State of the Estuary Report 2015

Summary

HABITAT – Tidal Marsh

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1. Brief description of indicator and benchmark

Attribute	Indicator	Benchmarks
Tidal marsh	Regional extent	The benchmark for tidal marsh regional extent in the Bay is 100,000 acres (a goal established by the 1999 *Baylands Ecosystem Habitat Goals Report* and approximately half the acreage circa 1800). A benchmark for tidal marsh regional extent in the Delta has not yet been determined. For context, we instead compare the current regional extent of Delta tidal marsh against three reference values: (1) half the tidal marsh acreage circa 1800 (~180,000 acres), (2) the current area of tidal marsh plus the area of diked land at intertidal elevations (~78,000 acres), and (3) the current area of tidal marsh plus the maximum acreage of tidal marsh restoration called for in the state's near-term habitat restoration initiative *California Eco Restore* (~17,000 acres).
Tidal marsh	Patch sizes	The benchmark is the historical (circa 1800) size distribution of tidal marsh patches, as measured by the percentage of tidal marsh area belonging to a patch >200 ha in size.

2. Indicator status and trend measurements

Indicator	Status	Trend	Details
Tidal marsh- Regional extent	Fair (Bay) to poor (Delta)	Improving	The historical decline of the Estuary's tidal marshes has ended and gradual restoration is underway, but there is still a long way to go. In the Bay, the extent of tidal marsh acreage is approximately halfway to the regional goal of 100,000 acres. In the Delta, where restoration efforts currently trail those underway in the Bay, the regional extent of tidal marsh is only a fraction of the historical acreage and clear regional goals are still needed (regional planning efforts are currently underway). There is now substantially less tidal marsh in the Delta than in the Bay (a reverse of the historical distribution).
Tidal marsh- Patch sizes	Good (Bay) to poor (Delta)	Unknown	In the Bay, the proportion of tidal marsh area belonging to patches large enough to support certain key ecological functions is very close to historical levels. In the Delta, however, this proportion has been reduced by more than two-thirds. More data are needed to determine recent trends.

3. Brief write-up of scientific interpretation

Tidal marsh- Regional extent

- *Provide 2-3 sentences to answer the question: What is this indicator?*

The regional extent of tidal marsh measures the combined area of all tidal marshes in the estuary and is derived from detailed maps of the estuary's wetlands. We report the regional extent of marsh in the Bay and the Delta separately.

- *Provide 2−3 sentences to answer the question: Why is it important?*

The regional extent of tidal marshes matters because many of the ecological and hydrological benefits they provide increase along with marsh extent. Put simply, as the total area of tidal marsh in the Estuary increases, so does the abundance and diversity of the plants and animals that utilize marshes, as well as the ecosystem services marshes provide for flood control, water quality, and recreation. Increasing the regional extent of marsh across the whole Estuary—from the South Bay to the North Delta—will ensure that marsh habitat exists along the full length of important ecological gradients (such as tidal influence, salinity, and vegetation), providing a range of options for marsh species. Tidal marshes in the Bay (which are salty or brackish) are not the same as tidal marshes in the Delta (which are fresh)—they have different physical characteristics, support different assemblages of plants and animals, and are subject to different stressors. Restoration in both regions is critical to provide the full suite of ecological functions provided by tidal marshes in the Estuary.

- *Provide 2−3 sentences to answer the questions: What is the benchmark? How was it selected?*

We utilize separate methods to evaluate the regional extent of tidal marsh in the Bay and in the Delta. For the Bay, we use a benchmark of 100,000 acres, a long-term tidal marsh acreage goal put forth by the 1999 *Baylands Ecosystem Habitat Goals Report*. This goal was the culmination of science-based public process that sought to evaluate the habitat needs of representative species and to identify changes needed to improve the Bay's ecological functioning and biodiversity. It is approximately half of the tidal marsh area that existed in the Bay at the beginning of the 19^{th} century. A scoring break between Fair and Poor was arbitrarily (?) set at 50,000 acres, or half of the benchmark.

Since no similar quantitative goals exist for tidal marsh regional extent in the Delta, we instead provide three different reference values for context for a benchmark and goal that is yet to be set. (1) 180,000 acres or approximately half of the tidal marsh area that existed in the Delta at the beginning of the 19^{th} century. This value is comparable to the one used to assess the regional extent of tidal marsh in the Bay. (2) 78,000 acres or the current area of tidal marsh plus the approximate area of diked lands in the Delta that are at intertidal elevations. This is the current area that would fall between high and low tide in the absence of levees and other water control structures and therefore exists at the right elevation for tidal marsh formation in the Delta. This acreage does not account for what percentage of the area will actually be available for restoration given other priority land uses. (3) 17,000 acres or the maximum area of tidal marsh that would exist in the Delta if the near-term habitat restoration goals laid out in the current version of *California Eco Restore* (the State's 5-year initiative for coordinating habitat restoration in the Delta) are met.

Provide 2−3 sentences to answer the question: What is the status and trend for this indicator?

The regional extent of tidal marsh in the Bay is characterized as "fair." In 2009 (the last year with standardized data), there were approximately 45,000 acres of tidal marsh in the Bay, which is 45% of the 100,000 acre goal. Since 2009, an additional 6,300 acres of land in the Bay have been opened to the tides. Much of this restored habitat is expected to transition into to tidal marsh in the future and, if counted in full, would bring the regional extent of tidal marsh to 51% of the 100,000 goal.

The regional extent of tidal marsh in the Delta is characterized as "poor." In 2002 (the last year with standardized data), there were approximately 8,000 acres of tidal marsh in the Delta. This area is only 4% of the 180,000 acre reference value (half the tidal marsh area circa 1800), 10% of the 78,000 acre reference value (the current area of tidal marsh plus the approximate area of diked lands in the Delta that are at intertidal elevations), and 47% of the 17,000 acre reference value (the maximum area of tidal marsh that would exist in the Delta if the near-term habitat restoration goals laid out in the current version of *California Eco Restore* are met). Although 260 acres of tidal wetlands have been restored since 2002, this relatively small area increases the percentages noted above by less than 2 percentage points.

- *Provide 4−6 sentences to answer the questions: What does it mean? Why do we care?*

In the Bay, the area of tidal marsh continues to increase towards the regional goal of 100,000 acres. A major milestone was passed in January 2015, when the levees of Cullinan Ranch were breached and the area of existing tidal marshes plus restored intertidal wetlands (much of which are expected to eventually develop into tidal marsh) moved past the goal's halfway mark of 50,000 acres. Looking forward, an additional approximately 24,000 acres of tidal marsh habitat in the Bay are currently planned as part of restoration, enhancement, and mitigation projects that have already been funded and/or permitted and therefore have a high probability of completion within the next 20-30 years.

Tidal marsh restoration efforts in the Delta trail those underway the Bay, as evidenced by the disparity in acres restored since the last standardized datasets indicating the extent of tidal marsh were produced. Part of this disparity can be explained by the extensive "subsidence" (sinking) of the Delta's peat islands—while these extensive areas once supported tidal marsh, many now sit 10-25 ft. below sea-level at an elevation that is much too low for tidal marsh vegetation establishment. (Subsidence is generally not as extreme in the Bay, although there are some diked areas in both North and South Bay where surface elevations would need to be increased to restore tidal marsh habitat). Because of the magnitude of subsidence in the Delta, lands that are at proper elevations for tidal marsh restoration are generally limited to the Delta periphery. Despite this, analyses of the landscape suggest that there are approximately 70,000 acres in the Delta of diked lands at the proper elevation for tidal marsh vegetation establishment. Looking forward, restoration and mitigation projects expected to break ground within the next two years would, if successful, add approximately 4,650 acres of tidal marsh to the current total. Clear regional habitat goals are still needed for the Delta in order to evaluate restoration progress. Planning efforts facilitated by the Delta Conservancy are currently underway.

Scientists are uncertain about how the Estuary's tidal marshes will fare in the future as sea-level rises ever more quickly. Although the Bay-Delta's tidal marshes have generally kept pace with sea-level rise over the las several thousand years, the rate of sea level rise and available sediment supply will have a major influence on whether they can continue to do so through the end of the century. Modeled scenarios of high sea-level rise rates and low sediment supply, which the latest evidence suggests is a likely trajectory, project that Bay tidal marshes will be unable to keep pace with rising tides and that their total regional extent will decrease; under scenarios of relatively low sea-level rise rates and high sediment supply, the total regional extent is projected to increase. Although similar projections have not been developed for the Delta, its tidal freshwater marshes (which have higher rates of organic matter production) are expected to be less sensitive to reduced sediment availability than the Bay's tidal salt marshes. Projections that assume marsh accretion can keep pace with estimated rates of sea-level rise in the Delta show an increase in the regional extent of tidal marsh over the next 50 years (assuming no major levee failures).

Tidal marsh- Patch sizes

- *Provide 2-3 sentences to answer the question: What is this indicator?*

Unlike the regional extent indicator, which assesses the total area of tidal marsh habitat, the tidal marsh patch sizes indicator assesses the size of individual patches of tidal marsh habitat in the Bay and Delta. Specifically, it measures the *distribution* of tidal marsh habitat into patches of different sizes by measuring the percentage of tidal marsh habitat belonging to patches larger than a particular size threshold. For the sake of this analysis we measure the proportion of total tidal marsh area belonging to patches >200 ha in size, a value that seems to be important for supporting the maximum possible densities of certain tidal marsh birds in the Estuary.

- *Provide 2−3 sentences to answer the question: Why is it important?*

The size of tidal marsh patches matters because when larger marshes are fragmented into smaller ones, their value as wildlife habitat tends to decrease. Larger marshes are more likely than smaller marshes to support a mosaic of marsh features (e.g., high marsh, low marsh, marsh pans), buffer native wildlife from nonnative predators, and have well developed tidal channel networks.

- *Provide 2−3 sentences to answer the questions: What is the benchmark? How was it selected?*

We developed a benchmark for both tidal marsh and tidal flat size by assuming that the historical distribution tidal marsh habitats is an appropriate measure for healthy tidal marsh habitats in the Estuary today. Considering this, the benchmark is the historical (circa 1800) size distribution of tidal marsh patches, as measured by the proportion of tidal marsh area belonging to a patch >200 ha in size. The benchmark is met if the current proportion is at least 80% of the historical proportion (measured separately for the Bay and Delta). A scoring break between Fair and Poor was arbitrarily (?) set at 40% of the historical proportion, or half of the benchmark.

- *Provide 2−3 sentences to answer the question: What is the status and trend for this indicator?*

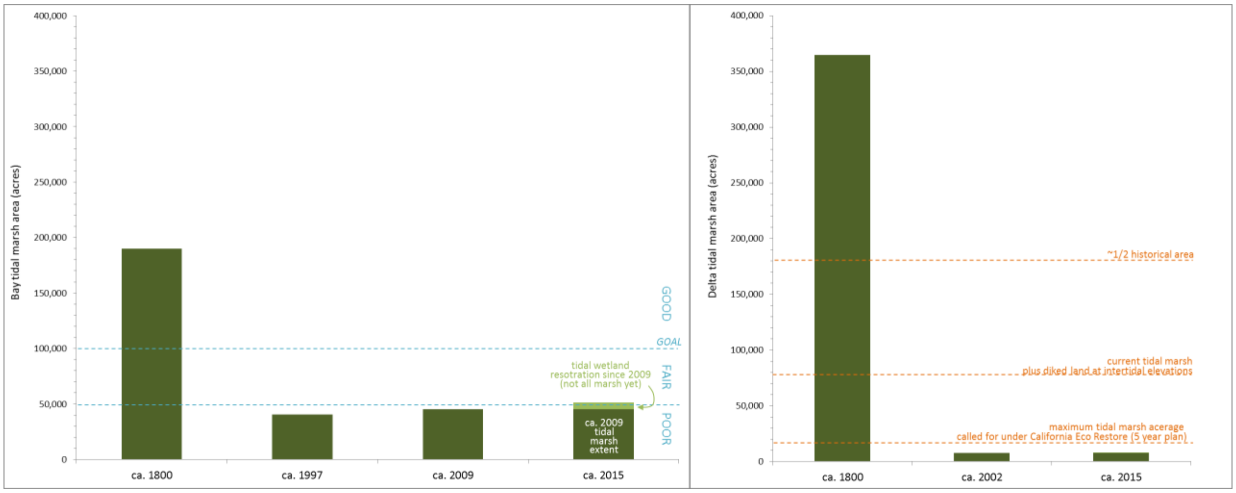
In general, the proportion of tidal marsh area belonging to patches smaller than 200 ha has increased, and the proportion belonging to patches greater than 200 ha has decreased, but this trend is much more pronounced in the Delta than in the Bay. In the Bay, the current proportion of total tidal marsh area belonging to patches greater than 200 ha in size is 88% of the historical proportion (considered "good"). In the Delta, the current proportion is only 30% of the historical proportion (considered "poor").

- *Provide 4−6 sentences to answer the questions: What does it mean? Why do we care?*

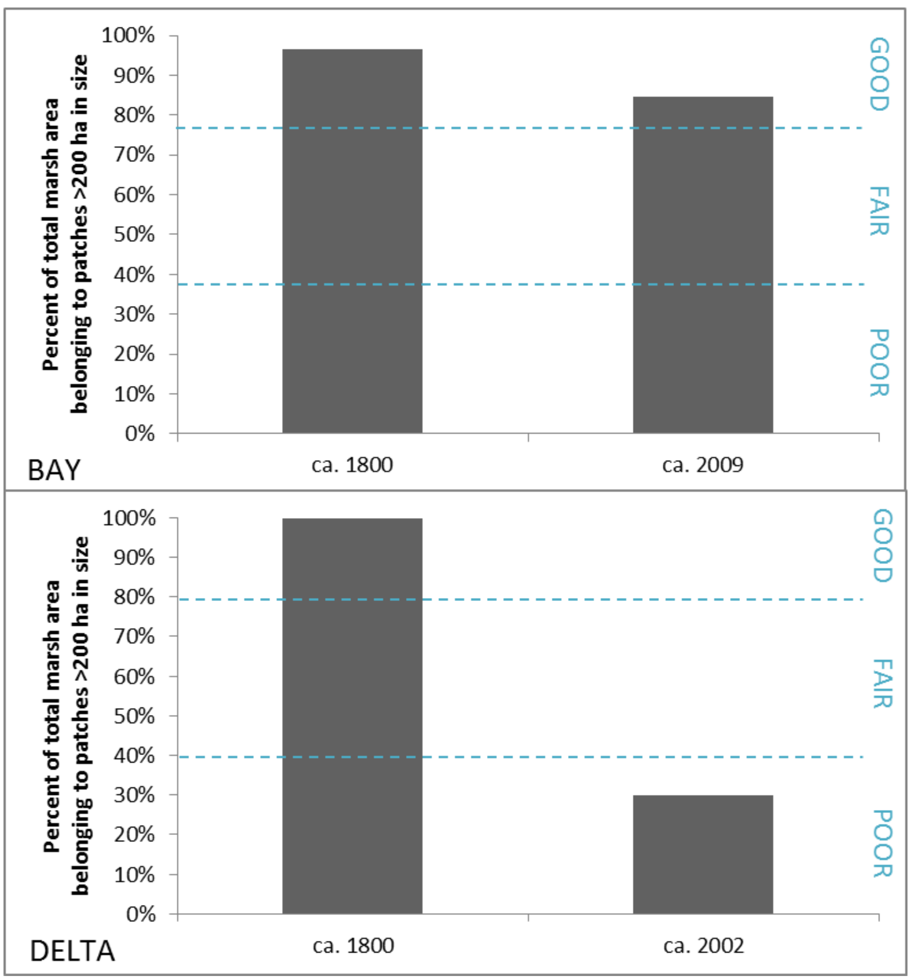
The decrease in the proportion of tidal marsh area belonging to patches greater than 200 ha is expected to have impacted resident tidal marsh birds like the endangered Ridgway's Rail, which only achieves its maximum population density in patches > 200 ha. Other species and ecological functions are likely impacted by the historical trend of fragmentation suggested by this indicator. Fragmented wetlands support smaller wildlife populations because of an increase in the relative proportion of "edge" habitat, with reduced population viability and a greater chance of local extinction within habitat fragments. The fact that the proportion of patches in the Bay larger than 200 ha is almost 90% of the historical proportion is reassuring, reflects the increasing size of individual tidal marsh restoration projects in the Bay over time, and highlights the need to restore and connect larger tidal marsh patches in the Delta.

4. Related figures

<u>Tidal marsh- Regional extent</u>



<u>Tidal marsh- Patch sizes</u>



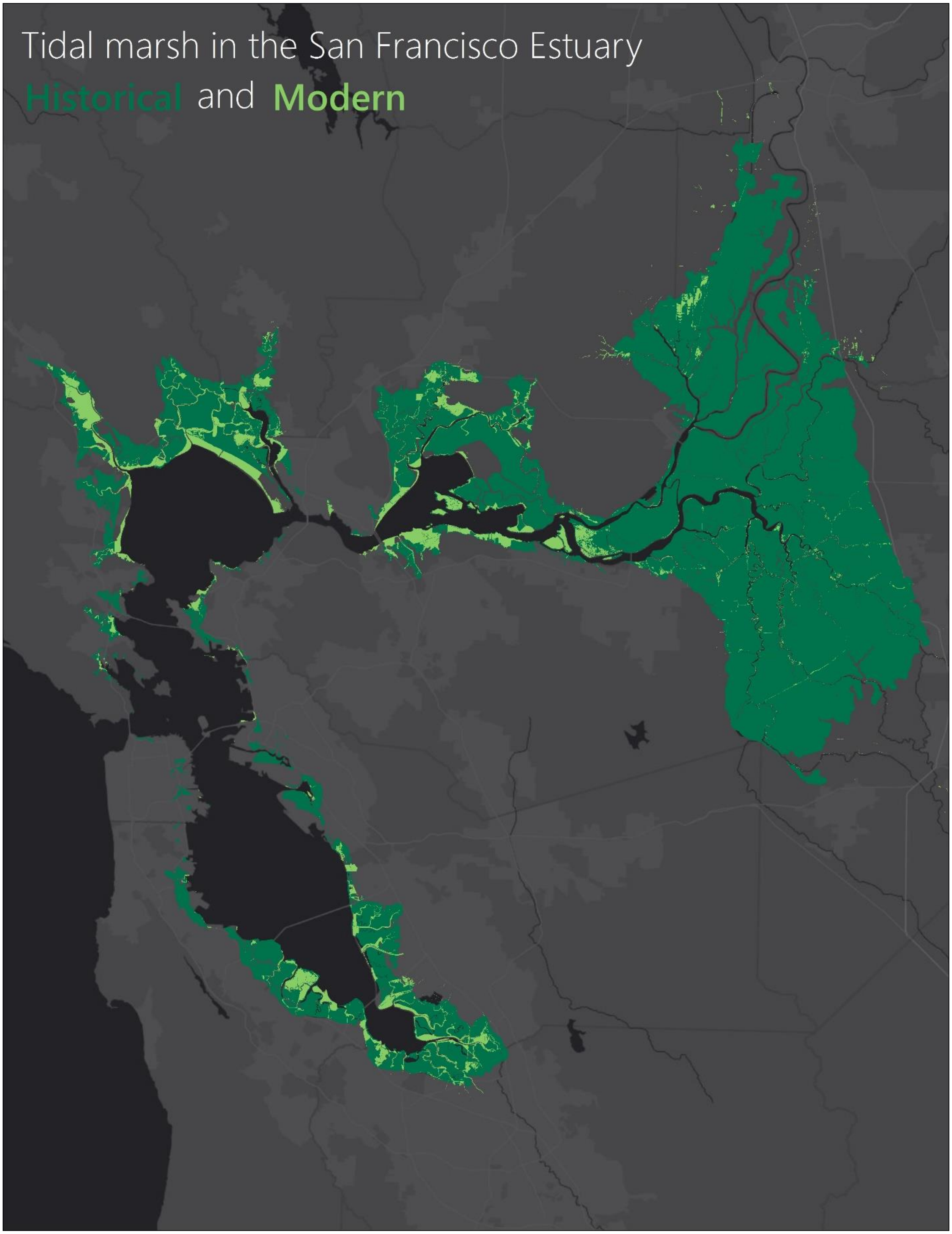
4. Related tables

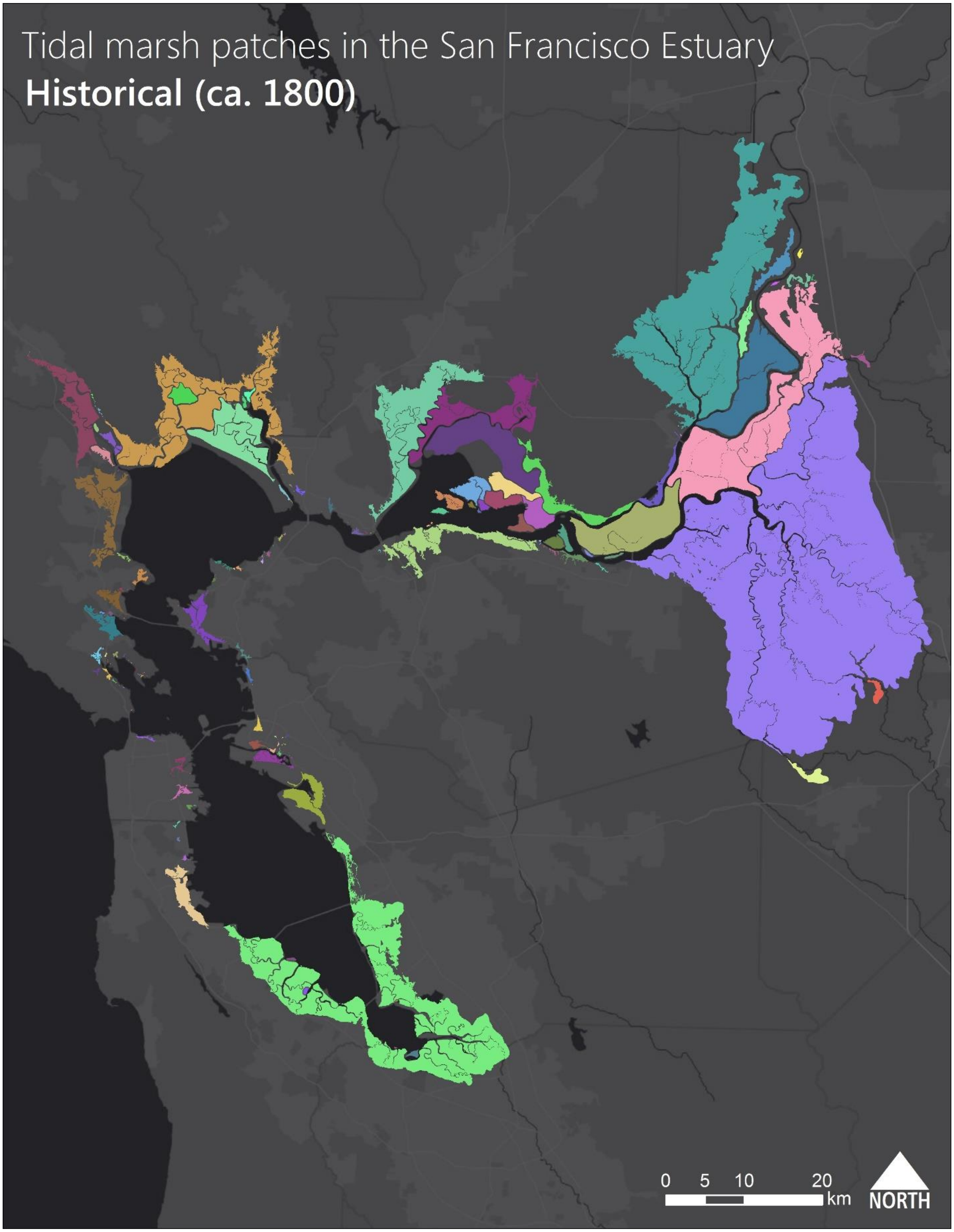
Table 1. Recent tidal wetland restoration. The areas listed below have been opened to tidal action since the datasets utilized in this study were developed (ca. 2009 for the Bay; ca. 2002 for the Delta). Although much of this restored tidal habitat is expected to transition into tidal marsh over time, these sites are not yet included in in the maps and charts summarizing the regional extent of tidal marsh.

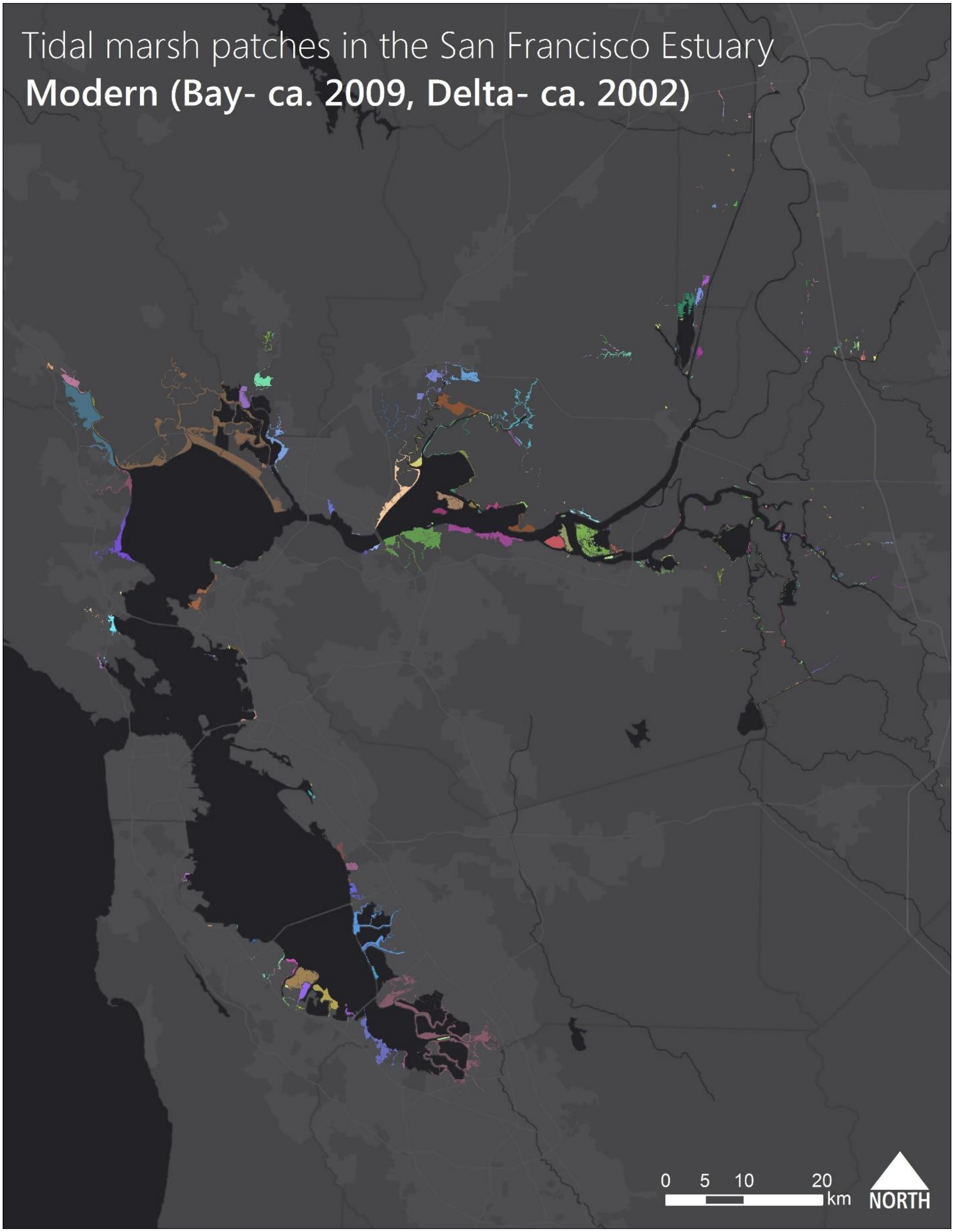
Site	Year opened to tidal action	Planned area of tidal wetland restoration (acres)
Bay (tidal wetland restoration since 2009)		
Napa Plant Site: Central Unit	2009	175
Alviso: Pond A6	2010	330
Napa Plant Site: South Unit	2010	1,080
Eden Landing: Ponds E8A/E9/E8X	2011	630
Alviso: Ponds A8/A7/A5	2012	1,400
Alviso: Pond A17	2012	130
Bair Island: Middle Bair	2012	646
Hamilton Marsh	2014	380
Bruener Marsh	2014	26
Cullinan Ranch	2015	1,549
Total (Bay)		6,346

Delta (tidal wetland restoration since 2002)		
Twitchell Island Setback Levee	2005	1
Sherman Island Setback Levee	2005	7
Liberty Island Conservation Bank and Preserve	2010	31
Cosumnes Floodplain Mitigation Bank	2011	73
Calhoun Cut	2014	147
Total (Delta)		259

5. Optional maps




Tidal marsh patches in the San Francisco Estuary
Historical (ca. 1800)
0 5 10 20
km
NORTH


Tidal marsh patches in the San Francisco Estuary
Modern (Bay- ca. 2009, Delta- ca. 2002)
0 5 10 20
km
NORTH

State of the Estuary Report 2015

Technical Appendix

HABITAT – Tidal Marsh

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Tidal marsh habitat indicators

Background and Rationale

Tidal marshes—including those found in the San Francisco Bay-Delta Estuary (the "Estuary")—provide a wide array of ecosystem services. They provide habitat and support food webs for wildlife, stabilize shorelines and protect them from storm damage, store floodwaters and maintain water quality, preserve biodiversity, store carbon, and offer profound opportunity for scientific study, education, recreation, and aesthetic appreciation (Costanza et al. 1997, Peterson et al. 2008, Palaima 2012, Zedler 2012).

Although tidal marshes have a wide array of functions, this study focuses on indicators that evaluate the Estuary's tidal marshes for their function as habitat for native wildlife. Specifically, the indicators selected here—the regional extent and patch sizes of tidal marsh—seek to help broadly assess the status of tidal marshes in the Estuary for their ability to support the life histories of native tidal marsh wildlife (defined as obligate or transitory plants or animals). It is worth mentioning, however, that although the focus here is on tidal marshes as habitat for native wildlife, the nature of the indicators (the regional extent of tidal marsh is perhaps the most fundamental measurement of tidal marsh habitat) means they likely integrate across the other services provided by the Estuary's tidal marshes. The focus on wildlife support is merited since much, if not most, of the interest and concern about tidal marshes relates to their function as habitat for native fishes, animals, and plants (e.g. BCDC 2008, SFBRWQCB 2010, SFEP 2011, USFWS 2013, SFEI-ASC 2014). Tidal marshes are especially valued for their contribution to the native biological diversity of the San Francisco Estuary. Many of the region's rare and endangered plants and animals rely on tidal wetlands for their survival, and legal mandates to protect these species provide the regulatory framework and funding behind a significant portion of tidal marsh restoration activities.

The San Francisco Bay and the Sacramento-San Joaquin Delta are often studied and managed as distinct entities. However, the Bay and Delta function as a unified and complex estuary, which crosses several ecologically significant physical gradients (e.g., in tidal influence, salinity, wave energy, suspended sediment). These physical gradients, in turn are manifested in gradients within the Estuary's tidal marsh ecosystems (e.g., in vegetation composition, physical structure, soils types, channel density). When planning for habitat restoration in the Estuary, these gradients are important to consider if we wish to support the full range of ecological functions provided by the estuary's tidal marshes. This analysis seeks to evaluate and inform restoration efforts by considering the Bay and the Delta's tidal marshes side by side in a single document. This said, we do report the status of the tidal marsh habitat indicators separately for the Bay and the Delta (a structure that is reflected throughout this State of the Estuary report). This distinction is driven by a few different considerations, including the following: freshwater and salt marshes are not equivalent (Odum 1988) and the state of the science surrounding each differs greatly within the Estuary; the Bay and Delta have different environmental histories and differences in current environmental stressors; the political realities, regulating authorities, regional goals, and history of restoration are different in the Bay and the Delta; and available data on tidal marsh extent are generally limited to one region or the other. Although the tidal marsh indicators are reported separately for each region, substantial effort was made to integrate the datasets before splitting them, ensuring a “seamless” divide in the analyses of each region.

The **tidal marsh regional extent indicator** measures the combined area of all tidal marshes in the estuary and is derived from detailed maps of the estuary’s wetlands.

The importance of tidal marsh extent as an indicator is based on the notion that greatest threat to tidal marsh ecosystems and the species they support is habitat loss (USFWS 2013). Measuring the areal extent of an ecosystem is a simple way to assess its quantitative loss and a critical component of ecosystem conservation (which, in turn, is a complement to species-level conservation; Noss et al. 1995). The regional extent of tidal marsh matters because many of the ecological and hydrological benefits the habitat provides increase along with marsh extent. Put simply, as the total area of tidal marsh in the Estuary increases, so does the abundance and diversity of the plants and animals that utilize marshes. Increasing the regional extent of marsh across the whole Estuary—from the South Bay to the North Delta—will ensure that marsh habitat exists along the full length of important ecological gradients (such as tidal influence, salinity, and vegetation) and provide a range of options for the species that utilize tidal marshes.

The **tidal marsh patch sizes indicator** measures the percentage of tidal marsh habitat belonging to patches (useable areas of habitat separated from each other by non-useable areas of habitat; Fahrig and Merriam 1985) over a particular size threshold. For the analysis presented in the main body of this report, we utilize a threshold of 200 ha (494 acres), a value based on observed intertidal rail densities relative to patch size (described in greater detail below).

Studies of patch size are a basic quantitative proxy for qualitative changes to the structure and function of marsh habitat caused by fragmentation and are generally grounded in the equilibrium theory of island-biogeography and species-area relationships, which hold that all else being equal, smaller areas hold smaller populations, which are more vulnerable to extinction than larger populations (MacArthur and Wilson 1967; Soule 1987; Noss et al. 1995). Habitat fragmentation, which is technically separate from, but usually coincident with habitat loss, affects habitat connectivity, metapopulation dynamics, and the physical conditions within habitats (e.g. Saunders et al. 1991). When larger marshes are fragmented into smaller ones, their value as wildlife habitat tends to decrease. Speaking generally, larger habitat patches are usually better than smaller patches for sustaining local animal populations (e.g., Andrén 1994, Kolozsvary and Swihart 1999, Lindenmayer and Fischer 2006). Larger marshes are more likely than smaller marshes to support a mosaic of marsh features (e.g., high marsh, low marsh, marsh pans), buffer native wildlife from nonnative predators, and have well developed tidal channel networks (all of these factors are, for example, positively associated with endangered Ridgway’s Rail densities in San Francisco Bay; Liu et al. 2012).

Both tidal marsh indicators build off of previous work. The tidal marsh regional extent indicator relies heavily on the work done for the *Baylands Ecosystem Habitat Goals Project* (“Goals Project”; Goals Project 1999), which assessed changes in the regional extent of bayland habitats, including tidal marsh, between ca. 1800 and ca. 1997. The regional extent of tidal marsh in the Bay was updated for both *The State of San Francisco Bay 2011* (SFEP 2011) and the forthcoming *Baylands Ecosystem Habitat Goals Science Update* (“Goals Project Update”; report in press, scheduled for release in fall 2015). This indicator also builds on studies analyzing the regional extent of marsh in the Delta over time (Atwater et al. 1979, The Bay Institute 1998, Whipple et al. 2012, SFEI-ASC 2014).

Methods for delineating and evaluating historical (circa 1800) and existing (circa 1997) tidal marsh patches in the Estuary were first developed/reported by Collins and Grossinger (2004) in a report analyzing the landscape dynamics of South San Francisco Bay. Using the same methodology, historical and contemporary tidal marsh patches were delineated for the full Bay in *The State of San Francisco Bay 2011* report (SFEP 2011; an analysis led by Dr. Josh Collins). The methods were first applied to the Delta's marshes for the CDFW-funded "Delta Landscapes Project" and published in *A Delta Transformed* (SFEI-ASC 2014). An analysis of marsh patch sizes that considered Bay and Delta marshes together was first presented as a poster at the 2014 State of the Estuary Conference (Safran et al. 2014), but this effort did not distinguish between tidal and non-tidal marshes. This current report therefore represents the first known effort to evaluate the patch size distribution of tidal marshes across the full Estuary. An analysis comparing ca. 1800 and ca. 2009 marshes will also be included in the forthcoming Goals Project Update (report in press).

The analysis of tidal marsh presented in this report differs from that of its predecessor, *The State of San Francisco Bay 2011*, in three main ways. First, this report incorporates the tidal marshes of the Delta and therefore draws upon additional data sources to capture the expanded study extent. Second, although the guiding principles and general methodology used to determine tidal marsh regional extent and to delineate tidal marsh patches in this report are similar to those utilized in *The State of San Francisco Bay 2011* report, the technical implementation of the methodology differs. The nature of and reasons for these changes are detailed below. Finally, the final method/calculation used to evaluate/report tidal marsh patch sizes in the main body of report differs. In the 2011 report, the authors calculated changes in patch size-frequency. Although we present an updated calculation of tidal marsh patch size-frequency in this technical appendix, the metric presented in the main body of the report is instead the percent of total tidal marsh area belonging to patches >200 ha (494 acres) in size.

Benchmarks

Tidal marsh – regional extent

We utilize separate benchmarks to evaluate the regional extent of tidal marsh in the Bay and in the Delta. **For the Bay, we use a benchmark of 100,000 acres, a long-term tidal marsh acreage goal put forth by the 1999 *Baylands Ecosystem Habitat Goals Report***. This goal was the culmination of science-based public process that sought to evaluate the habitat needs of representative species and to identify changes needed to improve the Bay's ecological functioning and biodiversity. It is approximately half of the tidal marsh area that existed in the Bay at the beginning of the 19th century.

Since no similar quantitative goal exists for tidal marsh regional extent in the Delta, we instead three different provide reference values for context:

(1) *180,000 acres* or approximately half of the tidal marsh area that existed in the Delta at the beginning of the 19th century. In that it equals approximately one half of the historical habitat acreage, it is comparable to the benchmark used to assess the regional extent of tidal marsh in the Bay. The value was calculated by dividing the total area of tidal freshwater emergent wetland identified by Whipple et al. (2012) as occurring in the Delta ca. 1800 (364,810 acres) by two and then rounding to the nearest 10,000 acres.

(2) *78,000 acres* or the current area of tidal marsh plus the approximate area of diked lands in the Delta that are at intertidal elevations. This is the current area that would fall between high and low tide in the absence of levees and other water control structures and therefore exists at the right elevation for tidal marsh formation in the Delta. It was calculated by adding the area of diked lands at intertidal elevations in the Delta (70,000 acres) as reported by Siegel (2014) to the ca. 2002 area of tidal marsh reported in this analyses (7,638 acres, see below) and rounding to the nearest 1,000 acres. This value is meant to contextualize the upper bounds of tidal marsh regional extent based on existing elevations alone and does not take into consideration the acreage of land that will be available for tidal marsh restoration given other priority land uses in the region (such as agriculture). As with the other reference values, this value is not presented as a goal or benchmark.

3) 17,000 acres or the current area of tidal marsh plus the maximum amount of tidal marsh habitat that would be restored over the next five years under the State's current plan for habitat restoration in the Delta (*California Eco Restore*). *California Eco Restore* currently calls for 9,000 acres of tidal and sub-tidal habitat restoration over the next five years (California Natural Resources Agency 2015). The 17,000 acre reference value was determined by adding these 9,000 acres to the existing (ca. 2002) area of tidal marsh habitat in the Delta (7,638 acres; see below) and rounding to the nearest 1,000 acres. This calculation assumes that all 9,000 acres of proposed tidal and sub-tidal habitat restoration become tidal marsh. It therefore represents the *maximum* regional extent of tidal marsh habitat that would exist in the Delta after successful implementation of the current iteration of *California Eco Restore*.

Tidal marsh – patch sizes

The benchmark for the tidal marsh patch sizes indicator is the historical (circa 1800) size distribution of tidal marsh patches, as measured by the percentage of tidal marsh area belonging to patches >200 ha (494 acres) in size. Justification for using the historical patch size distribution of tidal marshes as a benchmark to assess current patch size distribution was provided by Dr. Josh Collins in *The State of San Francisco Bay 2011* (SFEP 2011, Appendix D). The flowing three paragraphs are an excerpted and slightly modified version of that justification:

Three basic assumptions underlie the decision to use the historical (ca. 1800) patch size distribution of tidal marshes as a benchmark to assess current and future patch size distributions. First, it is assumed that the current patch size distribution, which reflects almost two centuries of tidal marsh fragmentation, is not an appropriate benchmark or goal for the future. The patchiness that existed at the starting dates of the State Wetland Conservation Policy of 1993 and the anti-degradation policy of 1968 might indicate the maximum acceptable amounts of fragmentation, but they do not represent the needed deceases in fragmentation. Second, it is assumed the historical patch size distribution successfully sustained the native species that are currently threatened or endangered. Although the increased fragmentation of their habitats is only one factor in the declining abundance of these species, it has likely increased the negative effects of other factors. For example, as the marsh patches have gotten smaller, the ratio of their edge length to their surface area has increased, their core-area ratio has decreased (Safran et al. 2012; SFEI-ASC 2014), and the distance between patches has increased (Collins et al. 2005; Safran et al. 2012; SFEI-ASC 2014). All of these changes have, in theory, increased tidal marsh wildlife's risk of predation, exposure to external stressors, and required dispersal distances (Troll 1971, Forman 1995, Turner 1989, 2005, Fahrig 2002). It should be noted however, that declines in the total quantity of habitat and in its quality can overshadow the effect of fragmentation (Bender et al. 1998, Harrison and Bruna 1999)—this is one reason the tidal marsh patch size indicator must be considered alongside the tidal marsh regional extent indicator. Third, larger habitat patches are usually better than smaller patches for sustaining local animal populations (e.g., Andrén 1994, Kolozsvary and Swihart 1999, Lindenmayer and Fischer 2006). The historical landscape included much larger tidal marsh patches than exist today (SFEI-ASC 2014).

The vertebrate communities of tidal marshes exhibit a high degree of endemism. Many species are entirely restricted to tidal marshes, and some are restricted to marshes of one or a few estuaries (Greenberg and Maldonado 2006, Greenberg et al. 2006, SBSPRP 2007). A reasonable assumption is that these species have adapted to the particular characteristics of the marshes they inhabit, including their salinity regimes, temperatures, substrate colors, hydrology, vegetation, predators, and the natural patchiness of their habitats.

This emphasis on categorical environmental patchiness as a determinant of community structure is common but not without controversy. The central concern is that the patch-based approach to the analyses of the distribution and abundance of plants and animals disregards the interactions between individuals or populations and gradients in their key resources and limiting factors (e.g., Cushman et al. 2010a,b). There are, however, gradients in habitat patch size within the geographic distribution of a species, and, for animals, these gradients usually include patches that are too small to support viable populations. In other words, patch size can be limiting for animals in highly fragmented habitats (Wilcox and Murphy 1985, Fahrig and Merriam 1985, Fahrig 2002). There are numerous studies of tidal marsh animals in the Estuary that clearly indicate their distributions vary along environmental gradients independent of patch size (e.g., Atwater and Hedel 1976, Shellhammer 2000, Albertson and Evens 2000, Watson and Byrne 2009). This is not unusual for estuaries that are characterized by strong gradients in salinity and other physical factors. It does not necessarily mean, however, that patch size is not important. It means that patch size is one of many inter-relating factors that together affect the distribution and abundance of tidal marsh species over time. In the absence of any known optimal patch sizes for tidal marsh species in the Estuary, and given the negative effect of past habitat fragmentation on the prospects for their survival, setting an initial benchmark for future patch sizes that reflect the historical, natural patch size-frequency seems reasonable.

The specific method for calculating, visualizing, and comparing patch size distribution across time in this report differs from the methods utilized in its predecessor (SFEP 2011). The 2011 report presented the percentage of patches in each of six patch size categories and then measured whether or not the current percentage of patches in each class was within 25 percent of the historical percentage. To report a final benchmark, the report then measured what percentage of the classes passed this test. In this report, the patch size distribution is calculated as the percentage of total tidal marsh area belonging to patches >200 ha (494 acres) in size. Measuring patch size distribution in this way allows us to consolidate the measurement of each year into a single value (as opposed to a range), utilize a single benchmark (as opposed to a separate one for each size category), and conform to the form of other indicators in this report (with “up” on the bar chart corresponding to “good”). Our hope is that this method of calculation is a simpler measurement of patch size distribution and is easily accessible to the report’s general audience.

The 200 ha (494 acre) threshold is based on indications that this is an ecologically significant size threshold for intertidal rails (the wildlife group for which patch boundaries were defined, see below). Specifically, we draw on research intro the distribution and population trends of Ridgway Rail that suggests their population density increases with marsh area up to approximately 200 ha (494 acres), at which point rail densities plateau (Liu et al 2012, Wood et al. 2013; Figure 1). There are indications that densities of Black Rail might plateau at a lower marsh patch size (~100 ha) than observed for Ridgway’s Rail (Nadav Nur, personal communication). Other results also point to 100 ha as a meaningful tidal marsh patch size threshold for Black Rails—Spautz and Nur (2002) and Spautz et al. (2005) report a significant negative correlation between Black Rail presence and the distance to the nearest 100 ha (247 acre) marsh (significant relationships were not observed when testing Black Rail presence against the distance to marshes of 25 or 50 ha). Despite this information, we utilized the larger 200 ha (494 acre) threshold under the assumption that, when considering tidal marsh patch sizes in the San Francisco Estuary, Ridgway's Rail can serve as an umbrella species for Black Rail. The main premise of the umbrella species concept is that the requirements of demanding species encapsulate those of many co-occurring, less demanding species (Roberge and Per Angelstam 2006). Ozaki et al. (2006) relate the concept specifically to patch sizes when they define umbrella species as "those with large area requirements for which protection of the species offers protection to other species that share the same habitat."

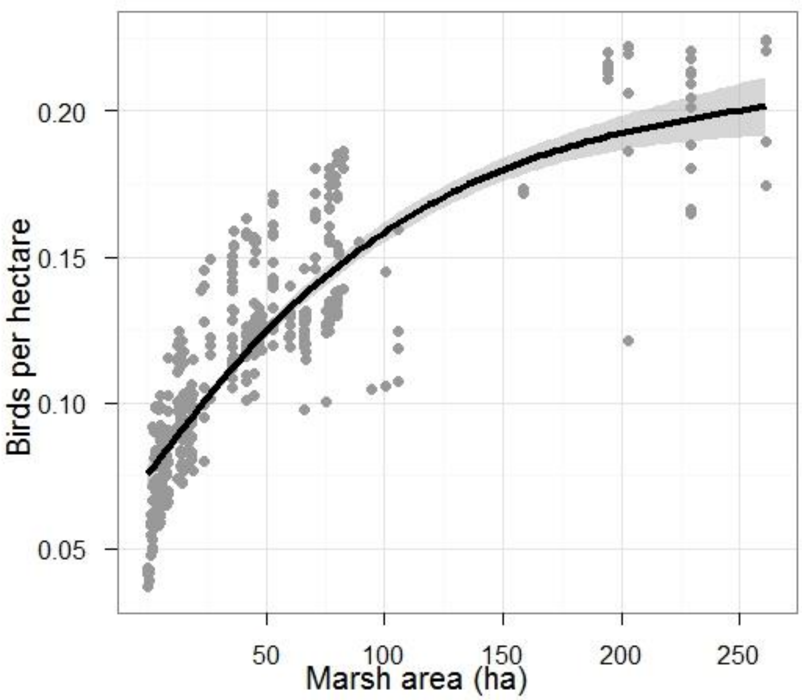


Figure 1 (*courtesy Julian Wood and Nadav Nur, Point Blue Conservation Science, adapted from Liu et al. 2012 and Wood et al. 2013).* The relationship between tidal marsh area and Ridgway Rail density. Rails appear to reach a maximum density at approximately 200 ha. This finding is used here to define a tidal marsh patch size threshold for the patch sizes indicator.

There are certain limitations to the benchmark, the first being its focus on tidal marsh as habitat for intertidal rails. Although, from the perspective of patch size, rails have relatively demanding habitat needs—a patch that is large enough for Ridgway's Rail, for example, should not be limiting (based on size alone) for small resident rodents—there are functions of marshes that are likely only realized at even larger sizes. One advantage of highlighting the full patch size-frequency distribution (as was done in the main body of the 2011 report) is that it involves no assumptions about the importance of any particular patch size and could therefore be used to assess a wider range of ecosystem services and ecological functions for which optimal size might differ (SFEP 2011, Appendix D). Additionally, although the benchmark is meant to measure the general distribution of patch sizes (aka, "a certain percentage of marsh area should belong to patches above a certain size"), it could give the impression that small tidal marsh patches are not valuable to wildlife. This is not the case and is not the intention of the benchmark. Small patches are likely important as "stepping stones" between larger patches, facilitating the movement and gene flow of marsh wildlife (e.g. Gilpin 1980, Simberloff et al. 1992, Fischer and Lindenmayer 2002, Murphy and Lovett-Doust 2004, Baum et al. 2004). Black rails, for example, have been observed in marsh patches as small as 2 ha (Hildie Spautz, personal communication). Finally, assigning a size threshold based on population density has some inherent limitations—density alone offers no indication of population resilience and demographic processes. The benchmark and size threshold used to analyze the distribution of tidal marsh patches should continue to be reevaluated as new information and techniques become available.

Data Sources

GIS data depicting the extent of tidal marshes in the Estuary were obtained from multiple regional wetland mapping efforts (Table 1).

Table 1. Geospatial datasets utilized in this study to determine the extent of tidal marshes in the Estuary.

Region/Year	Citation	Title	Source Institution	Year released	Years represented (range)	Year represented (primary)	Link (accessed 2/25/2015)
Bay							
ca. 1800	SFEI 1997a	EcoAtlas Baylands Maps ('Historical Baylands')	San Francsico Estuary Institute	1997	ca. 1800	ca. 1800	http://www.sfei.org/sites/default/files/EcoAtlas_SFEI.zip
ca. 1997	SFEI 1997b	EcoAtlas Baylands Maps ('Modern Baylands')	San Francsico Estuary Institute	1997	1985-1997	1997	http://www.sfei.org/sites/default/files/EcoAtlas_SFEI.zip
ca. 2009	SFEI 2011	Bay Area Aquatic Resource Inventory ('BAARI Baylands v01')	San Francsico Estuary Institute	2011	2005-2009	2009	ftp://dl.sfei.org/geofetch/BAARI.zip
Delta							
ca. 1800	Whipple et al. 2012	Sacramento-San Joaquin Delta Historical Ecology Investigation ('Historical Habitats Delta')	San Francisco Estuary Institute	2012	ca. 1800	ca. 1800	http://www.sfei.org/sites/default/files/Delta_Historical_Ecology_GISdata_SFEI_ASC_2012.zip
ca. 2002	CDWR 2013	Draft Bay-Delta Conservation Plan- Natural Communities	California Department of Water Resources	2013	2002-2010	2002	http://baydeltaconservationplan.com/Libraries/Dynamic_Document_Library/Public_Draft_BDCP_Chapter_2_-_Existing_Ecological_Conditions.sflb.ashx (Figure 2-14)

Boundary conditions defining the extent of the Bay and the Delta were enforced for each layer. Tidal marsh polygons were excluded from the Bay datasets if they were west of the Golden Gate or upstream of Broad Slough. Tidal marsh polygons were excluded from the Delta datasets if they were downstream of Broad Slough or outside of the Legal Delta boundary (although this latter condition did not ultimately exclude any areas mapped as tidal marsh in the Delta). Figure 2 provides a detailed view of the line dividing the Bay and the Delta at Broad Slough—it was derived from the eastern margin of the *Baylands Ecosystem Habitat Goals Project* study extent.

Figure 2. The dividing line (in yellow) between San Francisco Bay (the "Bay") and the Sacramento-San Joaquin Delta (the "Delta") utilized in this study.

The original source classifications we considered "tidal marsh" for this study are listed, by source, in Table 2. The crosswalk for the Bay sources was originally developed for the *Baylands Ecosystem Habitat Goals Update* (report in preparation, scheduled for release in spring 2015). The crosswalk for the Delta sources was originally developed for the Delta Landscapes Project (SFEI-ASC 2014).

Table 2. Original classifications considered "Tidal marsh" for this study, by source (see Table 1).

Bay ca. 1800 (SFEI 1997a; "CROSSWALK" field)
Tidal Marsh
Bay ca. 1997 (SFEI 1997b; "SHORT_DEFN" field)
Old High Tidal Marsh
Young High Tidal Marsh
Young High Tidal Marsh within Modern but not Historical extent
Young Low/Mid Tidal Marsh
Muted Tidal Marsh
Bay ca. 2009 (SFEI 2011; "CLICKLABEL" field)
Tidal Ditch
Tidal Marsh Flat
Tidal Panne
Tidal Vegetation
Delta ca. 1800 (SFEI 2012; "Habitat_Type" field)
tidal freshwater emergent wetland
Delta ca. 2002 (CDFW 2013; "SAIC_Type" field)
Tidal Freshwater Emergent Wetland
Tidal Brackish Emergent Wetland

The same tidal marsh datasets developed for the regional extent indicator were used for the tidal marsh patch sizes indicator.

Methods

Tidal marsh – regional extent

<u>Determining the regional extent of tidal marsh</u>

The total acreage of tidal marshes, as identified in the crosswalks reproduced in Table 2, was tabulated separately for each spatial dataset (Bay ca. 1800, Bay ca. 1997, Bay ca. 2009, Delta ca. 1800) using a Geographic Information System (GIS).

<u>Determining the extent of recent tidal wetland restoration</u>

To determine the acres of tidal wetlands that have been restored since the most recent standardized datasets were developed, we compiled a list of restoration sites that have been opened to tidal action since 2009 in the Bay and since 2002 in the Delta (the primary years of source imagery for the SFEI 2011 and CDFW 2013 datasets, respectively). Bay sites were initially identified using the EcoAtlas Project Tracker database (CWMW 2015) by querying projects within the administrative boundary of Regional

Board 2 with a planned habitat type of “Estuarine wetlands” and an event type entry of “Groundwork start” or “Groundwork end” since 2009. This resulting list was reviewed and edited by local scientists with knowledge of recent/ongoing restoration efforts (April Robinson and John Bourgeois, personal communication). Delta projects implemented since 2002 that seek to increase the acreage of tidal wetlands were initially identified by reviewing sources that summarize recent restoration efforts in the Delta (Cannon and Jennings 2014; CDWR 2012). The resulting list was also reviewed and edited by local scientists with knowledge of recent/ongoing restoration efforts (Kristal Davis-Fadtke, personal communication).

The planned area of tidal wetland restoration for each site was determined using publically available data (see Table 6). When available, we recorded the expected net gain in tidal wetland area (as opposed to total planned acreage of tidal wetlands). All sites were reviewed against the datasets used to determine the regional extent of tidal marsh to ensure the new sites were not already counted as tidal marsh.

For both the Bay and the Delta, the acreages of recent tidal wetland restoration were added to the acreage of tidal marsh determined for most recent standardized datasets to develop the regional extent totals for ca. 2015. This methodology assumes that the area of existing tidal marshes has not changed since 2009 in the Bay and since 2002 in the Delta, and that the only possible change in tidal marsh extent comes from intertidal wetland restoration. This assumption has obvious limitations. Future updates of this indicator will benefit from updated standardized regional maps of tidal wetland restoration. Finally, it is worth noting that, although the area of intertidal wetland restoration is included on the chart of tidal marsh regional extent, not all of this acreage is yet (or will ever become) tidal marsh. Although a significant portion of the tidal wetland restoration areas are expected to develop into tidal marsh over time (or already have), some percentage of the habitat will remain un-vegetated, either unintentionally or by design. Once available, the 2015 acreages reported here should be replaced by values derived from actual updated maps of the Estuary’s tidal marshes.

Determining the regional extent indicator status/score

Throughout this report, a three-tiered “Good—Fair—Poor” system is used to assign a qualitative score to the status of each indicator. With few exceptions, the line between “Good” and “Fair” is set at each indicator’s goal/benchmark and another means is used to establish the line between “Fair” and “Poor.”

Rules and thresholds for determining the status of the regional extent of tidal marsh in the Bay are shown in Table 3. The line between “good” and “fair” was set at the regional goal established by the *Goals Project* (1999) and, without any ecologically sound justification for another value, the line between “fair” and “poor” was simply set at half this amount. Since no quantitative benchmarks were developed for determining the regional extent of tidal marsh in the Delta, we did not develop rules and thresholds for determining the status of the indicator in that region. For now, we assigned the Delta a score of “poor” based on the fact that the current regional extent is less than one half the lowest reference value utilized in this study (see Table 5), but the system for scoring this indicator should be reevaluated in the future once a benchmark or regional goal is determined.

Table 3. Rules employed for determining the status of regional extent of tidal marsh in the Bay. No rules were developed for assigning the status of the indicator in the Delta.

Status	Regional extent	Explanation
Good	>100,000 acres	The indicator receives a score of "good" when it exceeds the 100,000 acre regional goal established by the *Goals Project* (1999).
Fair	50,000-100,000 acres	The indicator receives a score of "fair" when it exceeds one-half of the regional goal.
Poor	<50,000 acres	The indicator receives a score of "poor" when it is less than one-half of the regional goal.

Tidal marsh – patch sizes

Defining individual marsh patches

Note: although the guiding principles and general methodology used to delineate tidal marsh patches in this report are similar to those developed by Collins and Grossinger (2004) and utilized in *The State of San Francisco Bay 2011* report, the technical implementation of the methodology differs. The precise patch boundaries identified and utilized by the two studies may therefore vary. See below for more details.

Patches were generated using the tidal marsh datasets spatial described above. Since tidal marsh patches can span the boundary between the Bay and the Delta (Figure 2), the Bay and Delta tidal marsh polygons were combined before defining patches. "Historical patches" were generated after combining the 'Bay ca. 1800' and the 'Delta ca. 1800' polygons. "Modern patches" were generated after combining the 'Bay ca. 2009' and the 'Delta ca. 2002' datasets. For the sake of this analysis, patches that ultimately spanned the boundary of the Bay and Delta ("transboundary patches"—of which there were two in the historical patches and one in the modern patches) were assigned to the Bay. For the charts in this report, the modern patches located in the Bay are said to be representative of conditions ca. 2009 and the modern patches in the Delta are said to be representative of conditions ca. 2002 even though the single "transboundary patch" assigned to the Bay was generated from polygons representative of both years. The vast majority of patches were generated from a single spatial dataset representative of a single point in time (ca. 2009 for the Bay and ca. 2002 for the Delta).

In the GIS, discrete tidal marsh polygons were aggregated into a single "patch" if they were located within 60 m of one another. Groups of polygons separated by less than this distance were identified and aggregated using ArcGIS's 'Aggregate Polygons' tool and then assigned unique patch identification values. The full work flow for this analysis was implemented/automated using a custom tool developed with ArcGIS's Model Builder software.

The 60 m threshold for grouping marsh polygons was derived from the rule set for defining resident intertidal rail patches developed by Collins and Grossinger (2004), which was based on the best available data on rail habitat affinities and dispersal distances. For additional information on the development of rules for defining tidal marsh patches and analyzing tidal marsh fragmentation, please refer to Collins and Grossinger (2004) and *The State of San Francisco Bay 2011*, Appendix D (SFEP 2011).

In the absence of more specific data, we made the assumption that the rules developed for defining intertidal rail patches in the salt marshes of South San Francisco Bay are also applicable to the freshwater marshes of the Delta. Unlike Collins and Grossinger (2004), our analysis also only considered roads and levees as dispersal barriers if the width of these features (as mapped in the habitat type layers) exceeded the 60 m distance threshold described above. Similarly, we also did not consider channels that receive perennial freshwater discharge to be barriers unless they exceeded the 60 m distance threshold. Finally, we did not employ the rule that “two patches that come together at a point are considered two separate patches because the point of intersection creates a place of such high risk of predation that two patches are ecologically separate” (Collins and Grossinger 2004). These modifications to the rule set increase repeatability of the patch size analysis, which is important for its use an indicator that will be re-measured at regular intervals in the future. The patch-generating process was developed into an automated model using ArcGIS’s model builder tool to maximize repeatability.

It is worth noting that this model of a binary landscape (marsh and non-marsh) greatly simplifies the complexities of how species interact with their surroundings. It assumes, for example, that all patches of tidal marsh are equally suitable for intertidal rails, that the routes of travel between patches are linear, and that the only barrier to wildlife movement is distance (D’Eon et al. 2002).

Final patch boundaries can be seen in the map of historical patches (Figure 3) and the map of modern patches (Figure 4).

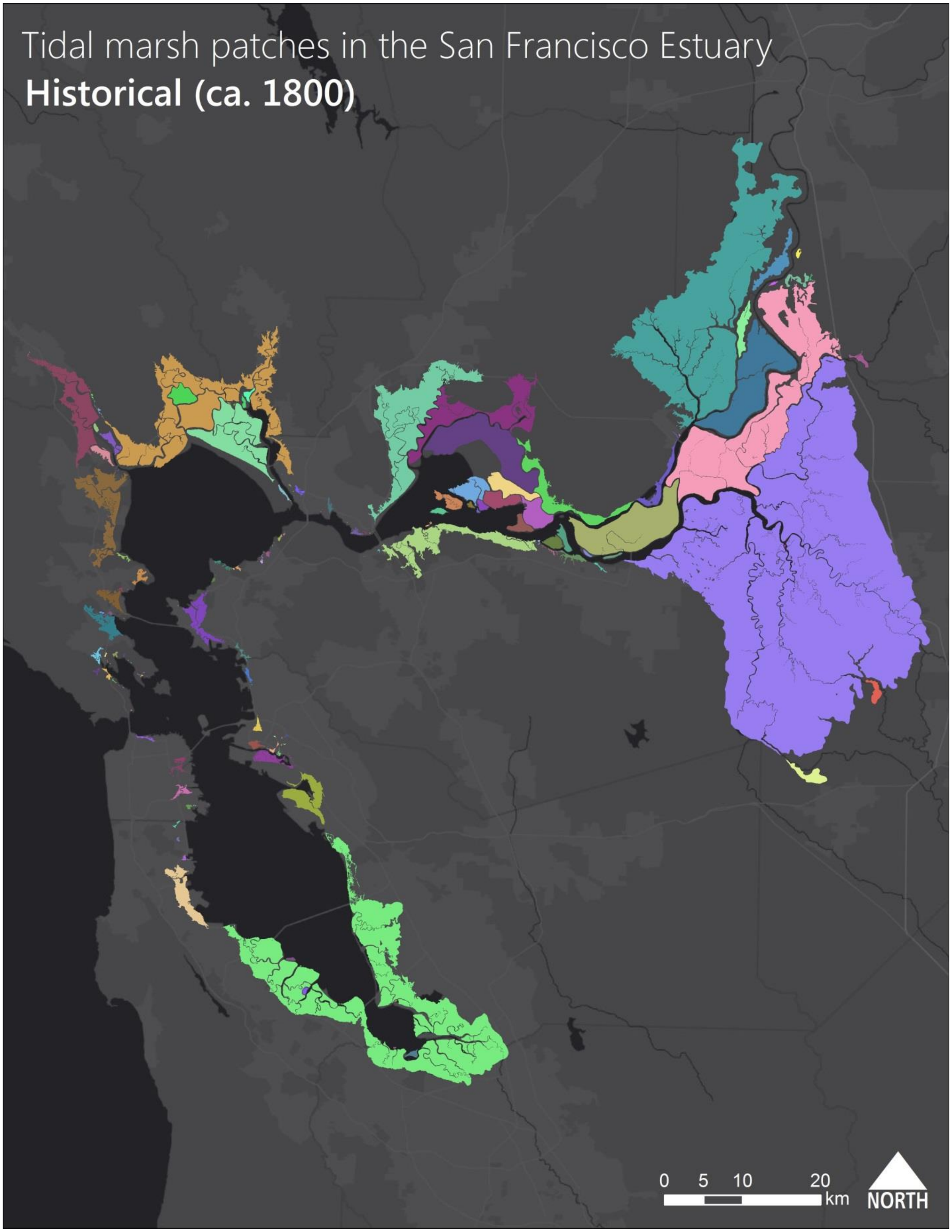


Figure 3. Tidal marsh patches in the historical San Francisco Estuary (ca. 1800). Each patch is given a different color. The rules for defining patches are described above. Compare with the map of modern tidal marsh patches in Figure 4.

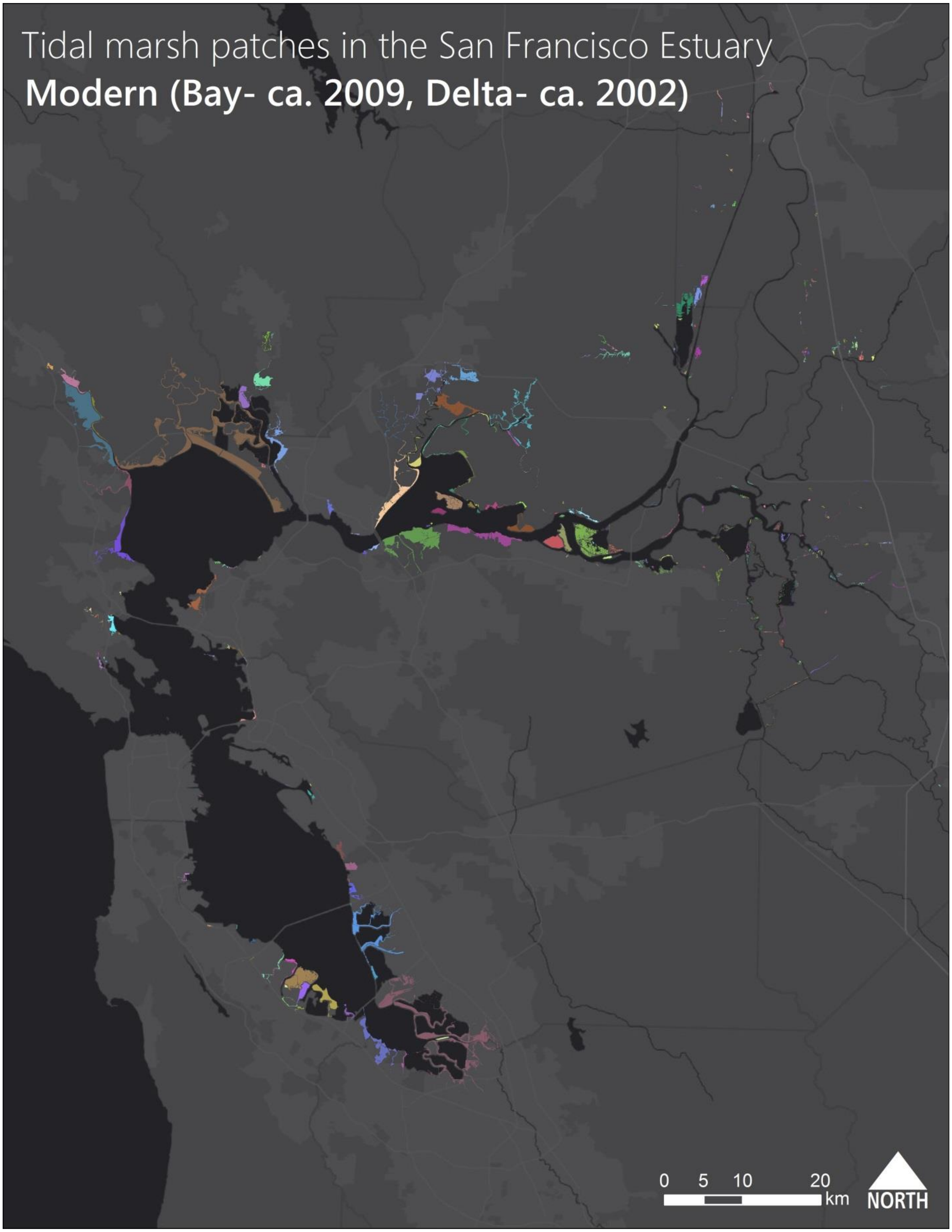


Figure 4. Tidal marsh patches in the modern San Francisco Estuary (ca. 2009 for the Bay and ca. 2002 for the Delta). Each patch is given a different color. The rules for defining patches are described above. Compare with the map of historical tidal marsh patches in Figure 3.

Measuring tidal marsh patch size distributions

After tidal marsh patch boundaries were defined, we calculated the size of each individual patch using ArcGIS. We assessed tidal marsh patch sizes using three methods: (1) calculating the percent of total marsh area belonging to a patch >200 ha (494 acres) in size, (2) calculating the patch size-frequency distribution, and (3) calculating the cumulative frequency distribution. For each method were only able to compare patch sizes at two points in time (ca. 1800 and ca. 2009 for the Bay, ca. 1800 and ca. 2002 for the Delta). The **percent of total marsh area belonging to patches >200 ha in size** was calculated for each time interval by summing the total area of tidal marsh belonging to patches greater than 200 ha (494 acres) and dividing by the total acreage of tidal marsh (the above section on benchmarks discusses how the 200 ha threshold was selected). For the **patch size-frequency distribution**, we calculated both the percent of total marsh patches and percent of total marsh area in each of the six size classes utilized in the 2011 report (SFEP 2011; refer to Appendix D for how patch size classes were selected). **Cumulative fraction functions** were generated using the patch size data for each region and time step and compared using two-sample Kolmogorov-Smirnov (K-S) tests (Kirkman 1996). All patch size distributions were non-normal. The resulting p-values were used to assess and compare the similarities and differences in patch size distributions.

Determining the patch sizes indicator status/score

Rules and thresholds for determining the status of the tidal marsh patch sizes indicator in both the Bay and the Delta are shown in Table 4. The line between “good” and “fair” was set at 80% of the historical proportion of marsh belonging to patches >200 ha (494 acres) in size. The line between “fair” and “poor” was simply set at half of this proportion (or at 40% of the historical proportion). From an ecological standpoint, these thresholds are, admittedly, somewhat arbitrary. They are guided by the notion that the size distribution of marsh is “good” if it is within some percentage of the historical distribution (either slightly below or slightly above). In *The State of San Francisco Bay 2011* (SFEP 2011), the proportion of tidal marsh patches in a size category was “good” if it was within 75 and 125% percent of the historical proportion. We follow this general guideline, but have changed the qualifying range to 80-120% of the historical proportion. This was done because we were seeking to create three scores (good-fair-poor) and 120% is evenly divisible by 3. Since, when using a 200 ha (494 acres) size threshold, the contemporary proportion cannot actually exceed 120% of the historical proportion, we did not define scores for current proportions that exceed the 120% of the historical proportion. This would only become necessary if the benchmark utilized a higher patch size threshold (and thereby decreased the historical proportion of marshes above the critical size).

Table 4. Rules employed for determining the status of the tidal marsh patch size indicator in the Bay and the Delta.

Status	Current proportion of total marsh belonging to patches > 200 ha	Explanation
Bay (historical proportion ca. 1800 = .964)		
Good	>0.771 (80-120% of historical proportion)	The indicator receives a score of "good" when the current proportion of tidal marsh belonging to patches >200 ha is 80-120% of the historical proportion. Since the upper bounds of this range exceeds 1, the indicator effectively receives a score of "good" when current proportions are greater than 0.771.
Fair	0.386-0.771 (40-80% of historical proportion)	The indicator receives a score of "fair" when the current proportion of tidal marsh belonging to patches >200 ha is 40-80% of the historical proportion (between 0.386 and 0.771).
Poor	<0.386 (0-40% of historical proportion)	The indicator receives a score of "poor" when the current proportion of tidal marsh belonging to patches >200 ha is <40% of the historical proportion (<0.386).
Delta (historical proportion ca. 1800 = .997)		
Good	>0.798 (80-120% of historical proportion)	The indicator receives a score of "good" when the current proportion of tidal marsh belonging to patches >200 ha is 80-120% of the historical proportion. Since the upper bounds of this range exceeds 1, the indicator effectively receives a score of "good" when current proportions are greater than 0.798.
Fair	0.399-0.798 (40-80% of historical proportion)	The indicator receives a score of "fair" when the current proportion of tidal marsh belonging to patches >200 ha is 40-80% of the historical proportion (between 0.399 and 0.798).
Poor	<0.399 (0-40% of historical proportion)	The indicator receives a score of "poor" when the current proportion of tidal marsh belonging to patches >200 ha is <40% of the historical proportion (<0.399).

Results

Tidal marsh- regional extent

The regional extent of tidal marsh for each region and time period is shown below both in Figure 5 and Table 5. Values for ca. 2015 were calculated for each region by adding the most recent regional extent of tidal marsh to the acreage of recent tidal wetland restoration (Table 6).

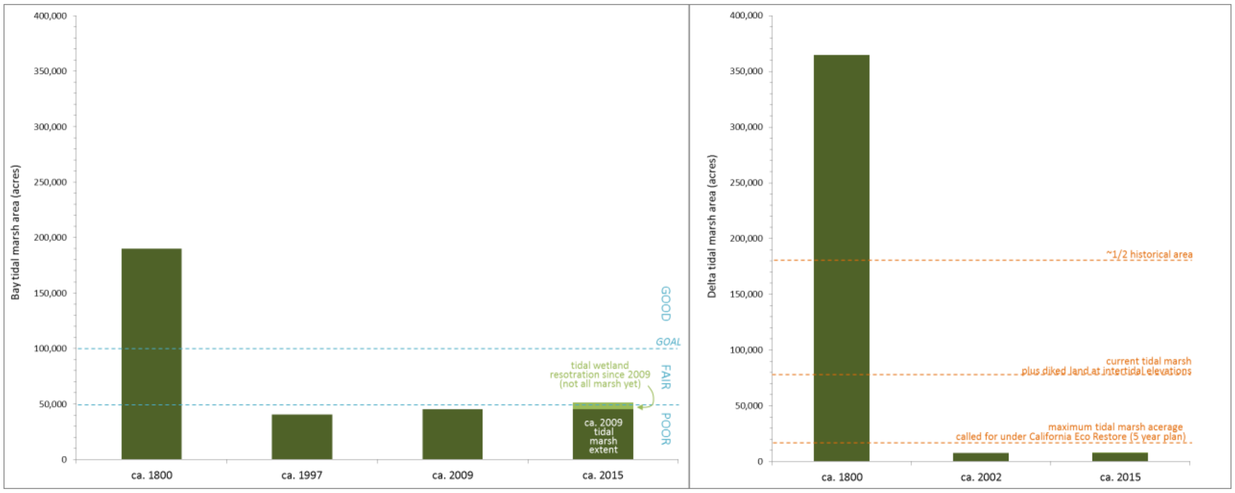


Figure 5. Tidal marsh regional extent in the Bay (left panel) and Delta (right panel) over time. Note that x-axes are not to scale. Circa 2015 regional extents are calculated by copying the previous time interval's regional extent and adding the extent of tidal wetland restoration that has occurred since (light green bar segments). Although much of this area is expected to transition into tidal marsh over time, some will remain unvegetated—it is shown to approximate progress since the last comprehensive spatial datasets of tidal marsh extent in the Bay and Delta were developed. Tidal wetland restoration since 2002 in the Delta is included, but is too small to be visible at this scale. Reference values on the Delta chart are colored orange to distinguish them from proper goals and benchmarks (colored blue).

Table 5. Regional extent of tidal marsh in the Bay and the Delta at multiple points in time. Data sources and the methods for defining regions are detailed above. In the main body of the report, values for ca. 2015 were calculated for each region by adding the most recent regional extent to the acreage of recent tidal wetland restoration (Table 6).

Year	Tidal marsh regional extent (acres)
Bay	
ca. 1800	190,113
ca. 1997	40,514
ca. 2009	45,052
Delta	
ca. 1800	364,545
ca. 2002	7,638

Historically, the area of (freshwater) tidal marsh in the Delta exceeded the area of (salt and brackish) tidal marsh in the Bay by a factor of nearly 2. Today, the reverse is true, and the area of tidal marsh in the Bay exceeds the area of tidal marsh in the Delta by a factor of nearly 6 (Figure 6).

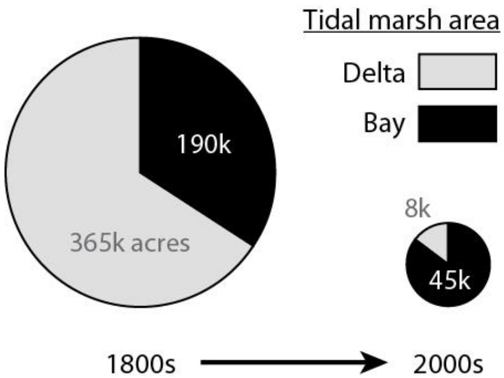


Figure 6. Historical (1800s) and modern (2000s) tidal marsh regional extent (in acres) by region. “2000s” data is ca. 2009 for the Bay and ca. 2002 for the Delta.

Based on the rules described in the methods section, the regional extent of tidal marsh in the Bay is characterized as “fair.” Since it is below 50,000 acres, the ca. 2009 extent of tidal marsh alone would only qualify as “poor.” The score of “fair” is based on the ca. 2015 regional extent value (51,398 acres), which combines the area of tidal marsh ca. 2009 with the area of tidal wetland restoration that has occurred since (Table 4), which together exceed the 50,000 acre threshold for “fair” (Table 3). This score is consistent with the ranking of “fair” previously reported for the indicator status in *The State of San Francisco Bay 2011* (SFEP 2011). The regional extent of tidal marsh in the Delta is characterized as “poor,” since, as described in the methods section, the current regional extent is less than one half the lowest reference value utilized in this study. The system for scoring this indicator should be reevaluated in the future once a true benchmark or regional goal is determined.

Recent tidal wetland restoration

In the Bay, approximately 6,350 acres have been restored to tidal action since 2009 (Table 6). This figure does not include an additional approximately 24,000 acres of tidal marsh restoration that are currently permitted and/or funded, but have not yet broken ground (Goals Project Update, report in preparation; calculated by subtracting the acreage of restoration since 2009 determined for this study from the total permitted/funded acreage of post-2009 tidal marsh restoration identified by the Goals Project Update).

In the Delta, tidal wetland restoration since 2002 has totaled approximately 250 acres (Table 6). Since this list only includes restoration projects that have broken ground, it does not capture the nearly 5,000 acres of tidal marsh restoration planned for the Delta in the near future (

Table 7).

Table 6. Recent tidal wetland restoration. The areas listed below have been opened to tidal action since the datasets utilized in this study were developed (ca. 2009 for the Bay; ca. 2002 for the Delta). Although much of this restored tidal habitat is

expected to transition into tidal marsh over time, these sites are not yet included in in the maps and charts summarizing the regional extent of tidal marsh.

Site / Project	Year opened to tidal action	Planned area of tidal wetland restoration (acres)	Source
Bay (tidal wetland restoration since 2009)			
Napa Plant Site: Central Unit	2009	175	1
Alviso: Pond A6	2010	330	2
Napa Plant Site: South Unit	2010	1,080	1
Eden Landing: Ponds E8A/E9/E8X	2011	630	2
Alviso: Ponds A8/A7/A5	2012	1,400	2
Alviso: Pond A17	2012	130	3
Bair Island: Middle Bair	2012	646	4
Hamilton Marsh	2014	380	5
Bruener Marsh	2014	26	6
Cullinan Ranch	2015	1,549	7
Total (acres)		6,346	

Delta (tidal wetland restoration since 2002)			
Twitchell Island Setback Levee	2005	1	8
Sherman Island Setback Levee	2005	7	9
Liberty Island Conservation Bank and Preserve	2010	31	10
Cosumnes Floodplain Mitigation Bank	2011	73	11
Calhoun Cut	2014	147	12
Total (acres)		259	

Sources
1 CWMW 2015
2 SBSPRP 2015
3 USFWS 2011
4 measured from SFEI 2011
5 California State Coastal Conservancy 2008
6 NOAA 2014
7 USFWS n.d.
8 CDWR 2011 (“Twitchell Island Setback Levee Habitat Enhancement Project”)
9 CDWR 2011 (“Sherman Island Setback Levee Habitat Enhancement Project”)
10 ICF Jones & Stokes 2009
11 Personal communication, Jeff Mathews (Westervelt Ecological)
12 Personal communication, Kristal Davis-Fadtke (Delta Conservancy)

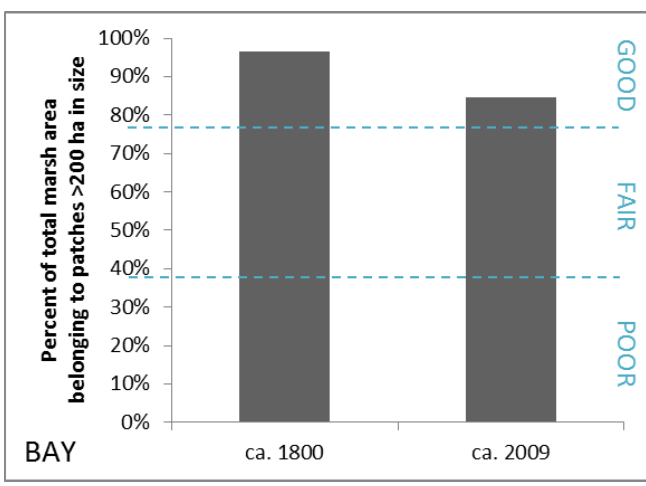
Table 7. Delta tidal marsh restoration projects planned for the near future. Together, these projects total approximately 4,650 acres. Projects and acreages come from Delta Conservancy scientists (Kristal Davis-Fadtke, personal communication).

Site / Project	EIR status	Planned area of tidal marsh restoration (acres)
Lower Yolo Ranch Tidal Restoration Project	Final EIR released July 2013	1,371
Prospect Island Tidal Habitat Restoration Project	Draft EIR expected 2015	1,528
North Delta Flood Control and Ecosystem Restoration Project	Final EIR released October 2010	1,200
Dutch Slough Tidal Marsh Restoration Project	Final EIR released March 2010; Final Supplemental EIR released September 2014	560
Total (acres)		4,650

Tidal marsh- patch sizes

Percent of total marsh area belonging to patches >200 ha in size

Historically, the proportions of tidal marsh in the Bay and the Delta belonging to patches >200 ha (494 acres) in size were both above 0.96 (Figure 7). This proportion has decreased over time (a greater percentage of total marsh area now belongs to patches <200 ha in size) in both the Bay and Delta, but the decrease is much more pronounced in the Delta. While nearly 100% of total marsh area in the Delta was once arranged in patches >200 ha (494 acres), this percentage has since dropped to less than 30%. Put another way, the patch size distribution in the Delta has skewed significantly towards patches that are too small to achieve maximum densities of intertidal rails (using the patch size threshold identified for Ridgway's Rail).



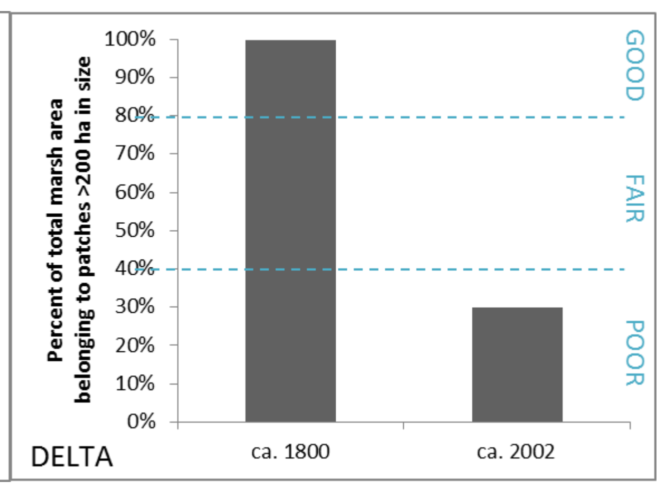


Figure 7. Percent of total marsh area belonging to patches >200 ha (494 acres) in the Bay (above) and Delta (below) over time.

It is worth mentioning that the overall results do not change dramatically if we use a smaller size threshold of 100 ha (the patch size at which Black Rails densities are known to plateau)—the proportion of total marsh area belonging to patches >100 ha has decreased in the Delta from 0.998 (ca. 1800) to 0.336 (ca. 2002) and in the Bay from 0.978 (ca. 1800) to 0.885 (ca. 2009). To document the effect of the patch size threshold on reported patch size distributions in the Bay and Delta over time, we include here the proportion of total marsh existing in patches of above 100 ha, 200 ha, 500 ha, 1,000 ha, and 10,000 ha (Table 8).

Table 8. Proportion of total tidal marsh area existing in patches above various minimum size thresholds.

Region	Historical (Bay-ca. 1800) (Delta- ca. 1800)	Modern (Bay- ca. 2009) (Delta- ca. 2002)
Proportion of total tidal marsh area in patches >100 ha		
Bay	0.98	0.88
Delta	1.00	0.34
Proportion of total tidal marsh area in patches >200 ha		
Bay	0.96	0.85
Delta	1.00	0.30
Proportion of total tidal marsh area in patches >500 ha		
Bay	0.93	0.62
Delta	0.99	0.21
Proportion of total tidal marsh area in patches >1,000 ha		
Bay	0.86	0.44
Delta	0.98	0.00
Proportion of total tidal marsh area in patches >10,000 ha		
Bay	0.42	0.00
Delta	0.90	0.00

Patch size-frequency distribution

Tidal marsh patch size-frequency plots generated for the historical and modern Bay and Delta were calculated with two different independent variables: the percentage of marsh patches (Figure 8) and the percentage of total marsh area (Figure 9) using the patch size classes identified in the 2011 report (SFEP 2011). The former measurement is considered a patch-centric approach ("what's the probability you'll land in a patch of a certain size if you're dropped in a *randomly selected patch*?"), while the latter measurement is effectively weighted by total area and considered "landscape centric" approach ("what's the probability you'll land in a patch of a certain size if you're dropped in a *randomly selected acre of marsh in the landscape?*") (McGarigal 2002). Measured either way, although the general shapes of the ca. 1800 and ca. 2009 tidal marsh patch size distributions in the Bay are similar, the current proportion of patches in the largest three size classes is still low. In the Delta, the difference between the historical and modern patch size distribution is more pronounced and heavily skewed towards the smallest size class. These trends are more pronounced when measured based on percent of total tidal marsh area (as opposed to percent of patches). Finally, it is worth noting that the patch size-frequency plots highlight just how small the 200 ha (494 acres) size threshold used in the tidal marsh patch size benchmark is relative to the historical range of patch sizes (more than 80% of the Bay's total tidal marsh extent and close to 100% of the Delta's was situated within patches larger than 5,000 acres).

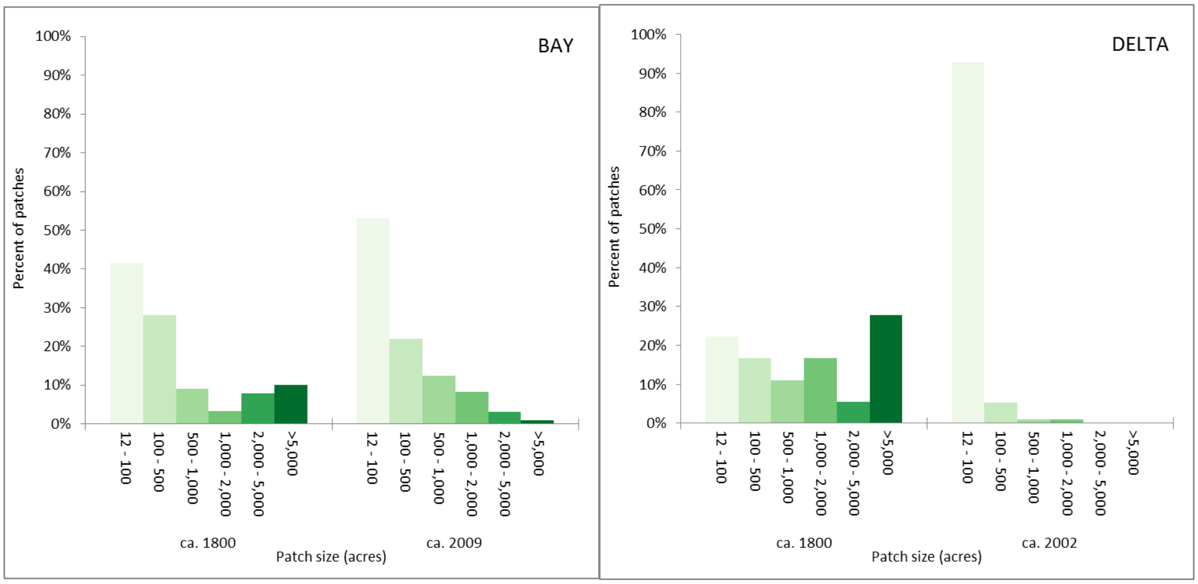


Figure 8. Patch size distributions of historical and modern tidal marsh patches in both the Bay (left panel) and Delta (right panel) as measured by the percent of tidal marsh patches in each of six patch size classes. A "patch-centric" measurement.

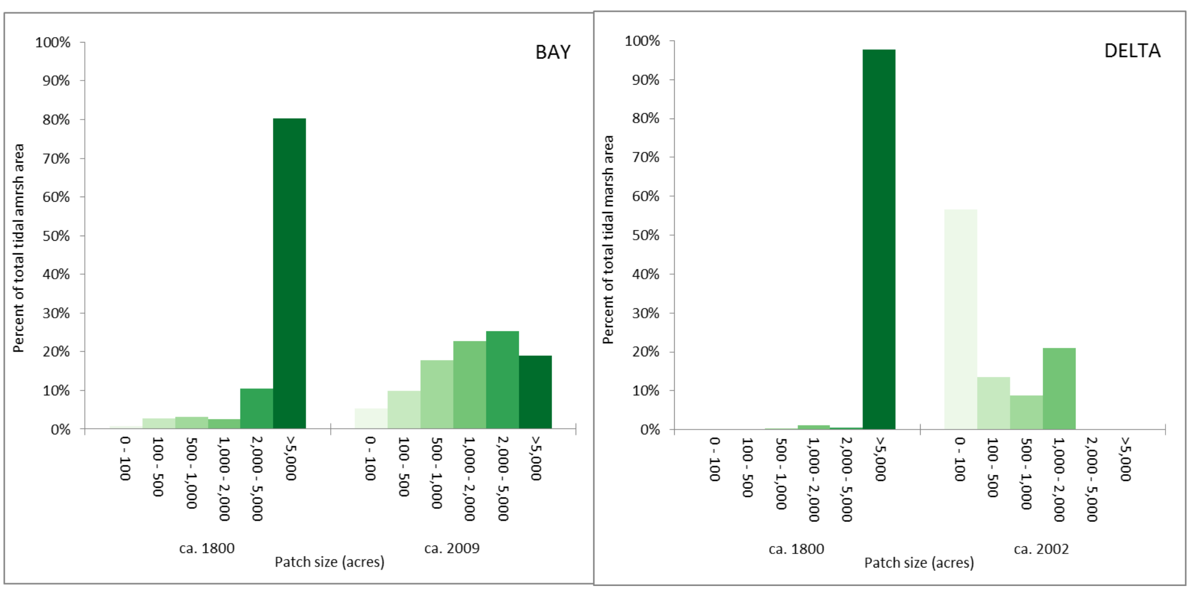


Figure 9. Patch size distributions of historical and modern tidal marsh patches in both the Bay (left panel) and Delta (right panel) as measured by the percent of total tidal marsh area in each of six patch size classes. A "landscape-centric" measurement.

Note that since the number of patches is highly sensitive to the minimum mapping unit [MMUs] of each dataset, we limited the smallest class in the charts of patch size-frequency distribution measured by the percent of patches (Figure 8) to 5 ha (equal to 12 acres and the largest minimum mapping unit employed by any of the source datasets). This effectively forced the modern datasets (with their slightly lower MMUs) to have the same MMU as the historical datasets. It is important to note that differences in minimum mapping unit have very little effect on the measurements calculated based on percent of total tidal marsh area (since the patches below 5 ha in are such a small percentage of the total tidal marsh area). We therefore utilized the full range of patch sizes when plotting the patch size-frequency distribution measured by the percent of total tidal marsh area (Figure 9).

Cumulative fraction functions

The cumulative fraction functions (Figure 10 - Figure 13) presented below to visualize and compare the full patch sizes across regions (Delta and Bay) and time (historical [ca. 1800] and modern [ca. 2020 or ca. 2009]). We generated four cumulative fraction plots (measuring the cumulative fraction of tidal marsh patches—not tidal marsh area—across the full range of patch sizes) comparing the historical Bay with the modern Bay (Figure 10), the historical Delta with the modern Delta (Figure 11), the historical Bay with the historical Delta (Figure 12), and the modern Bay with the modern Delta (Figure 13). Comparison of p-values suggests that the patch size distribution of the modern Bay is more similar to the patch size distribution of the historical Bay than the modern Delta is to the historical Delta (Figures 7 – 8). Additionally, comparison of p-values suggests that the distributions of tidal marsh patch sizes in the Bay and the Delta were more similar historically than they are today (Figures 9 -10).

As with the patch-size frequency measured with the percent of patches, we only considered patches above 5 ha for this analysis to force similar MMUs across all datasets (see the final paragraph of the previous section for further explanation).

Figure 10. Comparative cumulative fraction of tidal marsh patches (y-axis) across the full range of patch sizes (hectares; x-axis) in the ***Bay ca. 1800 (solid line) and the Bay ca. 2009 (dotted line)***. The maximum difference between the cumulative distributions, D, is 0.1606 with a corresponding P value of 0.168. The null hypothesis that the distributions are similar is

accepted (p > 0.05). In both conditions, patches are relatively evenly distributed across their full patch size range, but the maximum patch size in the historical Bay was an order of magnitude larger than in the modern Bay.

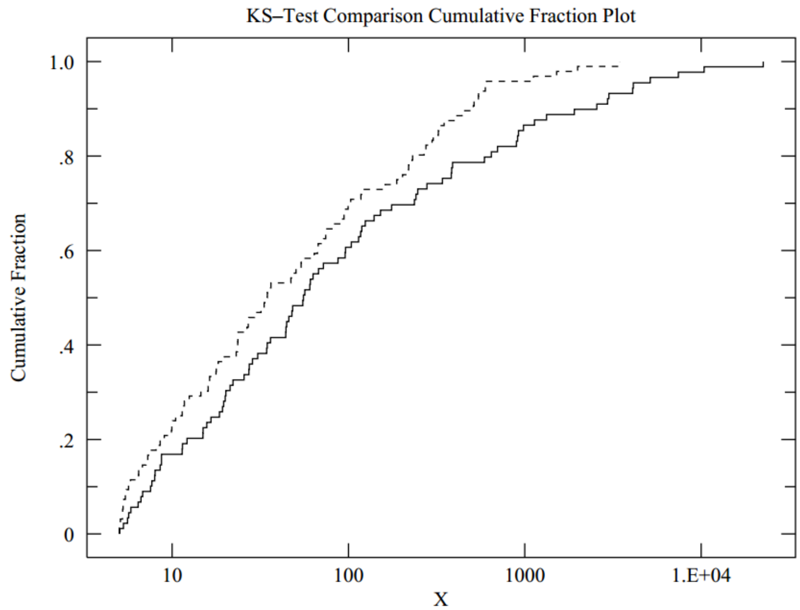


Figure 11. Comparative cumulative fraction of tidal marsh patches (y-axis) across the full range of patch sizes (hectares; x-axis) in the ***Delta ca. 1800 (solid line) and the Delta ca. 2002 (dotted line).*** The maximum difference between the cumulative distributions, D, is 0.8646 with a corresponding P value of 0.000. The null hypothesis that the distributions are similar is rejected (p < 0.05). Relative to historical conditions, the relative fraction of tidal marsh patches is skewed towards smaller patch sizes (more than 90% of patches less than 100 ha today versus ~30% historically). The maximum patch size in the historical Delta was two orders of magnitude larger than in the modern Delta.

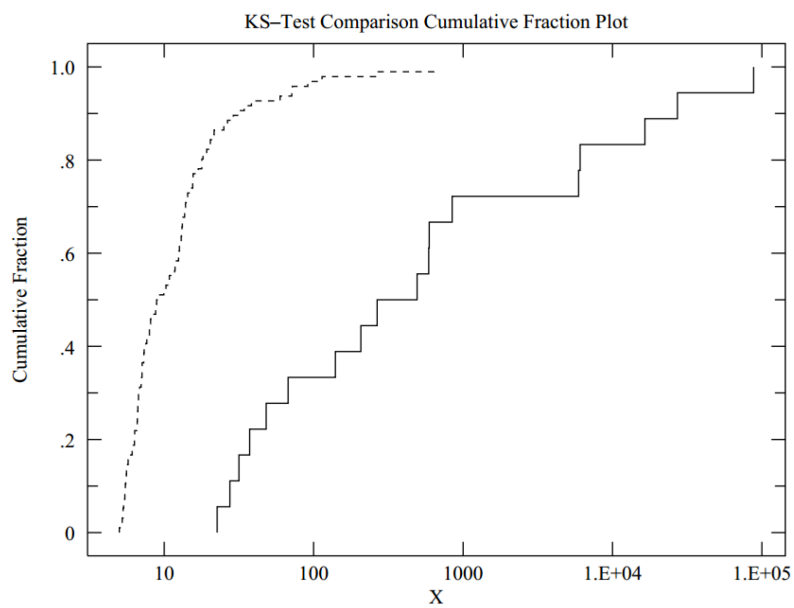


Figure 12. Comparative cumulative fraction of tidal marsh patches (y-axis) across the full range of patch sizes (hectares; x-axis) in the ***Bay ca. 1800 (solid line) and the Delta ca. 1800 (dotted line).*** The maximum difference between the cumulative distributions, D, is 0.3408 with a corresponding P value 0.047. Although the null hypothesis that the distributions are similar is rejected (p < 0.05), the p value is non-zero. Both distributions show similar distributions across their relative ranges in patch

sizes, but the relative fraction of historical Delta patches at any given size is lower than in the Bay (the historical Delta's patches skew larger). Maximum patch sizes in the historical Bay and the historical Delta were within 1 order of magnitude of each other.

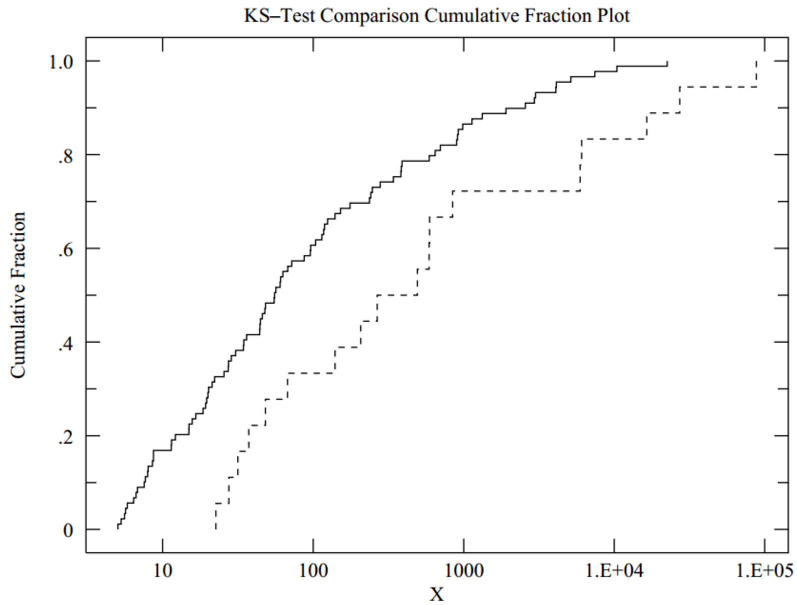
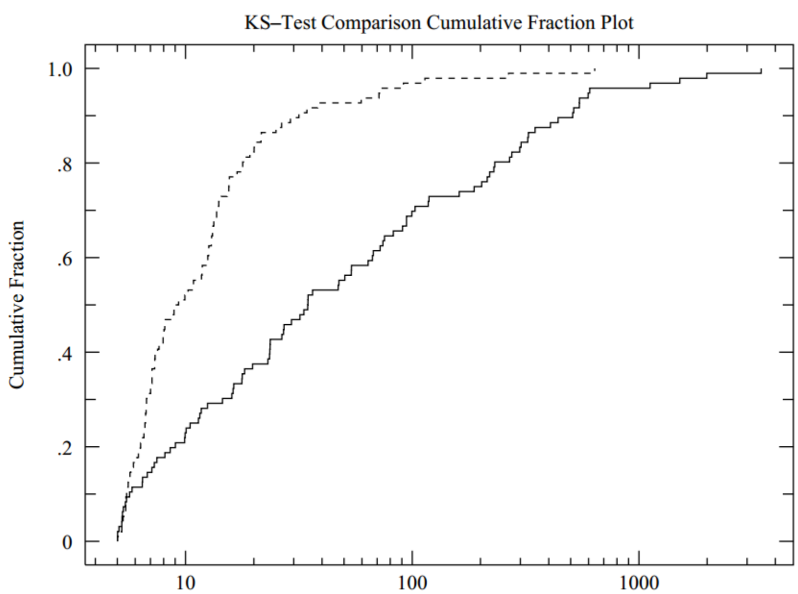


Figure 13. Comparative cumulative fraction of tidal marsh patches (y-axis) across the full range of patch sizes (hectares; x-axis) in the ***Bay ca. 2009 (solid line) and the Delta ca. 2002 (dotted line)***. The maximum difference between the cumulative distributions, D, is 0.4896 with a corresponding P value of 0.000. The null hypothesis that the distributions are similar is rejected ($p < 0.05$). Relative to the modern Bay, the relative fractions of tidal marsh patches in the modern Delta are skewed towards smaller patch sizes. The maximum patch size in the modern Bay is an order of magnitude larger than in the modern Delta.



Supplemental citations

For the sake of readability, text in the main body of the State of the Estuary report is presented without citations. To document the source for uncited material, key sentences from the Tidal Marsh section that are not otherwise reiterated above are copied here and supplemented with their supporting citations.

Page XX, paragraph XX:

> Part of this disparity can be explained by the extensive "subsidence" (sinking) of the Delta's peat islands—while these extensive areas once supported tidal marsh, many now sit 10-25 ft. below sea-level at an elevation that is much too low for tidal marsh vegetation establishment **(Ingebritsen et al. 2000)**.

Page XX, paragraph XX:

> Although the Bay-Delta's tidal marshes have generally kept pace with sea-level rise over the last several thousand years **(see Parker et al. 2011)**, the rate of future sea level rise and available sediment supply will have a major influence on whether they can continue to do so through the end of the century. Modeled scenarios of high sea-level rise rates and low sediment supply, which the latest evidence suggests is a likely trajectory, project that Bay tidal marshes will be unable to keep pace with rising tides and that their total regional extent will decrease; under scenarios of relatively low sea-level rise rates and high sediment supply, the total regional extent is projected to increase **(Stralberg et al. 2011)**. Although similar projections have not been developed for the Delta, its tidal freshwater marshes (which have higher rates of organic matter production) are expected to be less sensitive to reduced sediment availability than the Bay's tidal salt marshes **(Orr et al. 2003)**. Projections that assume marsh accretion can keep pace with estimated rates of sea-level rise in the Delta show an increase in the regional extent of tidal marsh over the next 50 years (assuming no major levee failures; **CDWR 2013, Appendix 3B)**.

Peer Review

This work has benefitted from review by staff at the Delta Science Program and Delta Conservancy, who provided comments on an earlier draft. Additionally, the methods for defining tidal marsh patches were reviewed as part of the development of the *Delta Transformed Report* by a technical review group of 19 scientists (SFEI 2014; referred to in the report as the "Landscape Interpretation Team").

Literature Cited

Alberston, J. D., and J. G. Evens. 2000. California Clapper Rail. Pages 332-340 *in* P. Olofson, editor. Baylands ecosystem species and community profiles. Life histories and environmental requirements of key plants, fish and wildlife. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency and San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

Andren, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos:355-366.

Atwater, B. F., S. G. Conard, J. N. Dowden, C. W. Hedel, R. L. Macdonald, and W. Savage. 1979. History, landforms, and vegetation of the estuary's tidal marshes. Page 493 p. *in* T. J. Conomos, editor. San Francisco Bay : the urbanized estuary : investigations into the Natural History of San Francisco Bay and Delta with reference to the influence of man : fifty-eighth annual meeting of the Pacific Division/American Association for the Advancement of Science held at San Francisco State University, San Francisco, California, June 12-16, 1977. AAAS, Pacific Division, San Francisco, Calif.

Atwater, B. F., and C. W. Hedel. 1976. Distribution of seed plants with respect to tide levels and water salinity in the natural tidal marshes of the northern San Francisco Bay estuary, California. U.S. Geological Survey Open-file report; 76-389, Menlo Park, CA.

Baum, K. A., K. J. Haynes, F. P. Dillemuth, and J. T. Cronin. 2004. The matrix enhances the effectiveness of corridors and stepping stones. Ecology **85**:2671-2676.

[BCDC] San Francisco Bay Conservation and Development Commission. 2008. San Francisco Bay Plan. San Francisco, CA.

Bender, D. J., T. A. Contreras, and L. Fahrig. 1998. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology **79**:517-533.

California Natural Resources Agency. 2015. Restoring the Sacramento San Joaquin Delta Ecosystem: California Eco Restore Fact Sheet, April 2015. http://resources.ca.gov/docs/ecorestore/ECO_FS_Overview.pdf

California State Coastal Conservancy. 2008. Hamilton final restoration plan. http://scc.ca.gov/webmaster/ftp/hamilton/hwrp-marsh-restoration-plan.pdf

Cannon, T., and B. Jennings. 2014. An Overview of Habitat Restoration Successes and Failures in the Sacramento-San Joaquin Delta. California Sportfishing Protection Alliance.

[CDWR] California Department of Water Resources. 2012. Delta Levees Program Habitat Projects. http://water.ca.gov/floodsafe/fessro/environmental/dee/map_2012.cfm

[CDWR] California Department of Water Resources. 2013. Bay Delta Conservation Plan (Public Draft). Prepared by ICF International Sacramento, CA.

Collins, J., C. Grosso, M. Sutula, E. Stein, E. Fetscher, R. Clark, and B. Close. 2005. Understanding tidal marsh fragmentation.*in* 6th Biennial Bay-Delta Science Conference, Sacramento, CA

Collins, J. N., and R. M. Grossinger. 2004. Synthesis of scientific knowledge concerning estuarine landscapes and related habitats of the South Bay Ecosystem. San Francisco Estuary Institute, Oakland.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature **387**:253-260.

Cushman, S., J. S. Evans, K. McGarigal, J. M. Kiesecker, and M. Joseph. 2010. Toward Gleasonian landscape ecology: from communities to species, from patches to pixels.

Cushman, S. A., K. Gutzweiler, J. S. Evans, and K. McGarigal. 2010. The gradient paradigm: a conceptual and analytical framework for landscape ecology. Pages 83-108 Spatial complexity, informatics, and wildlife conservation. Springer.

[CWMW] California Wetlands Monitoring Workgroup. 2015. EcoAtlas. Accessed February 2015. http://www.ecoatlas.org

D'Eon, R., S. M. Glenn, I. Parfitt, and M.-J. Fortin. 2002. Landscape connectivity as a function of scale and organism vagility in a real forested landscape. Conservation Ecology **6**:10.

Fahrig, L. 2002. Effect of habitat fragmentation on the extinction threshold: a synthesis. Ecological Applications **12**:346-353.

Fahrig, L., and G. Merriam. 1985. Habitat patch connectivity and population survival. Ecology:1762-1768.

Fischer, J., and D. B. Lindenmayer. 2002. Small patches can be valuable for biodiversity conservation: two case studies on birds in southeastern Australia. Biological Conservation **106**:129-136.

Forman, R. T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge University Press.

Gilpin, M. E. 1980. The role of stepping-stone islands. Theoretical population biology **17**:247-253.

Goals Project. 1999. Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency and S.F. Bay Regional Water Quality Control Board, San Francisco and Oakland, CA.

Goals Project Update. In preparation. The Baylands and Climate Change: What We Can Do. The 2015 Science Update to the Baylands Ecosystem Habitat Goals prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. California State Coastal Conservancy, Oakland, CA.

Greenberg, R., and J. E. Maldonado. 2006. Diversity and endemism in tidal-marsh vertebrates. Studies in Avian Biology **32**:32.

Greenberg, R., J. E. Maldonado, S. Droege, and M. McDonald. 2006. Tidal marshes: a global perspective on the evolution and conservation of their terrestrial vertebrates. BioScience **56**:675-685.

Harrison, S., and E. Bruna. 1999. Habitat fragmentation and large-scale conservation: what do we know for sure? Ecography **22**:225-232.

ICF Jones & Stokes. 2009. Liberty Island Conservation Bank Initial Study/Mitigated Negative Declaration. Sacramento, CA. Prepared for: Reclamation District 2039, Sacramento, CA.

Ingebritsen SE, Ikehara ME, Galloway DL, Jones DR. 2000. Delta subsidence in California: the sinking heart of the state. U.S. Geological Survey FS-005-00. 4 p.

Kirkman, T.W. 1996. Statistics to use. Accessed March 2015. http://www.physics.csbsju.edu/stats/

Kolozsvary, M. B., and R. K. Swihart. 1999. Habitat fragmentation and the distribution of amphibians: patch and landscape correlates in farmland. Canadian Journal of Zoology **77**:1288-1299.

Lindenmayer, D. B., and J. Fischer. 2006. Habitat fragmentation and landscape change: an ecological and conservation synthesis. Island Press.

Liu, L., J. Wood, N. Nur, L. Salas, and D. Jongsomjit. 2012. California Clapper Rail (Rallus longirostris obsoletus) Population monitoring: 2005-2011. PRBO Conservation Science, Petaluma, CA.

MacArthur, R. H., and E. O. Wilson. 1967. The Theory of Island Biogeography. AMC **10**:12.

McGarigal, K. 2002. Landscape pattern metrics. Encyclopedia of environmetrics.

Murphy, H. T., and J. Lovett-Doust. 2004. Context and connectivity in plant metapopulations and landscape mosaics: does the matrix matter? Oikos **105**:3-14.

[NOAA] National Oceanic and Atmospheric Administration. 2014. For a salt marsh on San Francisco Bay's eastern shore, restoration means a return to the tides. Office of Response and Restoration. http://response.restoration.noaa.gov/about/media/salt-marsh-san-francisco-bays-eastern-shore-restoration-means-return-tides.html

Noss, R., E. LaRoe, and J. Scott. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. National Biological Service Biological Report 28. U.S. Department of the Interior, Washington, D.C., USA.

Orr, M., S. Crooks, and P. B. Williams. 2003. Will restored tidal marshes be sustainable? San Francisco Estuary and Watershed Science **1**.

Ozaki, K., M. Isono, T. Kawahara, S. Iida, T. Kudo, and K. Fukuyama. 2006. A mechanistic approach to evaluation of umbrella species as conservation surrogates. Conservation Biology **20**:1507-1515.

Parker, T. V., J. C. Callaway, L. M. Schile, M. C. Vasey, and E. R. Herbert. 2011. Climate change and San Francisco Bay-Delta tidal wetlands. San Francisco Estuary and Watershed Science.

Peterson, C. H., K. W. Able, C. F. DeJong, M. F. Piehler, C. A. Simenstad, and J. B. Zedler. 2008. Practical proxies for tidal marsh ecosystem services: application to injury and restoration. Advances in marine biology **54**:221-266.

Roberge, J. M., and P. Angelstam. 2004. Usefulness of the umbrella species concept as a conservation tool. Conservation Biology **18**:76-85.

Safran, S., A. Robinson, J. Beagle, M. Klatt, K. Cayce, and R. Grossinger. 2013. A landscape ecology analysis of San Francisco Bay-Delta marsh then (1850) and now. State of the San Francisco Estuary Conference 2013, Oakland, CA.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation biology **5**:18-32.

[SBSPRP] South Bay Salt Ponds Restoration Project. 2007. South Bay Salt Pond Restoration Project Final Environmental Impact Statement / Report. Prepared for the US Fish and Wildlife Service and California Department of Fish and Game.

[SBSPRP] South Bay Salt Ponds Restoration Project. 2015.Track our progress. http://www.southbayrestoration.org/track-our-progress/

[SFBRWQCB] San Francisco Bay Regional Water Quality Control Board. 2010. San Francisco Bay Basin (Region 2) water quality control plan (Basin Plan). Oakland, CA. http://www.swrcb.ca.gov/rwqcb2/water_issues/programs/planningtmdls/basinplan/web/bp_ch2.shtml

[SFEI] San Francisco Estuary Institute. 1997. EcoAtlas Baylands Map ('Historical Baylands'). http://www.sfei.org/sites/default/files/EcoAtlas_SFEI.zip

[SFEI] San Francisco Estuary Institute. 1997. EcoAtlas Baylands Maps ('Modern Baylands'). http://www.sfei.org/sites/default/files/EcoAtlas_SFEI.zip

[SFEI] San Francisco Estuary Institute. 2011. Bay Area Aquatic Resource Inventory ('BAARI Baylands v01'). ftp://dl.sfei.org/geofetch/BAARI.zip

[SFEI-ASC] San Francisco Estuary Institute-Aquatic Science Center. 2014. A Delta Transformed: Ecological Functions, Spatial Metrics, and Landscape Change in the Sacramento-San Joaquin Delta.

Richmond, CA.

[SFEP] San Francisco Estuary Partnership. 2011. The State of San Francisco Bay 2011.

Shellhammer, H. 2000. Salt Marsh Harvest Mouse. Pages 219-228 *in* P. Olofson, editor. Baylands ecosystem species and community profiles. Life histories and environmental requirements of key plants, fish and wildlife. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency and San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

Siegel, S. 2014. Conundrum: Understanding Native Fish Functions of Emergent Tidal Marsh Restoration in a Highly Altered Landscape Largely Devoid of Tidal Marsh.*in* Bay-Delta Science Conference, Sacramento, CA.

Simberloff, D., J. A. Farr, J. Cox, and D. W. Mehlman. 1992. Movement corridors: conservation bargains or poor investments? Conservation biology **6**:493-504.

Soulé, M. E. 1987. Viable Populations for Conservation. Cambridge University Press.

Spautz, H., and N. Nur. 2002. Distribution and abundance in relation to habitat and landscape features and nest site characteristics of California Black Rail (Laterallus jamaicensis coturniculus) in the San Francisco Bay Estuary. Point Reyes Bird Observatory, Sacramento, CA.

Spautz, H. N., Nadav; Stralberg, Diana. 2005. California Black Rail (Laterallus jamaicensis coturniculus) Distribution and Abundance in Relation to Habitat and Landscape Features in the San Francisco Bay Estuary. USDA Forest Service Gen. Tech. Rep. PSW-GTR-191.

Stralberg, D., M. Brennan, J. C. Callaway, J. K. Wood, L. M. Schile, D. Jongsomjit, M. Kelly, V. T. Parker, and S. Crooks. 2011. Evaluating Tidal Marsh Sustainability in the Face of Sea-Level Rise: A Hybrid Modeling Approach Applied to San Francisco Bay. PLoS ONE **6**:e27388.

The Bay Institute. 1998. From the sierra to the sea: the ecological history of the San Francisco Bay-Delta watershed. The Bay Institute of San Francisco.

Troll, C. 1971. Landscape ecology (geoecology) and biogeocenology—a terminological study. Geoforum **2**:43-46.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. Annual review of ecology and systematics:171-197.

Turner, M. G. 2005. Landscape ecology: what is the state of the science? Annual review of ecology, evolution, and systematics:319-344.

[USFWS] U.S. Fish and Wildlife Service. n.d. Cullinan Ranch Restoration Project Final Environmental Impact Statement Record of Decision. San Pablo Bay Wildlife Refuge. Solano and Napa Counties, CA. http://www.fws.gov/cno/pdf/cullinanROD4-9-2010.pdf

[USFWS] U.S. Fish and Wildlife Service. 2011. Pond A16-A17 Environmental Action Statement. http://www.southbayrestoration.org/documents/permit-related/Pond%20A16&17%20Enviro%20Action%20Statement.pdf

[USFWS] U.S. Fish and Wildlife Service. 2013. Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California. Sacramento, CA.

Watson, E. B., and R. Byrne. 2009. Abundance and diversity of tidal marsh plants along the San Francisco Estuary: implications for global change ecology. Plant Ecology **205**:113-128.

Whipple, A. A., R. M. Grossinger, D. Rankin, B. Stanford, and R. A. Askevold. 2012. Sacramento-San Joaquin Delta Historical Ecology Investigation: Exploring Pattern and Process. San Francisco

Estuary Institute-Aquatic Science Center, Richmond, CA.

Wilcox, B. A., and D. D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. American naturalist:879-887.

Wood, J., L. Salas, N. Nur, M. Elrod, and G. Ballard. 2013. Distribution and Population Trends for the California Clapper Rail.*in* State of the Estuary, Oakland, CA.

Zedler, J. B. 2012. Diverse perspectives on tidal marshes. Page 265 *in* A. Palaima, editor. Ecology, conservation, and restoration of tidal marshes. University of California Press, Los Angeles.