A landscape ecology analysis of San Francisco Bay-Delta marsh then (1850) and now

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Introduction

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 gradients (i.e. tidal influence, salinity, and vegetation). These gradients are important when planning for restoration of wildlife corridors and interconnected habitats. While current regional management and restoration efforts emphasize a landscape-scale approach to restoration, few tools are available that illuminate what large, interconnected habitat restoration should look like for the Estuary as a whole.

To inform these efforts, the San Francisco Estuary Institute used newly developed datasets to perform multiple landscape ecology analyses of marsh in the Bay and Delta. These analyses— including **marsh patch size**, **nearest large neighbor distance**, and **core area ratio**—were performed in parallel on historical and contemporary datasets of the Estuary's aquatic resources. Landscape metrics were designed to to explicitly measure landscape pattern in a manner that is relevant to a particular organism or process by quantifying habitat extent, distribution, quality and connectivity for marsh birds. A literature search was conducted to identify ecologically-relevant thresholds for Clapper rails (*Rallus longirostris*) and black rails (*Laterallus jamaicensis*), which were then used to parameterize landscape metrics.

Ultimately, landscape metrics allowed us to characterize historical marsh habitat for key species, illustrate the current configuration of marsh habitat across the Estuary, and analyze net changes between c.1850 and 2009. This work has the potential to aid ongoing assessment of the region's progress towards targets established by the Baylands Ecosystem Habitat Goals Update and the Bay Delta Conservation Plan and is notable for both its synthesis of complementary regional datasets and its application across the whole San Francisco Estuary.

Methods

Datasets: Datasets used for this study came from multiple sources. Historical marsh polygons were extracted from the Ecoatlas Historical Aquatic Resources layer (a synthesis of 12 regional historical ecology studies carried out by SFEI since 1998; CWMW 2013) by selecting polygons classified as "Tidal / Salt Marsh" or "Marsh" (non-tidal marsh) and clipping to the combined extent of SFEI's Historical Baylands (1999) and Delta Historical Ecology (Whipple et al. 2012) studies. Modern marsh polygons were taken from 2009 BAARI data (2011) modified for the Baylands Ecosystem Habitat Goals Update (BEHGU) and from an unpublished Delta habitat type layer. This unpublished layer was synthesized and crosswalked by SFEI from DFW and BDCP layers (DFG 2007; DFW 2012; BDCP 2013). These polygons were clipped to the same extent as the historical dataset.

Defining patches: In the GIS, discrete marsh polygons were considered part of the same patch if they were located within 60 m of one another. This distance is based on a rule set for defining intertidal resident rail patches developed by Collins and Grossinger (2004). Our analysis, however, only considers roads and levees as dispersal barriers if they exceed the 60 m threshold. This simplistic model of a binary landscape assumes that all patches of marsh are equally suitable for rails, that the routes of travel between patches are linear, and that the only barrier to rail movement is distance (D'Eon et al. 2002).

Nearest large neighbor: Nearest large neighbor was calculated for each patch as the linear distance to the nearest neighboring marsh patch of at least 100 ha. This size threshold is based on (1) the regression model of Spautz and Nur (2002), which showed a significant negative correlation between Black Rail presence and distance to the nearest 100 ha marsh and (2) the work of Liu et al. (2012), which found that CA Clapper Rail densities decrease in patches < 100 ha. Patches greater than 100 ha received a NND of 0 m.

Core area ratio: For this analysis, core area ratio is defined as the percent of a marsh patch's total area that is greater than 50 m from the patch edge. This distance is based on the work of Spautz and Nur (2002), who used a buffer distance of 50 m to define core habitat when they determined that the probability of Black Rail presence increases significantly with marsh core area.

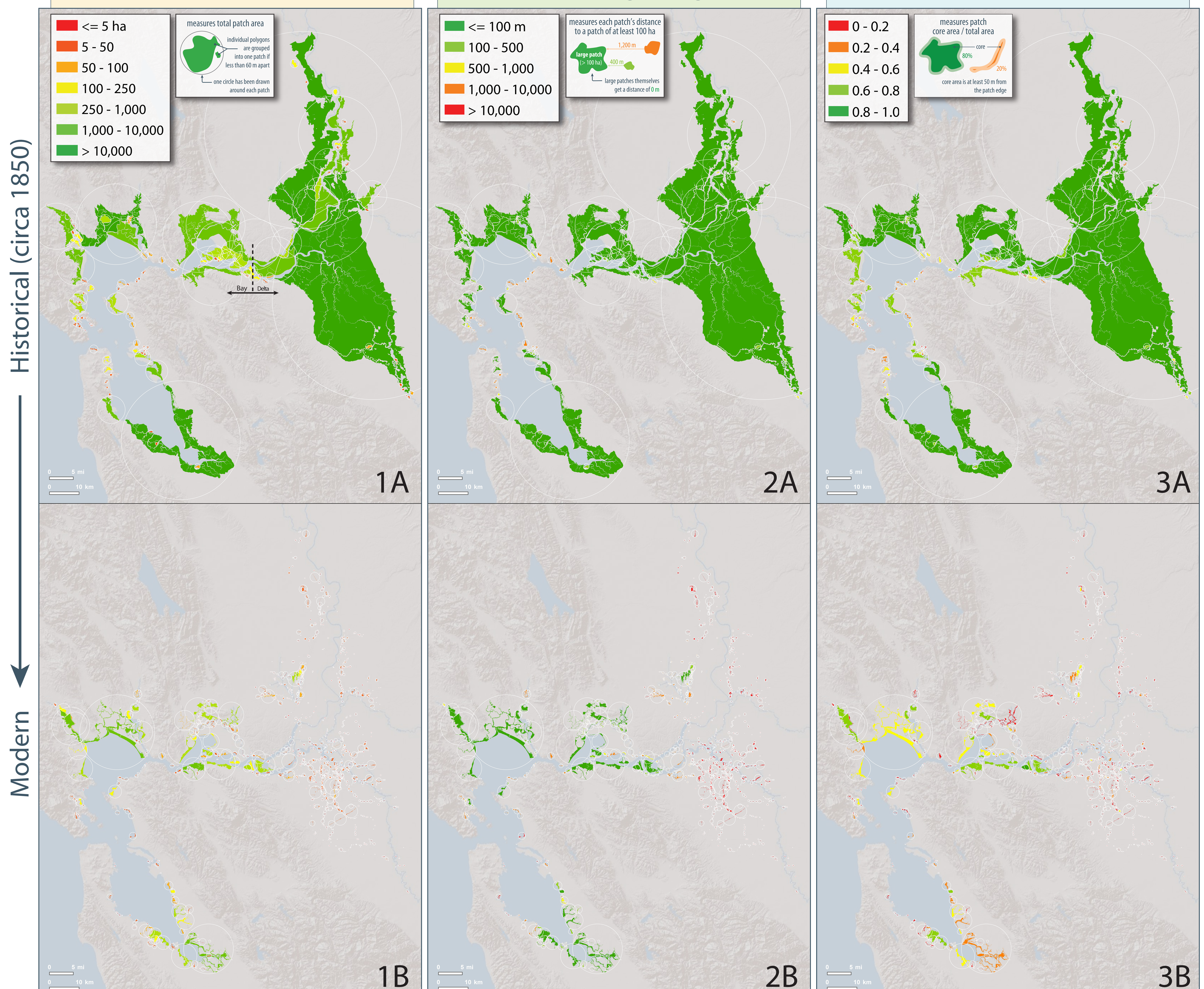
Results

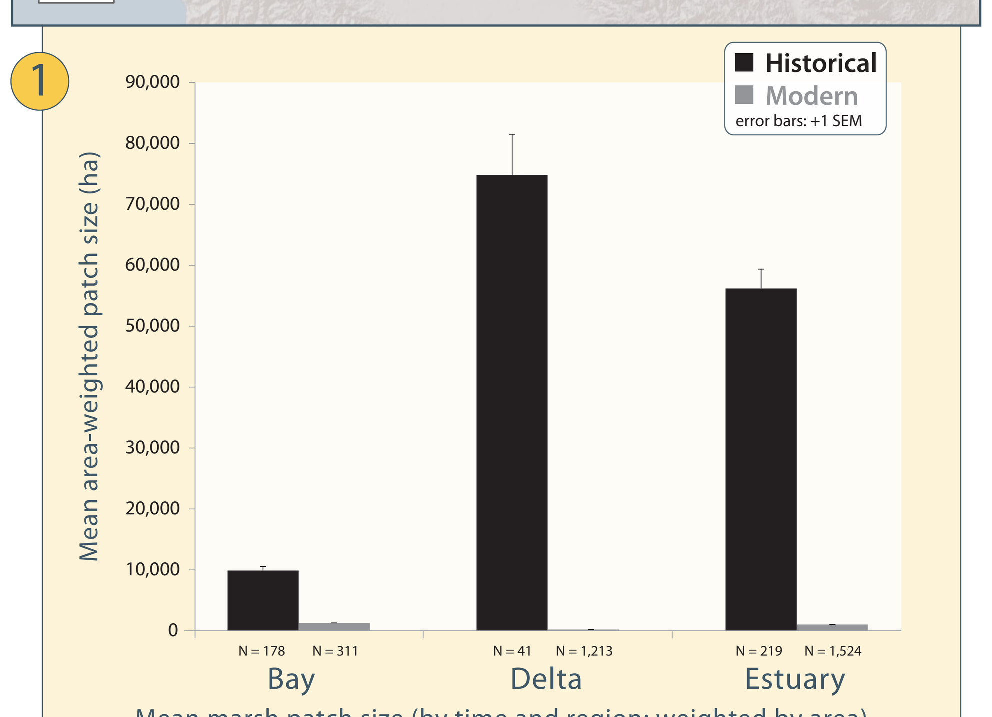
Patch size: Total marsh area and average patch size in the study area varied over time and by region. Our analysis identified 219 distinct marsh patches in the historical Estuary and 1,524 distinct patches in the modern Estuary. The net number of large patches (> 100 ha) has decreased, from 48 to 34. Compared to 76.8% today, 99.1% of the Estuary's total historical marsh area was part of a patch greater than 100 ha in size (only 28.4% of the marsh in the modern Delta is associated with a large patch). Mean patch size in the Estuary has decreased from 1,232.6 ha to 14.7 ha. Mean area-weighted patch size in the Estuary has decreased from 56,182.7 ha to 1,021.2 ha. While 71% of the Estuary's historical marsh existed in the Delta (with 29% in the Bay), today the Delta contains 20% of the Estuary's marsh (with 80% located in the Bay).

Nearest large neighbor: Mean area-weighted nearest large (> 100 ha) neighbor distance across all Estuary patches increased from 10.4 m historically to 2,607.6 m today. Mean area-weighted nearest large neighbor distance in the modern Delta (12,314.2 m) is more than 60x that of the modern Bay (198.7 m). Historical mean area-weighted nearest large neighbor distance was higher in the Bay (33.7 m) than in the Delta (1.1 m).

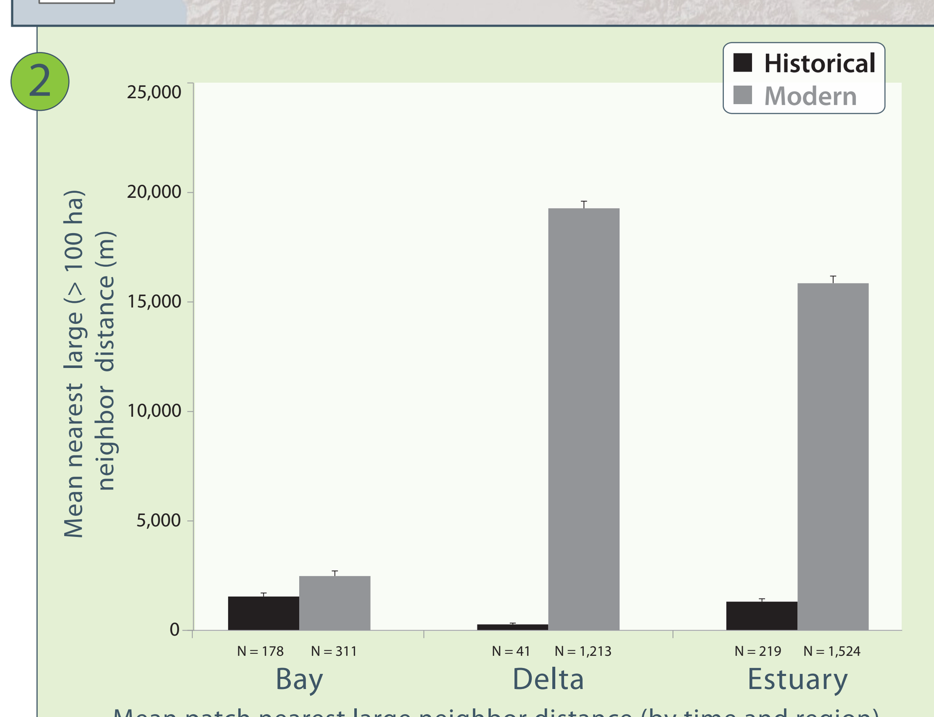
Core area ratio: Mean area-weighted core area ratio across all Estuary patches has decreased from 0.90 historically to 0.48 today. Mean area-weighted core area ratio in the modern Delta (0.26) is less than half that of the modern Bay (0.54 m). Patches in the Delta today account for only 10.6% of the Estuary's core marsh habitat (while historically accounting for 73.4%).

1 Marsh patch size | 2 Nearest large neighbor | 3 Core area ratio

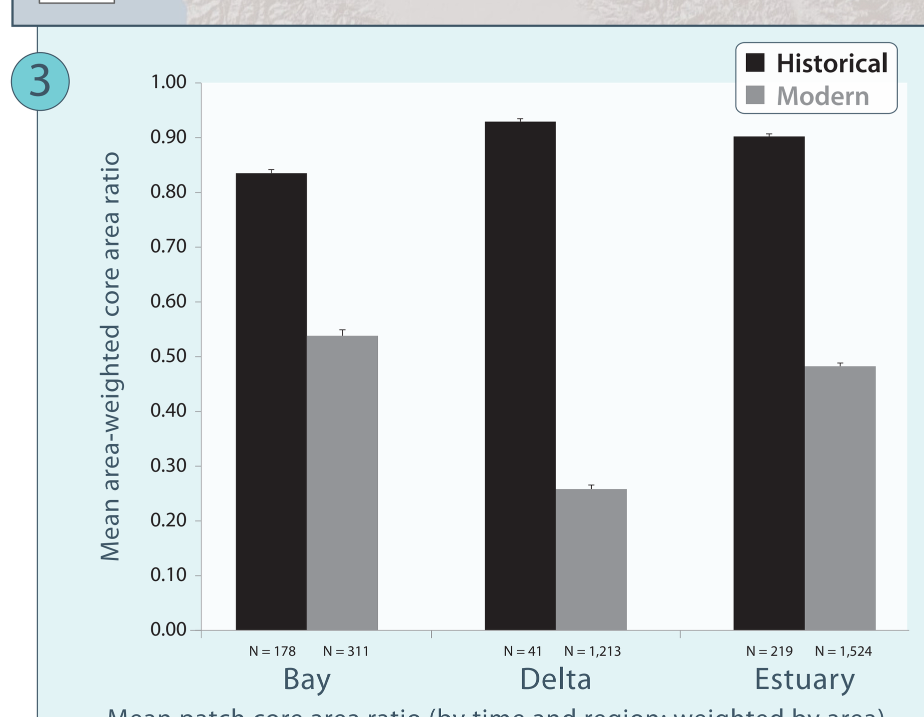




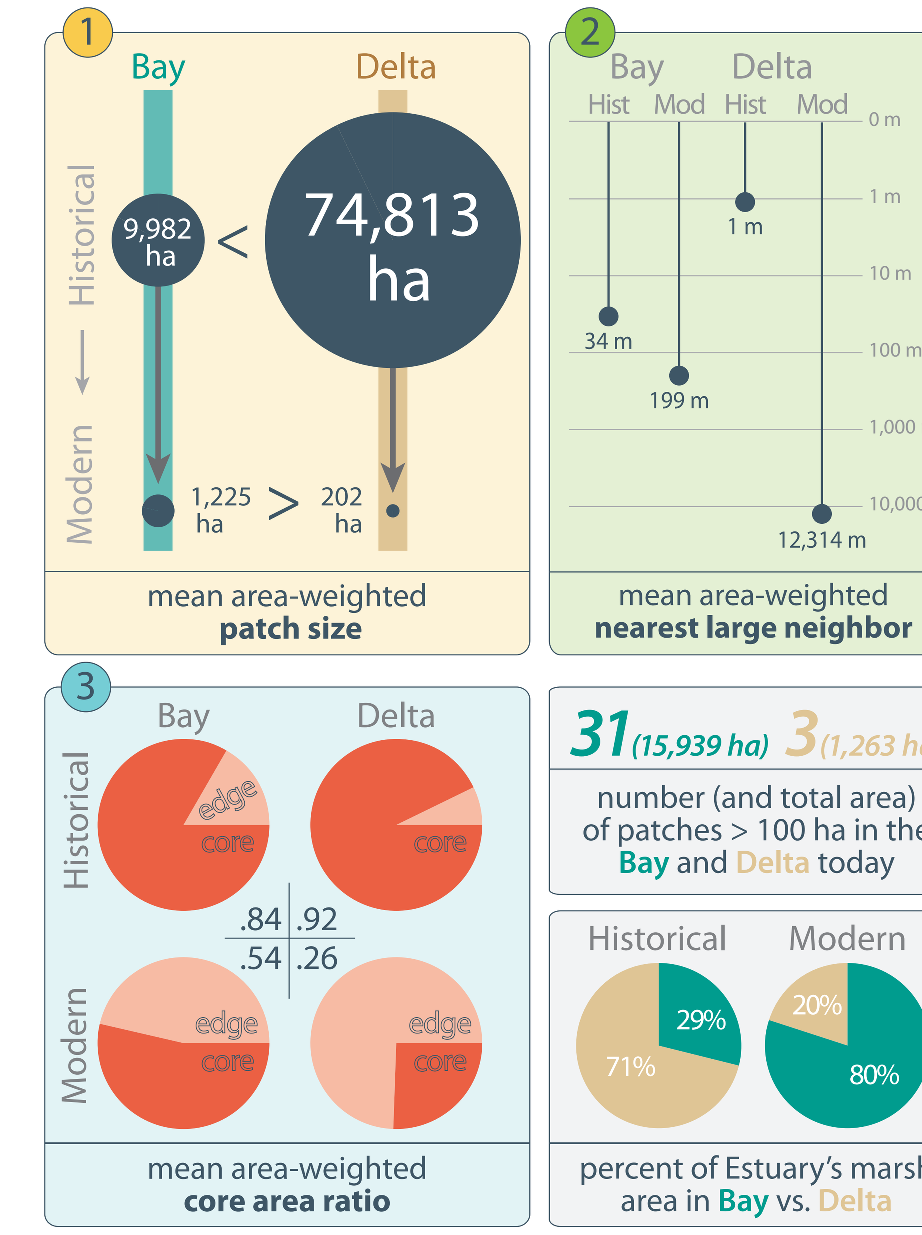
Mean marsh patch size (by time and region; weighted by area)



Mean patch nearest large neighbor distance (by time and region)



Mean patch core area ratio (by time and region; weighted by area)



		N	Patch size (ha) μ	σ	Area weighted μ	Area weighted σ	Min	Max	Nearest neighbor (> 100 ha) distance (m) μ	σ	Area weighted μ	Area weighted σ	Min	Max	Core area ratio μ	σ	Area weighted μ	Area weighted σ	Min	Max
Historical	Bay	178	435	2,034	9,892	8,581	< 1	22,501	1,551	2,109	34	362	0	8,594	0.26	0.32	0.84	0.09	0	0.95
	Delta	41	4,694	18,368	74,813	42,853	< 1	110,488	275	389	1	26	0	1,623	0.50	0.33	0.93	0.03	0	0.95
	Estuary	219	1,233	8,249	56,183	46,829	< 1	110,488	1,312	1,971	10	196	0	8,594	0.30	0.33	0.90	0.07	0	0.95
Modern	Bay	311	58	260	1,225	1,223	< 1	3,447	2,487	4,067	199	1,243	0	20,892	0.09	0.20	0.54	0.19	0	0.87
	Delta	1,213	4	27	202	327	< 1	858	19,279	11,093	12,314	11,956	0	61,359	0.02	0.07	0.26	0.26	0	0.69
	Estuary	1,524	15	122	1,021	1,178	< 1	3,447	15,853	12,130	2,608	7,283	0	61,359	0.03	0.11	0.48	0.24	0	0.87

Conclusions

- ***There has been dramatic net loss and fragmentation of the Estuary's marsh habitat over the last 150 years.*** Continuous marsh habitat no longer spans the Estuary and its many environmental gradients.
- ***Estuary-wide decreases in average marsh patch size and total area are more pronounced in the Delta than the Bay.*** Large marshes are more likely than small marshes to provide a mosaic of marsh types, buffer populations from predators, and to have a well-developed channel network (all factors known to promote rail densities; Liu et al. 2012).
- ***Estuary-wide increases in nearest large neighbor distance are more pronounced in the Delta than the Bay (where some networks are surprisingly well-connected).*** Greater distances to large neighbors are expected to translate to decreased connectivity between resident metapopulations and diminished long-term maintenance of genetic variability.
- ***Estuary-wide decreases in core area ratio.*** Because most of the Estuary's marshes now exists as narrow strips, core refuge areas are rare. In addition to the high rates of predation in edge habitat, this configuration increases the vulnerability of marshes to further climate change-associated fragmentation.
- ***A reversal over time in the relative proportion of marsh in the Bay vs. Delta.*** The extensive historical freshwater marsh of the Delta would have differed from the salt and brackish marshes in tidal influence, the timing of habitat availability, the composition and seasonality of available prey, and the composition and structure of the plant community.
- ***This landscape-scale analysis highlights the need for reestablishing marsh scale and connectivity along gradients across the Estuary.*** This is particularly important as we work to design sustainable marsh networks that allow native species to persist with anthropogenic climate change.

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