Downscaling climate change models to local site conditions: effects of sea-level rise and extreme events to coastal habitats and their wildlife

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Acknowledgments

USGS Climate Change Program
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North Pacific LCC
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U.S. Fish & Wildlife Service – Recovery Branch
U.S. Fish & Wildlife Service – Refuges: SFBNWR, SDNWR
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Webpage: www.werc.usgs.gov/SFBaySLR

About the Project

Executive Summary

Draft Final Report

Results by Site

Literature

Products and Contacts

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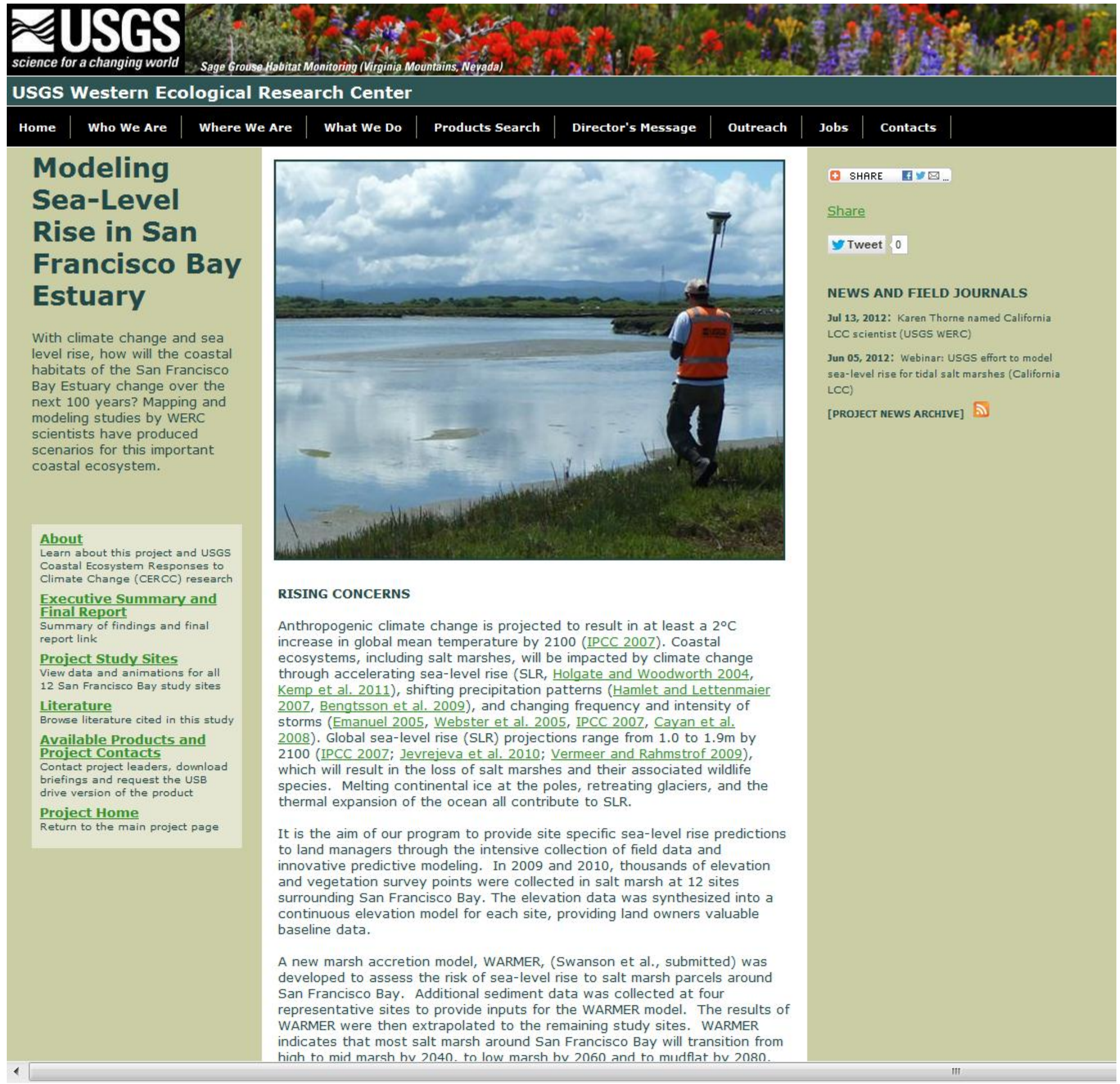

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Sage Grouse Habitat Monitoring (Virginia Mountains, Nevada)

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Modeling Sea-Level Rise in San Francisco Bay Estuary

With climate change and sea level rise, how will the coastal habitats of the San Francisco Bay Estuary change over the next 100 years? Mapping and modeling studies by WERC scientists have produced scenarios for this important coastal ecosystem.

About
Learn about this project and USGS Coastal Ecosystem Responses to Climate Change (CERCC) research

Executive Summary and Final Report
Summary of findings and final report link

Project Study Sites
View data and animations for all 12 San Francisco Bay study sites

Literature
Browse literature cited in this study

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Contact project leaders, download briefings and request the USB drive version of the product

Project Home
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RISING CONCERNS

Anthropogenic climate change is projected to result in at least a 2°C increase in global mean temperature by 2100 (IPCC 2007). Coastal ecosystems, including salt marshes, will be impacted by climate change through accelerating sea-level rise (SLR, Holgate and Woodworth 2004, Kemp et al. 2011), shifting precipitation patterns (Hamlet and Lettenmaier 2007, Bengtsson et al. 2009), and changing frequency and intensity of storms (Emanuel 2005, Webster et al. 2005, IPCC 2007, Cayan et al. 2008). Global sea-level rise (SLR) projections range from 1.0 to 1.9m by 2100 (IPCC 2007; Jevrejeva et al. 2010; Vermeer and Rahmstorf 2009), which will result in the loss of salt marshes and their associated wildlife species. Melting continental ice at the poles, retreating glaciers, and the thermal expansion of the ocean all contribute to SLR.

It is the aim of our program to provide site specific sea-level rise predictions to land managers through the intensive collection of field data and innovative predictive modeling. In 2009 and 2010, thousands of elevation and vegetation survey points were collected in salt marsh at 12 sites surrounding San Francisco Bay. The elevation data was synthesized into a continuous elevation model for each site, providing land owners valuable baseline data.

A new marsh accretion model, WARMER, (Swanson et al., submitted) was developed to assess the risk of sea-level rise to salt marsh parcels around San Francisco Bay. Additional sediment data was collected at four representative sites to provide inputs for the WARMER model. The results of WARMER were then extrapolated to the remaining study sites. WARMER indicates that most salt marsh around San Francisco Bay will transition from high to mid marsh by 2040, to low marsh by 2060 and to mudflat by 2080.

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NEWS AND FIELD JOURNALS

Jul 13, 2012: Karen Thorne named California LCC scientist (USGS WERC)

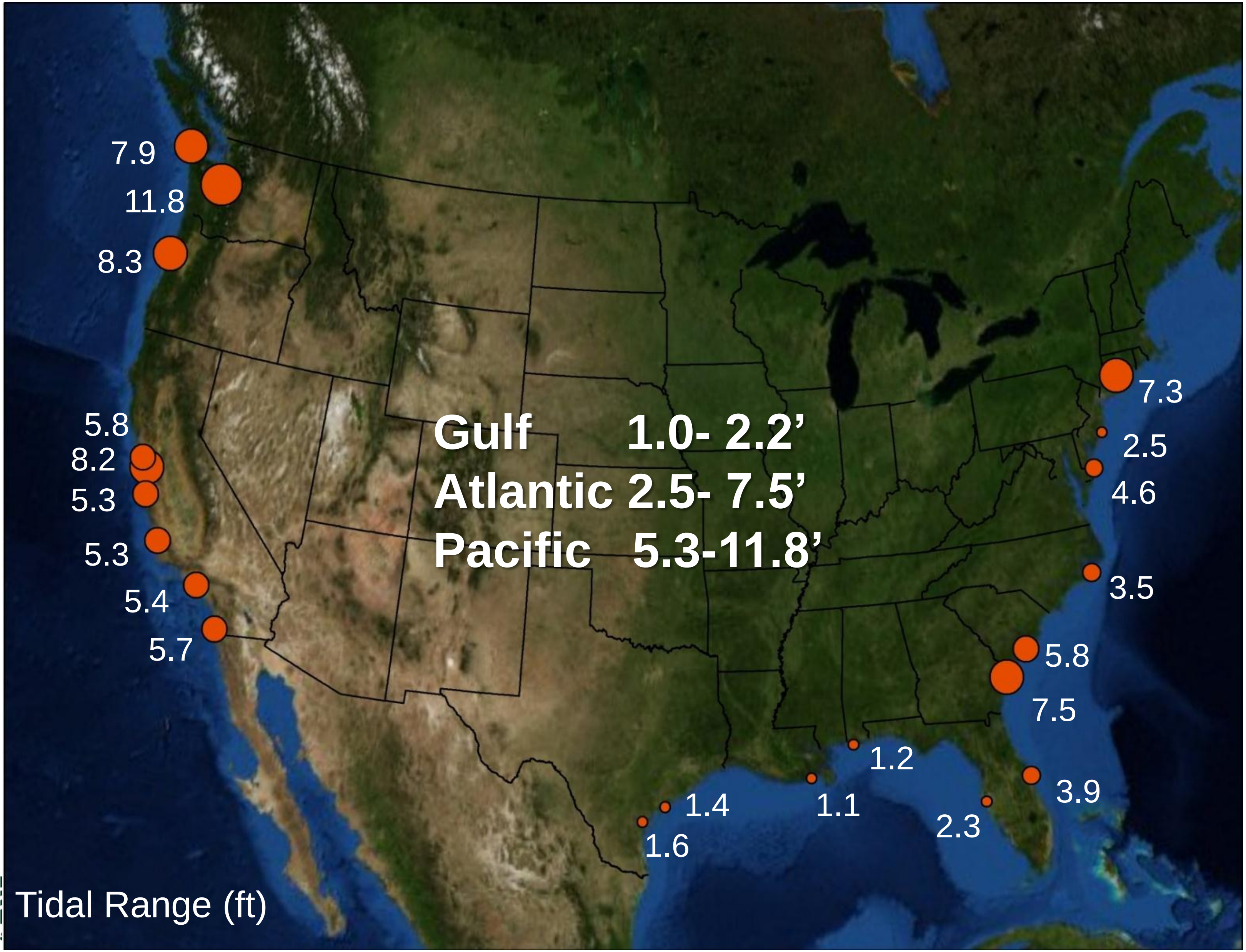
Jun 05, 2012: Webinar: USGS effort to model sea-level rise for tidal salt marshes (California LCC)

[PROJECT NEWS ARCHIVE]

Outline

- **SLR in SFB Tidal Marshes**
- Challenges at a Local Scale
- Consequences for Endemic Vertebrates
- Adaptive Management and Future Research

Continental Variation in Tidal Range



Threshold SLR Rates until Tidal Marsh “Drowns” or Becomes Subtidal

<u>Key Predictive Variables:</u>

1. Low Tidal Range (TR)
2. Low Suspended Sediment Concentration (SSC)

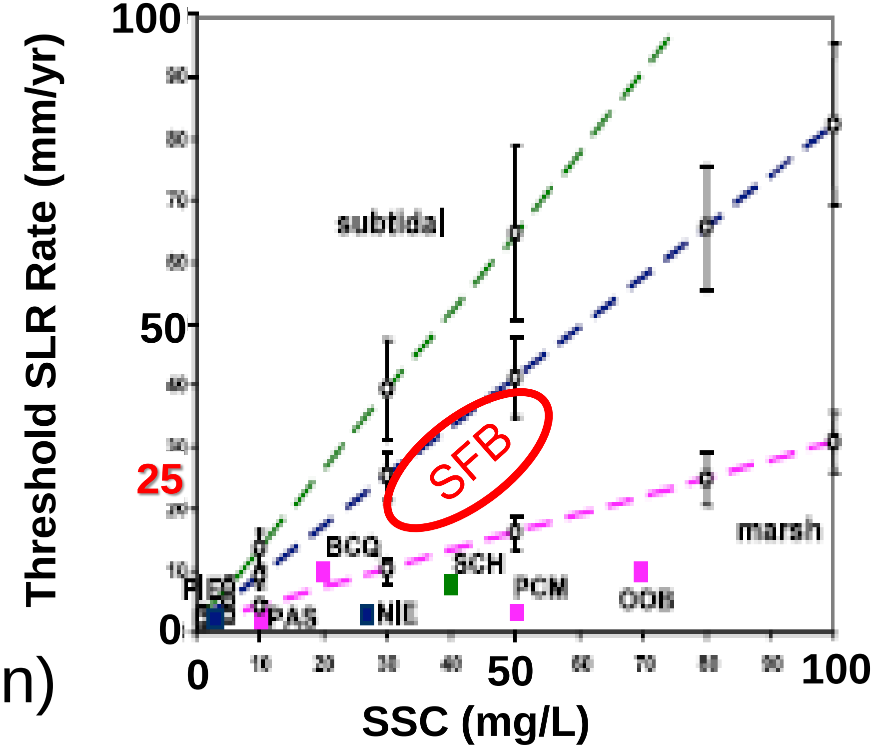
<u>Modeling Details:</u>

Mean of 5 models

TR: 1m (pink), 3m (blue), 5m (green)

SSC: (0-100 mg/L) for 8 estuaries

Atlantic cordgrass (*Spartina alterniflora*)



PIE – Plum Island, MA
PAS – Pamlico Sound, NC
BCQ – Bayou Chitique, LA
NIE – North Inlet, SC
SCH -- Schekle, Netherlands
PCM – Phillips Creek, VA
OOB – Old Oyster Bay, LA

(Kirwan etal. 2010, Geophys. Res. Letters)

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Pacific Coast States Variation in Tidal Range

Tidal Range 5.3-11.8 ft (1.6-3.6 m), South-to-North Gradient

Tidal Range (ft)

Salt marshes

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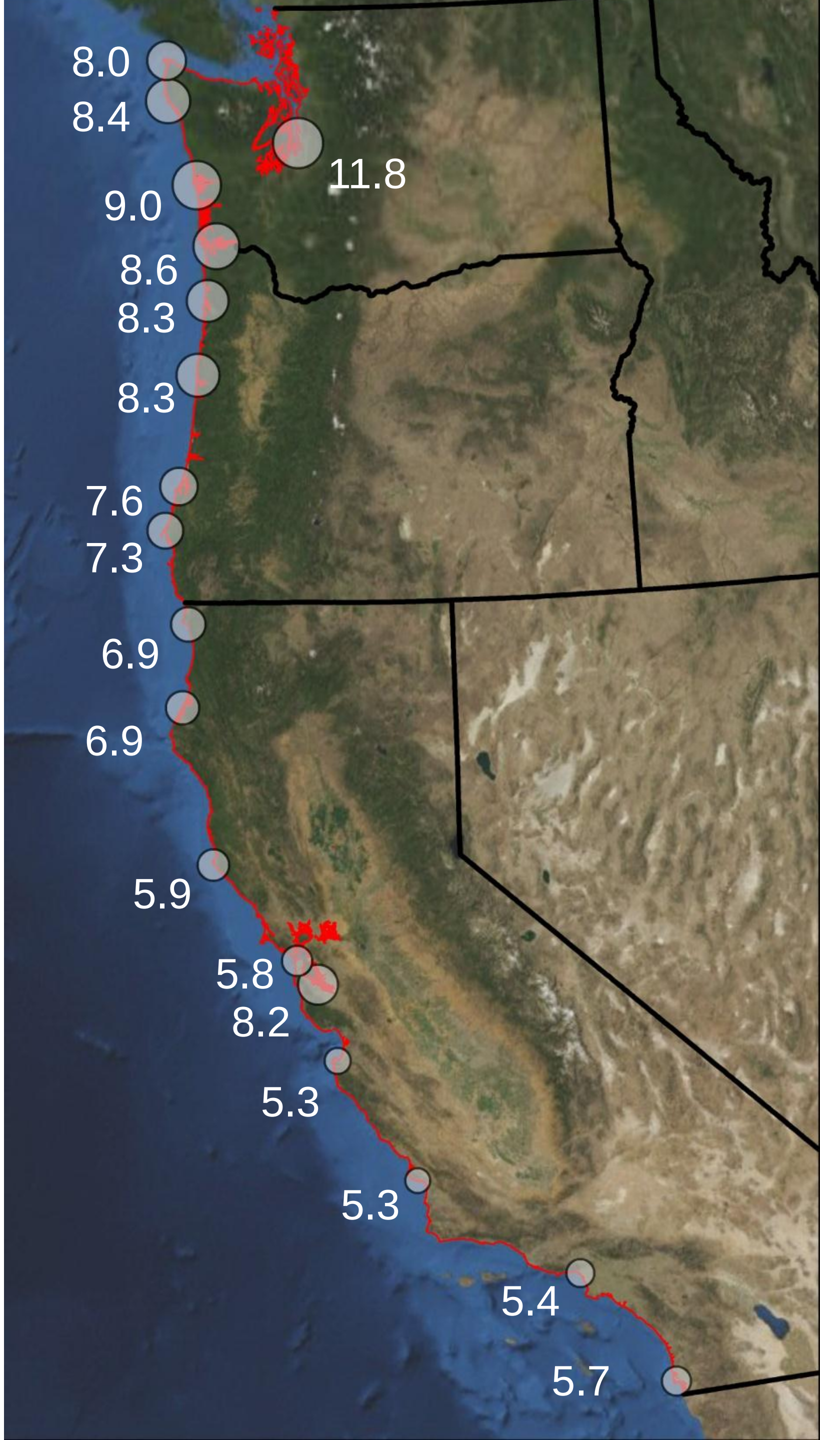
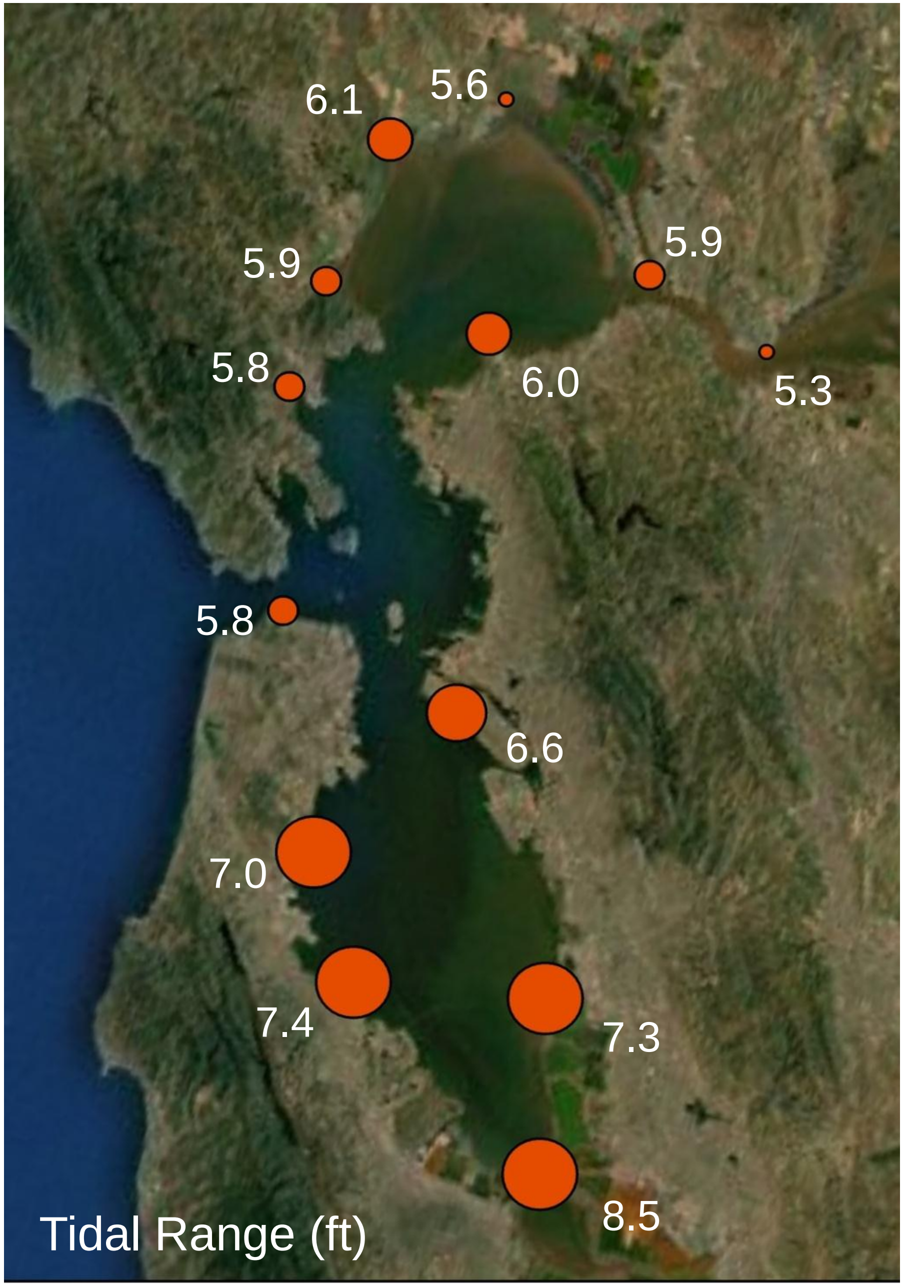


SFB Estuary Variation in Tidal Range

Tidal Range 5.3-8.5, Greater in South Bay

Suspended Sediment Concentration Range, (30-70 mg/L)



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San Franc

- Contains large po remaining tidal w Pacific coast.
- Home to >8M peo historic tidal wetl
- Remnant habitats 90% of California coastal wetlands.
- Tidal marsh spec impacts of many including fragme predation, invasiv and pollution.

(Takekawa SAB

U.S. Fish & Wildlife Service

Draft Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California

Salt Marsh Harvest Mouse
(Reithrodontomys raviventris)

$1.3B Recovery Plan

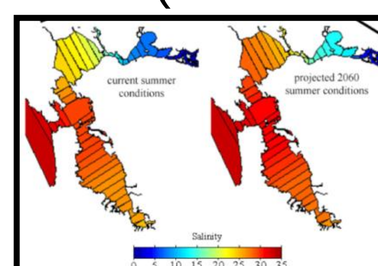
California Black Rail
(*Laterallus jamaicensis*)

California Clapper Rail
(Rallus longirostris obsoletus)

Climate change effects on Pacific coast estuaries

1. Western snowpack decreased 10-40% since 1950 and will continue to decline (Barnett et al. 2008).
2. Runoff will be earlier and shorter (Diffenbaugh et al. 2008).
3. Water temperatures and salinity will increase (Malamud-Roam 2002, Cayan et al. 2005).
4. SLR scenarios for 2100 range from 9-88 cm (IPCC 2007) without ice sheet melting to recent models of 57-110 cm (Jevrejeva et al. 2012) and 130-190 cm (Grinsted et al. 2009, Vermeer and Rahmsdorf 2010). For SFB, we apply a conservative value of 124 cm from the California Climate Adaptation Strategy Report (Cayan *et al.* 2009).
5. High & low tide events will be more extreme -- a 30 cm rise reduces storm events from 100 to 10 years.
6. 39-70% of intertidal habitats may become subtidal by 2100 (Galbraith et al., 2002).

salinity increase up-estuary (Cayan 2005)



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Objective: Investigate how sea-level rise might alter habitats and wildlife populations in salt marshes of San Francisco Bay

- **Goal 1: Develop a plant distribution and high resolution elevation model of the tidal salt marshes to be used to model sea-level rise scenarios.**

- **Goal 2: Determine and quantify the likely effect of sea-level rise on endemic vertebrate species and their salt marsh habitats at local and regional landscape levels.**

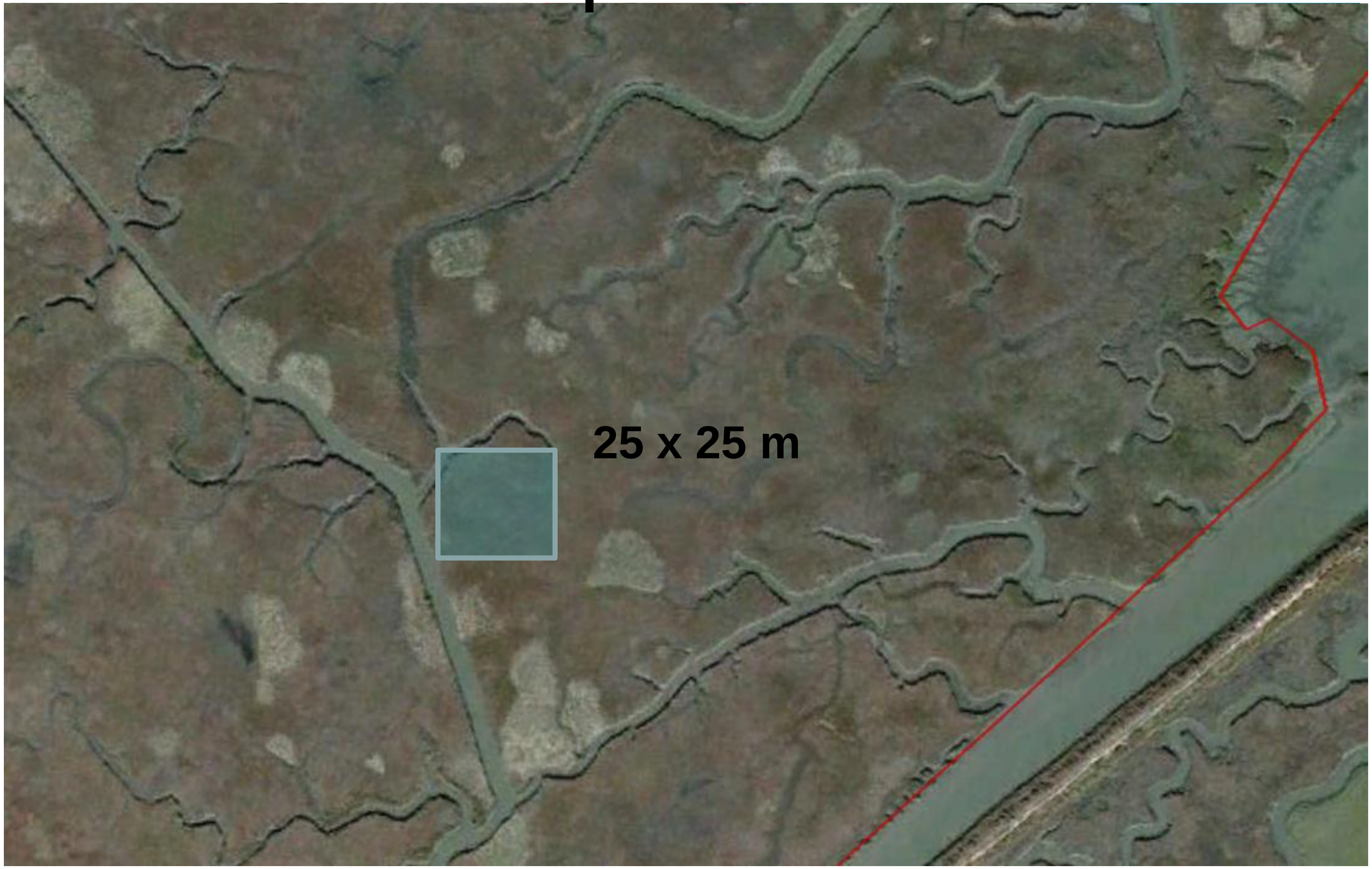
- **Goal 3: Evaluate whether remnant marshes are capable of accreting at rates that will guarantee sustainability through time or whether some will be "drowned" under predicted rates of sea-level rise.**

- **Goal 4: Downscale tidal cycles to assess inundation patterns in estuary marshes.**

Outline

- SLR in SFB Tidal Marshes
- **Challenges at a Local Scale**
- Consequences for Endemic Vertebrates
- Adaptive Management and Future Research

Top-down Climate Models vs. Bottom-up Parcel Models



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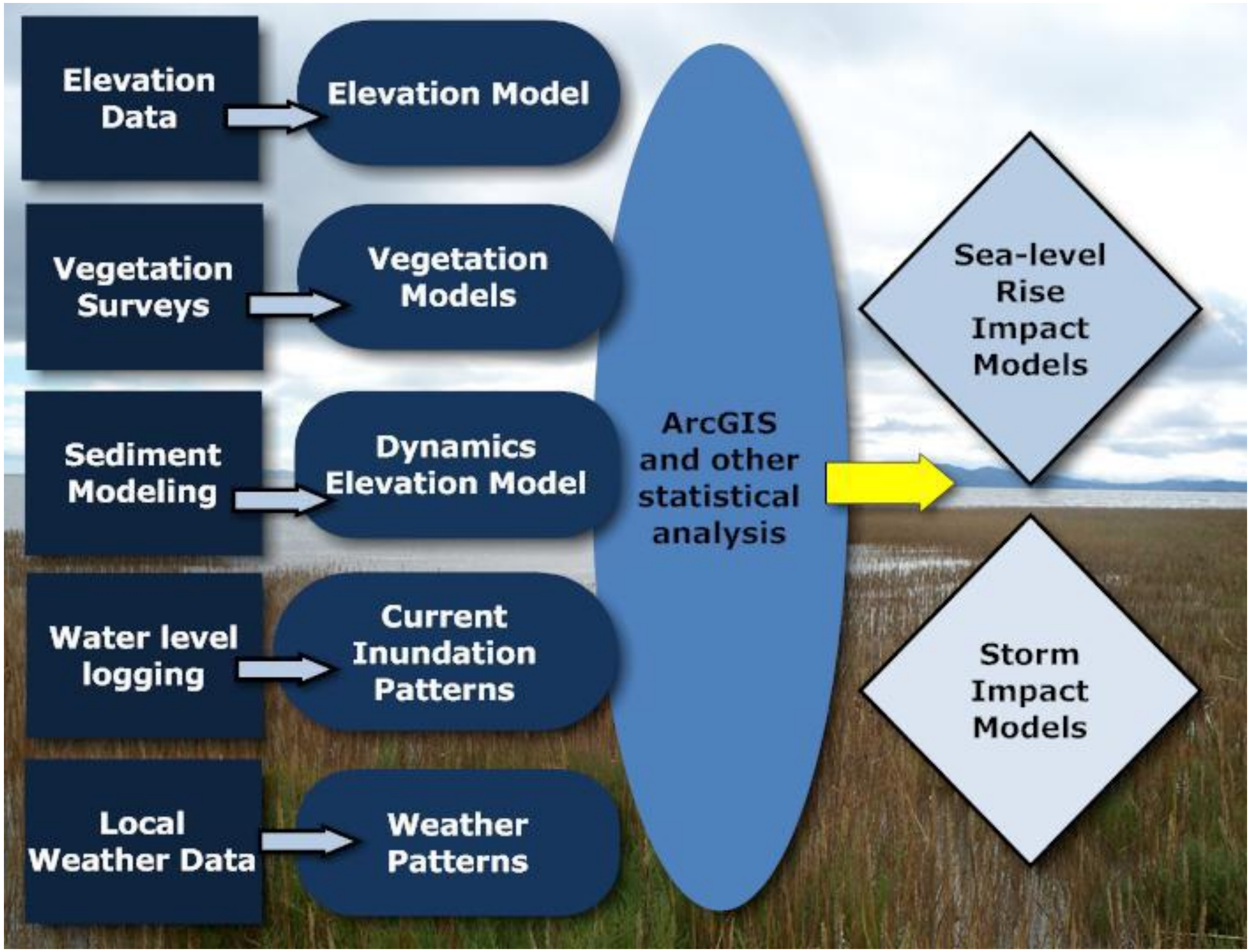
Tidal Marsh Parcel-based Management Model



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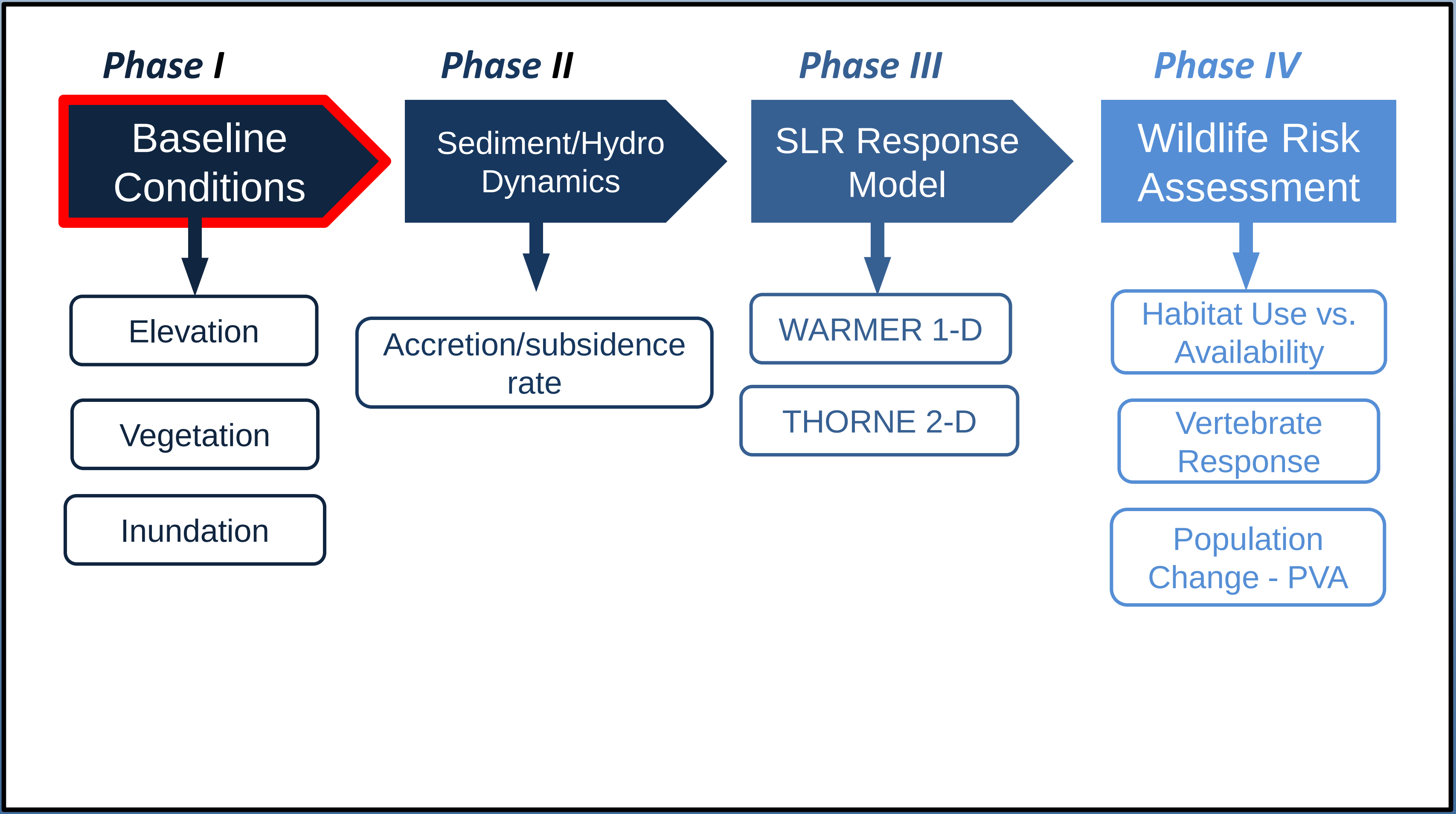
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Vertebrate Response
Population Change - PVA

Model Input

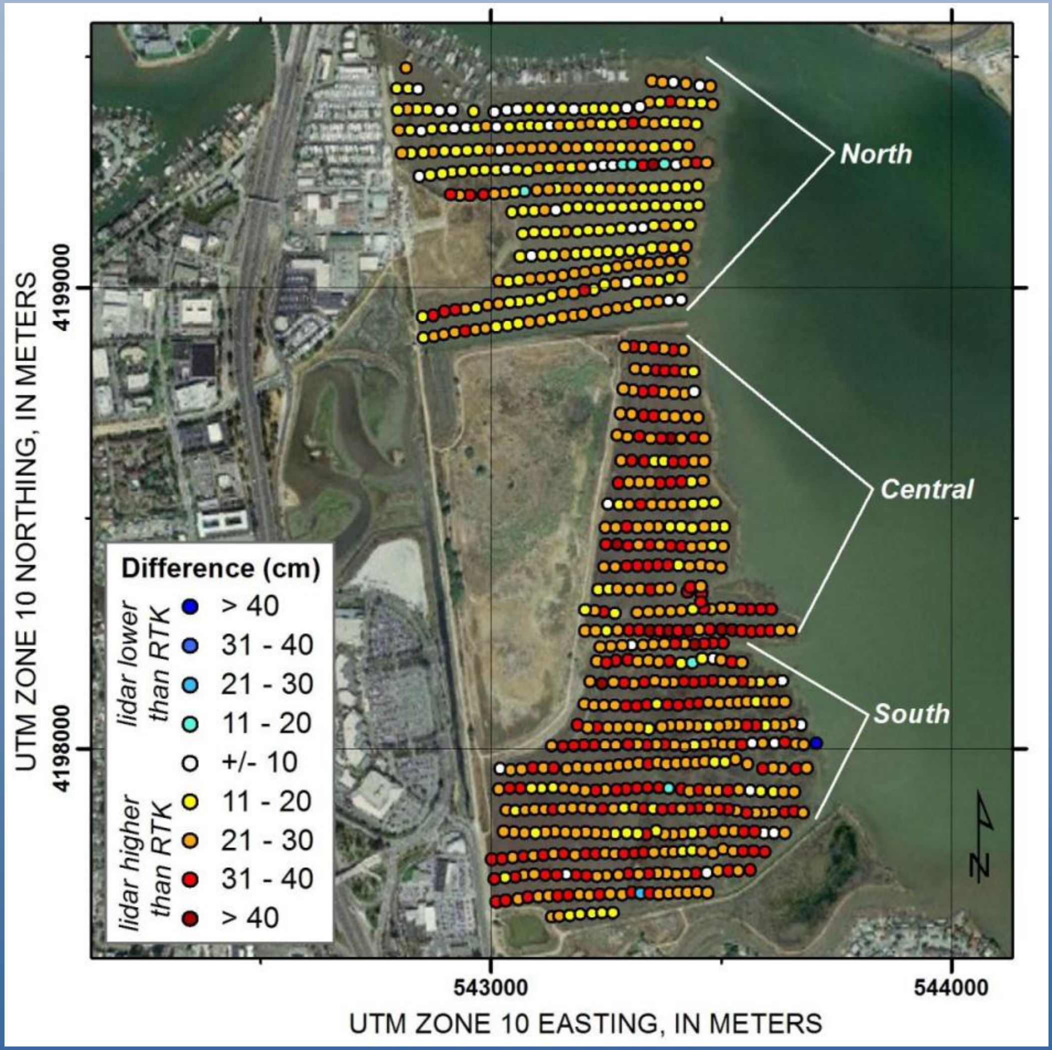
Data: Elevation data

- Leica Real Time Kinematics GPS Network (RTK GPS) determines x,y,z position. ~2 cm elevation accuracy

- Synthesized to develop elevation models using ArcGIS.

Modeling: RTK GPS vs. LiDAR elevation

- LiDAR
  - Works well in low vegetation cover or bare ground.
  - high spatial resolution (1x1 m)
  - Dense vegetation increases elevation error.



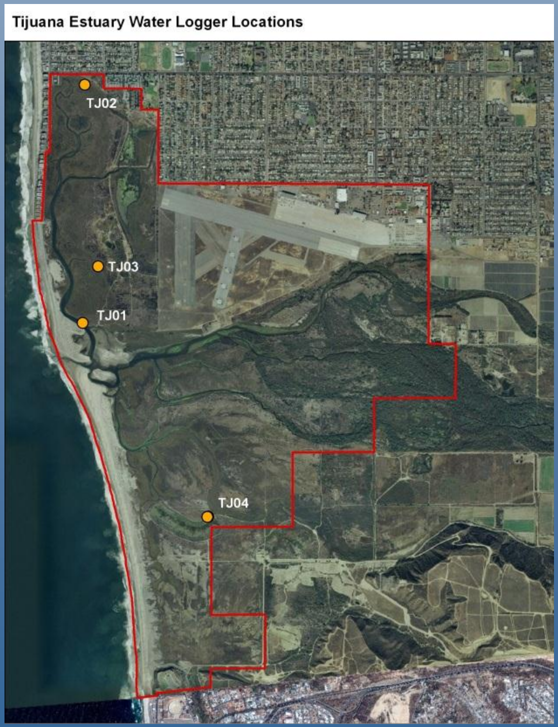
<u>Corte Madera Marsh: average elevation error = 23 cm</u>

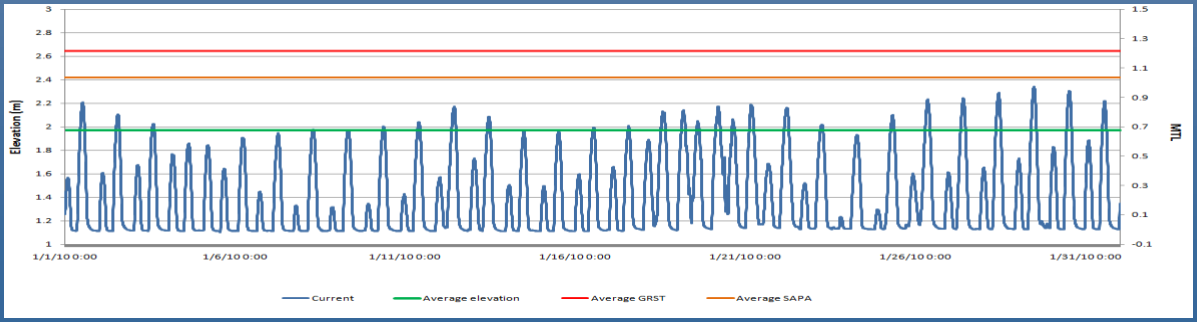
USGS Open-File Report OF 2011-1217. http://pubs.usgs.gov/of/2011/1217/

Model Input

Data: Water level monitoring

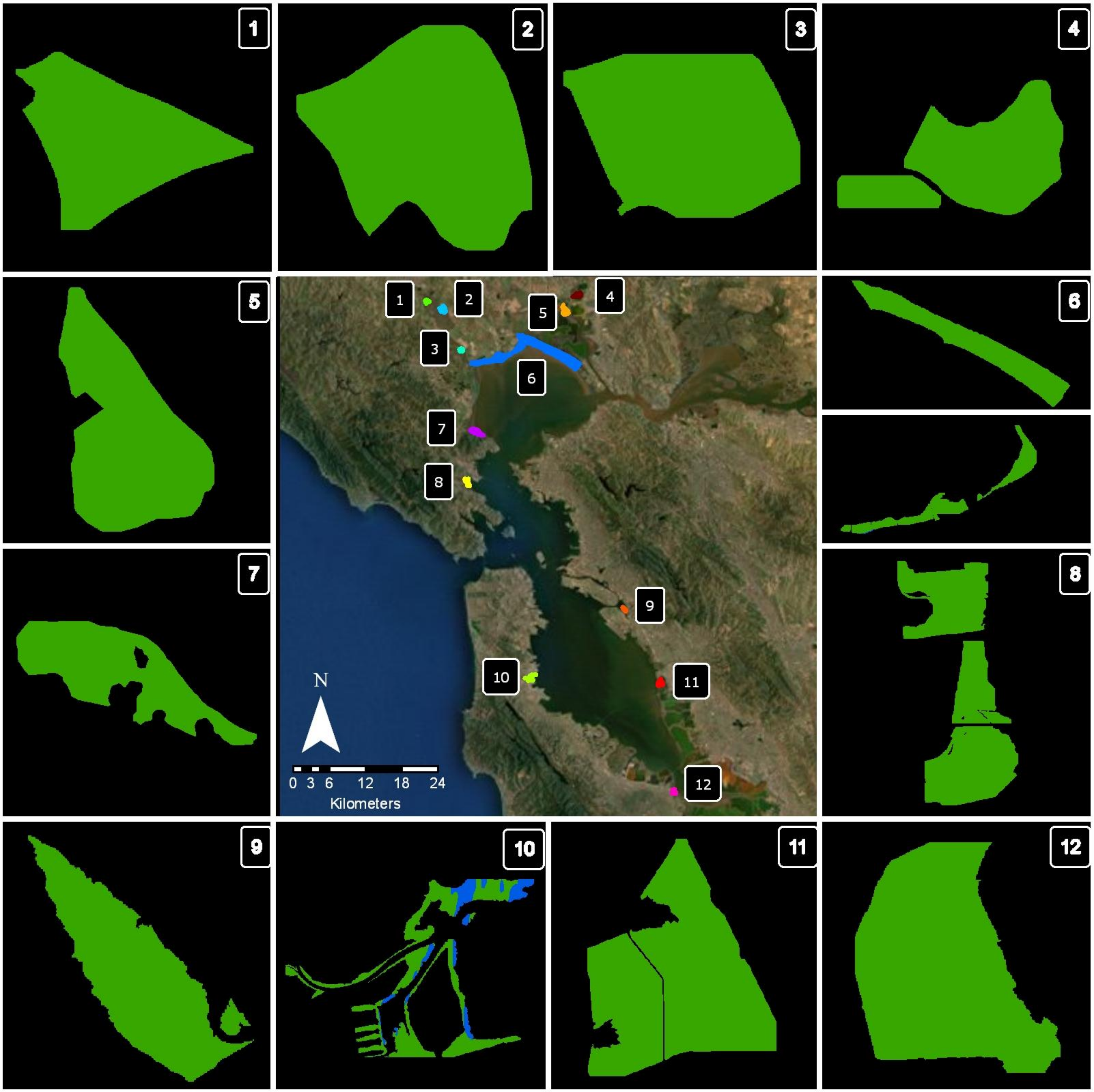
- Water level loggers are deployed in channels, 1-4 per site.
- Measures: depth, duration, conductivity, & temperature.
- Deployed up to 12 months.
- Used to develop local tidal datum relative to elevation.





Model Input
Data: Vegetation Survey

- 0.25 m^2 quadrats are surveyed along transects.
- Data collected include: species, elevation, percent cover, max and average heights.
- Related to tidal datum.



San Francisco Bay Area Salt Marshes

Inundation at Mean Tide Level

1	Gambonini	0%
2	Petaluma	0%
3	Black John	0%
4	Fagan	0%
5	Coon Island	0%
6	SPB NWR	<1%
7	China Camp	0%
8	Corte Madera	0%
9	Arrowhead	0%
10	Colma	19%
11	Cogswell	0%
12	Laumeister	0%

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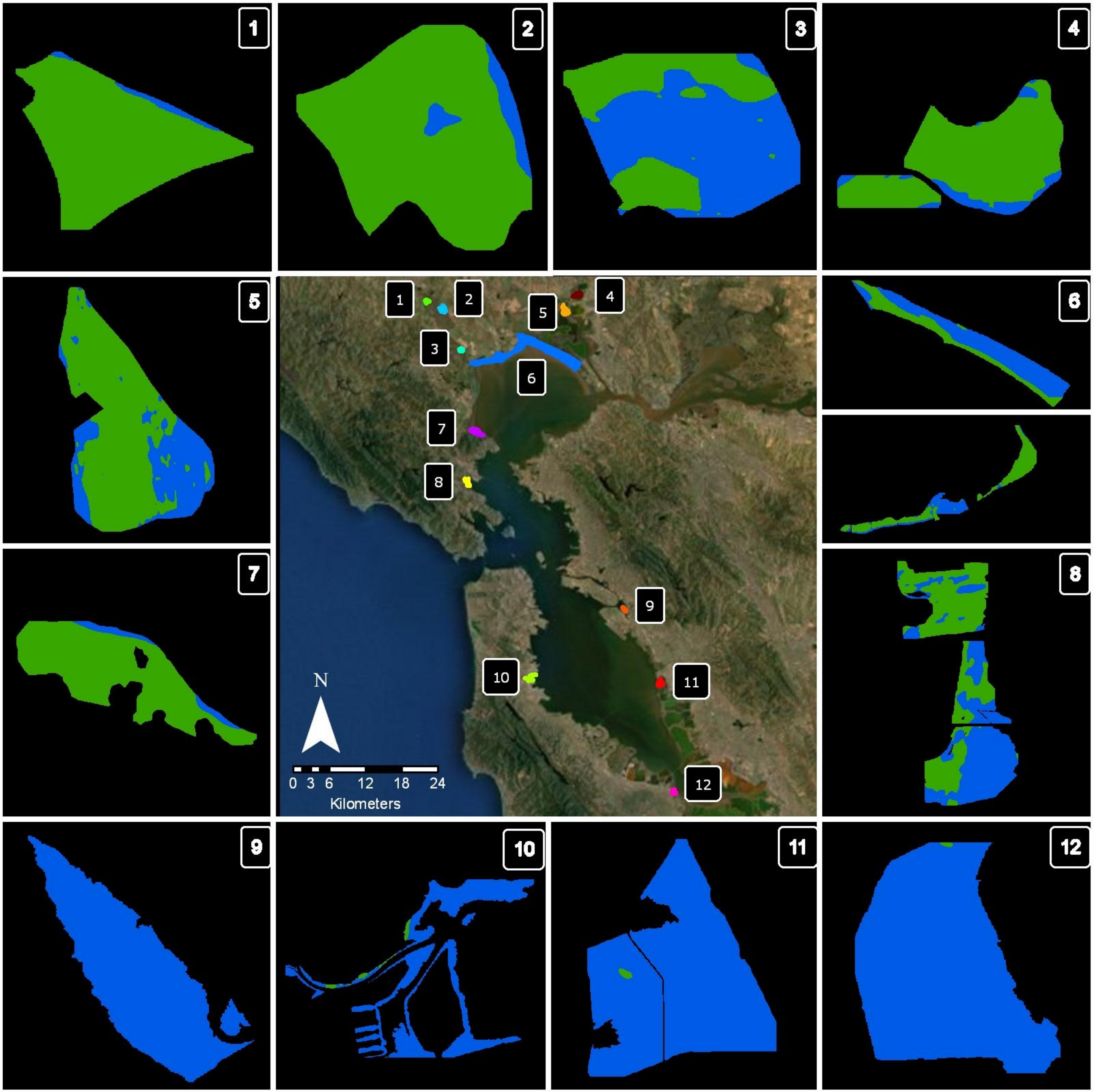
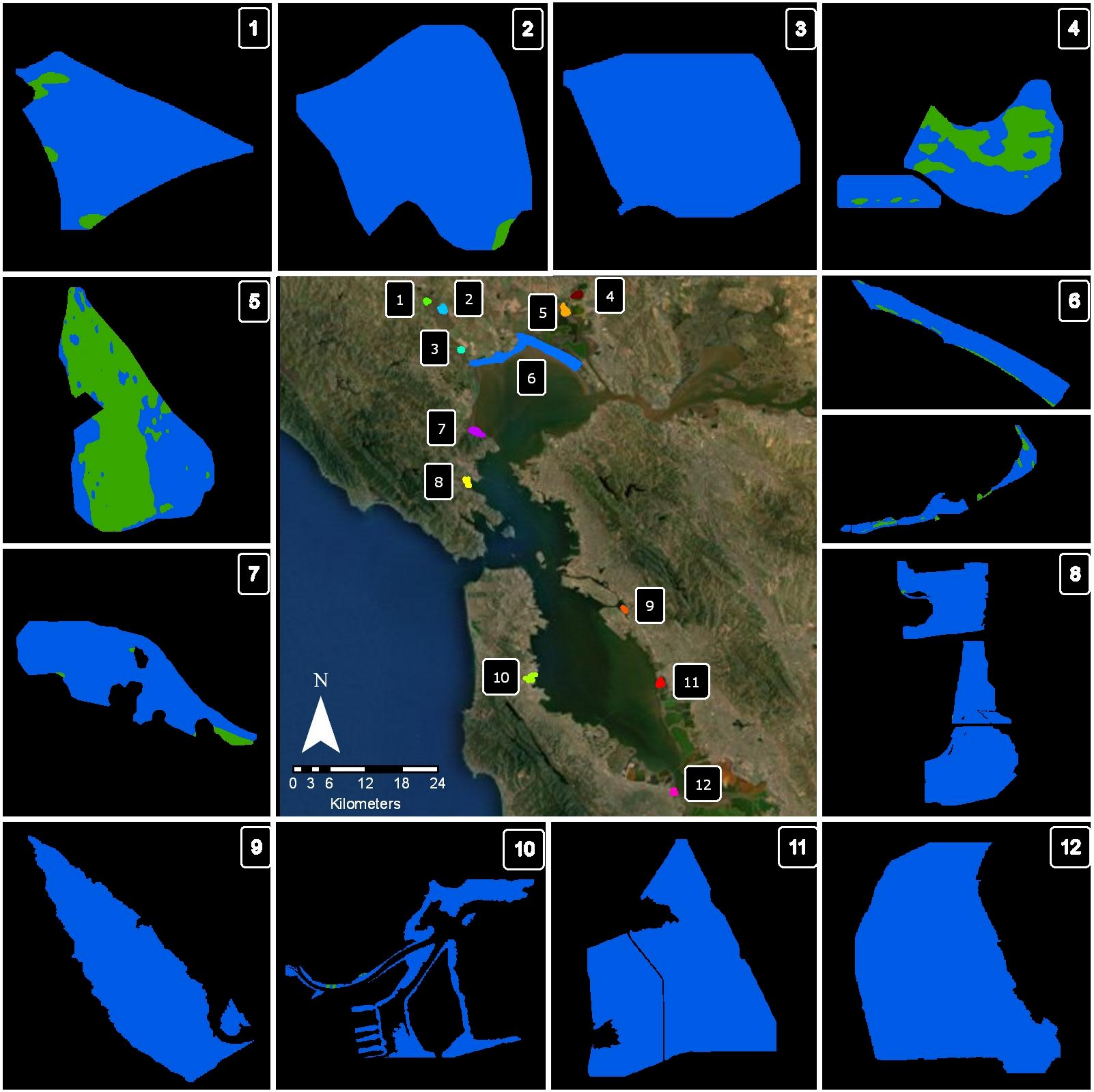


San Francisco Bay Area Salt Marshes

Inundation at Mean High Water

1	Gambonini	3%
2	Petaluma	6%
3	Black John	64%
4	Fagan	10%
5	Coon Island	28%
6	SPB NWR	56%
7	China Camp	6%
8	Corte Madera	48%
9	Arrowhead	100%
10	Colma	97.6%
11	Cogswell	99%
12	Laumeister	99.8%



San Francisco Bay Area Salt Marshes

Inundation at Mean Higher High Water

1	Gambonini	95.7%
2	Petaluma	99.1%
3	Black John	100%
4	Fagan	70%
5	Coon Island	38%
6	SPB NWR	93%
7	China Camp	97%
8	Corte Madera	99.8%
9	Arrowhead	100%
10	Colma	99.5%
11	Cogswell	100%
12	Laumeister	100%

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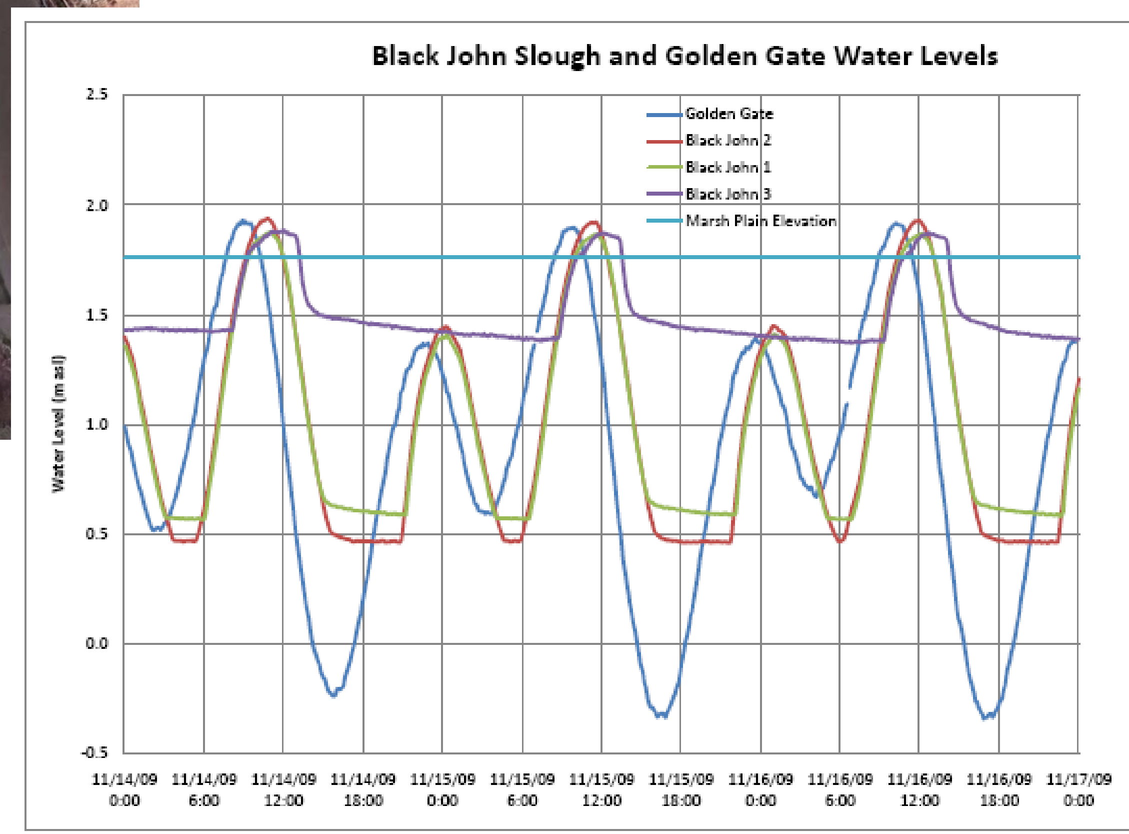
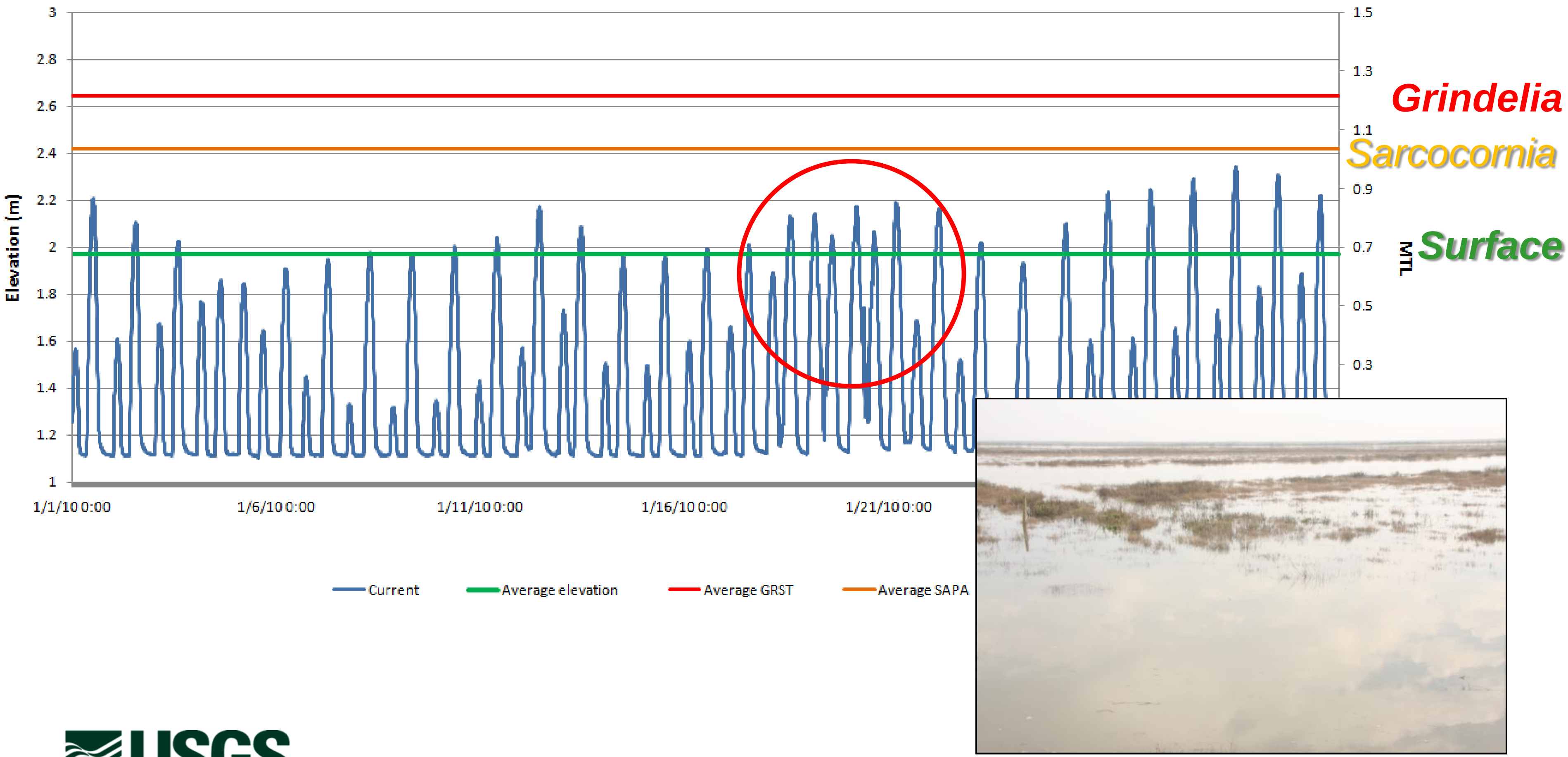
January King Tide at China Camp

Goal 4: Downscale tidal cycles to assess inundation patterns in estuary marshes.



Water level data



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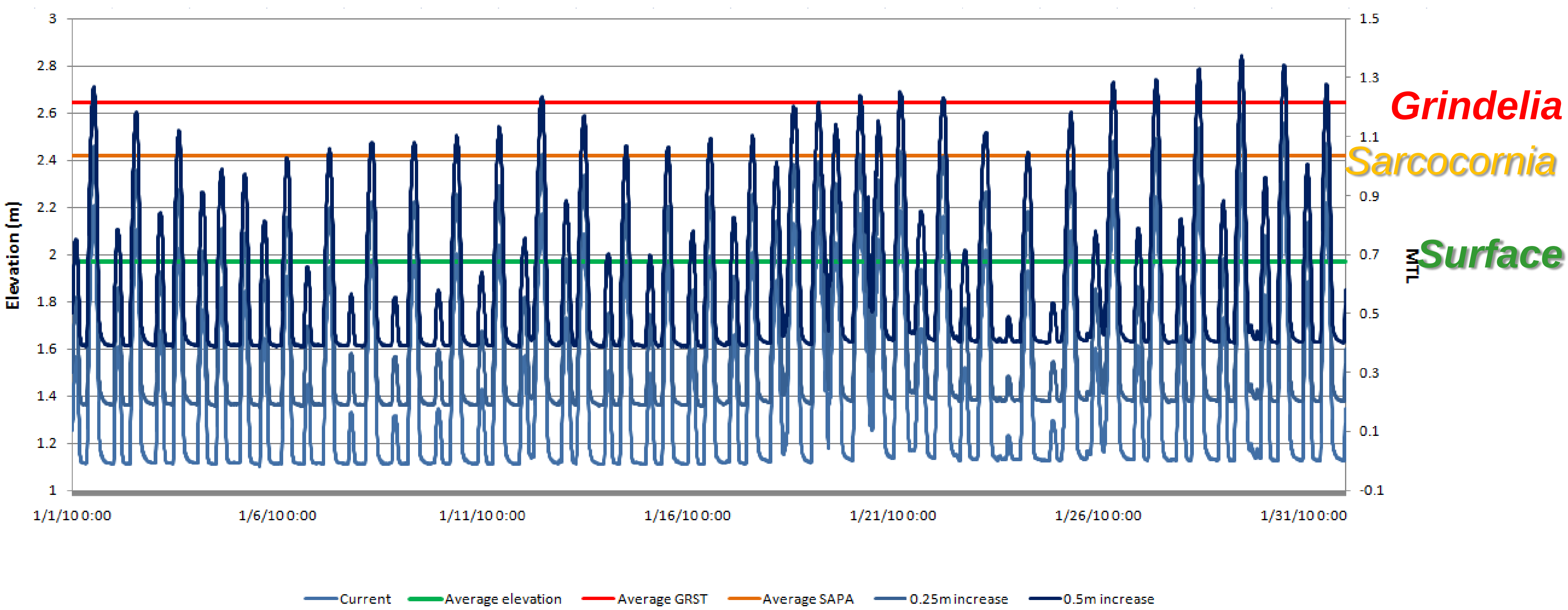
Water level data + 0.5 m SLR



"Potential Critical Threshold"

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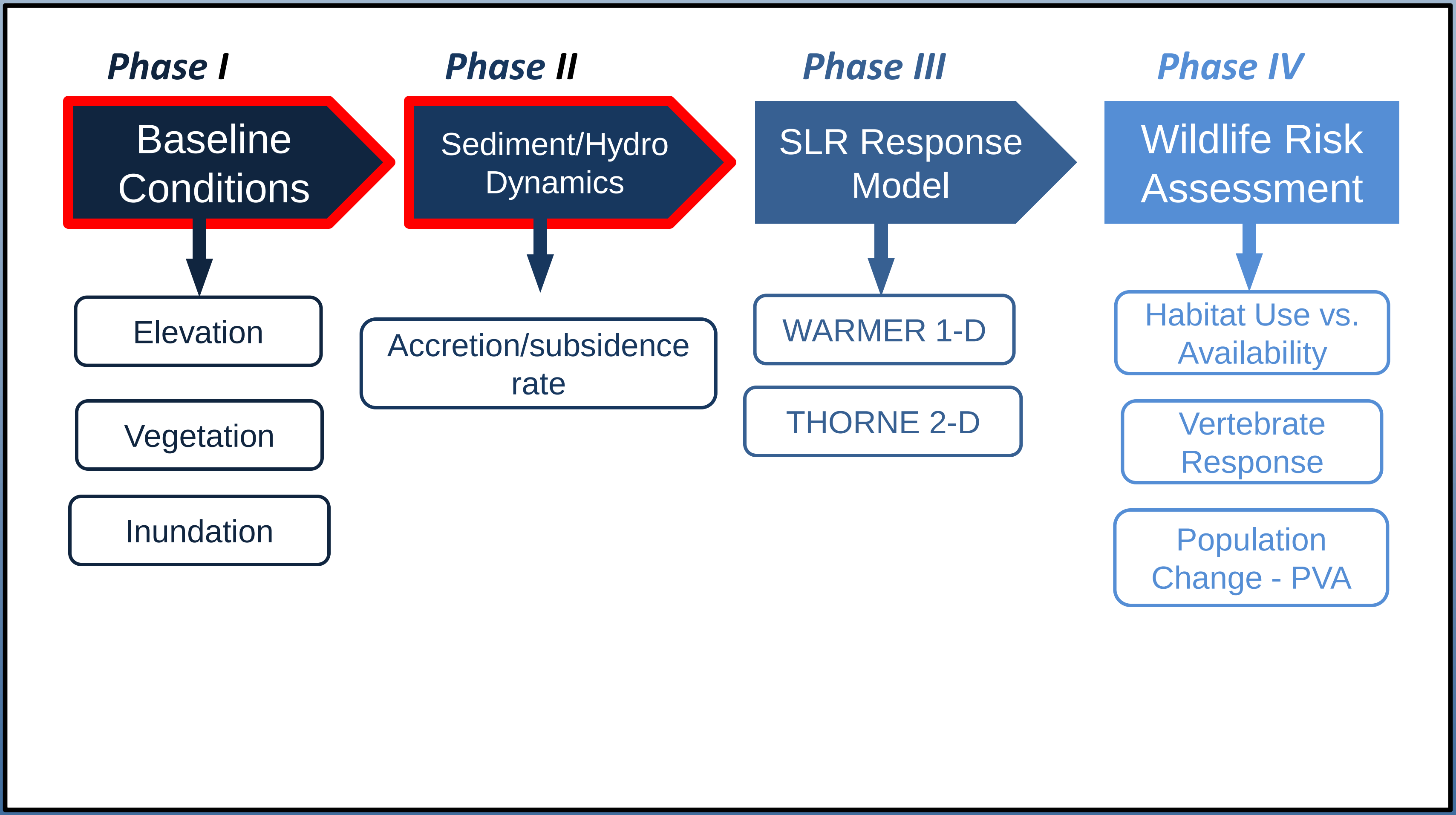
(NAVD88)


Phase I
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Elevation
Vegetation
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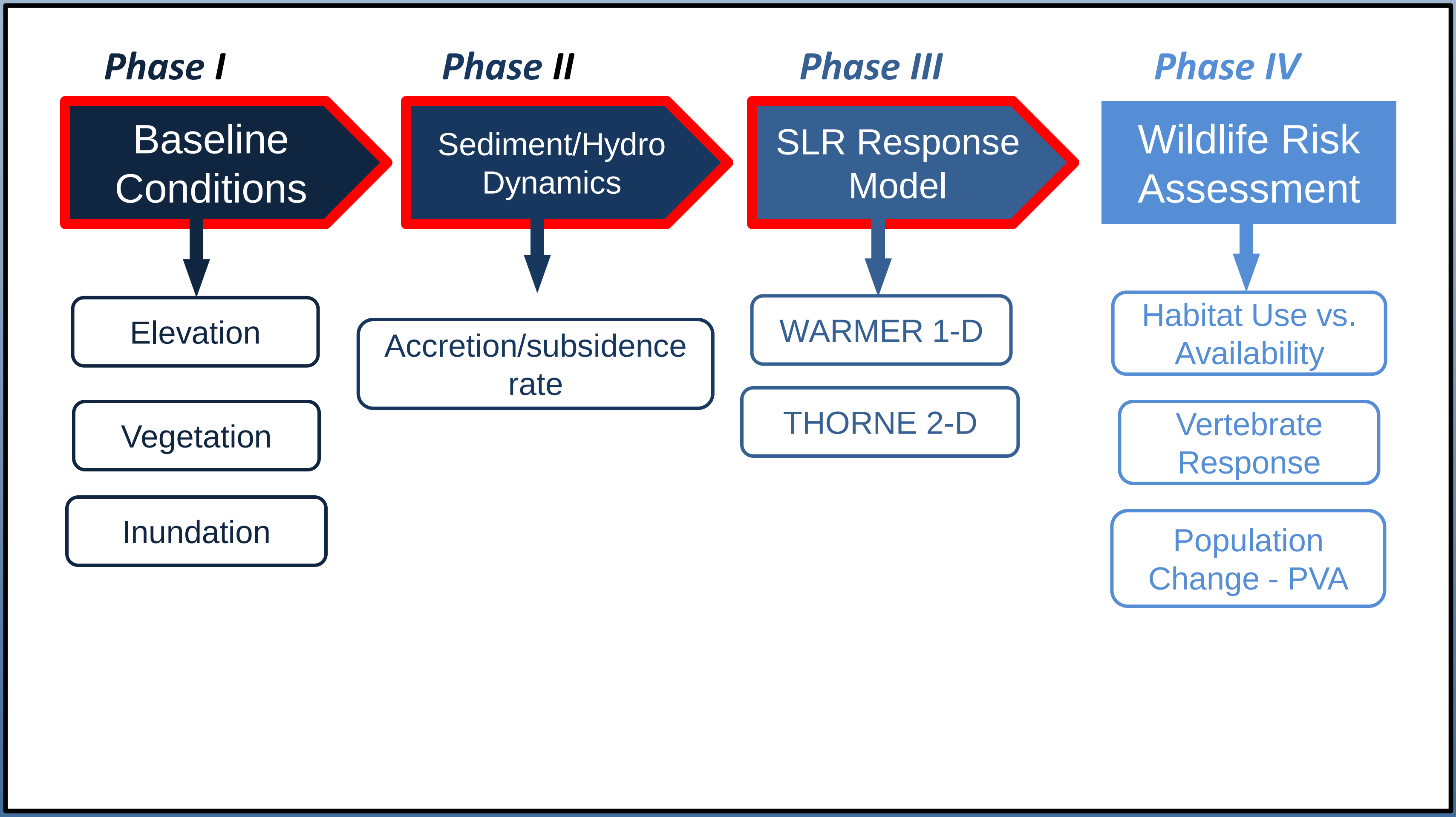
Phase III
SLR Response Model
WARMER 1-D
THORNE 2-D
Phase IV
Wildlife Risk Assessment
Habitat Use vs. Availability
Vertebrate Response
Population Change - PVA

Model Input

Data: Accretion rate

Method depends on available data:

- Sediment cores – 210Pb and 137Cs dating. Assess bulk density, % organic and inorganic matter.
- Surface Elevation Tables (SET) – deployed long-term leveling device to measure precise elevation change
- Spatially explicit elevation change* - direct measurements of surface elevation change with RTK GPS.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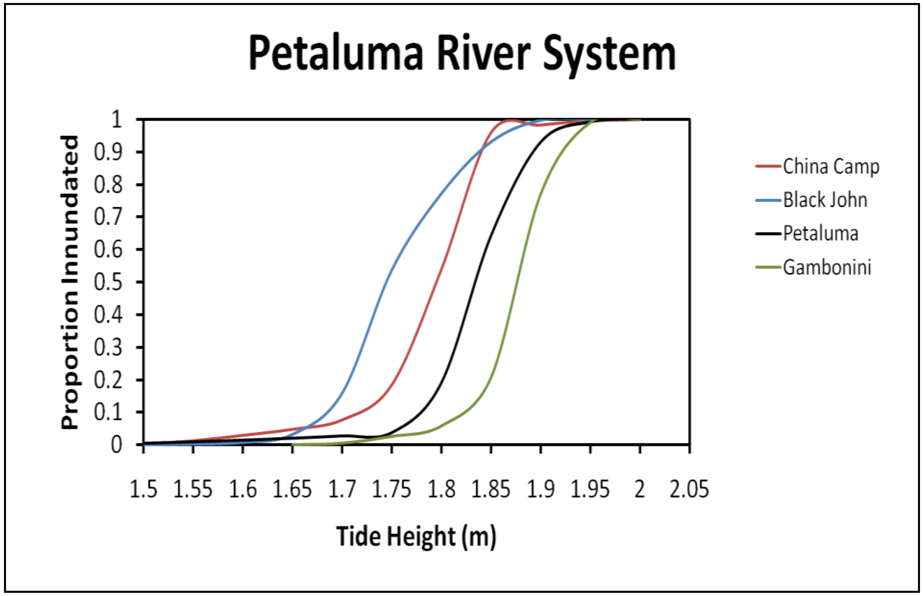
Integrated Application

- Can we anticipate the fate of a given wetland?
  - Will the wetland drown?
- What is the final inundation pattern?
  - Which species may be adversely affected and why?
  - Can we determine shifts in dominant vegetation type?



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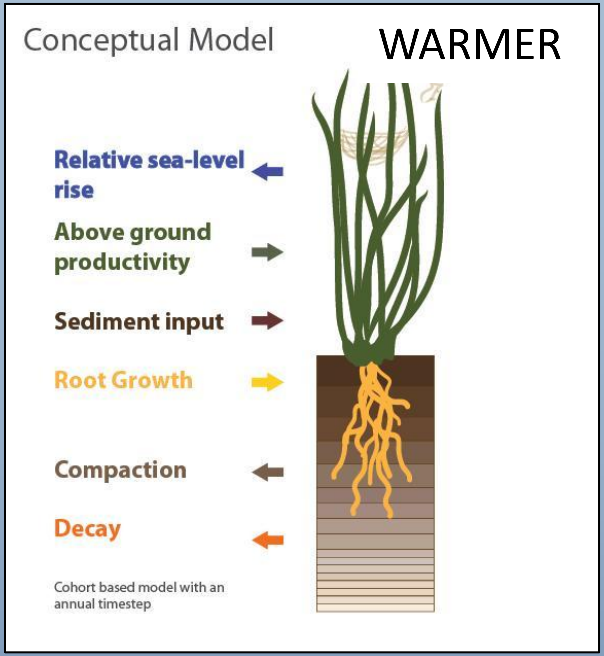
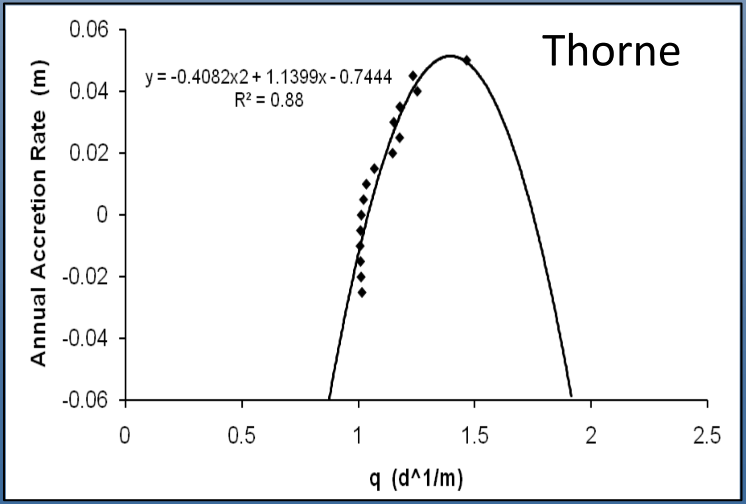
Sea-level rise modeling

- **<u>WARMER Model:</u>** <u>W</u>etland <u>A</u>ccretion <u>R</u>ate <u>M</u>odel for <u>E</u>cosystem <u>R</u>esilience 1-D model (*modified from Calloway et al. 1996*) – applied to 12 sites in San Francisco Bay with site or nearby core sediment data **(Swanson *et al.* in prep).**

- **<u>Thorne *et al.* Model:</u>** spatially explicit 2-D model relates observed accretion over time (for sites with repeat elevation surveys) with inundation and distance from sediment source **(Thorne *et al., in prep.*).**

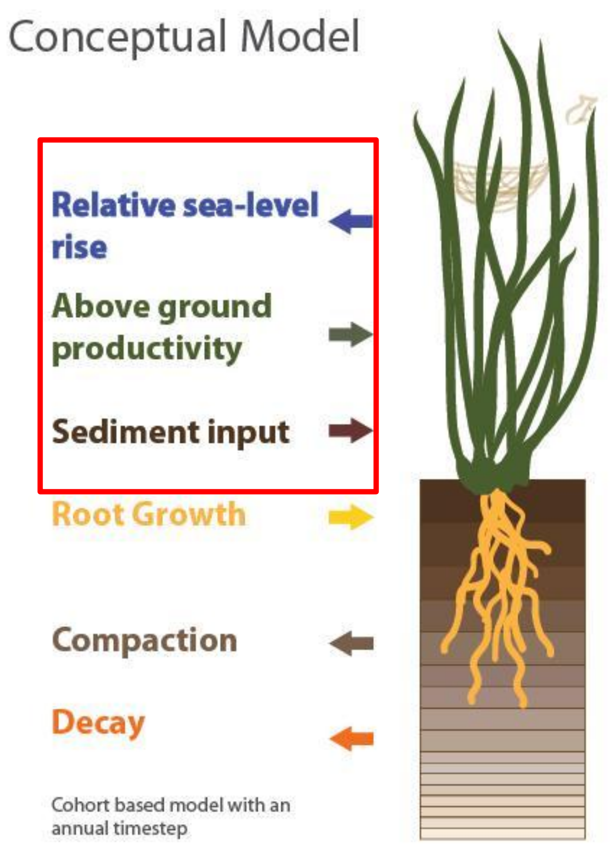


1-D model with biological and physical processes of accretion



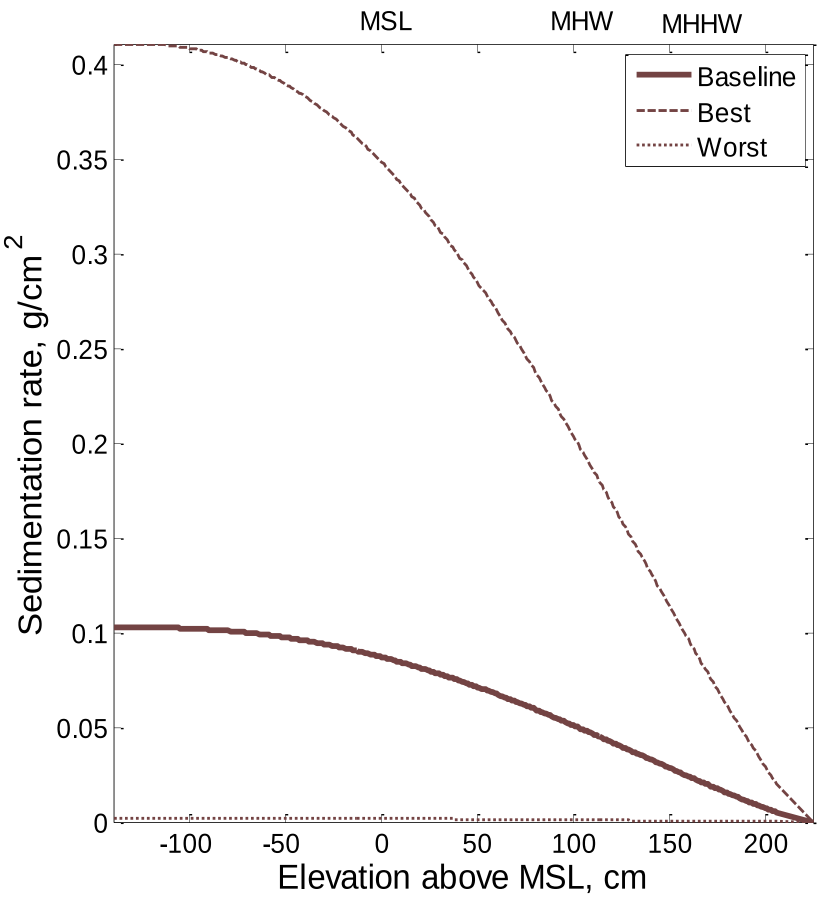
2-D spatially-explicit model for elevation change across a site

Wetland **A**ccretion **R**ate **M**odel of **E**cosystem **R**esilience *(Swanson etal., in review)*

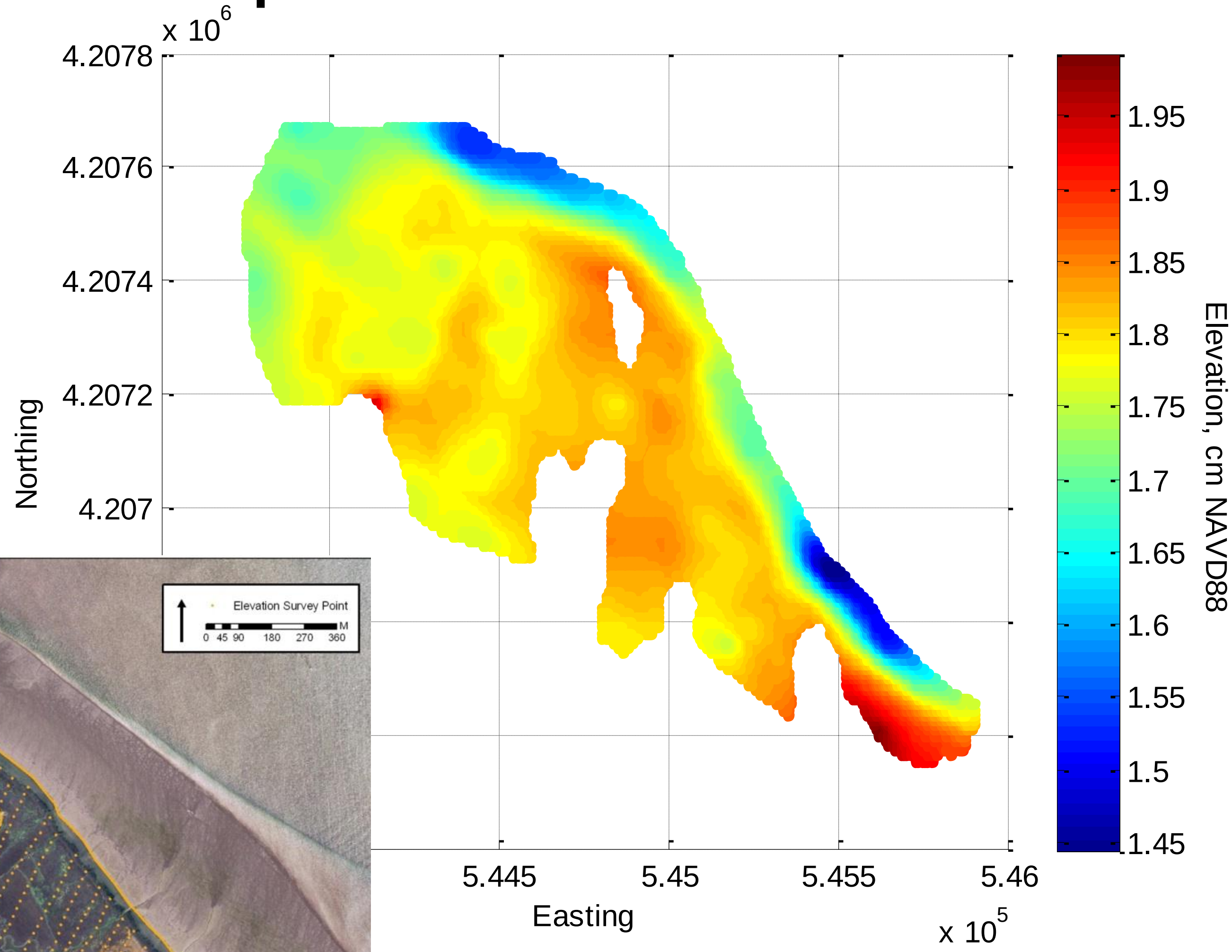


(modified from Callaway et al. 1996)

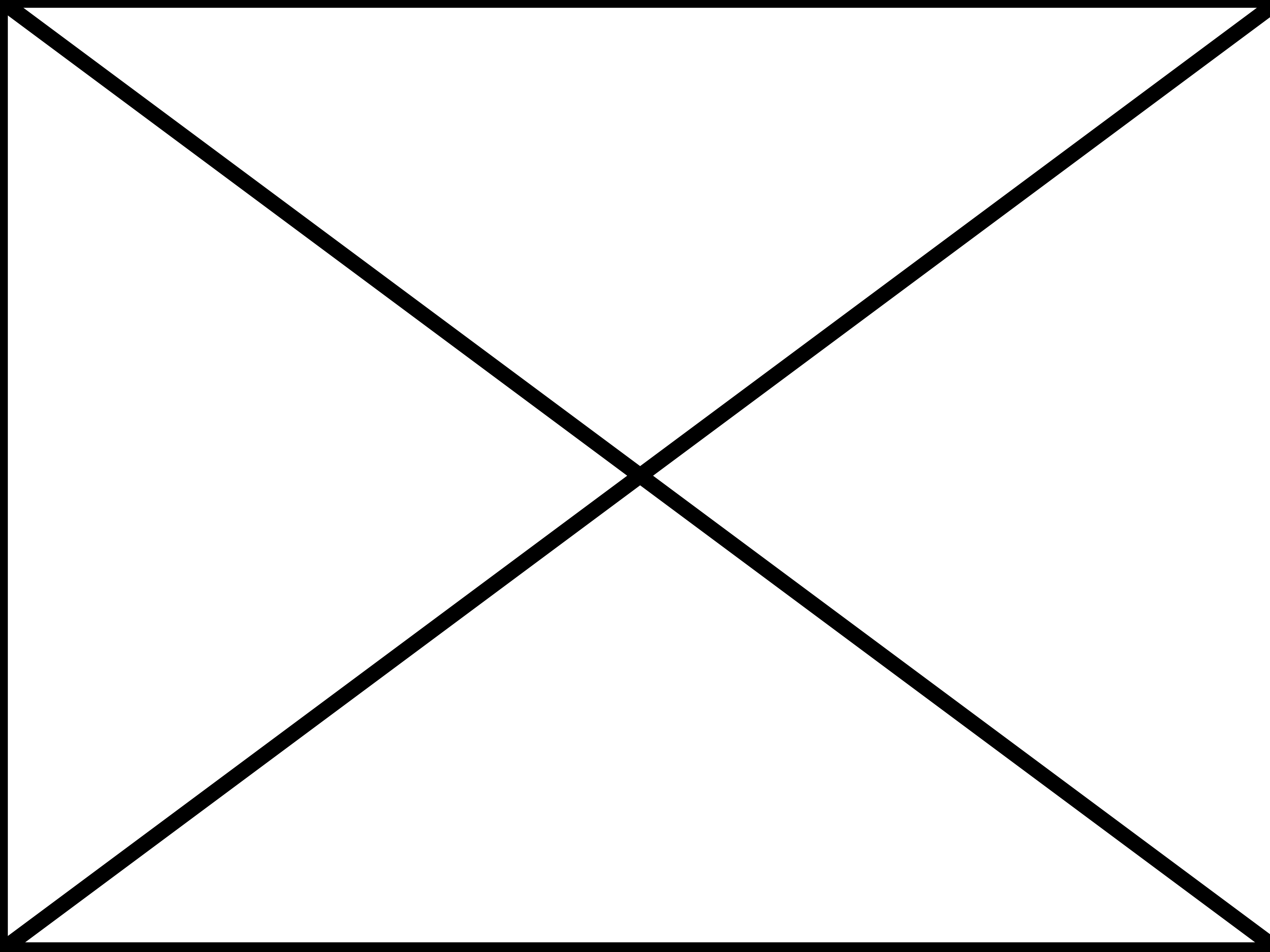
Sediment Input



China Camp Elevation Model

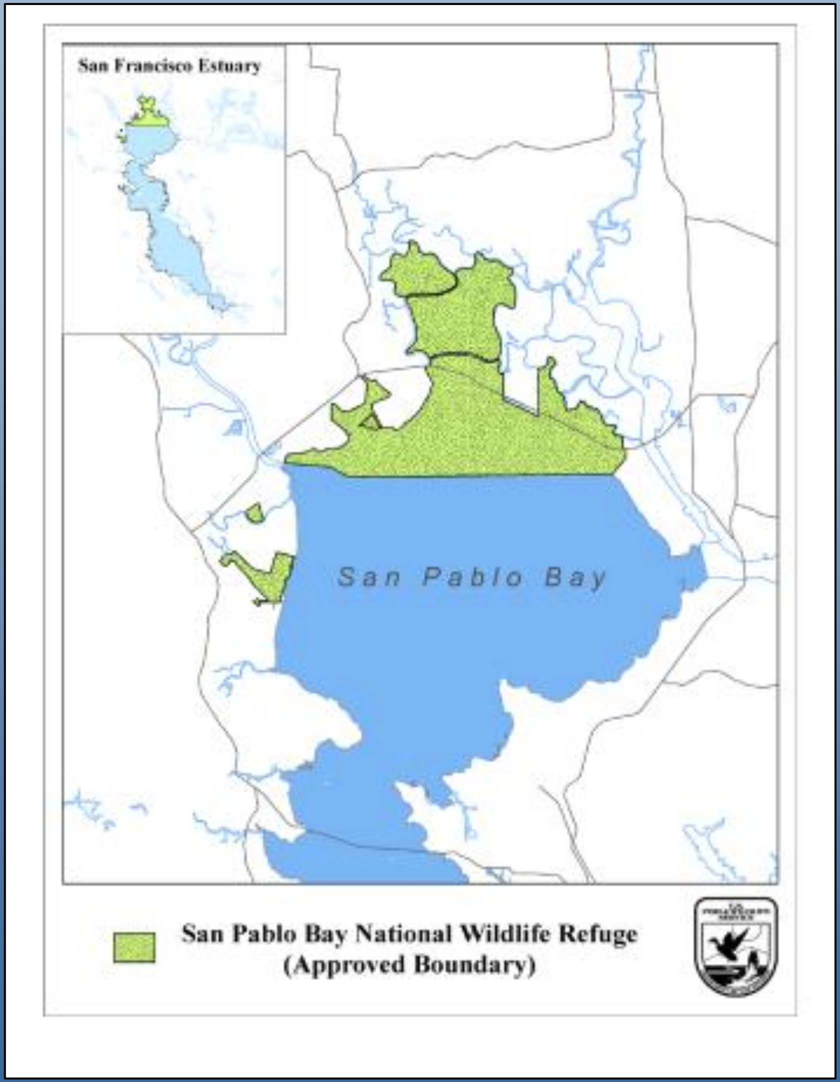


(Swanson etal., in review)



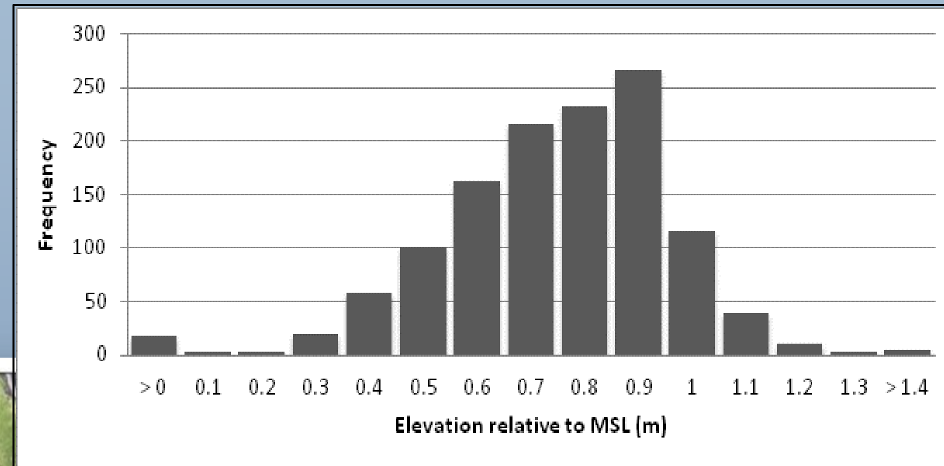
San Pablo Bay National Wildlife Refuge

- Second largest refuge in San Francisco Bay – 5,340 ha
- Includes: open bay waters, salt marsh, intertidal mudflats, restored wetlands
- Managed for listed species



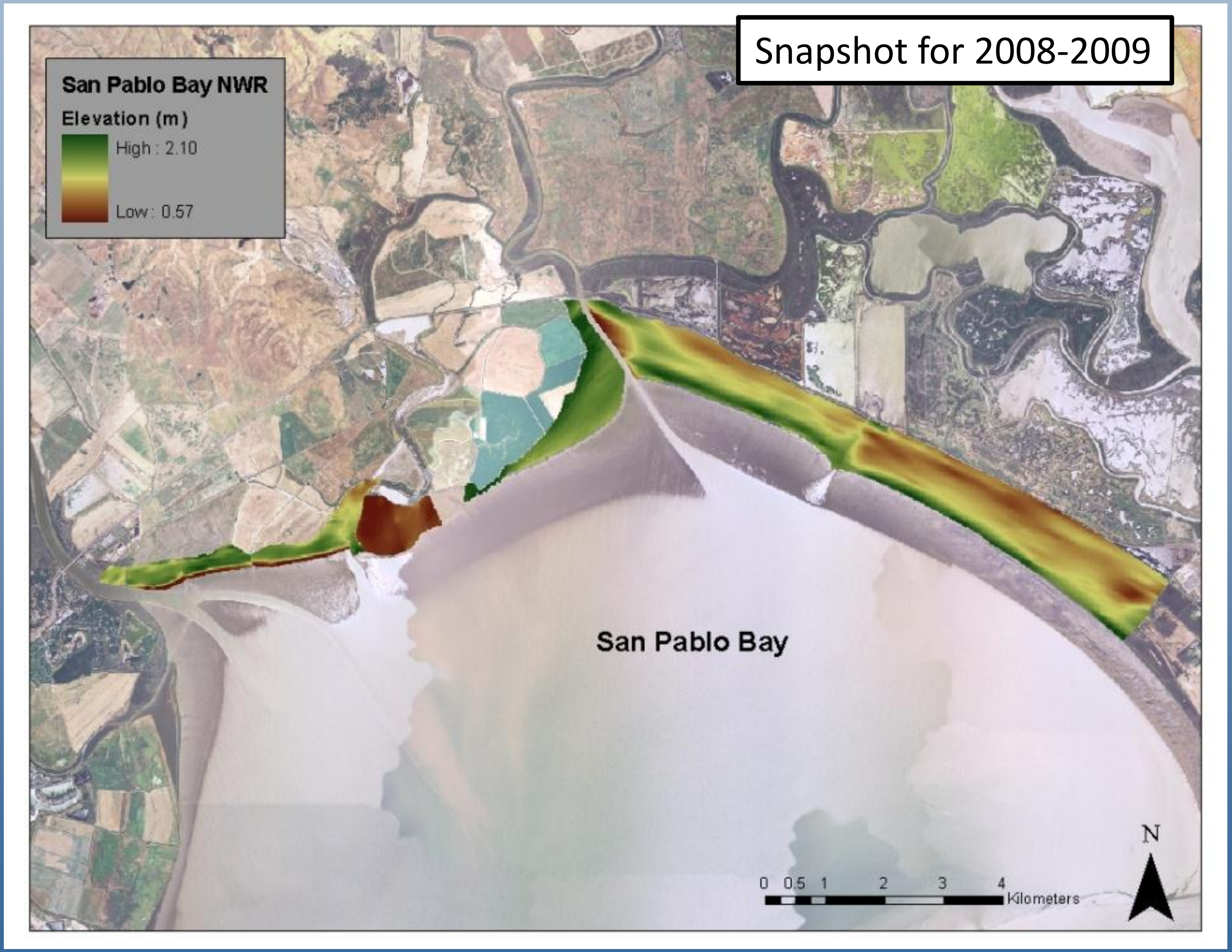
Goal: Develop high resolution elevation model

Data: Elevation Data



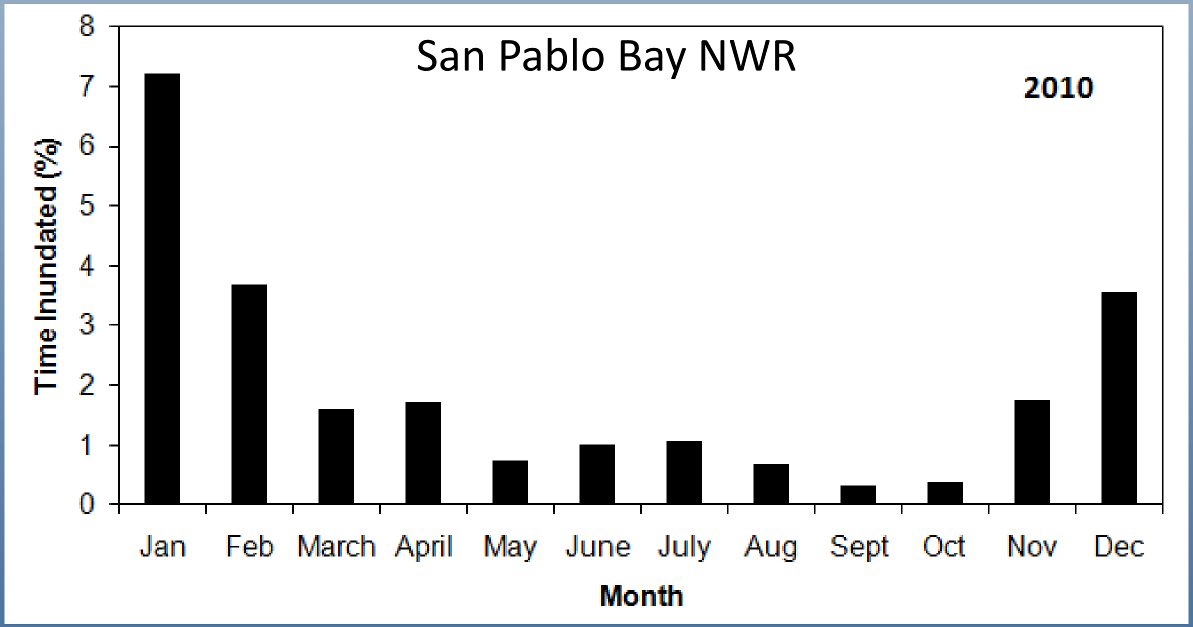
- •Field data collected in 1995 and 2008-2009.
- • 1700 elevation points collected.
- • 68% within 1.6 – 2.0 m

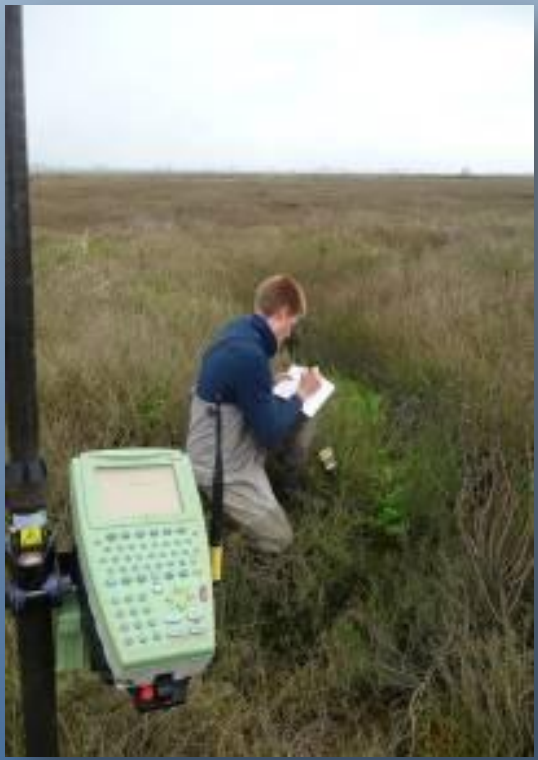
Elevation Model for San Pablo Bay NWR



Use downscale tidal cycles to assess inundation patterns

Data: Water level logging

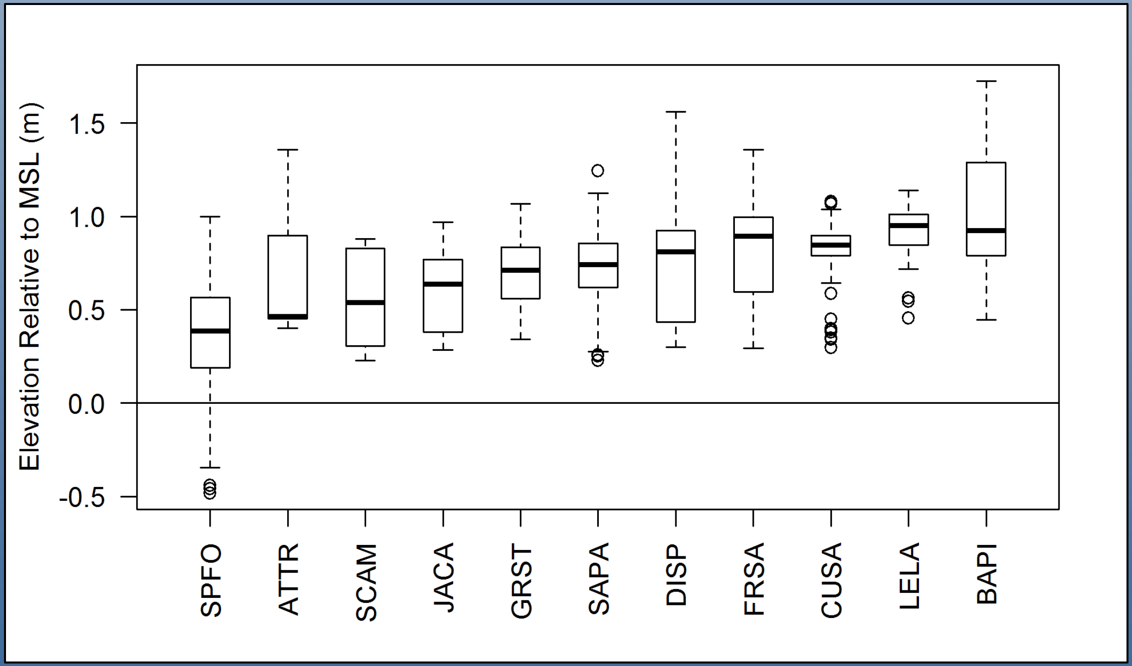


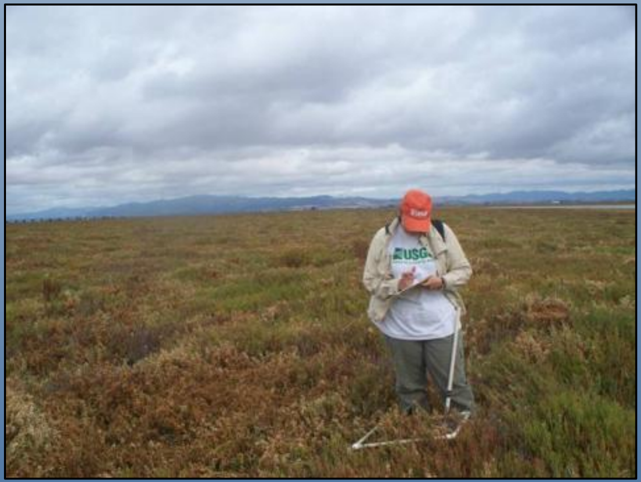


Water level data is used to understand seasonal patterns of inundation and to develop local tidal datum.

Goal: Quantify plant species distribution relative to elevation and tidal datum

Data: Vegetation Survey





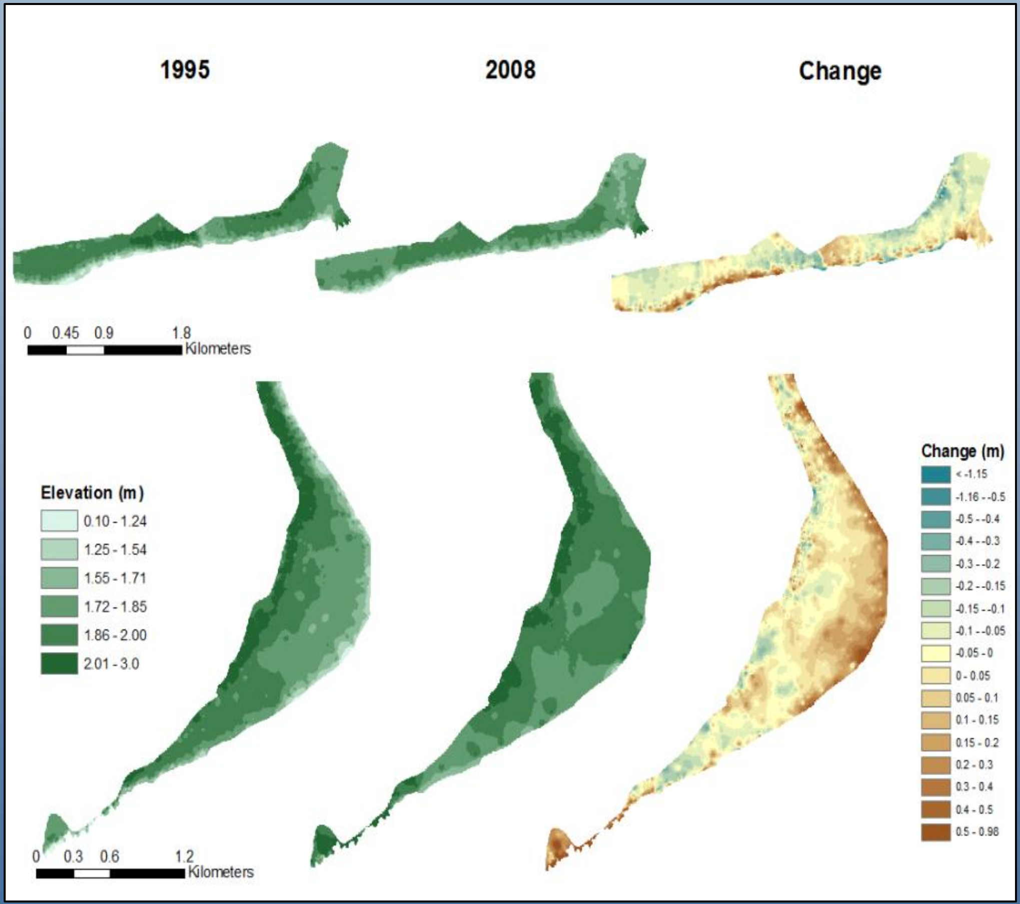
vegetation surveys at 800 elevation points

Annual Accretion Rate: Spatially explicit sea-level rise model

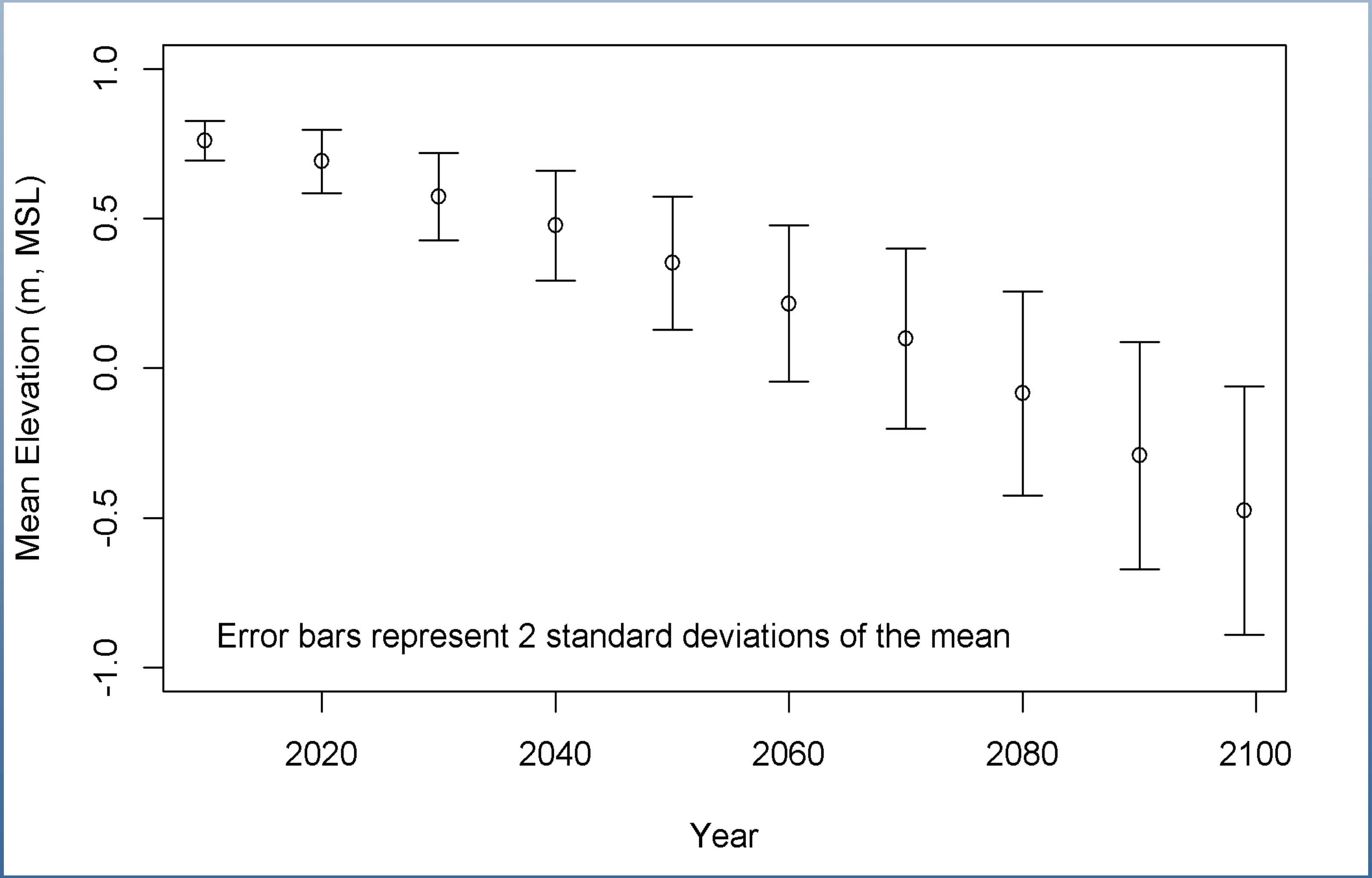
- Use historic elevation data (1995 - 2008) to determine Annual Accretion and Subsidence Rate (30 m x 30 m gridcells).

- Used this Annual Accretion and Subsidence Rate with:
  - ➢ Starting elevation
  - ➢ Inundation frequency
  - ➢ Distance to sediment source
  - ➢ Local sea-level rise rate

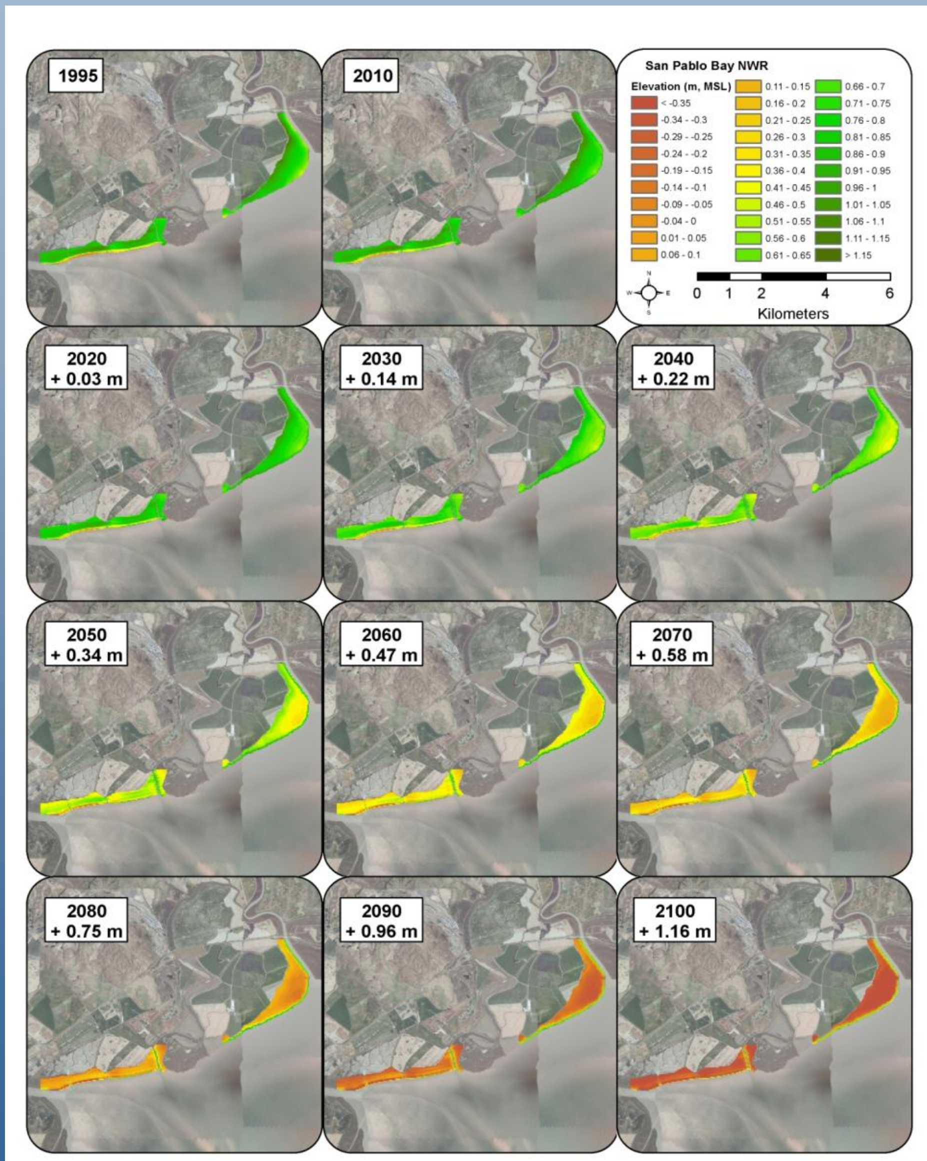
  to model the salt marsh response to sea-level rise to 2100 (Thorne *et al.* in prep).

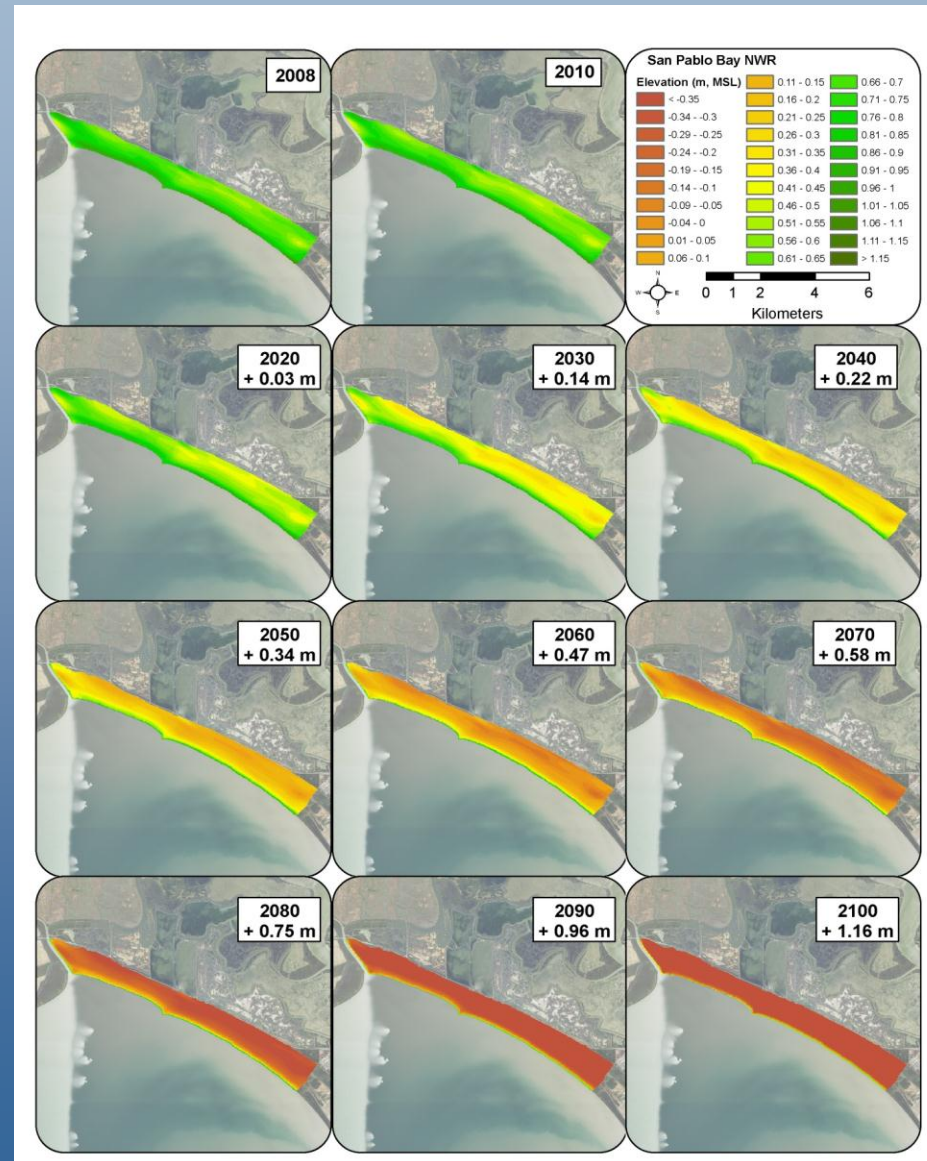


Projected decreasing surface elevations

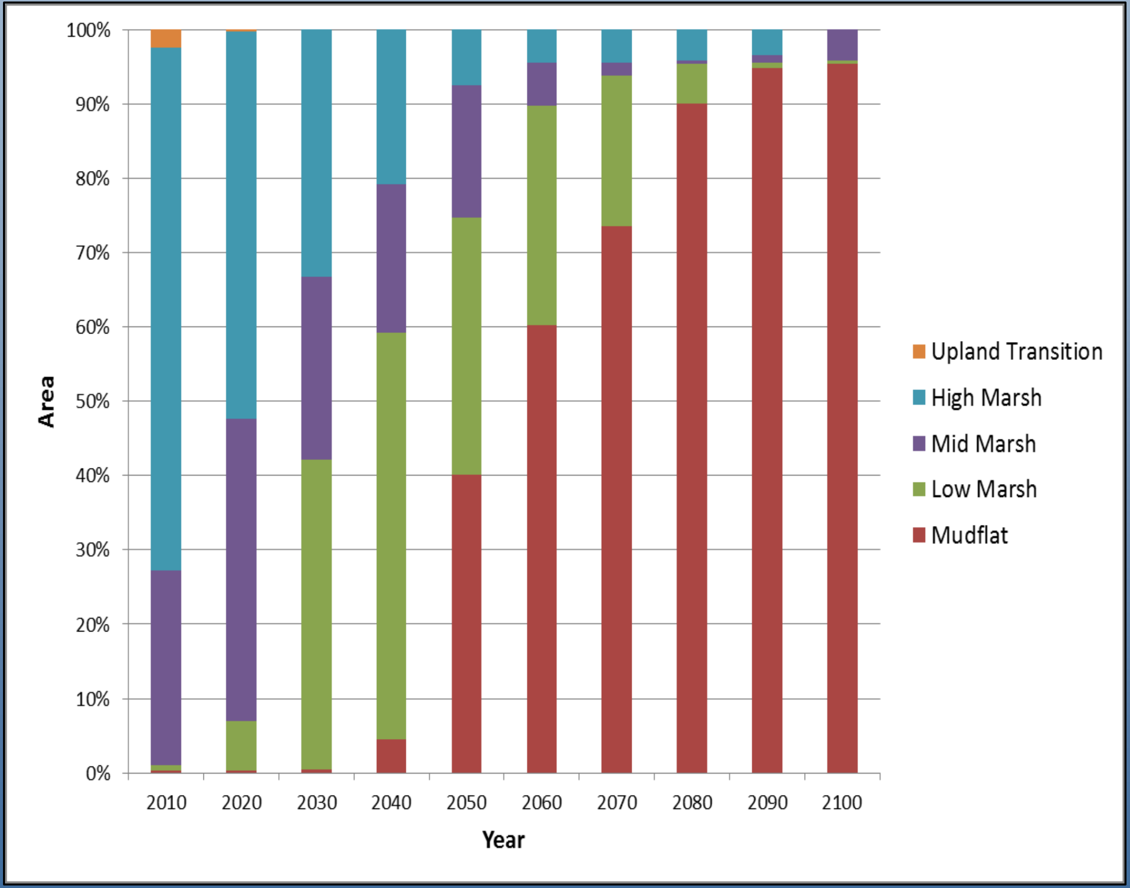


Site-level projected elevation change





Projected plant communities



Salt marsh plant community change

salt marsh harvest mouse

SFB Study Results Summary

- Our results showed that three marshes maintained marsh vegetation to 2100, but only comprised 4.2% of the total marsh area surveyed. The vast majority, 95.8%, of the areas in our study was projected to lose all marsh plant communities by 2100 and transition to mud flats.
- For more details, see www.werc.usgs.gov/SFBaySLR

Outline

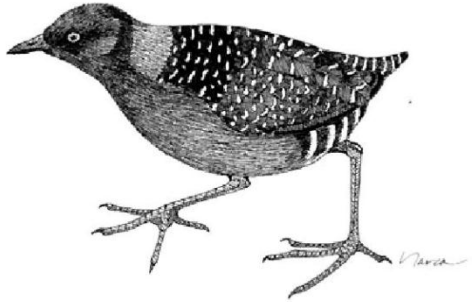
- SLR in SFB Tidal Marshes
- Challenges at a Local Scale
- **Consequences for Endemic Vertebrates**
- Adaptive Management and Future Research

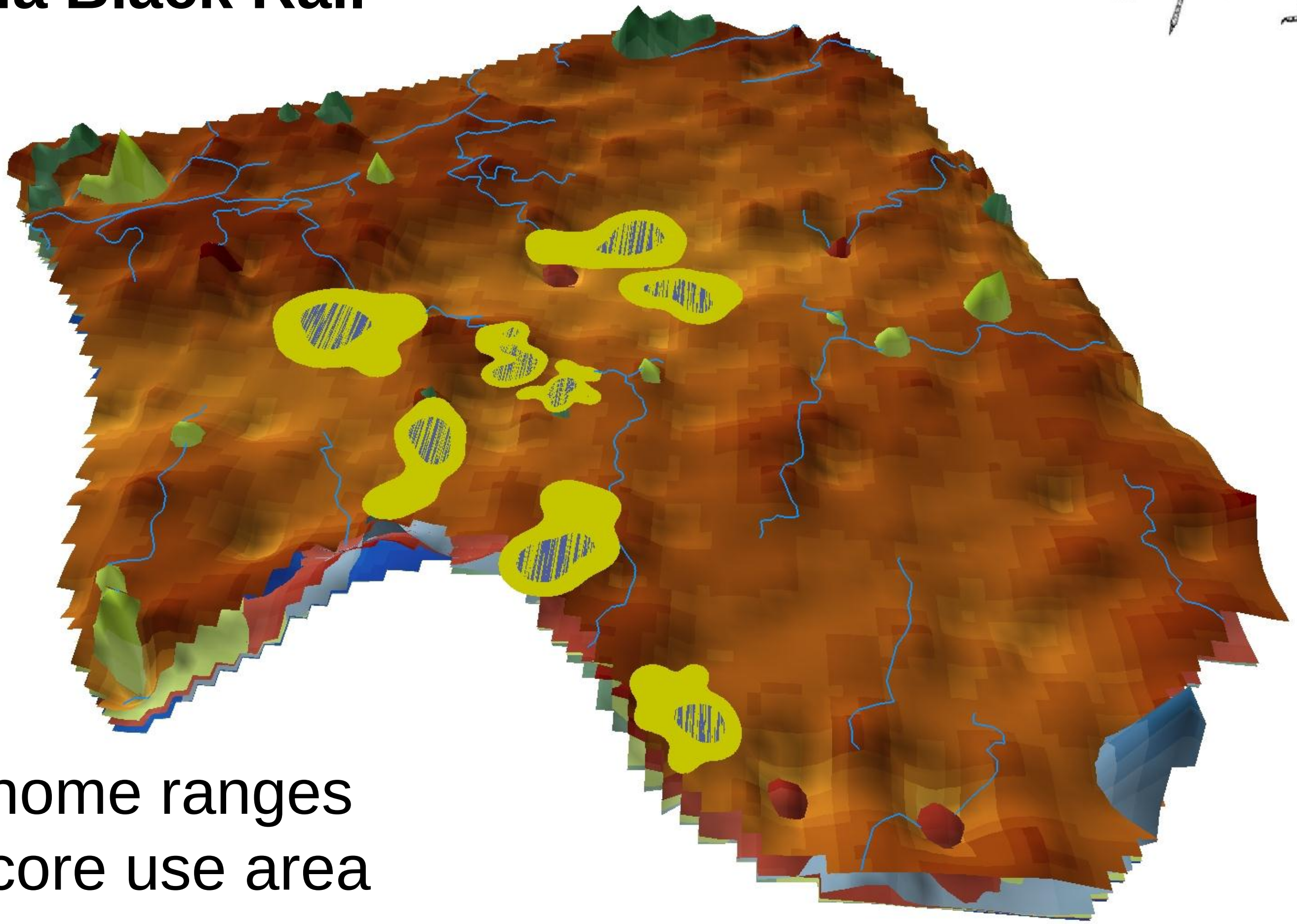
SLR Consequences for Endemic Vertebrates in Tidal Marsh Parcels

- **Distribution –** ***endemic vertebrates emigrate or are lost***
- **Survival –** ***individual survival decreases***
- **Reproduction –** ***productivity declines***

Distribution –

Petaluma Tidal Marsh
California Black Rail





0.59 ha home ranges
0.14 ha core use area

(Tsao et al. 2009, Condor 111:599-610)

Petaluma Tidal Marsh (red outline)

Petaluma Tidal Marsh
1.0 – 2.3 m NAVD88

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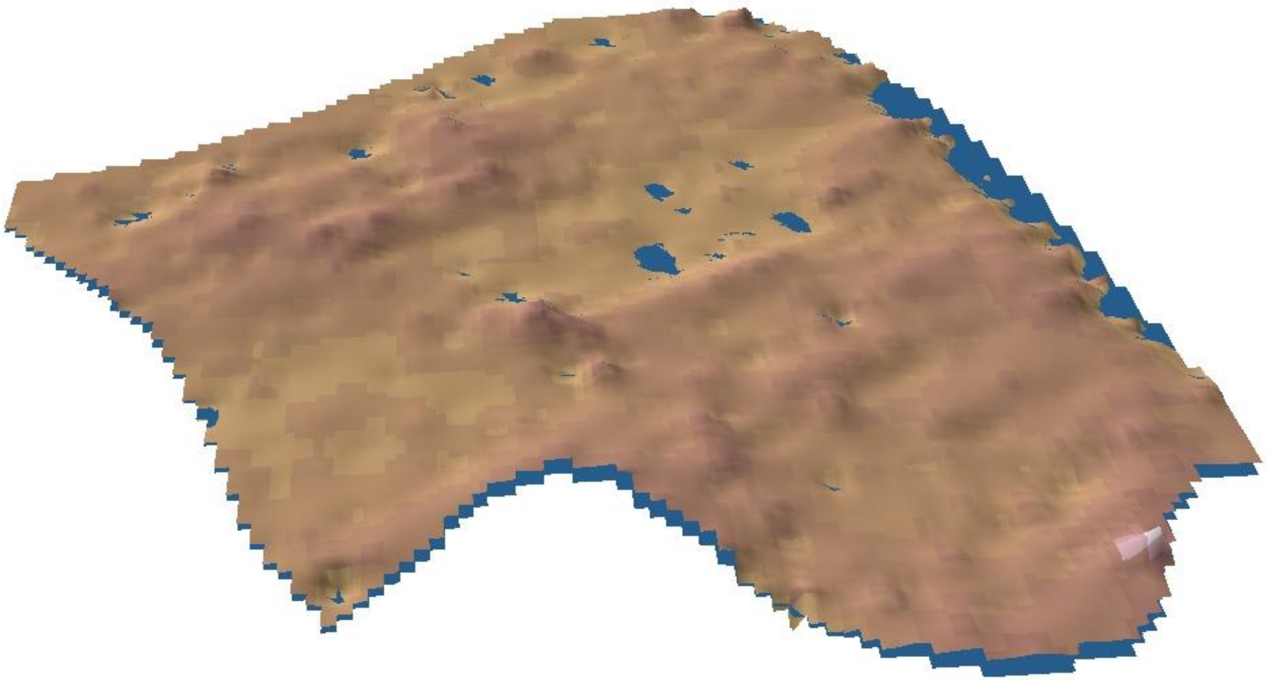
science for a changing world

Petaluma Tidal Marsh
water level = 1.75 m



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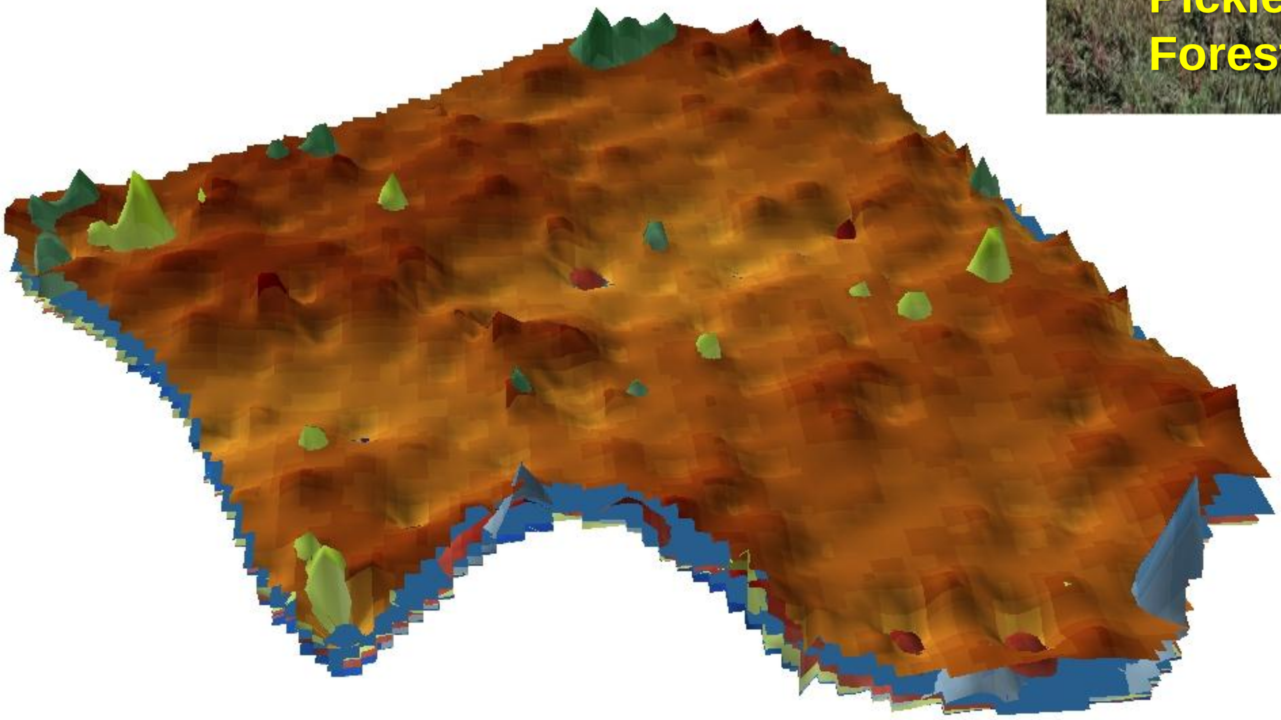
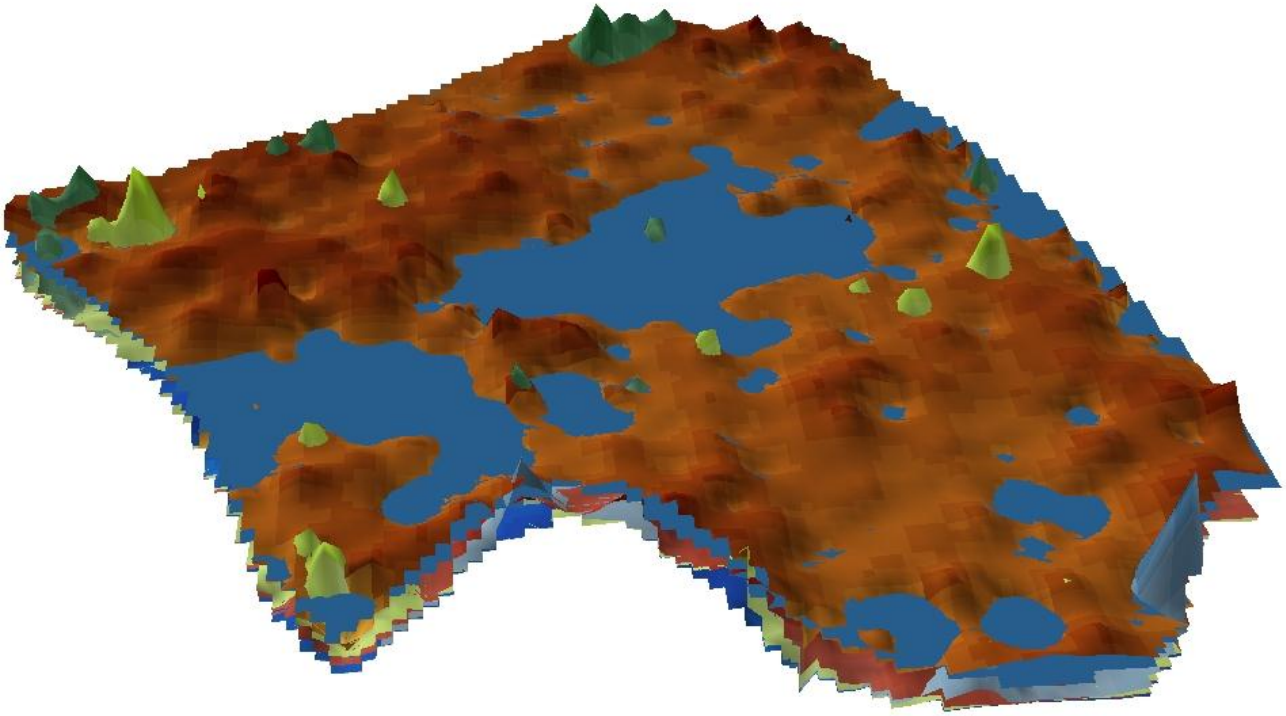
Petaluma Tidal Marsh
water level = 2.0 m
<1% inundated



Petaluma Tidal Marsh
water level = 2.25 m
35% inundated



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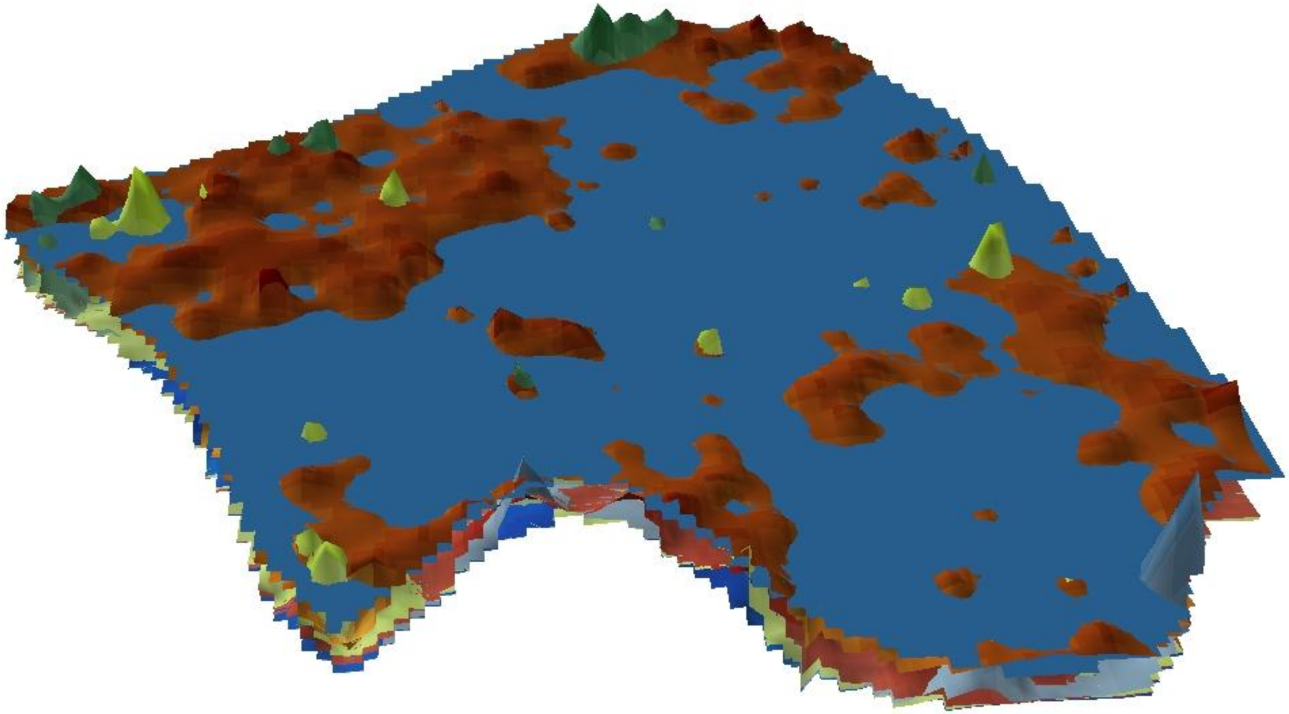
Petaluma Tidal Marsh
water level = 2.35 m
90% inundated



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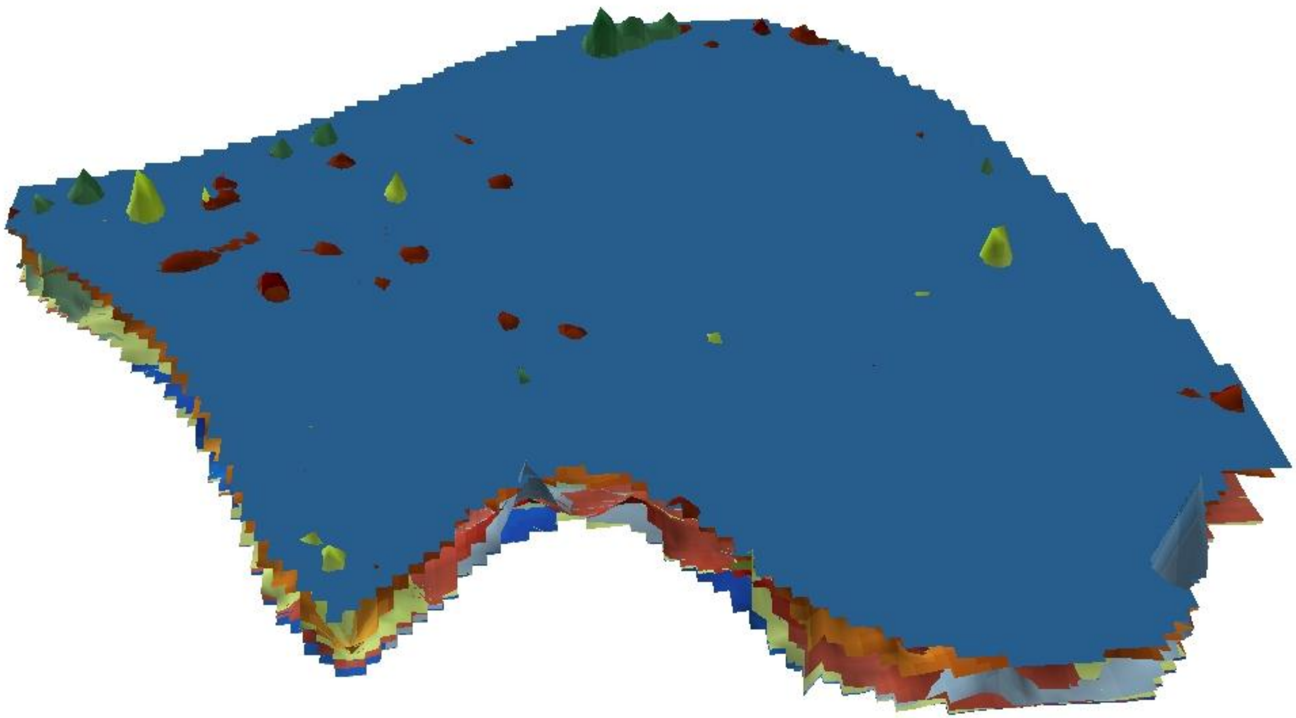
Petaluma Tidal Marsh
water level = 2.5 m
>99% inundated



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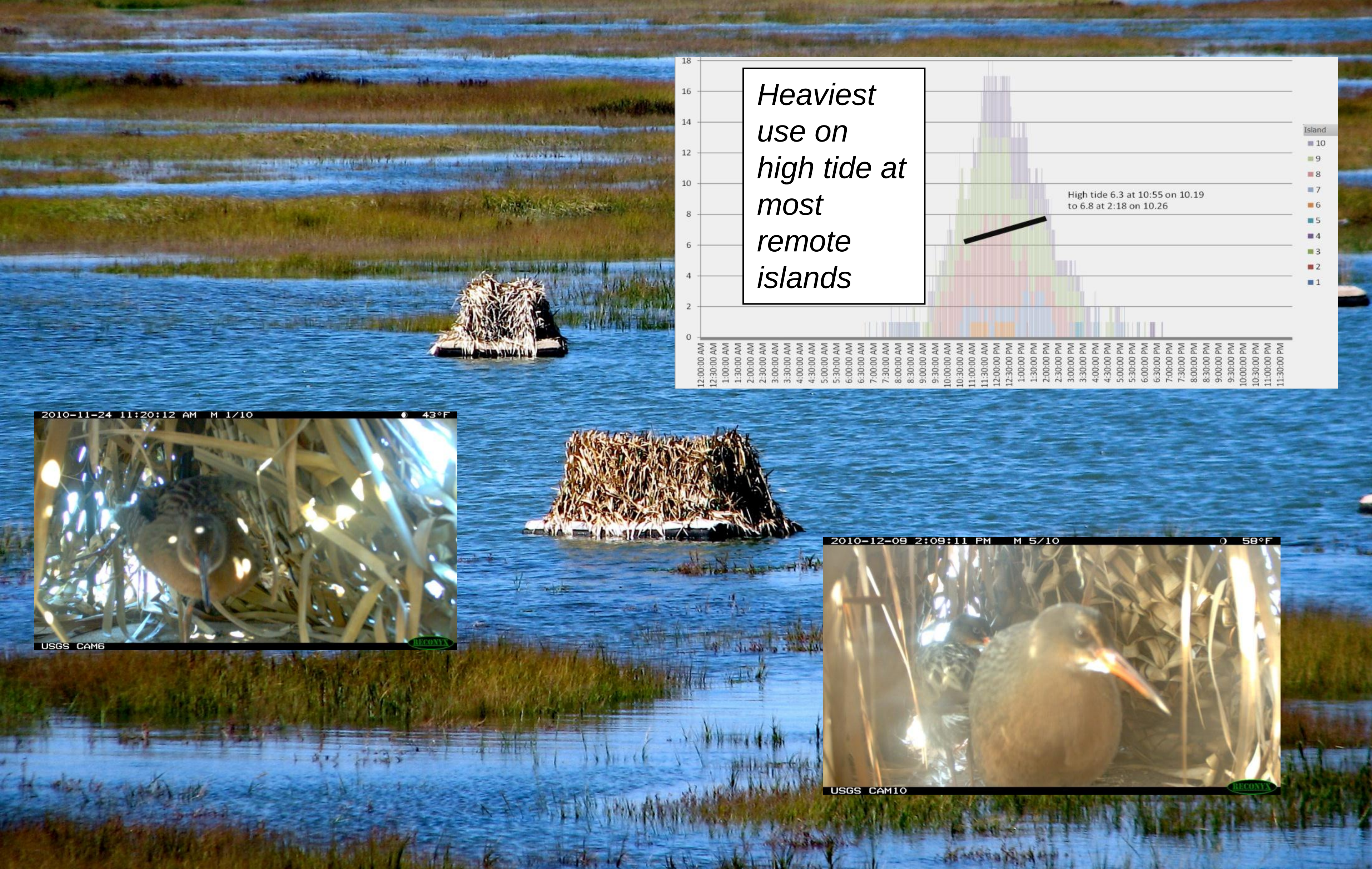
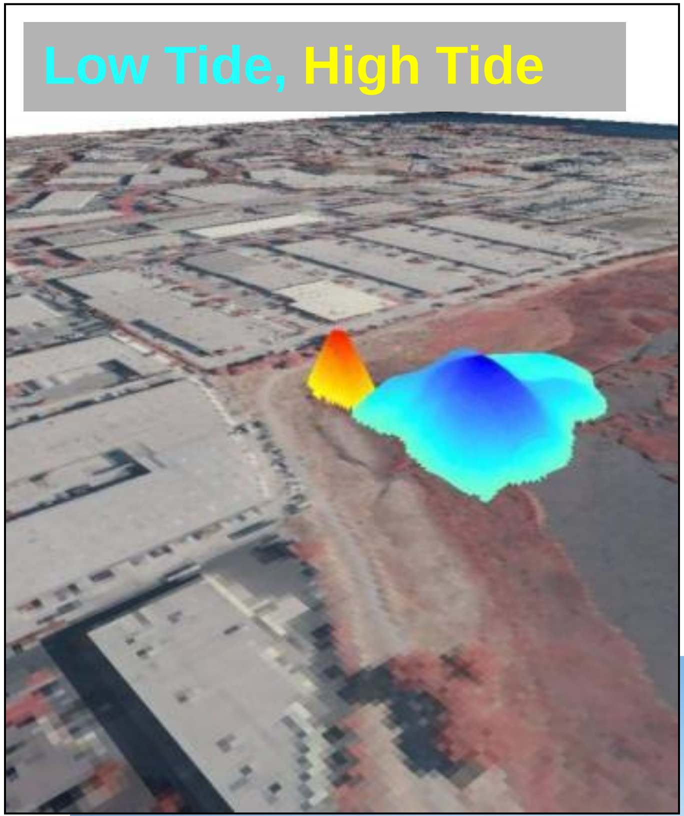
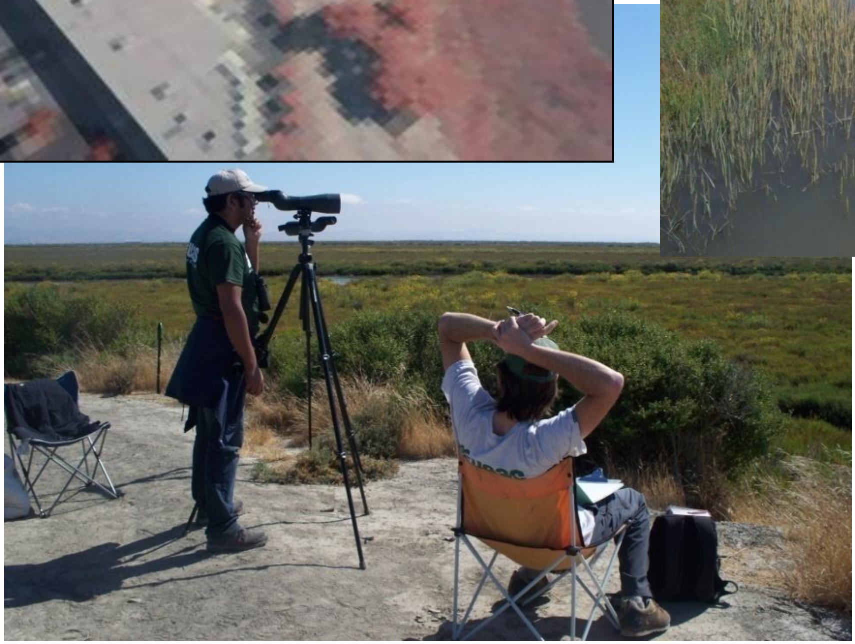
Distribution -- *refugia within marshes, Arrowhead Marsh artificial islands*

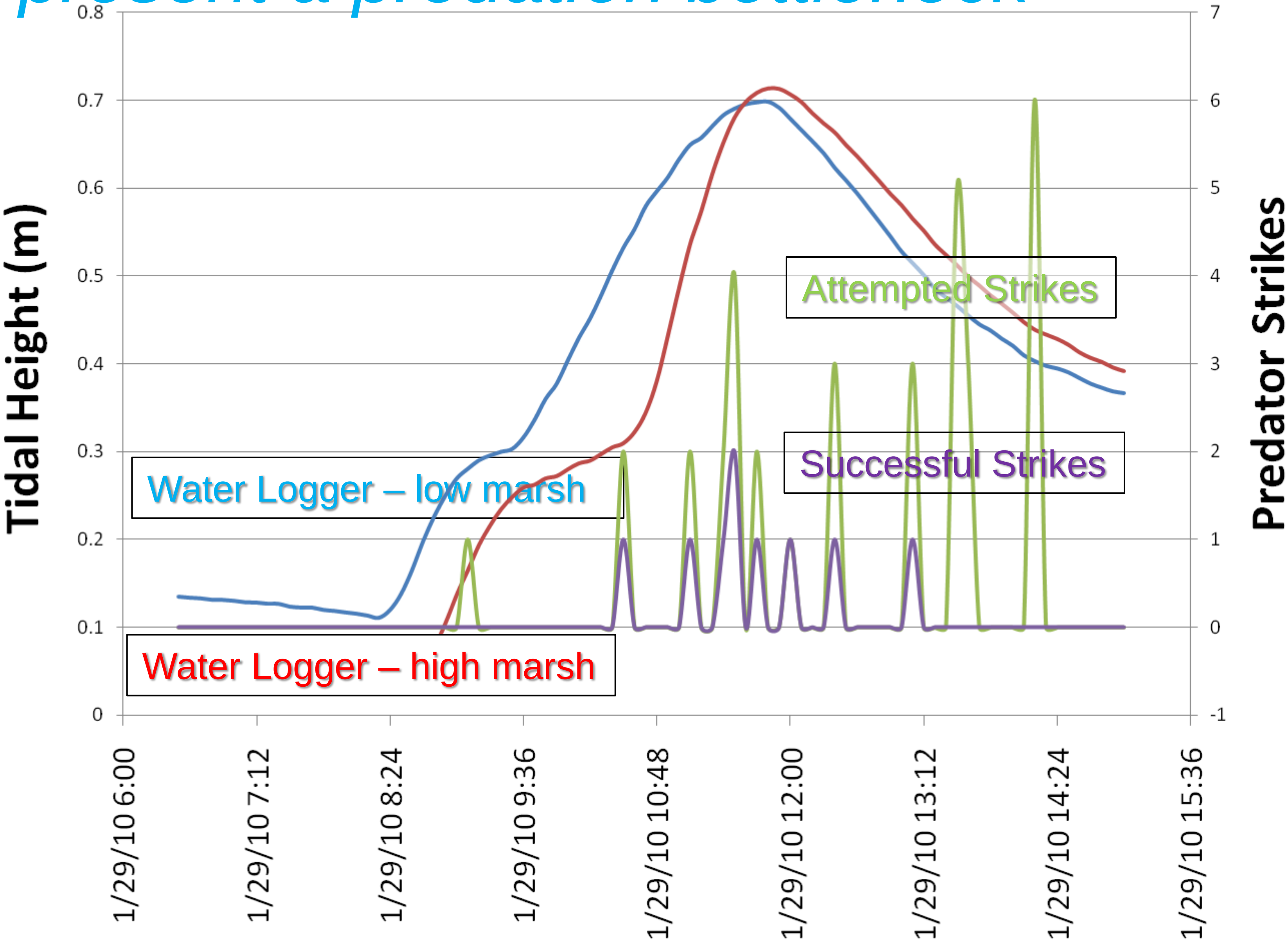


Survival -- King Tide Predation Surveys

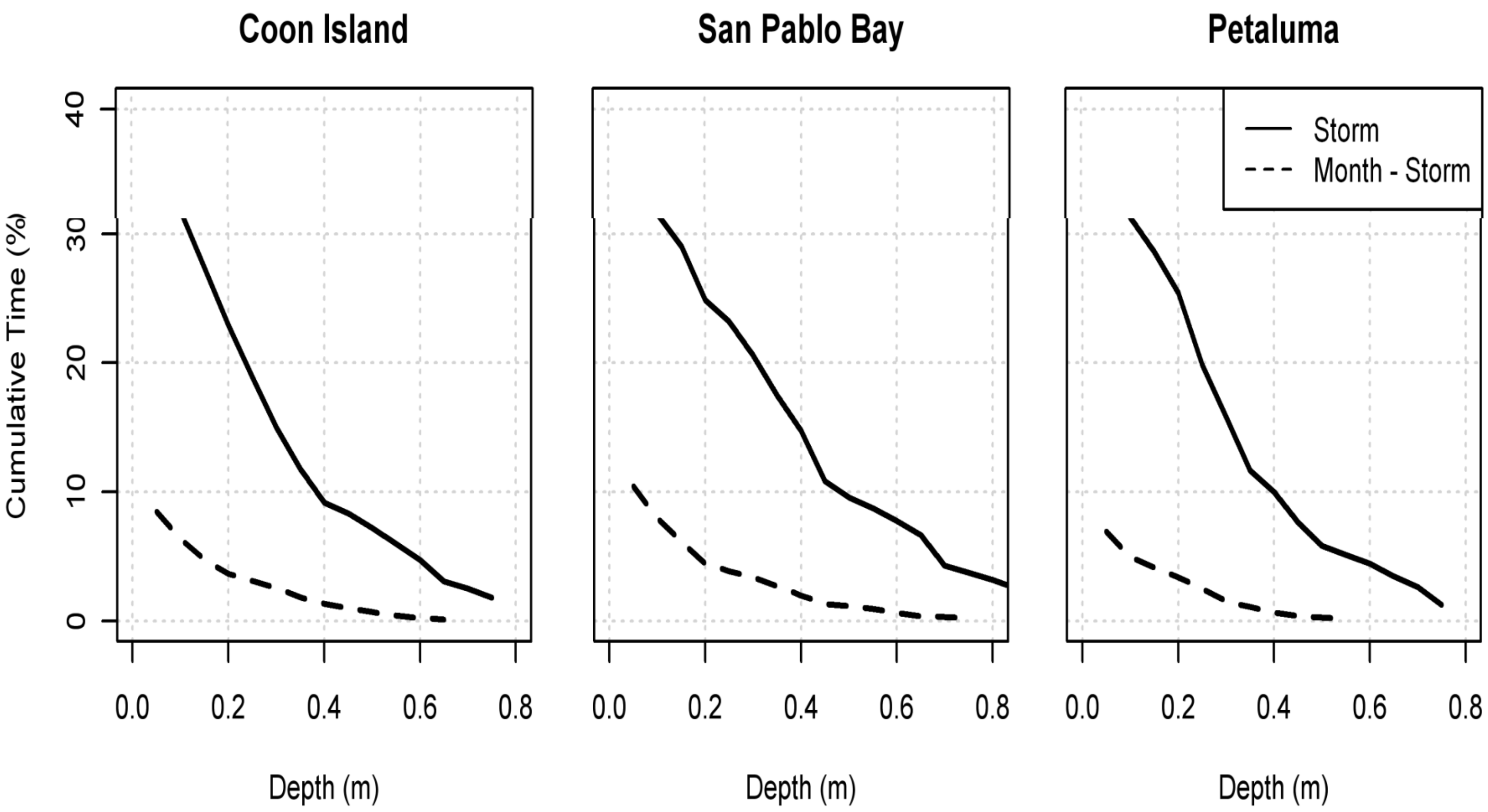




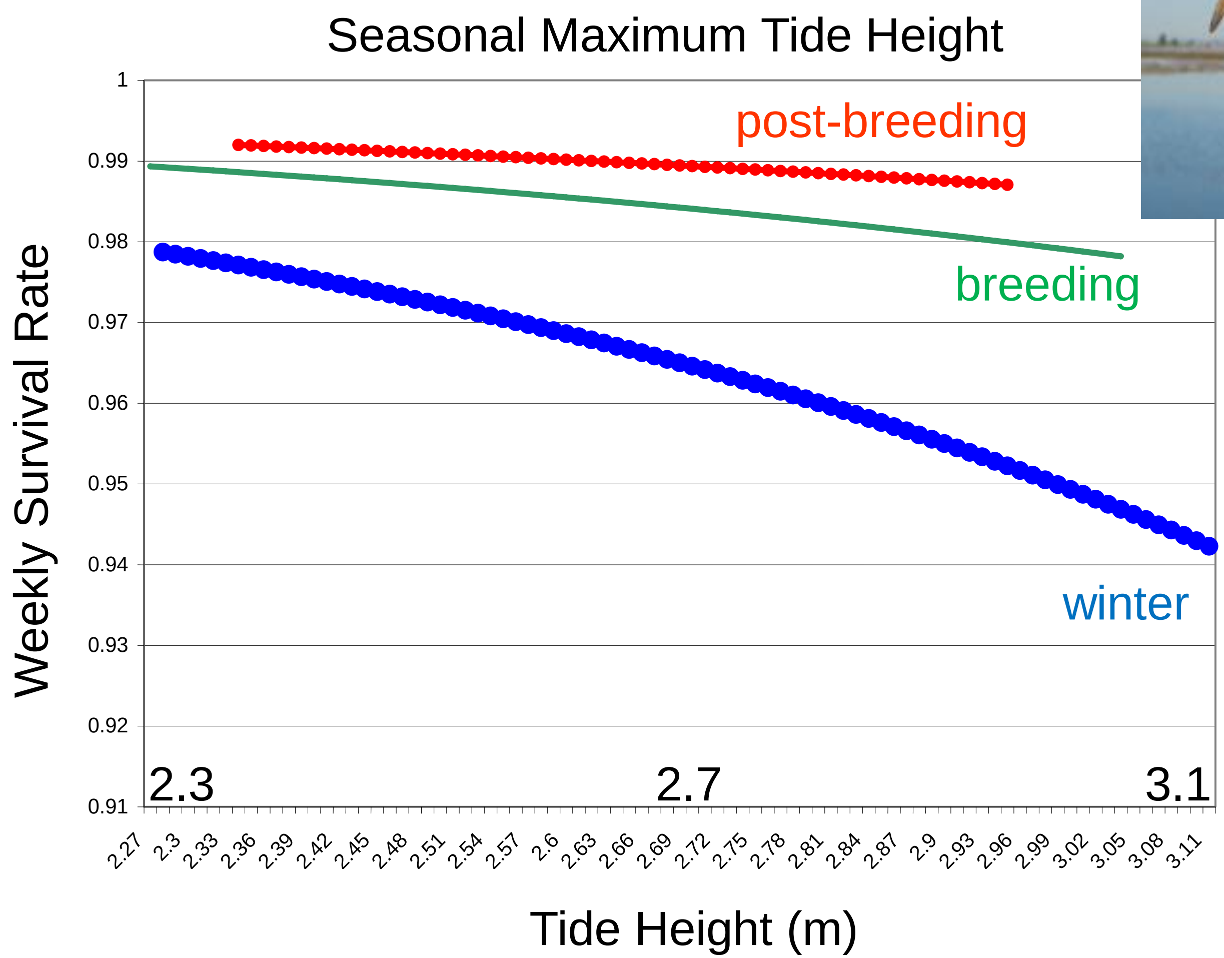
Survival – *increasing tides may present a predation bottleneck*



Survival – *storm events with long marsh plain inundation times may pose the greatest predation threat*



Survival -- Clapper Rail survival varies with seasonal tides



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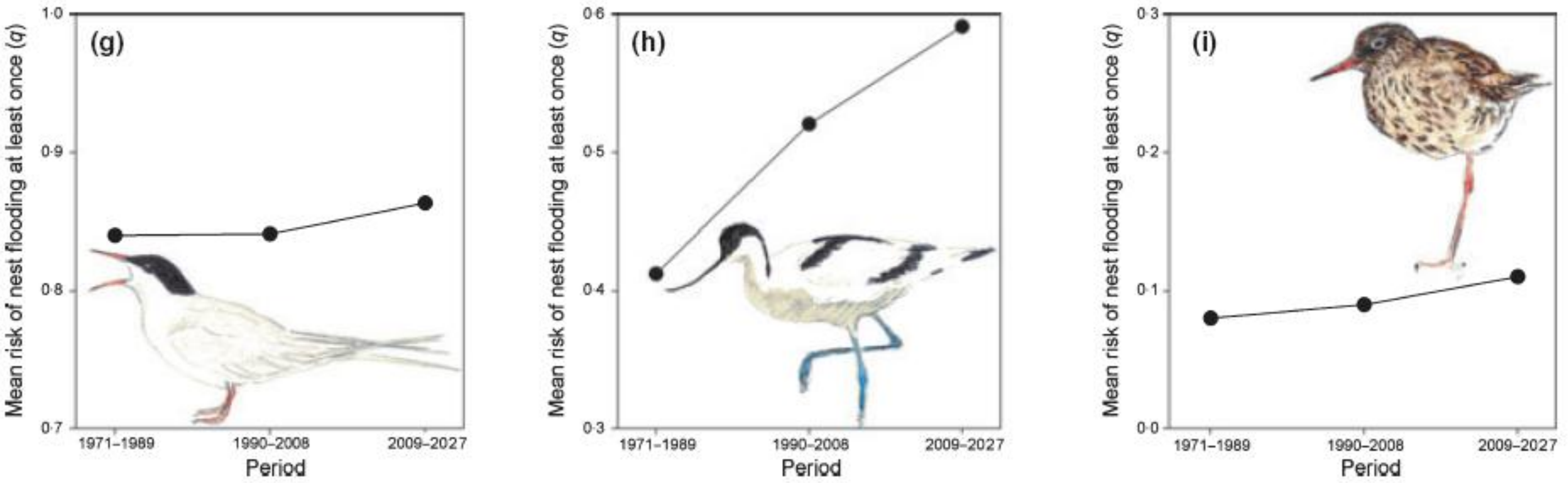
(C. Overton etal., in review)

Reproduction – *nesting birds*

- Max high tide increased 2x faster than mean high tide over 4 decades (0.8 vs. 0.4 cm/year) resulting in more frequent, catastrophic flooding of nests, especially at hatch

- Birds benefited most from nesting in higher areas, but low marsh was favored for proximity to feeding – creating an ecological trap?

(Van de Pol 2010 J. Appl. Ecol.)



Reproduction – *nesting Clapper Rail*

Success
Nest floats above tide

Failure
Nest is inundated

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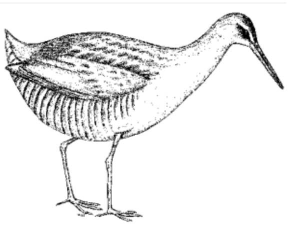
Site-Specific Population Response



Global Climate Models

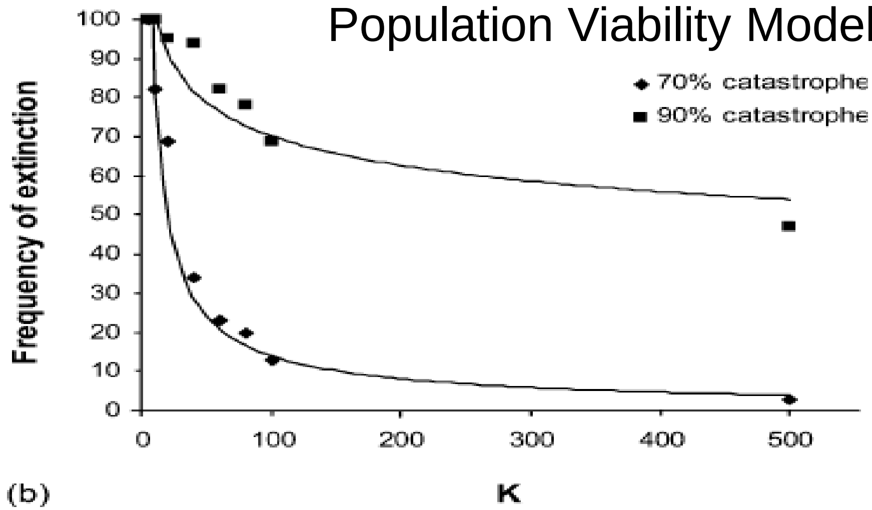
Downscaling

Ecosystem Response
California

Regional Habitat Response
San Francisco Bay

Habitat Requirement Response
Food
Cover
Reproduction

Population Viability Model



(Takekawa et al. 2006. SAB 32:238-246)

Outline

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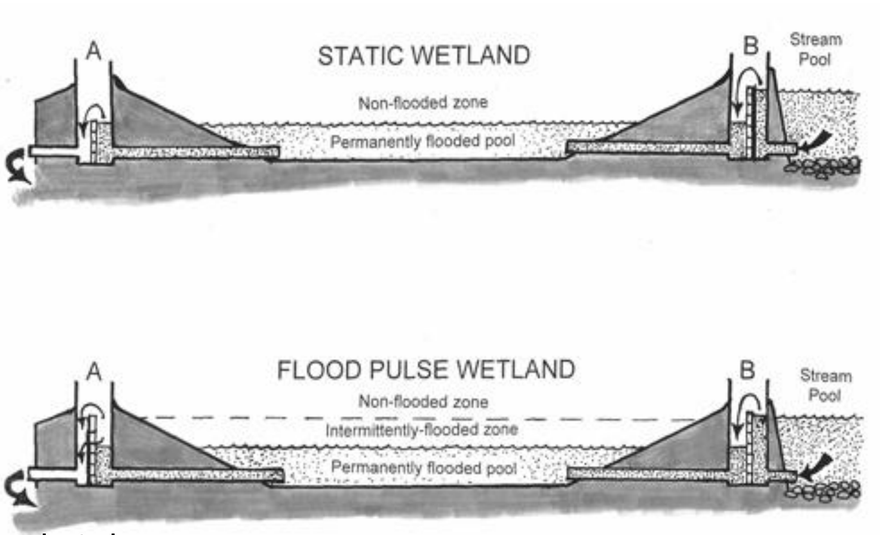
Response to Climate Change

"Adaptation is managing the unavoidable. Mitigation is avoiding the unmanageable."

(J. Lubchenko, NOAA Administrator)

Management Options

- Dynamic over static habitat management – easements and leases over fee-title?
- Protect marshes with upland transition
- Restore marshes with highest accretion potential
- Focus on marshes with largest vertebrate populations
- Create refugia -- elevated areas, artificial habitats
- Retain levees -- add water control



kent.edu

Summary

1. **Tidal marsh vertebrates are limited by habitat availability in SFB. Good baseline data will be key for projecting change.**

2. **Habitat reduction with fewer refugia and increased frequency of storm events may result in an ecological bottleneck.**

3. **With sea-level rise, upslope movement is constrained by urbanization and levees. Research should include linked habitats from subtidal to upland transition.**

4. **Planning may be best considered in two periods: short-term (10-50 years) during linear SLR for resilience and long-term (50-100 years) during exponential SLR for survival.**

5. **Adaptation strategies for tidal marsh recovery will require triage, identifying specific marshes or habitat features critical to save fragmented vertebrate populations.**

Coastal Ecosystem Response to Climate Change (CERCC) Study Sites (15) along Pacific coast

Northwest and Southwest Climate Science Center Projects

- Elevation, bathymetric, and vegetation surveys
- Water level monitoring
- Install SETs for long-term accretion monitoring
- Compare vulnerability to sea-level rise
- Integrate with projections of storms
- Develop wildlife response models