Automated Habitat Mapping
+
Shoreline Resilience Framework

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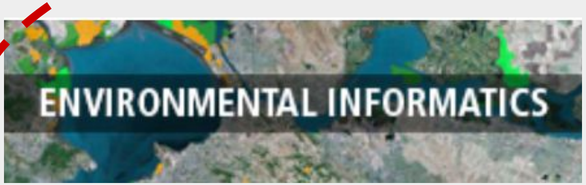
GIS Specialist/Environmental Scientist
San Francisco Estuary Institute

San Francisco Estuary Institute (SFEI)



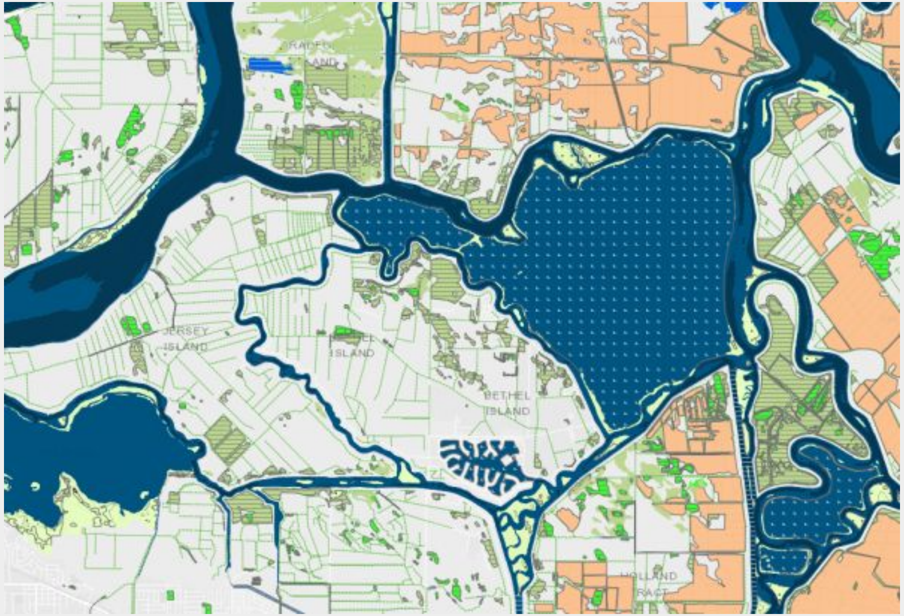
Deliver scientific information to a wide range of stakeholders in dynamic, expressive, and cogent ways

Develop innovative, long-range, nature-based strategies to improve the health of our shorelines, cities, and rural areas

Anticipates and meets the water water quality data needs of policy-makers, resource managers, and the public

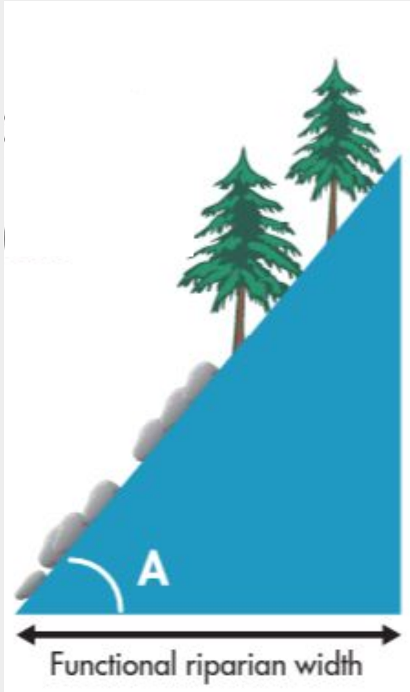
Habitat Mapping of the Past - *Heads-Up Digitizing*

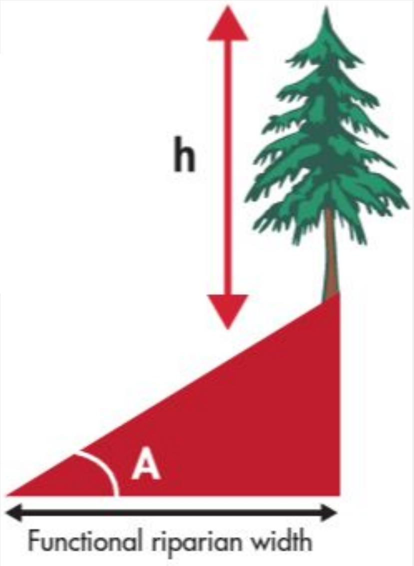
- Slow and costly
- Inconsistent in accuracy & precision
    - Possible differences among techniques or an array of mapping analysts
    - Change detection over time problematic and impractical
- Majority of NWI and NHD
- Shifting to more automated & semi-automated approaches



Automated Habitat Mapping - *Approaches*

- Simplified/Modeled (Functional Extent)
    - **Riparian Zone Estimator Tool (RipZET)**
    - Relative Tidal Elevation
- Image Analysis
    - Pixel-Based Image Analysis
    - Object-Based Image Analysis (OBIA)





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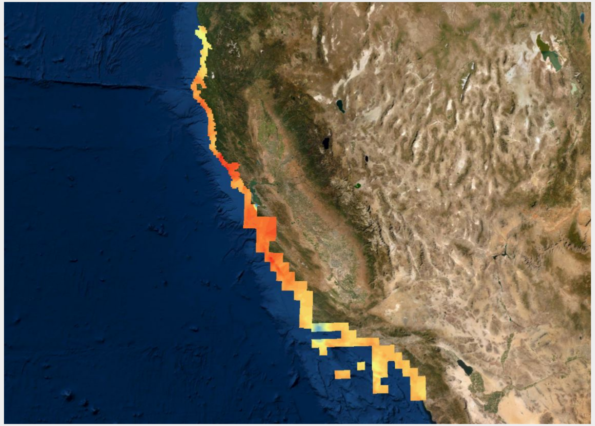

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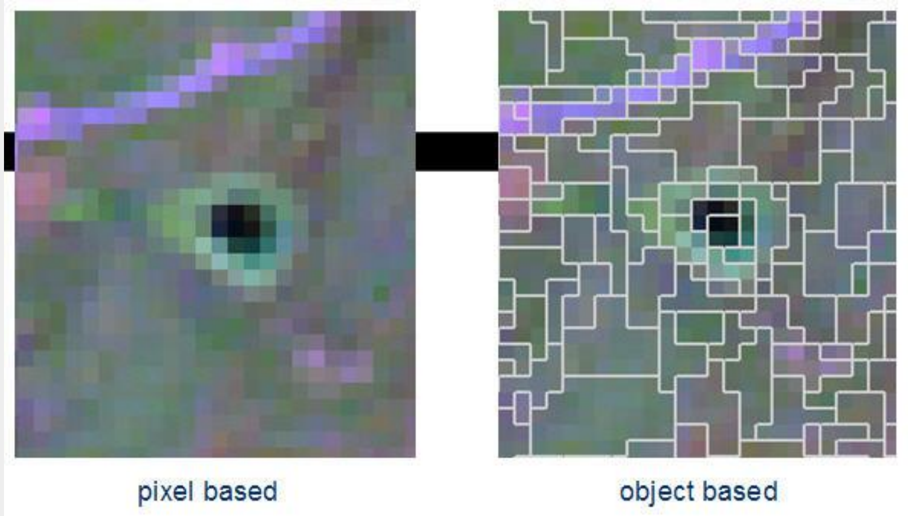

Image from Government of British Columbia (www2.gov.bc.ca)

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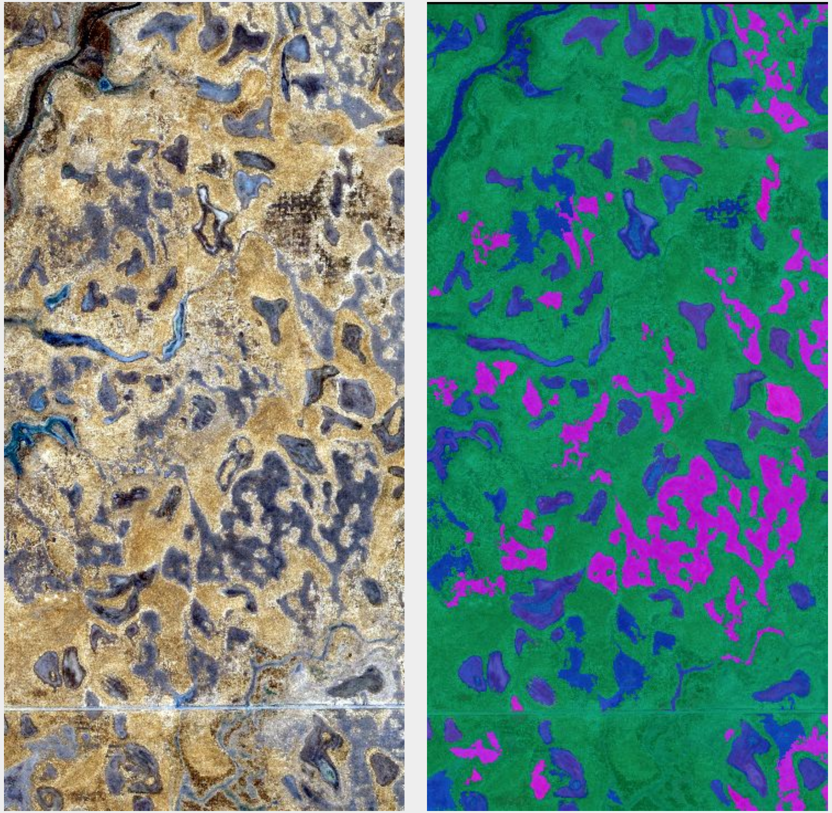
  - Pixel-Based Image Analysis
  - Object-Based Image Analysis
    - Machine Learning
      - **San Diego**
      - **Russian River**
      - **Vernal Pools**
    - Rule Set



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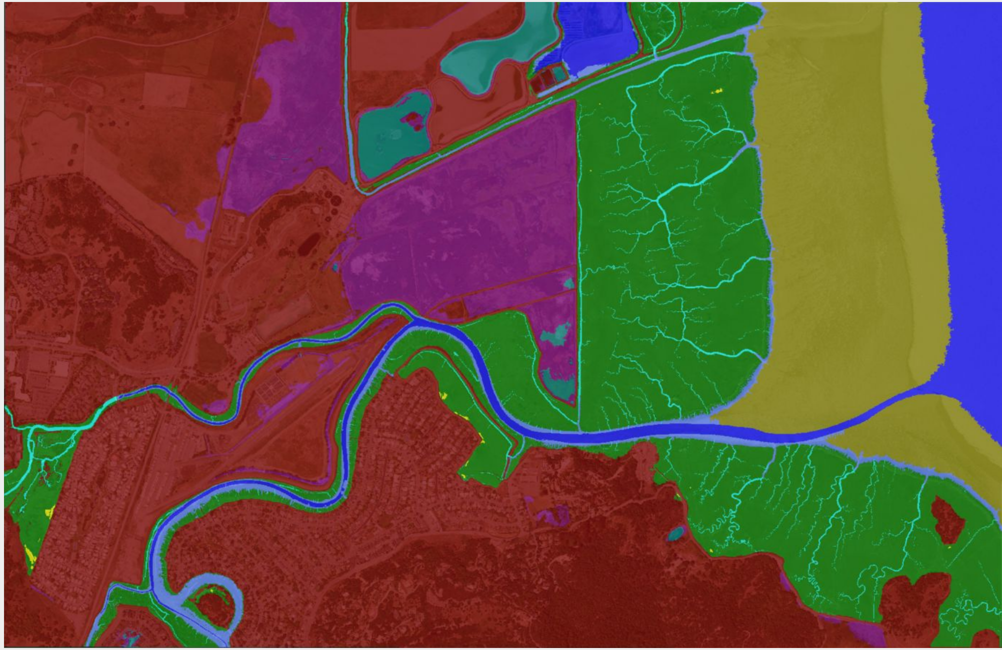
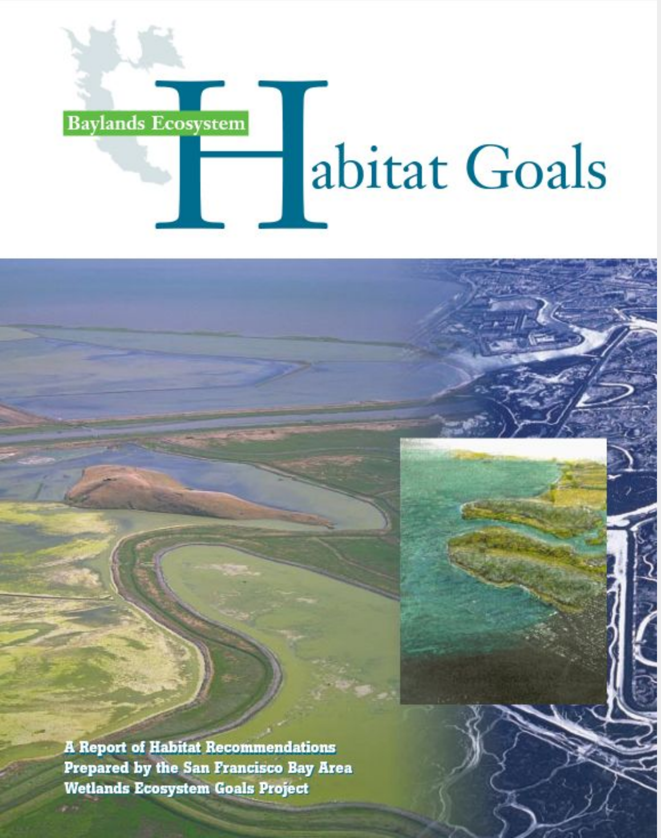
    - Object-Based Image Analysis
        - Machine Learning
        - Rule Set
            - **Baylands Change Basemap**



San Francisco Bay/Estuary

Landsat imagery courtesy NASA, April 2013

Baylands Ecosystem Habitat Goals (1999)/Update (2015)

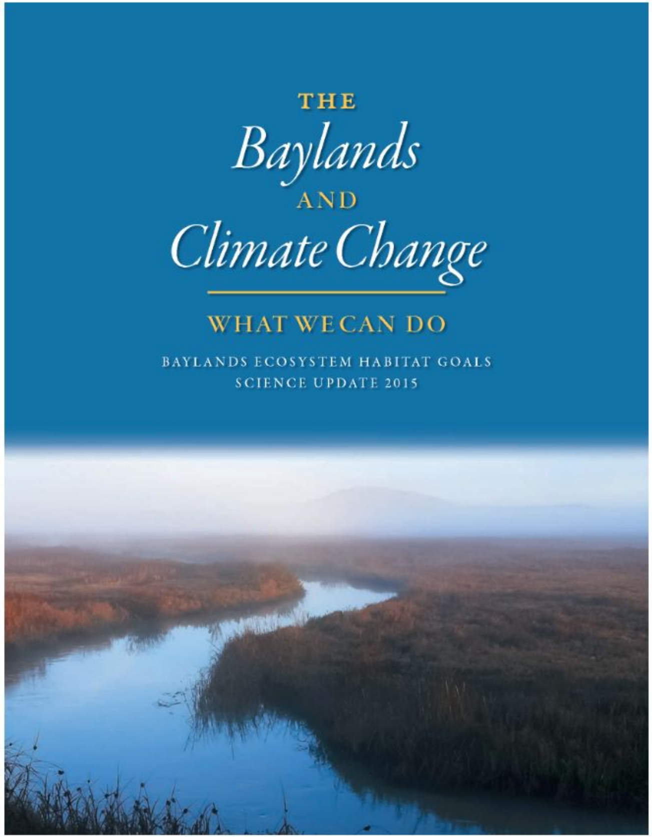


Baylands Ecosystem
Habitat Goals

A Report of Habitat Recommendations
Prepared by the San Francisco Bay Area
Wetlands Ecosystem Goals Project

Restore 60,000 acres of tidal marsh to reach 100,000 acres

—>

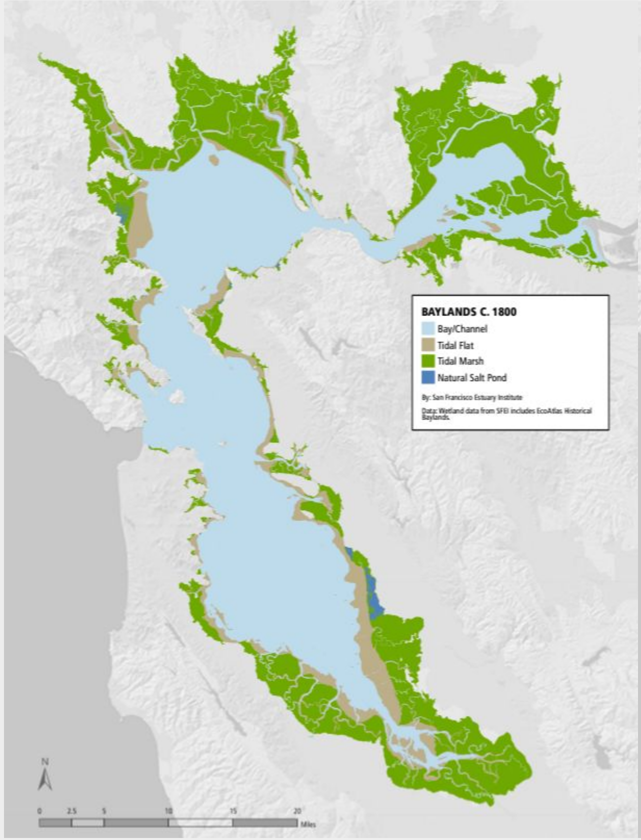


THE
Baylands
AND
Climate Change

WHAT WE CAN DO

BAYLANDS ECOSYSTEM HABITAT GOALS
SCIENCE UPDATE 2015

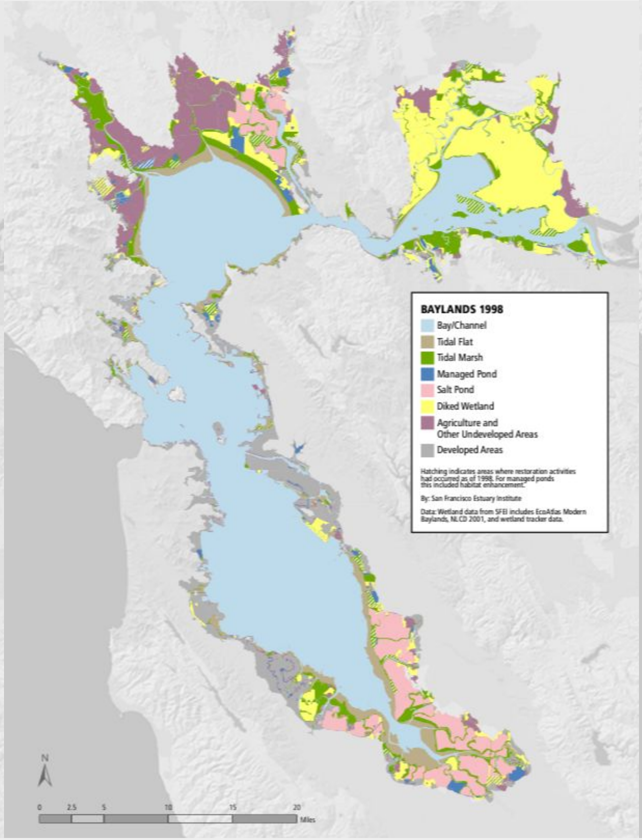
Historical Baylands (c. 1800)



By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes EcoAtlas Historical Baylands.

Modern Baylands (c. 1998)

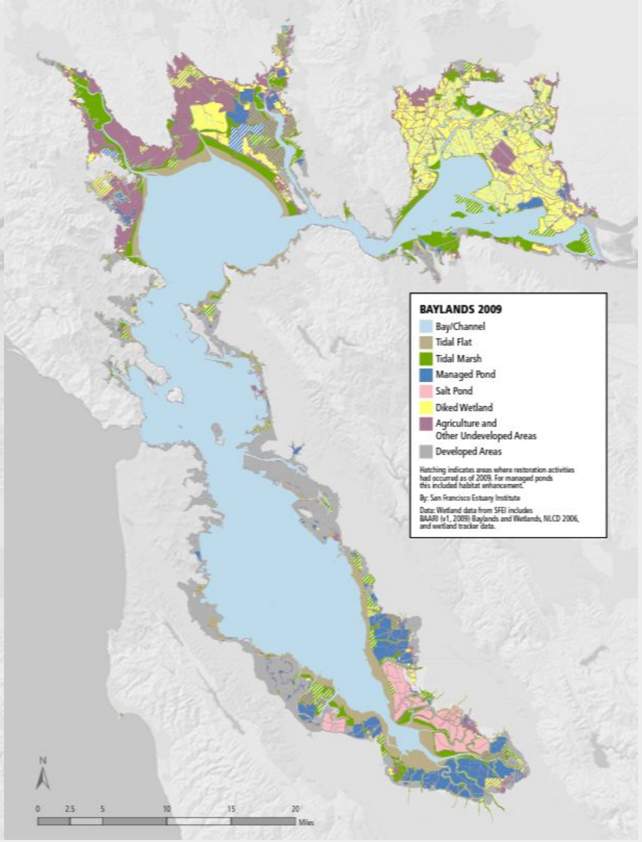


Hatching indicates areas where restoration activities had occurred as of 1998. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

Data: Wetland data from SFEI includes EcoAtlas Modern Baylands, NLCD 2001, and wetland tracker data.

Modern Baylands (c. 2009)



Hatching indicates areas where restoration activities had occurred as of 2009. For managed ponds this included habitat enhancement.

By: San Francisco Estuary Institute

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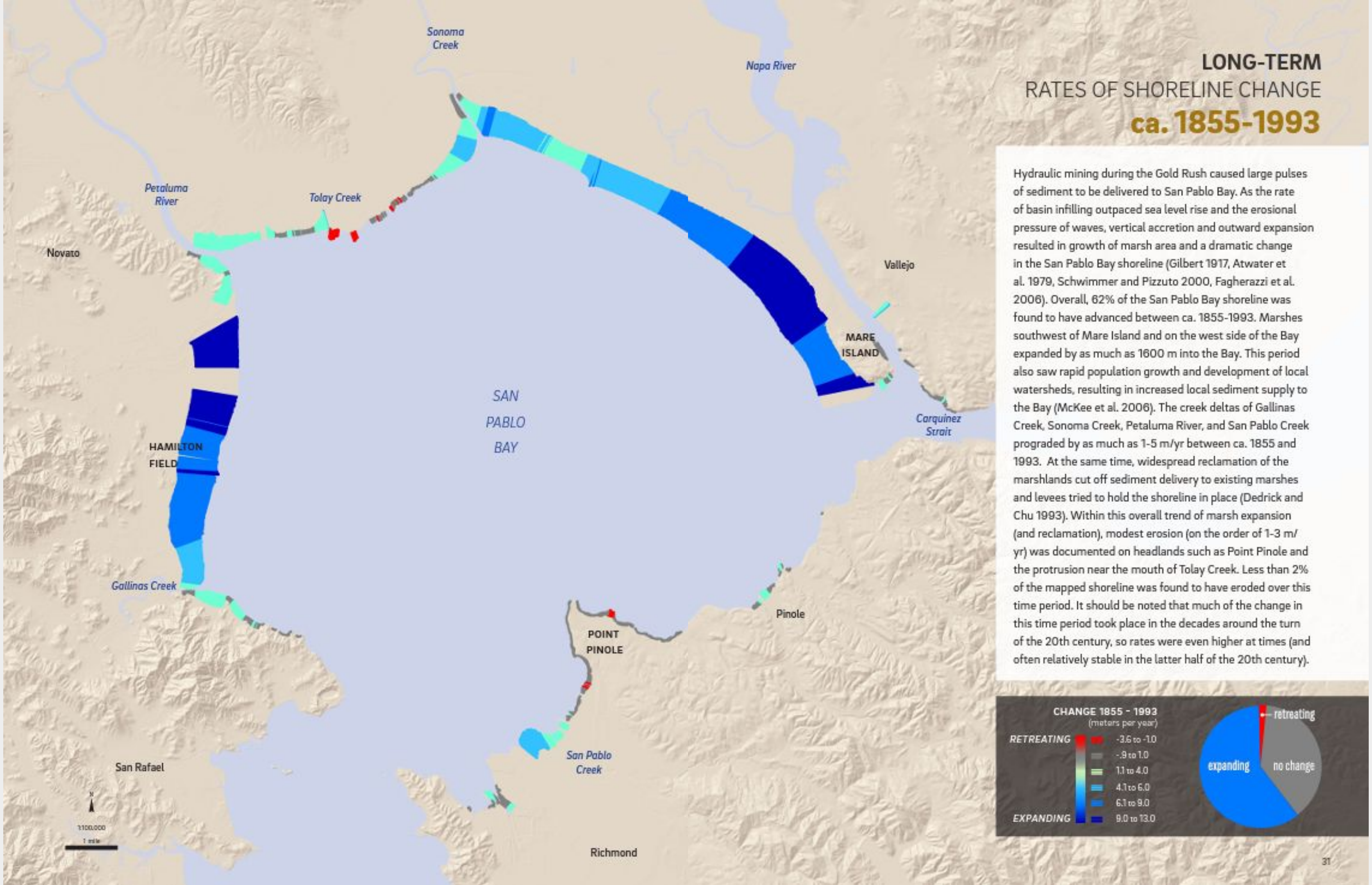
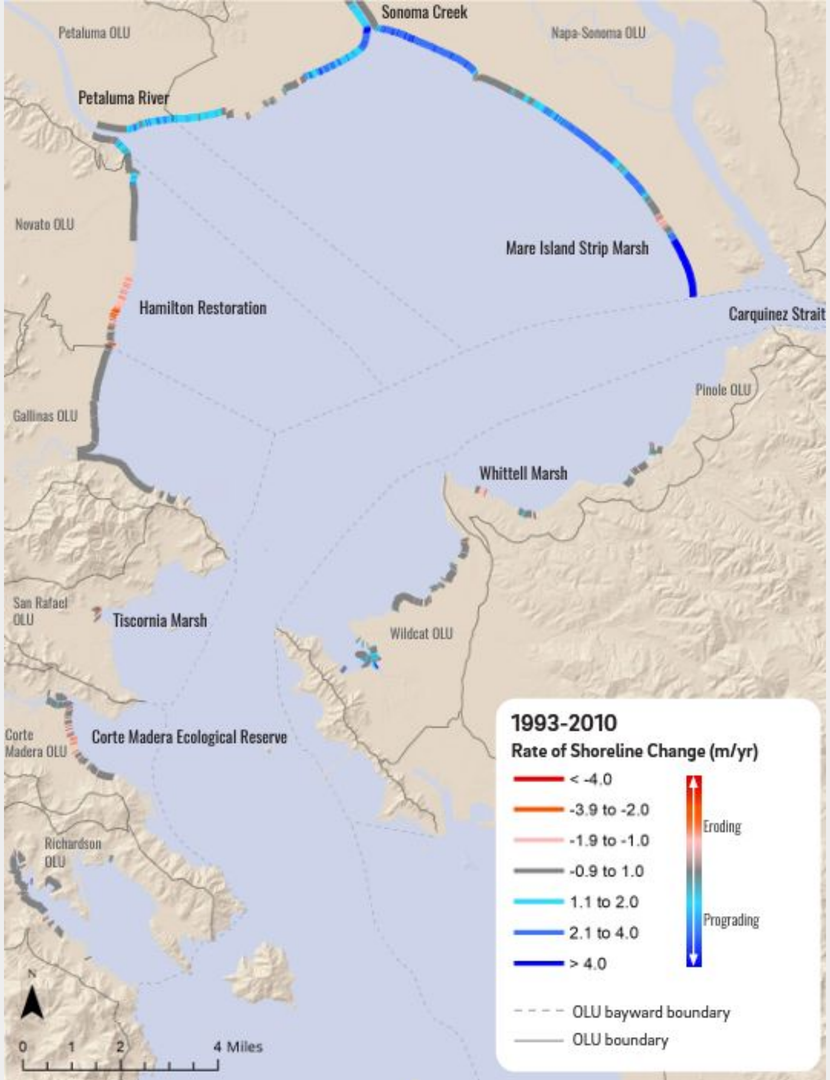
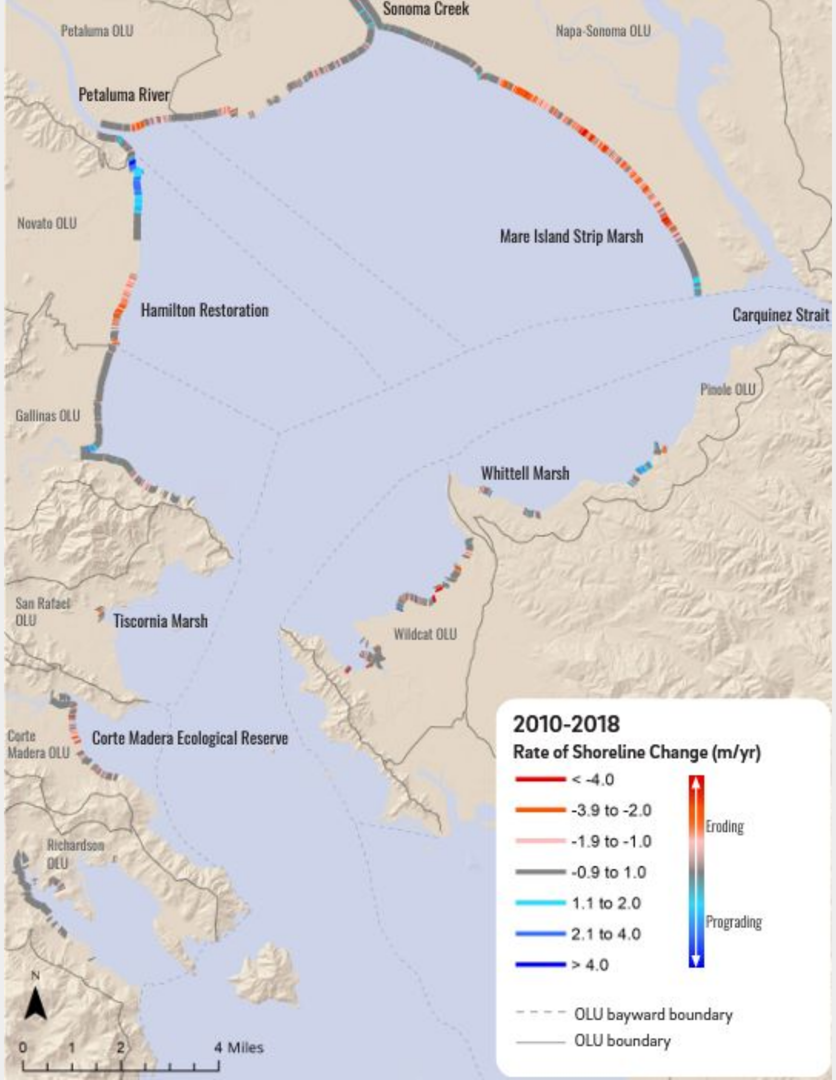
LONG-TERM
RATES OF SHORELINE CHANGE
ca. 1855-1993

Hydraulic mining during the Gold Rush caused large pulses of sediment to be delivered to San Pablo Bay. As the rate of basin infilling outpaced sea level rise and the erosional pressure of waves, vertical accretion and outward expansion resulted in growth of marsh area and a dramatic change in the San Pablo Bay shoreline (Gilbert 1917, Atwater et al. 1979, Schwimmer and Pizzuto 2000, Fagherazzi et al. 2006). Overall, 62% of the San Pablo Bay shoreline was found to have advanced between ca. 1855-1993. Marshes southwest of Mare Island and on the west side of the Bay expanded by as much as 1600 m into the Bay. This period also saw rapid population growth and development of local watersheds, resulting in increased local sediment supply to the Bay (McKee et al. 2006). The creek deltas of Gallinas Creek, Sonoma Creek, Petaluma River, and San Pablo Creek prograded by as much as 1-5 m/yr between ca. 1855 and 1993. At the same time, widespread reclamation of the marshlands cut off sediment delivery to existing marshes and levees tried to hold the shoreline in place (Dedrick and Chu 1993). Within this overall trend of marsh expansion (and reclamation), modest erosion (on the order of 1-3 m/yr) was documented on headlands such as Point Pinole and the protrusion near the mouth of Tolay Creek. Less than 2% of the mapped shoreline was found to have eroded over this time period. It should be noted that much of the change in this time period took place in the decades around the turn of the 20th century, so rates were even higher at times (and often relatively stable in the latter half of the 20th century).




Sonoma Creek
Petaluma OLU
Napa-Sonoma OLU
Petaluma River
Novato OLU
Mare Island Strip Marsh
Hamilton Restoration
Carquinez Strait
Pinole OLU
Gallinas OLU
Whittell Marsh
San Rafael OLU
Tiscornia Marsh
Wildcat OLU
Corte Madera OLU
Corte Madera Ecological Reserve
Richardson OLU
N
0
1
2
4 Miles
1993-2010
Rate of Shoreline Change (m/yr)
< -4.0
-3.9 to -2.0
-1.9 to -1.0
-0.9 to 1.0
1.1 to 2.0
2.1 to 4.0
> 4.0
Eroding
Prograding
OLU bayward boundary
OLU boundary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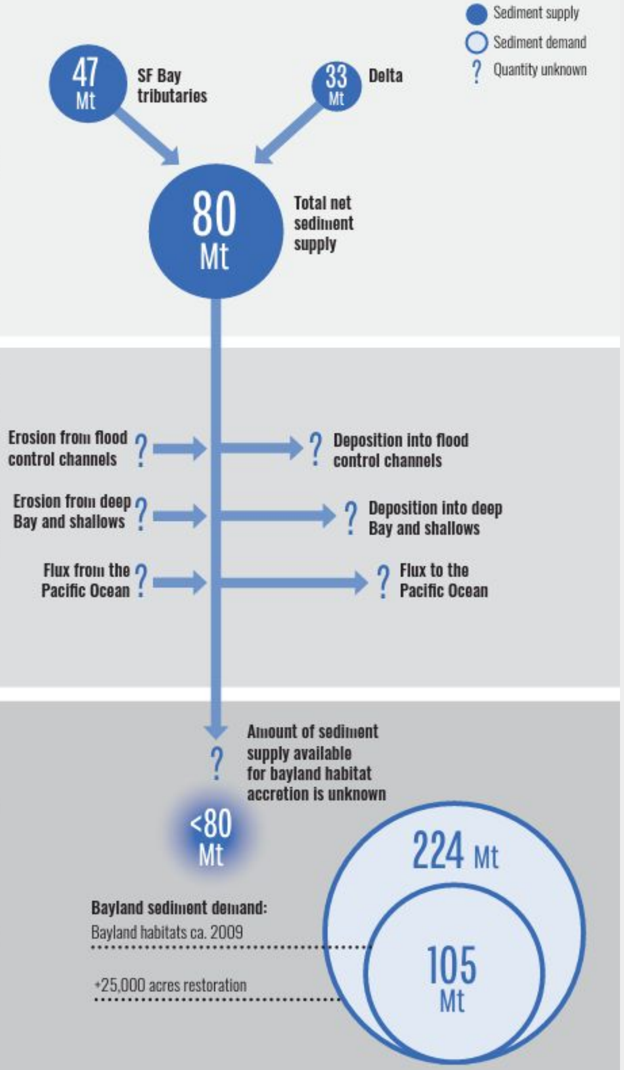


● Sediment supply
○ Sediment demand
? Quantity unknown

Tributary sediment supply at head of tide: The total net tributary sediment supply into SF Bay between 2010 and 2050 under a wetter climate future (CESM1-BGC 8.5) is approximately 80 Mt. About 40% of this estimate is based on sediment from Delta tributaries and 60% from Bay tributaries.

47 Mt **SF Bay tributaries**

33 Mt **Delta**

80 Mt **Total net sediment supply**

Sediment transport downstream of head of tide: As sediment travels out of the watershed and into tidal reaches, sediment supply to the baylands decreases as a result of in-channel sedimentation and deposition in the Bay's deep channels. Additional sediment will likely be lost from flux through the Golden Gate to the Pacific Ocean, the magnitude of which is unknown.

Erosion from flood control channels ?

Erosion from deep Bay and shallows ?

Flux from the Pacific Ocean ?

? **Deposition into flood control channels**

? **Deposition into deep Bay and shallows**

? **Flux to the Pacific Ocean**

Sediment deposition onto baylands habitats: Existing bayland habitats (ca. 2009) will need approximately 105 Mt of sediment to keep pace with 1.9 ft of SLR by 2050. If all tidal marsh restoration projects are underway during this time period, an additional 119 Mt of sediment will be needed to meet bayland habitat demands. More data is needed to determine the amount of sediment from Bay and Delta tributaries that would be deposited onto bayland habitats.

? **Amount of sediment supply available for bayland habitat accretion is unknown**

<80 Mt

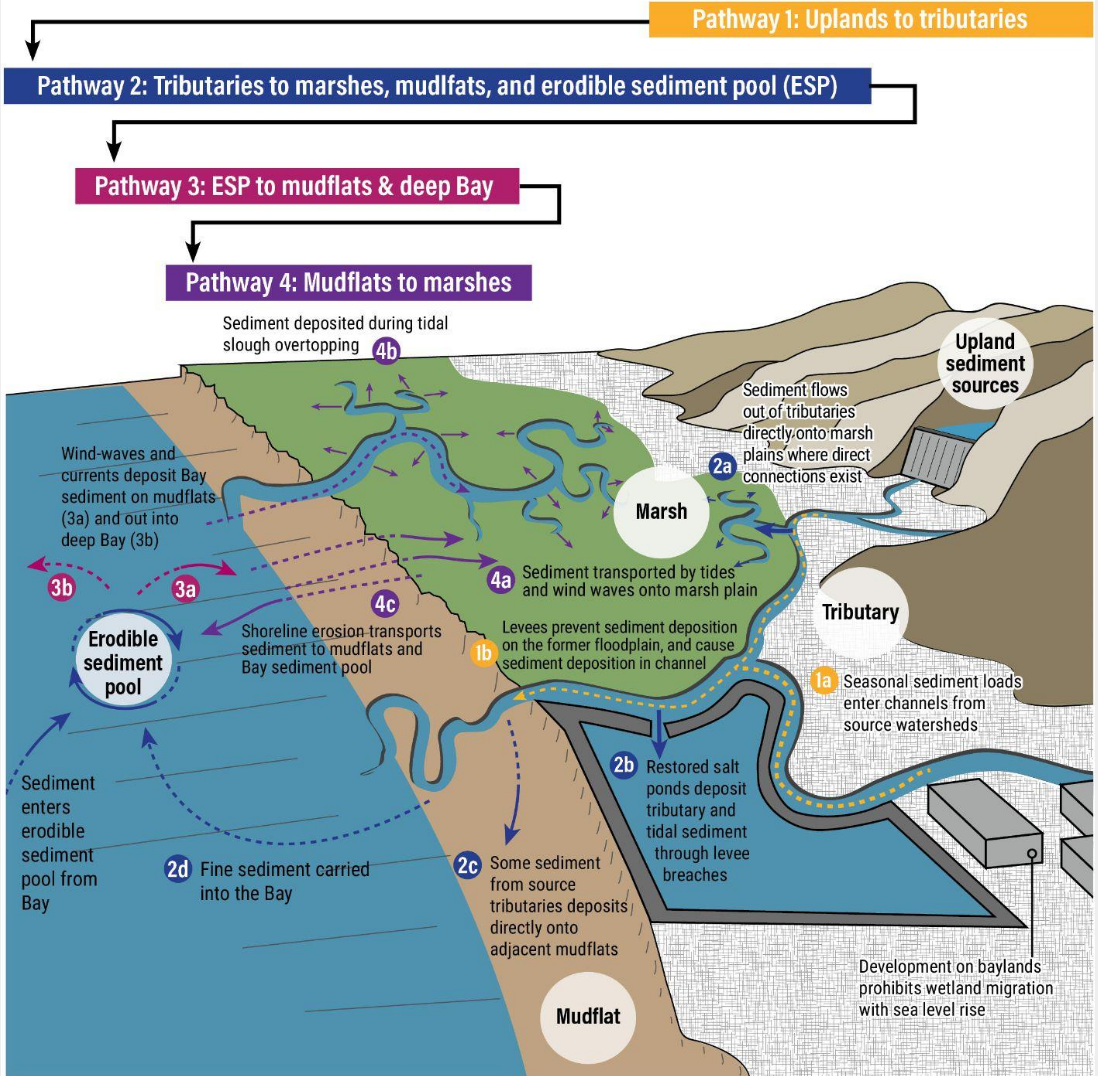
Bayland sediment demand:

Bayland habitats ca. 2009

+25,000 acres restoration

224 Mt

105 Mt



Pathway 1: Uplands to tributaries

Pathway 2: Tributaries to marshes, mudlfats, and erodible sediment pool (ESP)

Pathway 3: ESP to mudflats & deep Bay

Pathway 4: Mudflats to marshes

4b Sediment deposited during tidal slough overtopping

2a Sediment flows out of tributaries directly onto marsh plains where direct connections exist

Wind-waves and currents deposit Bay sediment on mudflats (3a) and out into deep Bay (3b)

4a Sediment transported by tides and wind waves onto marsh plain

4c Shoreline erosion transports sediment to mudflats and Bay sediment pool

1b Levees prevent sediment deposition on the former floodplain, and cause sediment deposition in channel

1a Seasonal sediment loads enter channels from source watersheds

2b Restored salt ponds deposit tributary and tidal sediment through levee breaches

Sediment enters erodible sediment pool from Bay

2d Fine sediment carried into the Bay

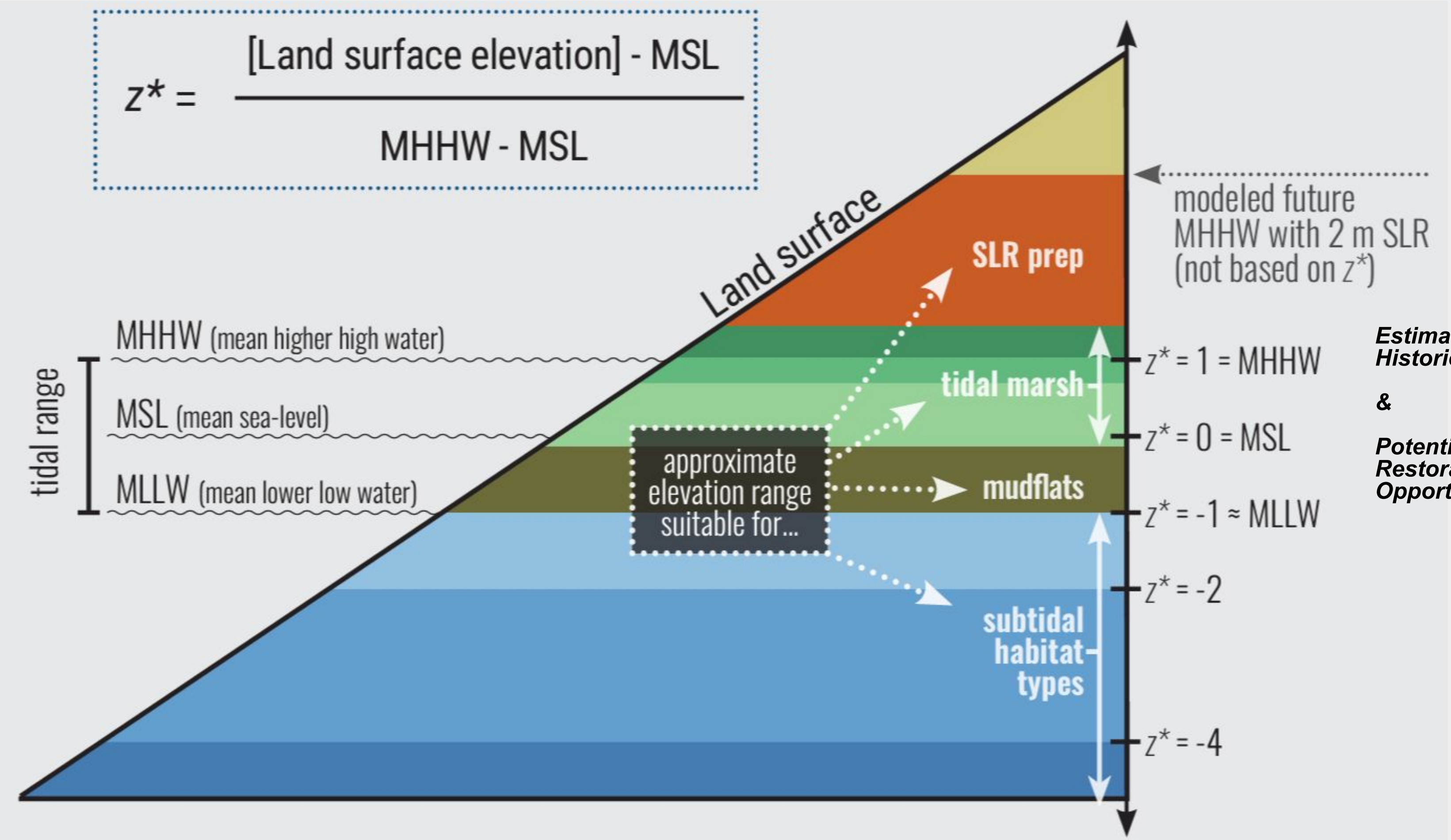
2c Some sediment from source tributaries deposits directly onto adjacent mudflats

Development on baylands prohibits wetland migration with sea level rise

Baylands Change Basemap/Shoreline Resilience Framework

- Track change over time in an efficient and effective way
  - Not only by habitat acreages
  - Provide target metrics that can be monitored over time to track shoreline resilience
  - Detect/Identify early warning signs of habitat loss/degradation
- Inform design/approach to adaptive management
  - Determine whether and how adaptation efforts are actually improving resilience
  - Having practical and quantitative metrics based on the ecosystem services managers hope to maintain will allow them to weigh the pros and cons of adaptation actions

Relative Tidal Elevation - Modeled Functional Extent



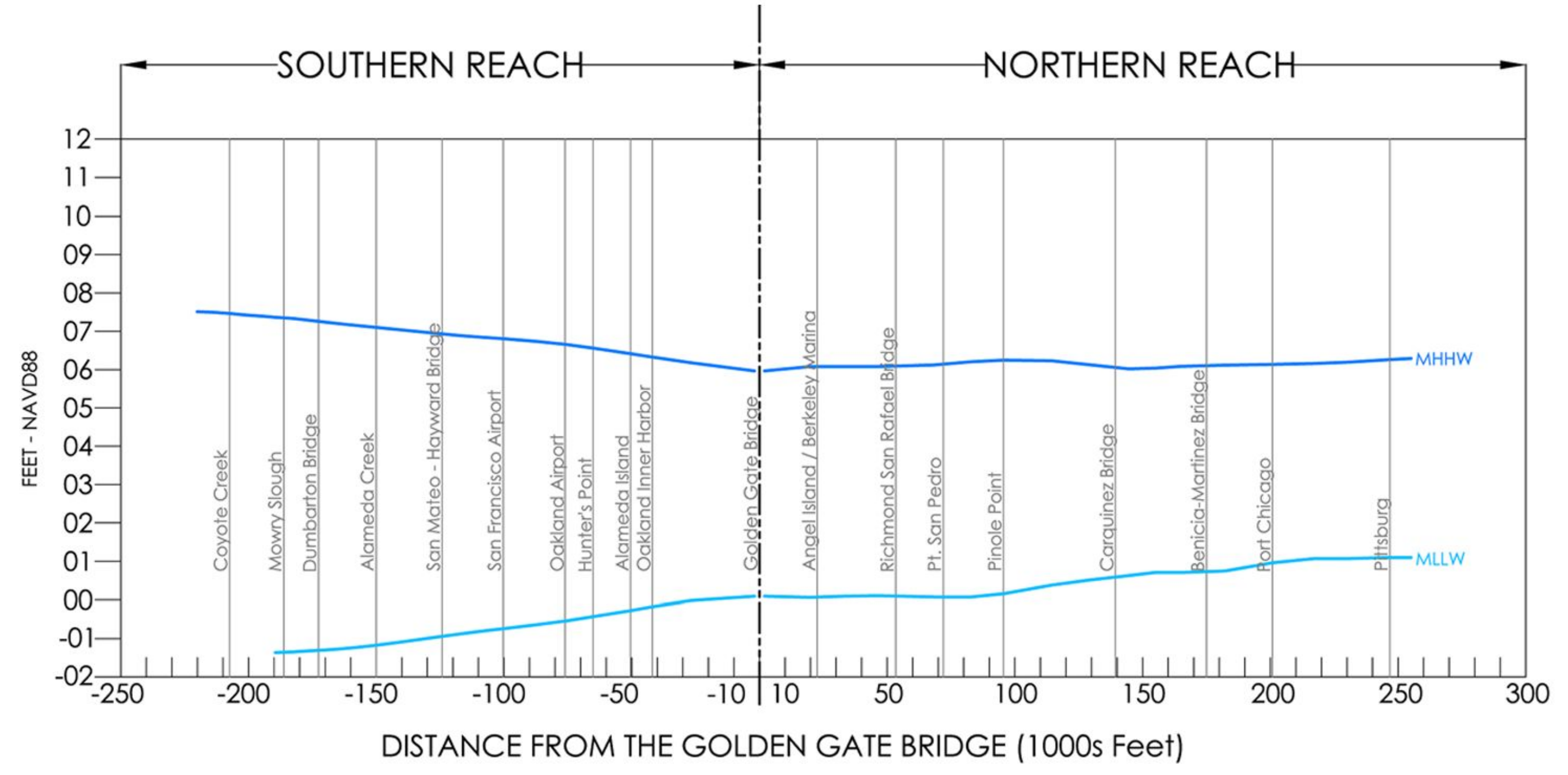
$$z^* = \frac{\text{[Land surface elevation]} - \text{MSL}}{\text{MHHW} - \text{MSL}}$$

Estimate Historical Extent

&

Potential Restoration Opportunities

Why Relative?



Marsh Vulnerability in the San Francisco Bay-Delta Estuary

Core Project Team

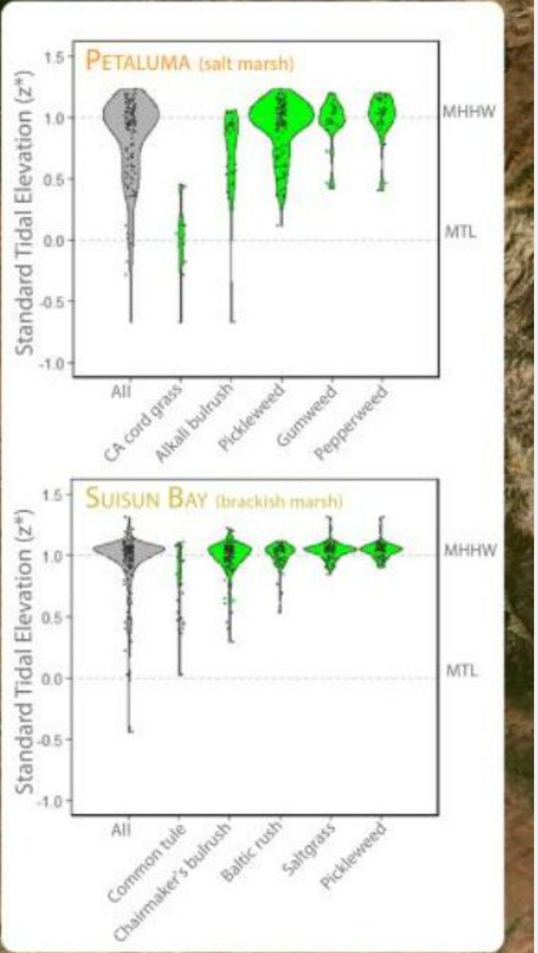
- Christopher Janousek (OSU)
- Kevin Buffington (USGS)
- Karen Thorne (USGS)
- Bruce Dugger (OSU)

Funding

- NOAA EESLR grant (NA15NOS4780171)
- USGS Western Ecological Research Center

Collaborators

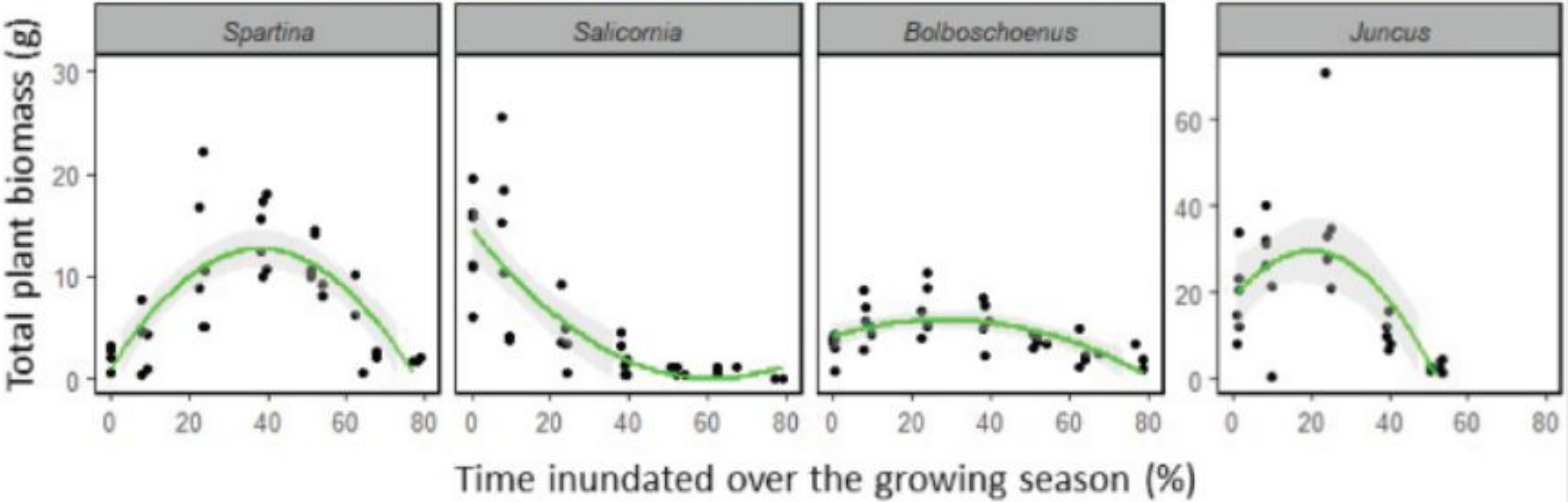
- NOAA Sentinel Site Cooperative - San Francisco
- National Estuarine Research Reserve
- East Bay Regional Parks
- CA Department of Fish & Wildlife



The figures at right show the relative abundance and tidal distribution of select common wetland plant species in saline (Petaluma) and brackish water marshes (Suisun).

Occurrences of individual species (green violins) and all species combined (grey violins) have been scaled to a unitless measure of elevation, z*, for each wetland area, where z* = 0 is the local mean tide level and z* = 1 is local mean higher high water. The widths of the violins are proportional to how commonly a species occurred in the dataset at that elevation.

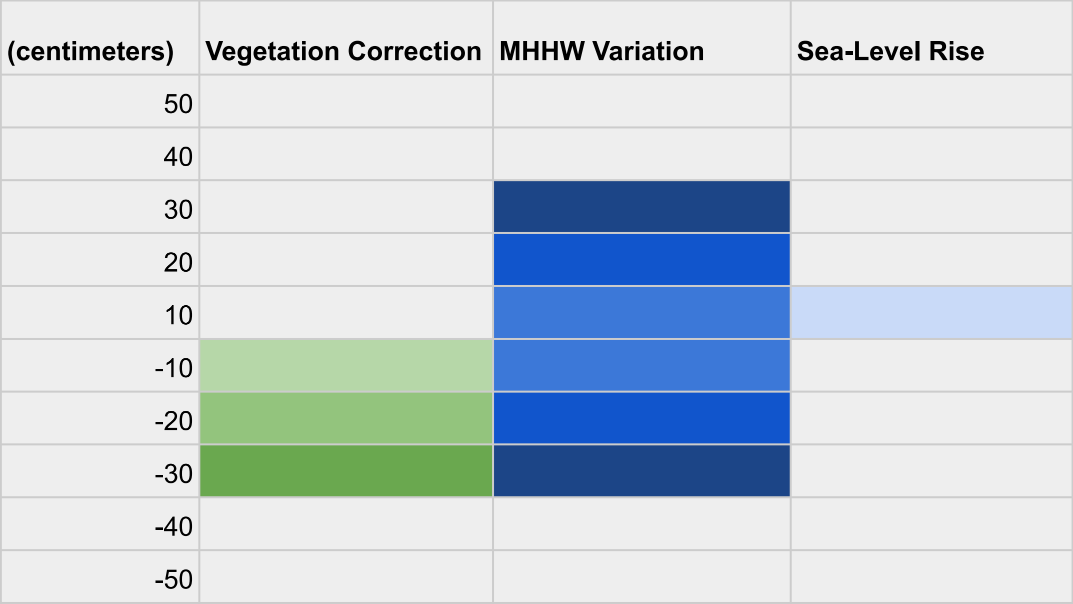
Plant Resilience to Inundation



Relative Tidal Elevation Examples

Uncertainty in Relative Tidal Elevation

- Vegetation Bias
- Tidal Datums
- Sea-Level Rise
- Sedimentation
- Subsidence



(centimeters)	Vegetation Correction	MHHW Variation	Sea-Level Rise
50			
40			
30		🟦	
20		🟦	
10		🟦	🟦
-10	🟩	🟦	
-20	🟩	🟦	
-30	🟩	🟦	
-40			
-50			

Uncertainty

- Vegetation Bias
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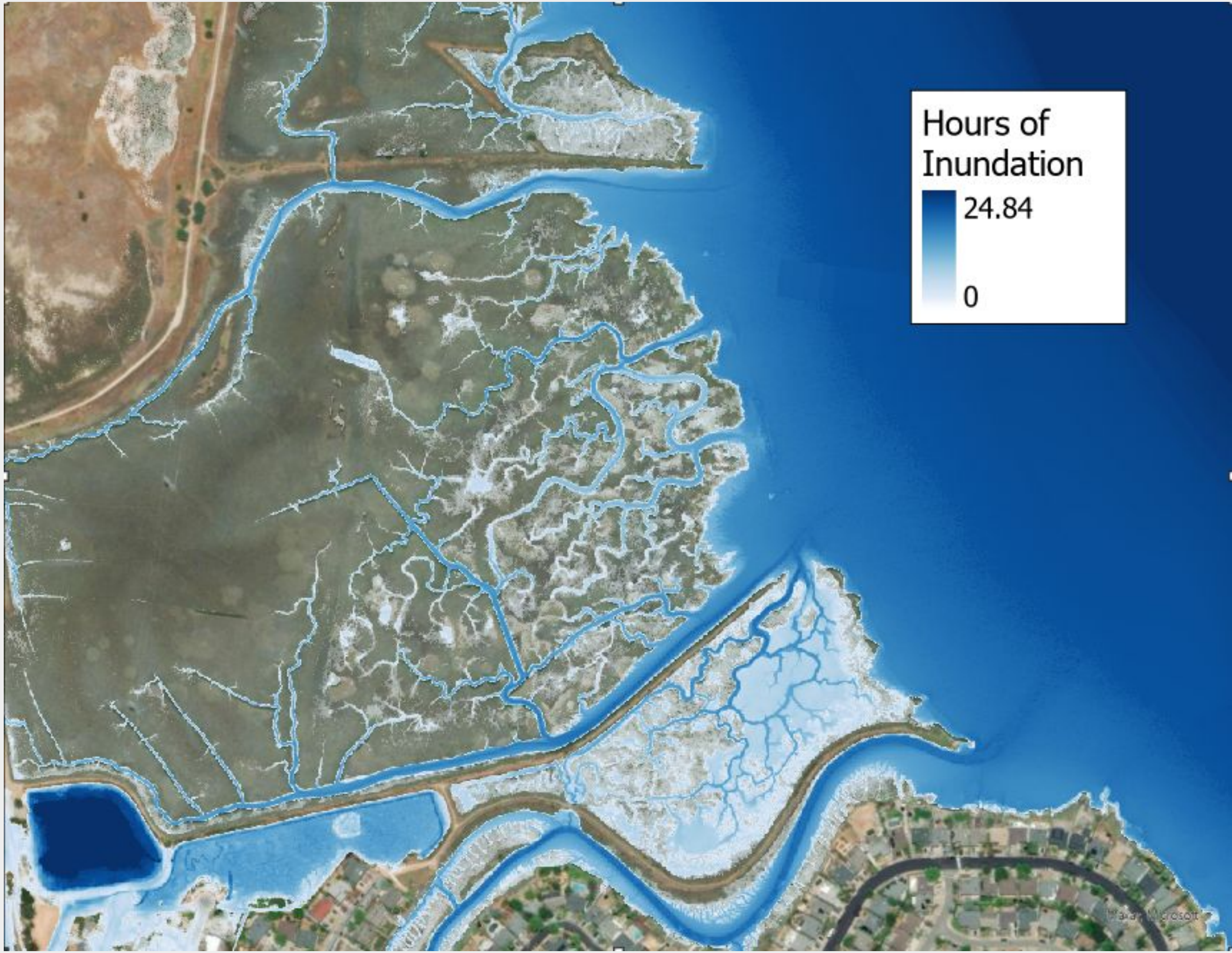

Uncertainty

- Vegetation Bias
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IMPROVING LIDAR-DERIVED ELEVATION WITH LEAN

LIDAR-DERIVED ELEVATION

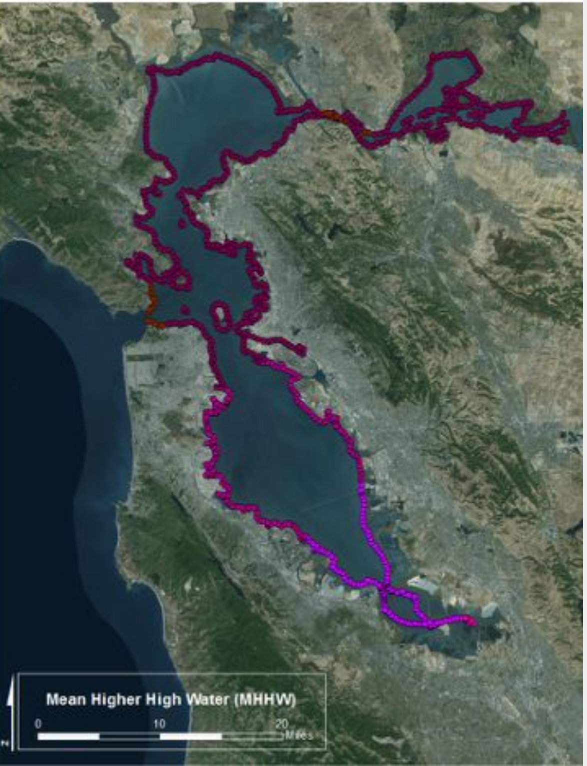
Lidar, which stands for *Light Detection and Ranging*, uses pulsed lasers to measure distances to the Earth. These pulses are used to create detailed maps of the shape of the ground surface, even penetrating tree canopies. In most environments the resulting map is accurate. However in dense vegetation, such as the far left marsh habitat above, the laser pulse is unable to penetrate the canopy, resulting in an overestimation of the ground elevation (red dot & line above).

LEAN-CORRECTED ELEVATION

By applying a simple correction, a more accurate estimate of the ground surface can be determined (blue line above). LEAN, which stands for *Lidar Elevation Adjustment with NDVI*, uses ground-truthed elevation data (GPS) and vegetation indices from high resolution remote sensing to correct the Lidar bias resulting from vegetation interference. Improving the accuracy of Lidar elevations in vegetated wetlands will greatly improve the accuracy of sea-level rise models.

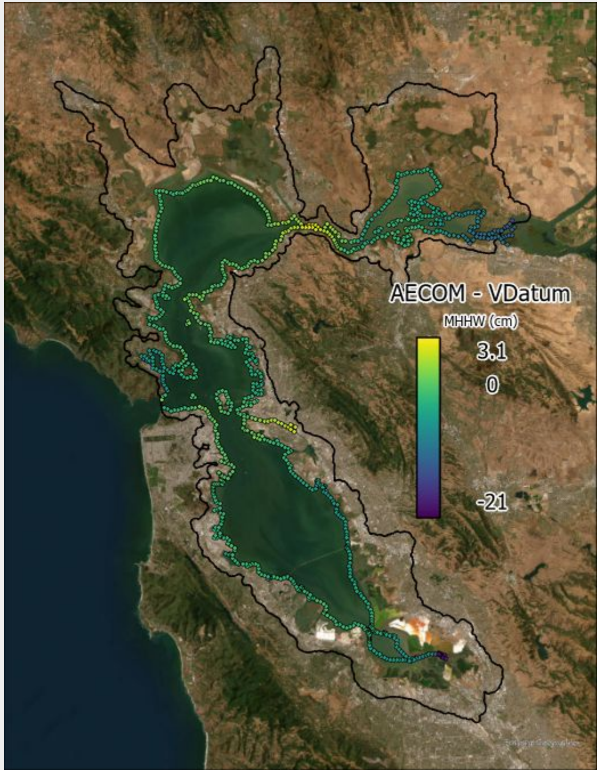
Tidal Datum Comparison

AECOM



NOAA VDatum

Comparison



Tidal Datum Comparison

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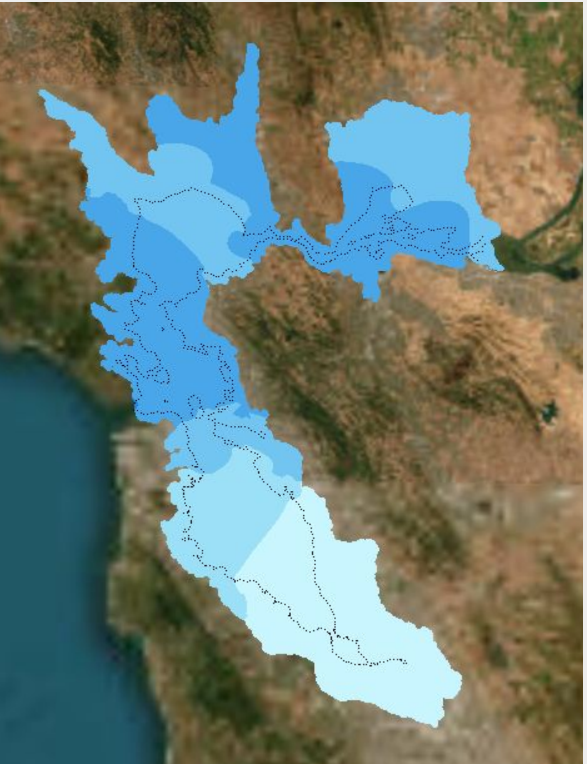
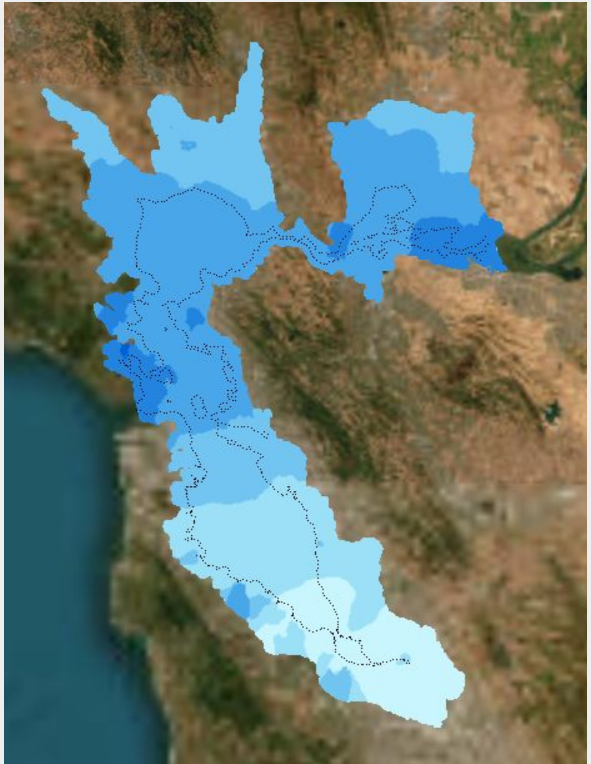
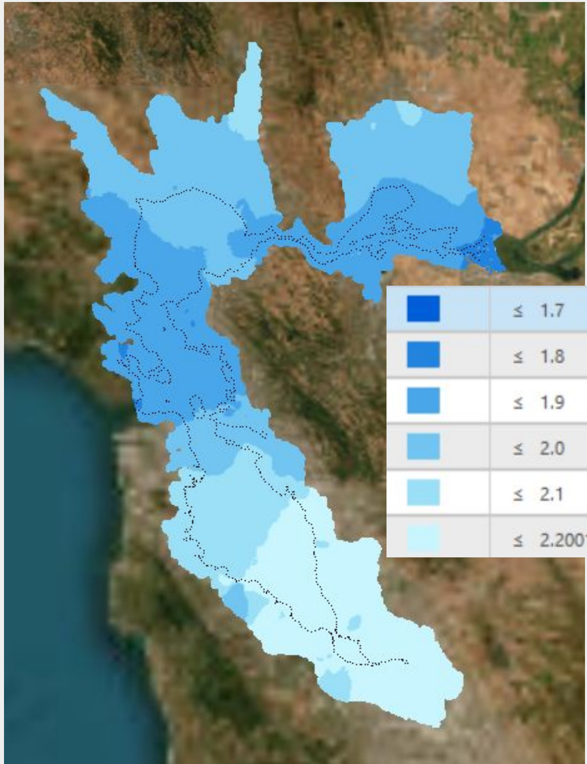


NOAA VDatum

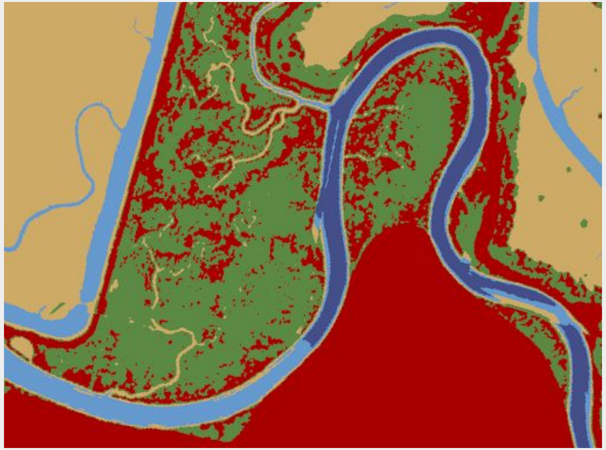


Adjusted

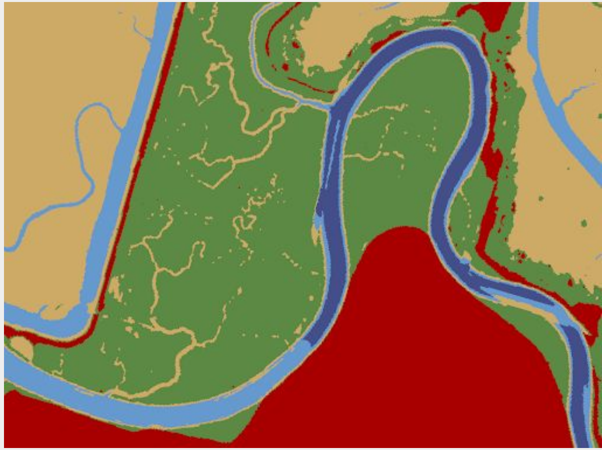


VDatum vs. AECOM-Corrected

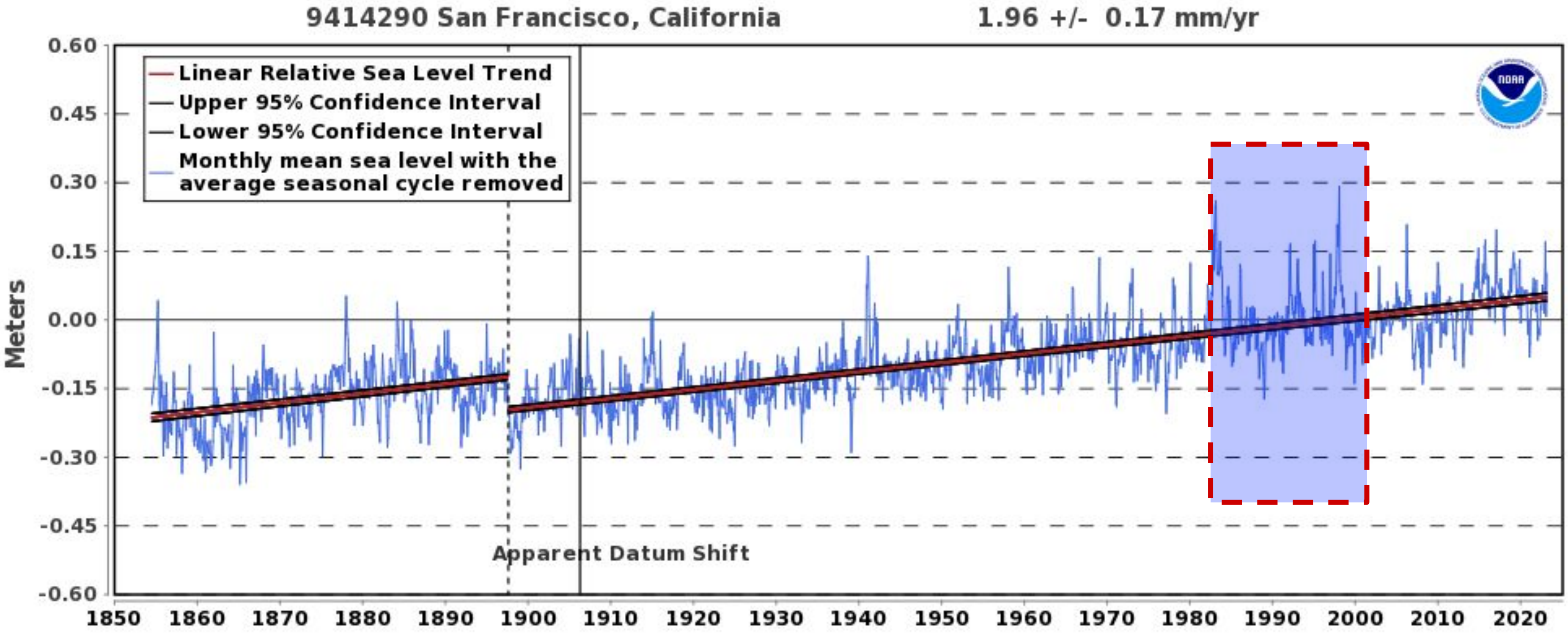
NOAA VDatum (Z* 1.4)



Adjusted (Z* 1.4)



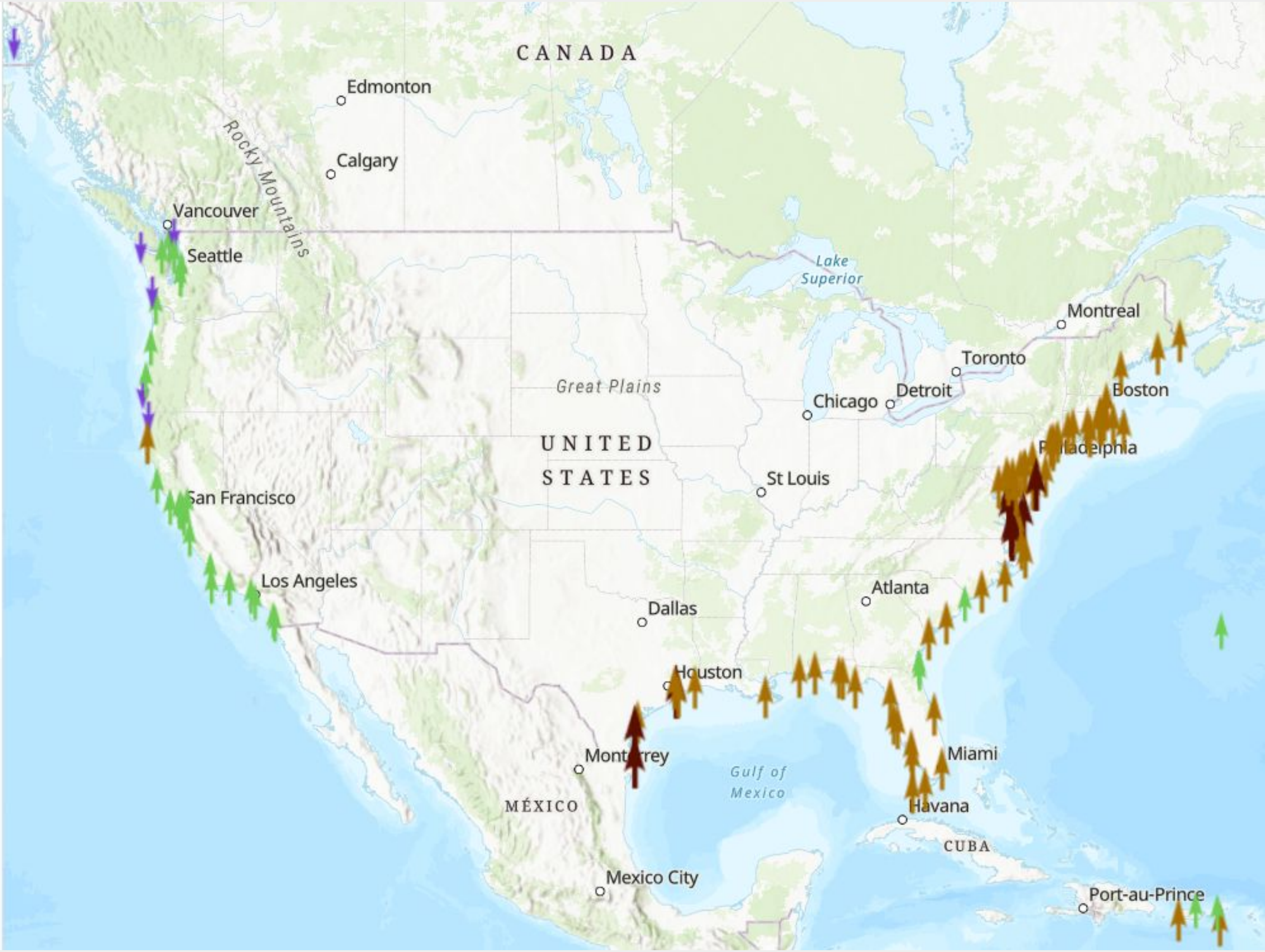
Current National Tidal Datum Epoch (NTDE)



Mean Sea Level (MSL)

MSL Difference 2002-2020 minus 1983-2001 (cm)

- ↑ >10 cm
- ↑ 5 to 10 cm
- ↑ 0 to 5 cm
- ↓ -5 to 0 cm
- ↓ -10 to -5 cm
- ↓ <-10 cm



The National Tidal Datum Epoch: Changes in Mean Sea Level and Mean Tide Level from 1983-2001 and 2002-2020 (NOAA, NOS, CO-OPS)

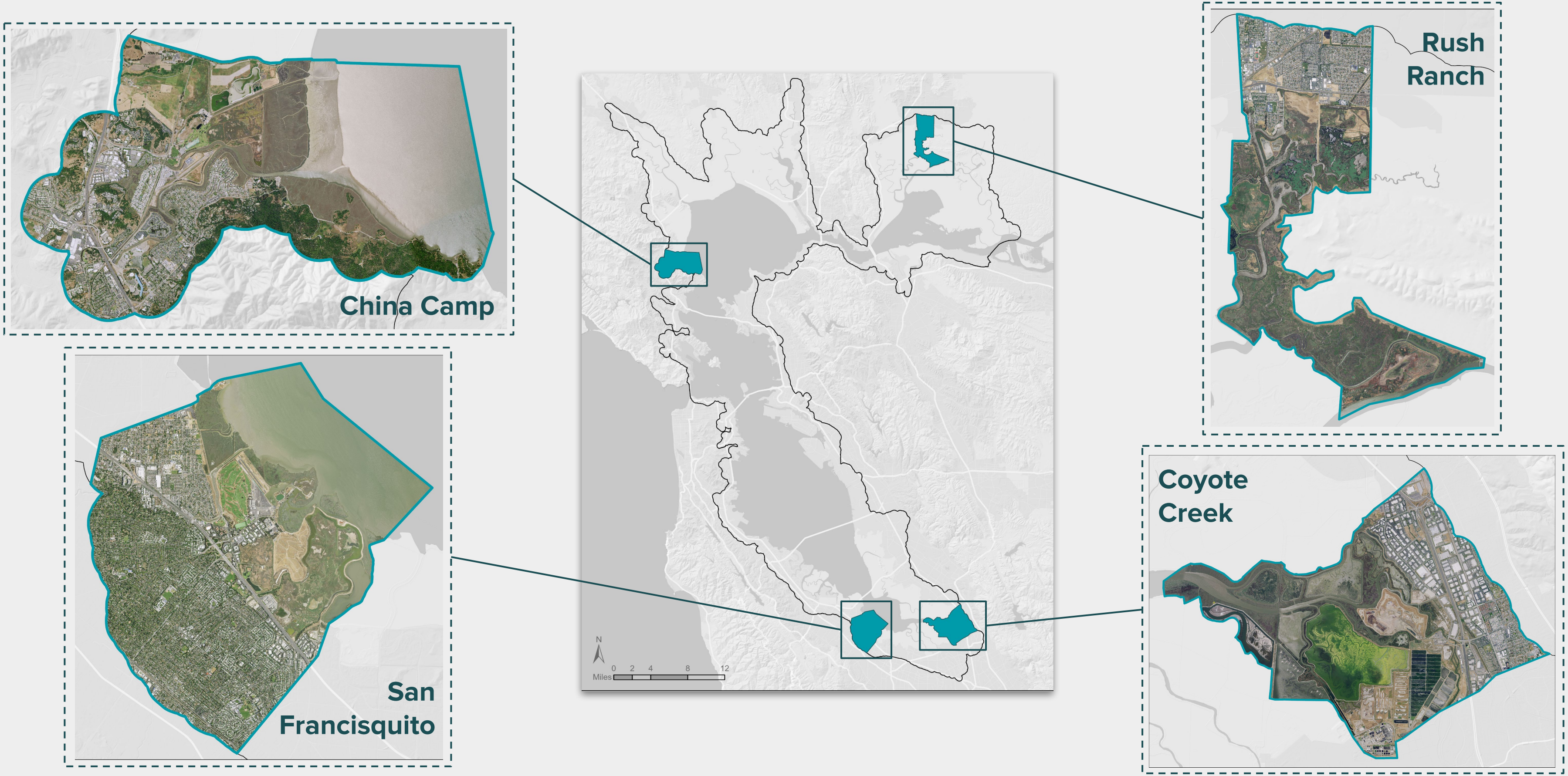
SF Bay USGS (2001-2019)

How to tell which is best?

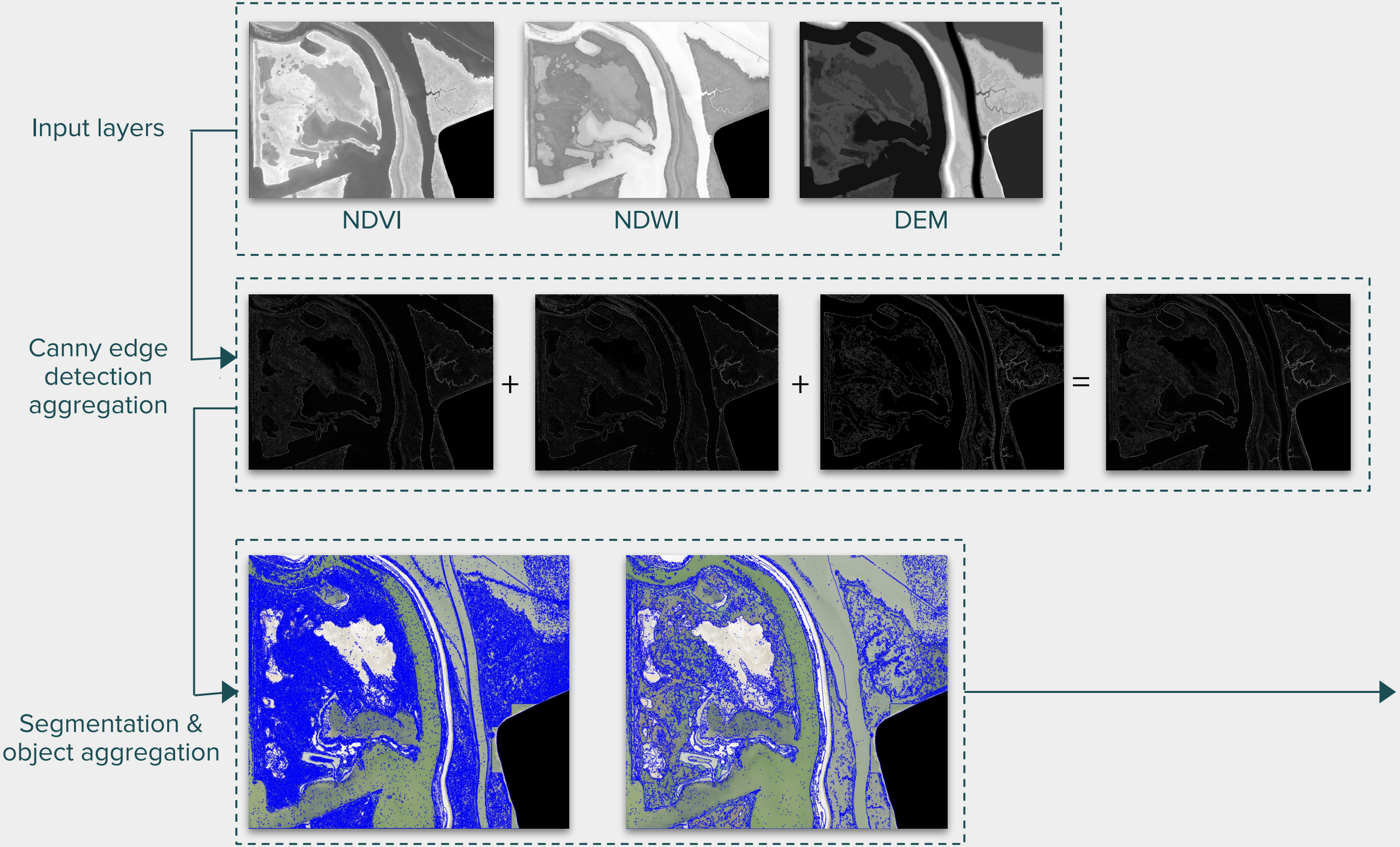
- Vegetation will provide clues

Image Credit: SFEI

Baylands Change Basemap Pilot Sites



Example Workflow



Input layers

NDVI

NDWI

DEM

Canny edge detection aggregation

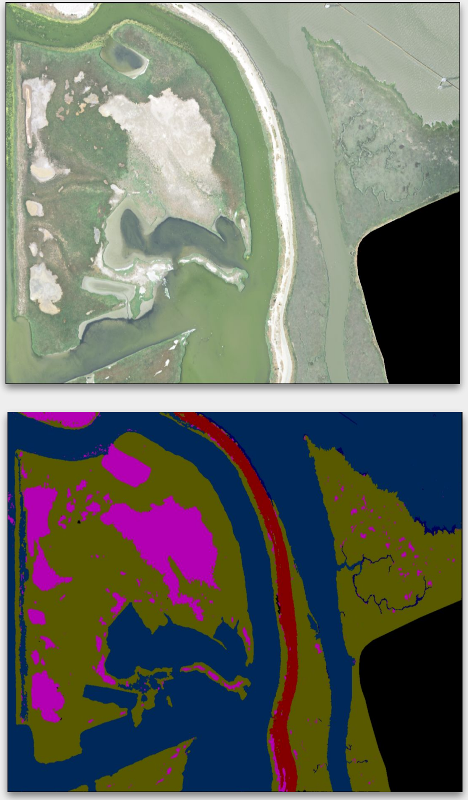
+

+

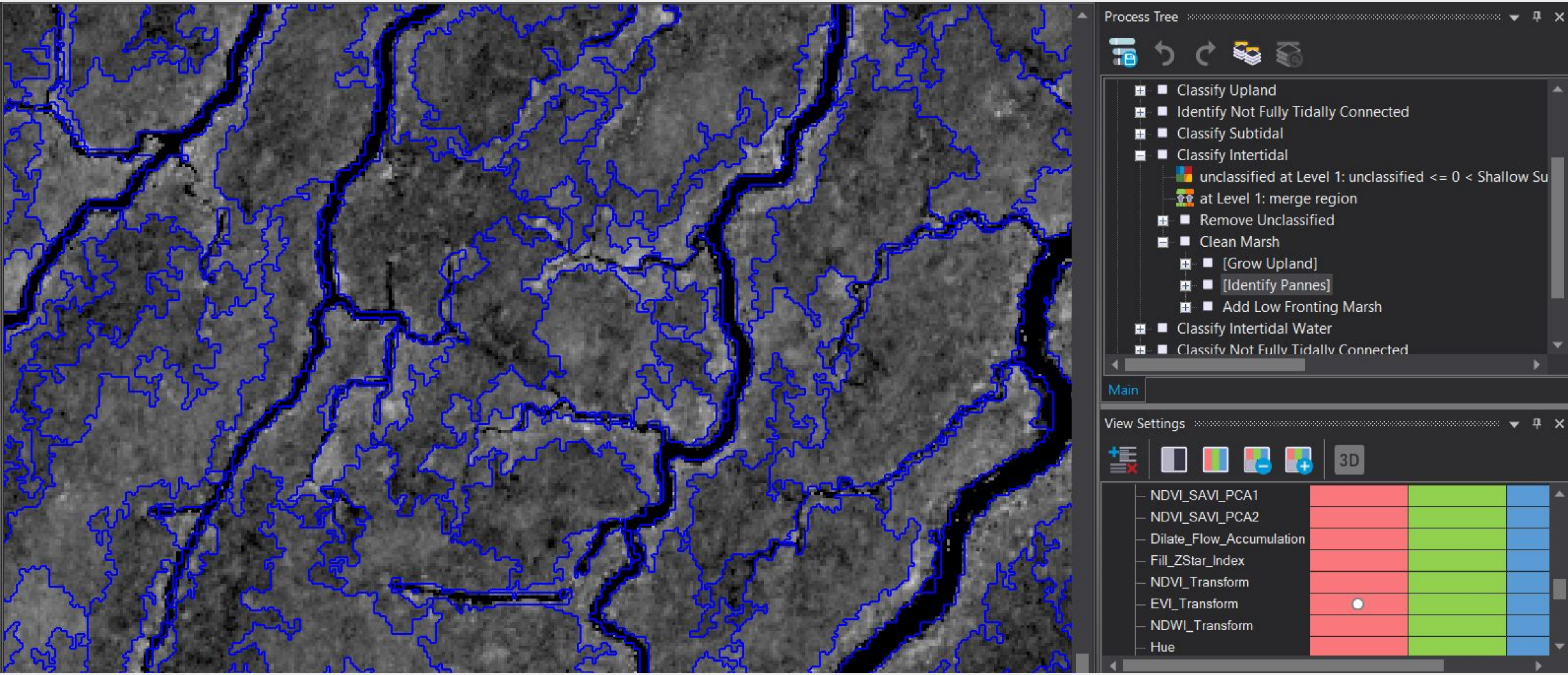
=

Segmentation & object aggregation

Test area shown in RGB and after an initial test classification.

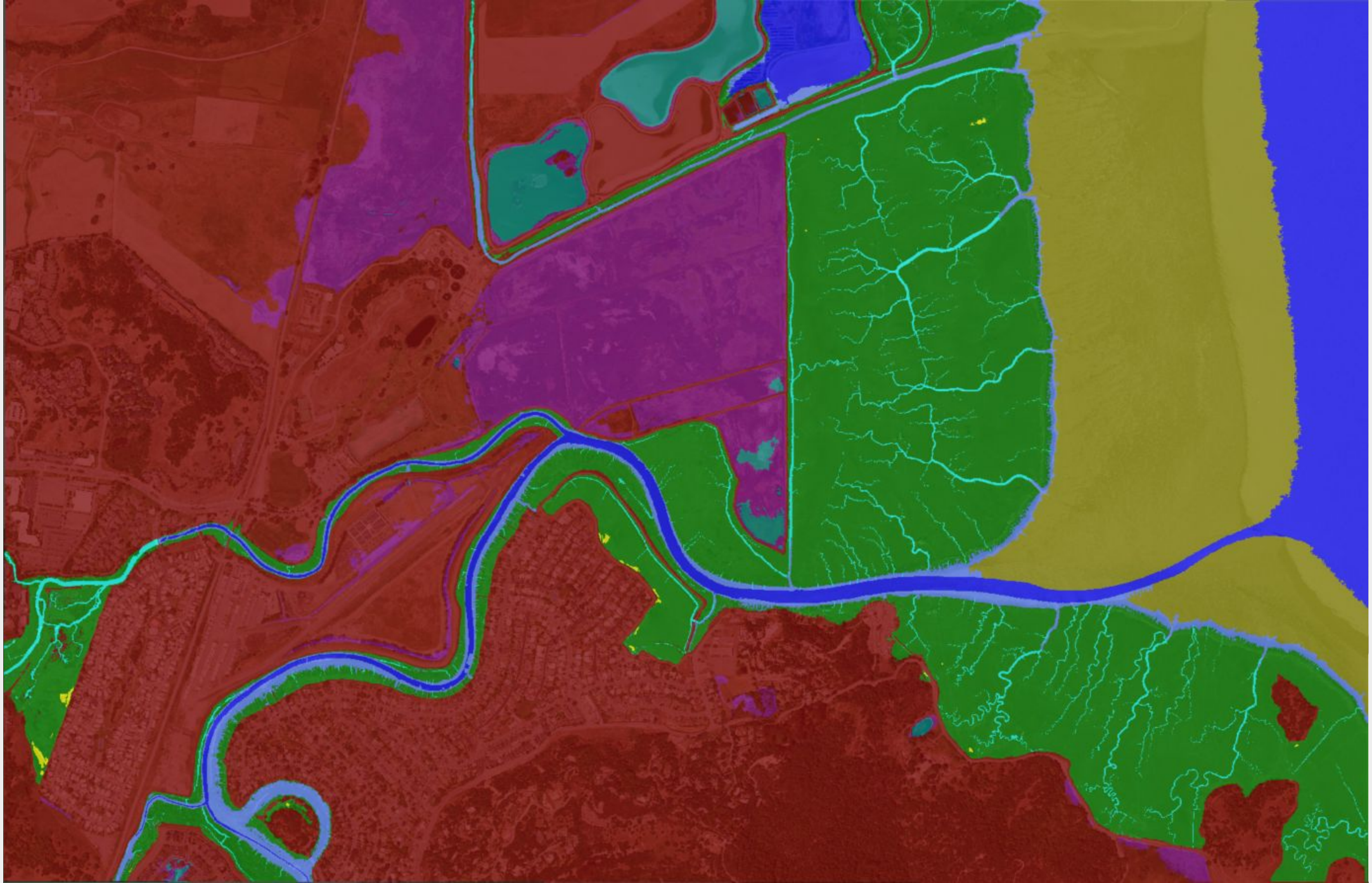


eCognition Developer

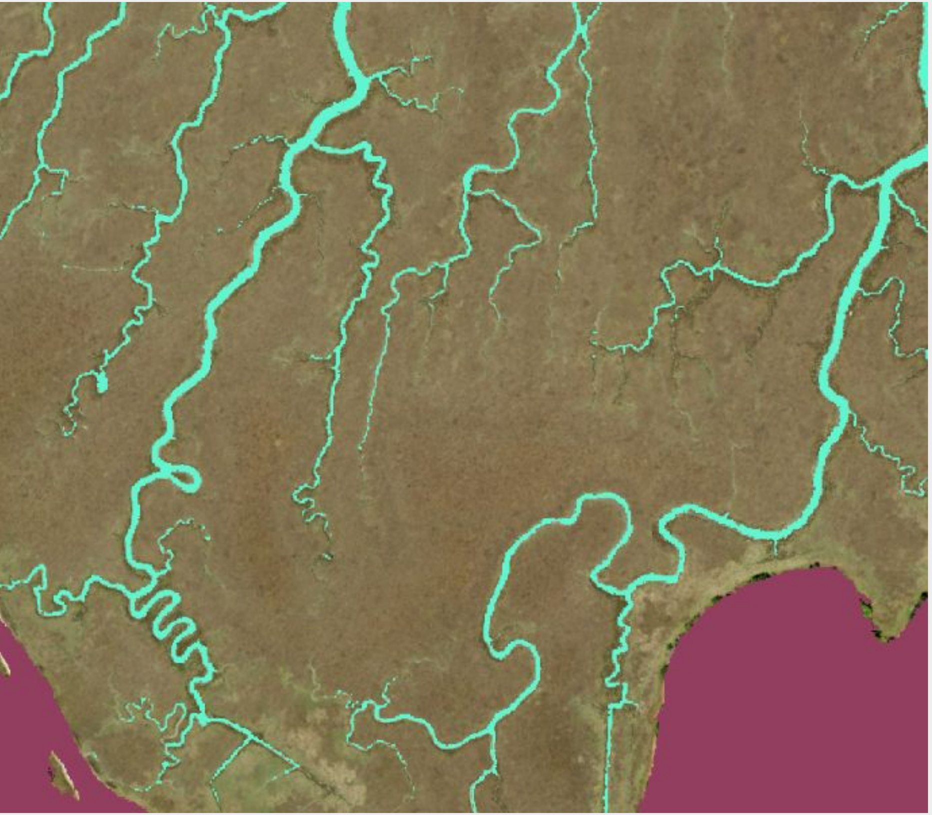


- Classify Upland
- Identify Not Fully Tidally Connected
- Classify Subtidal
- Classify Intertidal
  - unclassified at Level 1: unclassified <= 0 < Shallow Su
  - at Level 1: merge region
  - Remove Unclassified
  - Clean Marsh
    - [Grow Upland]
    - [Identify Pannes]
    - Add Low Fronting Marsh
- Classify Intertidal Water
- Classify Not Fully Tidally Connected

- NDVI_SAVI_PCA1
- NDVI_SAVI_PCA2
- Dilate_Flow_Accumulation
- Fill_ZStar_Index
- NDVI_Transform
- EVI_Transform
- NDWI_Transform
- Hue



Level of Detail



Bay-Scale Implementation

- Take rule set and apply to entire Bay
- Leverage Oracle cloud-computing resources

Subregion *

Select one or more spatial subregions or subembayments.

Figure 2.1. The study area includes the watersheds and bayland habitats located within San Francisco Bay, from the Golden Gate to Broad Slough. Subembayments are based on Operational Landscape Unit (OLU) boundaries and USGS sediment flux monitoring locations.

Wetland Regional Monitoring Program (WRMP)

- This regional (level 1) dataset will enhance the value and support other related sub-region (level 2) and site-specific (level 3) WRMP monitoring efforts
- On-the ground knowledge and data will help inform and feed into better products/methods for future mapping efforts
    - Tide Gauges
    - Elevation Improvements
    - Vegetation Studies


LANDSCAPE RESILIENCE FRAMEWORK

Operationalizing ecological resilience at the landscape scale

SAN FRANCISCO ESTUARY INSTITUTE
AQUATIC SCIENCE CENTER
SFEI
ASC

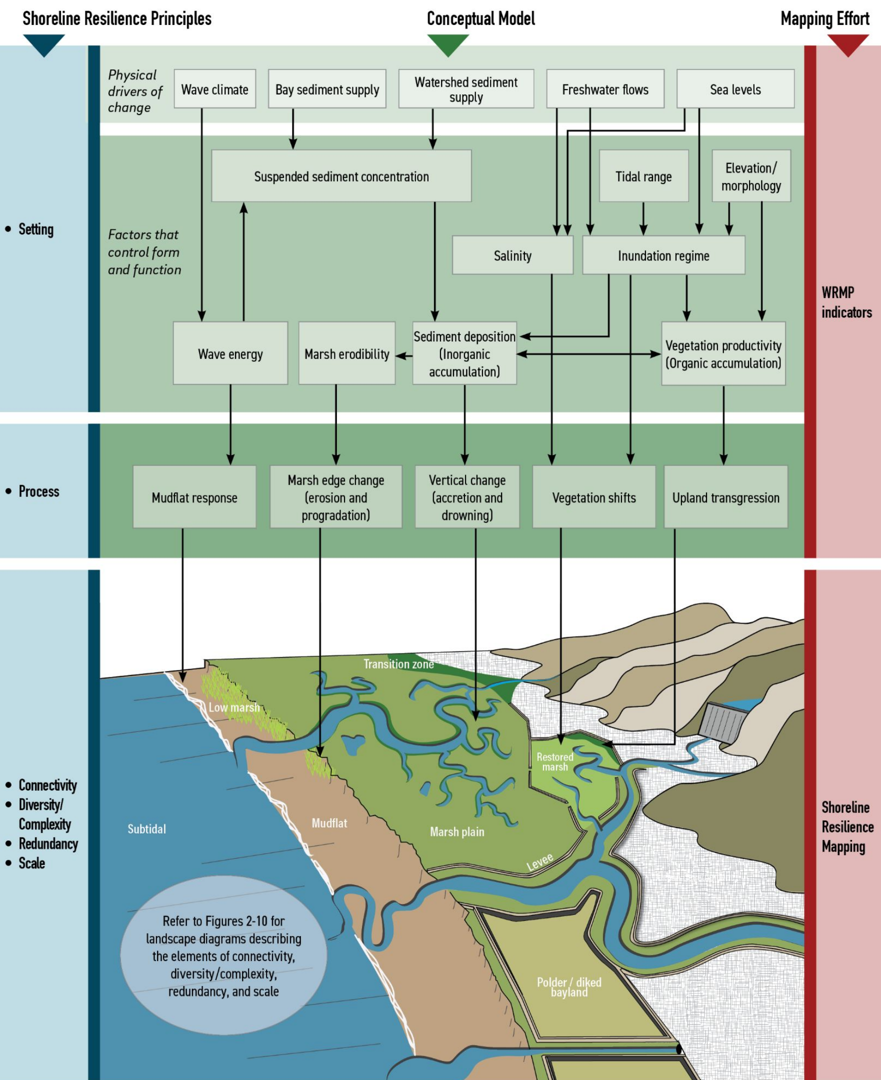
1	**SETTING**	Unique geophysical, biological, and cultural aspects of a landscape that determine potential constraints and opportunities for resilience
2	**PROCESS**	Physical, biological, and chemical drivers, events, and processes that create and sustain landscapes over time
3	**CONNECTIVITY**	Linkages between habitats, processes, and populations that enable movement of materials and organisms
4	**DIVERSITY & COMPLEXITY**	Richness in the variety, distribution, and spatial configuration of landscape features that provide a range of options for species
5	**REDUNDANCY**	Multiple similar or overlapping elements or functions within a landscape that promote diversity and provide insurance against loss
6	**SCALE**	The spatial extent and time frame at which landscapes operate that allows species, processes, and functions to persist
7	**PEOPLE**	The individuals, communities, and institutions that shape and steward landscapes

Shoreline Resilience Framework

- Define critical attributes & metrics to maintain given ecosystem services as sea-levels rise
    - **Wildlife support**
    - Carbon sequestration
    - Water Quality
    - **Flood Attenuation**

Goals

- Establishing **Where** & **Why** to take action
- Inform discussions of the use of NBS to increase resilience of ecosystem services to sea-level rise and adaptive management
- Help prioritize where to restore additional habitat or add sediment to existing marshes



Shoreline Resilience Principles

Conceptual Model

Mapping Effort

- Setting
- Process
- Connectivity
- Diversity/ Complexity
- Redundancy
- Scale

Physical drivers of change

Wave climate

Bay sediment supply

Watershed sediment supply

Freshwater flows

Sea levels

Factors that control form and function

Suspended sediment concentration

Tidal range

Elevation/ morphology

Salinity

Inundation regime

Wave energy

Marsh erodibility

Sediment deposition (Inorganic accumulation)

Vegetation productivity (Organic accumulation)

Mudflat response

Marsh edge change (erosion and progradation)

Vertical change (accretion and drowning)

Vegetation shifts

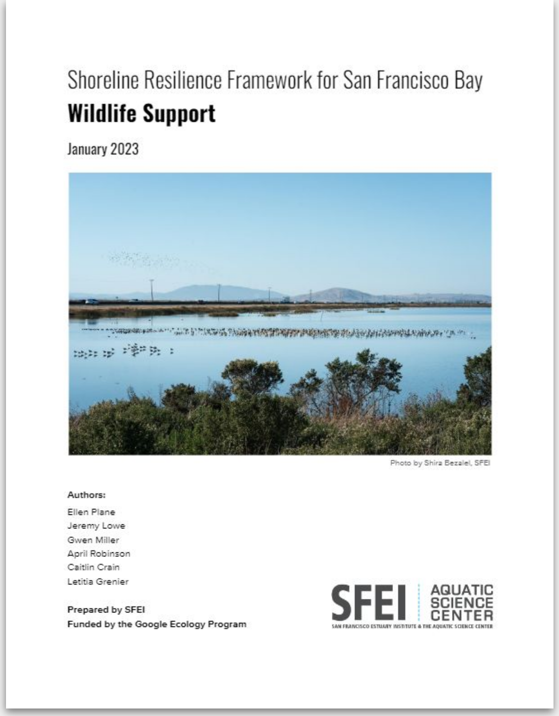
Upland transgression

WRMP indicators

Shoreline Resilience Mapping

Refer to Figures 2-10 for landscape diagrams describing the elements of connectivity, diversity/complexity, redundancy, and scale

Working from Framework documents



Shoreline Resilience Framework for San Francisco Bay

Wildlife Support

January 2023

Photo by Shira Bezalel, SFEI

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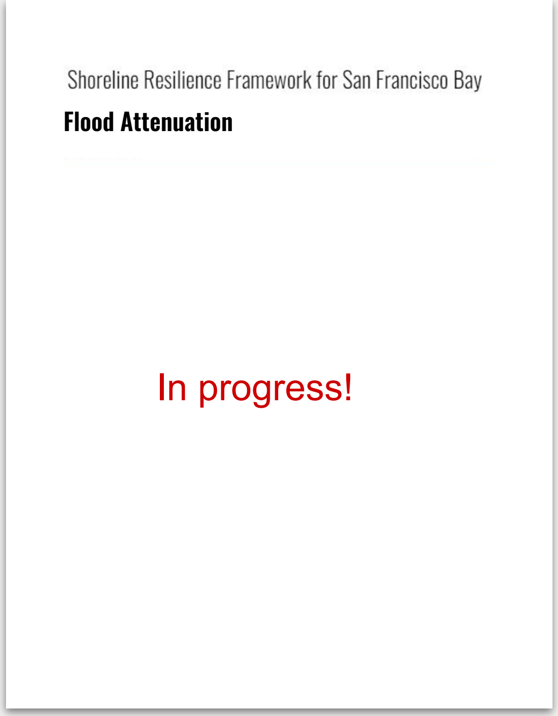
Funded by the Google Ecology Program



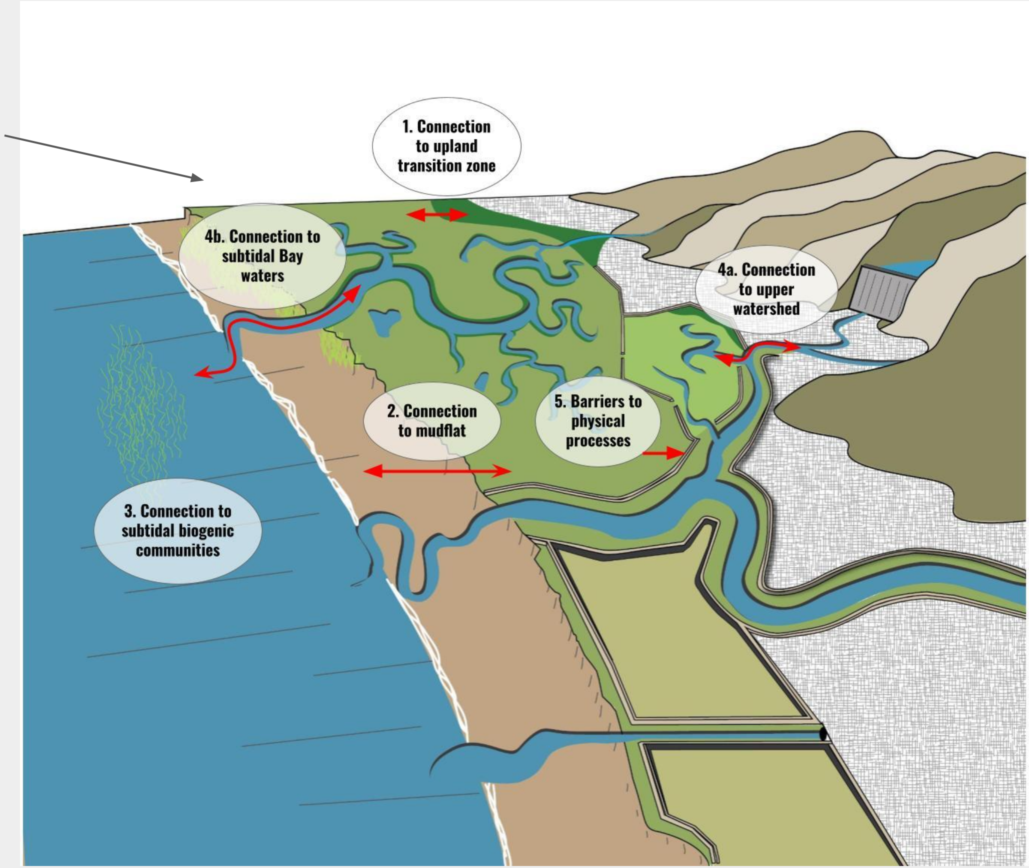
Shoreline Resilience Framework for San Francisco Bay

Flood Attenuation

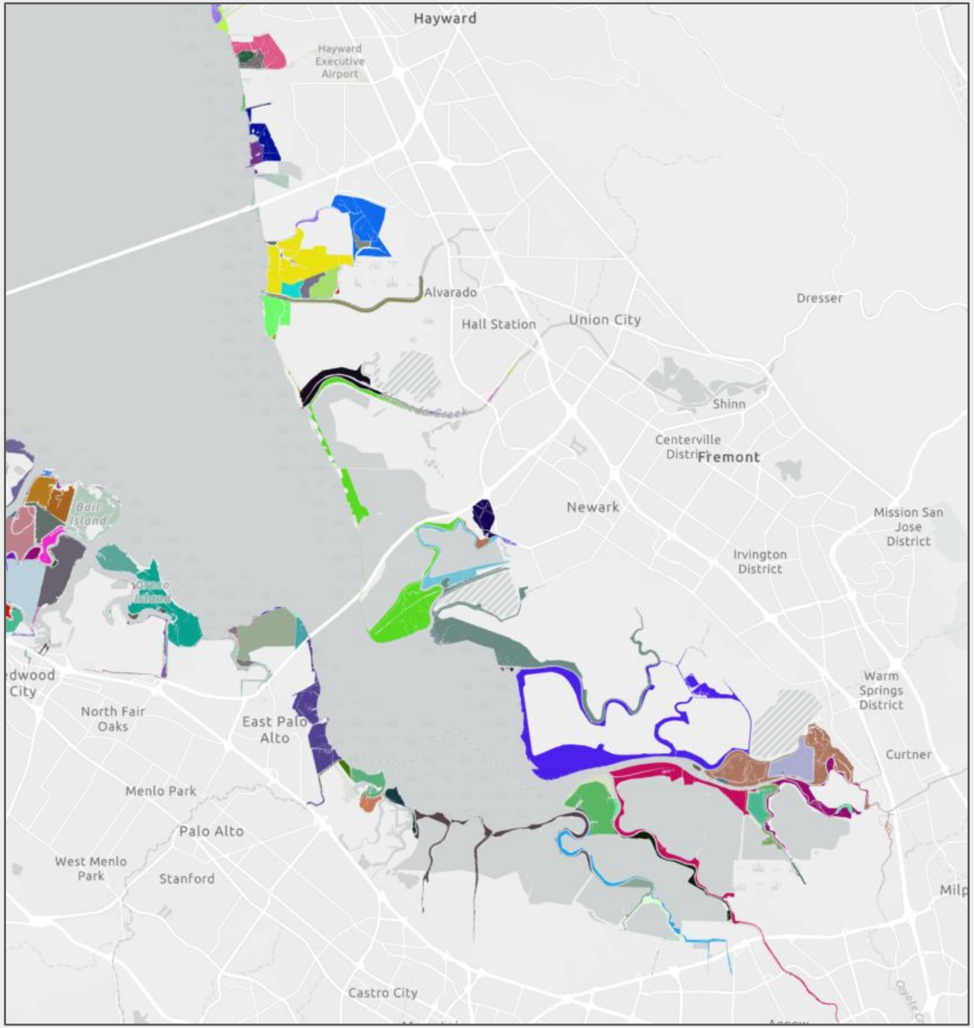
In progress!

Elements of Shoreline Resilience for Wildlife Support

1. Connectivity within the complete marsh (upland to subtidal)
2. Connectivity among marshes
3. Diversity/complexity of channel networks
4. Topographic complexity
5. Diversity/complexity of salinity patterns
6. Redundancy
7. Spatial scale
8. Time scale

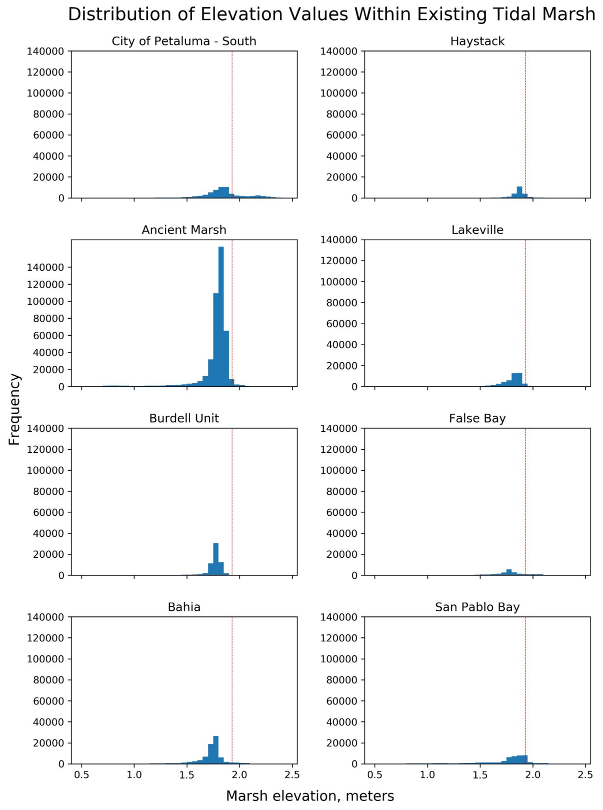


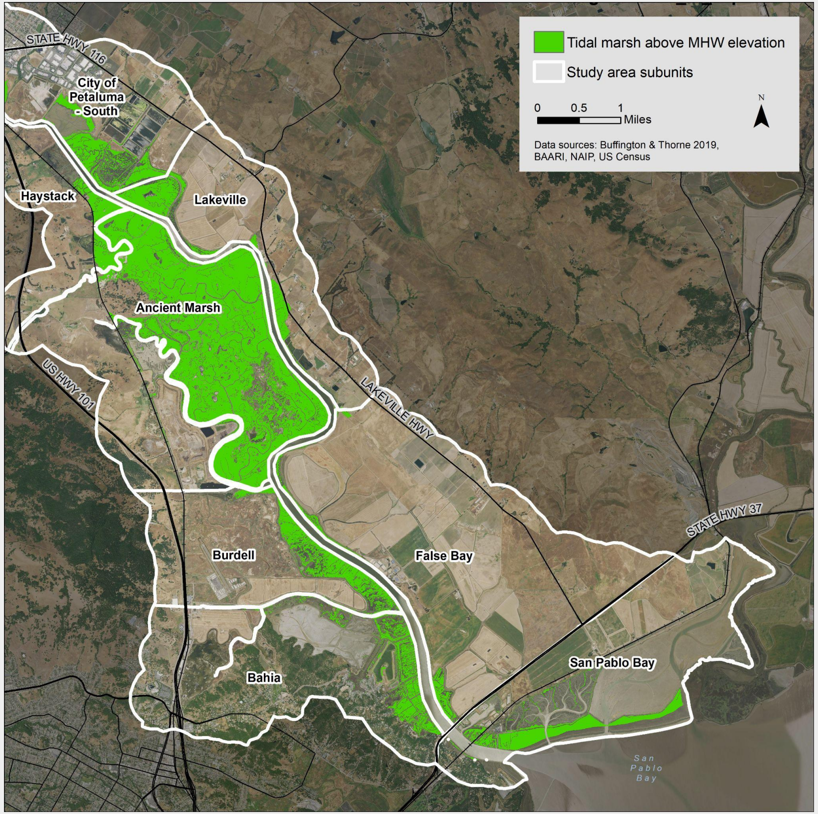
Mapping at Marsh Management Scale



Topographic complexity

Proportion of marsh at high elevation in tidal range

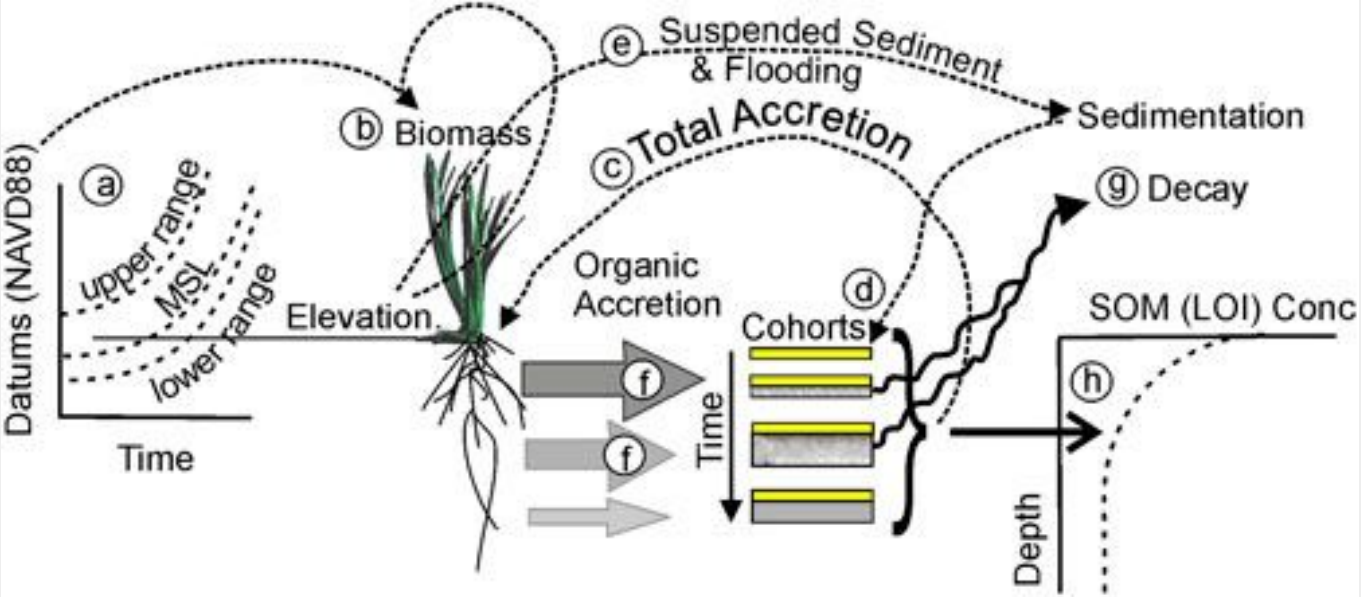




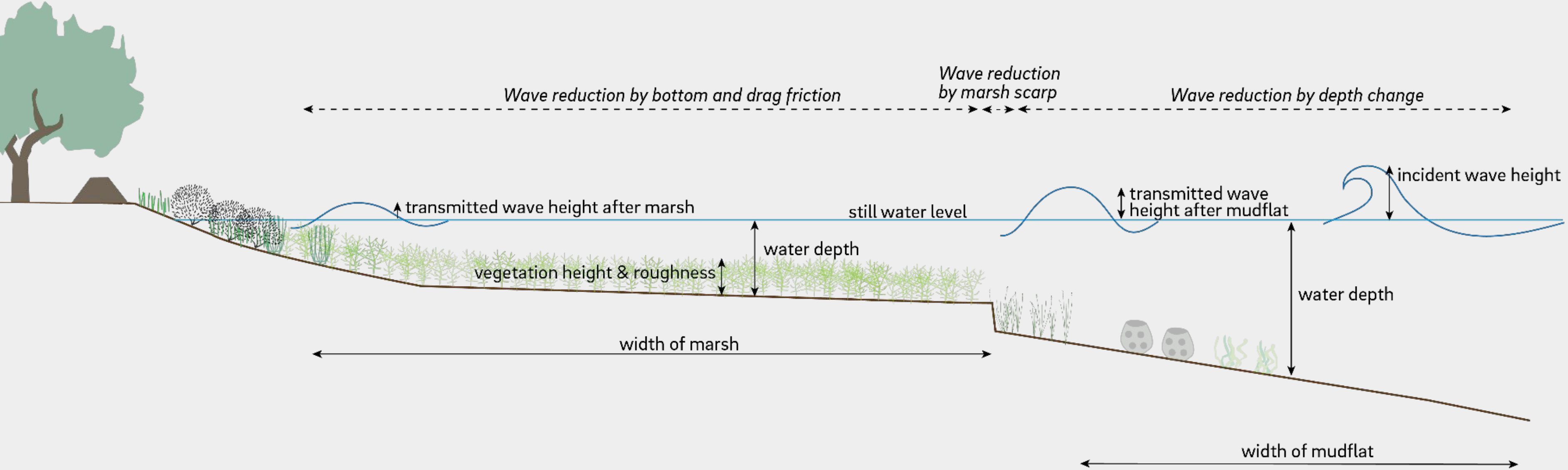
Data sources: Buffington & Thorne 2019, BAARI, NAIP, US Census

Marsh Equilibrium Model (MEM)

- Morris et al 2002; 2021

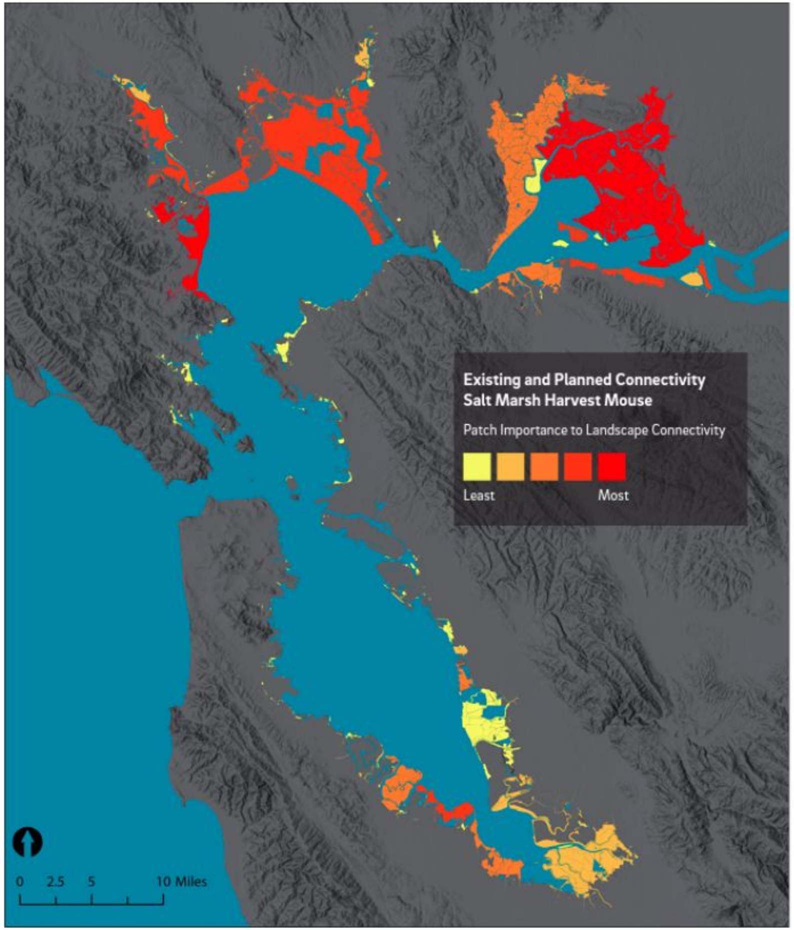


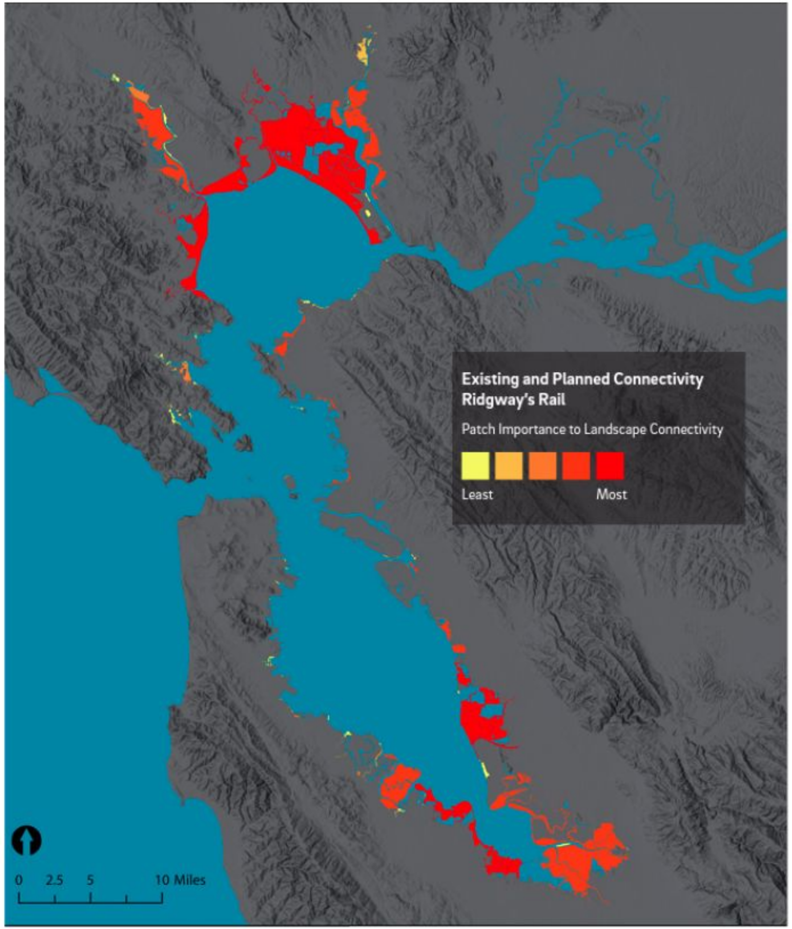
Wave height reduction across coastal habitats



Adapted from Narayan et al. 2016

Connectivity





Questions?

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