself represents a potential short-term threat to CCR populations. Reliable trend data for CCR may help elucidate the impact of the invasive *Spartina*, and treatments for its removal, on CCR.

Second, several government and non-government organizations around the Bay began assessments of long-term impact of sea-level rise (Veloz et al. 2012, Nur et al. 2012, Knowles 2009). Plans to mitigate the impact of climate change have been developed or completed, in order to propose actions and prioritize marsh restoration. It is important to understand how such actions may affect CCR Estuary-wide. A better understanding of the habitat variables favorable to CCR will help assess the impact of sea-level rise and marsh management actions on the species.

Third, nation-wide efforts to better monitor secretive marsh birds are now being pursued (Conway 2011), including proposed new standard methodologies. CDFG and the USFWS, both government institutions mandated to preserve the species, may want to implement these new methods in the San Francisco Bay Estuary and possibly prioritize areas for monitoring. A better understanding of factors affecting the detection and abundance of CCR, as well as spatial patterns of abundance, would be helpful in guiding any long-term monitoring decisions.

Methods

Study Area

Previous studies have identified tidal salt marsh, vegetated wetlands that are subject to daily tidal action and characterized by pickleweed (*Sarcocornia pacifica*) and the native Pacific cordgrass (*Spartina foliosa*), as the primary habitat for California Clapper Rails. Less saline marshes, i.e., brackish tidal and muted-tidal marsh, may support small, low-densities populations of CCR (Albertson and Evens 2000). For the purpose of assessing trends in abundance and overall population size, surveys by PRBO and collaborators targeted tidal marshes that have been identified as harboring CCR. Sites that had characteristics associated with CCR habitat such as appropriate tidal marsh plant species, (Albertson and Evens 2000) and sites that historically had CCR were also surveyed.

For each marsh site, a group of survey stations were laid out, on average 9 per marsh site, but with a range of 1 to 21 stations. We refer to this group of stations as a "transect." In general there was a one-to-one relationship between a transect and a marsh. All stations were within, bordering or adjacent to a marsh site. However, in some cases due to habitat differences or management treatment, a marsh site was divided into more than one transect, i.e., into subsites. In areas with small, divided marsh parcels, a single transect covered 2 or more of these small marsh sites.

Sites included in this report were located throughout San Pablo Bay (Pt. San Pedro and Pt. San Pablo east to Carquinez Bridge), South San Francisco Bay (San Francisco-Oakland Bay Bridge south), Central San Francisco Bay (Bay Bridge to Pt. San Pedro-Pt. San Pablo) and Suisun Bay (including Carquinez Straits). A total of 212 sites were surveyed using Type A protocol (see Appendix 1 for description of protocols), with 81 sites covering 8,753 ha in San Pablo Bay, 25 sites covering 295 ha in Central San Francisco Bay, 102 sites in South San Francisco Bay covering 4,019 ha, and 4 sites covering 187 ha in Suisun Bay (Figure 1, 2A-H, Table 1). Data from sites surveyed using Type B, C and D surveys were not used to estimate densities.

Field Surveys

Several organizations used a Type A field survey protocol (Appendix 1). The Type A call-count method is a 10-minute point count at a survey station, also referred to as a point. Each station is surveyed at least 3, and up to 5 times within a season with at least 1 week between visits. Surveys were conducted by experienced, permitted biologists. Survey stations were generally located at least 200 meters apart, although in a few instances stations were only 70 meters apart.

Surveys were conducted from 15 January to 15 April, with a small number of surveys performed as early as 19 December and as late as 26 May due to logistical constraints. Most transects were visited 3 times; PRBO visited some higher-abundance marshes 5 times beginning in 2009 as a result of our analysis showing a higher accuracy population estimate from additional visits (Liu et al. 2009). Other participating organizations also visited some sites more than 3 times. Conversely, some transects were visited less than 3 times in a season due to logistical constraints. All Clapper Rails, as well as other rail species, including California Black

Rail (*Laterallus jamaicencis coturniculus*), Virginia Rail (*Rallus limicola*), and Sora (*Porzana carolina*) detected from a survey station were recorded along with the time, bearing and the estimated distance from the observer to the individual.

No CCR vocalizations were broadcast ("call-broadcast") in the first two visits. If no Clapper Rails were detected within 200 meters of a survey station after the first 2 passive surveys, call-broadcast surveys were used on the 3rd visit. The call-broadcast surveys consisted of an initial 5 minutes of passive listening, and if no Clapper Rails were detected, then 1 minute of call-broadcast, with call-broadcast stopping immediately after a Clapper Rail detection, followed by 4 more minutes of passive listening. If 4th and 5th visits were made to a marsh, they were conducted passively. Because the call-broadcast and length was conditional on previous CCR detections, that portion of the survey was not used to analyze abundance, only the passive survey portion. The actual number of birds detected was recorded, or if the detection was not heard clearly because of confounding circumstances (e.g., distance from observer or environmental conditions) a range of number of rails (e.g., 1 to 2, 2 to 4) was recorded. Observers determined whether each detection was unique or if it had been detected more than once based on the location of each detection. Detections were plotted on a map and summarized by the observer to determine unique individuals. Generally, detections that overlapped or were within 5 degrees were considered to be the same bird(s) previously detected. Clapper Rails detected during transit between survey stations as well as before or after the 10-minute listening period were also recorded, but not used in any of the analyses.

Additional surveys, Types B, C, and D (Appendix 1), were, concentrated in South San Francisco Bay and Suisun Bay, using different methodologies which were incompatible with our analyses. The results of Type C surveys were used to help validate our models and results of Type B and D surveys at 8 sites totaling 422 ha in South San Francisco Bay were used to supplement our population estimates (see below).

Analyses

Only detections with recorded distance or averaged distance range less than or equal to 200 m were used; Clapper Rails detected outside the 10-minute survey periods at each survey station were excluded. When detections were associated with a possible range of number of birds detected (e.g., 1 to 2 Clapper Rails), the lower estimate was used. We included only records where a survey station was visited more than once per season. We excluded from analysis any portion of visits during or after playback of rail vocalization, so only passive surveys were considered. We only considered Type A surveys in San Pablo Bay and San Francisco Bay, as detections in Suisun Bay were extremely rare. For the analyses, we divided the Bay into North Bay and South Bay at the San Francisco-Oakland Bay Bridge, lumping Central San Francisco Bay and San Pablo Bay together, as we had found that there were too few surveyed marshes in Central San Francisco Bay for reliable trend estimates (Liu et al. 2009).

We analyzed the dataset using imperfect-detection abundance models (also referred to "zero-inflated models"; Zuur et al. 2009) that are specifically designed for the analysis of data with a repeated-visit structure (Royle 2004). These models assume that species detections are made incurring some error, because detectability of each and every individual of the species within the search radius is not 100%, and that the repeated visits to each station help estimate the magnitude of the detection probability of a bird during a visit. Multiple visits to a station were assumed to be replicate surveys; that is, we assumed no immigration or emigration at a station from one visit to another within the survey season. Imperfect detectability means that some visits with no detections are in fact false zeroes, meaning an individual was present but not detected (Zuur et al. 2009). By correcting for imperfect detection, the statistical models are able to produce unbiased estimates of abundance of rails and more appropriately determine the relevance of covariates associated with abundance.

Model Approach

We developed four distinct statistical models, each tailored to its distinctive objective(s). The dependent variable in the models is density, which is abundance per unit area (usually hectares). The first model we refer to as the "ecological model". This model analyzes the relationship of density to ecological variables of interest, reflecting habitat and landscape characteristics, while controlling for variables that affect detection probability. The second we refer to as the "site" model. This model estimates variation in density with respect to individual marsh sites, while controlling for differences in detection probability and year-to-year differences. It thus produced marsh-specific density estimates, which can be converted into estimates of abundance by marsh. The third model is the "year" model. This model estimates variation in density from year to year, while controlling for differences in detection probability and marsh-to-marsh differences in density.

The first three models are state-of-the-art models for analyzing the actual survey data collected at the marshes surveyed. Another objective was to estimate the population of rails in the whole estuary, whether surveyed or not. We developed the fourth statistical model, the "landscape" model, to meet this objective. Our approach was to model density in relation to 15 physical variables (described in detail below) available for all marshes (Veloz et al. 2012). For this we used the corrected estimates of density at each station, obtained from the site model, as our inputs, so detection probability was controlled for. This allowed us to extrapolate density estimates to areas that had not been surveyed to obtain an estimate of total rail abundance for the entire Estuary. We then combined the marsh-specific estimates from areas surveyed (obtained from the site model) with the estimates of the unsurveyed areas (from the landscape model).

Ecological Model

The objective of the ecological model was to identify predictors of Clapper Rail density, while controlling for factors affecting detection probability. The model comprises two sub-models to determine the effects of the covariates on (1) detection probability (detection sub-model) and on (2) density (abundance sub-model).

Detection Sub-model

The detection sub-model is a generalized linear logistic regression function, where the response variable is 1 or 0 for each possible bird present at a station, depending on whether the bird was detected or not, respectively. Note that this is not the probability of detection of *any* bird of the species, but the probability of detection of *each* bird within the survey radius. We evaluated the following covariates for the detection model: year of survey, bay, time of survey relative to sunrise/sunset, Julian day (where 1 = 1 Jan), and quadratic forms of time difference to sunrise/sunset and Julian day (Table 2A). Based on prior knowledge of relative influence of these covariates (Liu et al. 2012), we tested models that included 20 different combinations of a subset of variables, along with an intercept-only model and a full model (all covariates included). Temperature, wind speed, and cloud cover were also candidate variables for inclusion (and were previously examined by Liu et al. 2012), but excessive missing data precluded them from being included in the set of models analyzed.

<u>Abundance Sub-model</u>

The abundance sub-model is a generalized linear model (with a negative binomial error distribution) of the counts, conditional on the probability of detection. Hence, both detection and abundance sub-models are fitted simultaneously, such that the result is the combination of estimated detection probabilities and counts that best fit the data. We considered the following covariates of abundance in the ecological model: year of survey, bay, the combined year x bay effect, percent cover of marsh habitat within a 200-m radius of the survey station, spring salinity, tidal range, restoration status (never been restored, restored < 20 years ago, or restored 20 or more years ago), marsh elevation, distance to bay and percent invasive *Spartina* cover (Table 2A). Based on prior analyses (Veloz et al. 2012), we evaluated 12 competing abundance sub-models from these covariates, in addition to intercept-only and the full (all covariates) model. The combined year x bay effect was evaluated because of prior knowledge that North and South Bay CCR populations behave differently over time (Liu et al. 2009). The two regions are quite different from each other in many of the covariates considered, particularly tidal range (larger in South Bay), salinity effects (there is a stronger freshwater influence in North Bay), predators (greater association of predators with humans in the more populated, developed South Bay) and impacts of land development (stronger in the South Bay).

The resulting ecological model is obtained from the simultaneous fitting of the detection and abundance sub-models. We considered 22 competing detection sub-models and 14 competing abundance sub-models, which results in a potentially large group of models (308) to evaluate. Instead of evaluating all possible models, we followed an informed approach similar to that outlined by Zuur et al. (2012). We used a basic abundance sub-model (year, bay, year x bay, percent marsh) and explored all 22 detection sub-models. Once we identified the best detection sub-model, we compared the remaining 13 abundance sub-models until we obtained the top abundance sub-model. However, with the top abundance sub-model at hand, we still evaluated other potential competing detection sub-models to ensure that the ecological model included the best combination of detection and abundance sub-models. Model selection was based upon coefficients of covariates, values of probability of detection, and parametric bootstrapping as recommended by Fiske and Chandler (2011).

To explore the effects of marsh size and shape on abundance, we altered the ecological model twice, separately including one of the following covariates in the abundance sub-model: log(marsh size) and shape index, defined as log(perimeter)/log(area).

We report the coefficients of covariates of abundance and detection, and constructed partial dependence plots to illustrate their influence on probability of detection and density. The partial dependence plots were constructed by calculating predicted density values from the model for a range of values of the covariate of interest while holding all other covariates at a constant value. We used the mean value of every covariate being held constant and took 40 equally spaced values of the covariate of interest, starting and ending with its lowest and highest values in the data.

Site model

The objective of the site model was to provide marsh-specific estimates of density. These estimates were then applied to the area of the study marsh, to obtain an abundance estimate for the entire marsh. These marsh-specific abundance estimates contributed to our estimate of the number of Clapper Rails for the entire Estuary (see below).

The site model was comprised of a detection sub-model and an abundance sub-model. The detection sub-model included the same covariates for detection probability as the ecological model (time relative to sunrise/sunset as quadratic, Julian day; Table 2A). The abundance sub-model included year, bay, year x bay interaction and marsh ID (a categorical variable). Marsh ID and year were estimated as additive effects. Thus, we estimated marsh-level differences in abundance and year-specific differences, but we assumed that annual differences were the same across marshes, and only differed between the North Bay and South Bay. For the purposes of this model we were not interested in habitat and landscape variables, which were included in the full ecological model (described above) and in the landscape model (described below).

The site model produced estimates for each station in each marsh, accounting for the possible effect of spatial correlation between stations located within the same marsh.

Year Model

The objective of the year model was to estimate year to year changes in CCR density, while controlling for differences in site density, as well as differences in detection probability. The former was necessary because of unequal sampling of sites from year to year.

The year model included the same set of variables as the detection and abundance sub-models of the site model. Fundamentally, they are the same statistical model, but the year model was used to estimate differences in density among years rather than marshes.

The year model provided density estimates separately for the North and South Bay. That is, we included a year x bay interaction as well as bay and year main effects (the effects of interest), while controlling for marsh ID and percent marsh. In addition, we estimated year to year variation in density across the whole estuary by fitting the same model but without bay or the year x bay interaction, but still controlling for marsh ID and percent marsh.

Landscape Model

The objective of this model was to estimate CCR density at marshes not surveyed and therefore where CCR abundance was unknown. This was done using 15 physical predictor variables that characterize marsh habitat and the surrounding landscape. These predictor variables were available for all marsh locations, whether surveyed or not. The input for the landscape model was the marsh-specific densities obtained from the site model (i.e., sites that had been surveyed; see above). For the landscape model, we used a boosted regression trees (BRT) model (Elith et al. 2008). BRT is a data mining (also known as "machine learning") method that combines large numbers of relatively simple models adaptively, to optimize and achieve high predictive performance. BRTs are able to fit very complex models, with large numbers of covariates, and easily incorporate covariate interactions among predictor variables. The amount of residual error explained by each successive tree added to the model is a "learning parameter" or weight that can also be optimized (Elith et al. 2008). To optimize our model, we tested learning rates of 0.1, 0.05, 0.01, 0.005 and 0.001, in conjunction with tree complexities of 1 to 5 nodes per tree. The optimal model used a learning rate (0.05) and tree complexity (3) that resulted in a model with 6,950 trees.

Model variables were obtained from geospatial datasets, including: channel density, summer salinity, spring salinity, distance to levee, distance to channel, marsh elevation, distance to bay, distance to urban areas, percent low marsh, percent mid-marsh, percent high marsh, marsh slope, standard deviation of marsh elevation, tidal range and bay (Table 2B). Each covariate dataset was a raster grid of 50-meter x 50-meter cell size spanning the entire Estuary (Veloz et al. 2012). Variables derived from elevation were originally at a 5-m resolution and resampled to 50-m using bilinear interpolation. We used the final, optimized model to predict on the set of geospatial data grids, but added a correction factor, so that the predicted abundance of CCR was for a cell (0.25 ha), not for the area of a survey station (12.56 ha).

We produced partial dependence plots for the landscape model in a manner similar to that described for the ecological model. However, because the landscape model is very complex, its results were sensitive to input values of the covariates, and so we decided to hold all other covariates at their mean value and used the actual distribution of values in the dataset for the covariate being analyzed, rather than using 40 equally spaced values within the range of values of the covariate. In this way, we can show not just the effect of the covariate but also the sample size of the covariate throughout its range. For the plots we used predicted values for the year 2011 for illustration, and evaluated the partial dependence of density with respect to each covariate separately for North and South Bay regions.

Population Estimates

Only some of the year-to-year variation in estimates of population size reflects underlying variation in true population size; a substantial fraction reflects sampling variance or error (Gould and Nichols 1998). Therefore, we opted for estimating total current population size based on the last three years in the dataset: 2009-2011, to provide a more robust and accurate estimate. To this end, we used the site model (see above), but just for the most recent three years. The site model thus produced annual abundance estimates for each site surveyed, after multiplying estimated density (birds/ha) by site area (ha). Site area was determined in ArcGIS 9.3.1 (ESRI 2009) by digitizing site boundaries, based on aerial imagery, created by the project partners, and the San Francisco Estuary Institute's EcoAtlas Version 1.50b4 (SFEI 1998). Using the Zonal Statistics tool in ArcGIS, we summed the value of the pixels generated by the landscape model and compared the results to estimated density obtained by the site model. We also masked these sites and as well as 8 sites where our partners provided summary population estimates (type B and D surveys) from the landscape model and summed all remaining values to obtain an estimate of CCR abundance in marshes not surveyed at all or not surveyed using standard methods. The sum of the estimates of abundance derived from the site model, the 8 sites provided by our partners, and the estimated abundance of the unmasked portion of the landscape model provided us with our best estimate of the total abundance of rails for the entire Estuary.

Since the estimates from the site model are an average of years 2009-2011 for each marsh, we considered the minimum and maximum values at each marsh to construct a range around our mean estimate. The estimates from our partners included minimum and maximum values as well. Thus, our minimum value was calculated as the sum of minimum values from marshes from the site model for 2009-2011, the minimum value from our partners for the 8 marshes, and the abundance value from the landscape model. The maximum value was calculated analogously.

We also summed the pixels in regions of the Estuary, using the marsh complexes defined in the Draft Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California (U.S. Fish and Wildlife Service 2009). The summaries provided us with a basis to compare the results of the landscape model with the site model at the sub-regional level.

Results

A total of 5,897 Clapper Rails were detected at 17,585 visits at 1,078 distinct survey stations. These detections were mostly in the South Bay: 3,039 detections in the South Bay (52%), compared to 2,857 (48%) in the North Bay and 1 in Suisun. But the number of survey events (one visit at one station = one survey event) was also higher in the South Bay (10,065 or 57%) compared to North Bay (7,356 or 42%) and Suisun (152 or 1%). Accounting for this difference in survey effort, the rate of detection in South Bay is 0.302, or about one rail per every 3 survey events. In the North Bay the rate is slightly higher, 0.388. The number of stations in the South Bay was also highest: 523 stations, compared to 510 in the North Bay and 42 in Suisun. At the site level, California Clapper Rails were detected at 159 of the 212 sites (75%) surveyed.

Ecological Model

<u>Detection sub-model</u>.
The influence of four covariates on probability of detection was assessed. Year of survey and bay did not contribute to the model of best fit. In the final model (which included covariates of detection and abundance), Julian day and time relative to sunrise/sunset were included in the

model of best fit (optimizing AIC; Table 3). The effect of Julian day was quadratic and peaked in mid-February (Figure 3). The probabilities shown in the figure are conditional on time of survey and are based on the average time since sunrise or sunset, so they should not be taken as absolute values. The effect of time since sunrise/sunset was also quadratic and peaked about 25 minutes before sunrise and 25 minutes after sunset (Figure 4). The symmetry in the model is imposed by the sampling structure, in that it is impossible to distinguish a pattern in the data between morning surveys and evening surveys, but in reality peaks may differ slightly. Liu et al. (2012) concluded that the difference in peaks was about 5 min. As with the partial dependence plot for Julian day, the values of probability of detection hold survey date at a constant, average value.

<u>Abundance Sub-model</u>.

A total of 10 covariates were assessed for inclusion in the abundance sub-model (Table 2). Influential covariates ultimately included in the model of best-fit were year, bay, year x bay interaction, hybrid *Spartina* cover, tidal range, spring salinity, and percent marsh habitat (Table 3). Restoration status, marsh elevation, and distance to bay were not significant and not included in the final model. The year x bay interaction was significant meaning that the pattern of annual variation differed between North Bay and South Bay (see *Annual Variation in Density* below). We found a significant effect of bay; the South Bay overall had lower density estimates than the North Bay overall. Also, hybrid *Spartina* cover, tidal range and spring salinity had significant positive effects on CCR density (Figure 5). Spring salinity and tidal range have the strongest effects on abundance in terms of magnitude, showing five-fold changes in abundance through their range of values. Percent marsh habitat (within 200 m of the survey station) was also highly significant (Table 3): the more marsh habitat surrounding the survey station, the higher was density.

The over-dispersion coefficient of the negative binomial function (coefficient alpha in Table 3) is significantly different from 1, thus demonstrating over-dispersion and justifying the use of the negative binomial distribution instead of a Poisson distribution.

The best fit for the ecological model included a detection sub-model with linear and quadratic terms for difference in time to sunrise or sunset, and linear term for Julian day. Although there is a peak of detection related to Julian day, which we have illustrated (Figure 3), the best fit ecological model did not include a quadratic term of Julian day in the detection sub-model once other variables were included in the abundance model.

Density also varied with the size and shape of the marsh: the larger the marsh, the greater the estimated density. However, there is a diminishing-returns gain in density with respect to marsh size, after about 100 hectares (Figure 6). The shape of the marsh is strongly correlated to Clapper Rail density, where strip marshes and marshes with a high perimeter-area ratio host lower densities, and compact marshes with low perimeter-area ratios have higher densities (Figure 7).

In addition to restoration status (a categorical variable), we carried out a separate analysis to explore the effect of year since restoration (i.e., year since levee breach). We found that

Clapper Rail density increases with age of the marsh following restoration, but the increase is only apparent starting at about 17 to 20 years after the initiation of restoration (Figure 8), reflecting in large part the lag before marsh vegetation takes hold. Year since restoration was not evaluated for inclusion in the abundance sub-model because the exact year was not available for all sites.

Site Model

The site model was able to provide estimates for 200 sites out of the 212 surveyed. The 12 sites were filtered out because of missing data prior to model fitting. Fifty-eight sites of the estimated 200 had no detections ever recorded (thus the abundance estimate reflects abundance under conditional imperfect detection) and are excluded from our model results (Table 4). The number of marshes for which estimates were obtained varied by year: a minimum 68 in 2005 and a maximum 115 in 2009. The percent of marshes with density estimates equal to 0 also varied by year, with minimum 0.8% (2010) and maximum 4.4% (2005). Density per site averaged between 0.14 (2008) and 0.29 (2005), with maximum values ranging from 0.69 (2008) and 3.1 (2009). The number of sites with density greater than or equal to 1 (equivalent to approximately 12 CCR per station) ranges from 0.9% (2009) to 7% (2005). The global average for all marsh estimates for the entire period is 0.2 rails/ha.

After estimating density by year and site, we calculated average density at each site for each year in the data. From this we then calculated average abundance at each site for the two time periods 2005-2008 and 2009-2011 (Table 4). For the abundance calculation, we rounded to the whole number and rounded up to one any values between 0 and 1. Although the site model produces estimates for marshes with 0 detections in any given year because it assumes that some of these 0's are the result of imperfect detection, we opted for a cautionary approach and removed estimates from these. Thus, in Table 4 we provide estimates for 142 marshes known or suspected to have CCR and for which an estimate could be obtained from the data. Figure 9A & B shows the estimates from the site model overlaid on the marsh map.

At the sub-regional level, we examined density estimates for 2009-11 and compared trends from 2005-2008 to 2009-2011 for six marsh complexes in the North Bay, and eight marsh complexes in the South Bay (Table 5). For the comparison, we first eliminated sites that were not surveyed in both time periods, and sites for which we only had summarized data using other survey methods and were not able to analyze density. We then calculated abundance from the density estimates (rounding to integer numbers) and summed the abundance estimates by complex. Marsh complexes with the highest mean densities 2009-11 were: segment g, China Camp to Petaluma River (0.40 birds/ha); segment i, Corte Madera (0.30 birds/ha); and segment h, Point Pinole (0.21 birds/ha). Marsh complexes with core populations (as defined in the Recovery Plan) that declined the least (15-23%) were Petaluma River (segment f), East Palo Alto-Guadalupe Slough (segment o), and Point Pinole. We found that estimates of abundance at three complexes dropped by over 40%: Bair-Greco-Ravenswood, Mowry-Dumbarton, and Cogswell-Hayward Shoreline/Oro Loma/Robert's Landing complexes (segments n, q, and t, respectively). These represent three of the four largest complexes among the complexes for which we can calculate regional trends in the South Bay. Meanwhile, the three largest complexes in the North Bay, China Camp to Petaluma River, Petaluma River (segment f), and Corte Madera decreased by 33% or less. Complexes with larger declines in the North Bay were less populous ones.

Annual Variation in Density

Changes in density from 2005 to 2011 are depicted for North Bay and South Bay in Figure 10A. Both bay regions showed strong, significant declines overall during this period, 37% and 51% declines, respectively, comparing 2011 to 2005 (Table 6). However, the details of the trends differ between North Bay and South Bay. In the South Bay, the population increased through 2007, then dropped 61% between 2007 and 2008 (by a magnitude that is greater than observed in the North Bay) and demonstrating recovery only in the most recent year (2011). In the North Bay, on the contrary, the population declined from 2005 to 2008. The decline from 2005 to 2007 was shallow and not significant, but demonstrated a significant decline from 2007 to 2008, but not as strong as observed for the South Bay. The reversal of the declining trend occurred in 2009 but has been essentially flat since.

Looking at the entire Estuary, there were significant differences in density in years 2008 to 2011 when compared to the period 2005-2007 (Figure 10B). The trend plot for the Estuary shows a marked decline of 50% in density (birds per hectare) between 2007 and 2008, a low point observed in 2008, and then a reversal and slow and slight recovery from 2009 to 2011 (Figure 10B).

Landscape Model

The model identified the relative importance of each of the 15 covariates (Table 7). At the landscape level, channel density is the most important determinant of Clapper Rail density, followed by tidal range and summer salinity. Even after other landscape-level covariates have been incorporated in the model, there is a small effect captured by the Bay factor, meaning that some of the differences between North Bay and South Bay are not explained by the other landscape covariates, and are best captured by the Bay factor. The other covariates used include (in descending order of relative importance in the model): distance to bay, percent mid-marsh habitat, distance to nearest channel and percent of high marsh habitat.

The partial dependence plots for both North Bay and South Bay show a peak value in channel density such that Clapper Rail density is highest between 50 m and 150 m of channel per hectare of marsh (Figure 11); note these values exclude the smallest, e.g., first-order, channels. Optimal amounts of low- mid- and high-marsh habitat were approximately 5%, 40% and 5%, respectively (Figure 12). Tidal range was also an important covariate; we found that ranges around 2.4m were optimal for the South Bay (Figure 13).

The predicted density by cell is shown in Figures 14A (North Bay), 14B (South Bay) and 14C (Suisun Bay), and can be compared with the estimates from the site model (Figures 9A & B). The marsh complexes with the highest predicted densities were China Camp to Petaluma River and Point Pinole, with 1.49 and 0.95 birds/ha (Figure 14A). Other areas with relatively high predicted densities included East Palo Alto and Middle Bair Island (Figure 14B). Low density areas included all of Suisun Bay (Figure 14C), Napa-Sonoma marshes, and Petaluma Marsh.

Population Estimates

Using the site model, we calculate 955 CCR at the 159 sites with detections (Table 8). For this calculation we assumed that marshes without a single detection during the survey period had a true density of 0.0. Using the minimum and maximum values at each site for 2009-11, we obtained a range from 773 to 1,179. Using the landscape model results from unsurveyed marshes, we calculated a total of 118 CCR. During the same three-year period, there were an additional 94 CCR reported at sites surveyed by EBRPD and Don Edwards San Francisco Bay National Wildlife Refuge (EBRPD unpublished data, USFWS unpublished data). Thus, for 2009-11, we estimated the total CCR population in the Estuary at 1,167 individuals (range 954 to 1,426). Applying the same methodology to 2005-08 results, we estimated that the average population during that time period was 1,719 individuals (range 1,169 to 2,172). There were also 17 sites, mostly in Petaluma Marsh in San Pablo Bay, which were not surveyed in 2005-08; the 2009-11 average estimate at those sites was 69 CCR (range 61 to 76).

Excluding the estimates from unsurveyed marshes, the population in the Estuary is divided evenly between San Pablo Bay and South San Francisco Bay. There are approximately 501 individuals (range 400 to 631) representing 48% of the population in San Pablo Bay and 474 individuals (range 397 to 569) representing 45% of the population in South San Francisco Bay. About 7% of the population, 70 individuals (range 58 to 77), is in Central San Francisco Bay.

Discussion

Detection probability

We found that detection probability was strongly related to two factors: time of survey relative to sunrise/sunset and the day of the year within the survey season. Detection probabilities were highest at an intermediate optimum within the recommended survey period (day of year or time), thus confirming that the standard protocol specifies an appropriate time period. One conclusion from our study is that surveys should not be conducted outside the recommended time period (which is within 1 hour of sunrise or sunset and between 15 Jan and 15 April) because of low detection probability. Nevertheless, our results also demonstrate strong variation in detection probability with date and time, even when the survey is conducted within the recommended period. In addition, results indicate that even under the optimal day of year and time of day, less than one third of individuals are detected at a given site in a given year. Thus, with passive surveys, there is a need for, and a benefit from, using statistical models to estimate detection probability. Conversely, our finding points to the value of testing the national survey protocol that uses playback at all surveys (see below) which may reduce survey timing effects on detection probability.

There have been few studies analyzing detection probability for California Clapper Rails. In an earlier analysis, Liu et al. (2012) found that time relative to sunrise/sunset (minutes before or after sunrise or sunset) and Julian day were the most important determinants of detection probability, a finding that this study confirmed. In fact, the magnitude of the difference is quite high, even for surveys conducted during the recommended 2-hour block and during the prescribed 15 Jan to 15 April period.

The earlier analysis also found that temperature and wind affected detection probability, and that tide height and moon phase had no significant effect (Liu et al. 2012). The latter two may have had no demonstrable effect because the protocol stipulates that surveys not be conducted on especially high tides and not during the full moon. In this study we were not able to successfully include temperature and wind in our models of best fit. Thus our results do not shed light on the importance of those two factors.

Habitat Suitability

Our analysis has identified key attributes that predict density (and to an extent, occurrence) of Clapper Rails. These include both within marsh attributes and characteristics of the marsh in relation to surrounding non-marsh habitat. A suite of variables successfully predicts variation in Clapper Rail density. Thus, habitat suitability for CCR can be assessed and this information can be used to guide acquisition, restoration, and management directed towards conservation and recovery of Clapper Rails (see below). In addition, if we project how habitat suitability will change in the future, either due to land-use change or climate change, then we will be able to predict, and manage for, future habitat suitability for this species.

Habitat suitability for Clapper Rails increased with respect to increasing salinity, increasing percent invasive *Spartina*, increasing marsh size, compactness of marsh shape, and age since restoration. The positive relationship with salinity has been noted by others (Harvey 1977, H.T. Harvey and Associates 1989) but lacks a satisfactory mechanistic explanation (Goals Project 1999). Salinity plays an important role in determining prey community composition but this has not been well analyzed and may be a key driver for Clapper Rail density and distribution. In particular, salinity affects vegetation (Goals Project 2000), which in turn affects rail distribution. It may be that salinity is a useful proxy for combinations of variables related to vegetation and prey composition. Intermediate optima were observed for channel density, percent low marsh, percent mid-marsh, and percent high marsh in the area surrounding the survey location. All of these relationships provide a strong basis for assessing suitability of habitat for Clapper Rails with regard to past conditions (where this is known), present conditions and under future scenarios. More ambiguous was the relationship of Clapper Rail density to tidal range. Both the ecological model and the landscape model identified tidal range as important and both indicated that habitat suitability increases as tidal range increases from 1.8 m up to and including 2.4 m. Beyond 2.4 m, the models diverge: the landscape model indicates decreased density at highest tidal range, but the ecological model suggests density continues to increase for the highest tidal ranges. It is likely that the tidal range variable serves as a proxy for another variable or combination of variables that were either not measured or not appropriately represented in our models. Nonetheless, tidal range is an important component of tidal marsh ecosystems and further work is needed to confirm or clarify the relationship with this variable.

An important caveat is that high habitat suitability does not guarantee that Clapper Rails will be present or at the predicted densities. Marshes that demonstrate substantial discrepancy between the model-estimated density and the observed density (obtained by the site model) are marshes that need to be further studied. For such marshes, is the low observed density due to historical factors leading to loss of Clapper Rail numbers (e.g., predation by the non-native red fox) coupled with lack of re-colonization in recent years? Or is the low density due to current factors, such as change in habitat due to *Spartina* control, feral cats, etc.? The important point is that habitat suitability is only one part of the equation for maintaining and recovering Clapper Rail populations: in addition, survival, reproductive success, and dispersal rates must also be sufficiently high (see below and Nur et al. 2012). That said, evaluation of habitat suitability, which can be targeted by managers, is an important tool in the practitioner's toolkit.

Note that percent invasive hybrid *Spartina* cover only spans the range 0-14%. We lack data to evaluate the effect of hybrid *Spartina* cover beyond 14% and the suitability of habitat for Clapper Rails may change for percent cover above 14%. Nordby et al. (2009) found that tidal marsh Song Sparrows would nest in invasive *Spartina* habitat, but that such nests were more subject to flooding than nests not in invasive *Spartina*.

Population size of California Clapper Rail and its implications

Our analysis provides a range of values for the recent size of the California Clapper Rail population, which center on our best estimate of 1,167 individuals. Thus, we must underscore the uncertainty associated with our estimates. Nevertheless, all estimates indicate a low total population size for this subspecies, as low as 950 individuals and very likely fewer than 1,430 individuals. These represent exceedingly low numbers for an entire subspecies. By contrast, the number of California Black Rails in the San Francisco Estuary exceeds 10,000 individuals (Evens and Nur 2002, Veloz et al. 2012) and the number of tidal marsh Song Sparrows (three subspecies) exceeds 150,000 individuals (Veloz et al. 2012). The IUCN recognizes 2,500 individuals as one important criterion, among several, in distinguishing an endangered population compared to a vulnerable population (http://www.iucnredlist.org/static/categories_criteria_3_1).

Given such low numbers, attention must focus on population trends and not simply on estimated numbers. The recent decline observed for CCR is of great concern, though 2009-2011 demonstrate fairly stable trends. Determining change in density since 2011 is a priority, as are developing management actions that will promote population growth (see Recommendations).

Change in population size, recent trends, and shifts in distribution

Our results confirm the dramatic decrease in density between 2007 and 2008 seasons, and the overall negative trend from 2005-08, previously reported (Liu et al. 2009).

For the entire Bay, our analysis identifies three distinct trends within the period 2005-2011: relatively little change between 2005 and 2007, a decline from 2007 to 2009, and a slight rebound (weak positive slope) since 2009. At the same time, a key finding is that trends differed between North Bay and South Bay. Between 2007 and 2008 both North Bay and

South Bay evidenced declines, but the decline was much greater in the South Bay. In part the decline observed in the South Bay may be attributed to invasive *Spartina* control in the several years preceding 2008 (Olofson Environmental 2011). However, the decline cannot entirely be attributed to invasive *Spartina* control since there was also a modest but noticeable decline in the North Bay, which experienced very little invasive *Spartina* control during the period preceding 2008.

Since 2008, North Bay populations have demonstrated substantially greater increases in density than South Bay populations. The reasons for the difference may be attributable to a normal population fluctuation in this species, or a large number of externalities such as increased predation or decreased breeding success from extreme weather whose impact was not uniform throughout the Estuary (e.g., storms may have been more intense in one end of the Estuary than the other or the storm's impact on Clapper Rails may have differed by region, perhaps due to other simultaneous pressures, such as predation).

We had previously estimated that for the period 2005-08 about 57% of the total CCR population was in South San Francisco Bay and 33% in San Pablo Bay (Liu et al 2009). It appears that the shift in population towards the North Bay, now at 48% of the population estimate, is largely driven by the decline in the South Bay.

Historical abundance and distribution, comparison with the present

The most recent survey effort, prior to 2005, took place 1992-93 and was limited to the northern reaches of the Estuary (Collins et al. 1994). Survey methods differed significantly from current protocols: sites were surveyed as late as July 1; stations were mostly visited only once (i.e., 86.5% of stations in 1992 and 48% of sites in 1993); point count duration was 6 minutes and utilized 1 minute of call-broadcast after 5 minutes of passive listening (Collins et al. 1994). The use of call-broadcast increases detection probability of Clapper Rails by up to 111% (Conway and Nadeau 2010), and reduces the temporal variance in detection probability. Analytical methods also differed: site densities were calculated based on 100-meter radii around survey stations; every unique detection was assumed to represent 1.5 pairs of rails (e.g., 1 kek=3 individuals) to account for individuals not detected; and a coefficient of variation of 0.25 was estimated using data from 11 sites (Collins et al. 1994). Thus, from 181-251 detections in 1993, a conservative estimate of 408-564 individuals (204-282 pairs) was derived for the northern reaches of the Estuary, with a "more optimistic" estimate of 486-810 individuals using the high count at sites surveyed multiple times (Collins et al. 1994).

A direct comparison of population estimates, given the large disparity between methodologies precludes us from analyzing both time periods together. However, trends and a qualitative comparison can be made of the densities at sites which were surveyed in both time periods (Appendix Table 3). We compared density estimates in 1992-1993 with density estimates in 2005-2008 and 2009-2011 using the site model, and calculated percent change from one time period to other for selected sites. Some of the smaller populations which were documented in 1992-93 were not found in our surveys. In San Pablo Bay, we did not find any Clapper Rails at Mare Island Point (0.12 birds/ha 1992-93), Fagan Slough (0.04) or Pt. Pinole (0.04), although a type C survey in 2010 did detect 1-2 CCR at Pt. Pinole North (McBroom et al. 2011). In Suisun

Bay, type A and C surveys conducted by project partners have only detected CLRA in two years, 2006 and 2011 (Estrella 2007; PRBO unpub. data). Similarly, the 1992-93 surveys describe occurrences in Suisun as "sporadic" (Collins et al. 1994). In other areas, density indices have dropped sharply, such as White Slough (-79%) and Sonoma Creek mouth (-79%), and Hamilton shore (-65%). Some sites which had high density indices remained high or increased in 2005-11, notably marshes in the Gallinas Creek (+186%) and Corte Madera (+124 to 408%) areas. Notably, Creekside Marsh shows a 408% gain from the earliest period to the latest, but the gain was 826% in 2005-2008. Density at this site progressed from 0.08 rails/ha to 0.74 and then down to 0.41. In general, marshes that declined between 1992-1993 and 2005-2008 maintained the decline to 2009-2011; conversely, marshes that gained rails between 1992-1993 and 2005-2008 maintained the gain into the period 2009-2011, with the exception of Coon Island, where the gains in the first period were offset by the losses in the later period.

Previously, we estimated for 2005-08 a minimum population for the sites surveyed within the Estuary using program DISTANCE (1,403 individuals) and also an observer-based method (1,448 individuals) that did not take into account detection probability but included detections outside of the survey protocol period (Liu et al. 2009). Neither estimate accounted for unsurveyed sites. Combining estimates from sites surveyed in 2005-2008 using the site model, unsurveyed sites using the landscape model, and sites with other data (non-type A counts and summarized data), we estimate there were 1,734 CCRs with a range of 1,220 to 2,248 for the period 2005-08. Thus, we estimate that CCR population has decreased from approximately 1,730 individuals in 2005-2008 to approximately 1,170 individuals in 2009-2011. At the same time the difference between estimates of 1,730 and 1,425 for 2005-2008 reflects improved methodology and our explicit goal of estimating the number of Clapper Rails in unsurveyed areas.

Evaluation of the landscape model

We developed and implemented the landscape model, above all, in order to estimate the number of Clapper Rails in potential habitat that has not been surveyed. Estimating the number of individuals in unsurveyed areas is an important management question for any species of conservation concern, especially a subspecies with such an apparently small population. Our conclusion is that relatively few individuals were in habitat not surveyed during survey period 2005-2011, a little more than 100 individuals. Thus, approximately 90% of the entire population in the San Francisco Estuary is likely found in areas that are being surveyed or have been recently. The model did not predict large pockets of Clapper Rails in these unsurveyed marshes. That said, the landscape model indicates areas of high suitability for Clapper Rails (Figure 14 A-C) and thus can be used to point to areas that will benefit from surveys in the future, as opposed to unsurveyed areas unlikely to currently support Clapper Rails, as we detail below.

Though the landscape model was not intended to provide site-specific estimates, it is informative to compare estimates from the landscape model at the "marsh complex" scale (also referred to as "segments") with estimates from the site mode. To do so we compared the results of the two models in 15 marsh complexes surveyed in 2009-11 (Appendix Table 3).

The percentage difference between the site model and the landscape model ranged from -99% to +251.4%, with an average difference of +14.4% and a median of -15.4%. The two models predict similar magnitudes of abundance in 11 of 15 complexes. For the San Mateo and Hwy. 84 to Hwy. 92 complexes the landscape model correctly identifies them as relatively low-density areas, predicting 26 birds compared to 13 estimated by the site model. The landscape model, compared to the site model, underpredicts the Petaluma River complex by 61% and overpredicts the Point Pinole complex by 251%; this result may indicate different processes affecting the Clapper Rail populations not captured by the models which could be important for future population estimates and research. As pointed out above ("Habitat suitability"), the landscape model only assesses habitat suitability and no other factors such as predator abundance and habitat connectivity. For example, the marshes in Point Pinole are more isolated from each other compared to the marshes in the Petaluma River complex, which are larger and connected by narrow strip marshes that can serve as corridors for dispersal. We also compared the landscape model results to a set of 32 sites where type C surveys were conducted and zero birds detected with this methodology. Type C surveys are used primarily in marshes where the expected density of CCR is very low and call-broadcast is used on every visit to improve detection probability. The landscape model at these 32 sites predicted an aggregate of just over 2 birds, with no site over 1 bird.

The landscape model also predicts a little over 50 CCR in unsurveyed areas in San Pablo Bay and the same in South San Francisco Bay, and 5 or less in Suisun Bay and Central San Francisco Bay. The Suisun Bay estimate is likely an underestimate, as other researchers have documented 5 in a single season (Estrella 2007). The Central San Francisco Bay estimate is most likely close to correct, as very little unsurveyed marsh habitat remains there.

Improved accuracy to some of the geospatial datasets may improve the accuracy of the landscape model. In particular, the salinity grids are relatively coarse and do not capture the actual salinity gradient in a large marsh pointing to the need for within-marsh salinity data. Also, the LiDAR data for the baylands may have errors in excess of 1-m (Foxgrover and Jaffe 2005). There are numerous pixels within marshes which had no predicted value because their apparent elevations were outside the range of values for tidal marsh. It is possible that the refinement of these variables as well as others would reduce the range of predicted densities and improve the accuracy of the landscape model. Nevertheless, the model can be a very useful tool to identify marshes with a higher probability of detecting Clapper Rails, and prioritizing surveys accordingly. Marshes of interest identified by the model including the upstream reach of Novato Creek, the fringe marsh along Redwood Creek at Outer Bair Island, and the Oral B fragment (upper reach of Belmont Slough).

Recommendations

Conservation and Management Recommendations

Below is a summary of management recommendations to conserve CCR and maximize population health, based on our results. Not only must conservationists and managers consider factors that promote high density of Clapper Rails, but attention must also be paid to maintaining viable and resilient populations (Nur et al. 2012).

- Mosaic of marsh types- Managing for a mosaic of marsh types with respect to low-, mid-, and high-marsh will benefit Clapper Rail. This mosaic is relevant at the 1- 4 hectare scale (i.e., 2 to 10 acres). Clapper Rail density peaks at about:
    - 5-10% low marsh (i.e., -0.5 to -0.3 m elevation relative to MHHW),
    - 30-60% mid-marsh (i.e., -0.2 to 0.1 m elevation), and
    - 5-10% high-marsh (0.2 to 0.3 m elevation).

- High salinity- Focus rail conservation efforts, (restoration, acquisition, habitat enhancements, etc.) in areas with high salinity (all else being equal) or manage for high salinity (e.g., direct treated sewage outflow away from marsh habitat or increase tidal exchange in marshes receiving freshwater inflows). Clapper Rail density peaks at the highest spring salinity levels (about 25 psu). The positive effect of spring salinity may be associated with more abundant or higher-quality prey items.

- Larger marshes- Clapper Rail density increases with marsh size but there is little increase in density beyond about 100 ha (247 ac). Marshes smaller than 50 ha (124 ac) show a steep drop in density. Larger marshes are more likely to provide a mosaic of marsh types, have more "core" area relative to marsh edge, buffer rail populations from predators, especially human-associated predators and are more likely to have a well-developed channel network. Analysis of tidal marsh Song Sparrow reproductive success indicated that nest failure increased as proximity to adjacent upland habitat increased, likely due to predators (Chan et al. 2002).

- Compact marsh shapes- rounder marshes that are more compact with low perimeter-area ratios have higher densities than marshes high perimeter-area ratios such as linear strips of marsh. The size and shape of the marsh should be considered with respect to acquisition of marsh habitat and restoration design.

- Manage for high channel cover- sites with well-developed channel networks are known to benefit rails. Clapper Rail density peaks when channel density (meters of channel) is between 50 m and 150 m per hectare.

- Restore tidal marsh habitat- Clapper rail response to restoration starts about 17 to 20 years after a site is returned to tidal action. The speed of colonization by vegetation and Clapper Rails depends in large part on the starting elevation of the site and amount of suspended sediment available. Sites starting at higher elevations or with high suspended sediment concentrations should expect earlier colonization by Clapper Rails.

One of the most important points is that the quality of the habitat is as important, or more important than, the quantity of habitat. The configuration of marsh habitat within the larger landscape is also critical. Thus, larger marshes will support more Clapper Rails per hectare than smaller marshes, but the increasing benefit slows beyond about 100 ha. Hence two 100 ha-size marshes may be preferable (from a metapopulation perspective) to one 200 ha marsh: the two marshes will spread the risk of deleterious events and if located close enough to each other or to other marshes harboring CCR, will allow for a connected metapopulation. The health of CCR in the future depends on such metapopulations: a set of marshes that support high productivity of young, low mortality of juveniles and adults, and that allow for successful dispersal and movement from one marsh to another.

Monitoring Recommendations

We recommend that annual monitoring, using the standard protocol continue at a minimum of 45 to 60 sites per year. A large number of sites should be monitored each year in order to:

- Analyze effects of invasive *Spartina* control on Clapper Rails. Moreover, current work should target the response of Clapper Rails to change in vegetation, and recovery of Clapper Rail habitat, as healthy vegetation returns to the tidal marsh.

- Analyze marsh level change in density in relation to factors that affect population fluctuations, such as abundance of predators, predator access to tidal marsh habitat, adjacent land-use, and flooding of habitat.

- Tie population fluctuations at the marsh level, marsh complex level, and bay level to population dynamic modeling of CCR (Nur et al. 2012), allowing scientists to determine which factors are determining future population trends and population fluctuations. In this way, population bottlenecks can be identified and management action can address the most critical of these bottlenecks.

- Determine rates at which marshes with Clapper Rails demonstrate local extirpation as well as the converse: marshes without Clapper Rails are recolonized (successfully or not). The rates at which these two transitions occur are very important in projecting and maximizing the future health of Clapper Rail populations.

- Determine success of tidal marsh restoration in providing important habitat for CCR.

Two particular important next steps, both requiring funding, are to develop and implement improved, nationally-standardized monitoring methods ("Pilot protocol") and implement monitoring of reproductive success at a sample of tidal marshes ("Clapper Rail life history and demography") as described here.

Next Steps and Recommendations for future studies

<u>Pilot protocol</u>

PRBO and partners in 2012 began a 3-year test of a pilot protocol that is compatible with the Standardized North American Marsh Bird Monitoring Protocol (Conway 2011). Several unique protocols are used for secretive marsh bird studies in the San Francisco Bay Estuary, and none of them are compatible with the North American protocol (Appendix 1). The current protocol analyzed here targets a single species (California Clapper Rail). Other tidal marsh bird species are the subject of different survey protocols (WRMP 2003). With regard to Clapper Rails, call-broadcast to elicit vocal responses is used under some conditions and not others, which causes difficulties in estimating detection probability. In our case, we excluded surveys with broadcast calls, but exclusion of data is not desirable, even if justified. Any modification of the protocol to improve detection probability or its estimation, will improve our ability to infer population sizes and trends. Also, the effectiveness of management actions such as tidal marsh restoration projects can be more easily evaluated with a survey protocol that is standardized across all participants. Tidal marsh restoration benefits an entire suite of species, and thus methods that are applicable to other marsh bird species are desirable. For these reasons, we have been participating in the development, application, and integration of the pilot protocol into Clapper Rail monitoring programs.

The primary difference with the current protocol is that call-broadcast occurs on every survey. After 5 minutes of passive listening, 30-second vocalizations of 5 marsh bird species are broadcast in the subsequent 5 minutes with 30 seconds of silence in between to elicit responses. The pilot protocol is designed to facilitate data sharing at the national level, as well as reduce variation in detection probability and increase detection probability. The use of call-broadcast has been found to increase by 2 to 7 times the number of birds detected per station for three of the most common secretive marsh bird species in the Estuary: Virginia Rail, 1.25 birds detected per station vs. with 0.17 in passive surveys; Sora 0.71 birds per station vs. 0.27 in passive surveys; and Clapper Rail (1.30 birds per station vs. 0.19 in passive surveys; Conway and Gibbs 2005). The final 2 years of pilot protocol surveys are unfunded and will need to be completed and compared with surveys using the current protocol in order to ensure that old data can be integrated with a new protocol. Our goal is to:

- Collect two additional years of pilot protocol survey data
- Analyze effects of pilot protocol on rail detection probability
- Compare abundance estimates from standard protocol with pilot protocol

Clapper Rail life history and demography
Future population trajectories, and in particular, the likelihood that Clapper Rails will increase in abundance in the future depend on survival rates of adults, of juveniles, on reproductive success, and on the ability of juveniles and adults to disperse from and to marsh sites (Nur et al. 2012). None of these parameters have been well studied in this species, though a recent radio-transmitter study of Clapper Rails at several marsh sites has greatly increased our knowledge regarding survival (Overton, C., pers. comm.). However, survival estimates for an extended time period are not yet available nor do we have estimates for North Bay CCR. Without information on these parameters, we cannot project future trends. More information is needed so that we can determine population viability and how best to increase and maintain it.

There is a significant gap in our knowledge of current components of CLRA reproductive success. The most recent studies all date from 1999 or earlier, and it is probable that lower nest survival was a component of the recent population decline observed in the South Bay (Nur et al. 2012). Information on nest survival (and the factors influencing nest success) would be relatively easy to obtain. Our results show that Clapper Rail population growth is relatively sensitive to differences in nest survival, and not just due to differences in over-winter survival. A modest change in nest survival may be feasible and effective in stabilizing or reversing population declines. Without studies that calculate nest survival of Clapper Rails at present and that provide insight into the causes of nest failure, we may not be managing for the right variables that will maximize long-term population viability of populations or increase population size (Nur et. al. 2012).

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TABLES AND FIGURES

Table 1. Bay region, marsh name, map ID, area, and year(s) of survey data (indicated by an x) used to estimate the density of California Clapper Rails in the Estuary.

Bay	Marsh Name	ID	Area (ha)	2005	2006	2007	2008	2009	2010	2011
Central San Francisco	Lower Corte Madera Creek	1	10.1		x	x	x	x	x	x
	Corte Madera Creek Mouth	2	2.7			x	x		x	x
	Upper Corte Madera Creek	3	5.3		x	x	x	x	x	x
	College of Marin Ecological Reserve	4	1.8		x	x	x		x	x
	Creekside Park	5	7.8		x	x	x	x	x	x
	Greenbrae Boardwalk	6	4.2	x		x	x	x	x	x
	Heerdt Marsh	7	31.5	x	x	x	x	x	x	x
	Larkspur Ferry Cove	8	0.7			x	x		x	x
	Marta's Marsh	9	5.1	x	x	x		x	x	x
	Muzzi Marsh	10	53.0	x	x	x	x	x	x	x
	Piper Park East	11	14.4			x		x	x	x
	San Clemente Creek	12	6.9	x	x	x		x	x	x
	Blackie's Pasture	13	5.9			x				
	Greenwood Beach Rd/Richardson Bay	14	3.7			x				
	Harbor Cove Fragment	15	1.0			x				
	Strawberry Point	16	10.3			x				
	Bothin Marsh/Tam High Fragment	17	42.2			x	x	x	x	x
	Hoffman Marsh	18	14.1				x		x	x
	Meeker Slough	19	9.3			x	x	x	x	
	Stege Marsh	20	11.3				x	x	x	x
	Beach Fragment	21	3.4					x		
	Loch Lomond Marina	22	3.1					x		
	Pickleweed Park	23	5.5			x	x	x	x	x
	San Rafael Canal Mouth	24	7.1			x	x	x	x	x
	Emeryville Crescent - west	25	34.1		x	x	x	x	x	x

Table 1. Continued.

Bay	Marsh Name	ID	Area (ha)	2005	2006	2007	2008	2009	2010	2011
San Pablo	China Camp	26	98.6	x	x	x	x	x	x	x
	Gallinas Creek- middle reach	27	16.1	x	x	x	x	x	x	x
	Gallinas Creek- upper reach	28	8.2	x	x	x	x	x	x	x
	Gallinas Creek south	29	9.7	x	x	x	x	x		
	Hamilton North	30	21.2	x	x					x
	Mitchell Fragment	31	11.1	x	x	x	x	x		x
	McInnis Marsh	32	136.0	x	x	x	x	x	x	x
	Hamilton South	33	93.7	x	x	x	x	x	x	x
	Santa Venetia	34	8.5	x	x	x	x	x	x	x
	Cullinan Ranch	36	607.2	x	x	x				
	Dutchman Slough Mouth	37	11.7	x	x			x		
	Guadacanal Village	38	15.6	x	x			x		
	Napa Centennial Marsh	39	85.0		x				x	x
	Pond 2A Restoration	40	210.8	x	x	x			x	x
	White Slough Marsh	41	203.7	x	x	x	x	x		x
	Bahia Channel	42	14.4	x		x	x	x	x	x
	Bahia upland	43	38.3	x	x	x	x	x	x	x
	Bahia Restoration Marsh	44	144.2	x	x	x	x	x	x	x
	Black John Slough A	45	31.4	x	x	x	x	x	x	x
	Black John Slough B	46	43.5			x				
	Black John Slough north	47	137.3		x	x		x	x	x
	Petaluma River-west side	48	31.0	x	x	x	x	x	x	x
	Green Point Marsh	49	33.4	x	x	x	x	x	x	x
	Green Point Restoration Marsh	50	25.9	x	x	x	x	x	x	x
	Petaluma River east side	51	38.1	x	x	x	x	x	x	x
	Carl's Marsh	52	22.1	x	x	x	x	x	x	x
	China Slough	53	94.3	x	x	x			x	x
	Napa Tract Intake Pond 1	54	176.8		x	x				

Table 1. Continued.

Bay	Marsh Name	ID	Area (ha)	2005	2006	2007	2008	2009	2010	2011
San Pablo	Napa Tract Salt Pond 2	55	314.4	x	x	x			x	
	Napa Tract Salt Pond 3	56	543.8	x	x				x	x
	Napa Tract Salt Pond 4	57	387.9	x	x	x			x	x
	Napa Tract Salt Pond 5	58	311.8	x			x	x	x	x
	Napa Tract Salt Pond 7	59	124.2					x		
	Napa Tract Salt Pond 7A	60	121.2					x		
	Napa Tract Salt Pond 9 & 10	61	69.3			x	x	x		
	Mare Island A	62	84.6							x
	Mare Island B	63	78.1							x
	Strip Marsh/Boxer Marsh	64	949.6					x		x
	Novato Creek Mid Reach	65	34.0		x					
	Novato Creek Mouth N&S	66	102.6		x		x	x	x	x
	Novato Creek Upper Reach	67	21.0		x					
	False Slough	68	43.0		x				x	
	Gambinini Marsh	69	32.4				x			
	Petaluma R.- Lakeville Marina	70	29.3		x				x	
	Petaluma Marsh A Mira Monte Sl. W	71	95.9					x		x
	Petaluma Marsh B Mira Monte Sl. E	72	111.6							x
	Petaluma Marsh D Mud Hen Sl. E	73	66.6					x		x
	Petaluma Marsh E Mud Hen Sl. W	74	61.3					x		
	Petaluma Marsh Expansion Project	75	41.6					x		
	Upper San Antonio Ck.	76	52.7					x		
	Schultz Slough	77	151.4		x		x			
	Tule Slough	78	216.9		x				x	
	Woloki Slough	79	182.6		x			x	x	
	Day Island Wildlife Area	80	42.9		x	x	x	x	x	x

Table 1. Continued.

Bay	Marsh Name	ID	Area (ha)	2005	2006	2007	2008	2009	2010	2011
San Pablo	Southern Marsh	81	3.7							x
	Pinole Creek mouth	82	5.3			x				
	Pt. Pinole south/Parchester Marsh	83	11.2		x			x	x	x
	Pt. Pinole north/Whittel Marsh	84	23.5	x	x			x		x
	Pt Pinole south pocket marshes	85	10.0			x	x	x	x	x
	San Pablo Creek	86	52.3			x	x	x	x	x
	Wildcat Marsh S/Castro Creek	87	17.3	x		x	x	x	x	x
	Wildcat Marsh N/Castro Creek	88	119.6	x	x	x	x	x	x	x
	Petaluma River Mouth	89	73.1		x	x	x	x	x	x
	Sonoma Baylands restoration	90	118.5		x	x	x	x	x	x
	Sonoma Marina	91	26.0	x	x	x	x	x	x	x
	Skaggs Island Bridge / Napa Slough	92	232.7		x					
	Sonoma Creek Mouth	93	70.4		x	x	x			x
	Sonoma Baylands east	94	57.0	x	x	x	x	x	x	x
	Tolay Creek	95	113.8	x	x	x	x	x	x	x
	Tubbs Island Restoration	96	25.4	x	x	x	x	x	x	x
	Lower Tubbs Island	97	100.3	x	x	x	x	x	x	x
	Bull Island	98	43.8	x		x	x	x		
	Coon Island	99	162.4	x			x	x	x	x
	Fagan Slough	100	217.8	x		x	x	x		
	Hudeman Slough	101	101.9	x			x	x	x	x
	Mud Slough	102	67.0	x			x	x	x	x
	Napa Slough	103	46.2	x			x	x	x	x
	Ellis Creek	104	203.2		x		x		x	x
	Gray's Ranch	105	66.4		x				x	x
	Petaluma Dog Park	106	36.2						x	

Table 1. Continued.

Bay	Marsh Name	ID	Area (ha)	2005	2006	2007	2008	2009	2010	2011
South San Francisco	Alviso Slough	107	105.3			x			x	
	Charleston Slough	108	16.9				x	x	x	x
	Guadalupe Slough	109	89.8			x				
	Long Point	110	7.5				x	x	x	x
	Alviso Slough mouth	111	7.8			x			x	
	Mountain View Slough	112	27.5				x	x	x	
	Whisman Slough-Stevens Creek	113	23.7				x	x	x	x
	Belmont Sl.	114	59.8	x	x		x	x	x	x
	Corkscrew Sl.	115	80.4	x	x	x	x	x	x	x
	Greco Island North	116	202.6	x	x	x	x	x	x	x
	Greco Island South	117	94.4		x			x	x	x
	Middle Bair East	118	82.5	x	x	x	x	x	x	x
	Middle Bair SE	119	78.9	x	x	x	x	x	x	x
	Middle Bair West	120	260.8		x		x	x	x	x
	B2 North Quadrant	121	228.9	x	x	x	x	x	x	x
	Outer Bair West	122	158.5		x			x	x	x
	Redwood Shores	123	66.3	x	x			x	x	x
	Steinberger Sl.	124	46.9	x	x	x	x	x	x	x
	West Point Slough NW	125	2.4	x	x					x
	West Point Slough SW/SE	126	16.5		x		x			x
	OAC Central Island	127	66.3	x				x		x
	Cargill Mitigation Marsh	128	18.6					x		x
	Mt. Eden Creek	129	19.0	x				x		x
	N Whale's Tail	130	66.2	x	x	x	x	x		x
	S Whale's Tail	131	59.1	x	x			x		x
	Coyote Point Marina	132	5.0	x						
	Mills Creek Mouth	133	1.7				x			
	Sanchez Marsh/Park Plaza Fragment	134	5.8	x	x					
	Coyote Creek South East	135	100.1						x	x
	Audubon Marsh East	136	7.3						x	
	Audubon Marsh West	137	8.4	x	x	x	x	x	x	x
	Audubon East	138	36.5						x	
	Dumbarton Marsh East	139	27.8						x	

Table 1. Continued.

Bay	Marsh Name	ID	Area (ha)	2005	2006	2007	2008	2009	2010	2011
South San Francisco	Dumbarton Marsh West	140	194.1	x	x	x	x	x	x	x
	Rail Road Marsh-Barge Canal	141	22.4		x	x	x	x	x	x
	Bockman Channel	142	1.0	x	x	x	x	x	x	x
	Bunker Marsh	143	13.4	x	x	x	x	x	x	x
	Citation Marsh	144	44.5	x	x	x	x	x	x	x
	Cogswell Marsh, B	145	76.6		x	x	x	x	x	x
	Dogbone Marsh	146	2.8	x	x	x	x	x	x	x
	East Marsh	147	14.8	x	x	x	x	x	x	x
	Hayward Landing	148	4.7		x	x	x	x		
	H.A.R.D. Marsh	149	26.4		x	x	x	x	x	x
	Hayward Landing Canal	150	2.3		x	x	x			
	Johnson's Landing	151	5.0		x	x	x	x	x	x
	North Marsh	152	35.7	x	x	x	x	x	x	x
	Oro Loma East	153	79.7		x	x	x	x	x	x
	Oro Loma West	154	52.9	x	x	x	x	x	x	x
	San Lorenzo Creek & Mouth	155	12.7	x	x	x	x	x	x	x
	Hayward SMHM Reserve	156	26.6				x	x	x	x
	Sulphur Creek	157	3.3		x	x	x	x	x	x
	Triangle Marsh	158	5.0		x	x	x	x	x	x
	Calaveras Point	159	180.2			x				
	Mowry Slough	160	75.8	x			x			
	Mowry Marsh North	161	137.6					x		
	Newark Slough	162	75.0	x	x	x	x	x	x	x
	LaRiviere Marsh	163	38.3	x	x	x	x	x	x	x
	Alameda Flood Control Channel	164	109.0	x	x	x	x	x	x	x
	Ideal Marsh north	165	15.3	x	x	x	x	x		
	Ideal Marsh south	166	51.4	x	x	x	x	x		x
	Cooley Landing restoration	167	70.3		x	x	x	x	x	x
	Faber Marsh	168	41.8	x	x	x	x	x	x	x
	Laumeister Marsh	169	36.6	x	x	x	x	x	x	x
	Palo Alto Baylands	170	45.8	x	x	x	x	x	x	x
	Palo Alto Harbor-Hook Island	171	41.3	x	x	x	x	x	x	x
	San Francisquito Ck.	172	2.2	x	x	x	x	x	x	x

Table 1. Continued.

Bay	Marsh Name	ID	Area (ha)	2005	2006	2007	2008	2009	2010	2011
South San Francisco	Ravenswood Open Space	173	14.4			x	x	x	x	x
	Ravenswood Slough	174	48.2		x	x	x	x	x	x
	Colma Creek	175	5.8			x	x	x	x	
	Confluence Marsh	176	2.8	x	x	x	x	x	x	x
	Inner Harbor	177	5.9	x	x	x	x	x	x	x
	Navigable Channel	178	1.8			x	x	x	x	
	Old Marina	179	2.1	x	x	x	x	x	x	
	San Bruno Creek	180	2.3	x	x		x	x	x	
	San Bruno Marsh	181	14.3	x	x	x	x	x	x	x
	San Bruno Point	182	0.6	x	x	x	x	x	x	x
	Sam Trans Peninsula	183	5.7	x	x	x	x	x	x	x
	Lew Galbraith Golf Course	184	0.8			x	x	x	x	
	Oyster Bay Reg. Shoreline	185	7.3			x	x	x	x	
	Airport Channel	186	4.9	x	x	x	x	x	x	x
	Alameda Island East	187	1.6		x	x	x	x	x	x
	Arrowhead Marsh	188	16.9	x	x	x	x	x	x	x
	Bay Farm Island	189	3.0		x	x	x	x		
	Coliseum Channels	190	6.8		x	x	x	x	x	x
	Crown Beach Mudflat clones	191	0.2		x	x	x	x	x	x
	Doolittle Pond	192	1.2		x	x	x	x	x	x
	Elsie Roemer	193	6.9		x	x	x	x	x	x
	Fan Marsh	194	8.7	x	x	x	x	x	x	x
	MLK Regional Shoreline	195	18.5	x	x	x	x	x	x	x
	MLK Restoration Marsh	196	14.0	x	x	x	x	x	x	x
	Oakland Inner Harbor	197	14.2		x	x	x	x	x	x
	San Leandro Creek	198	4.0	x	x	x	x	x	x	x
	Seal Slough	199	23.5	x	x	x	x	x	x	x
	SFO	200	35.5			x	x	x	x	x
	Seaplane Harbor	201	2.5				x	x	x	x
	Brisbane Lagoon	202	7.3			x	x	x		
	Pier 98/Heron's Head	203	4.5							x
	Oyster Cove	204	1.3			x	x			
	Sierra Point	205	1.1			x	x	x		
	Burlingame Lagoon	206	3.1		x					

Table 1. Continued.

Bay	Marsh Name	ID	Area (ha)	2005	2006	2007	2008	2009	2010	2011
	Eden Landing - Pond 10	207	89.1	x				x		x
	Eden Landing - North Creek	208	14.5					x		x
Suisun	Martinez Shoreline	209	43.8		x					
	Benicia SRA	210	72.2						x	x
	Grizzly Island	211	63.8						x	
	Arnold Ranch/Navy Pt.	212	6.8							x

Table 2A. Variables used in the ecological, site, and year models of California Clapper Rail density in the Estuary.

Covariate name	Definition	Source
Year	Year when survey data were collected	Observational data
Bay	Whether survey station in North or South Bay, with dividing line at the Bay bridge	Veloz et al. 2012
Time difference sunrise/sunset	Time difference in minutes from start of survey to sunrise/sunset time	http://www.esrl.noaa.gov/gmd/grad/solcalc/sunrise.html
Julian day	Day of the year	Observational data
Percent marsh	Percent marsh habitat within the 200-m radius of the survey station	Observational data
Restoration status	Whether the marsh has never been restored, restored < 20 years ago, or restored 20 or more years ago.	PRBO Conservation Science unpublished data
Spring salinity	Salinity in parts per thousand	Veloz et al. 2012
Tidal range	Difference in meters between the mean highest high water and mean lowest low water marks at the survey station	Veloz et al. 2012
Marsh elevation	Mean marsh elevation in centimeters, estimated as the average elevation within a 50-m radius from a given 5-m cell	Veloz et al. 2012
Distance to bay	Distance in meters from the survey station to the nearest bay shoreline	Veloz et al. 2012
Invasive Spartina cover	Percent cover of the invasive *Spartina* hybrid within the marsh where the station is located	Invasive Spartina Project unpublished data

Table 2B. Variables used in the landscape model of California Clapper Rail density in the Estuary.

Covariate name	Definition	Source
Bay	Whether survey station in North or South Bay, with dividing line at the Bay bridge	Veloz et al. 2012
Distance to bay	Distance in meters from the survey station to the nearest bay shoreline	Veloz et al. 2012
Distance to levee	Distance in meters to the nearest levee	Veloz et al. 2012
Tidal range	Difference in meters between the mean highest high water and mean lowest low water marks at the survey station	Veloz et al. 2012
Marsh elevation	Mean marsh elevation in centimeters, estimated as the average elevation within a 50-m radius from a given 5-m cell	Veloz et al. 2012
Percent high marsh	The percent of high marsh habitat (0.2m – 0.3m MHHW) within a 50-m radius from a given 5-m cell	Veloz et al. 2012
Percent mid marsh	The percent of mid marsh habitat (-0.2m – 0.1m MHHW) within a 50-m radius from a given 5-m cell.	Veloz et al. 2012
Percent low marsh	The percent of low marsh habitat (-0.5m – -0.3m MHHW) within a 50-m radius from a given 5-m cell	Veloz et al. 2012
Elevation variability	The standard deviation in elevation within a 50-m radius from a given 5-m cell	Veloz et al. 2012
Spring salinity	Spatial interpolation of observed salinity concentrations in spring (PSU, practical salinity units)	Veloz et al. 2012
Summer salinity	Spatial interpolation of observed salinity concentrations in summer (PSU, practical salinity units)	
Marsh slope	Mean value of topographic slopes within a 50-m radius circle	Veloz et al. 2012
Distance to urban areas	Distance in meters to the nearest urban area	Veloz et al. 2012
Channel density	Mean channel density (meter of channel/m^2 of marsh area) within a 200-m radius from a given 10-m cell	PRBO unpublished data
Distance to channel	Distance in meters to the nearest channel	PRBO unpublished data

Table 3. Coefficient estimates of the ecological model of California Clapper Rail density in the Estuary.

Model	Covariate	Estimate	St.Err.	z	P-value
Abundance	Intercept	-2.25421	0.5088	-4.43	<0.0001
Abundance	Year 2006	-0.32059	0.2252	-1.424	0.1550
Abundance	Year 2007	-0.50541	0.2181	-2.318	0.0205
Abundance	Year 2008	-0.80024	0.2174	-3.628	0.0002
Abundance	Year 2009	-0.77013	0.2125	-3.625	0.0003
Abundance	Year 2010	-0.68504	0.2068	-3.312	0.0009
Abundance	Year 2011	-0.59697	0.206	-2.899	0.0038
Abundance	Bay: South Bay	-2.34095	0.3315	-7.061	<0.0001
Abundance	Percent marsh	0.679677	0.1287	5.279	<0.0001
Abundance	Percent Spartina cover	0.063565	0.0199	3.191	0.0014
Abundance	Spring salinity	0.079079	0.0125	6.304	<0.0001
Abundance	Tidal range	0.162126	0.0251	6.458	<0.0001
Abundance	YearxBay: 2006xSB	0.527263	0.3071	1.717	0.0860
Abundance	YearxBay: 2007xSB	0.72489	0.3037	2.387	0.0170
Abundance	YearxBay: 2008xSB	0.356387	0.3065	1.163	0.2450
Abundance	YearxBay: 2009xSB	0.050391	0.3024	0.167	0.8680
Abundance	YearxBay: 2010xSB	-0.12665	0.2995	-0.423	0.6720
Abundance	YearxBay: 2011xSB	0.124909	0.2967	0.421	0.6740
Detection	Intercept	-1.88263	0.0433	-43.49	<0.0001
Detection	Time difference Sunrise/Sunset	-0.00836	0.0006	-13.96	<0.0001
Detection	Time difference Sunrise/Sunset^2	-0.0001	0.00002	-5.82	<0.0001
Detection	Julian day	-0.00134	0.0006	-2.17	0.0303
Over-dispersion	Alpha	-1.5172	0.041	-37	<0.0001

Table 4. Estimates of density of California Clapper Rail in surveyed sites in the Estuary for years 2005 to 2011, and average estimates for the periods 2005-2008 and 2009-2011.

Bay	Complex	Site	ID	2005	2006	2007	2008	2009	2010	2011	area	Average 2009-11	Average 2005-08
Central San Francisco	Segment i	CMCL	1		0.012	0.011	0.006	0.045	0.005	0.007	10.1	1	1
Central San Francisco	Segment i	CMCM	2			0.134	0.030		0.027	0.099	2.7	1	1
Central San Francisco	Segment i	CMCU	3		0.058	0.057	0.030	0.027	0.162	0.068	5.3	1	1
Central San Francisco	Segment i	CMER	4		0.000	0.000	0.000		0.000	0.000	1.8	1	1
Central San Francisco	Segment i	CRPA	5		0.973	0.798	0.453	0.573	0.273	0.373	7.8	3	6
Central San Francisco	Segment i	GBBW	6	0.000		0.000	0.000	0.000	0.000	0.000	4.2	1	1
Central San Francisco	Segment i	HEER	7	1.438	0.720	1.008	0.505	0.696	0.592	0.712	31.5	21	29
Central San Francisco	Segment i	MART	9	0.068	0.083	0.068		0.147	0.055	0.110	5.1	1	1
Central San Francisco	Segment i	MUZZ	10	0.905	1.250	0.673	0.324	0.462	0.328	0.448	53.0	22	42
Central San Francisco	Segment i	PIF	11			0.240		0.168	0.200	0.222	14.4	3	3
Central San Francisco	Segment i	SCLE	12	0.032	0.039	0.032		0.096	0.014	0.041	6.9	1	1
Central San Francisco	Segment i	THF	17			0.169	0.128	0.181	0.104	0.129	42.2	6	6
Central San Francisco	Segment i	PIPK	23			0.500	0.429	0.288	0.599	0.438	5.5	2	3
Central San Francisco	Segment i	SRCM	24			0.078	0.042	0.121	0.040	0.115	7.1	1	1
Central San Francisco	Segment l	MEEK	19				0.031	0.051	0.062		9.3	1	1
Central San Francisco	Segment l	EC	25		0.146	0.167	0.062	0.101	0.123	0.090	34.1	4	4
San Pablo	Segment d	NACM	39		0.013				0.026	0.008	85.0	1	1
San Pablo	Segment d	PTAR	40	0.012	0.005	0.004			0.003	0.003	210.8	1	1
San Pablo	Segment d	WSM	41	0.250	0.174	0.200	0.053	0.067		0.062	203.7	13	34
San Pablo	Segment d	BUIS	98	0.000							43.8	0	1
San Pablo	Segment d	COIS	99	0.432			0.167	0.118	0.167	0.117	162.4	22	49
San Pablo	Segment d	FAGA	100	0.000		0.000	0.000	0.000			217.8	1	1
San Pablo	Segment d	HUDE	101	0.091			0.041	0.094	0.039	0.049	101.9	6	7
San Pablo	Segment d	MUDS	102	0.014			0.006	0.006	0.033	0.008	67.0	1	1
San Pablo	Segment e	SOCR	93		0.156	0.184	0.128			0.057	70.4	4	11
San Pablo	Segment e	SOBE	94	0.038	0.083	0.036	0.050	0.020	0.021	0.037	57.0	1	3
San Pablo	Segment e	TCM	95	0.032	0.047	0.031	0.016	0.022	0.027	0.014	113.8	2	4
San Pablo	Segment e	TMM	97	0.120	0.139	0.163	0.101	0.065	0.051	0.081	100.3	7	13
San Pablo	Segment f	BACH	42	0.152		0.128	0.088	0.100	0.113	0.060	14.4	1	2
San Pablo	Segment f	BJA	45	0.057		0.077	0.041	0.037	0.040	0.208	31.4	3	2
San Pablo	Segment f	BJSN	47		0.493	0.290		0.250	0.319	0.299	137.3	40	54

Table 4. Continued.

Bay	Complex	Site	ID	2005	2006	2007	2008	2009	2010	2011	area	Average 2009-11	Average 2005-08
San Pablo	Segment f	GRCM	48	0.201	0.197	0.144	0.101	0.137	0.255	0.281	31.0	7	5
San Pablo	Segment f	GRPT	49	0.405	0.483	0.409	0.402	0.248	0.300	0.435	33.4	11	14
San Pablo	Segment f	GRRM	50	0.250	0.281	0.245	0.114	0.308	0.356	0.415	25.9	9	6
San Pablo	Segment f	PETE	51	0.010	0.015	0.013	0.006	0.006	0.006	0.032	38.1	1	1
San Pablo	Segment f	PRM	52	0.445	0.485	0.633	0.149	0.243	0.209	0.457	22.1	7	9
San Pablo	Segment f	FASL	68						0.212		43.0	9	0
San Pablo	Segment f	LAMA	70						0.000		29.3	1	0
San Pablo	Segment f	PEAA	71					0.025		0.057	95.9	4	0
San Pablo	Segment f	PEAB	72							0.031	111.6	4	0
San Pablo	Segment f	SAAN	76					0.129			52.7	7	0
San Pablo	Segment f	TUSL	78						0.060		216.9	13	0
San Pablo	Segment f	WOSL	79					0.111	0.073		182.6	17	0
San Pablo	Segment f	RMA	89			0.254	0.176	0.147	0.258	0.106	73.1	12	16
San Pablo	Segment f	SOBR	90			0.016	0.009	0.021	0.025	0.010	118.5	2	1
San Pablo	Segment f	SOMA	91	0.000	0.000	0.000	0.000	0.000	0.000	0.000	26.0	1	1
San Pablo	Segment f	ELCR	104				0.000		0.000	0.000	203.2	1	1
San Pablo	Segment f	GRAY	105						0.042	0.020	66.4	2	0
San Pablo	Segment f	PDF	106						0.062		36.2	2	0
San Pablo	Segment g	CCM	26	0.571	0.781	0.686	0.445	0.266	0.225	0.387	98.6	29	61
San Pablo	Segment g	GACRM	27	0.552	0.469	0.414	0.185	0.283	0.276	0.479	16.1	6	7
San Pablo	Segment g	GACRN	28	0.091	0.113	0.204	0.081	0.104	0.153	0.077	8.2	1	1
San Pablo	Segment g	GACRS	29	0.651	0.865	0.720	0.357	0.203			9.7	2	6
San Pablo	Segment g	HAAF	30	0.055						0.097	21.2	2	1
San Pablo	Segment g	MIF	31	0.807	0.882	0.900	0.506	0.807	0.845	0.693	11.1	9	9
San Pablo	Segment g	MIM	32	1.433	1.161	0.983	0.628	0.602	0.748	1.089	136.0	111	143
San Pablo	Segment g	MIN	33	1.067	1.042		0.687	0.532	0.609	0.607	93.7	55	87
San Pablo	Segment g	STVE	34	0.319	0.382	0.347	0.240	0.114	0.231	0.314	8.5	2	3
San Pablo	Segment g	BMAK	65		0.000						34.0	0	1
San Pablo	Segment g	NCRM	66		0.173		0.090	0.136	0.228	0.107	102.6	16	14
San Pablo	Segment g	BPF	80		0.300	0.224	0.086	0.105	0.062	0.147	42.9	4	9
San Pablo	Segment h	SOUM	81							0.000	3.7	1	0
San Pablo	Segment h	PTPN	84	0.000	0.000			0.000		0.000	23.5	1	1

Table 4. Continued.

Bay	Complex	Site	ID	2005	2006	2007	2008	2009	2010	2011	area	Average 2009-11	Average 2005-08
San Pablo	Segment h	RCRA	85			0.224	0.138	0.265	0.199	0.310	10.0	3	2
San Pablo	Segment h	RIF	86			0.452	0.502	0.240	0.324	0.409	52.3	17	25
San Pablo	Segment h	WICA	87	0.149		0.164	0.041	0.040	0.039	0.049	17.3	1	2
San Pablo	Segment h	WIMA	88	0.237	0.303	0.323	0.314	0.383	0.155	0.155	119.6	28	35
South San Francisco	Segment j	COCR	172			0.044	0.068	0.019	0.019		5.8	1	1
South San Francisco	Segment j	CONF	173	0.019	0.020	0.021	0.037	0.039	0.009	0.012	2.8	1	1
South San Francisco	Segment j	INHA	174	0.279	0.226	0.211	0.053	0.051	0.050	0.064	5.9	1	1
South San Francisco	Segment j	NACH	175			0.124	0.196	0.054	0.053		1.8	1	1
South San Francisco	Segment j	OLDM	176	0.000	0.000	0.000	0.000	0.000	0.000		2.1	1	1
South San Francisco	Segment j	SBCR	177		0.000		0.000	0.000	0.000		2.3	1	1
South San Francisco	Segment j	SBMA	178	0.170	0.397	0.350	0.215	0.158	0.087	0.110	14.3	2	4
South San Francisco	Segment j	SBPT	179		0.024	0.026	0.065	0.011	0.011	0.014	0.6	1	1
South San Francisco	Segment j	STPN	180	0.827	0.676	0.570	0.265	0.163	0.186	0.204	5.7	1	3
South San Francisco	Segment j	SFO	197			0.124	0.060	0.067	0.051	0.079	35.5	2	3
South San Francisco	Segment j	HEHE	200							0.092	4.5	1	0
South San Francisco	Segment j	OYPC	201			0.073	0.018				1.3	0	1
South San Francisco	Segment j	SIPT	202			0.089	0.028	0.067			1.1	1	1
South San Francisco	Segment k	OYBA	182			0.064	0.013		0.012		7.3	1	1
South San Francisco	Segment k	AICH	183	0.048	0.086	0.112	0.047	0.024	0.026	0.053	4.9	1	1
South San Francisco	Segment k	ALAM	184		0.060	0.060	0.013	0.029	0.013	0.016	1.6	1	1
South San Francisco	Segment k	ARHE	185					3.081	2.666		16.9	49	94
South San Francisco	Segment k	BFIS	186		0.159	0.218	0.057	0.045			3.0	1	1
South San Francisco	Segment k	COCH	187		0.006	0.019	0.003	0.003	0.003	0.003	6.8	1	1
South San Francisco	Segment k	DOPO	189		0.122	0.217	0.134	0.138	0.090	0.064	1.2	1	1
South San Francisco	Segment k	ELRO	190		0.255	0.158	0.089	0.066	0.046	0.057	6.9	1	1
South San Francisco	Segment k	FANM	191	0.205	0.328	0.347	0.218	0.232	0.215	0.205	8.7	2	2
South San Francisco	Segment k	MLKS	192	0.118	0.253	0.214	0.118	0.120	0.096	0.107	18.5	2	3
South San Francisco	Segment k	NEMA	193	0.269	0.447	0.559	0.290	0.266	0.237	0.327	14.0	4	5
South San Francisco	Segment k	SLEA	195	0.051	0.087	0.094	0.034	0.028	0.039	0.033	4.0	1	1
South San Francisco	Segment m	BELM	114		0.089		0.058	0.067	0.089	0.053	59.8	4	4
South San Francisco	Segment m	RESH	123		0.089			0.026	0.018	0.021	66.3	1	6
South San Francisco	Segment m	STEIN	124	0.000		0.000	0.000	0.000	0.000	0.000	46.9	1	1

Table 4. Continued.

Bay	Complex	Site	ID	2005	2006	2007	2008	2009	2010	2011	area	Average 2009-11	Average 2005-08
South San Francisco	Segment m	SEAL	196	0.472	0.588	0.749	0.138	0.156	0.108	0.182	23.5	3	11
South San Francisco	Segment n	CORK	115	0.058	0.085	0.057	0.031	0.050	0.110	0.058	80.4	6	5
South San Francisco	Segment n	GRIN	116	0.401	0.258	0.315	0.201	0.160	0.136	0.141	202.6	29	60
South San Francisco	Segment n	GRIS	117		0.490			0.408	0.384	0.614	94.4	44	46
South San Francisco	Segment n	MBE	118	1.092	1.426	1.216	0.624	0.527	0.356	0.586	82.5	40	90
South San Francisco	Segment n	MBSE	119	0.078	0.101	0.076	0.168	0.041	0.046	0.083	78.9	4	8
South San Francisco	Segment n	OBE	121	0.340	0.351	0.372	0.177	0.192	0.108	0.202	228.9	38	71
South San Francisco	Segment n	WPSN	125	0.000	0.000					0.000	2.4	1	1
South San Francisco	Segment n	WPSS	126		0.000					0.000	16.5	1	1
South San Francisco	Segment n	RAV	171		0.249	0.203	0.074	0.059	0.077	0.074	48.2	3	8
South San Francisco	Segment o	ALSL	107			0.000			0.000	0.000	105.3	1	1
South San Francisco	Segment o	GUSL	109			0.038					89.8	0	3
South San Francisco	Segment o	MAL	111			0.000			0.000	0.000	7.8	1	1
South San Francisco	Segment o	MVSL	112				0.081	0.089	0.092		27.5	2	2
South San Francisco	Segment o	COLA	164		0.026	0.042	0.022	0.030	0.011	0.033	70.3	2	2
South San Francisco	Segment o	FABE	165	1.117	1.376	1.236	0.630	0.907	0.933	1.364	41.8	45	46
South San Francisco	Segment o	LAUM	166	0.842	1.198	0.826	0.418	0.345	0.356	0.633	36.6	16	30
South San Francisco	Segment o	PAB	167	0.564	0.784	0.797	0.285	0.291	0.253	0.417	45.8	15	28
South San Francisco	Segment o	PAHA	168	0.197	0.215	0.196	0.147	0.198	0.296	0.247	41.3	10	8
South San Francisco	Segment o	SFQC	169	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.2	1	1
South San Francisco	Segment q	AUEA	138						0.029		36.5	1	0
South San Francisco	Segment q	DUMW	140	0.456	0.663	0.468	0.229	0.232	0.170	0.248	194.1	42	88
South San Francisco	Segment q	RLRD	141		0.000	0.000		0.000	0.000	0.000	22.4	1	1
South San Francisco	Segment q	CAPT	159			0.000					180.2	0	1
South San Francisco	Segment q	MOSL	160	0.212			0.156				75.8	0	14
South San Francisco	Segment q	MOWN	161					0.000			137.6	1	0
South San Francisco	Segment q	NEW	162	0.084	0.123	0.142	0.039	0.057	0.065	0.130	75.0	6	7
South San Francisco	Segment q	LARI	210					0.536	0.379		38.3	18	20
South San Francisco	Segment s	ALCK	127					0.000		0.000	66.3	1	0
South San Francisco	Segment s	EDEN	129					0.000		0.000	19.0	1	0
South San Francisco	Segment s	WTM	130					0.026		0.078	66.2	3	0
South San Francisco	Segment s	WTS	131					0.000		0.000	59.1	1	0

Table 4. Continued.

Bay	Complex	Site	ID	2005	2006	2007	2008	2009	2010	2011	area	Average 2009-11	Average 2005-08
South San Francisco	Segment s	AFCC	163					0.165			109.0	18	25
South San Francisco	Segment t	BUNK	143	0.157	0.178	0.108	0.071	0.094	0.063	0.118	13.4	1	2
South San Francisco	Segment t	CITA	144	0.144	0.151	0.167	0.119	0.072	0.079	0.151	44.5	4	6
South San Francisco	Segment t	COGS	145		0.511	0.397	0.267	0.196	0.189	0.173	76.6	14	30
South San Francisco	Segment t	DOGB	146	0.023	0.041	0.086	0.012	0.012	0.012	0.015	2.8	1	1
South San Francisco	Segment t	EAST	147	0.003	0.003	0.002	0.001	0.001	0.001	0.012	14.8	1	1
South San Francisco	Segment t	HALA	148		0.000	0.000	0.000	0.000		0.000	4.7	1	1
South San Francisco	Segment t	HARD	149		0.000	0.000	0.000	0.000	0.000	0.000	26.4	1	1
South San Francisco	Segment t	JOLA	151		0.000	0.000	0.000	0.000	0.000	0.000	5.0	1	1
South San Francisco	Segment t	NORT	152	0.214	0.289	0.289	0.155	0.135	0.145	0.177	35.7	5	8
South San Francisco	Segment t	ORLE	153		0.004	0.003	0.007	0.002	0.007	0.002	79.7	1	1
South San Francisco	Segment t	ORLW	154	0.022	0.069	0.047	0.016	0.011	0.012	0.014	52.9	1	2
South San Francisco	Segment t	SLRZ	155	0.090	0.142	0.169	0.038	0.036	0.057	0.083	12.7	1	1
South San Francisco	Segment t	SULF	157		0.000	0.000	0.000	0.000	0.000	0.000	3.3	1	1
South San Francisco	Segment t	TRMA	158		0.030	0.009	0.005	0.005	0.003	0.006	5.0	1	1

Table 5. Regional density estimates and changes in estimated abundance of California Clapper Rail in the Estuary. Estimates only include marsh abundance model sites.

Marsh complex	2009-11 density estimate	2005-08 abundance estimate	2009-11 abundance estimate	Percent change
North Bay				
Segment d Napa	0.04	94	45	-52.1%
Segment e Petaluma River to Sonoma Creek	0.04	31	14	-54.8%
Segment f Petaluma River	0.09	112	95	-15.2%
Segment g China Camp to Petaluma River	0.40	341	237	-30.5%
Segment h Point Pinole	0.21	65	50	-23.1%
Segment i Corte Madera	0.30	97	65	-33.0%
South Bay				
Segment j San Francisco	0.07	18	13	-27.8%
Segment k Oakland	0.11	18	16	-11.1%
Segment l Berkeley	0.09	5	5	0.0%
Segment m San Mateo	0.05	22	9	-59.1%
Segment n Bair-Greco-Ravenswood	0.20	290	166	-42.8%
Segment o East Palo Alto-Guadalupe Slough	0.20	119	93	-21.8%
Segment q Mowry-Dumbarton	0.07	96	49	-49.0%
Segment t Cogswell-Hayward Shoreline/Oro Loma/Robert's Landing	0.07	57	34	-40.4%

Table 6. California Clapper Rail densities in the Estuary. Estimates by year, bay and percent change from prior year.

Region	Year	Density	SE	% change from year prior
North Bay	2005	0.546	0.090	
North Bay	2006	0.457	0.075	-16.3%
North Bay	2007	0.460	0.071	0.6%
North Bay	2008	0.282	0.043	-38.6%
North Bay	2009	0.361	0.052	27.6%
North Bay	2010	0.368	0.050	2.2%
North Bay	2011	0.344	0.046	-6.5%
South Bay	2005	0.409	0.072	
South Bay	2006	0.603	0.073	47.5%
South Bay	2007	0.585	0.072	-3.0%
South Bay	2008	0.229	0.029	-60.8%
South Bay	2009	0.154	0.020	-32.9%
South Bay	2010	0.146	0.019	-5.0%
South Bay	2011	0.201	0.024	37.5%
Entire Bay	2005	0.390	0.081	
Entire Bay	2006	0.379	0.074	-3.0%
Entire Bay	2007	0.379	0.072	-0.1%
Entire Bay	2008	0.187	0.034	-50.7%
Entire Bay	2009	0.196	0.032	4.7%
Entire Bay	2010	0.205	0.032	4.8%
Entire Bay	2011	0.211	0.033	2.9%
North Bay	2005-08	0.436		
North Bay	2009-11	0.358		-18.0%
South Bay	2005-08	0.368		
South Bay	2009-11	0.183		-50.4%

Table 7. Relative importance index of covariates in the landscape model of California Clapper Rail abundance in the Estuary.

Covariate	Relative importance
Channel density	22.8
Tidal range	13.3
Summer salinity	8.8
Spring salinity	8.3
Distance to bay	7.7
Percent mid-marsh	6.5
Distance to channels	5.4
Percent high marsh	5.3
Slope	4.8
Distance to levees	4.4
Percent low marsh	3.9
St. dev. marsh elev.	3.3
Mean elevation	3.2
Distance to urban areas	2.2
Bay	0.1

Table 8. California Clapper Rail abundance estimates. The estimates are presented as the sum of three additive components: the site model estimates (from Table 5), the partner estimates from other surveys for marshes not included in the site model, and the landscape model estimates from all other marshes not surveyed. The sum of these three component estimates results in the total abundance estimate for each period. Minimum and maximum values are also shown and used to calculate the total estimate's range.

Period	Parameter	Site model	Other surveys	Landscape model	Estimated total
2009-2011	Average	955	94	118	1167
	Minimum	773	63	118	954
	Maximum	1179	129	118	1426
2005-2008	Average	1386	215	118	1719
	Minimum	897	154	118	1169
	Maximum	1802	252	118	2172

Figure 1. Location of 212 tidal marshes around the Estuary where California Clapper Rail surveys were conducted between 2005 and 2011, and the spatial extent of the landscape model used in the population estimate.

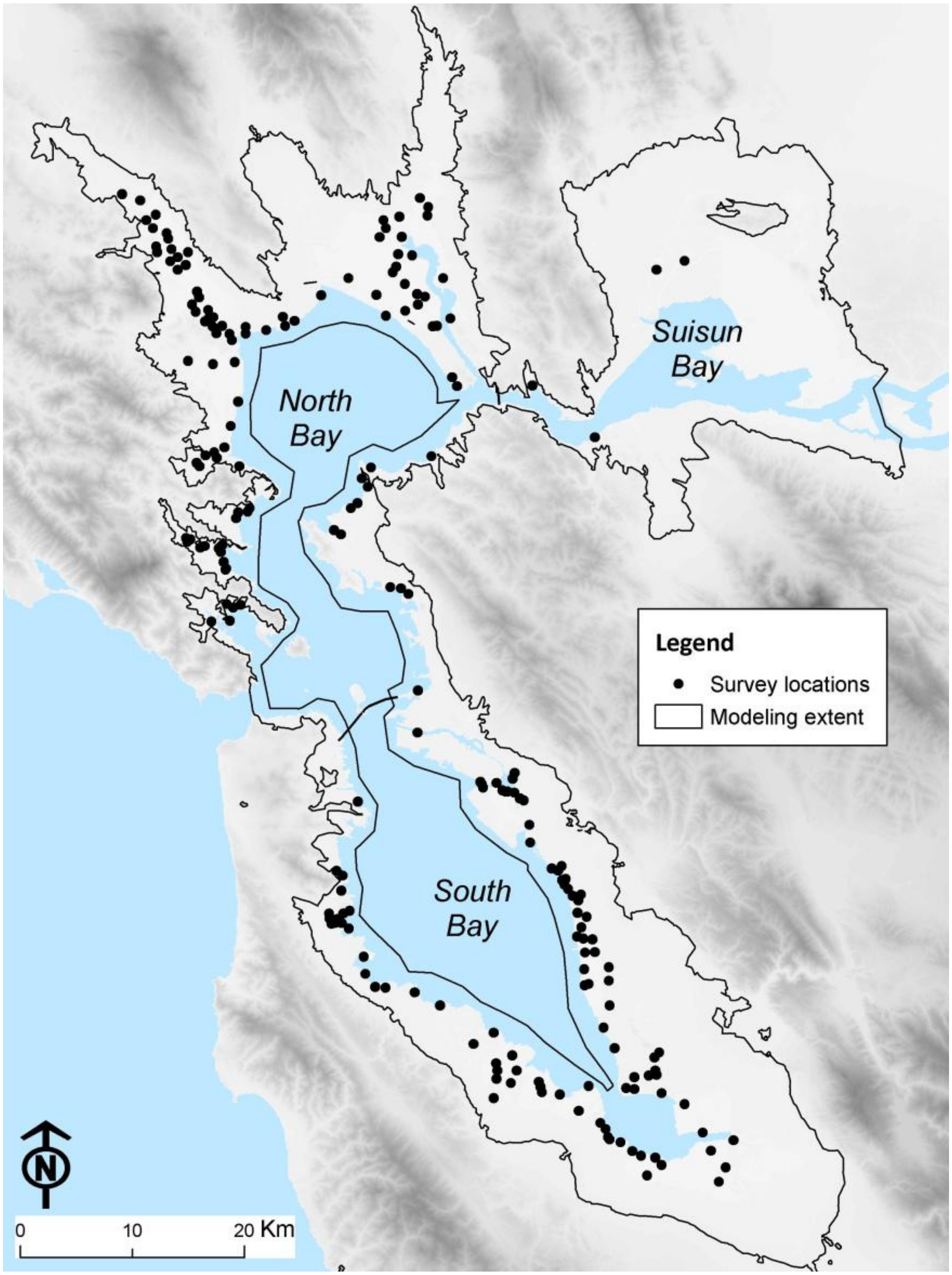


Figure 2A. Marshes of west San Pablo Bay and Petaluma River. Figures 2A-H include marsh sites and survey stations surveyed using Type A protocol between 2005 and 2011 for California Clapper Rail density estimates. Marshes in green may have been surveyed using other protocol but were not used in the analyses. Numbering corresponds to descriptions in tables 1 and 4.

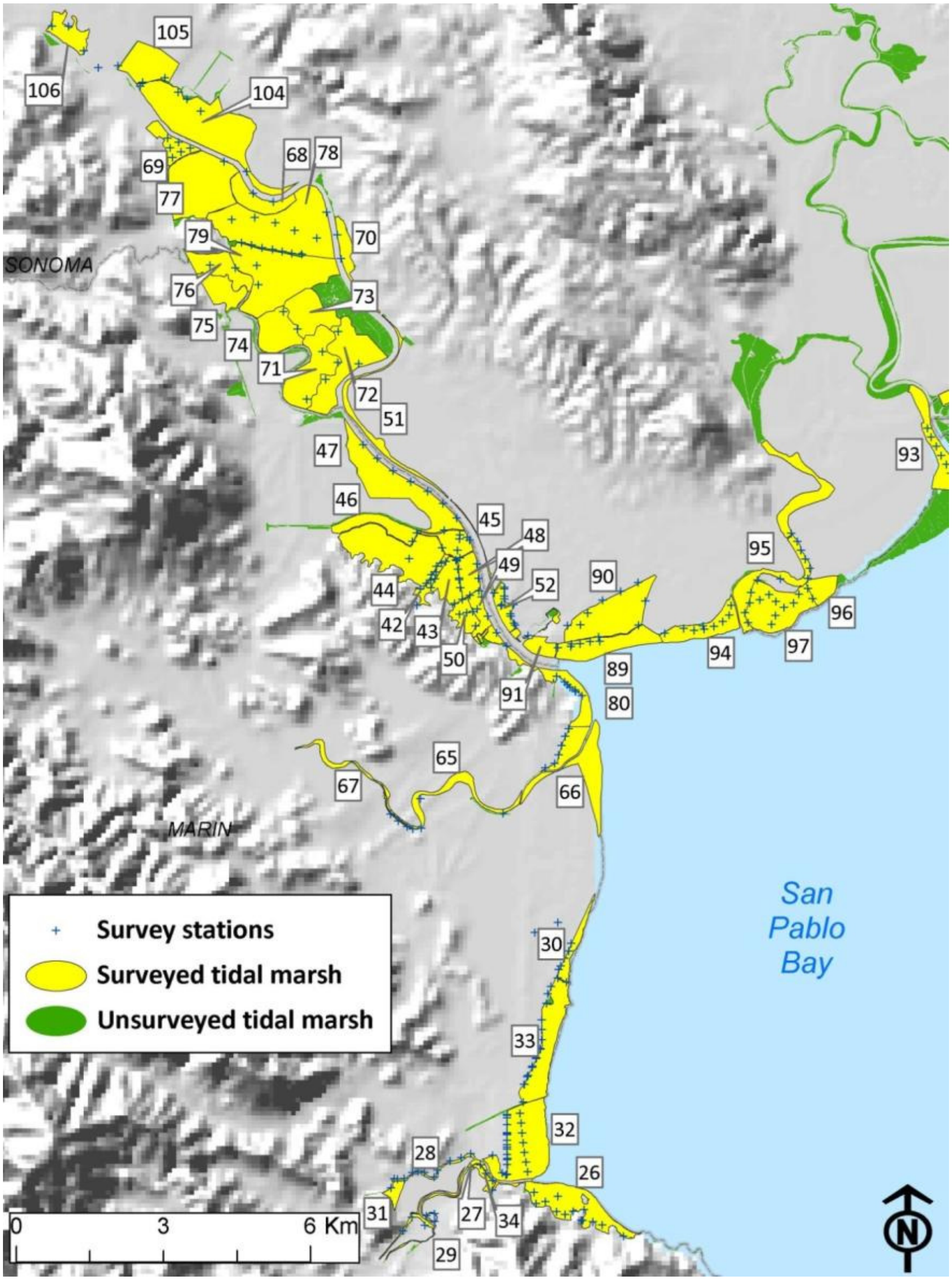


Figure 2B. Marshes of east San Pablo Bay and Napa River. Marshes in green may have been surveyed using other protocol.

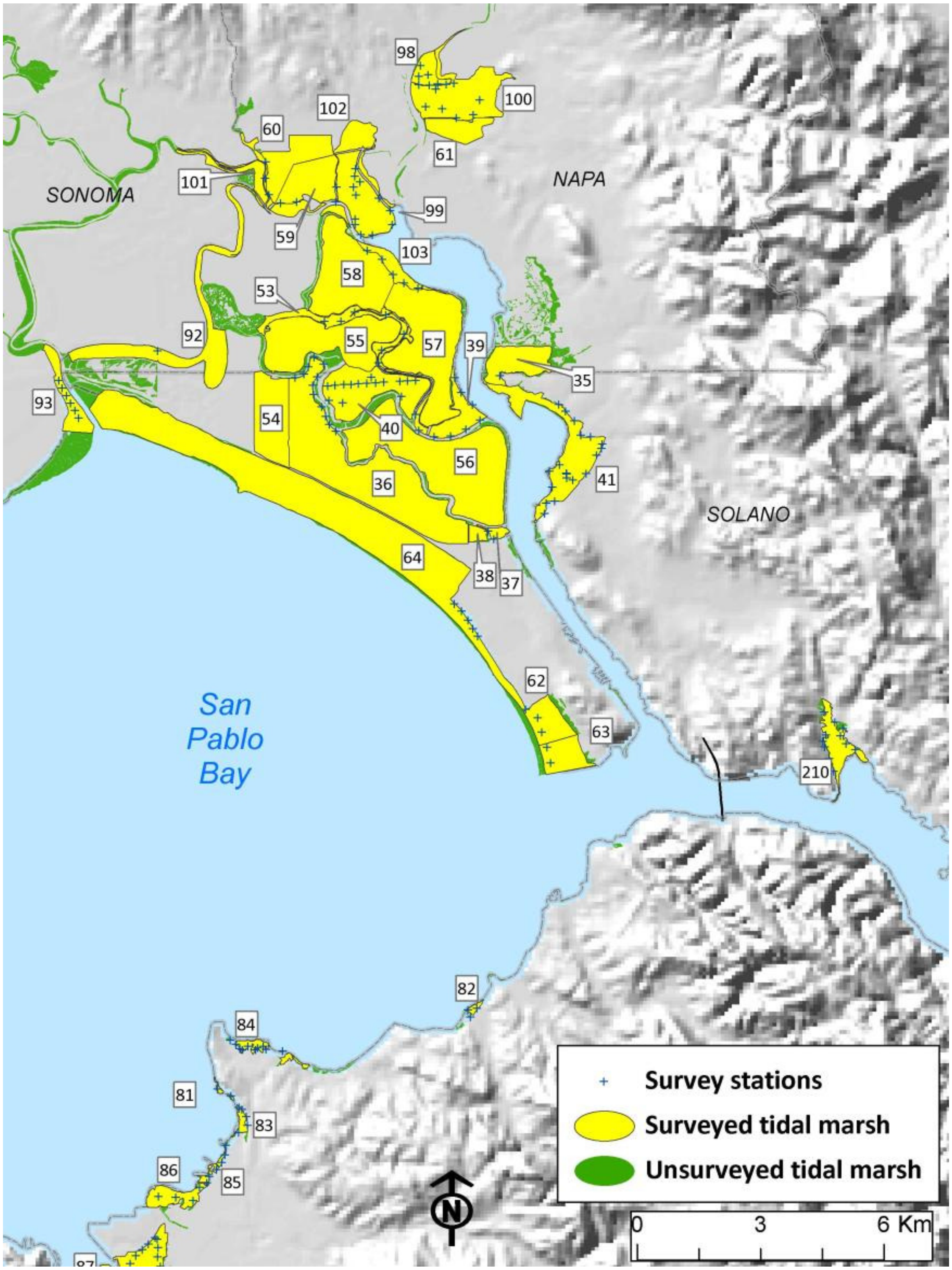


Figure 2C. Marshes of Suisun Bay. Marshes in green may have been surveyed using other protocol.

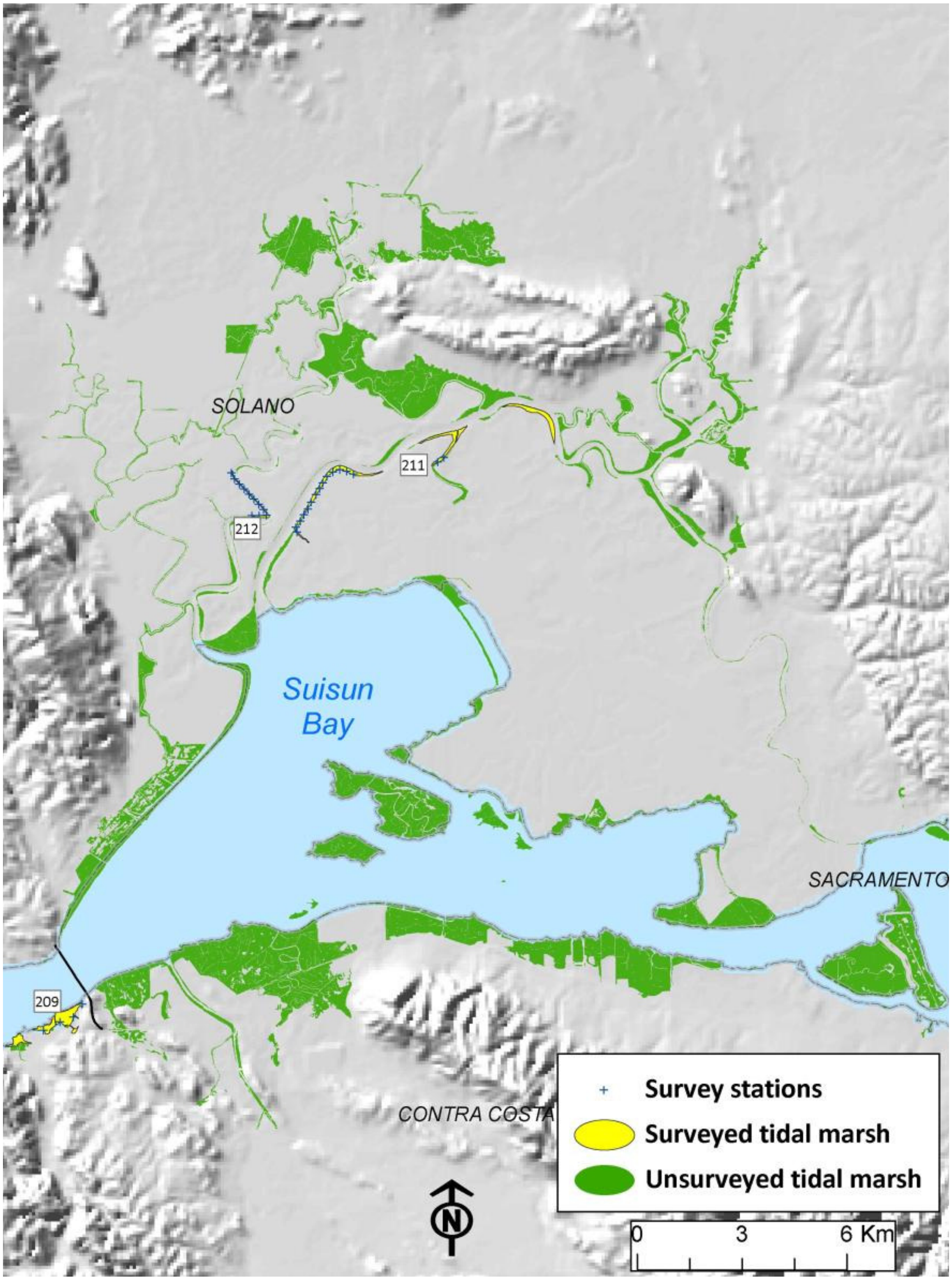


Figure 2D. Marshes of Central San Francisco Bay and southeast San Pablo Bay. Marshes in green may have been surveyed using other protocol.

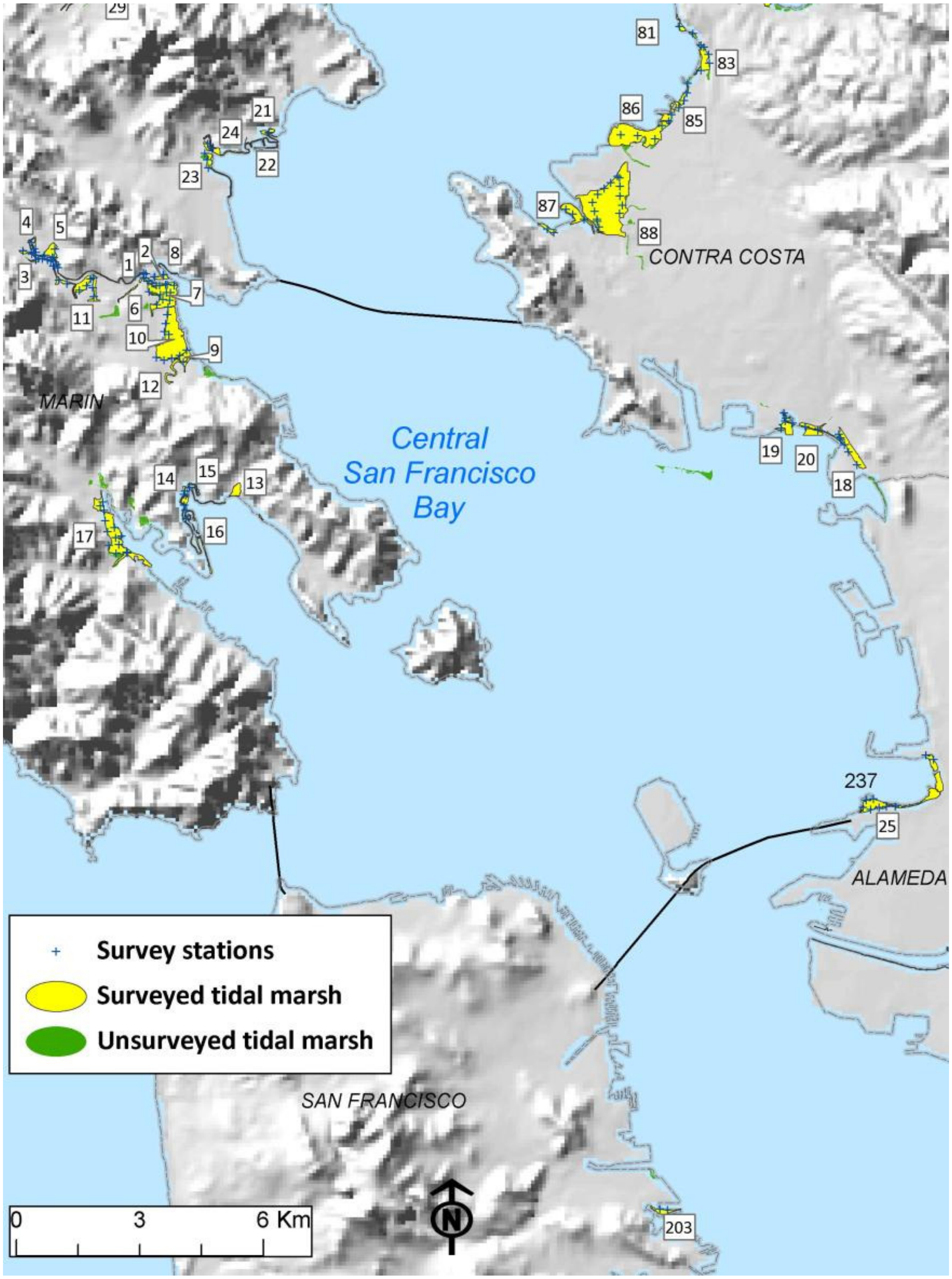


Figure 2E. Marshes of Oakland, San Leandro Bay, and Hayward shoreline. Marshes in green may have been surveyed using other protocol.

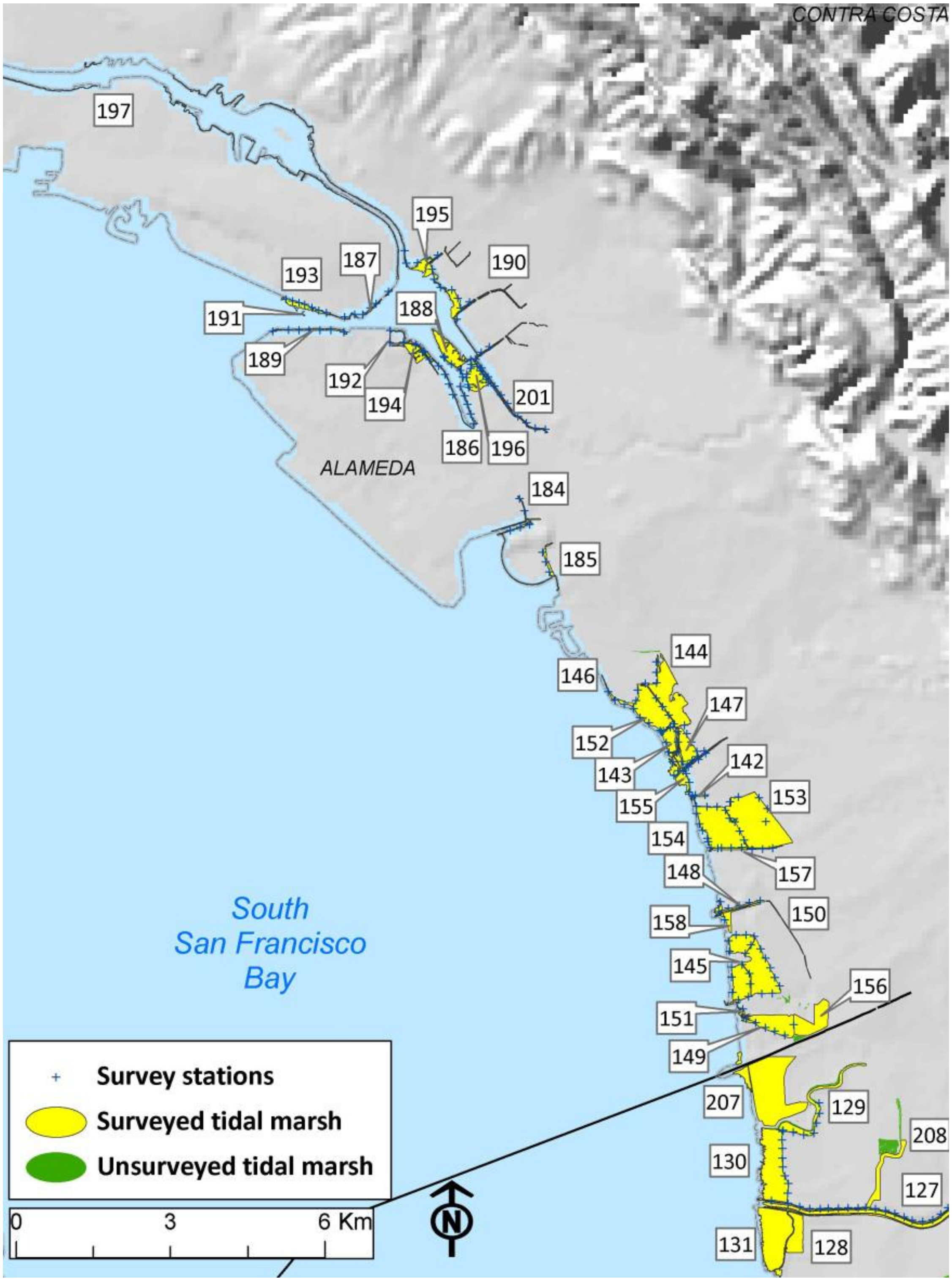


Figure 2F. San Mateo shoreline marshes. Marshes in green may have been surveyed using other protocol.

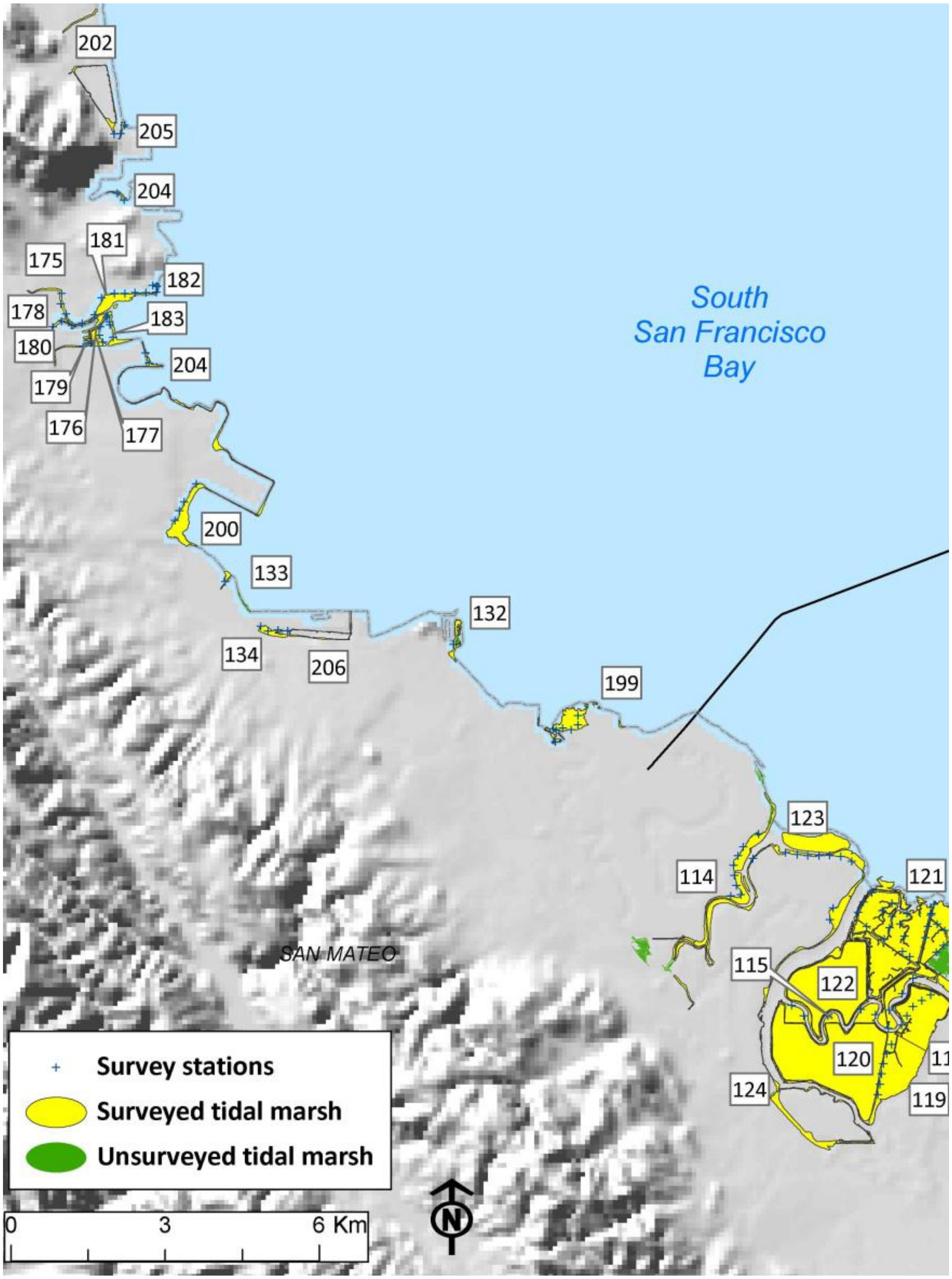


Figure 2G. Marshes of South San Francisco Bay; details of Eden Landing, Don Edwards SFBNWR, Palo Alto. Marshes in green may have been surveyed using other protocol.

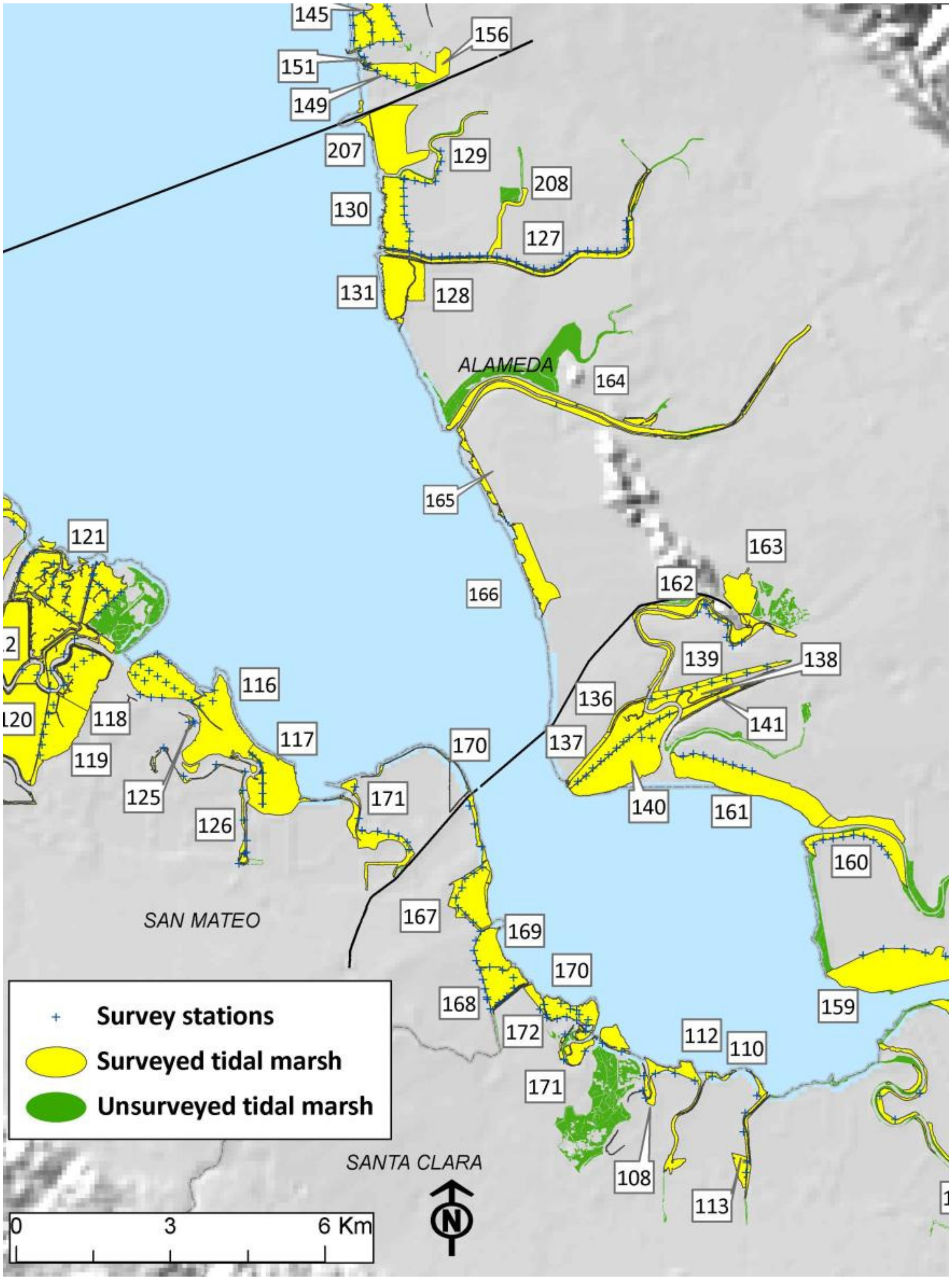


Figure 2H. Marshes of South San Francisco Bay; details of Mowry/Calaveras and Alviso marshes. Marshes in green may have been surveyed using other protocol.

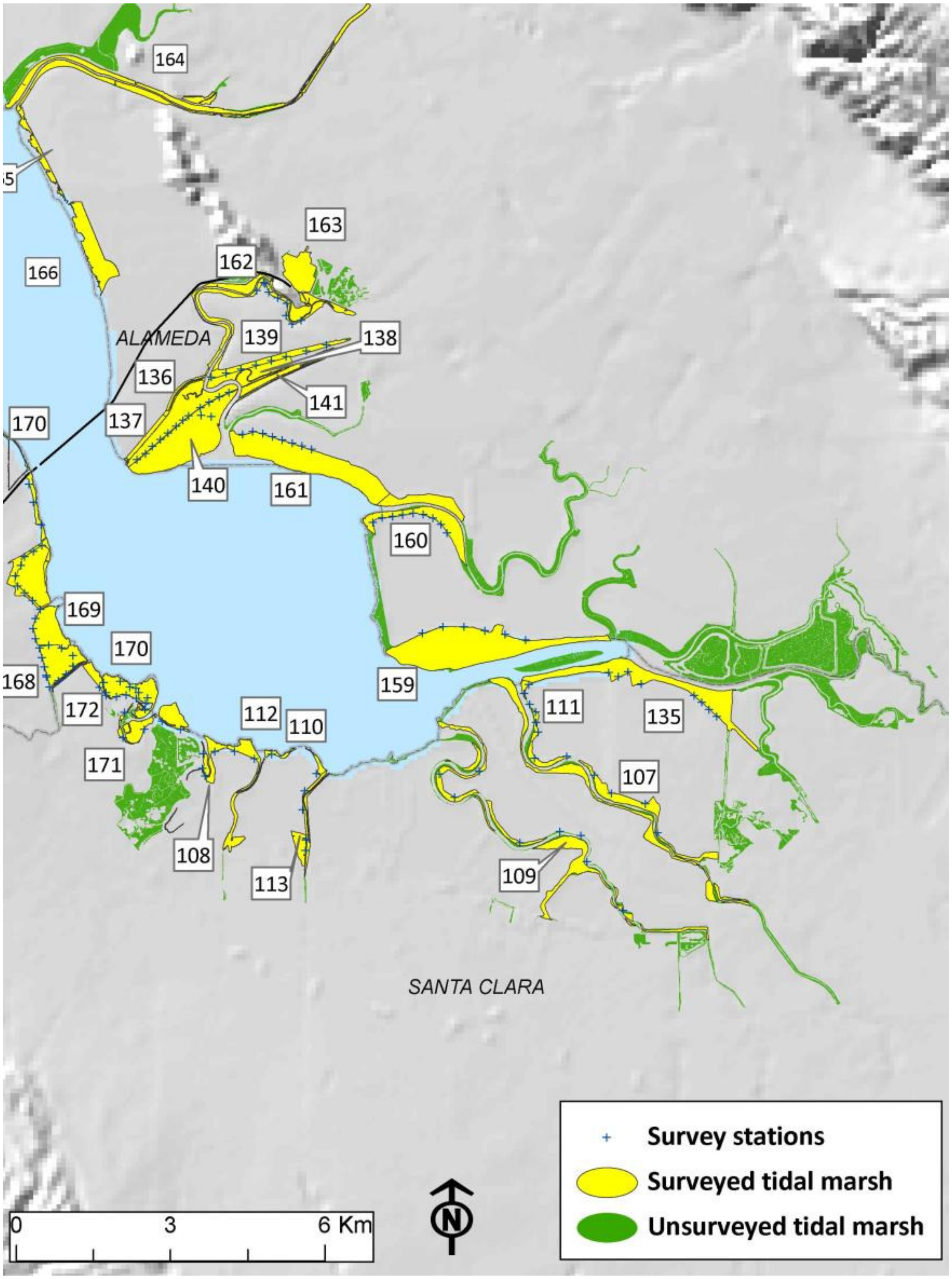


Figure 3. Effect of day of the year (i.e., Julian day) on probability of California Clapper Rail detection in the Estuary. Probability of detection peaks mid-February.

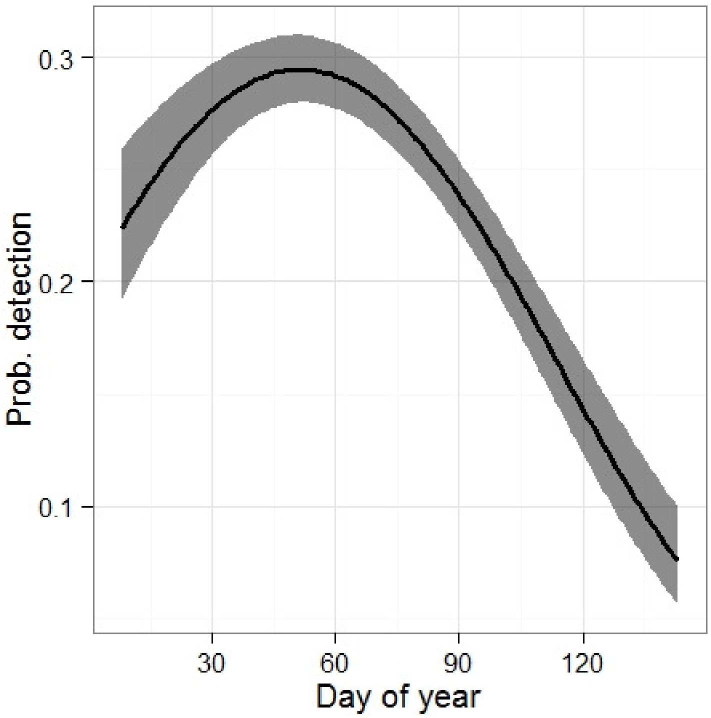


Figure 4. Effect of time to sunrise or sunset on probability of California Clapper Rail detection in the Estuary. Negative values mean minutes before sunrise or minutes after sunset, while positive values mean minutes after sunrise or before sunset.

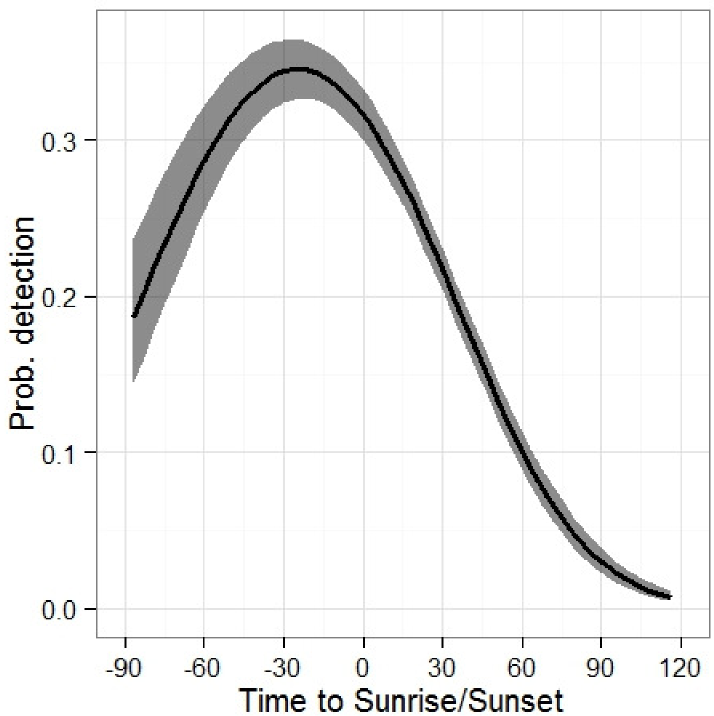


Figure 5. Effect of invasive hybrid *Spartina* cover (%), Spring salinity (practical salinity units - psu) and tidal range (m) on California Clapper Rail density in the Estuary. Proportional abundance is with respect to the mean abundance (i.e., 2 = 2 x mean abundance). Data for the % hybrid *Spartina* cover plot are from South Bay in 2007; data for the Spring salinity and tidal range plots are from North Bay in 2011.

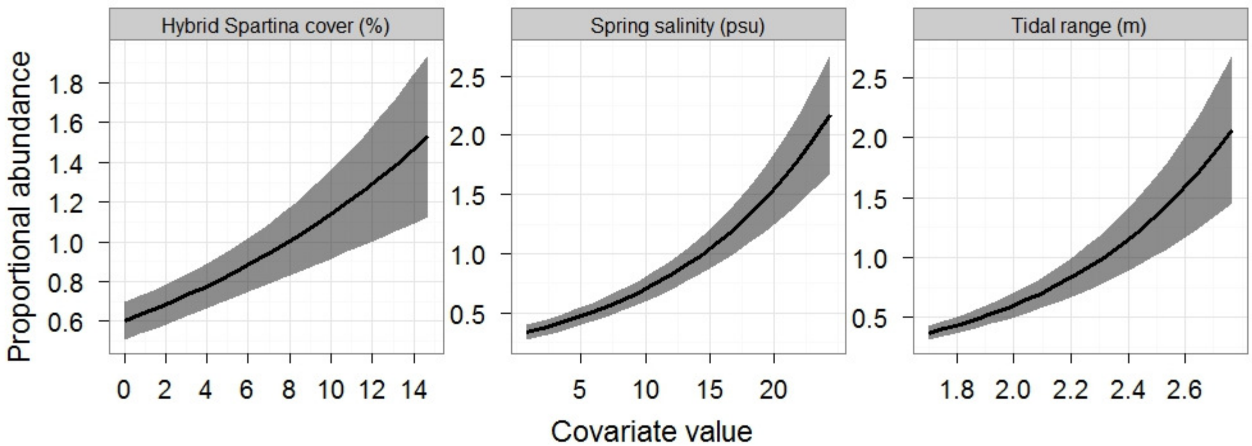


Figure 6. Relationship between marsh size (hectares) and California Clapper Rail density in tidal marshes from tidal marshes around the Estuary (data from marshes in the North Bay for year 2005).

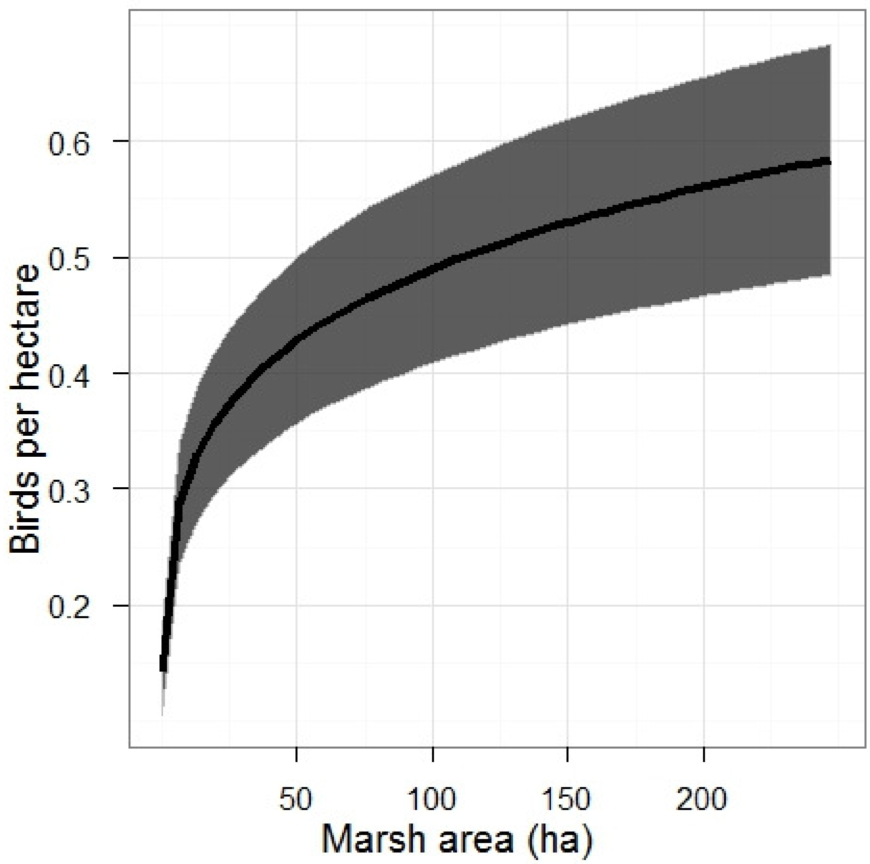


Figure 7. Relationship between marsh shape and California Clapper Rail density from tidal marshes around the Estuary (data from marshes in the North Bay for year 2005). Shape index = log(perimeter)/log(area). A low shape index indicates a more compact marsh shape.

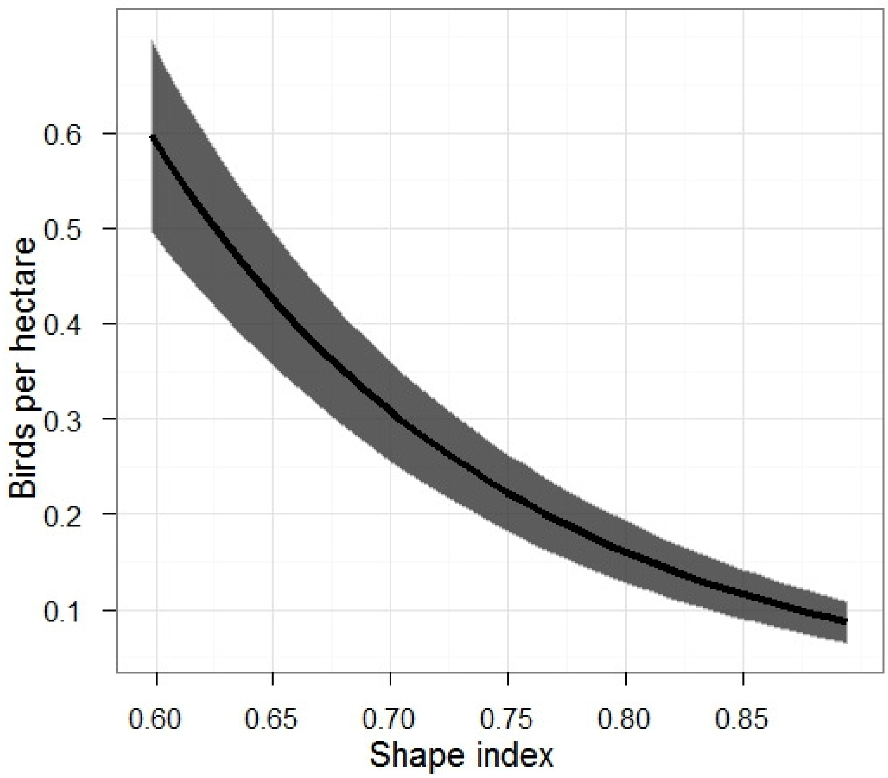


Figure 8. Relationship between age since restoration and California Clapper Rail density for tidal marshes around the Estuary. Density estimates are for each marsh any year surveyed, between 2005 and 2011. The regression spline shown is the best model fit from cross-validation, with only one knot at 18.5 years.

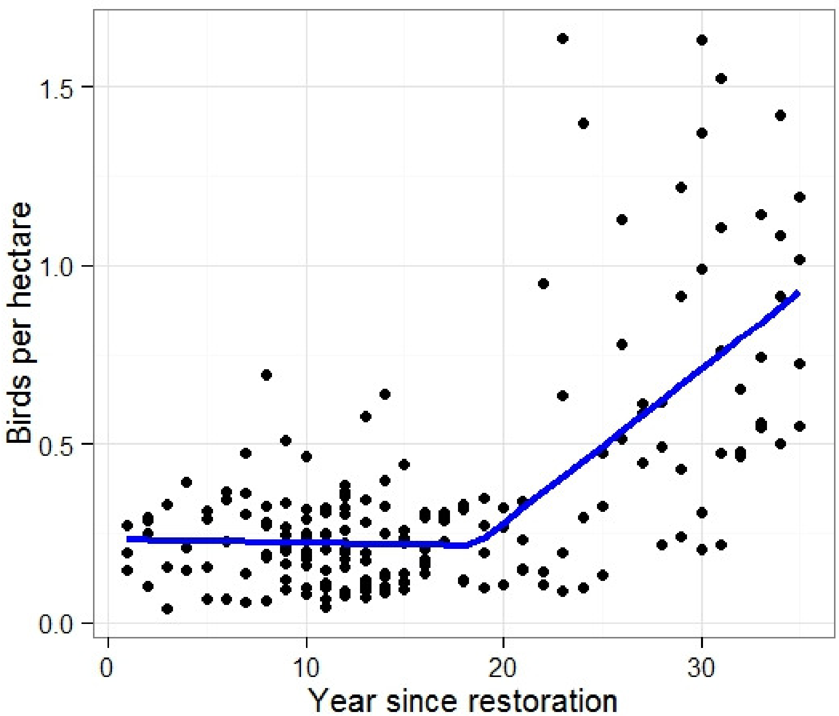


Figure 9A. Site model estimates of California Clapper Rail density in the North Bay.

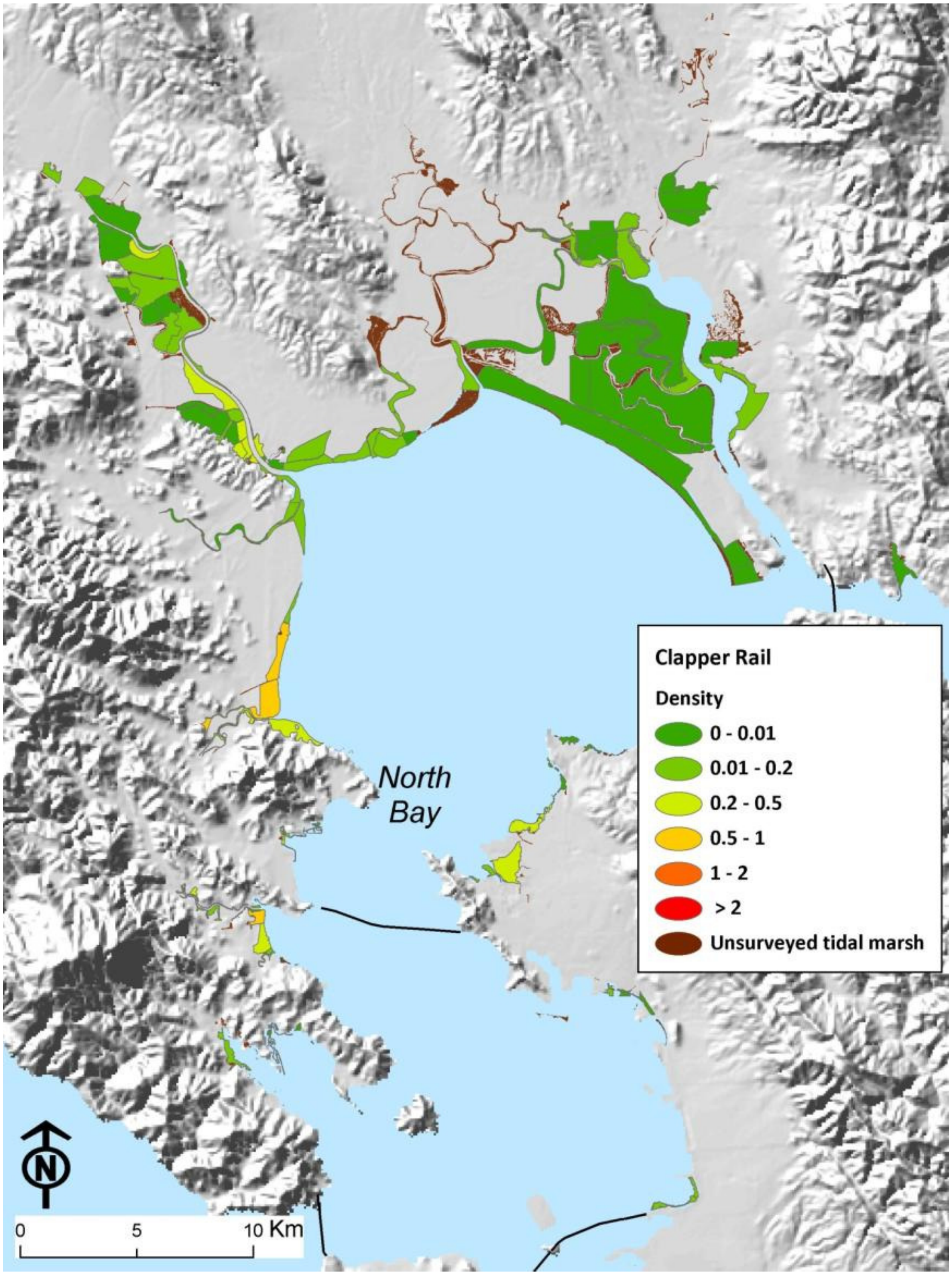


Figure 9B. Site model estimates of California Clapper Rail density in the South Bay.

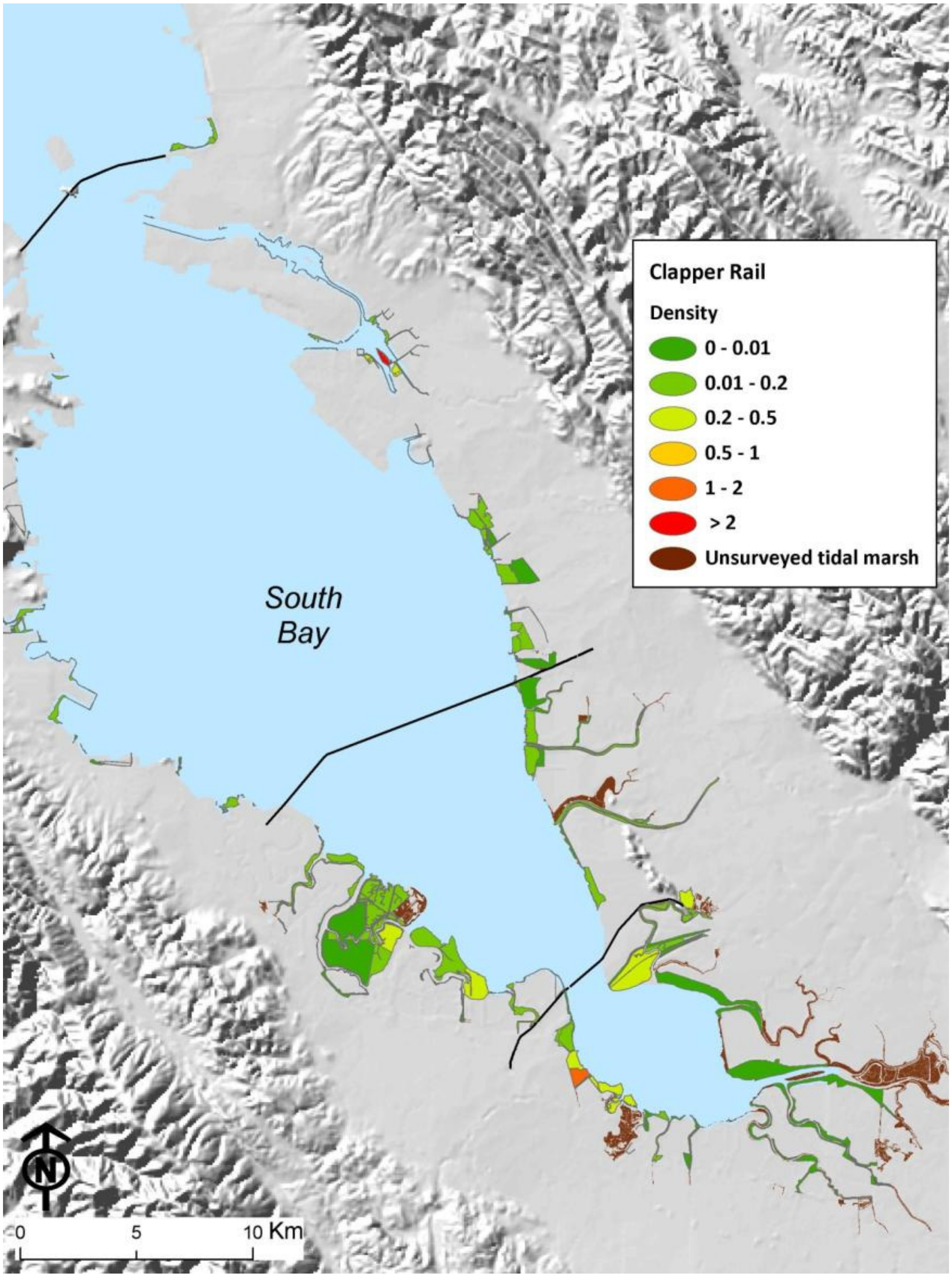


Figure 10A. Trend in California Clapper Rail density in the North Bay and South Bay of Estuary. The error bars represent the standard error of the estimates.

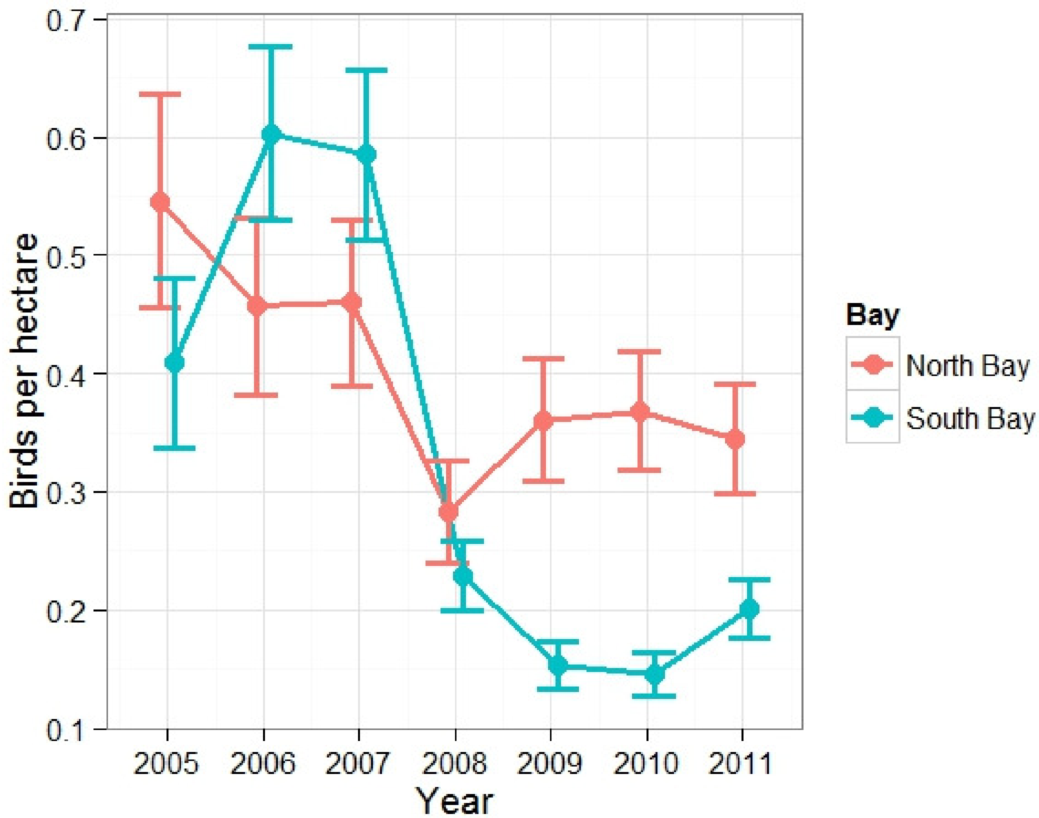


Figure 10B. Trend in California Clapper Rail density for the entire Estuary. The error bars represent the standard error of the estimates.

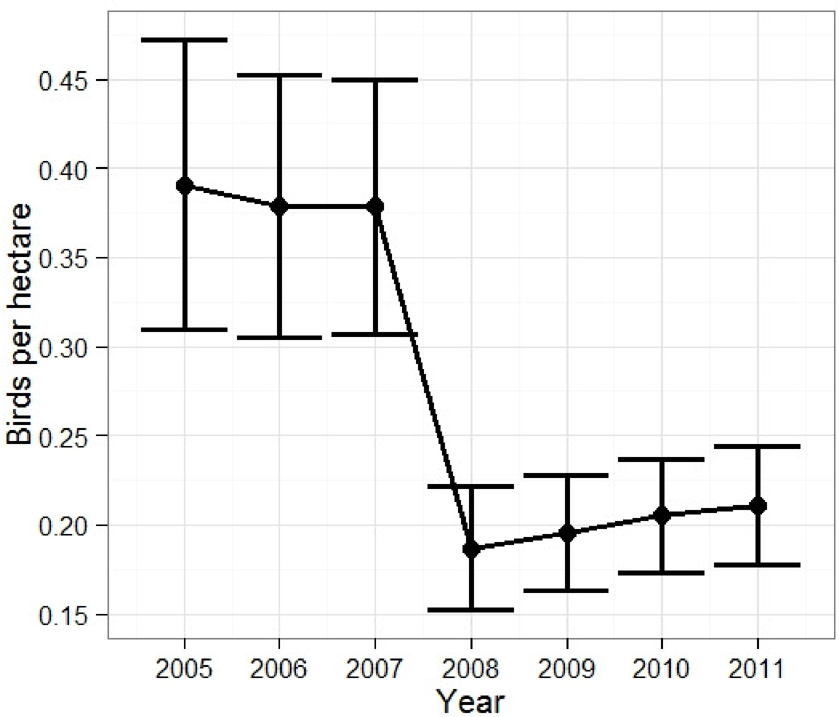


Figure 11. Relationship between channel density (meters of channel/ha of marsh area) and California Clapper Rail density from tidal marshes in the South Bay for year 2011.

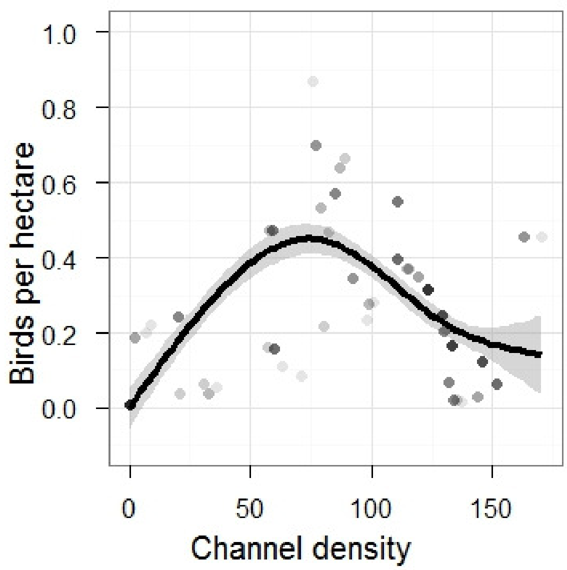


Figure 12. Relationship between percent marsh type (low-, mid- or high-marsh) and California Clapper Rail density from tidal marshes in the North Bay for year 2011. Blue ellipses indicate marsh percentages with highest rail density. Low-marsh = -0.5 to -0.3 m, mid-marsh = -0.2 to 0.1 m, high-marsh = 0.2 to 0.3 m relative to MHHW; all elevation values using NAVD88 as reference.

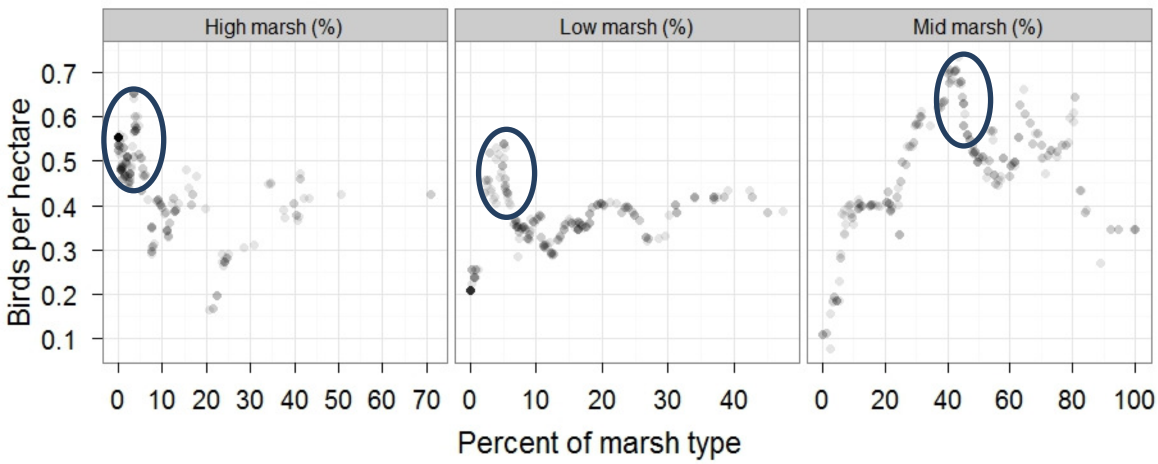


Figure 13. Relationship between tidal range and California Clapper Rail density from marshes in the South Bay for year 2011.

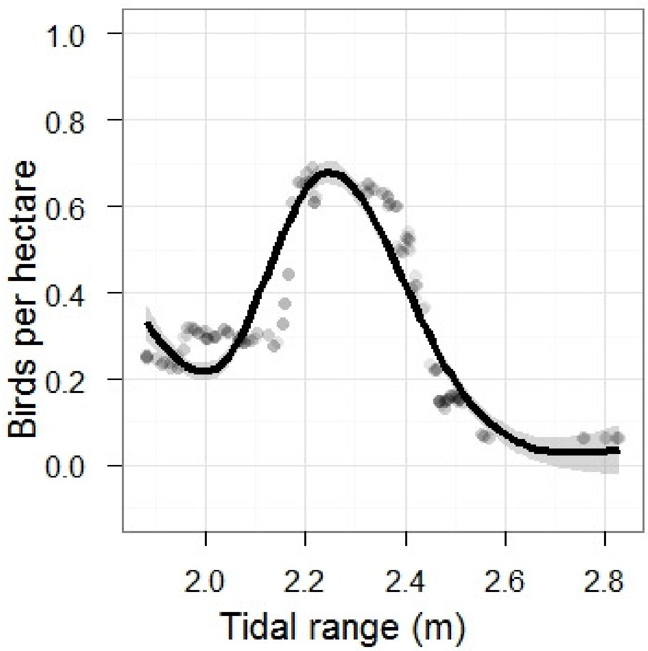


Figure 14A. Estimated density from the landscape model of California Clapper Rail in South Bay of the Estuary

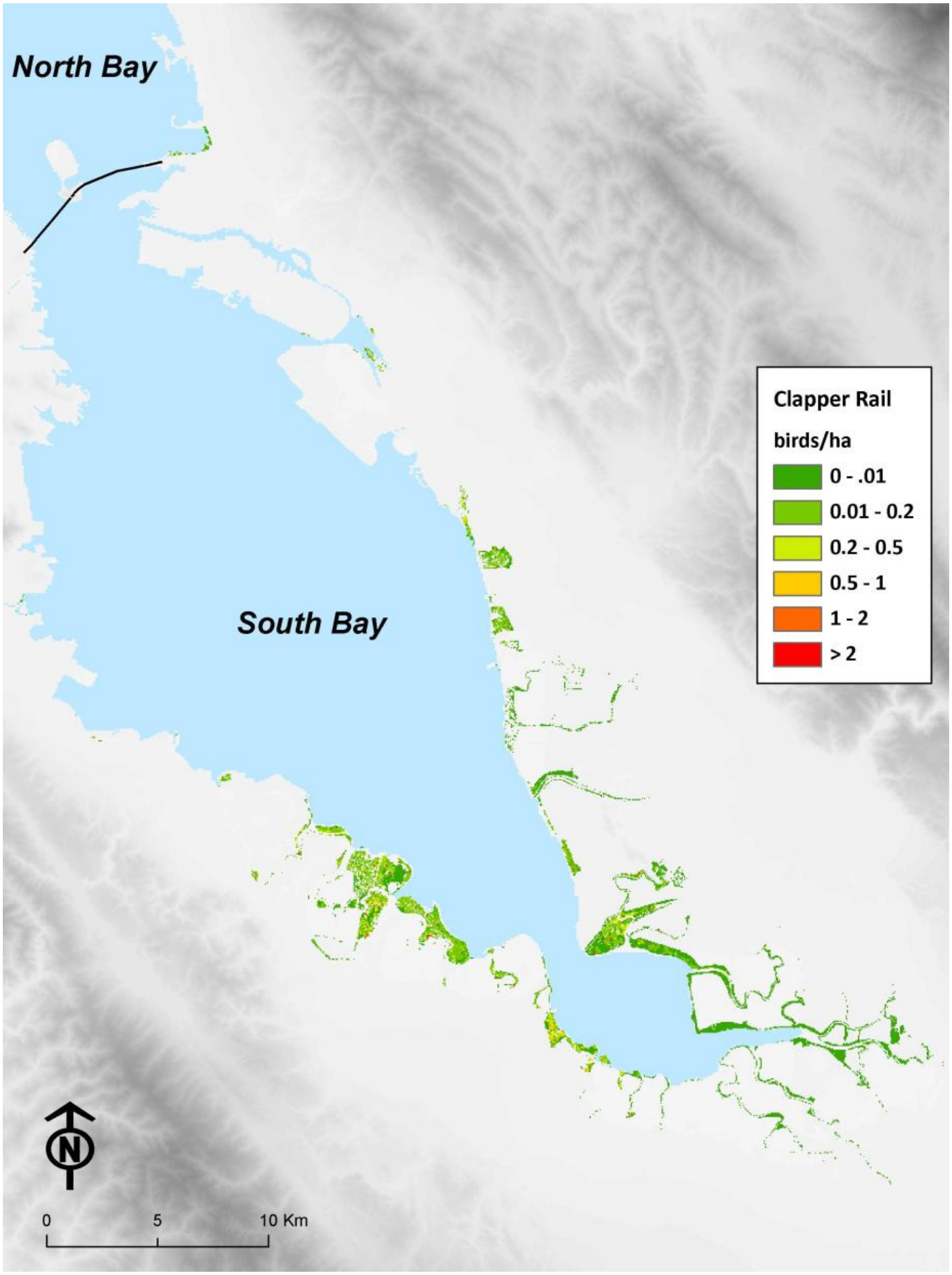


Figure 14B. Estimated density from the landscape model of California Clapper Rail in North Bay of the Estuary.

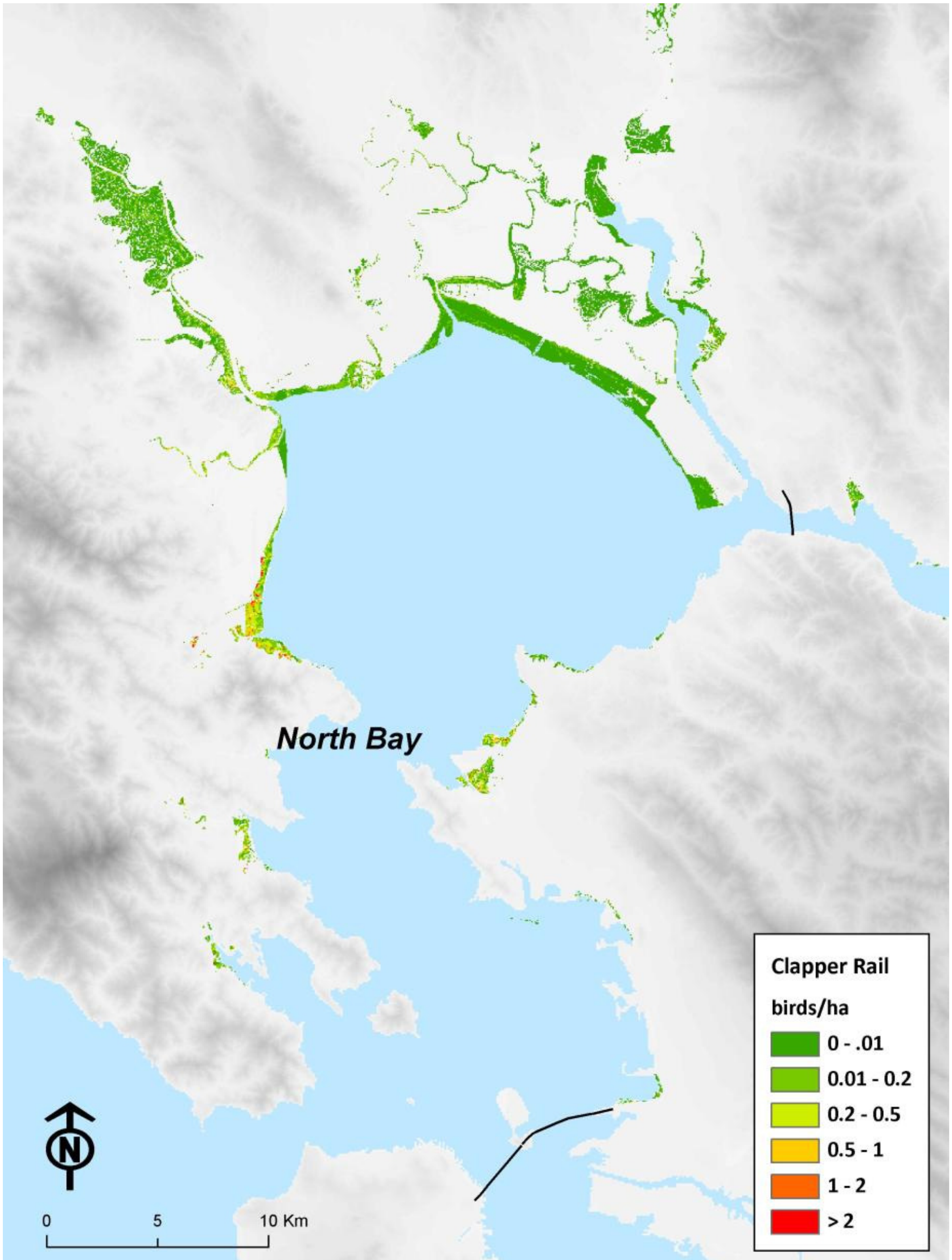
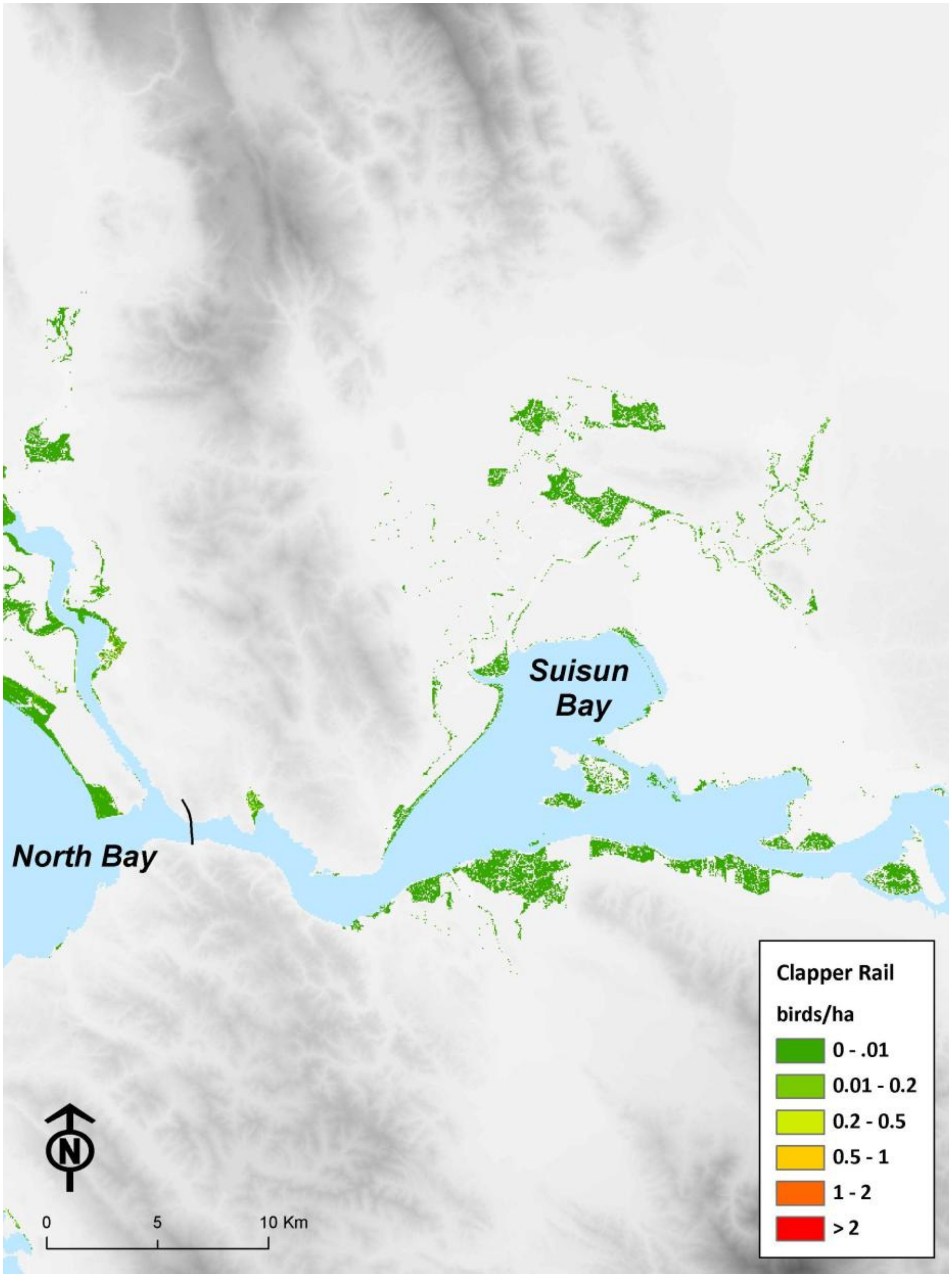


Figure 14C. Estimated density from the landscape model of California Clapper Rail in Suisun Bay of the Estuary.



Appendix 1. Summary of California Clapper Rail survey methods (McBroom 2007).

Type	Protocol Name	Protocol Description
A	Walking Transect Survey	One or more observers move from station to station for 10-minute periods. Three survey rounds, with recording of Clapper Rail vocalizations played on 3rd round if no prior detections.
B	Stationary Survey	Requires one person at each station for 1½ hour. Typically 3 survey rounds, with recording played at end of 3rd round if no prior detections.
C	ISP Presence/Absence Survey	Used to determine presence or absence of CLRA at sites slated for *Spartina* control. Same as Type A, except recording can be played from first survey round, and surveys can be discontinued upon detection.
D	DESFBNWR Modified Transect Survey	Used by DESFBNWR biologist in narrow strip marshes with medium to high rail density - Similar to Type C, except densities are extrapolated by Refuge biologist.
E	Winter High Tide Survey	CLRA are flushed out of marsh habitat by airboat and counted during winter high tide.

Appendix 2. Comparison of the density (birds per hectare) of California Clapper Rail at 15 different marshes in the Estuary, between estimates from 1992-1993, 2005-2008, and 2009-2011.

Marshes	ID	Density 1992-93	Density 2005-08	Density 2009-11	% change 1992-93 2005-08	% change 1992-93 2009-11
Mare Island Point	62, 63	0.118		0.00001		-100.0%
Strip Marsh (Boxer Marsh)	64	0.000		0.00002		
Pt. Pinole North	84	0.040	0.000	0.00001	-99.9%	-100.0%
Pt. Pinole South	83	0.123	0.000	0.00002	-100.0%	-100.0%
Hamilton shore	30, 33	0.675	0.281	0.23806	-58.3%	-64.7%
Wildcat Creek	88	0.070	0.294	0.23116	320.5%	230.2%
Muzzi Marsh	10	0.184	0.788	0.41263	328.3%	124.3%
Heerdt Marsh	7	0.293	0.918	0.66642	212.9%	127.2%
Creekside marsh	5	0.080	0.741	0.40621	826.4%	407.8%
Gallinas Ck. area	26, 27, 29, 32	0.197	0.833	0.56426	322.4%	186.0%
Novato Ck./ Sonoma Baylands	65, 66, 80, 89, 94	0.211	0.132	0.11155	-37.4%	-47.2%
Sonoma Crk. mouth	93	0.270	0.156	0.05746	-42.3%	-78.7%
White Slough	41	0.299	0.169	0.06434	-43.4%	-78.5%
Coon Is.	99	0.190	0.299	0.13392	57.5%	-29.5%
Fagan Slough	98, 100	0.040	0.000	0.00002	-99.9%	-100.0%

Appendix 3. Comparison of site model and landscape model estimates of California Clapper Rail abundance by marsh complex in the Estuary. Results for selected complexes.

Marsh complex	Site model 2009-11 abundance	Landscape model abundance	Difference	% difference
Segment d Napa	44.05	15.47	-28.58	-64.9%
Segment e Petaluma River to Sonoma Creek	14.48	21.58	7.10	49.0%
Segment f Petaluma River	150.65	58.83	-91.81	-60.9%
Segment g China Camp to Petaluma River	235.60	648.11	412.51	175.1%
Segment h Point Pinole	47.95	168.53	120.58	251.4%
Segment i Corte Madera	59.52	21.77	-37.75	-63.4%
Segment j San Francisco	6.17	0.06	-6.11	-99.0%
Segment k Oakland	8.84	4.85	-3.99	-45.1%
Segment l Berkeley	4.09	2.04	-2.05	-50.1%
Segment m San Mateo	9.11	25.78	16.67	183.0%
Segment n Bair-Greco-Ravenswood	166.10	140.48	-25.62	-15.4%
Segment o East Palo Alto-Guadalupe Slough	89.96	86.12	-3.84	-4.3%
Segment q Mowry-Dumbarton	49.39	73.63	24.24	49.1%
Segment r-s Hwy 84 to Hwy 92	3.45	0.08	-3.37	-97.7%
Segment t Cogswell-Hayward Shoreline/Oro Loma/Robert's Landing	27.24	29.87	2.63	9.7%