Alternative Monitoring Approaches for Large Bay-Delta Estuarine Wetland Restoration Projects

Adapting to Uncertainty or Novelty during Accelerated Climate Change

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Estuarine Wetland Restoration

San Francisco Bay Area historical context

ERA	CONTEXT
“First-generation” SFE marsh restoration (1970s-1980s)	• **Regulatory permit & policy** (CWA, McAteer-Petris Act, Endangered Species Act • compensatory mitigation • USACE dredge material marsh creation national program; estuarine sediment surplus
“Second-generation” SFE marsh restoration	• **Goals Project era transition** to **regional planning and larger scale restoration** • Wetland policy conflict resolution • Geomorphic pattern & process emphasis

21st century SFE marsh restoration	• **BEHGU (Goals Project update) era**:
	  • Accelerated sea level rise
	  • Estuarine sediment deficit
	  • Climate event extremes, species invasions as “new normal”
	  • advances in wetland sciences

Estuarine Wetland Restoration

San Francisco Bay Area examples

ERA	EXAMPLES
First-generation SFE marsh restoration (1970s-1980s)	• **Muzzi Marsh (MRN)** • **Pond 3 Alameda (ALA)**
Second-generation SFE marsh restoration (1990s)	• **Sonoma Baylands (SON)** • **Hamilton Wetland Restoration (MRN)** • **Montezuma Wetlands (SOL)**
21st century SFE marsh restoration (climate change)	• **Sears Point (SON)** • **Aramburu Island (MRN)** • **Cullinan Ranch (SOL)** • **Oro Loma Ecotone ("horizontal levee") (ALA)** • South Bay and Napa-Sonoma Marsh **Salt Pond Restoration Projects** (SOL, NAPA, ALA, SCL)

Traditional wetland restoration monitoring San Francisco Estuary

- 1980s-1990s permit conditions,
- Compliance/performance monitoring
- Landscape context: breached dikes, dike-bound parcels
- Monitoring mirrors simplifying assumptions about tidal marsh evolution and ecological succession
- Deterministic assumptions: progressive change
- Monitoring emphasis:
  - suspended sediment deposition rate
  - mudflat/marsh surface average elevation
  - threshold for pioneer (low marsh) vegetation establishment and acreage net gain
  - channel formation

Restoration uncertainties should be anticipated and incorporated in monitoring

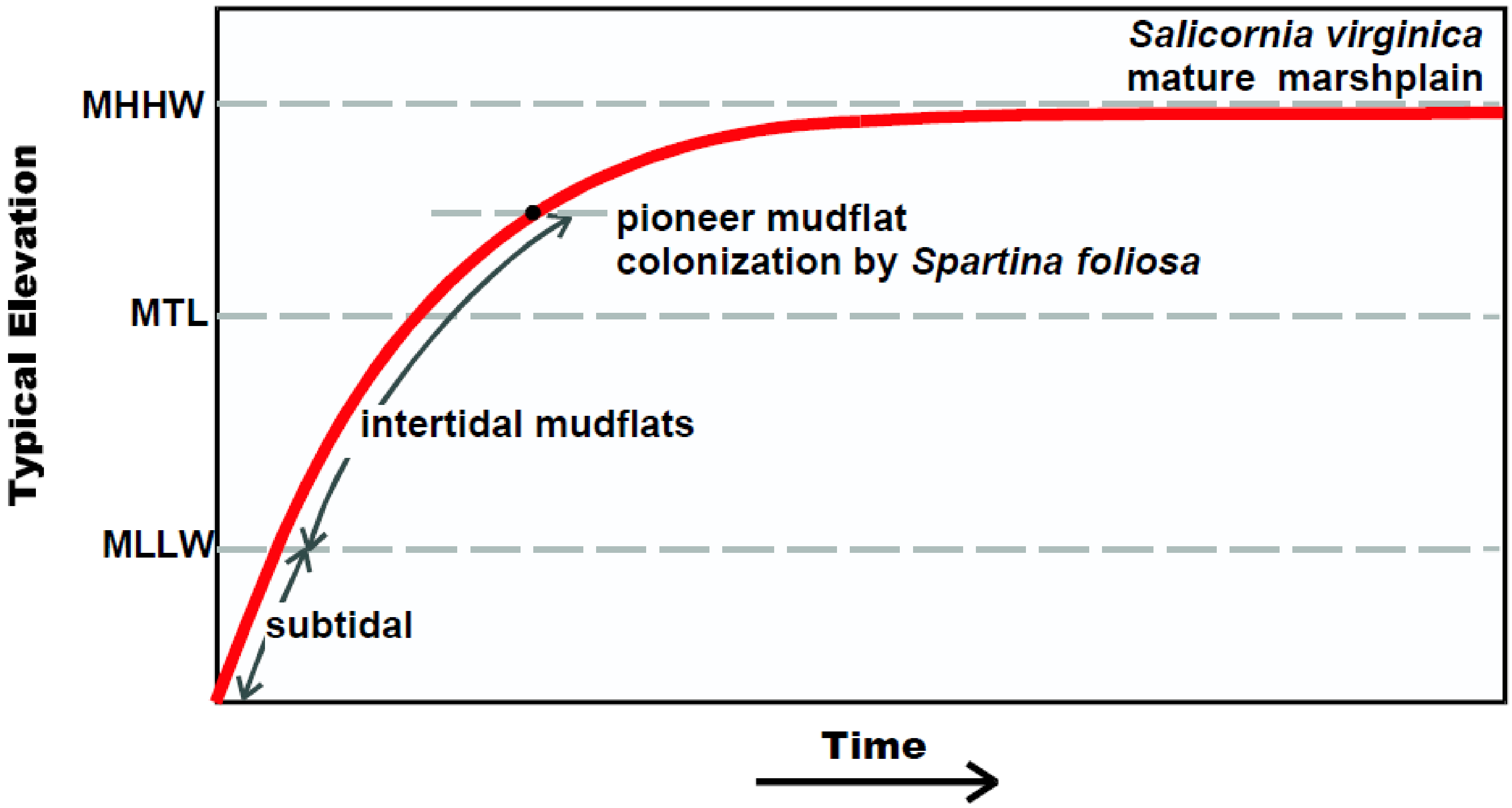
- Restoration uncertainties
  - Drought and flood events
  - Storm events (deposition, erosion, shoreline position)
  - Rapid invasions
  - Changed salinity regimes
  - Changed sediment regimes
  - Site water management pre-restoration

Ecological surprises

- pre-restoration site conditions (changed baseline)
- site legacy effects (buried constraints)

Traditional **salt** marsh geomorphic evolution model for restoration
Conceptual model for monitoring

PWA 2004 Tidal Marsh Restoration Guidelines



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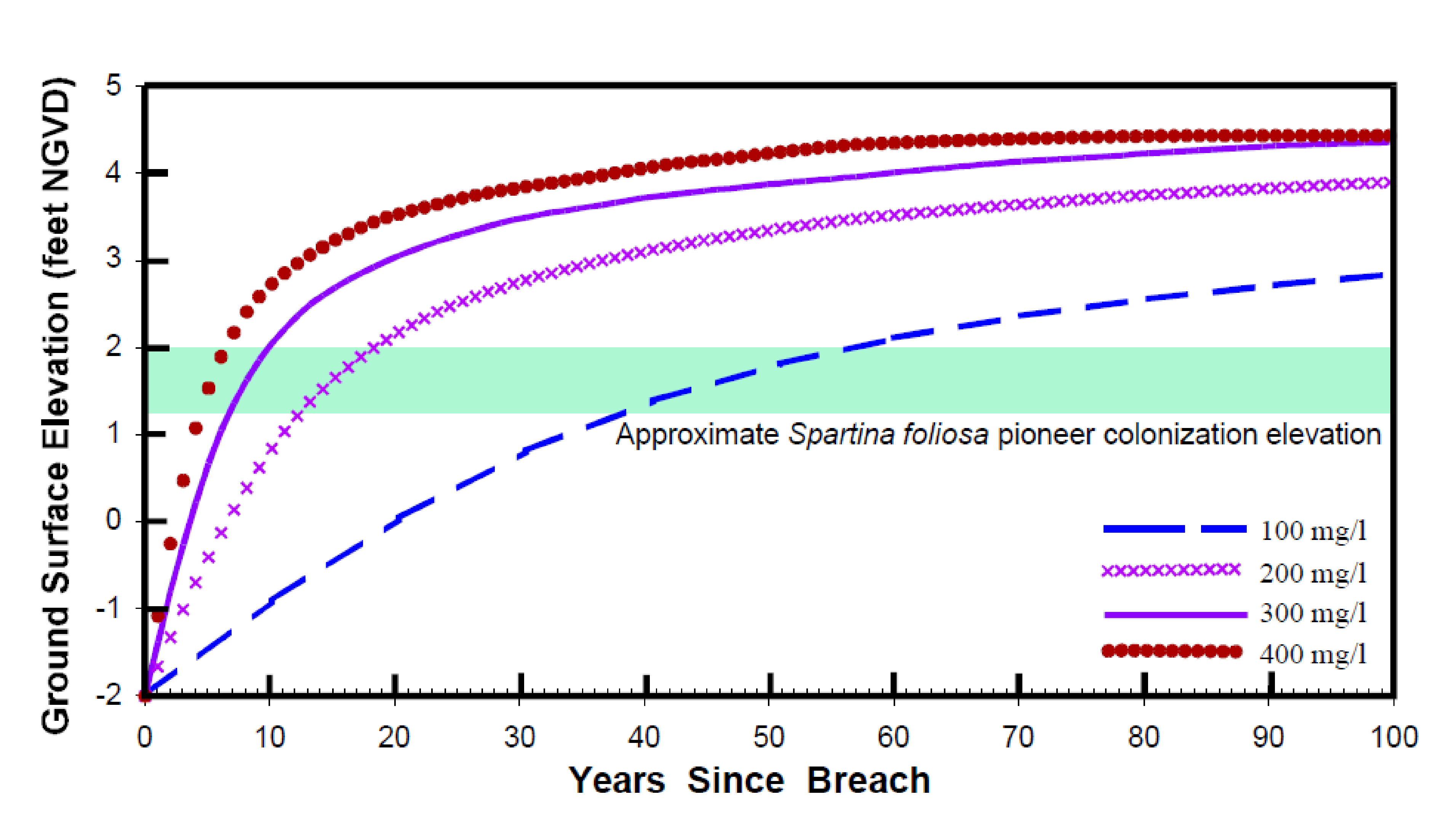

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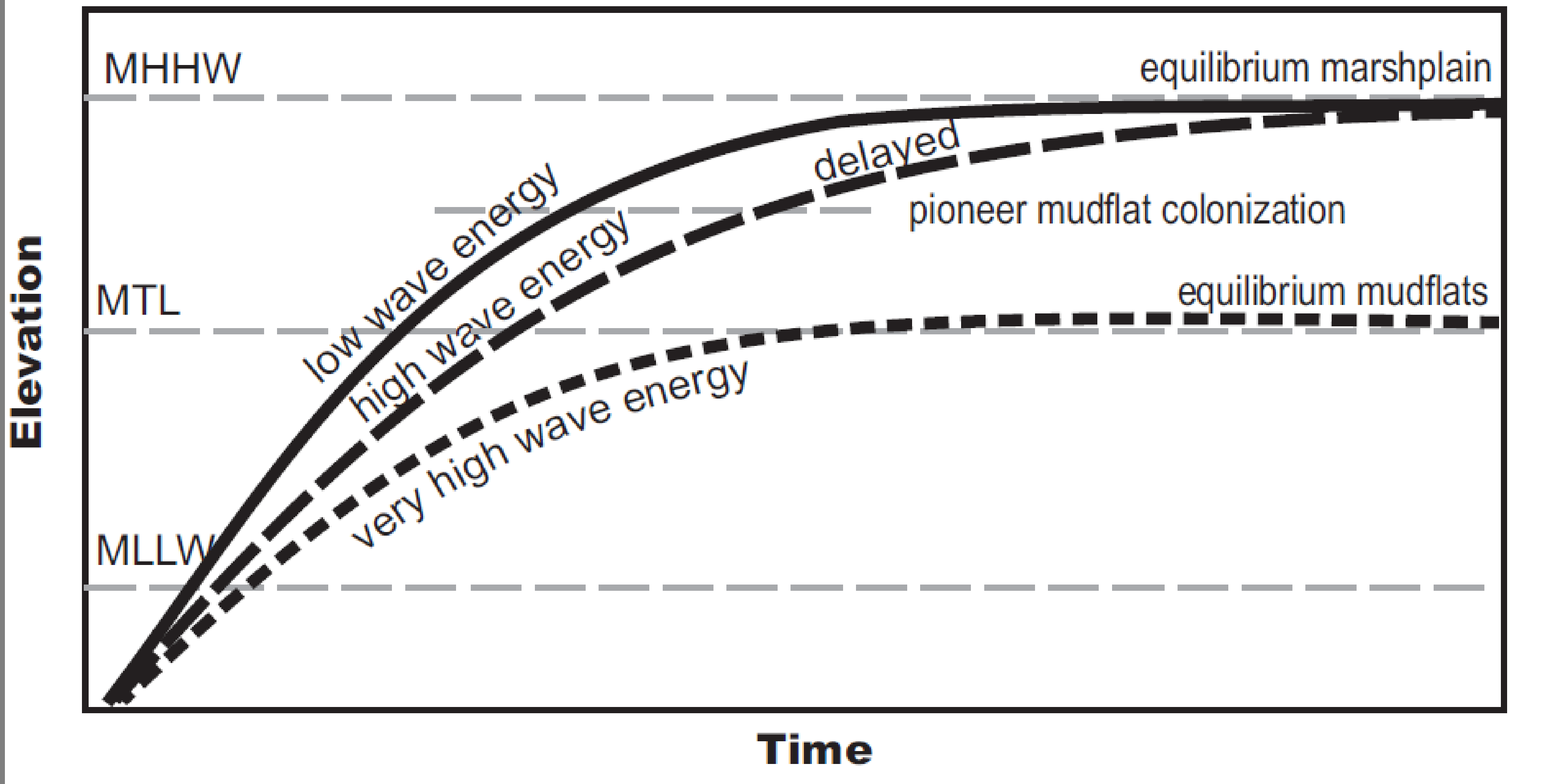
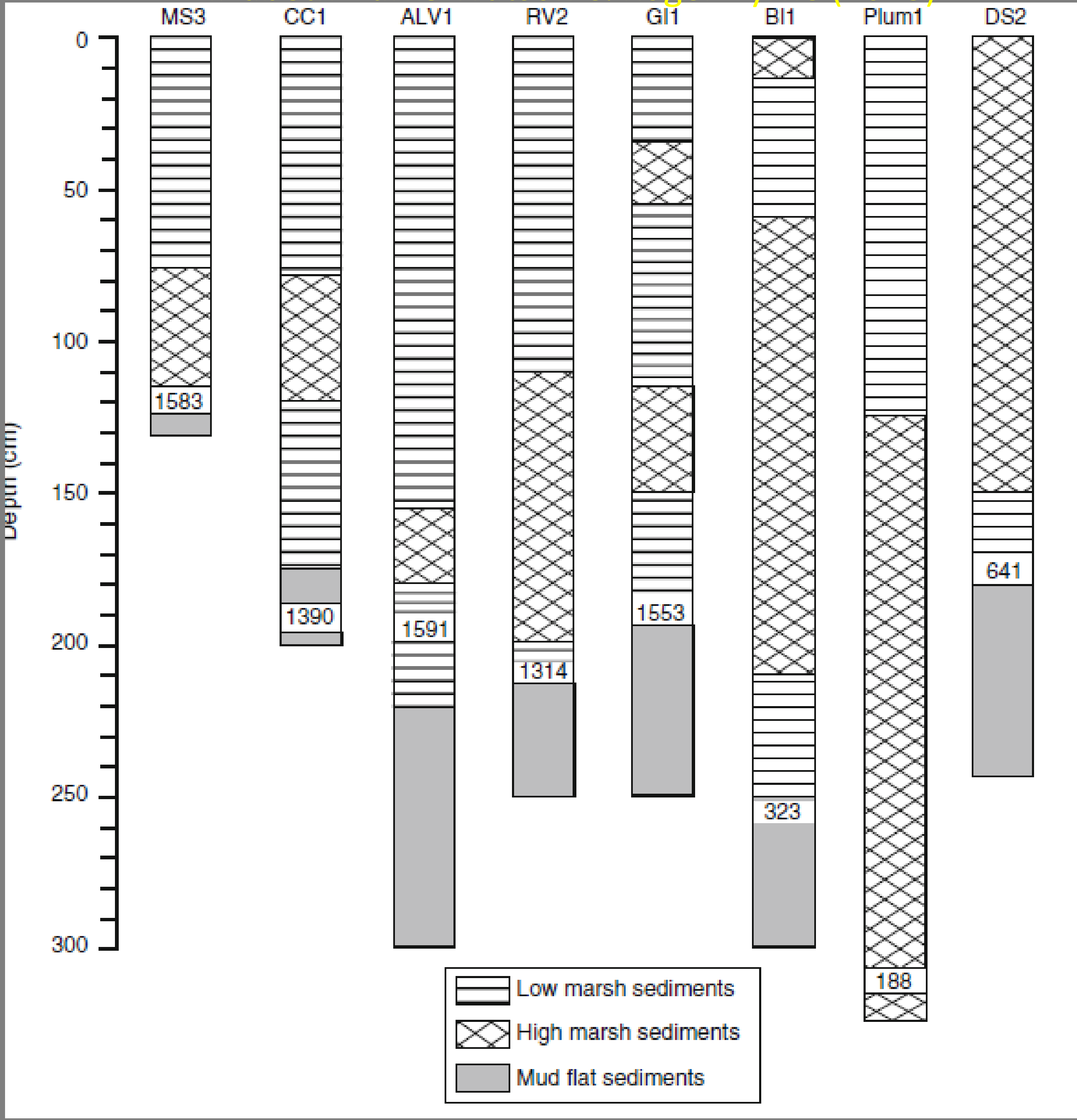


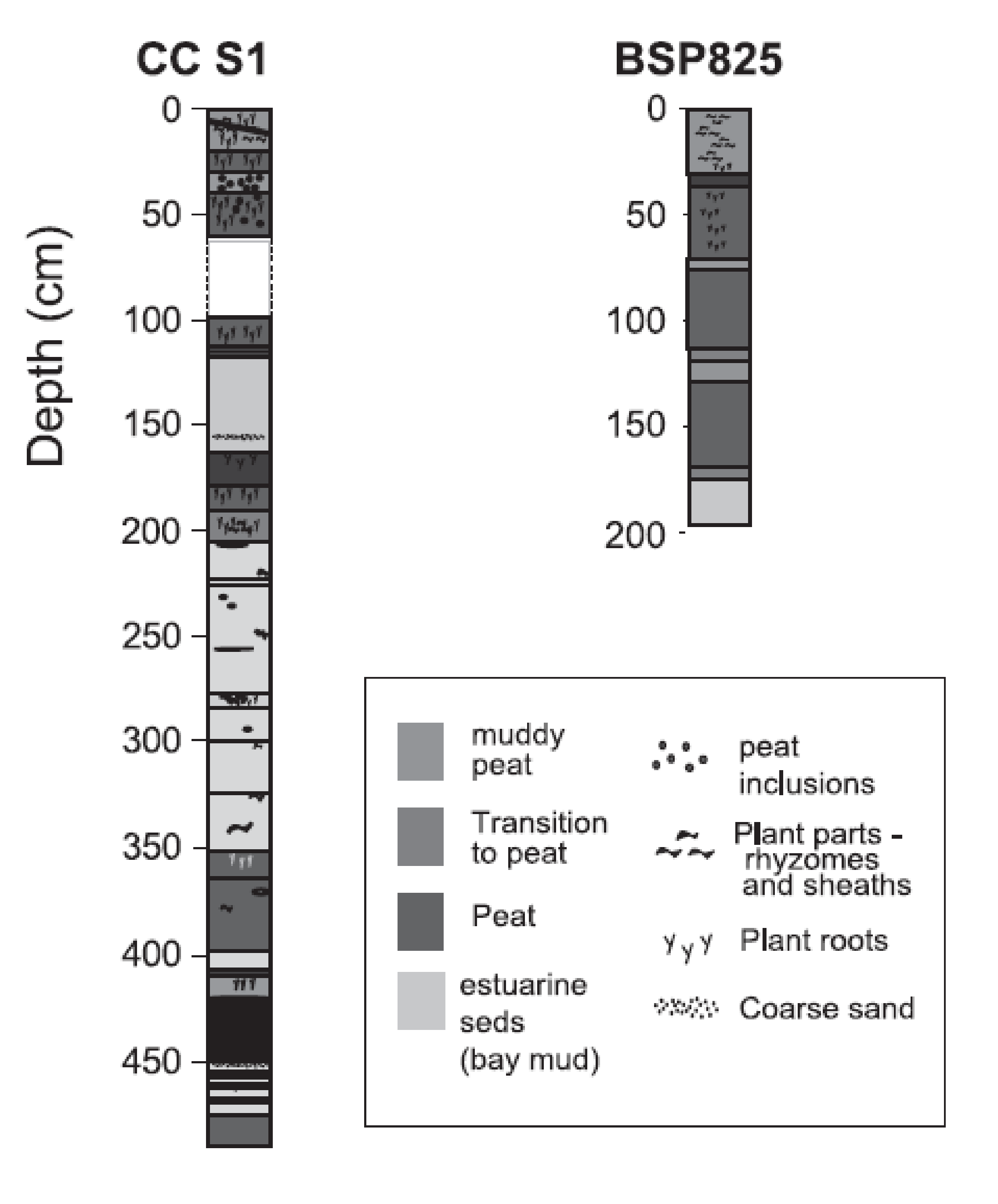
Elizabeth Burke Watson & Roger Byrne (2013)



South SF Bay sediment cores: Non-linear long-term marsh succession revealed in stratigraphy

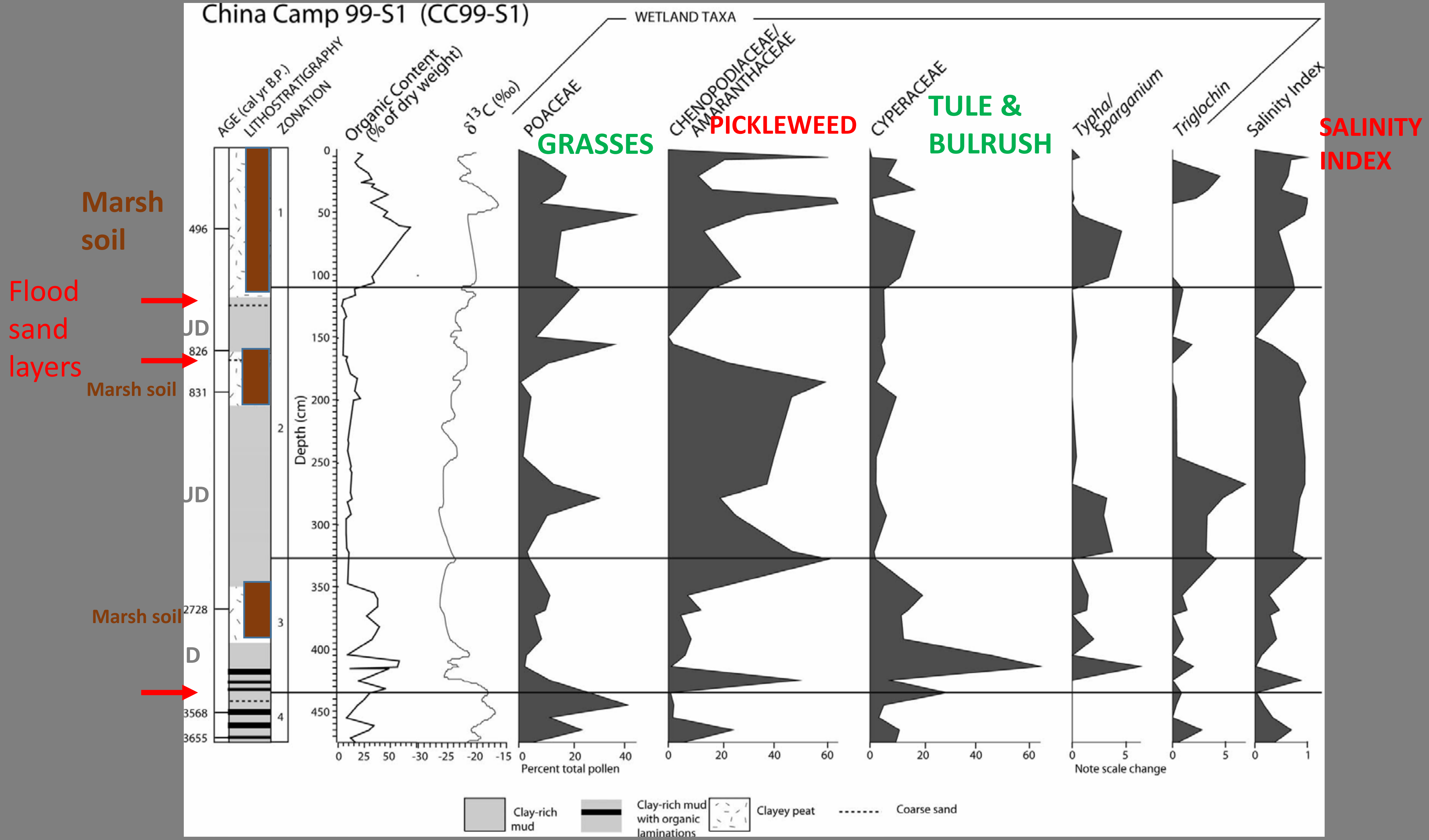
Tidal Marsh stratigraphy: paleoclimate & paleoecological records of punctuated, non-linear change even under slow SLR

Implications for climate change and wetland restoration monitoring



Late Holocene δ ^{13}C and pollen records of paleosalinity from tidal marshes in the San Francisco Bay estuary, California (2004)

Frances Malamud-Roam, B. Lynn Ingram



Goman & al. 2004. Holocene Environmental History and Evolution of a Tidal Salt Marsh in San Francisco Bay, California

Goals Project and BEHGU era
Wetland restoration monitoring concerns

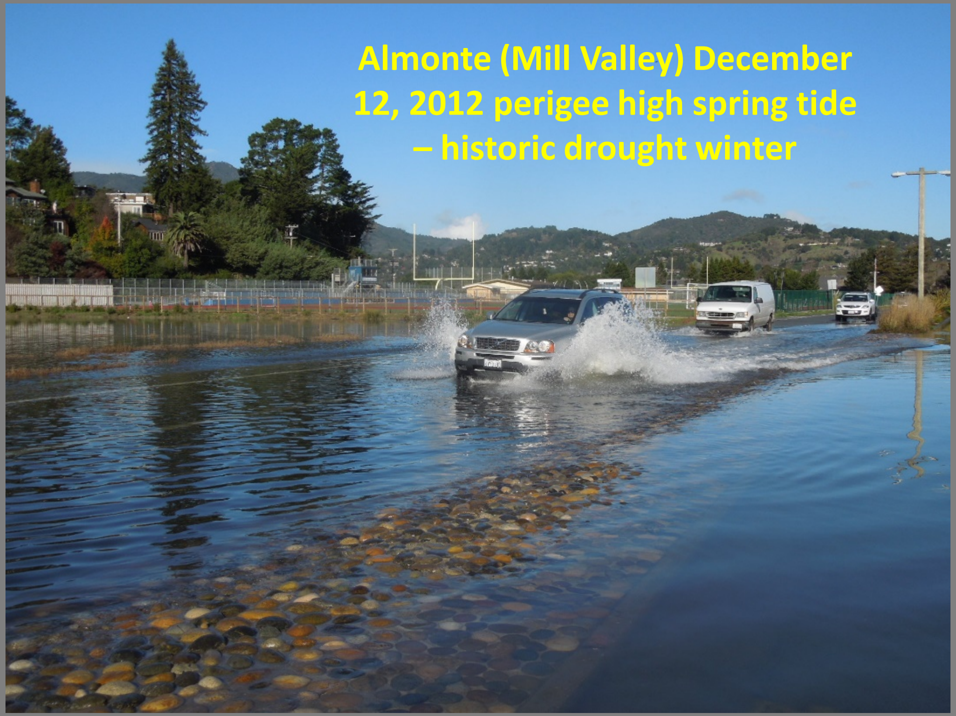
- Marsh platform (plain & low marsh) v. edge (high marsh and supratidal ecotone) evolution
- High marsh and terrestrial ecotones as limiting habitats for biological diversity conservation
- Horizontal marsh instability (wave erosion) > vertical instability (Kirwan & Megonigal 2013, Nature 504; Fagherazzi 2013) – shoreline change
- Local watershed connections: terrigenous sediment, freshwater
- Invasive species

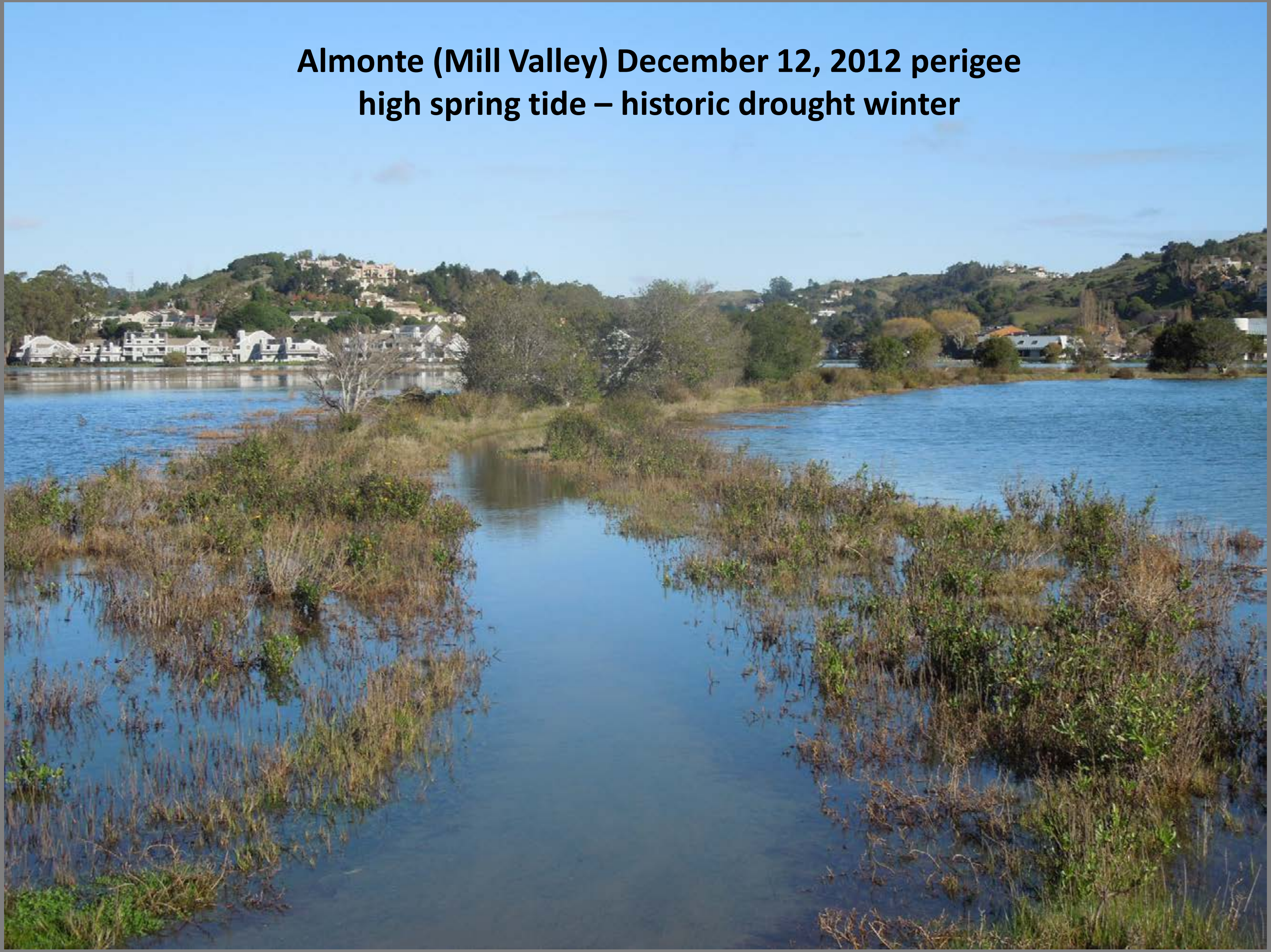
ENSO events and SLR: Changing perspectives on restoration and monitoring

- **High marsh plain evolution processes and stability**
- **Fine mineral sediment supply and marsh plain vertical accretion**

(Schoellhammer 2011 Estuaries & Coasts 34)

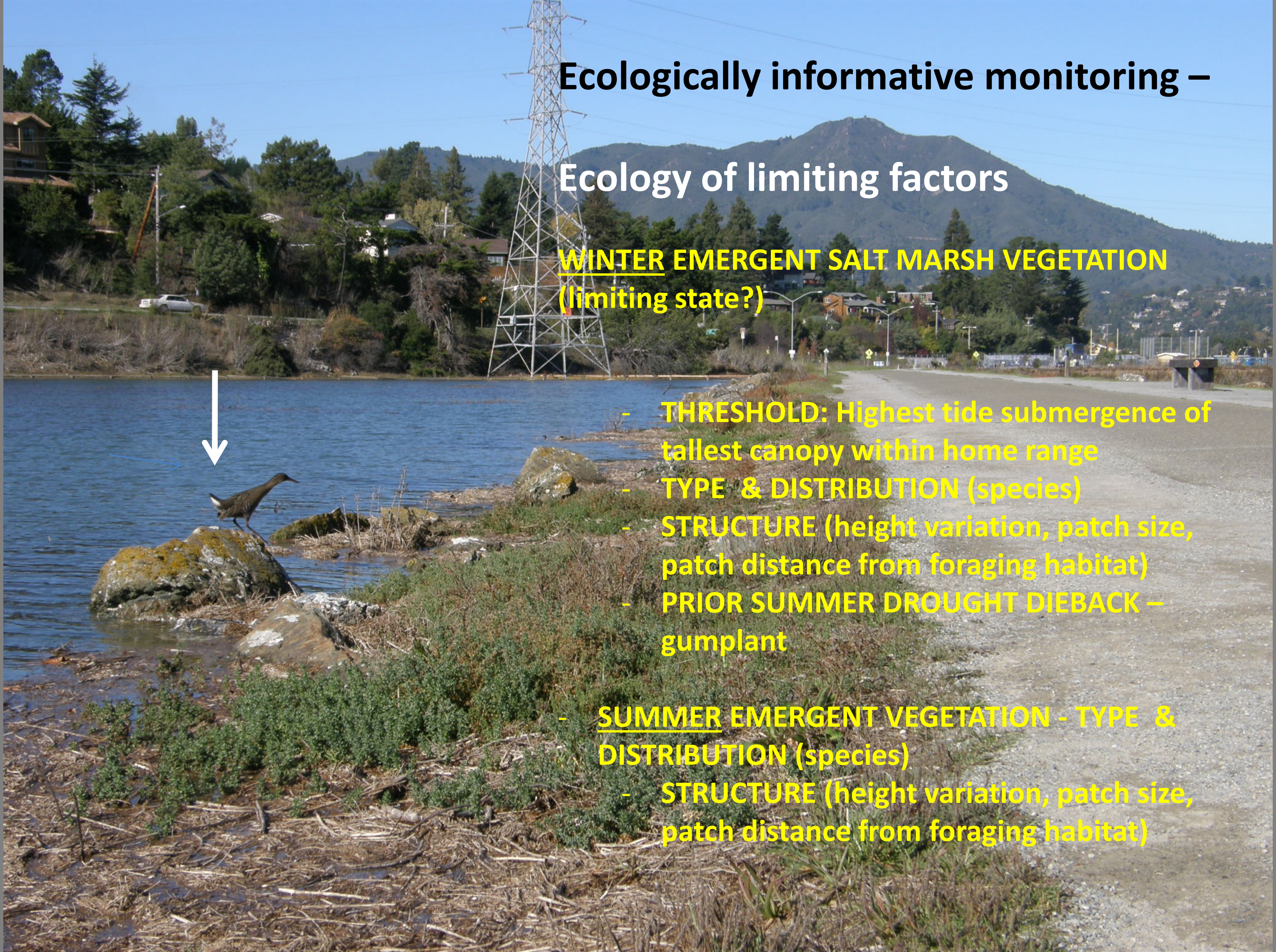
- **High marsh and terrestrial transition zones as limiting habitats for wildlife and plant species conservation**




Almonte (Mill Valley) December 12, 2012 perigee
high spring tide – historic drought winter

High tide cover adjacent to levee recreational trail: Ridgeway's rail vigilance (predator detection) v. cryptic behavior (predator avoidance)


Bothin Marsh, Richardson Bay
November 2009 high tide
Limiting habitat: internal (channel bank) emergent vegetation cover
Ridgeway's rail without high tide cover
Structure intensifies with ENSO and SLR


Ecologically informative monitoring –
Ecology of limiting factors
WINTER EMERGENT SALT MARSH VEGETATION (limiting state?)
- THRESHOLD: Highest tide submergence of tallest canopy within home range
- TYPE & DISTRIBUTION (species)
- STRUCTURE (height variation, patch size, patch distance from foraging habitat)
- PRIOR SUMMER DROUGHT DIEBACK – gumplant
- SUMMER EMERGENT VEGETATION - TYPE & DISTRIBUTION (species)
- STRUCTURE (height variation, patch size, patch distance from foraging habitat)

Ecology of limiting factors: geographic variation

WINTER EMERGENT SALT v. OLIGOHALILNE MARSH VEGETATION
(limiting state?)

Suisun Marsh – Rush Ranch
Dec 13, 2012 high perigee tide

Extensive high marsh emergent canopy

Suisun Marsh – Rush Ranch
Dec 13, 2012 high perigee tide

Highest cover = low marsh

Example: Muzzi Marsh, Corte Madera

Muzzi Marsh monitoring emphasis:

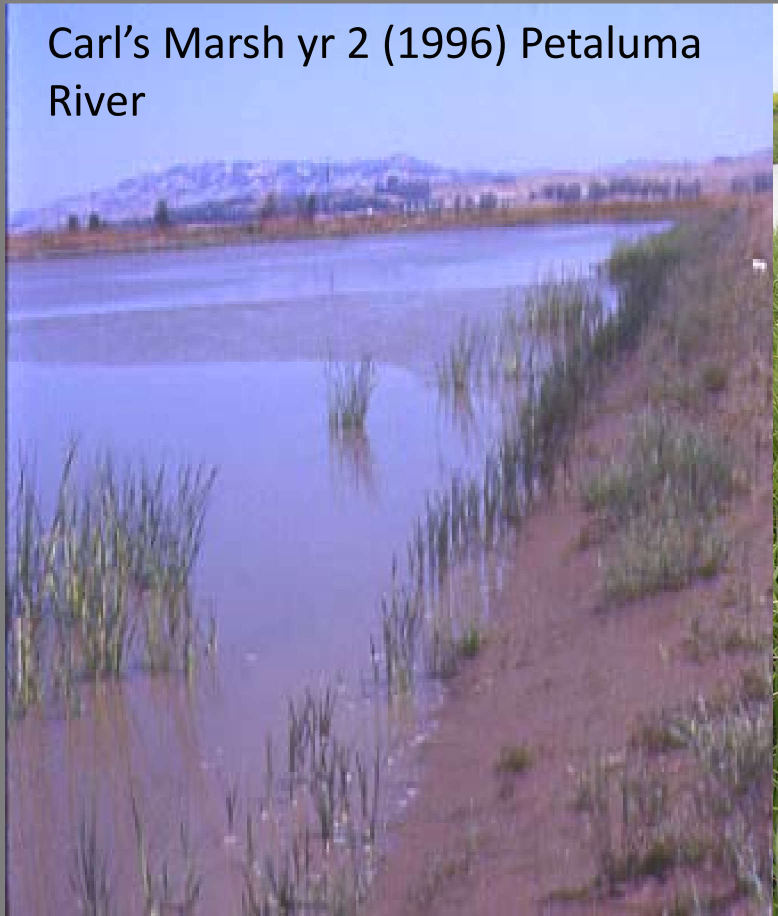
- Channel formation
- Sediment accretion and elevation change
- Dominant vegetation change
- Hybrid Spartina invasion
- Special-status wildlife populations (Ridgeway's rail)

Muzzi Marsh, Corte Madera, San Francisco Bay
45 yrs old – "mature" tidal marsh restoration project
January 2010 high tide: marsh submergence
Limiting habitat: internal (channel bank) emergent vegetation cover – winter ENSO perigee spring tides

Monitoring for limiting process: colonization by infrequent or short-dispersal plants

Efficient, fast-colonizing plants dominate young tidal marshes.

Relatively few early succession, pioneer species with ability to spread rapidly and compete well in relatively homogeneous habitats **dominate the flora of young marshes** …. especially non-native invasive colonizers.



Northern salt marsh bird's-beak
Chloropyron maritimum subsp. *palustre*

Remnant population at CMER (Heerdt Marsh) adjacent to Muzzi Marsh

No colonization at Muzzi Marsh in 45 years

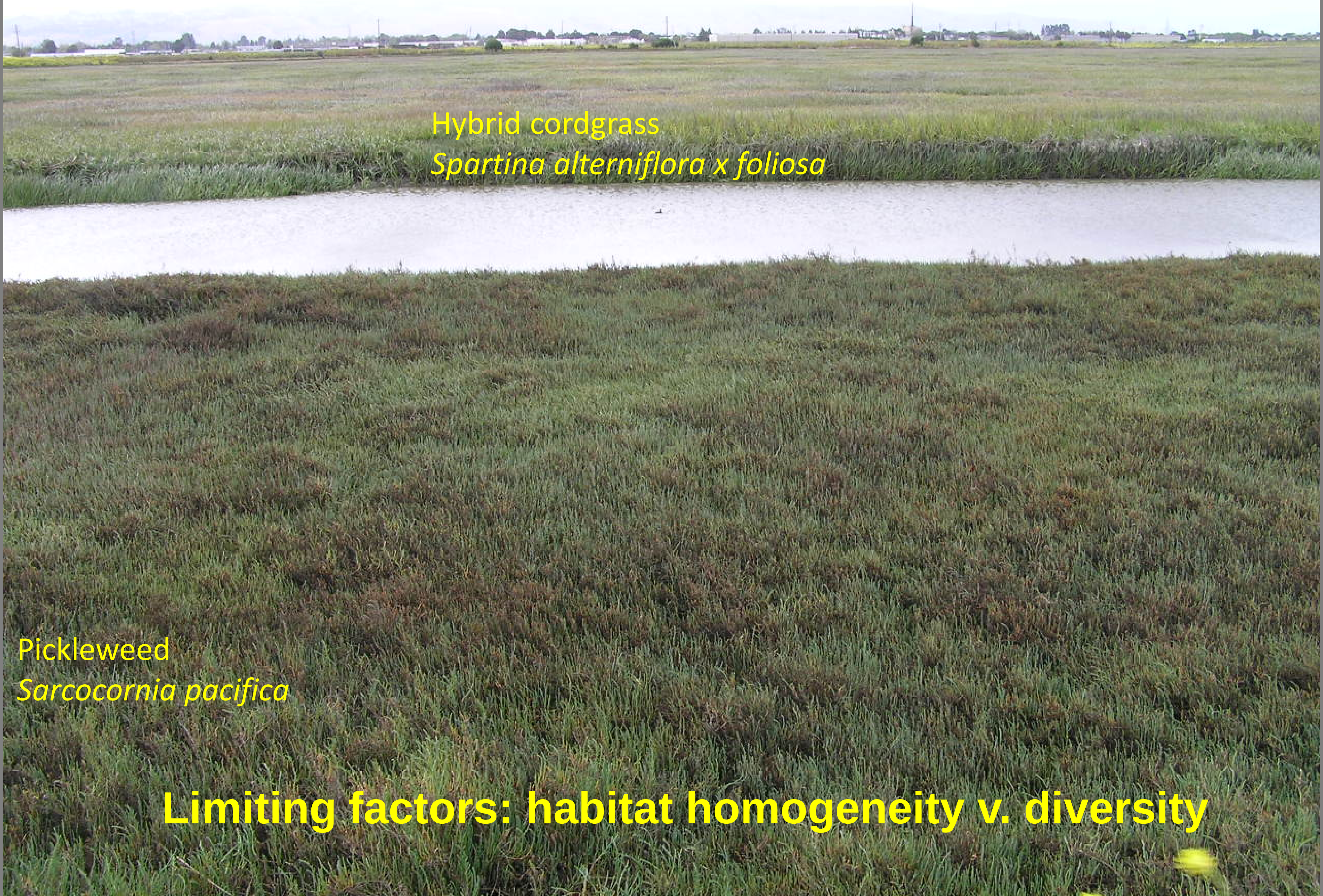
Contrast with Richardson Bay: extensive spread to unoccupied salt marsh after 1998 (ENSO event)

Historically widespread native annual high salt marsh forbs reduced to rarity

Salt marsh owl's-clover (*Castilleja ambigua*)
Smooth goldfields (*Lasthenia glabrata)*

HIGH TIDAL MARSH-DEPENDENT SPECIES OF CONCERN

Cogswell Marsh, Hayward - mostly monotypic salt marsh vegetation (2007)



Unintentional artificial analogs of alluvial fans (splays) in tidal wetland restoration – not designed, not monitored

Montezuma Wetlands 2013

Sediment size sorting gradient:
coarser upslope, finer downslope

Sonoma Baylands 1996

MONITORING UNANCITIPATED CONSTRUCTION OUTCOMES –

HYRAULIC SPLAY (ALLUVIAL FAN) DEPOSITION

Naturalistic marsh edge gradient & process

Wave damping potential

New unintended approach to high marsh construction

SONOMA BAYLANDS 2003

Passive construction of gentle shore slopes

HYDRAULIC DEPOSITION OF DREDGED MATERIAL – SPLAY (FAN) DEPOSITION

Natural analog model:
Sears Point alluvial fan deposition process

Natural reference site for monitoring evolution of fans: China Camp Marsh alluvial fan at tidal marsh edge

Shallow sediment burial of vegetation
Slurry-like storm runoff – gully slopewash (mud)
Regeneration of tidal marsh-terrestrial transition zone, 2006-2012

2006

2012

10 years after deposition and tidal restoration, Sonoma Baylands dredge sediment fans supported unanticipated target extensive high salt marsh habitat in matrix of low marsh and mudflat

Inertia: No change in monitoring focus

1996

2006

Effects of fan deposition

- high marsh – terrestrial ecotone
- wave damping (>10 m fringing marsh
- rapid initiation of marsh progradation even where mudflat colonization is slow

Monitoring Estuarine Restoration Settings to Understand Restoration Sites

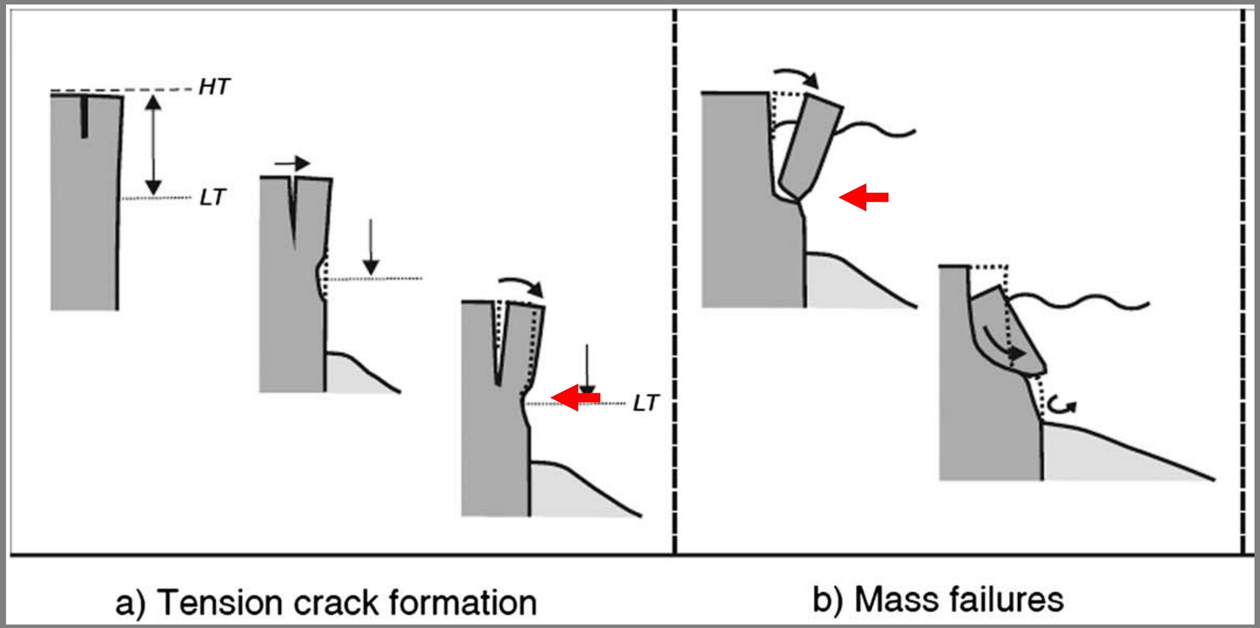
Shoreline Change

Wind-wave erosion and instability of tidal marsh ecosystems

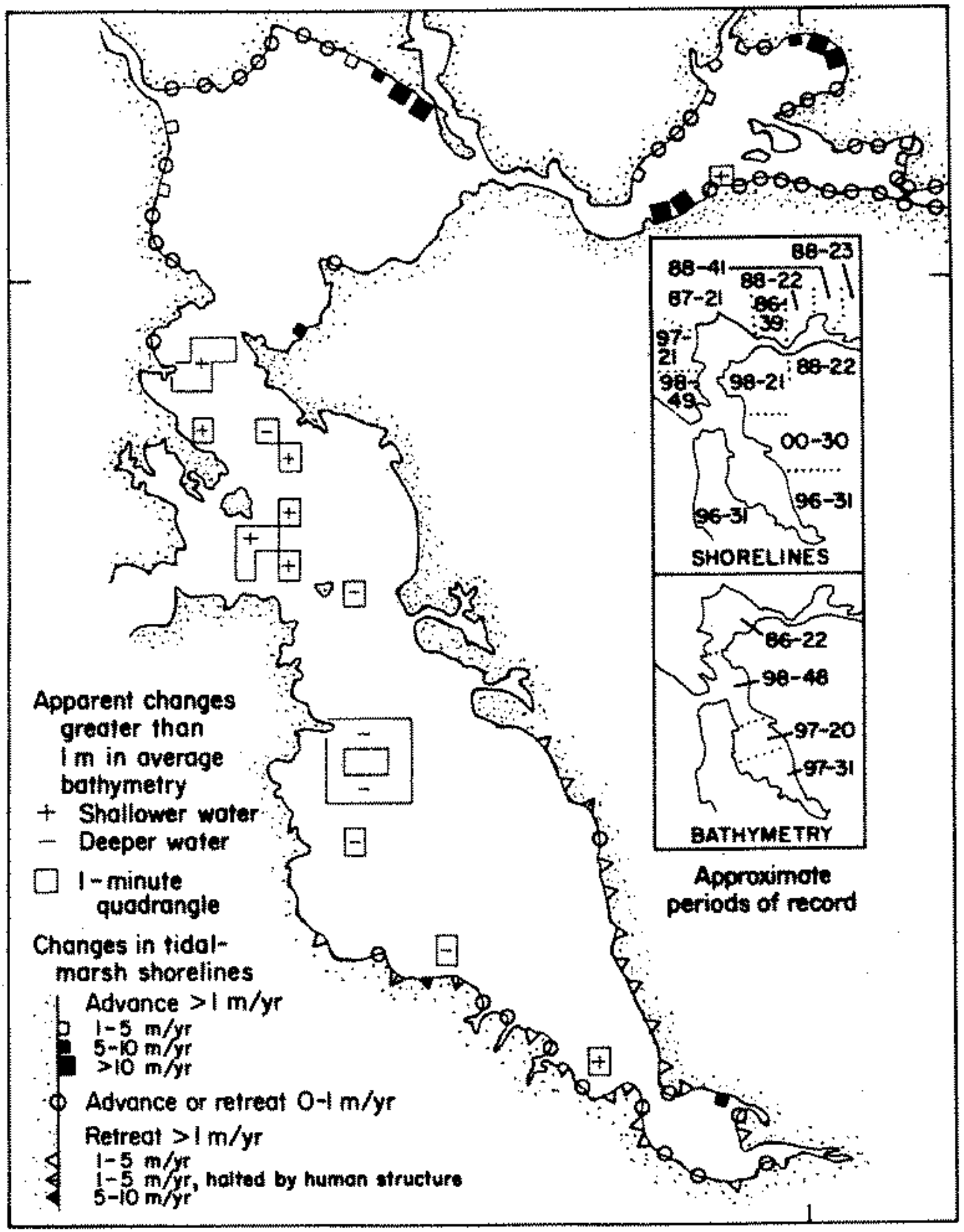
Lateral retreat of eroding outer marsh edge = primary mechanism coastal marsh loss globally;

Wind-wave erosion processes dominate slope failure: undercut base of scarp

- Marani *et al*. 2011, *Geophys Res Lett 38*.
- Fagherazzi 2013, *Geology* 41



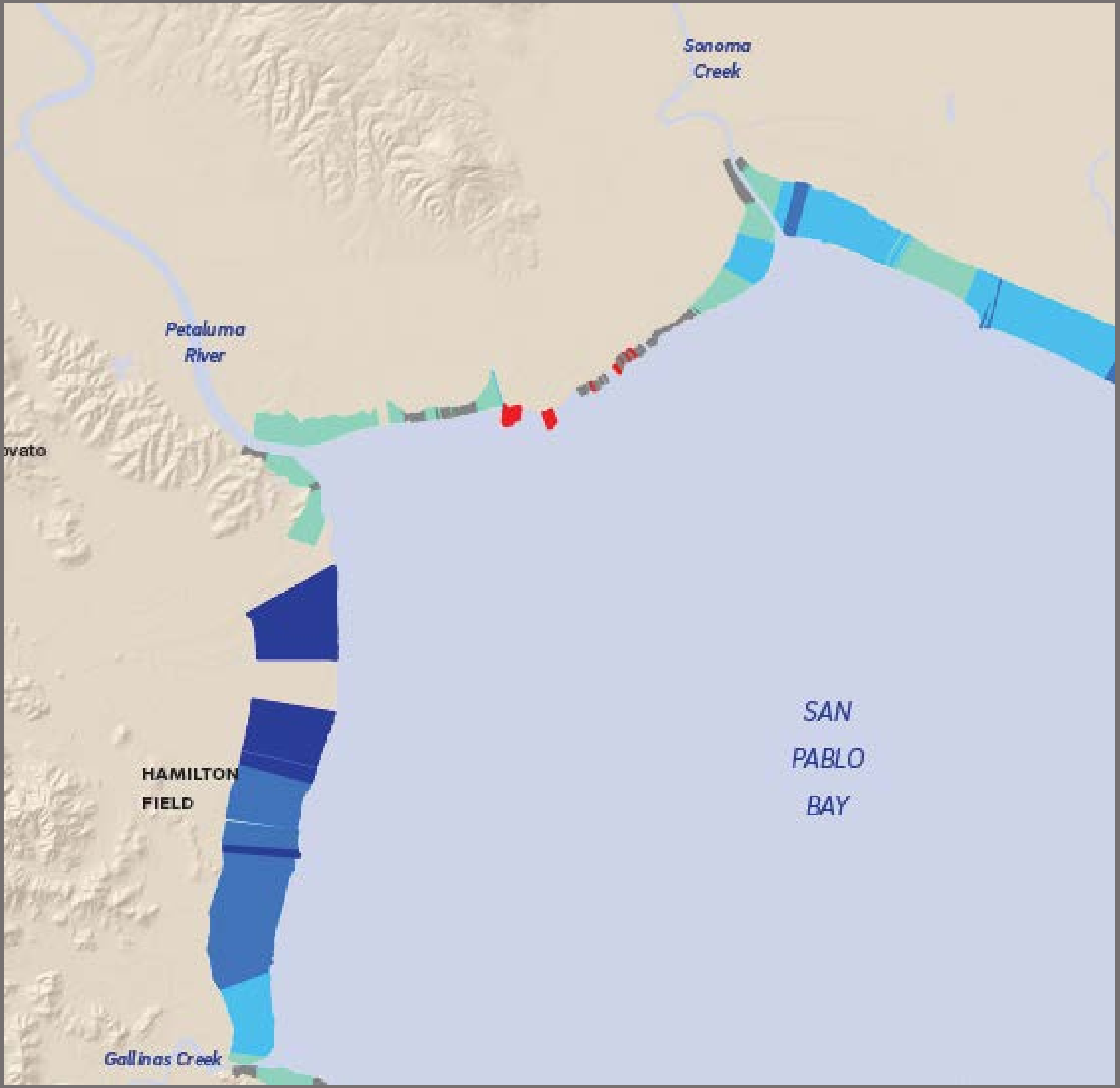
Typical undercutting mechanisms of failure observed in some of the experiments by Francalanci *et al.* 2013

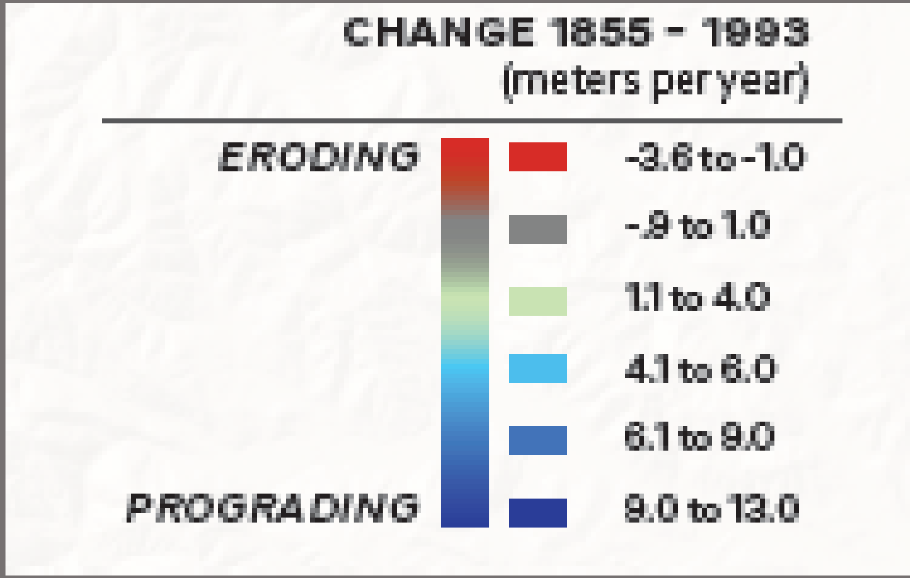


B. LATEST NINETEENTH AND EARLY TWENTIETH CENTURIES

Atwater *et al*. 1979
History, Landforms, and Vegetation of the Estuary's Tidal Marshes

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





SFEI 2015
Beagle J. *et al.*

Shifting Shores: Mapping Shoreline Change in San Pablo Bay

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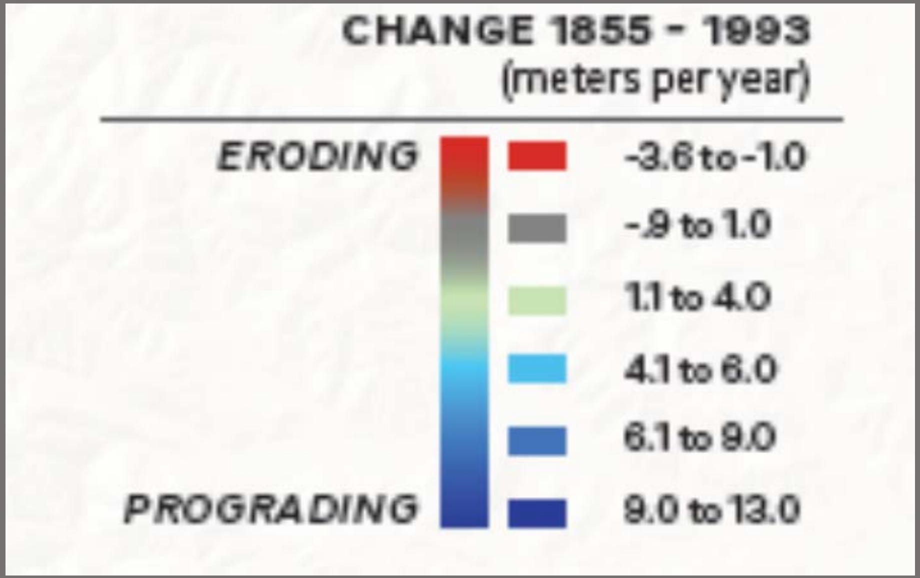

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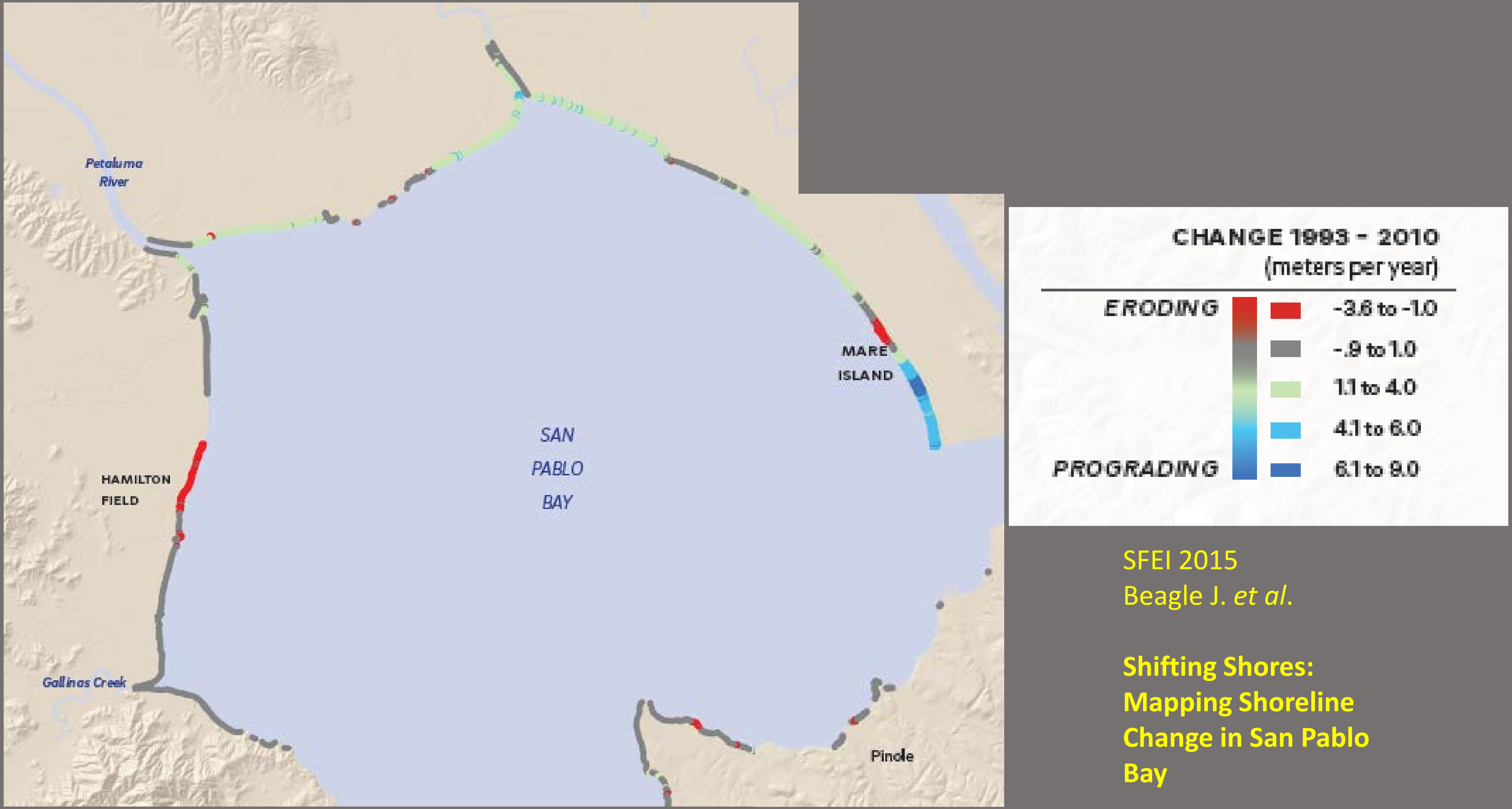

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Shifting Shores: Mapping Shoreline Change in San Pablo Bay

Northern San Francisco Estuary marsh edges

San Francisco Estuary Institute (SFEI) marsh shoreline change study San Pablo Bay 1993-2010 trends:

Retreating marsh edges

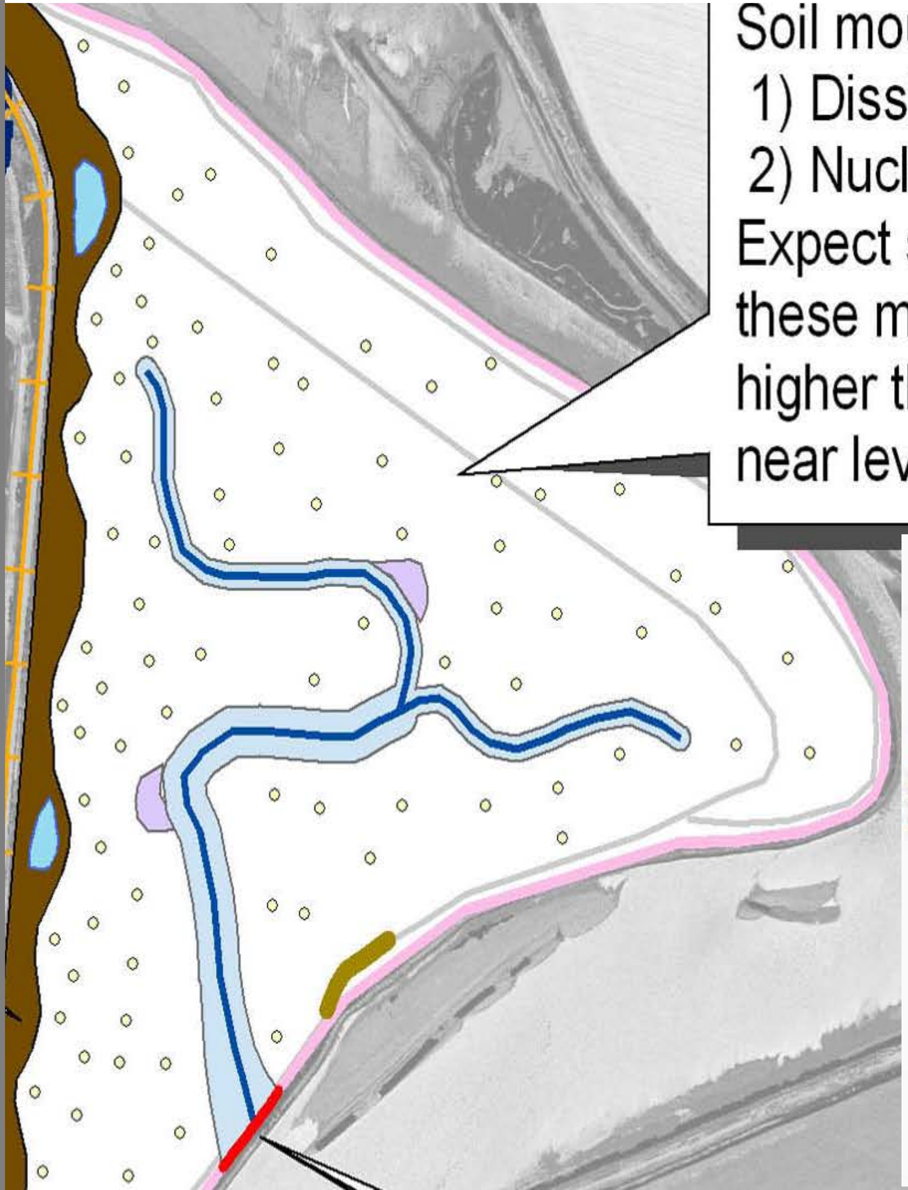
-0.9-1.0 m/yr (protruding marsh shores)

- **higher local rates -1.0-3.6 m/yr – convex marsh shores, pocket marshes**

Marsh progradation (widest mudflats, gentlest tidal flat gradients

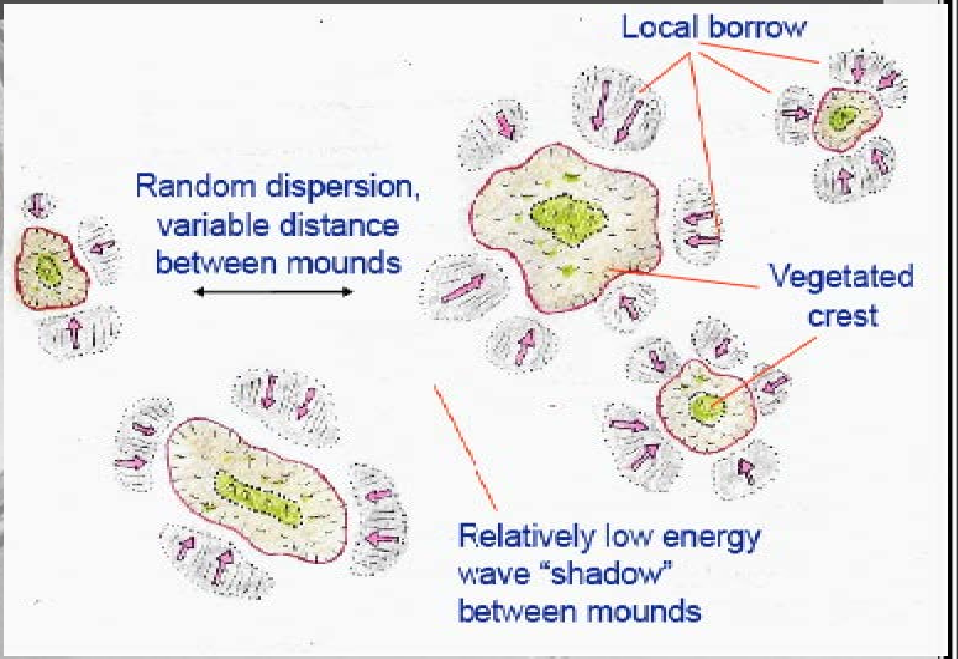
- **widespread prograding marsh edges +1.1-4.0 m/yr**
- **…despite erosional morphology**

SEARS POINT INTERTIDAL MOUNDS (marsh nuclei)
Adapt monitoring to restoration design and modified geomorphic evolution process



Soil mound; typical purposes are:
1) Dissipate wave energy
2) Nuclei for marsh vegetation colonization

Expect smaller channels will form around these mounds. Actual mound density will be higher than shown, with greatest densities near levees requiring erosion protection



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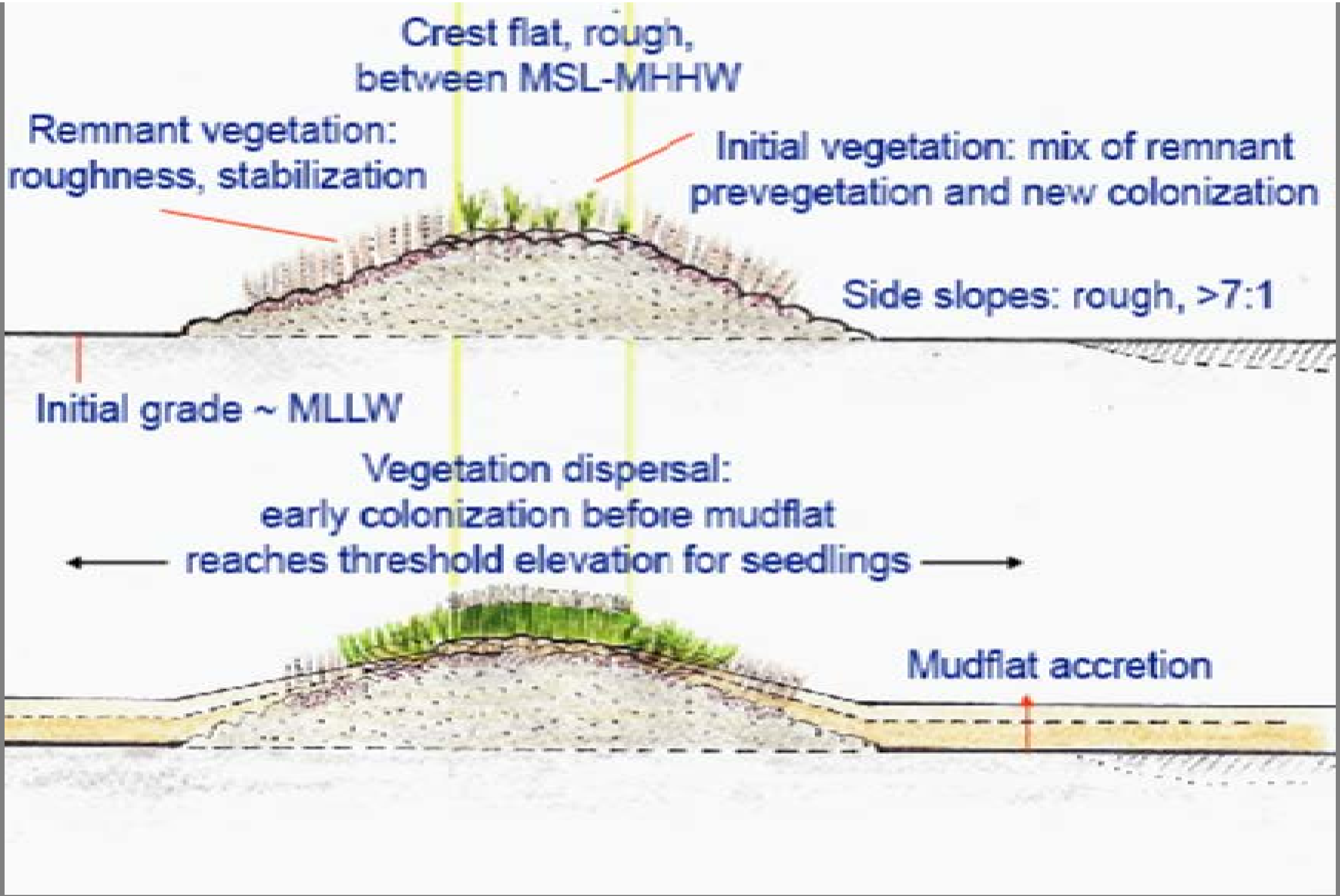


Sears Point Wetland Restoration – pre-breach (April 2015)

Bahia marsh mounds –Nov 15 2012 (constructed 2008) perigee spring tide

Potential past and future monitoring opportunities:

Hypothesis testing for tidal restoration designs integrated into monitoring

MARSH MOUNDS - MARSH NUCLEATION PROCESSES

- **Radial marsh progradation rate?**
- **Seedling recruitment rates?**
- **Vertical accretion rate and stabilization versus mudflat?**
- **Frequency of pioneer plant colonization on adjacent mudflats?**

MONITORING UNEXPECTED OUTCOMES

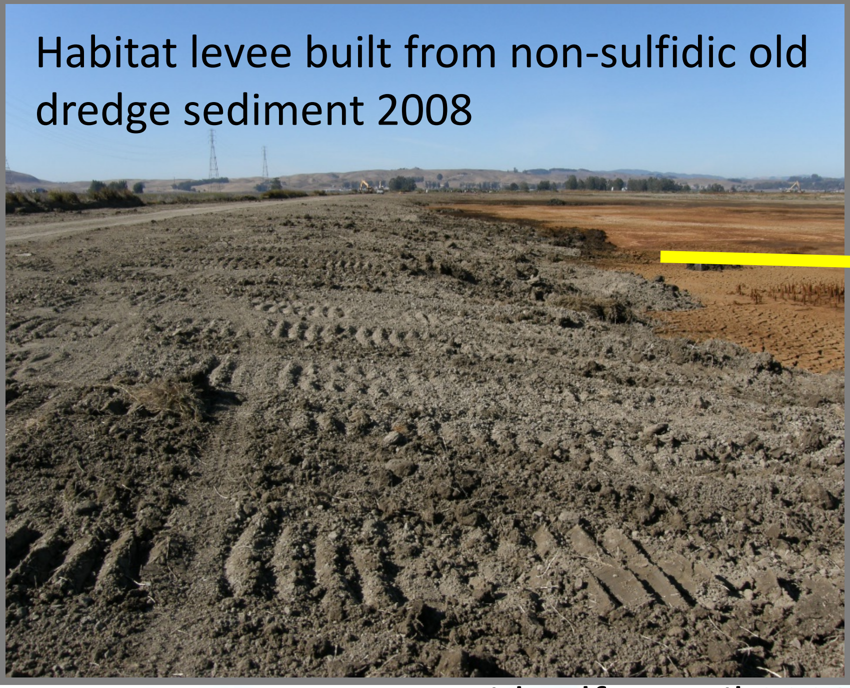
Capturing ecological surprises

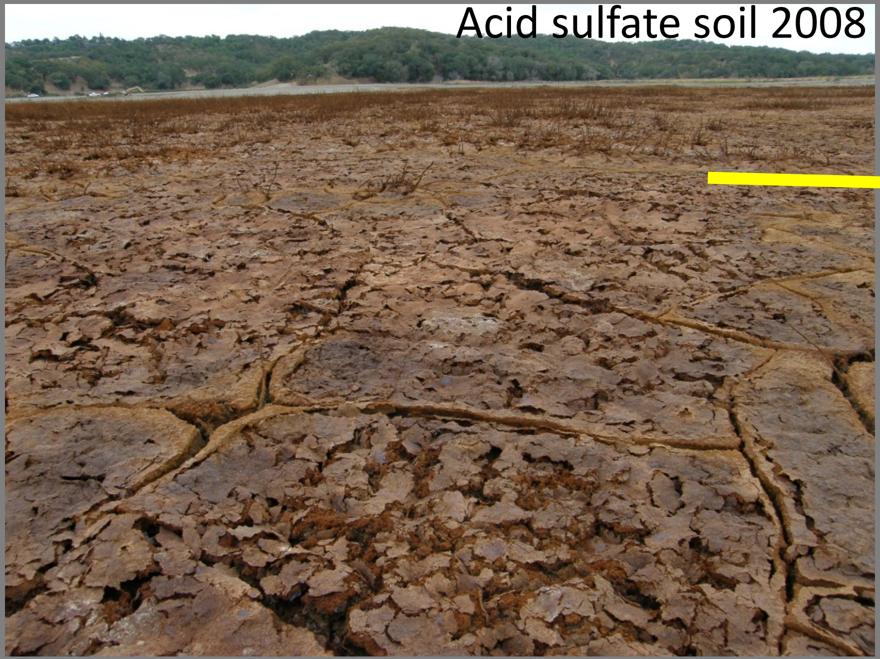
Undirected, exploratory observations of wetland restoration should guide monitoring modifications if significant discoveries occur

Bahia Wetland Restoration Project, Novato

- Intensive acid sulfate sediment formation
- Rapid evolution during pre-restoration site conditions
- Strong residual effects on vegetation establishment of levees built from sulfidic muds

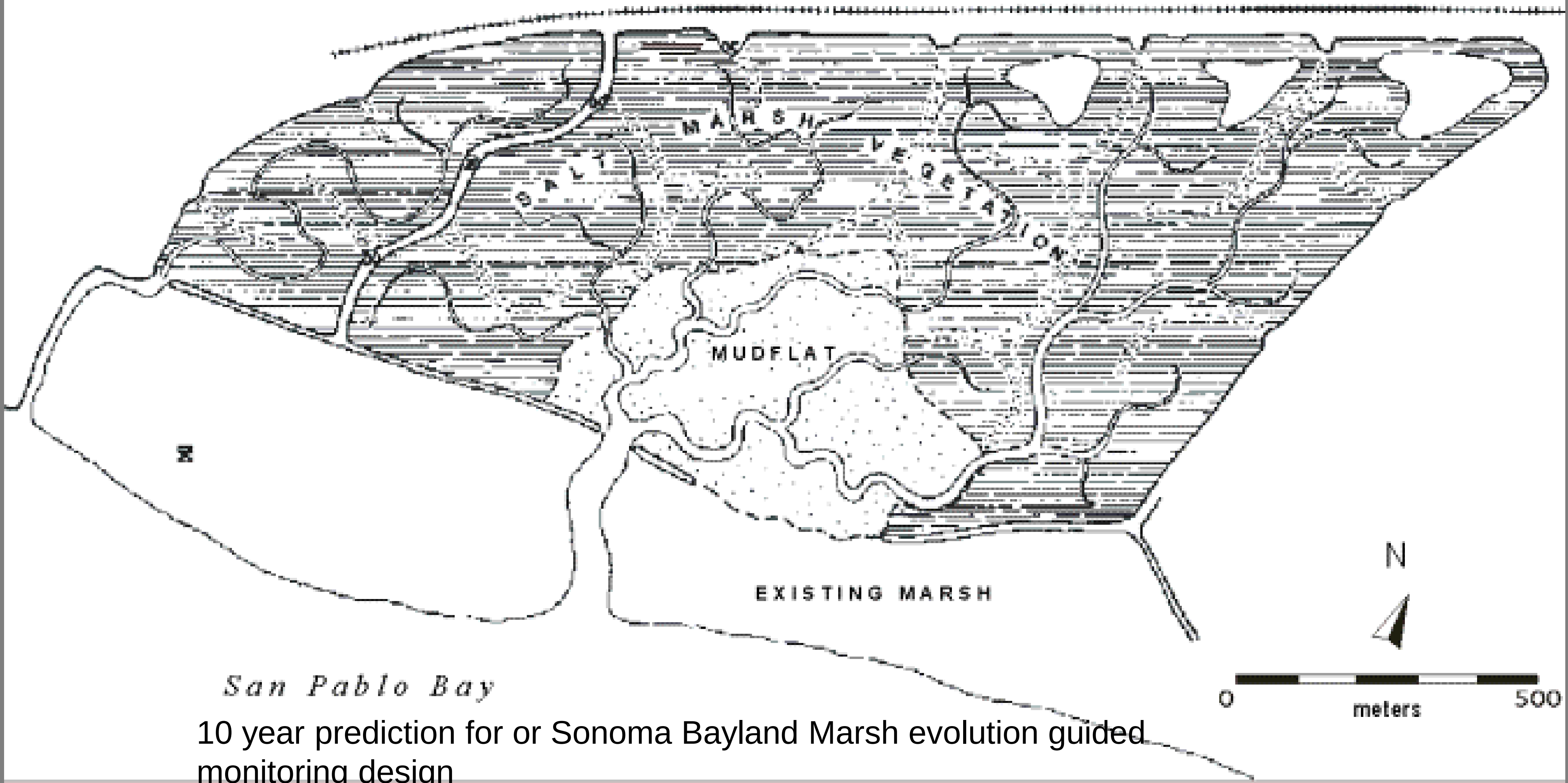
MONITORING UNEXPECTED OUTCOMES Capturing ecological surprises



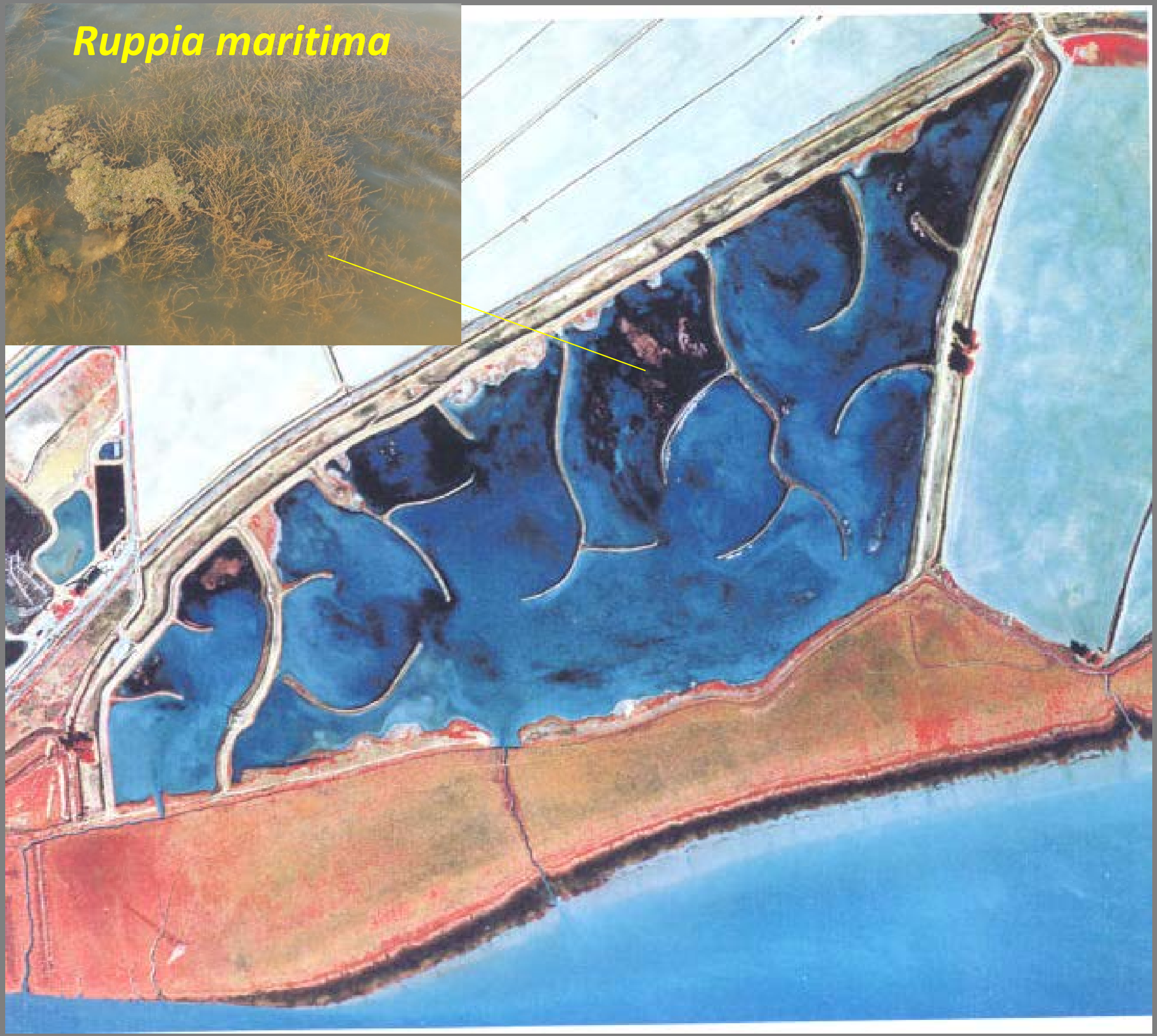


Sonoma Baylands (plan 1992; breach 1996)

- **Dredged material placement** to compensate for subsidence of diked bayland to near MLW (lower intertidal). Mud platform constructed to elevation below MHW
- **Internal wavebreak berms** subdivide tidal drainage cells; objective = reduced wind-wave resuspension, increase sedimentation rate
- **Bay levee lowering**; new landward flood control levee (USACE) 7:1 bay slope
- **Passive plant colonization** of tidal mudflat by seed from adjacent source marshes (prehistoric Petaluma, Tolay marshes)
- **Passive tidal inlet channel erosion** through pre-existing undersized ditches



10 year prediction for or Sonoma Bayland Marsh evolution guided monitoring design



Sonoma Baylands Oct **1998-1999**

SAV (*Ruppia maritima*) dominant during tidal choking lagoon phase

High waterbird use;

Fish habitat?

Montezuma Wetlands – 2015
New pioneer Pondweed-Tule succession under novel low suspended sediment conditions

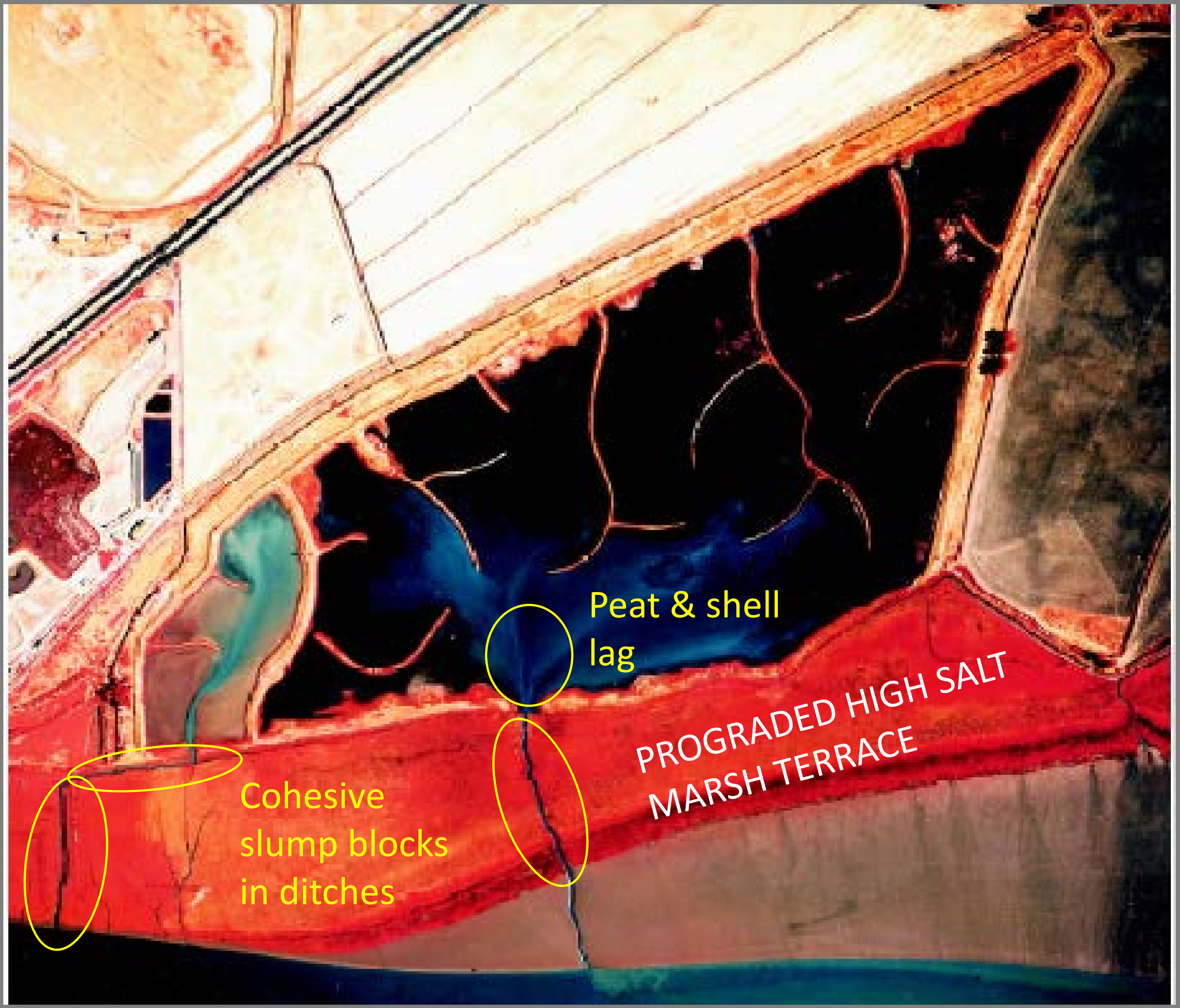
Monitoring SAV in Future Suisun Marsh
Potential alternative state of tidal restoration/breaching in subsided diked baylands

MONITORING UNEXPECTED OUTCOMES

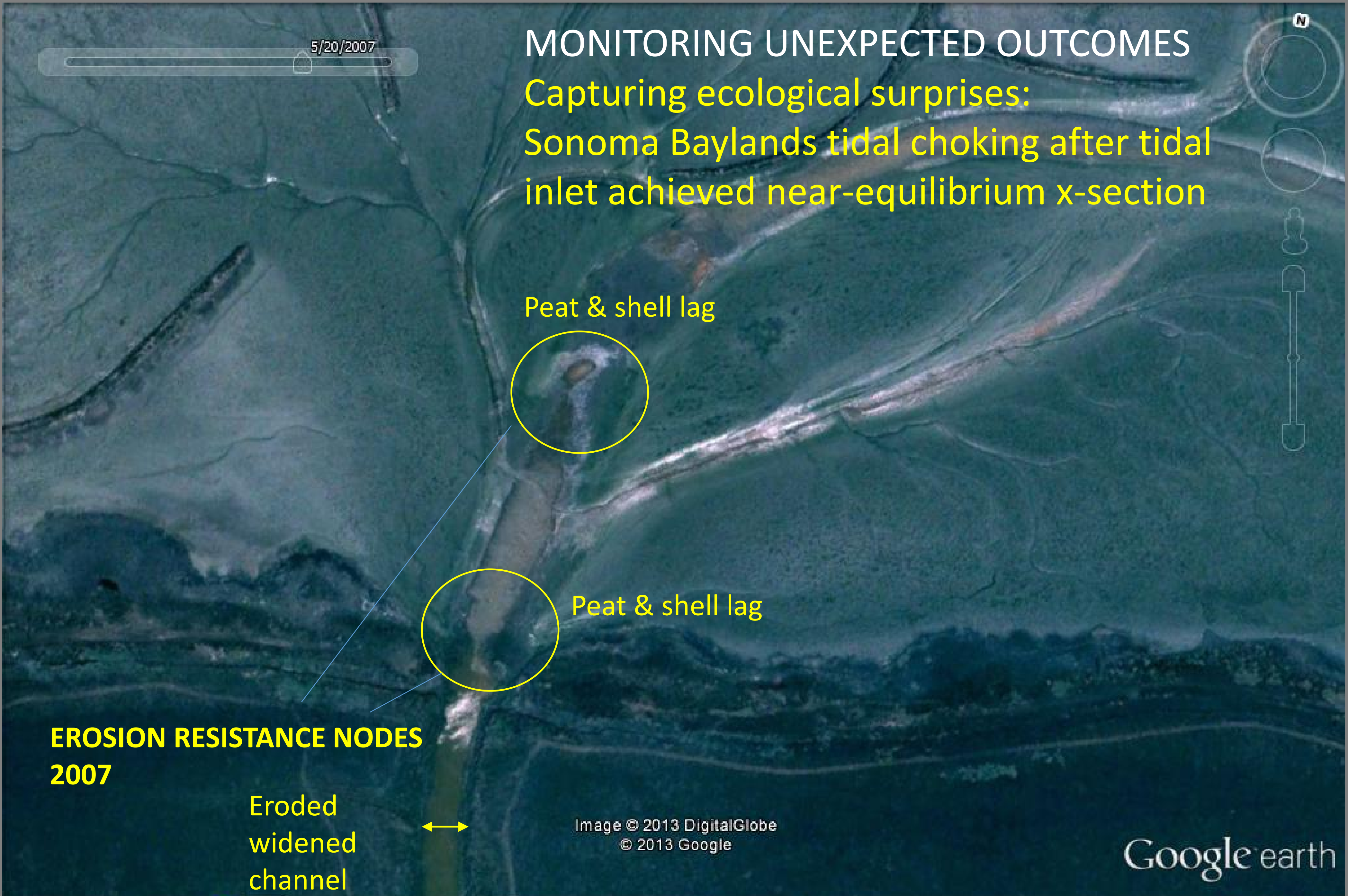
- Capturing ecological surprises: linear “wind-row” (scraper line) patterning of pioneer cordgrass and alkali-bulrush
- Incidental field observations → Ph.D. thesis (Stuart Siegel)
- No project monitoring of vegetation pattern or process
- Restorationn design basis for alternative marsh nuclei (marsh mounds)

Sonoma Baylands April 2015 (year 19)

gradual mudflat-marsh succession



Sonoma Baylands Aug 2002 (year 6)
Persistent tidal choking at inlet channels (mosquito & drainage ditches)


5/20/2007
MONITORING UNEXPECTED OUTCOMES
Capturing ecological surprises:
Sonoma Baylands tidal choking after tidal inlet achieved near-equilibrium x-section
Peat & shell lag
Peat & shell lag
EROSION RESISTANCE NODES 2007
Eroded widened channel
Image © 2013 DigitalGlobe
© 2013 Google
Google earth

Pilot Unit: 2004-2005 “sill” outcrop of resistant underlying pre-reclamation salt marsh soils, interior of breach (plant macrofossil and shell lag)

Diagnostic or “troubleshooting” adaptive monitoring:

Unexpected erosion-resistant peat marsh soil and shell lag outcrop – Sonoma Baylands Main Unit

2004-2005

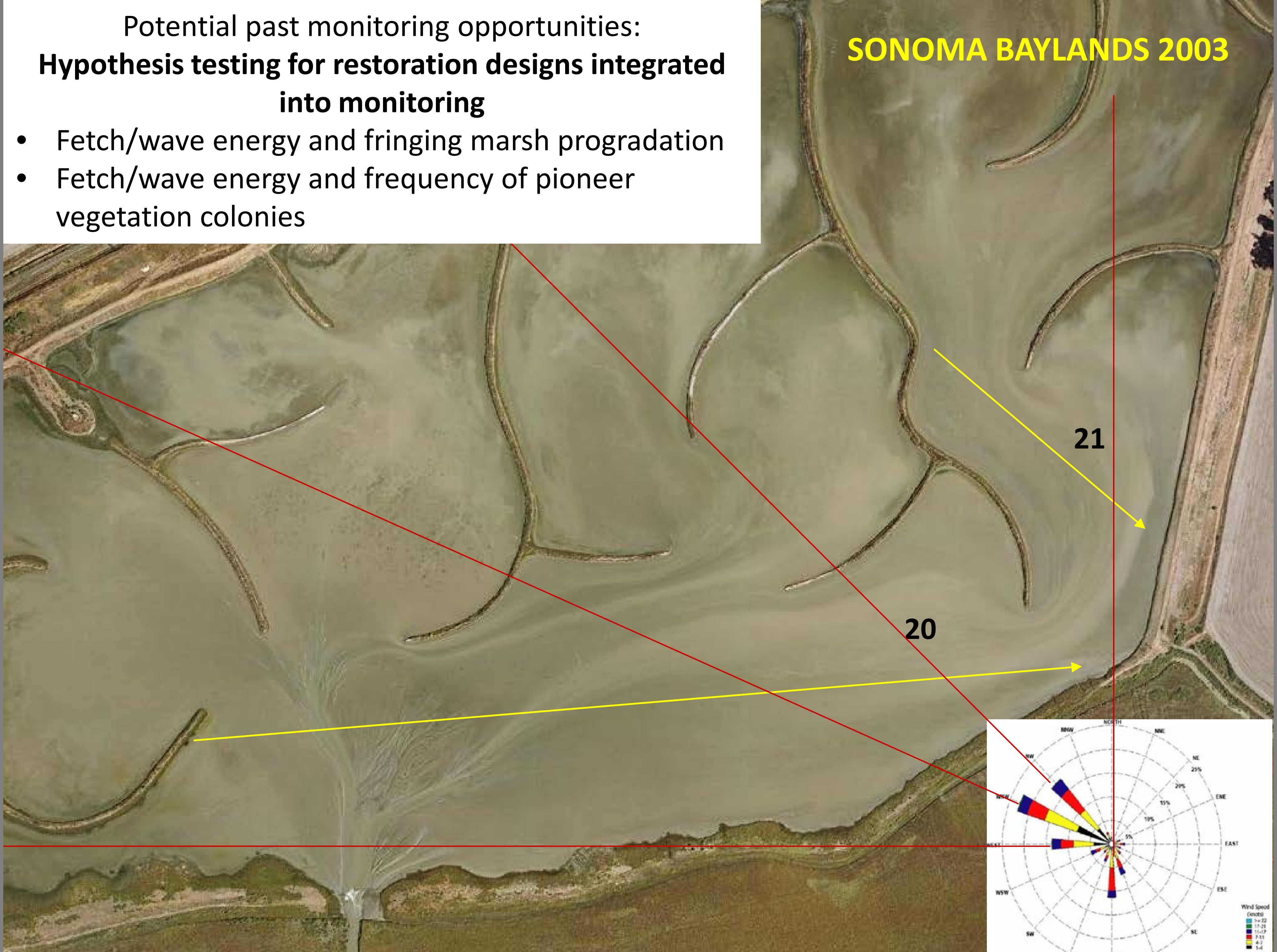
Diagnostic or “troubleshooting” adaptive monitoring:

Unexpected erosion-resistant peat marsh soil and shell lag – Sonoma Baylands Main Unit

Potential past monitoring opportunities:

Hypothesis testing for restoration designs integrated into monitoring

- Fetch/wave energy and fringing marsh progradation
- Fetch/wave energy and frequency of pioneer vegetation colonies



Potential past monitoring opportunities:

Hypothesis testing for tidal restoration designs integrated into monitoring

Pre-vegetation" – nontidal marsh management pre-breach treatment

TEST

- **bed roughness and sediment deposition rate, pattern**
- **erosion resistance**
- **facilitation of pioneer tidal marsh vegetation**

PETALUMA MARSH EXPANSION PROJECT, NOVATO

Marin Audubon Society

PWA

Peter Baye

Potential past monitoring opportunities:

Hypothesis testing for tidal restoration designs integrated into monitoring

Pre-vegetation" – nontidal marsh management pre-breach treatment

PETALUMA MARSH EXPANSION PROJECT, NOVATO

Marin Audubon Society

PWA

Peter Baye

Pilot projects: estuarine (low-energy) beach replenishment for bayland habitat enhancement

Potential future monitoring opportunities:

Hypothesis testing for tidal restoration designs integrated into monitoring

Coarse sediment transport cross-shore and alongshore

Pier 94 North salt marsh, San Francisco (2015)
Sand & gravel sediment placed 2005

Aramburu Island, Richardson Bay (Marin County) sediment placed 2011-2012

Marin County Parks Aramburu Island Erosion control by beach nourishment: Monitoring outcomes versus processes

2010

2012

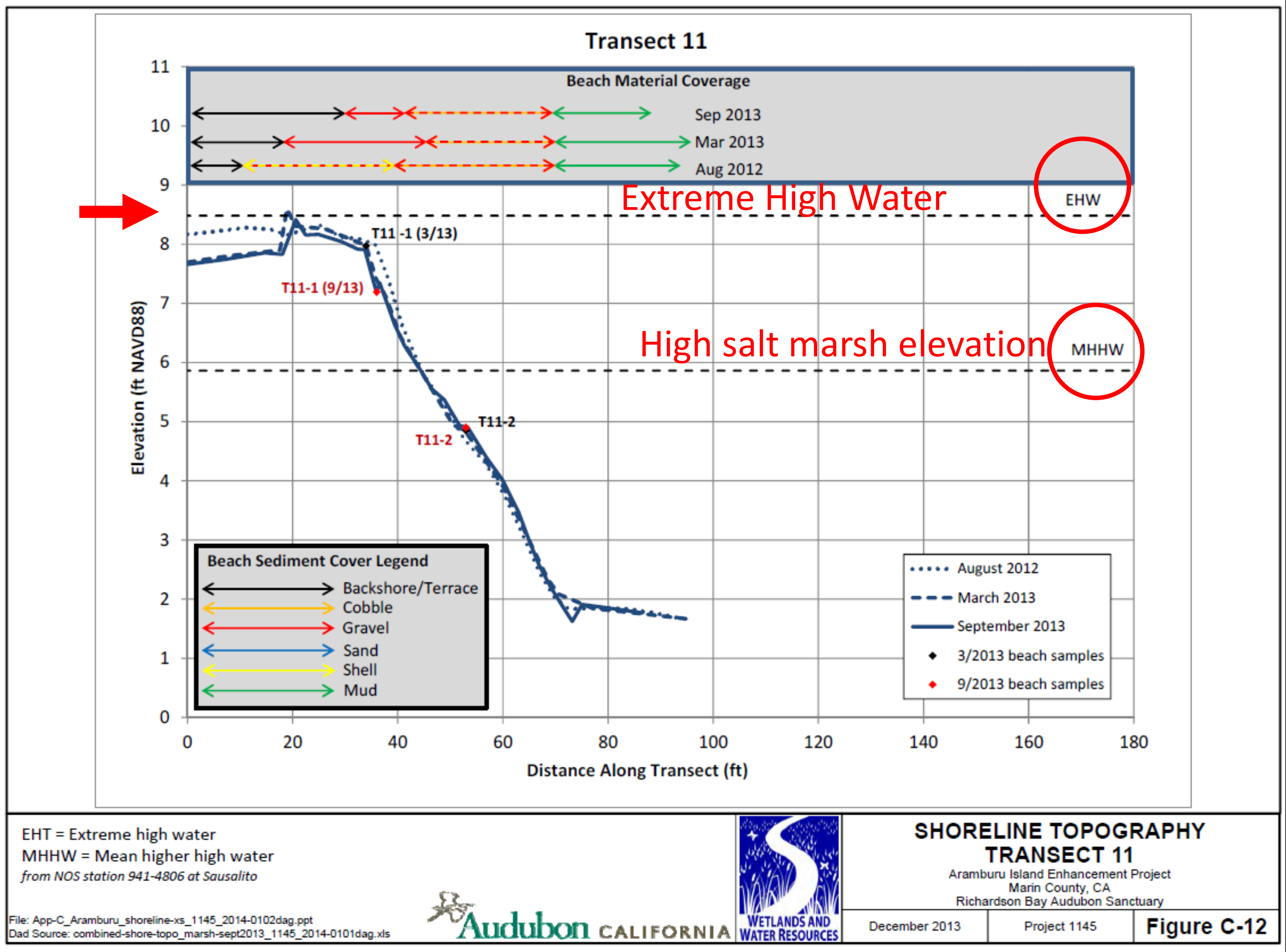
Richardson Bay Audubon Sanctuary
Wetlands and Water Resources

Goals: *wave erosion control* of shoreline and shorebird, tern habitat enhancement

Mixed coarse beach design for variable wave energy (sand, shell hash, gravel, cobble)

Large woody debris "micro-groins" to inhibit strong longshore drift

Limited annual beach elevation transect monitoring
Seasonal change? Seasonal cross-shore transport process?



Wetland restoration
Goals, objectives and adaptive monitoring

Plant ecology and monitoring: measuring *dynamic processes*

- **Colonization rate** (recruitment to age-class)
- **Patch size or size-class, distribution**
- **Colony spread rates** (lateral spread)
- **Reproductive variables** (flowering, seed set, seed output)
- Frequency and density classes
- Logarithmic abundance classes

- Adjusting vegetation measurements to overcome plant life-form bias
  - (cover estimation methods and scale)
- Measurement of **relevant plant structure**
  - height, density, seasonal distribution, reproductive traits

Wetland restoration ecological function monitoring
Soil and sediment properties

- **Traditional emphasis on suspended mineral tidal sediment deposition**
- **Soil organic matter (SOM) and litter production rate**
- **C drives soil microbial processes**
- **Brackish marsh – higher rates**
- **Bulk density and soil shear strength** (erosion resistance)

Wetland restoration *programmatic* goals, objectives and adaptive monitoring

- Permit compliance goals (traditional)
  - public interest resource protection; confirmation of impact mitigation adequacy
  - Triggers for remedial actions or alternative compensation
- Working hypothesis testing for adaptive management decisions
- Scientific hypothesis testing (experimental restoration)
- Significant unexpected outcome detection
  - Triggers for adapting monitoring scope or methodology

Wetland restoration project monitoring **temporal scale:**
Monitoring period duration and wetland ecological succession

- Approach: Spread 5-10 year monitoring effort over longer time period

- Why? Conventional (administrative) 5-10 year monitoring **inconclusive** even for vegetation: early pioneer vegetation succession, founder populations

- Climate cycles and wetland resilience: wetland establishment through drought and wet climate cycle
  - Capture at least 1-2 ENSO events during succession
  - Climate events may shift marsh state (vegetation trajectory)

Perspectives

- Unexpected outcomes may be more informative for adaptive management than predicted ones.
- Marsh succession and geomorphic evolution are not necessarily linear or progressive processes, so monitoring plans should not assume linear trends.
- Climate change and estuarine paleoecology suggest step changes in marsh restoration outcomes
- Marsh-forming events and their sequence, not just time passage, shape wetland succession. Monitoring plans should anticipate them
- Wetland teleological science?: monitoring *processes* and *patterns of wetland complex evolution* rather than achievement of wetland/wildlife "goals" in large-scale non-mitigation wetland restoration projects
-