Evaluating nature-based shoreline stabilization in a tidal wetland restoration project in the San Francisco Estuary

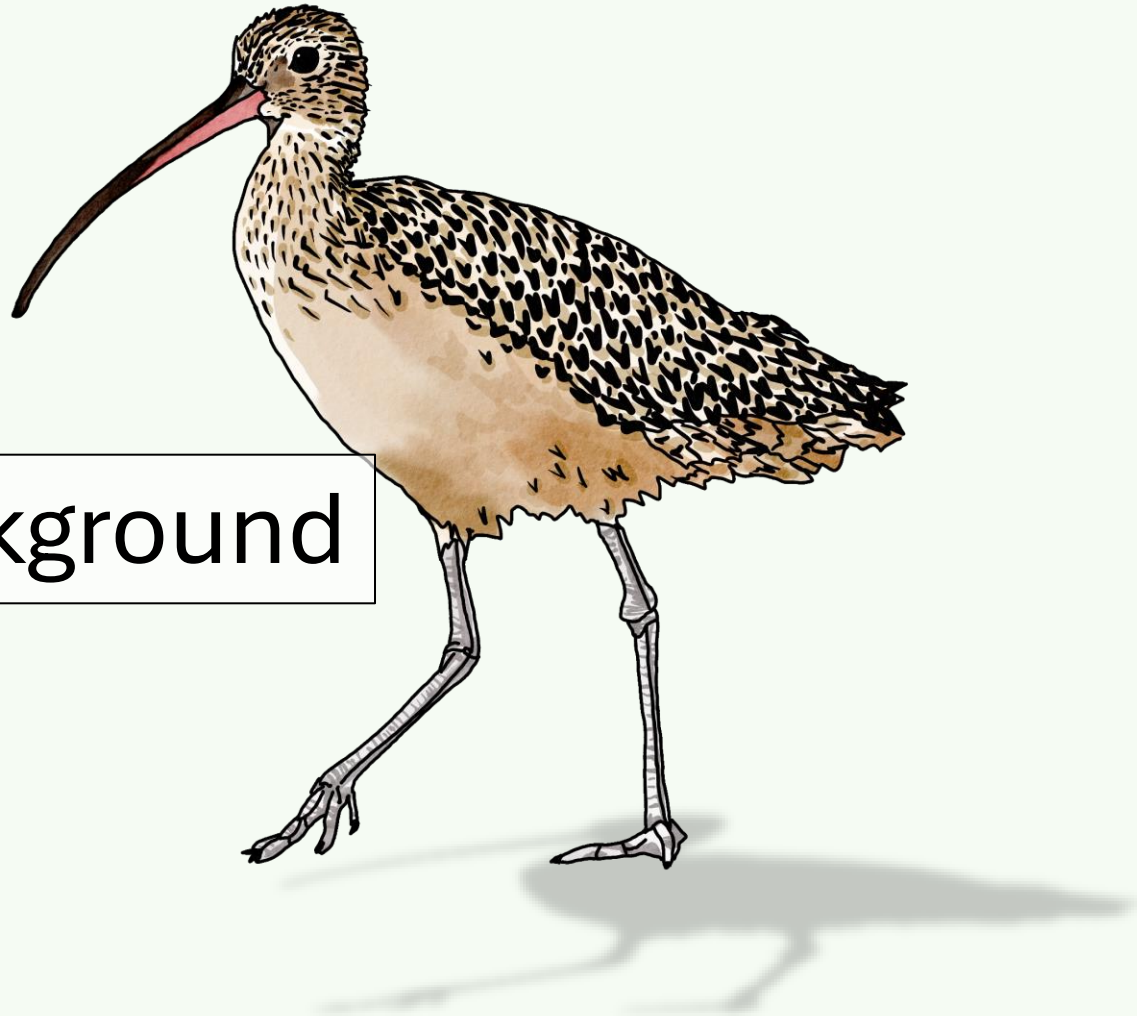
San Francisco State University
Estuary & Ocean Science Center
At the Romberg Tiburon Campus

Rebecca Morris

Thesis Defense 11/14/2024

Committee: Dr. Stuart Siegel; SFB NERR
Dr. Peter Baye; Coastal Ecologist
Dr. Katharyn Boyer; SFSU-EOS

Background



What is a tidal salt marsh?

- Coastal wetland
- Found in bays and lagoons
- Flooded and drained by saltwater
- Salt-tolerant plants
- Habitat for many organisms







Background

Image: Rail: Dean LaTry, ebird, 2024; SM Harvest Mouse: GrassrootsEcology, 2024; Bass: MarylandBiodiversity.com, 2024; Delta smelt: CDFW, 2024

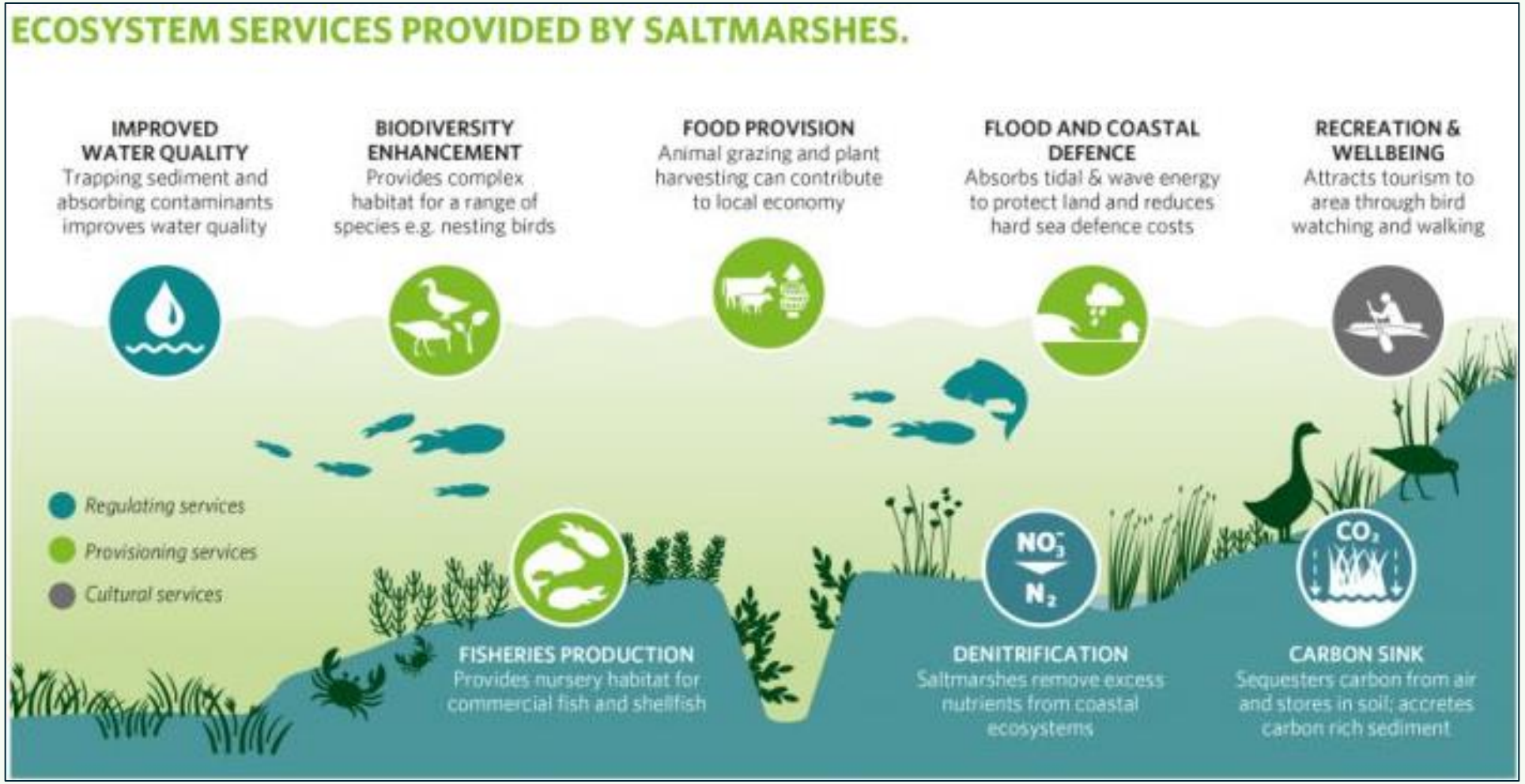


Image: UK Environment Agency, *Saltmarsh Restoration Handbook,* 2021

Background

Image: Harriot Manley, Friends of China Camp, 2024

Background

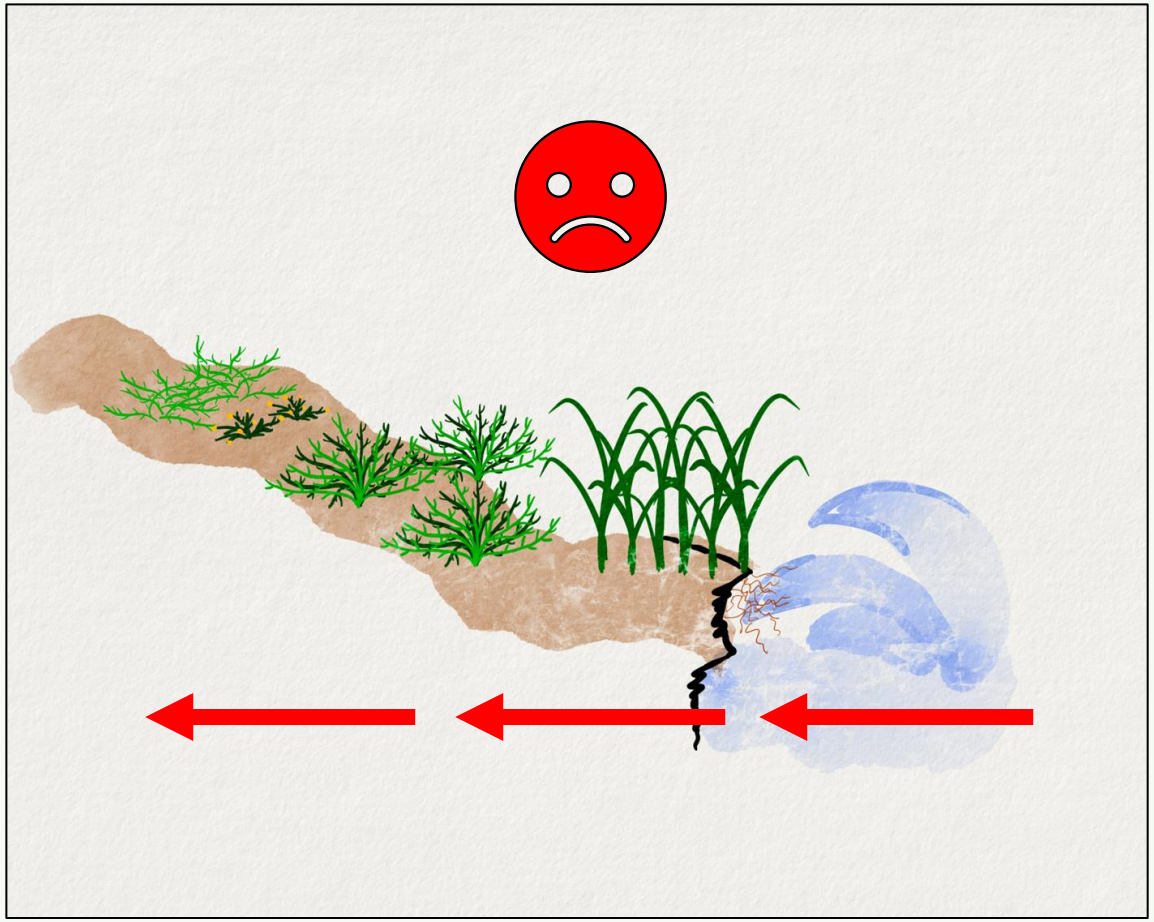
Sea level rise puts coastal habitats at risk of drowning.

Crosby *et al.*, 2016

Lateral Bay Edge Retreat

Thought to be main cause of global marsh loss!!

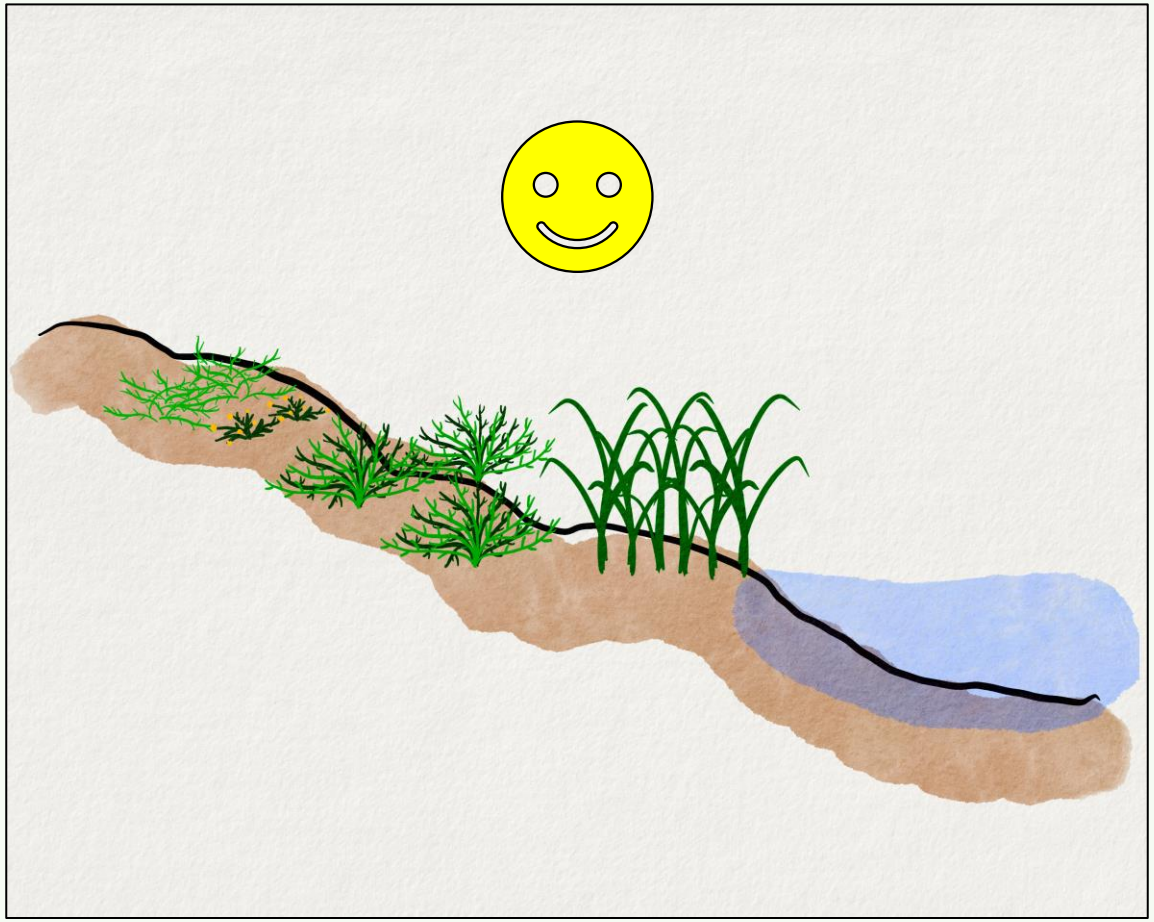
(Fagherazzi, 2013)

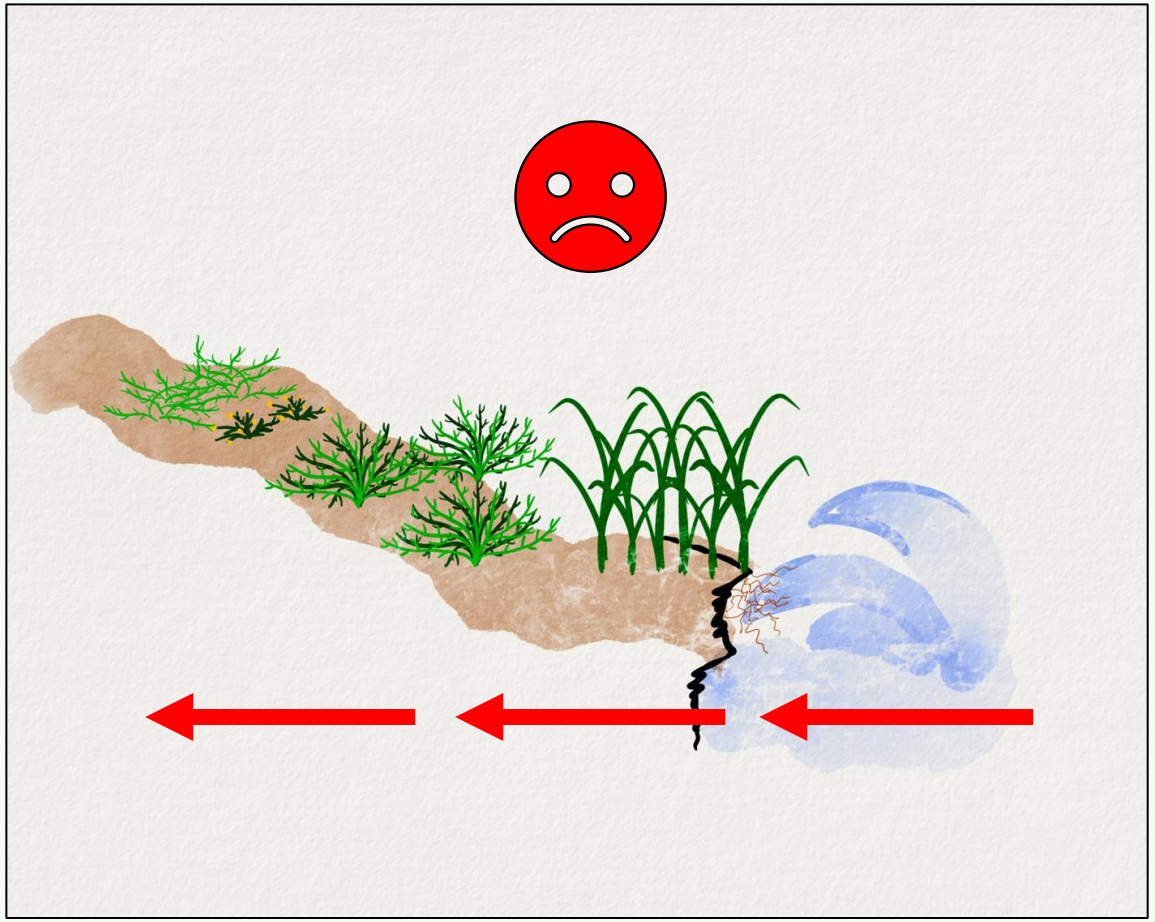


Background

Lateral Bay Edge Retreat

Brinson *et al.*, 1995





Background

Tidal Marshes are Dynamic!

Influences on marsh evolution:

- Elevation with respect to the tide
- Orientation
- Wave energy
- Vegetation type
- Shoreline structure
- Sediment supply
- Land availability

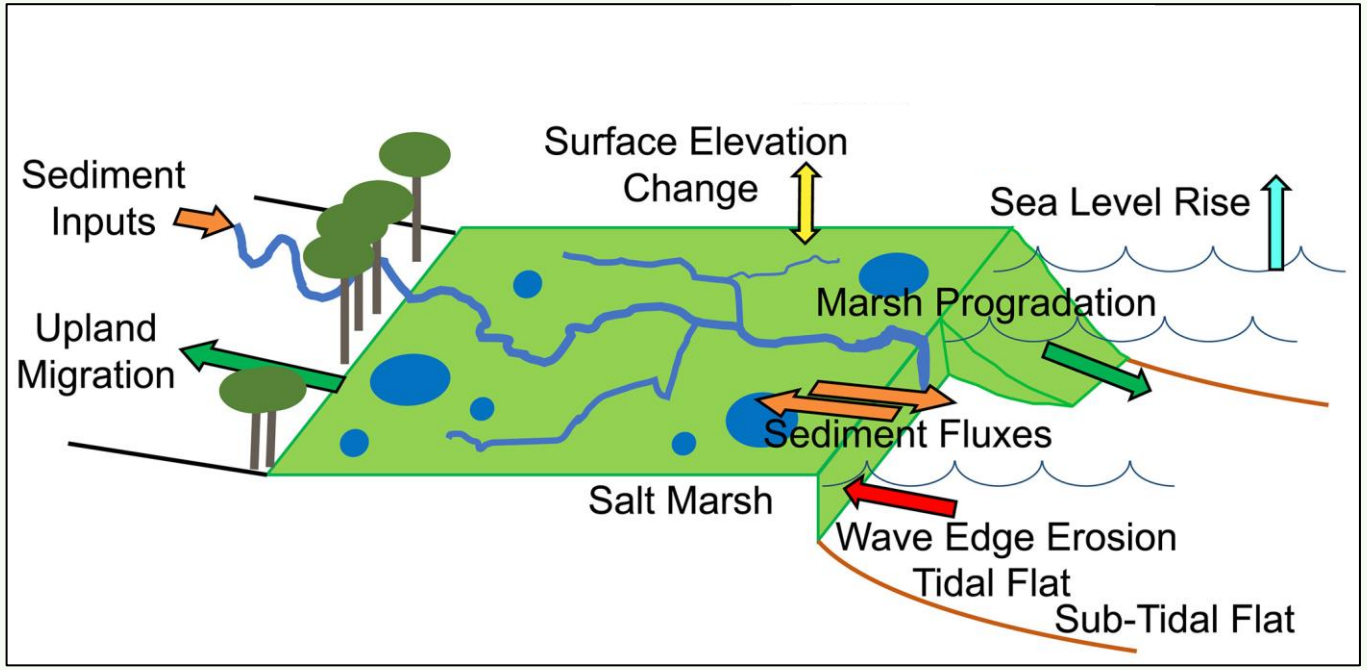


Image: Fagherazzi et al., 2020

Background

Tidal Marshes are Dynamic!

Influences on marsh evolution:

- **Elevation with respect to the tide**
- Orientation to wind direction
- Wave energy
- Vegetation type
- Shoreline structure
- Sediment supply
- Land availability

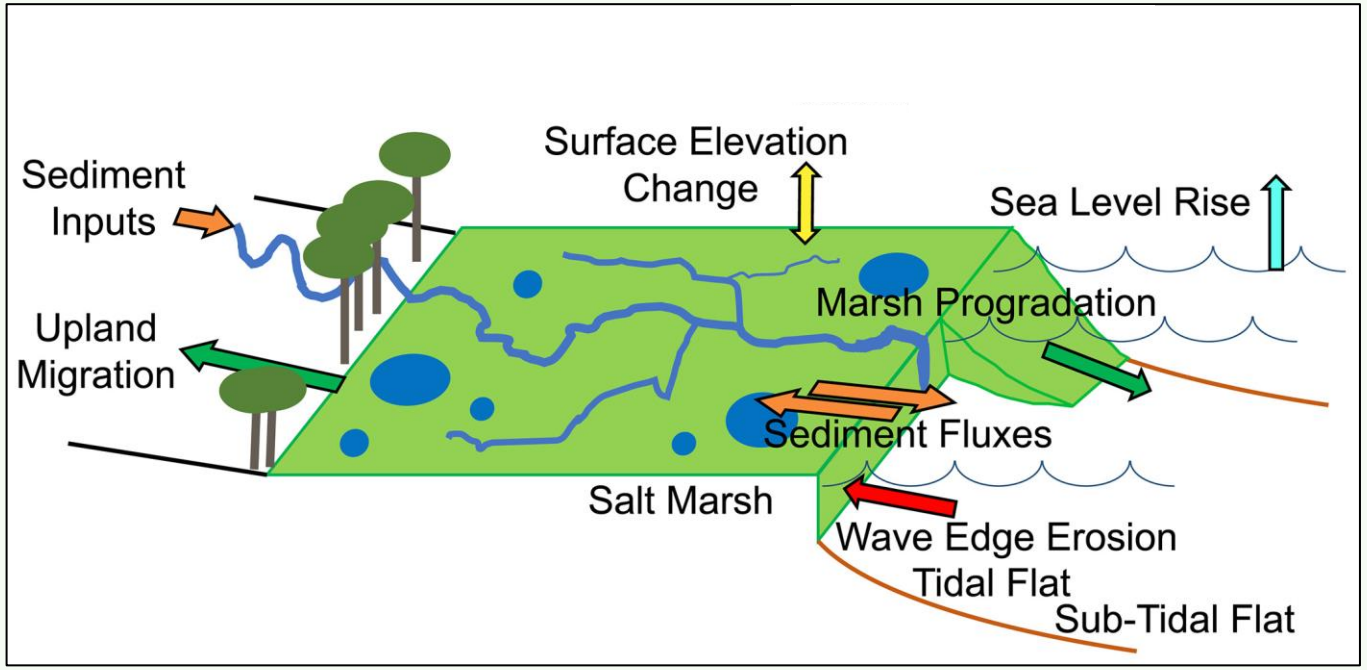


Image: Fagherazzi et al., 2020

Background

Tidal Marshes are Dynamic!

Influences on marsh evolution:

- Elevation with respect to the tide
- **Orientation to wind direction**
- Wave energy
- Vegetation type
- Shoreline structure
- Sediment supply
- Land availability

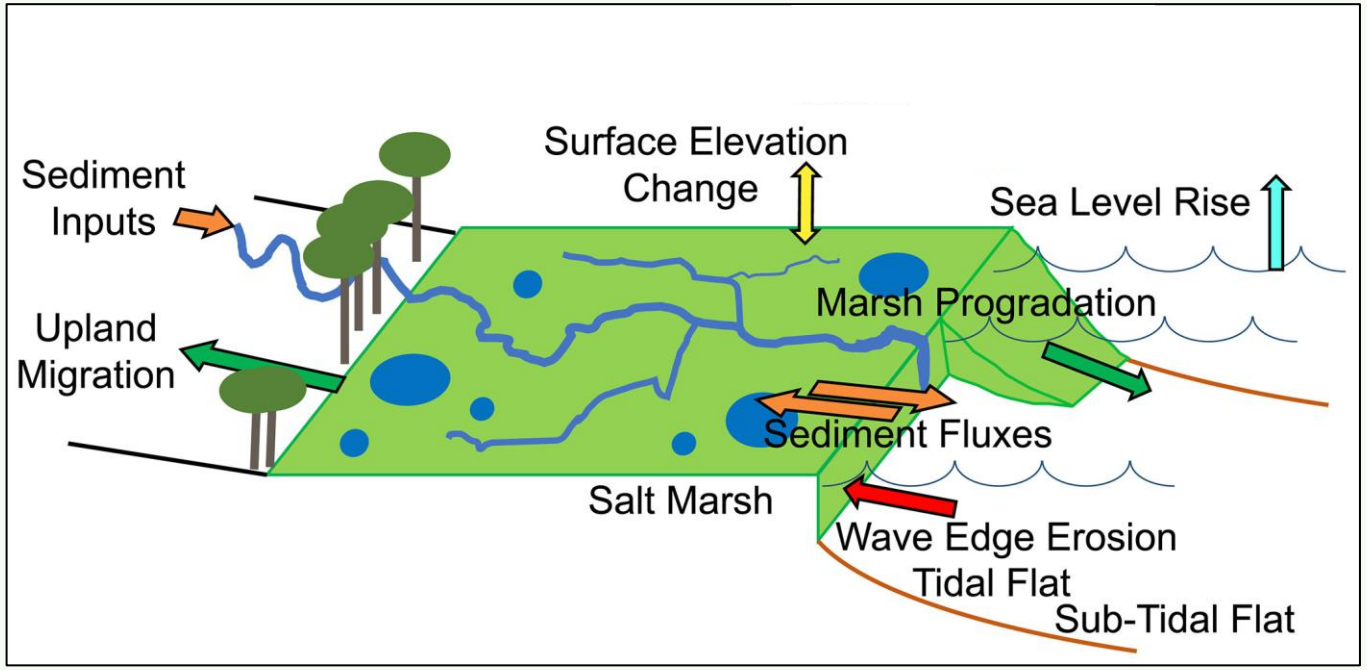


Image: Fagherazzi et al., 2020

Tidal Marshes are Dynamic!

Influences on marsh evolution:

- Elevation with respect to the tide
- Orientation to wind direction
- **Wave energy**
- Vegetation type
- Shoreline structure
- Sediment supply
- Land availability

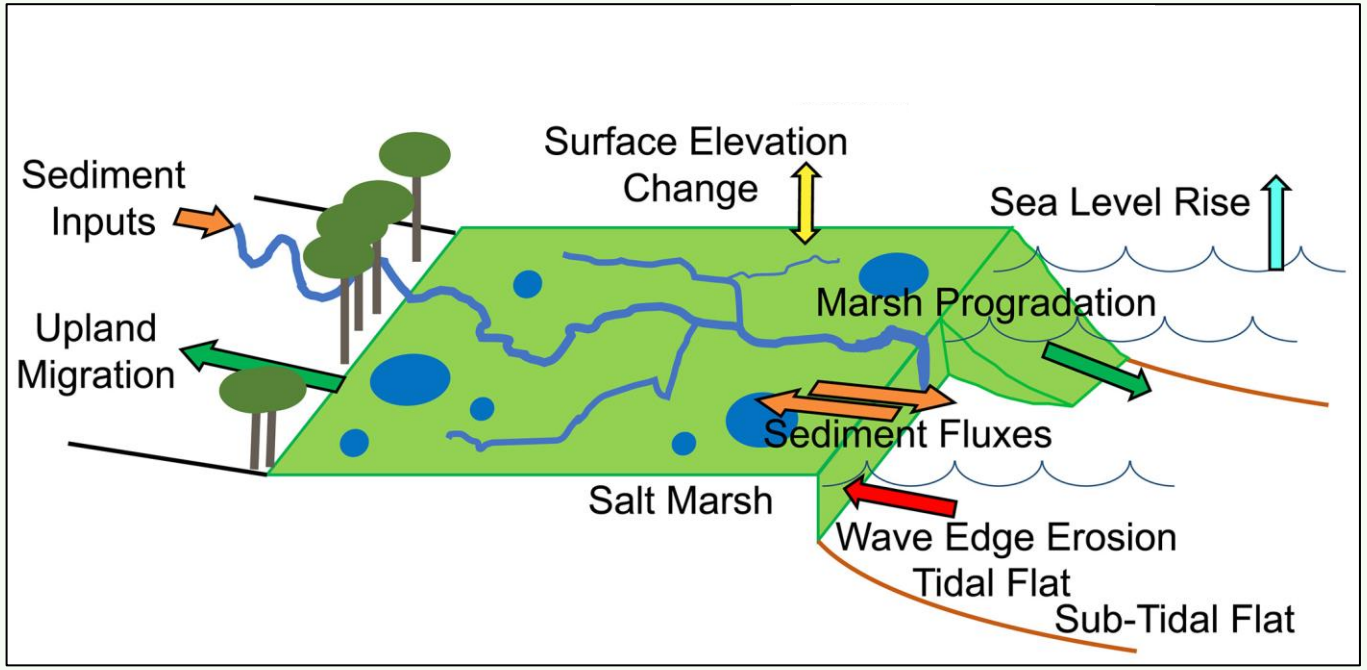


Image: Fagherazzi et al., 2020

Background

Tidal Marshes are Dynamic!

Influences on marsh evolution:

- Elevation with respect to the tide
- Orientation to wind direction
- Wave energy
- Vegetation type
- Shoreline structure
- **Sediment supply**
- Land availability

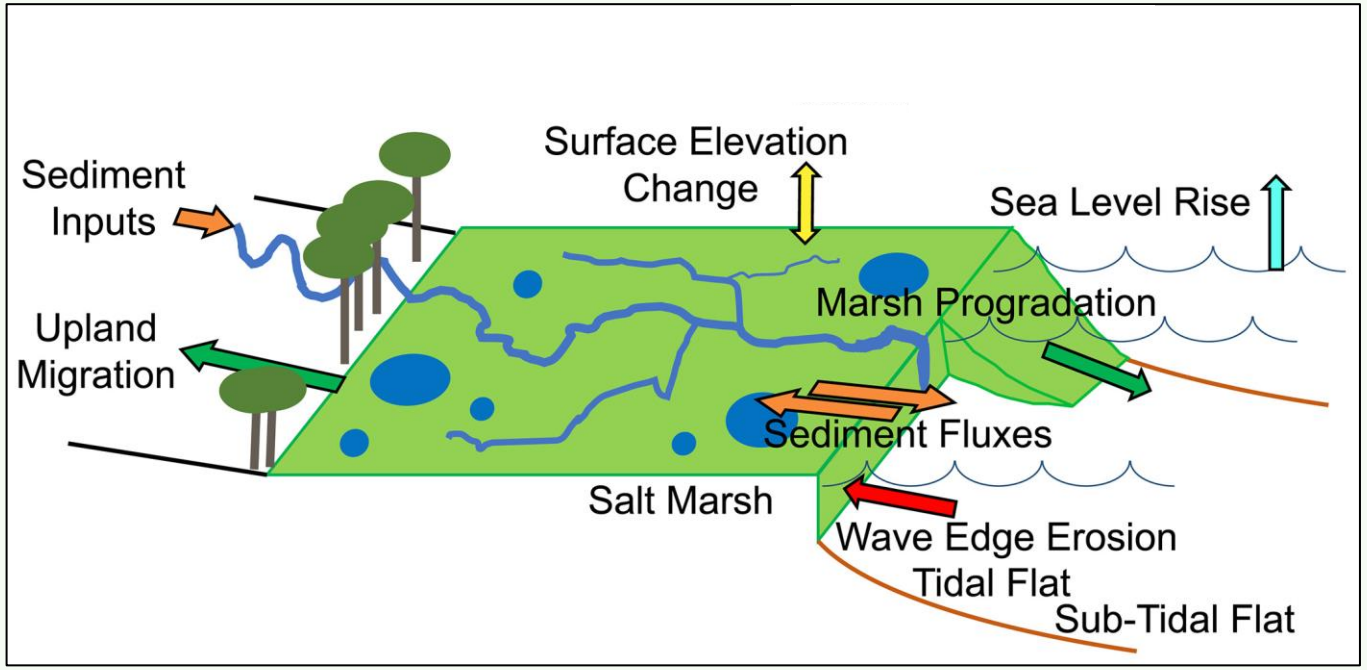


Image: Fagherazzi et al., 2020

Background

Marsh Evolution to Avoid Drowning

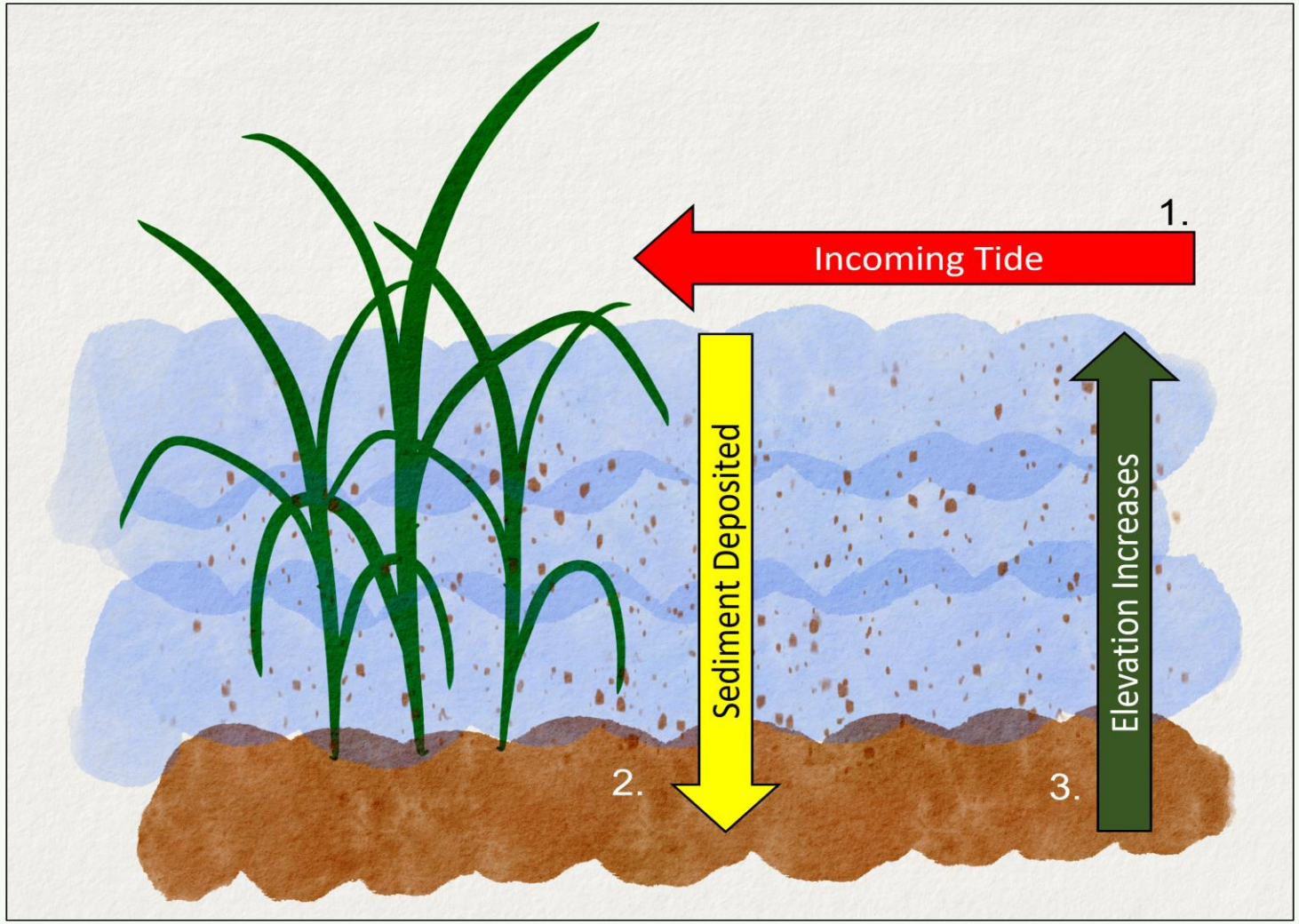
1. **Vertical Accretion**
2. **Landward Migration**

Marsh Evolution to Avoid Drowning

1.

Vertical Accretion: Vegetation-Sedimentation Feedback Loop

Redfield, A. C., & Rubin, M., 1962



+ plant decaying matter, root/rhizome expansion

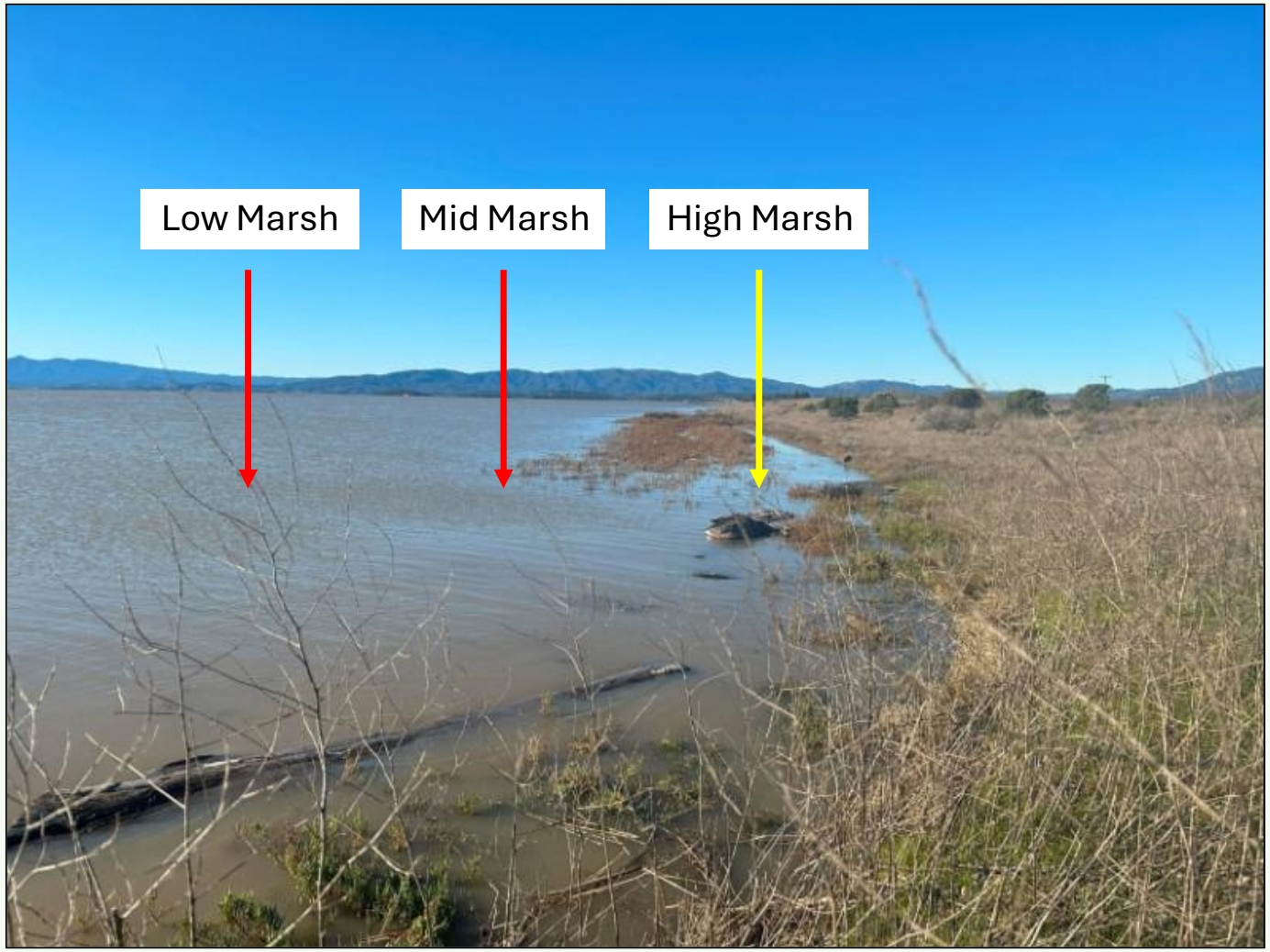
Background

Marsh Evolution to Avoid Drowning

2.

Landward Migration

Fagherazzi *et al.*, 2019



King Tide, Sears Point, 2023

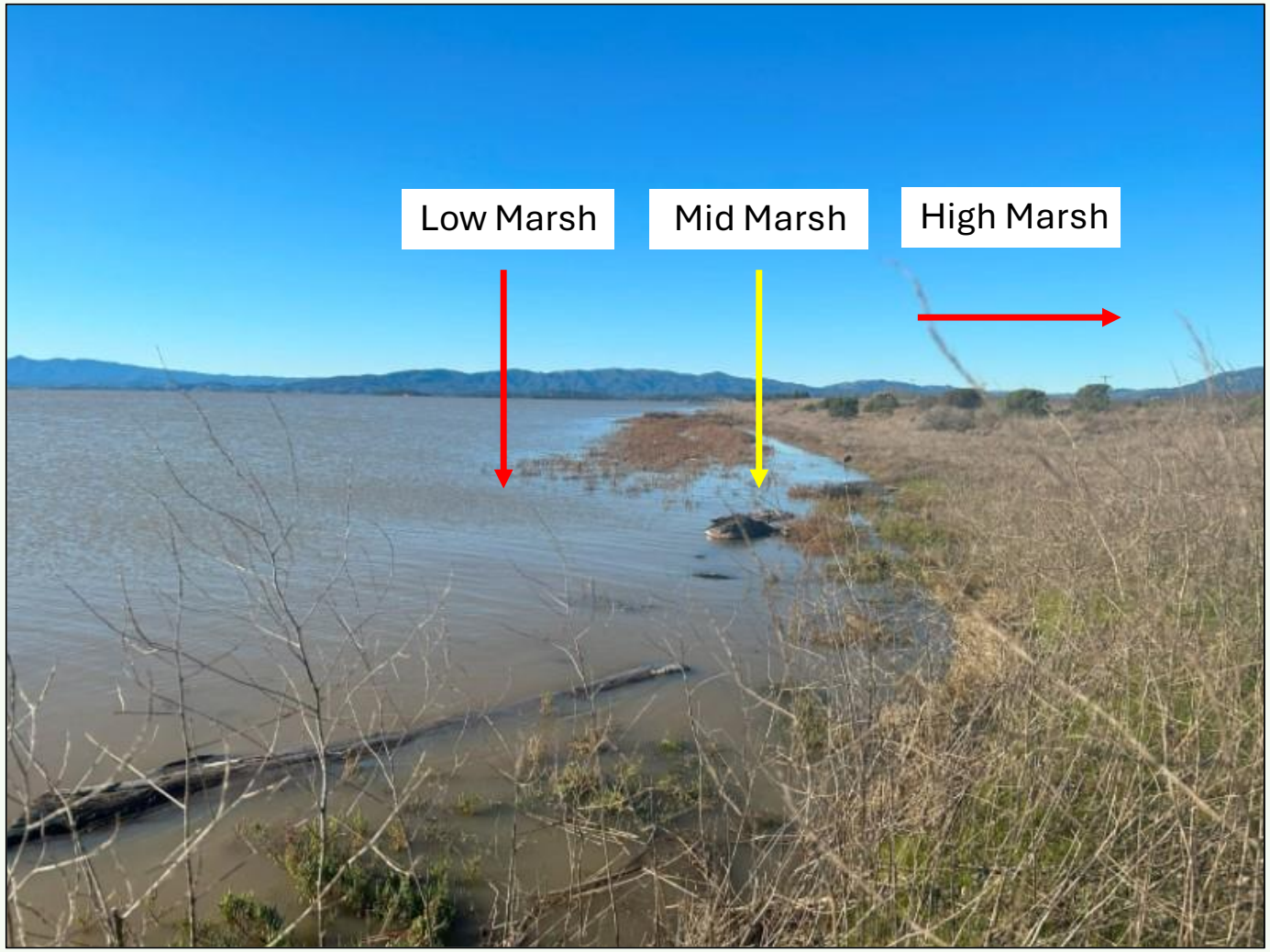
Background

Marsh Evolution to Avoid Drowning

2.

Landward Migration

Fagherazzi *et al.*, 2019



King Tide, Sears Point, 2023

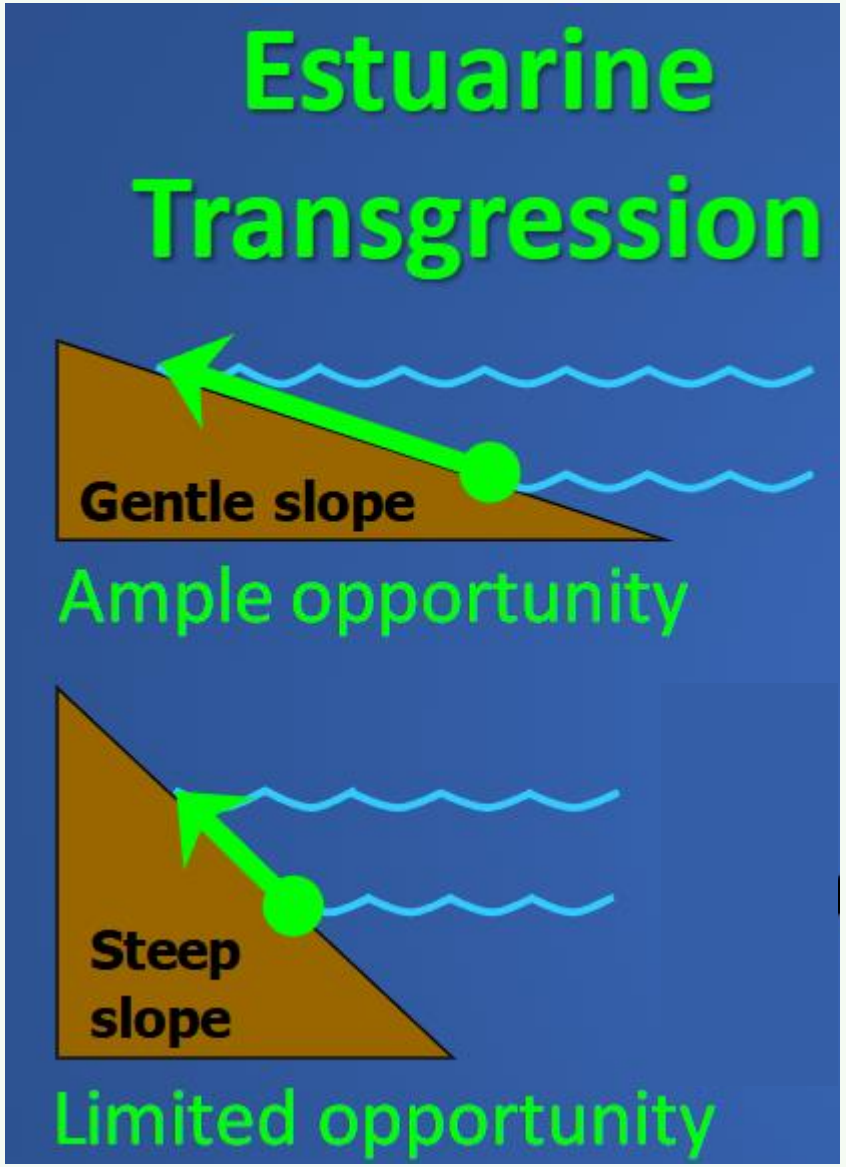
Background

Marsh Evolution to Avoid Drowning

2.

Landward Migration

Fagherazzi *et al.*, 2019



Extend of landward migration potential depends on edge slope:

- Flatter - more
- Steeper - less
- and whether edge blocked by infrastructure.

Background

Marsh Evolution to Avoid Drowning

“Coastal Squeeze”

Doody, 2004

Image: COMPASS Apartment Listing , Seabrook Island, SC, 2024

Background

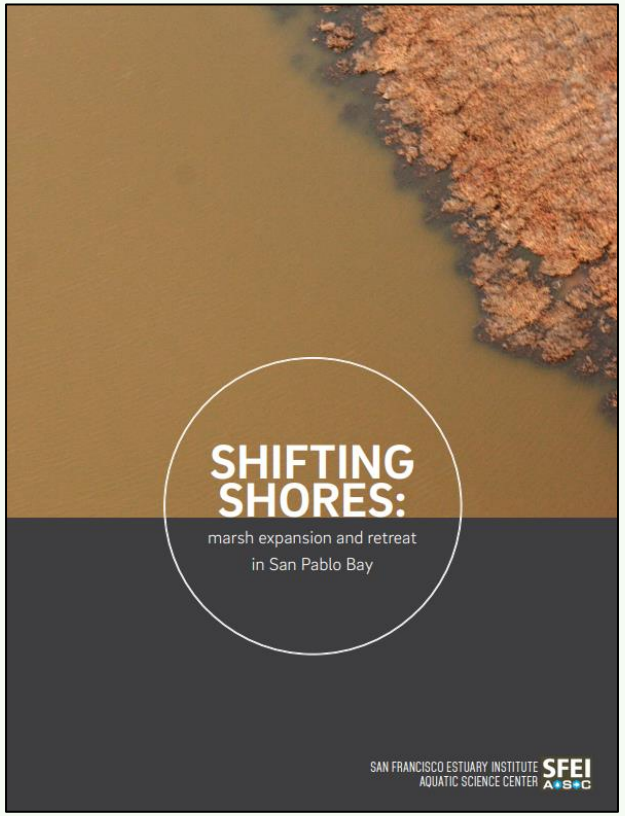
Lateral Bay Edge Retreat

Brinson *et al.*, 1995

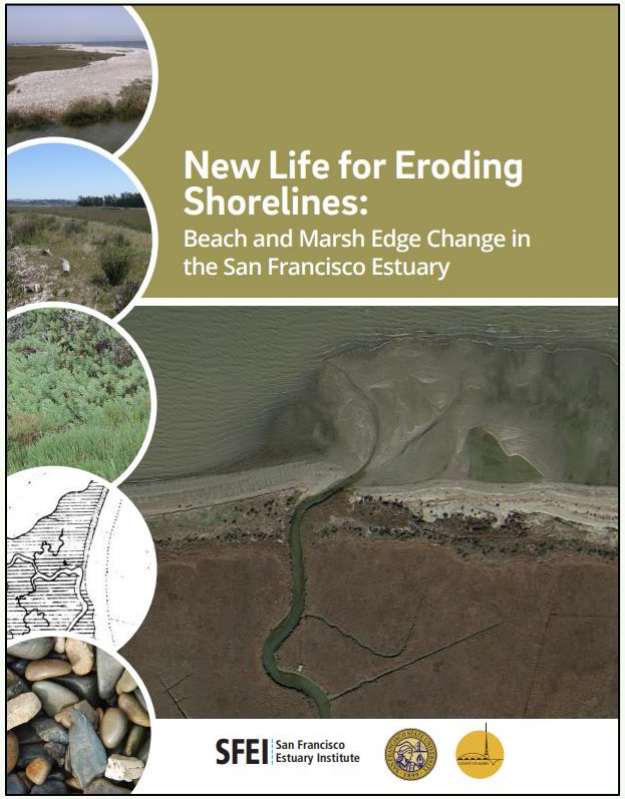
Images: Peter Baye, Sears Point, 2019

Background

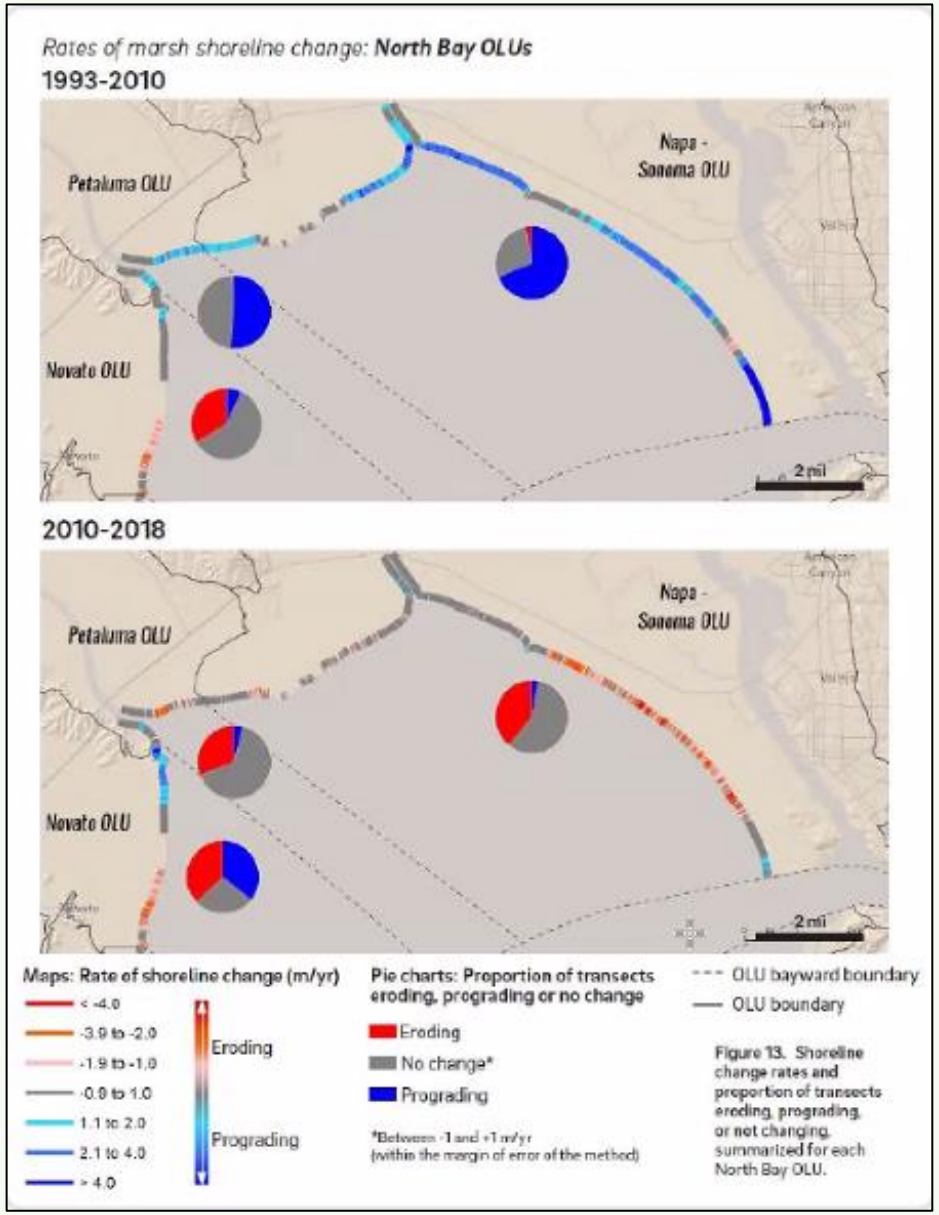
Lateral Bay Edge Retreat



Beagle & Solomon, 2015



Baye & SFEI, 2020



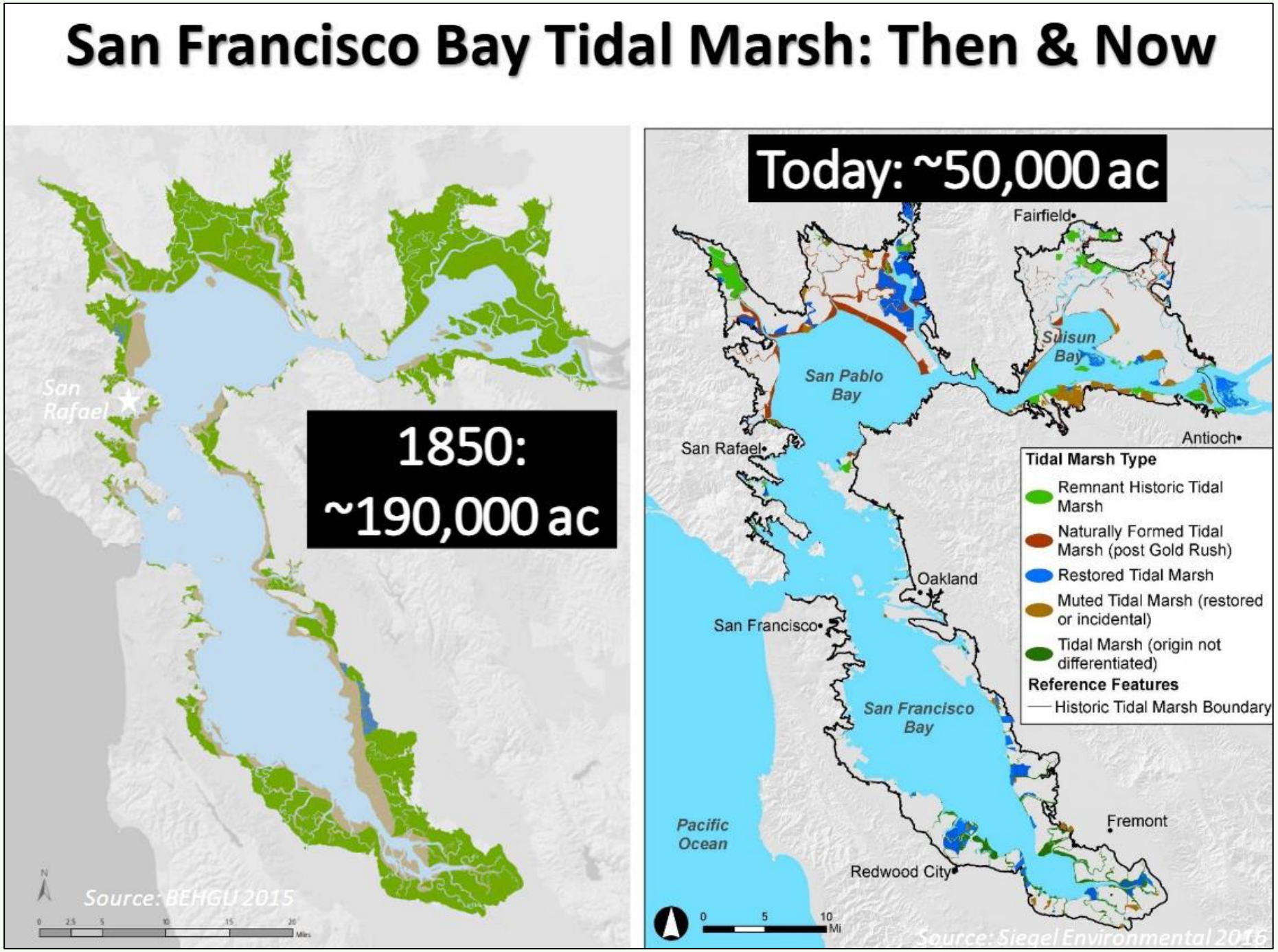
Background

90% of SF Bay's historic tidal salt marshes have been lost.

Nichols *et al.*, 1986

Background

San Francisco Bay Tidal Marsh: Then & Now



Project Aim

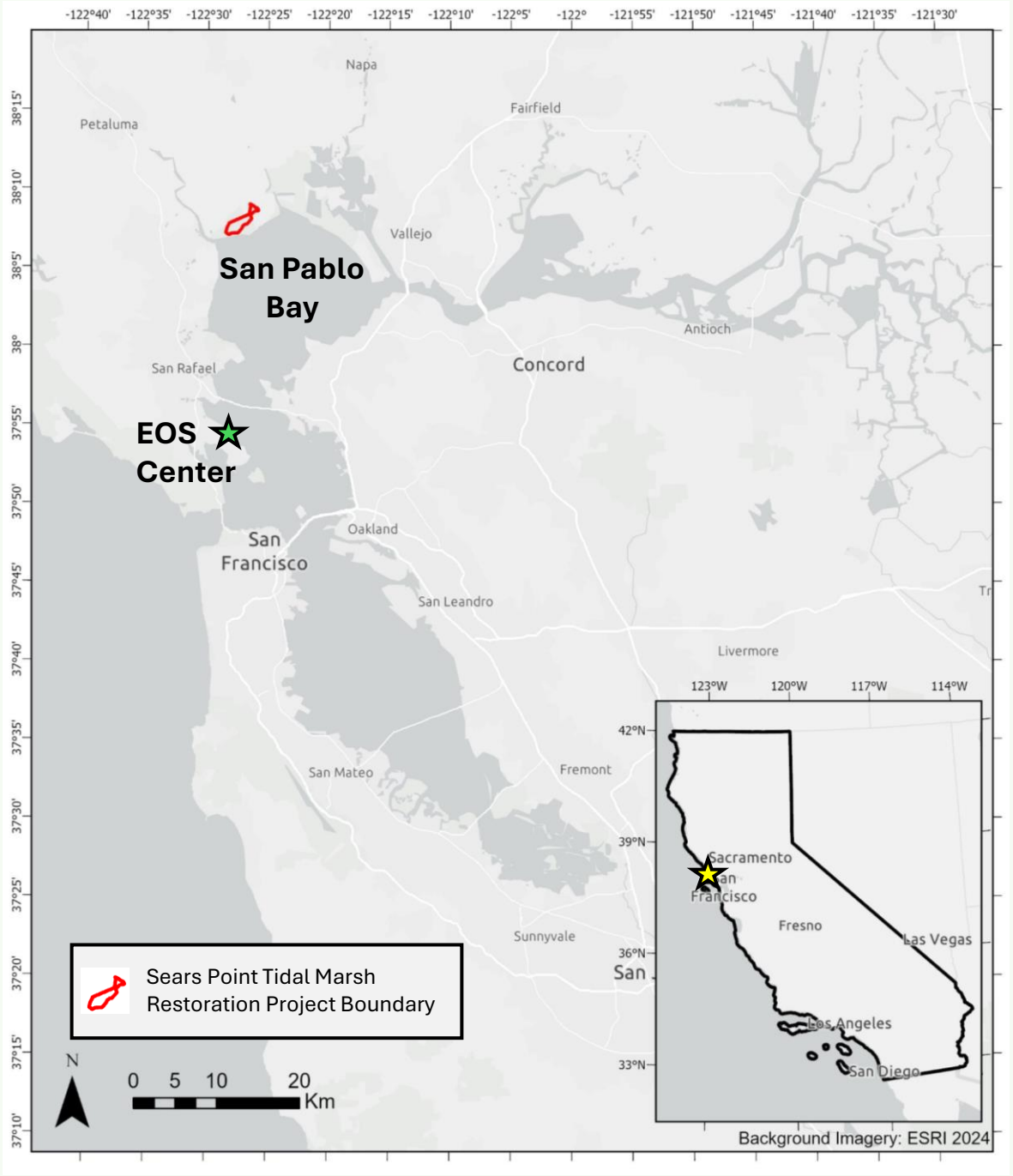
To inform future restoration projects on methods that could be beneficial for nature-based shoreline protection strategies.

Background

Project Site

Project Site: Sears Point

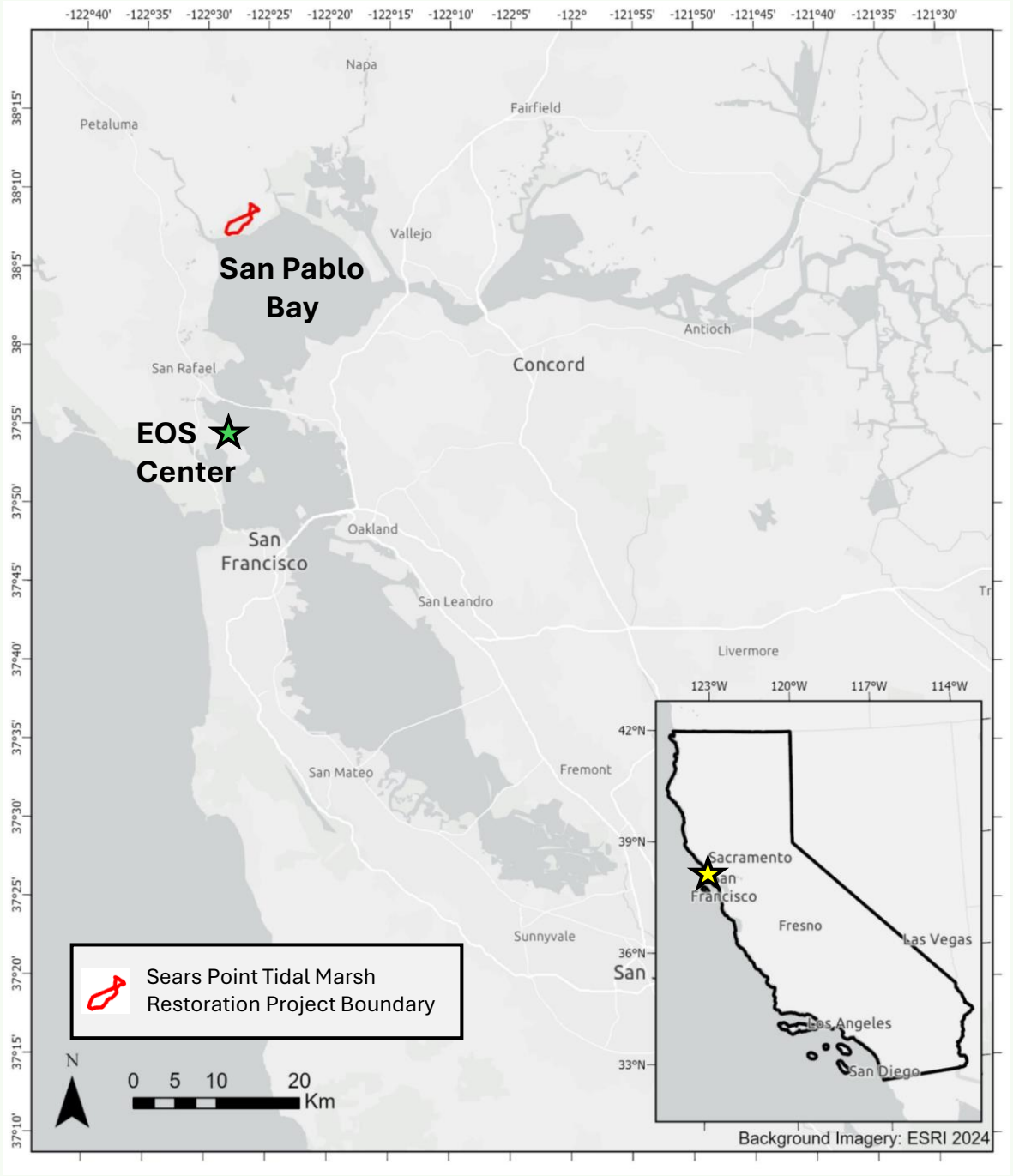
- San Pablo Bay -- Sonoma, California



Background

Project Site: Sears Point

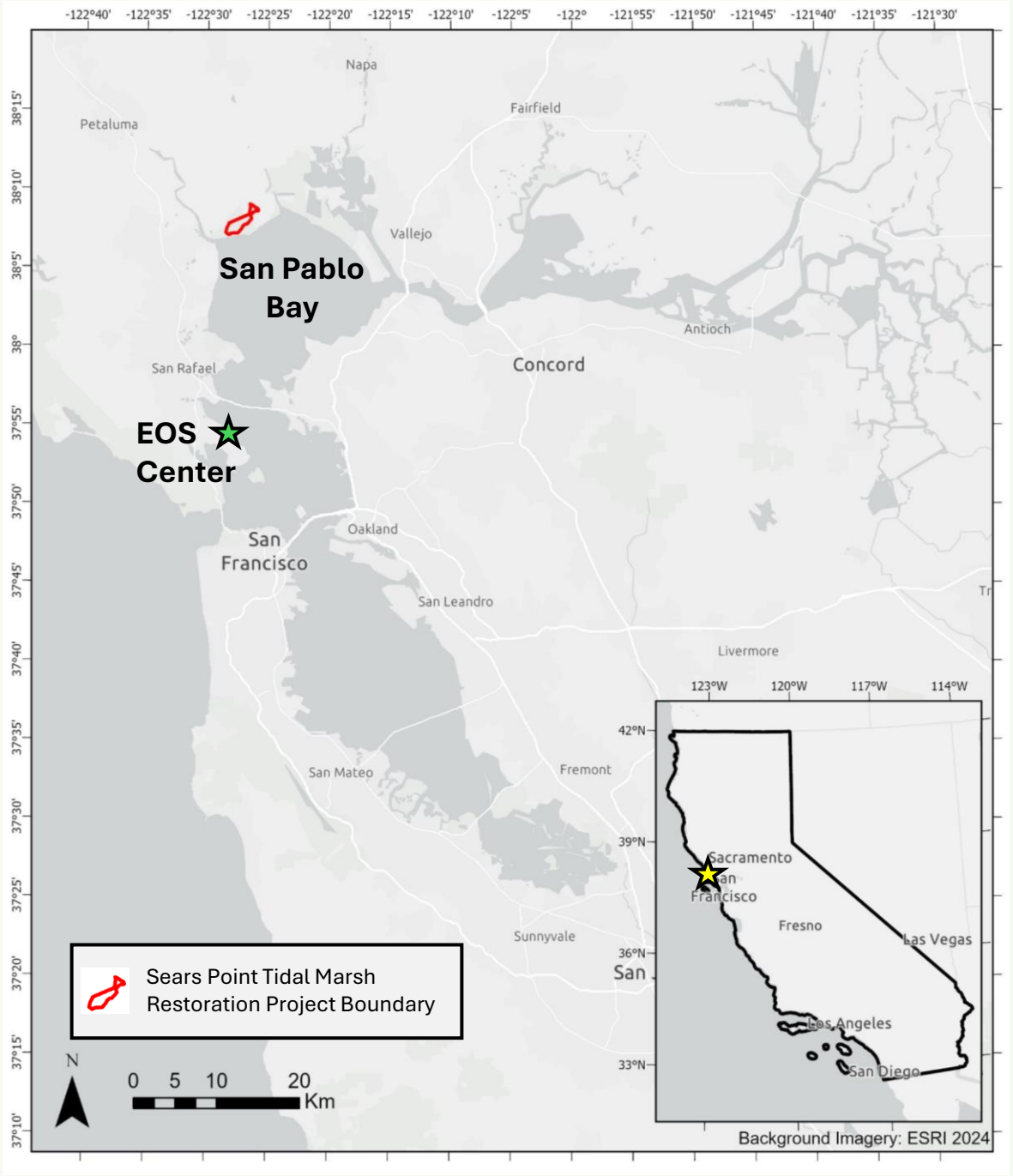
- San Pablo Bay -- Sonoma, California
- ~380 hectares (939 acres)
- Historic marsh land



Background

Project Site: Sears Point

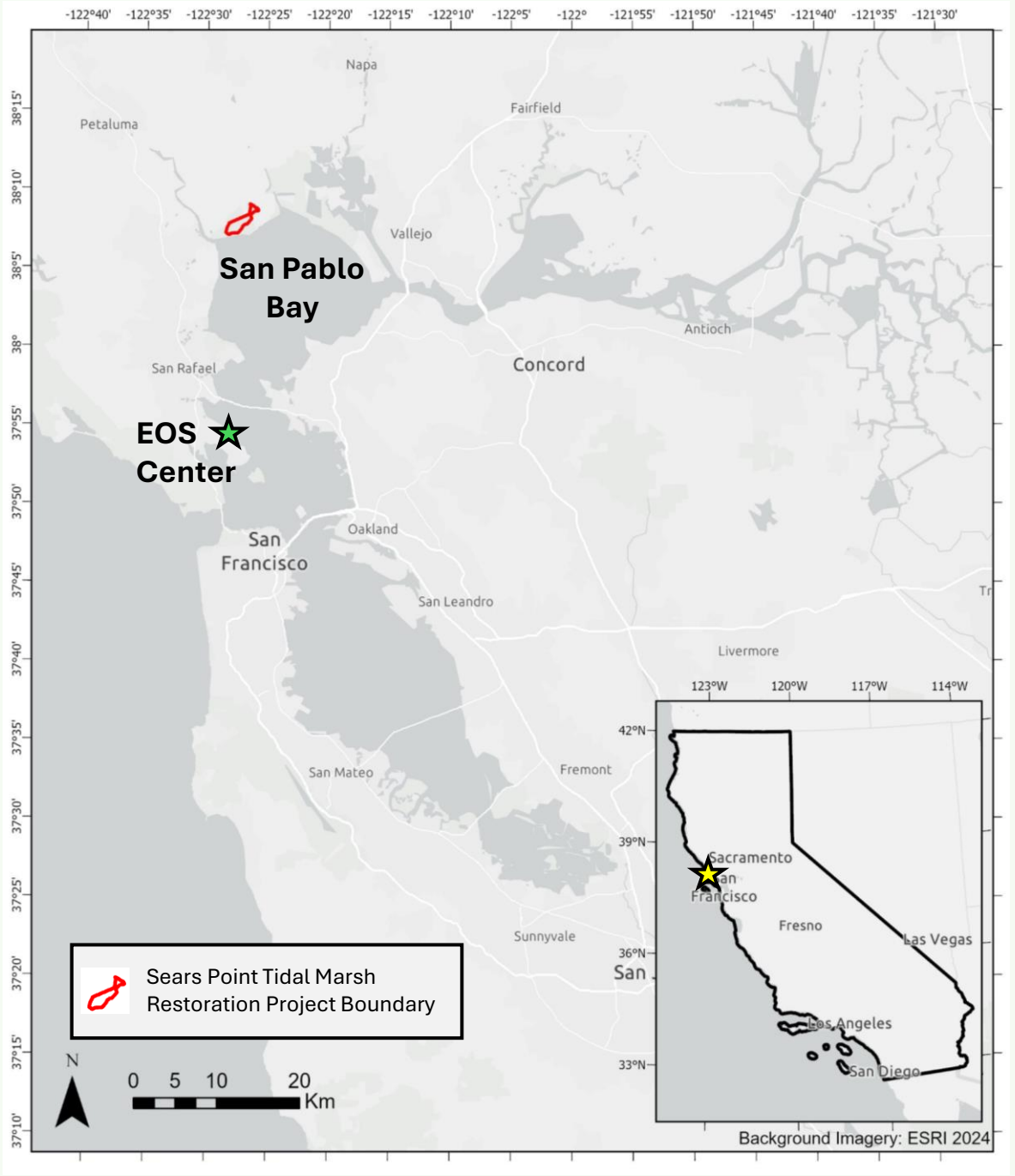
- San Pablo Bay -- Sonoma, California
- ~380 hectares (939 acres)
- Historic marsh land
- Diked/Farmed for last 150 years



Background

Project Site: Sears Point

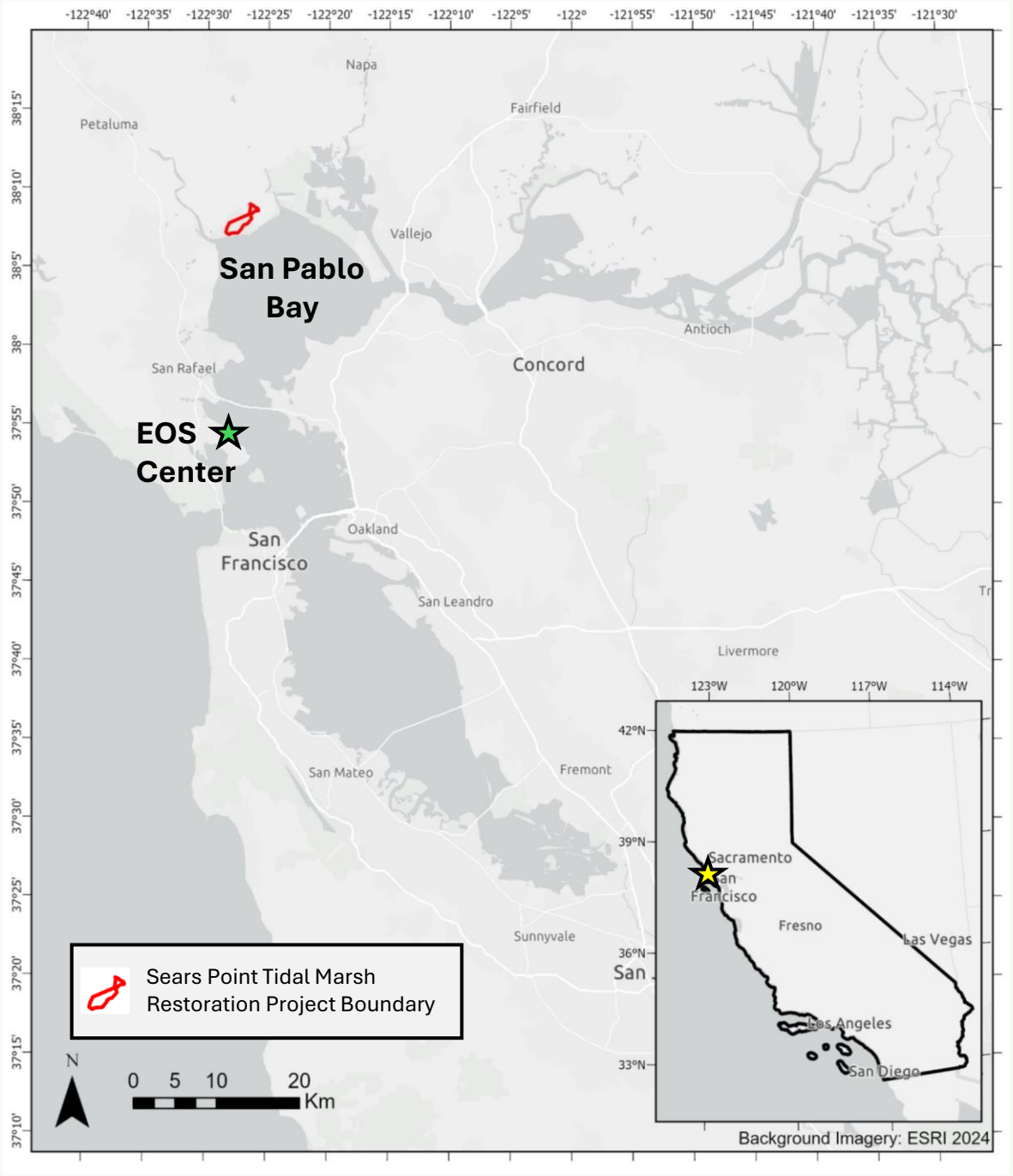
- San Pablo Bay -- Sonoma, California
- ~380 hectares (939 acres)
- Historic marsh land
- Diked/Farmed for last 150 years
- Subsided ~ 2m (6 ft)



Background

Project Site: Sears Point

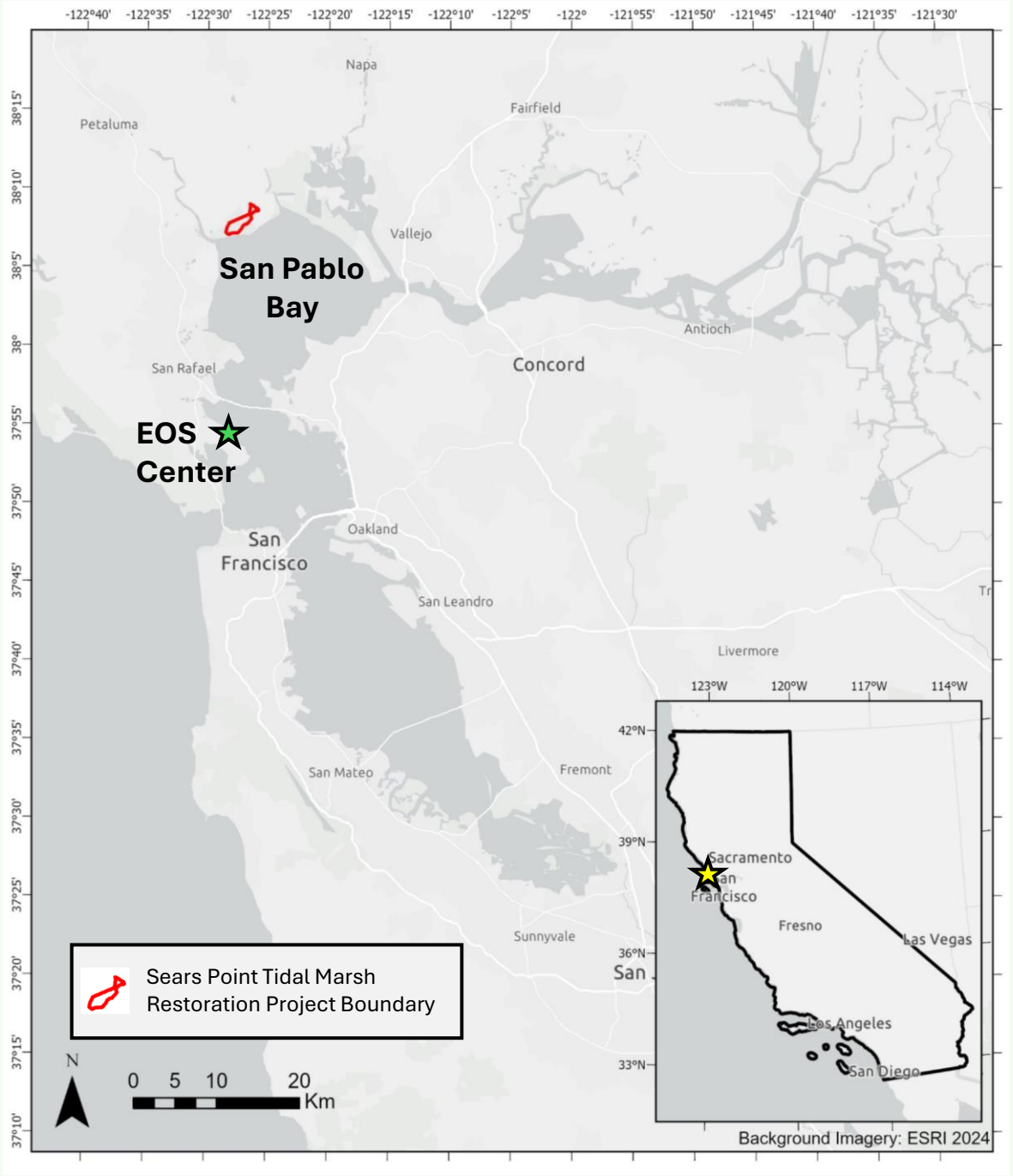
- San Pablo Bay -- Sonoma, California
- ~380 hectares (939 acres)
- Historic marsh land
- Diked/Farmed for last 150 years
- Subsided ~ 2m (6 ft)
- Acquired by Sonoma Land Trust 2004



Background

Project Site: Sears Point

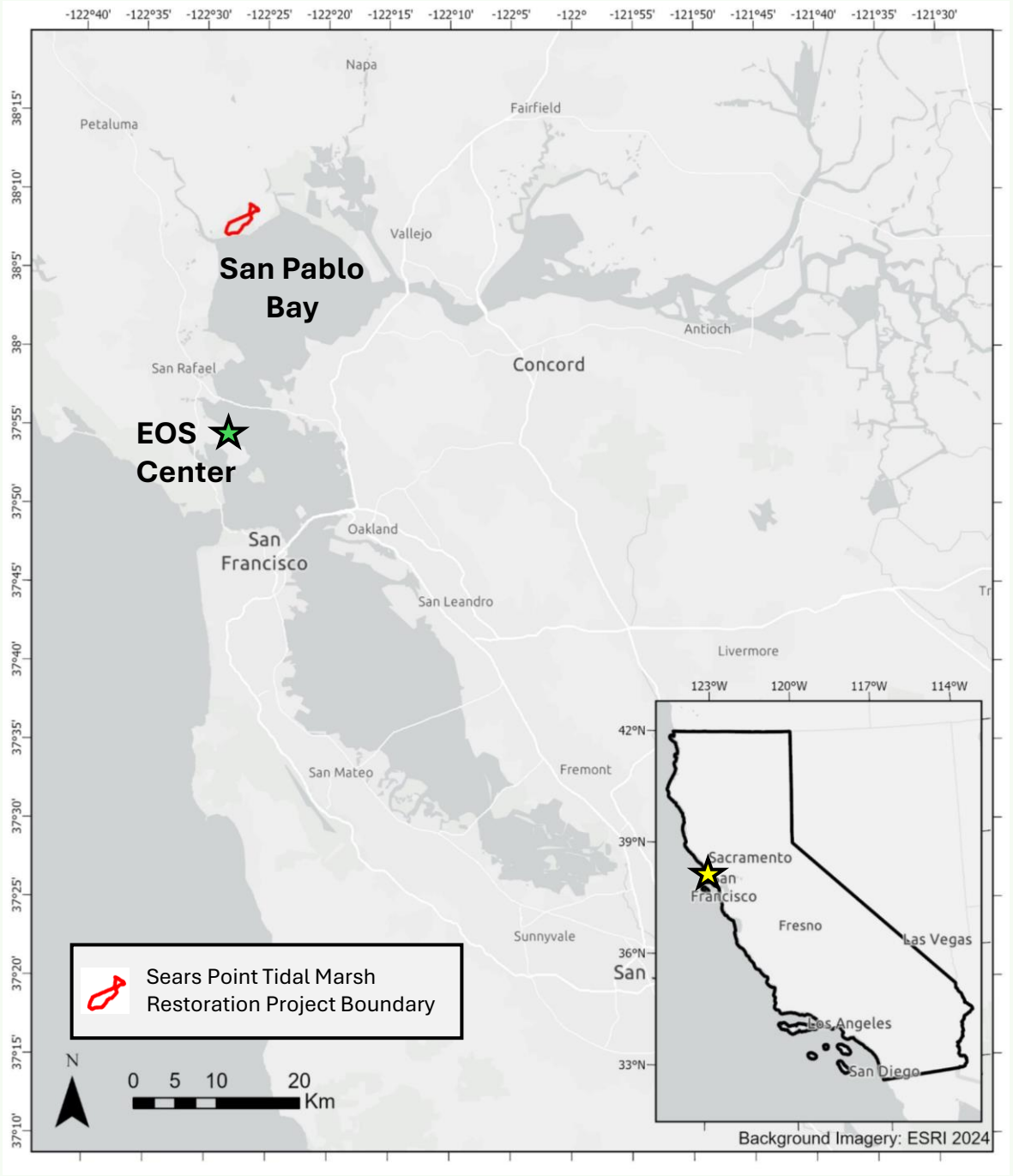
- San Pablo Bay -- Sonoma, California
- ~380 hectares (939 acres)
- Historic marsh land
- Diked/Farmed for last 150 years
- Subsided ~ 2m (6 ft)
- Acquired by Sonoma Land Trust 2004
- Initial restoration 2015



Background

Project Site: Sears Point

- San Pablo Bay -- Sonoma, California
- ~380 hectares (939 acres)
- Historic marsh land
- Diked/Farmed for last 150 years
- Subsided ~ 2m (6 ft)
- Acquired by Sonoma Land Trust 2004
- Initial restoration 2015
- Shoreline Repair 2021



Background

Project Site:
Sears Point Tidal Marsh Restoration Project

Initial Restoration 2015:

Goal:

- Protect dike lands to the north including Highway 37.
- Restore tidal marsh habitat for native flora and fauna.
- Provide public recreational access.
- Using nature-based strategies.

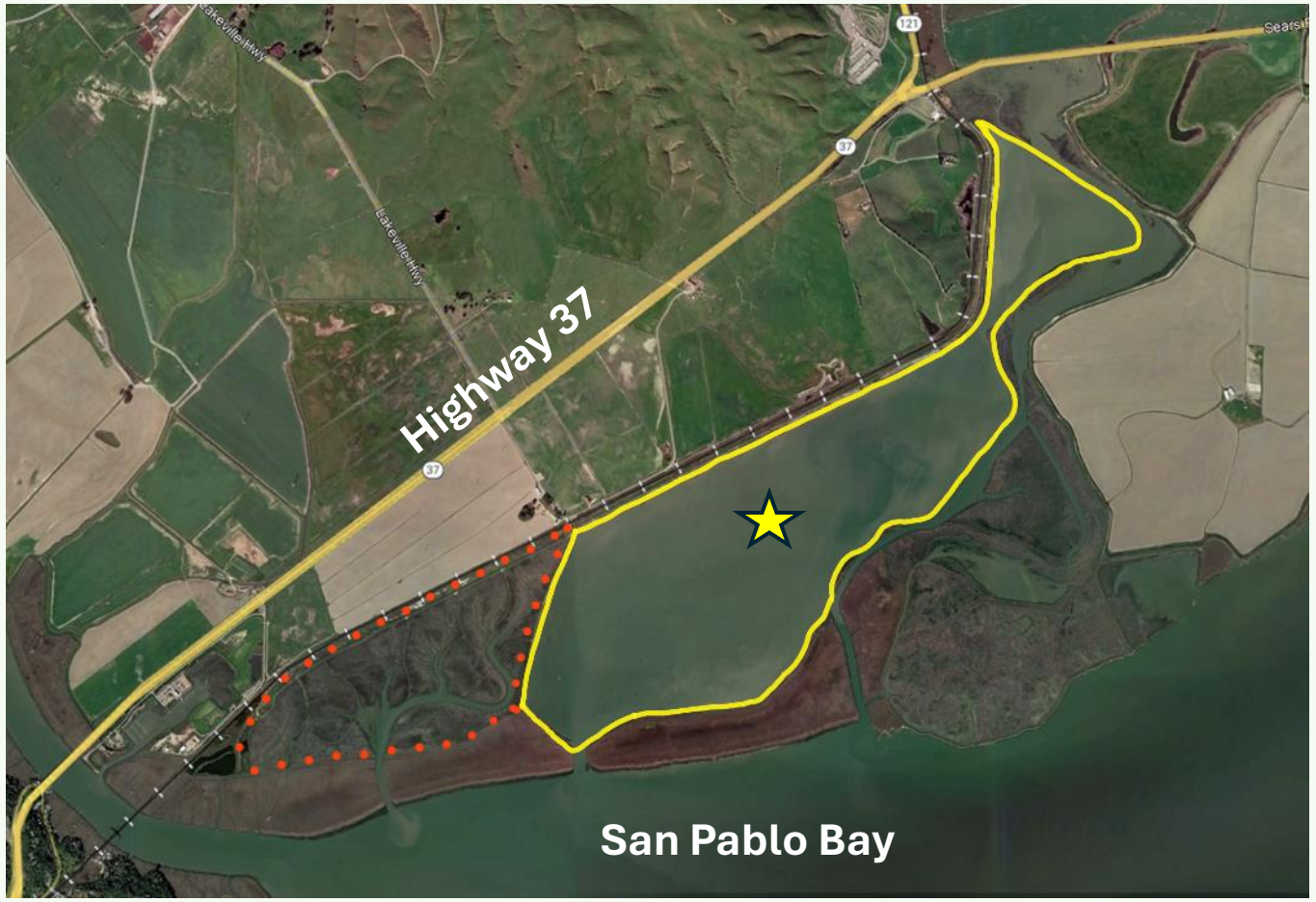


Image: Google Earth

Background

Nature-Based Strategies

Uses nature AND human-made structures

KEY: The latter does NOT dominate

Bilkovich et al. 2016

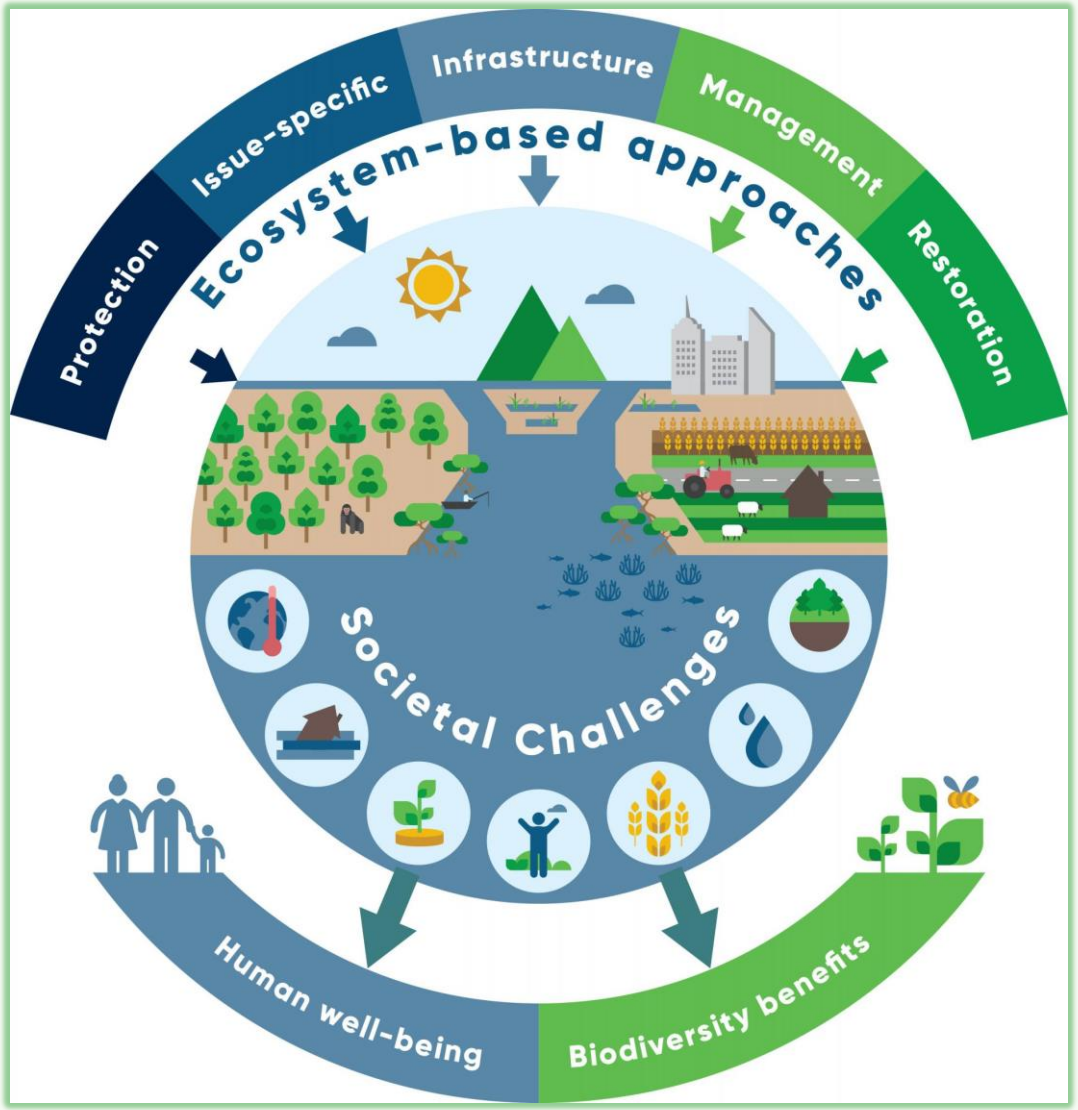


Image: IUCN World Conservation Congress

Background

Nature-Based Strategies

- Living Shoreline
- Green or blue-green infrastructure
- Soft Structure
- Ecosystem-based adaptation

Image: IUCN World Conservation Congress

Background

Project Site:
Sears Point Tidal Marsh Restoration Project

Initial Restoration 2015:

- Habitat control levee ✓

Background

Project Site:
Sears Point Tidal Marsh Restoration Project

Initial Restoration 2015:

- Habitat control levee ✓
- 500 marsh mounds ✓

Background

Project Site:
Sears Point Tidal Marsh Restoration Project

Initial Restoration 2015:

- Habitat control levee ✓
- 500 marsh mounds ✓
- Sacrificial vegetation on mounds and levee ✗

Background

Project Site:
Sears Point Tidal Marsh Restoration Project

Initial Restoration 2015:

- Habitat control levee ✓
- 500 marsh mounds ✓
- Sacrificial vegetation on mounds and levee ✗

Result:

- Erosion on levee and marsh mounds

Background

Project Site:
Sears Point Tidal Marsh Restoration Project

Initial Restoration 2015:

- Habitat control levee ✓
- 500 marsh mounds ✓
- Sacrificial vegetation on mounds and levee ✗

Result:

- Erosion on levee and marsh mounds
- Risk to flood control function

Background

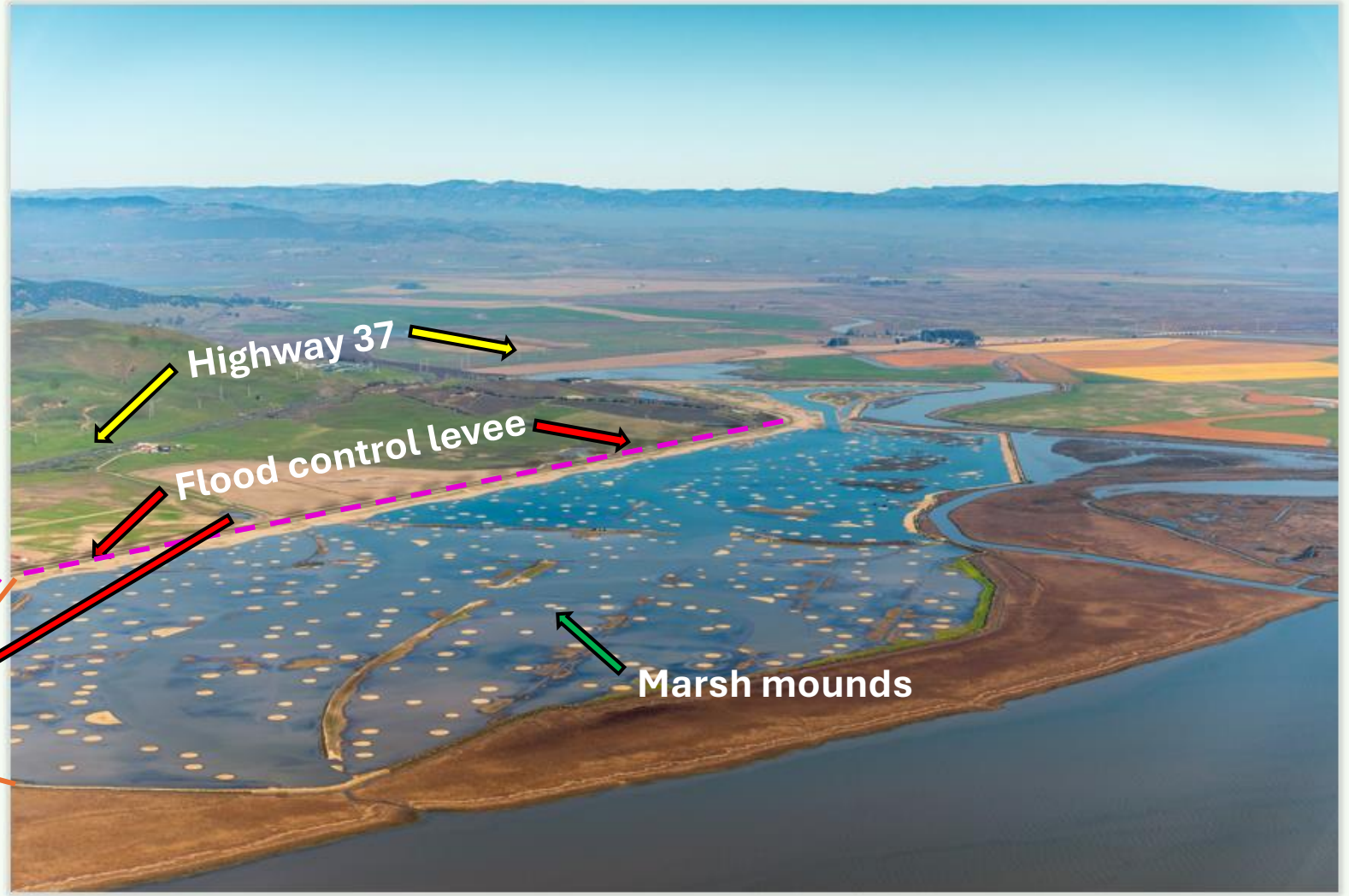
Project Site:
Sears Point Tidal Marsh Restoration Project

Initial Restoration 2015:

- Habitat control levee ✓
- 500 marsh mounds ✓
- Sacrificial vegetation on mounds and levee ✗

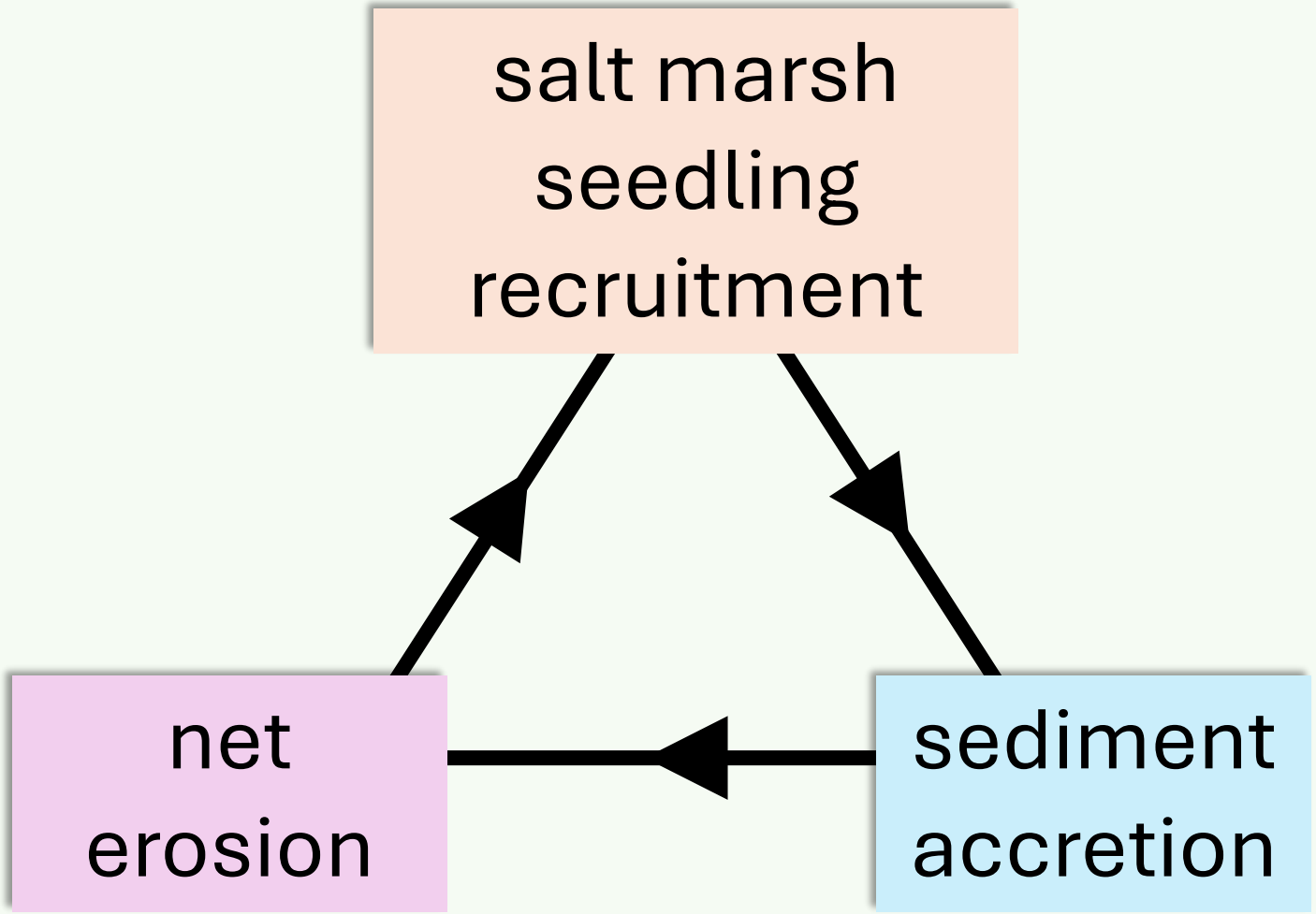
Result:

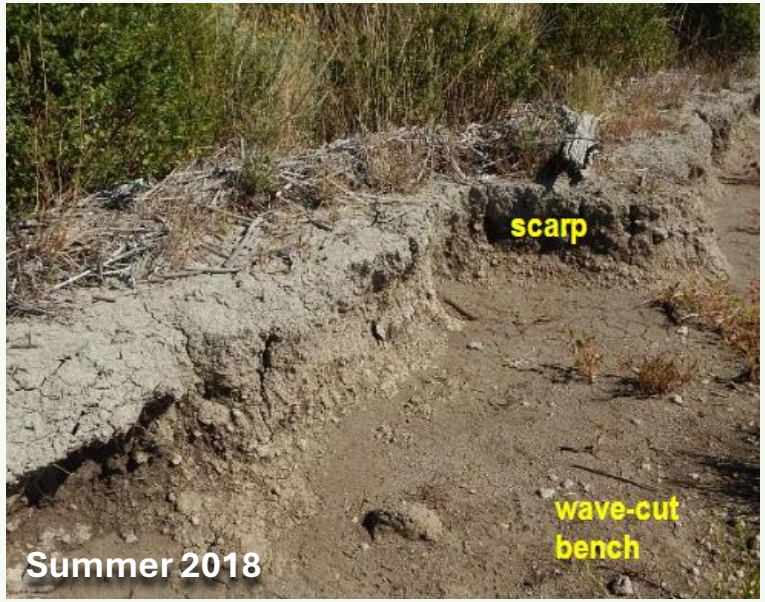
- Erosion on levee and marsh mounds
- Risk to flood control function
- Failure for habitat to form



Background

The cyclical erosion continued...



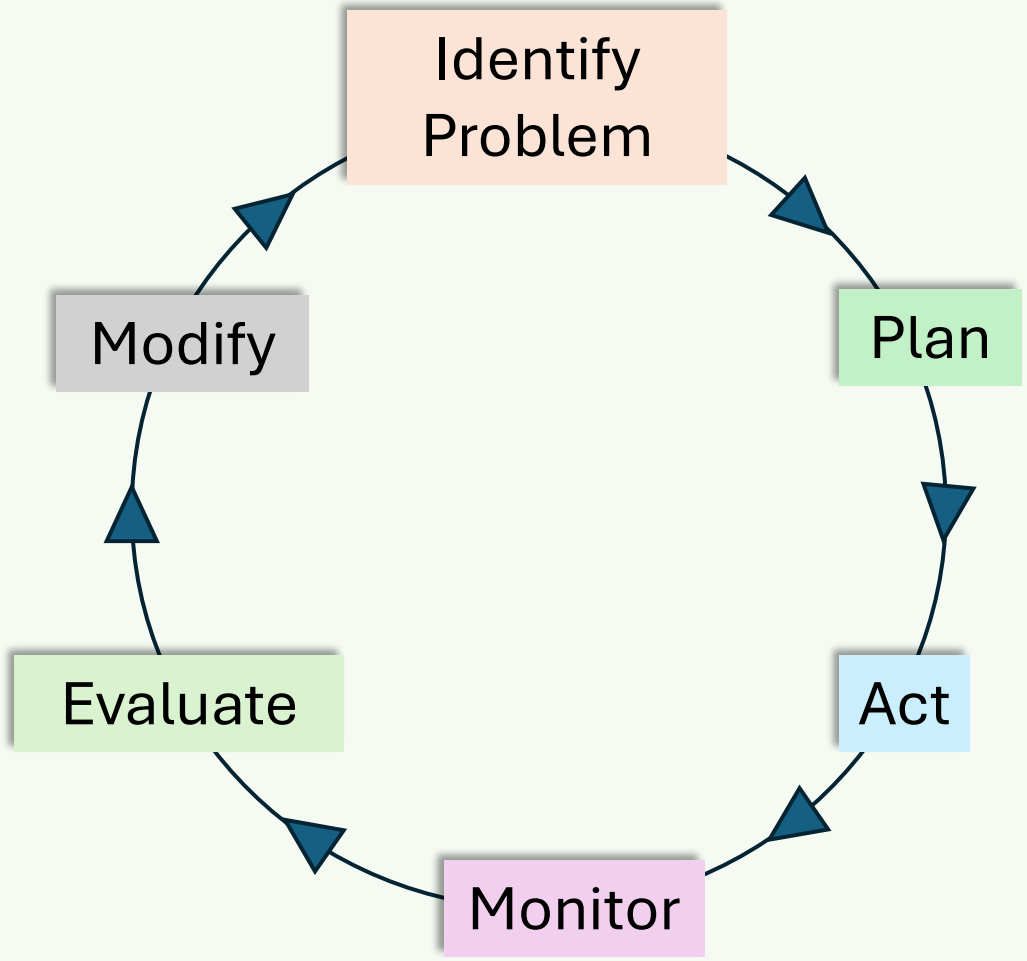


Images: Peter Baye, 2019

An adaptive management approach was needed...

Adaptive Management Cycle

C.S. Holling, 1973; Lancia *et al.*, 1996



Project Site:
Sears Point Levee Adaptive Management Project

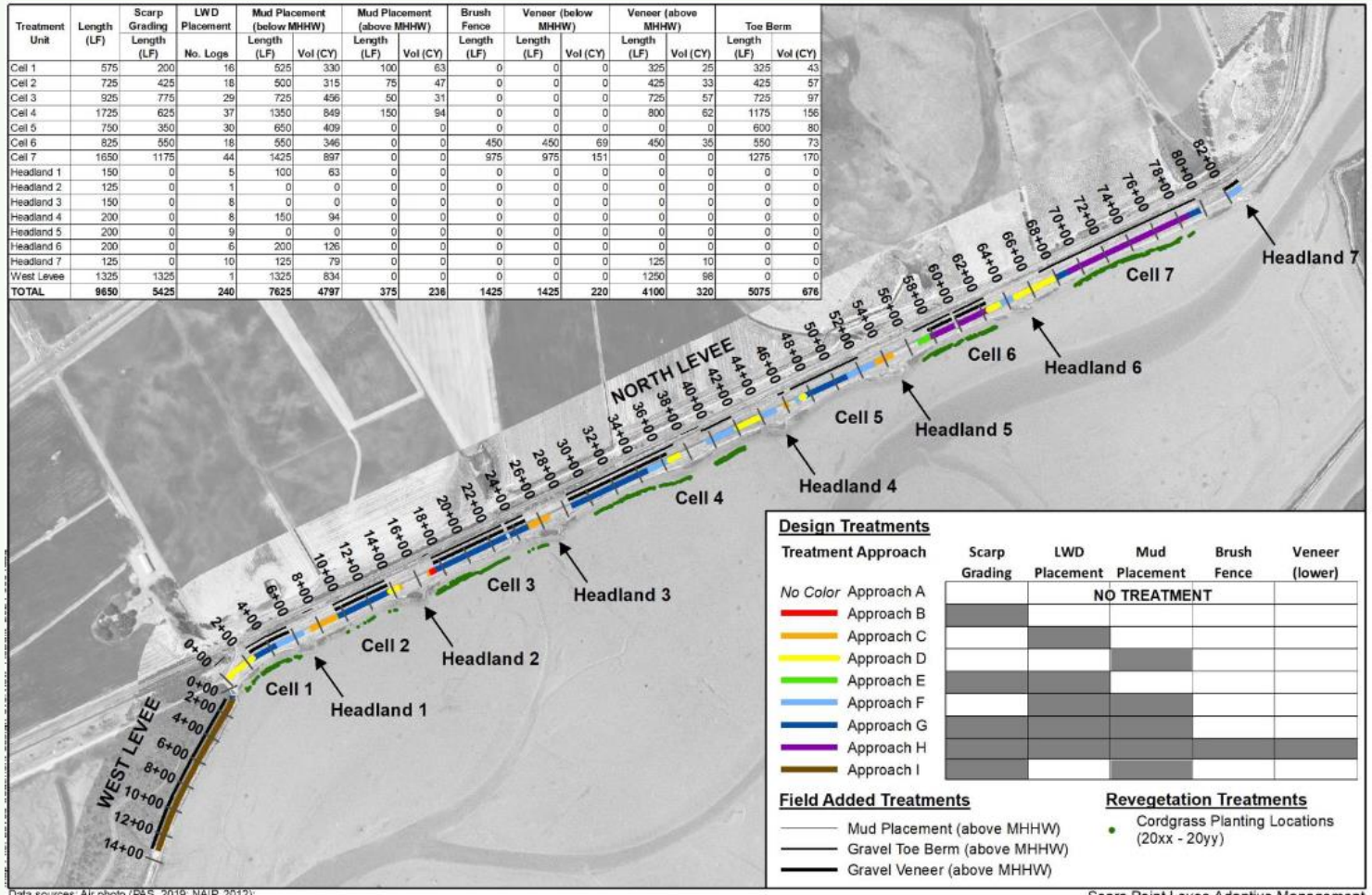
Shoreline Repair 2021:

Goal:

- Stop lateral erosion
- Restore habitat levee slopes
- Encourage:
  - emergent marsh vegetation
  - vertical accretion

Background

Treatment Unit	Length (LF)	Scarp Grading Length (LF)	LWD Placement No. Logs	Mud Placement (below MHHW) Length (LF)	Mud Placement (below MHHW) Vol (CY)	Mud Placement (above MHHW) Length (LF)	Mud Placement (above MHHW) Vol (CY)	Brush Fence Length (LF)	Veneer (below MHHW) Length (LF)	Veneer (below MHHW) Vol (CY)	Veneer (above MHHW) Length (LF)	Veneer (above MHHW) Vol (CY)	Toe Berm Length (LF)	Toe Berm Vol (CY)
Cell 1	575	200	16	525	330	100	63	0	0	0	325	25	325	43
Cell 2	725	425	18	500	315	75	47	0	0	0	425	33	425	57
Cell 3	925	775	29	725	456	50	31	0	0	0	725	57	725	97
Cell 4	1725	625	37	1350	849	150	94	0	0	0	800	62	1175	156
Cell 5	750	350	30	650	409	0	0	0	0	0	0	0	600	80
Cell 6	825	550	18	550	346	0	0	450	450	69	450	35	550	73
Cell 7	1650	1175	44	1425	897	0	0	975	975	151	0	0	1275	170
Headland 1	150	0	5	100	63	0	0	0	0	0	0	0	0	0
Headland 2	125	0	1	0	0	0	0	0	0	0	0	0	0	0
Headland 3	150	0	8	0	0	0	0	0	0	0	0	0	0	0
Headland 4	200	0	8	150	94	0	0	0	0	0	0	0	0	0
Headland 5	200	0	9	0	0	0	0	0	0	0	0	0	0	0
Headland 6	200	0	6	200	126	0	0	0	0	0	0	0	0	0
Headland 7	125	0	10	125	79	0	0	0	0	0	125	10	0	0
West Levee	1325	1325	1	1325	834	0	0	0	0	0	1250	98	0	0
TOTAL	9650	5425	240	7625	4797	375	236	1425	1425	220	4100	320	5075	676



Project Site:
Sears Point Levee Adaptive Management Project

Shoreline Repair 2021:

- **Salt marsh vegetation added** (2019-2021)

Image: Stuart Siegel

Image: SP Restoration Project Monitoring Report 2015-2020

Background

Project Site:
Sears Point Levee Adaptive Management Project

Shoreline Repair 2021:

- **Shoreline regraded into a low angle slope**

Image: SPLAMP Report 2022

Background

Project Site:
Sears Point Levee Adaptive Management Project

Shoreline Repair 2021:

- Shoreline regraded into a low angle slope
- **Large-woody debris installation (logs)**

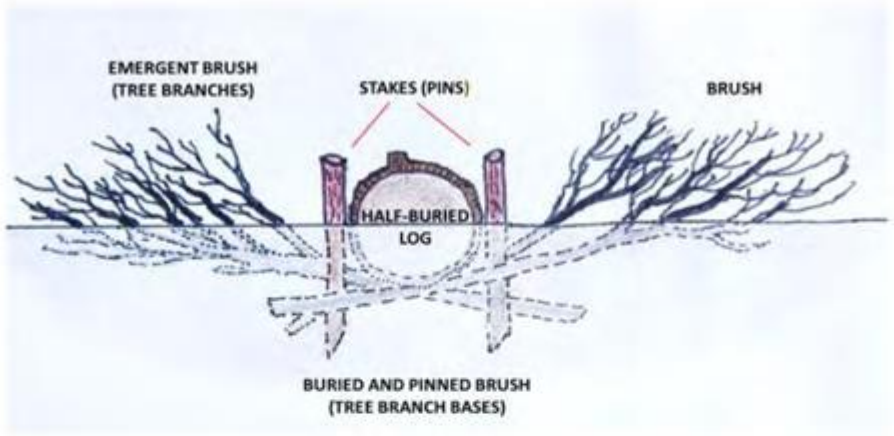


Figure 9. Cross Section View of Typical Woody Debris Structure

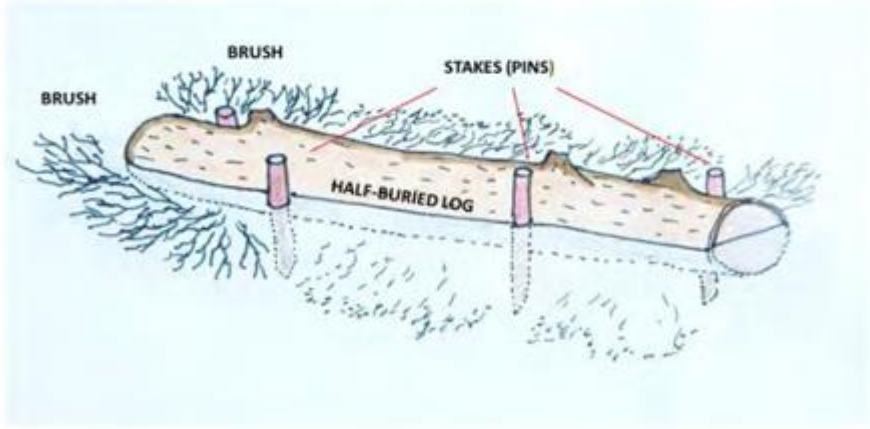


Figure 10. Oblique View of Typical Woody Debris Structure

Images: SPLAMP Report 2022

Background

Project Site:
Sears Point Levee Adaptive Management Project

Images: SPLAMP Report 2022

Background

Project Site:
Sears Point Levee Adaptive Management Project

Shoreline Repair 2021:

- Shoreline regraded into a low angle slope
- Large-woody debris installation
- **<u>Bay side of Logs</u>**:
  - **Loose crushed dried bay mud**

Bay

Images: SPLAMP Report 2022

Background

Project Site:
Sears Point Levee Adaptive Management Project

Shoreline Repair 2021:

- Shoreline regraded into a low angle slope
- Large-woody debris installation
- Bay side of Logs:
  - Crushed dried bay mud
- **Land side of logs:**
  - **Thin layer small angular gravel**
  - **Small rounded gravel**

Images: SPLAMP Report 2022

Background

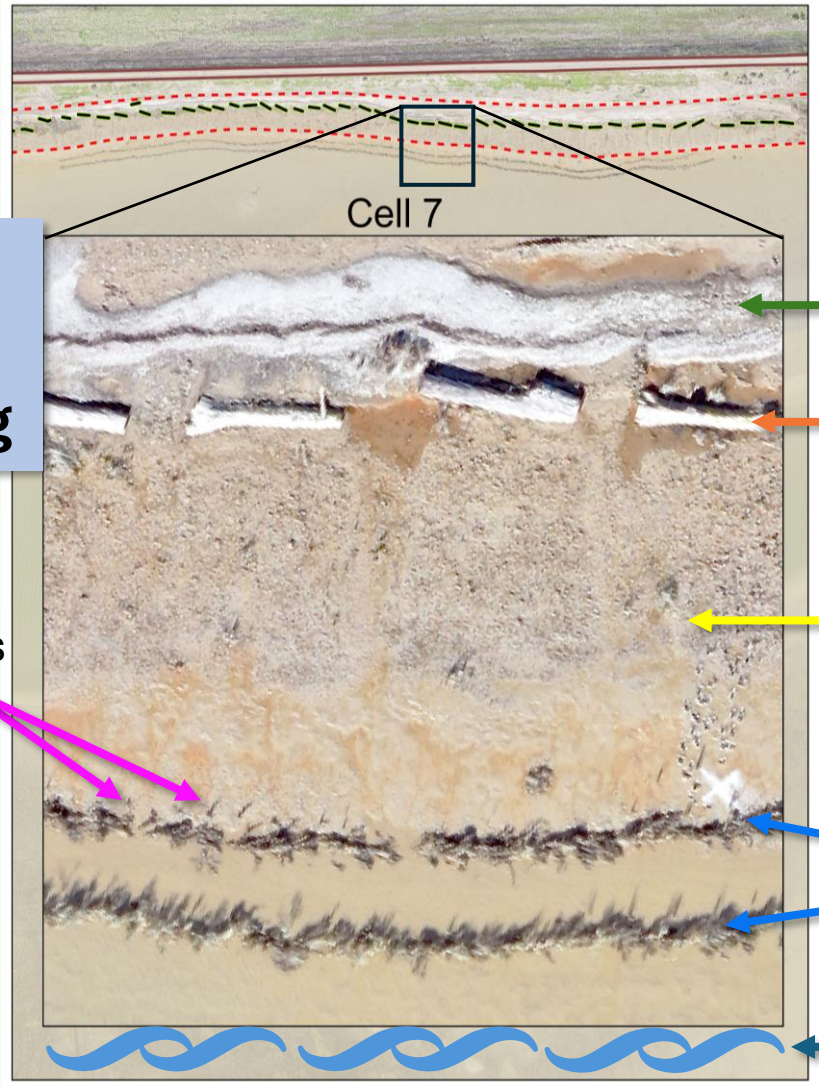
Project Site:
Sears Point Levee Adaptive Management Project

Shoreline Repair 2021:

- **Supplementary treatments**
  - **East end ONLY:**
    - **Sacrificial coyote brush fencing**

Coyote Brush

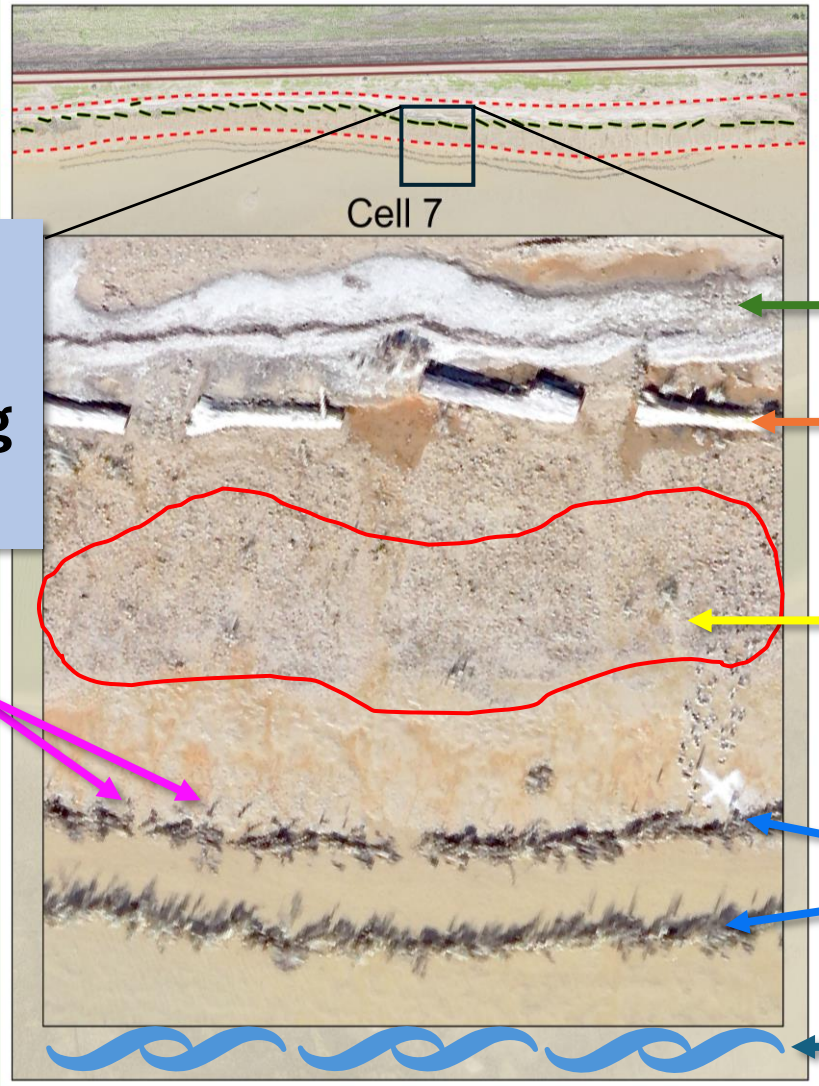
Background



Project Site:
Sears Point Levee Adaptive Management Project

Shoreline Repair 2021:

- **Supplementary treatments**
  - **East end ONLY:**
    - **Sacrificial coyote brush fencing**
    - **Lag gravel armoring**



Background

Nature-Based Treatments by Shoreline End

West and Central Shoreline

- Gravel toe berms
  1. Small angular gravel
  2. Pea-sized round gravel
- Logs
- Loose crushed dried bay mud
- Salt marsh plantings

East End

- Gravel toe berm
  1. Small angular gravel
  2. Pea-sized round gravel
- Logs
- Loose crushed dried bay mud
- Salt marsh plantings

Nature-Based Treatments by Shoreline End

West and Central Shoreline

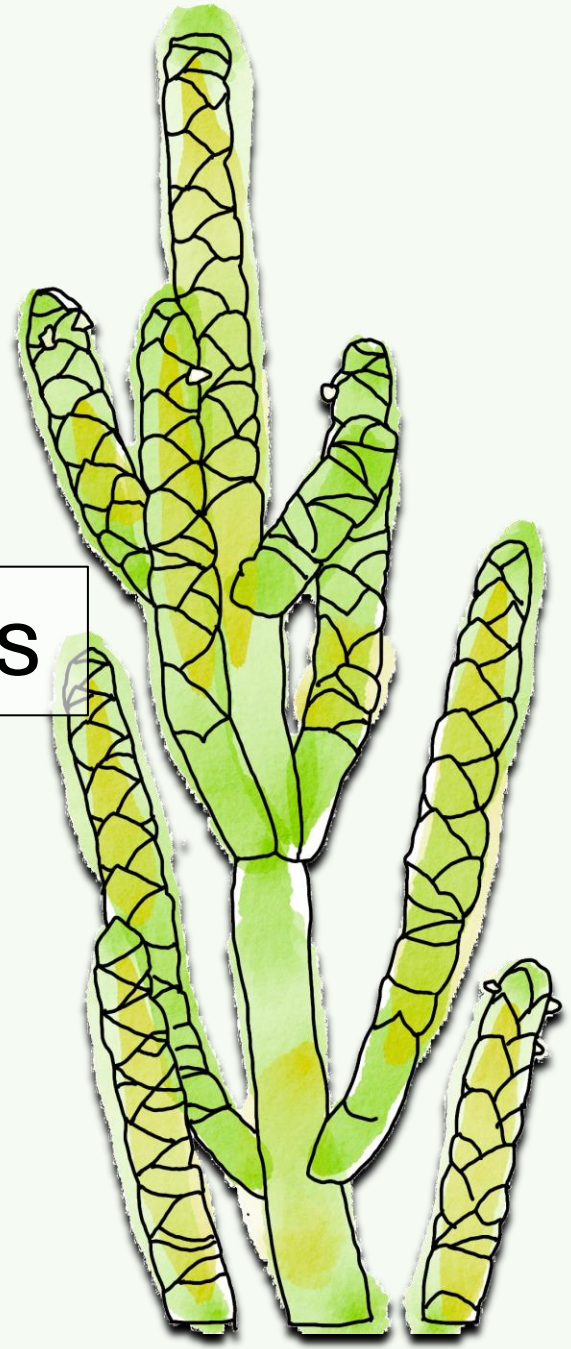
- Gravel toe berms
  1. Small angular gravel
  2. Pea-sized round gravel
- Logs
- Loose crushed dried bay mud
- Salt marsh plantings

East End

- Gravel toe berm
  1. Small angular gravel
  2. Pea-sized round gravel
- Logs
- Loose crushed dried bay mud
- Salt marsh plantings

+ Coyote brush fencing
+ Lag gravel armoring

Research Questions



How does the intertidal marsh zone change over time?

Research Questions

More specifically…

How effective are the NBS treatments at minimizing erosion, and encouraging emergent marsh establishment along the habitat levee?

Research Questions

How does vegetation-sedimentation compare…

1. **West vs. east**
2. **Logs vs. between logs**
3. **Between marsh zones**

Research Questions

How does vegetation-sedimentation compare…

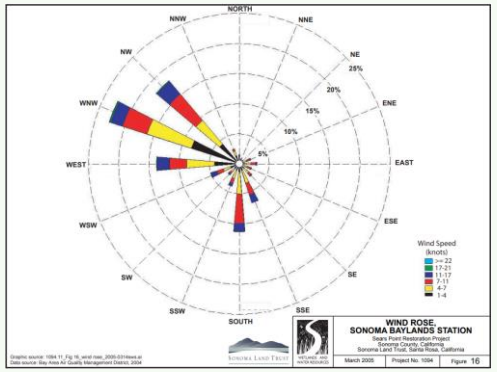
1. **West vs. east?**

Research Questions

How does vegetation-sedimentation compare…

1. **West vs. east?**

   A. **West End – sheltered from southern storm winds, broad muflat**



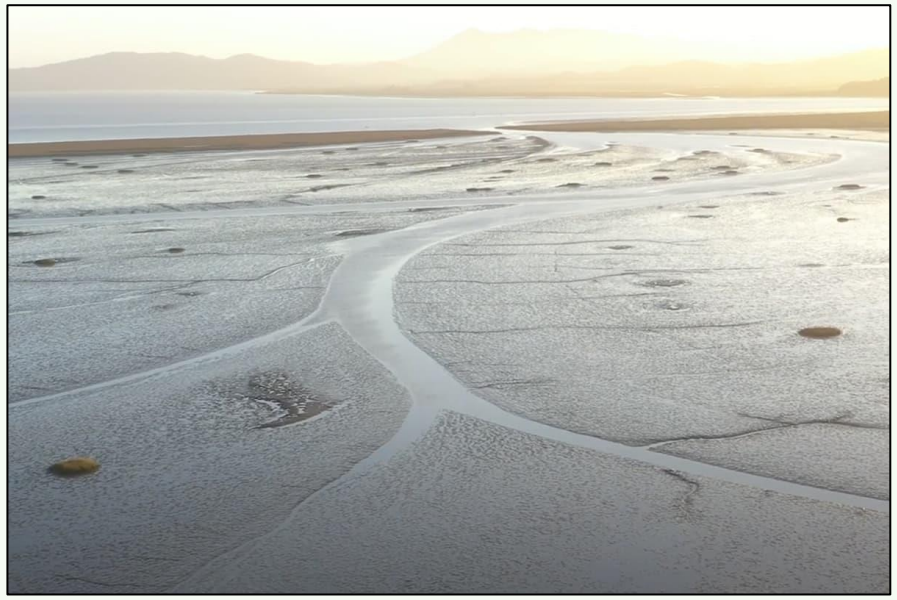
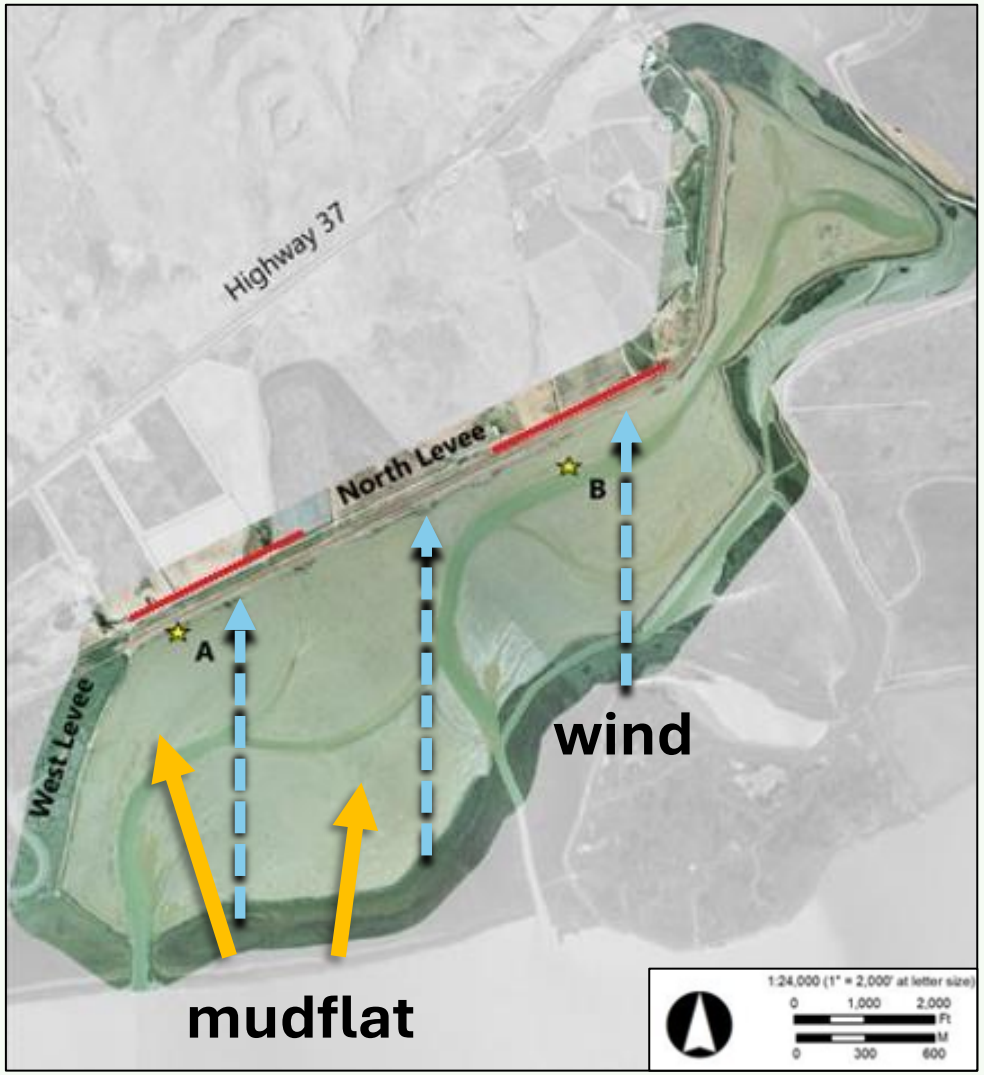


Image: SFB Joint Venture, 2022



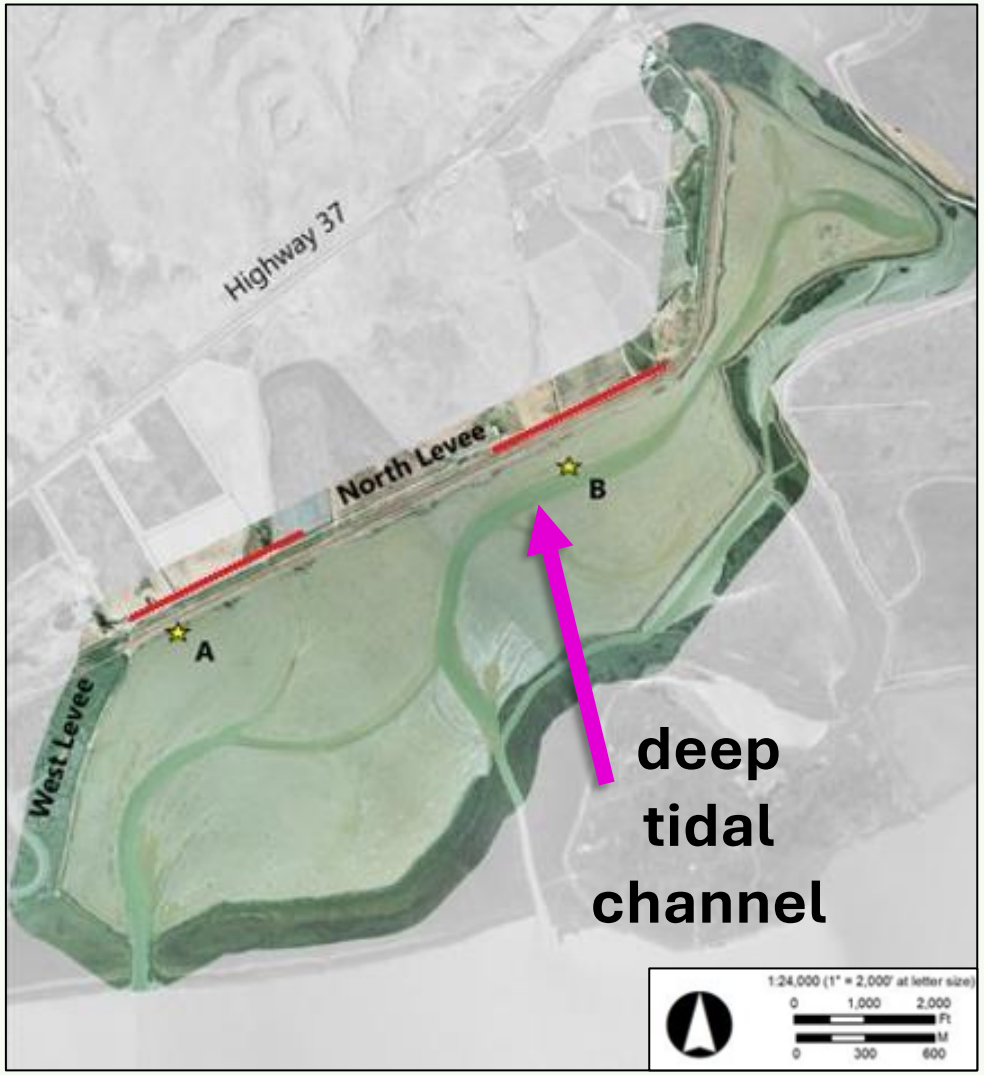
Research Questions

How does vegetation-sedimentation compare…

1. **West vs. east?**

   A. West End – more sheltered from southern storm winds, broad mudflat

   B. East End – less shelter from southern storm winds and close proximity to large deep tidal channel



Research Questions

How does vegetation-sedimentation compare…

1. **West vs. east?**

Hypothesis:

- More sheltered west end experiences less wind wave energy, and therefore, more vegetation establishment and accretion.

Research Questions

How does vegetation-sedimentation compare…

2. At <u>logs with mud</u> vs. <u>between logs without mud</u>?

At Log

Between Log

Research Questions

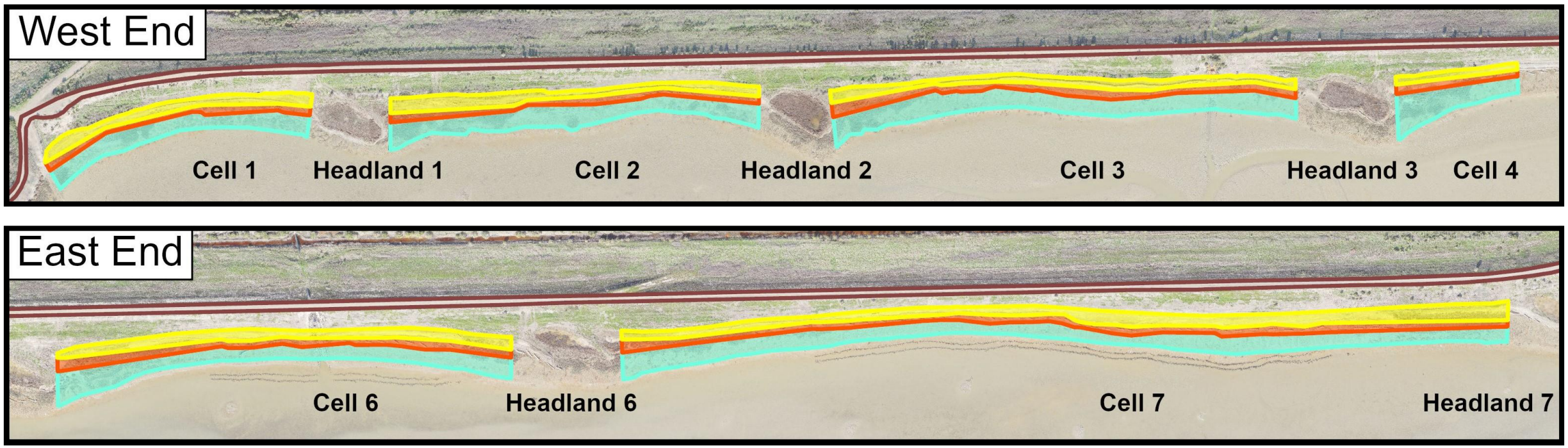
How does vegetation-sedimentation compare…

2. At <u>logs with mud</u> vs. <u>between logs without mud</u>?

Hypothesis:
Logs will create sheltered, sediment-rich areas on the bay side, promoting vegetation growth, while shallow drainage troughs with no or sparse vegetation, primarily *Spartina foliosa*, will form between the logs.

How does vegetation-sedimentation compare…

3. Between the upper, middle, and lower marsh zones?



Research Questions

How does vegetation-sedimentation compare…

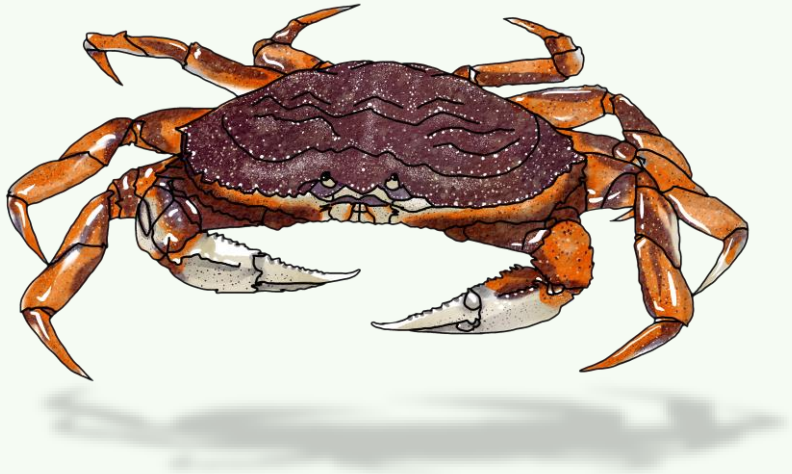
3. Between the upper, middle, and lower marsh zones?

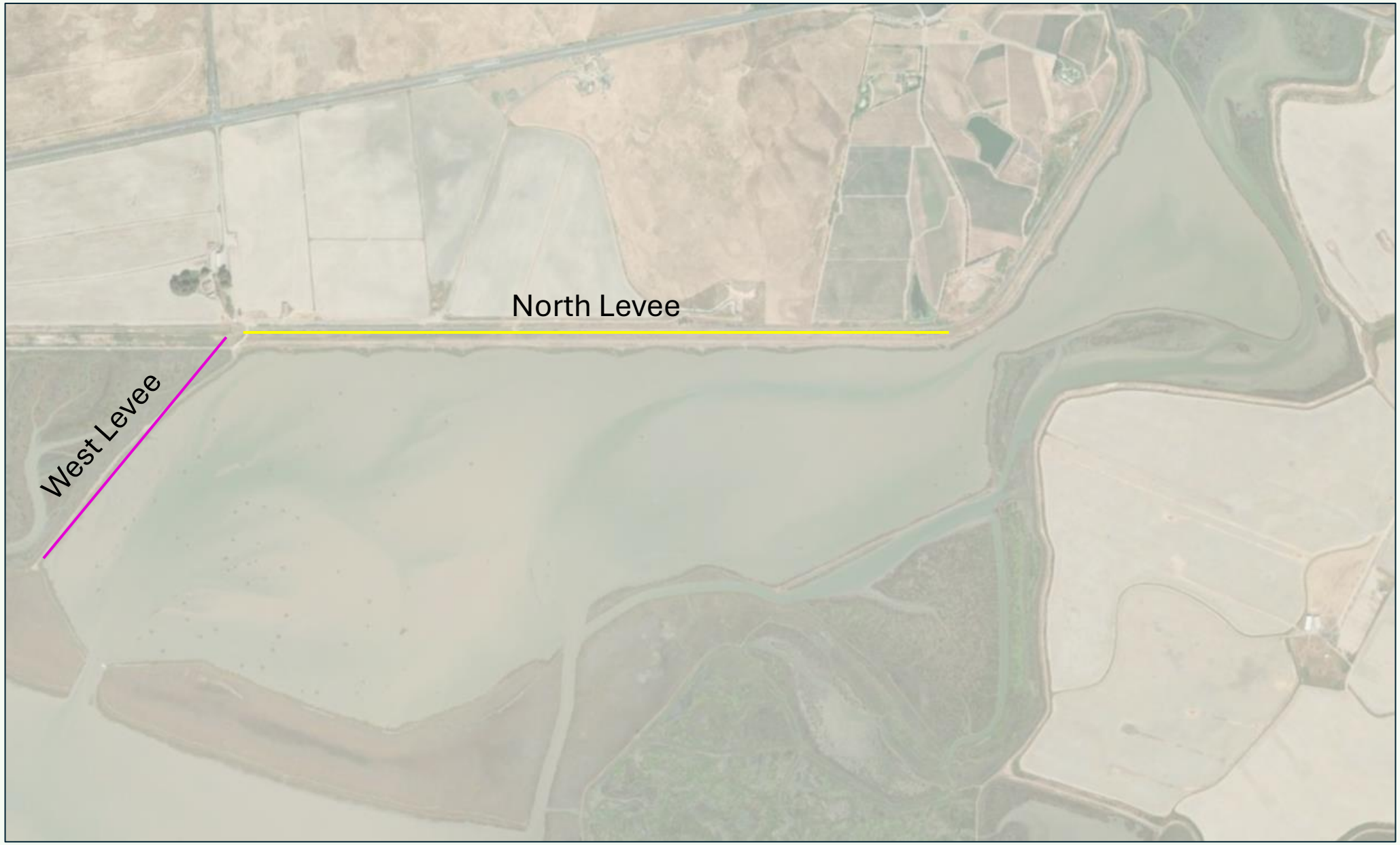
Hypothesis:
In tandem with the other treatments, the logs would shelter the existing vegetation above them and trap sediment, resulting in two primary outcomes.

- First, a reduction in lateral wave erosion in the upper zone.

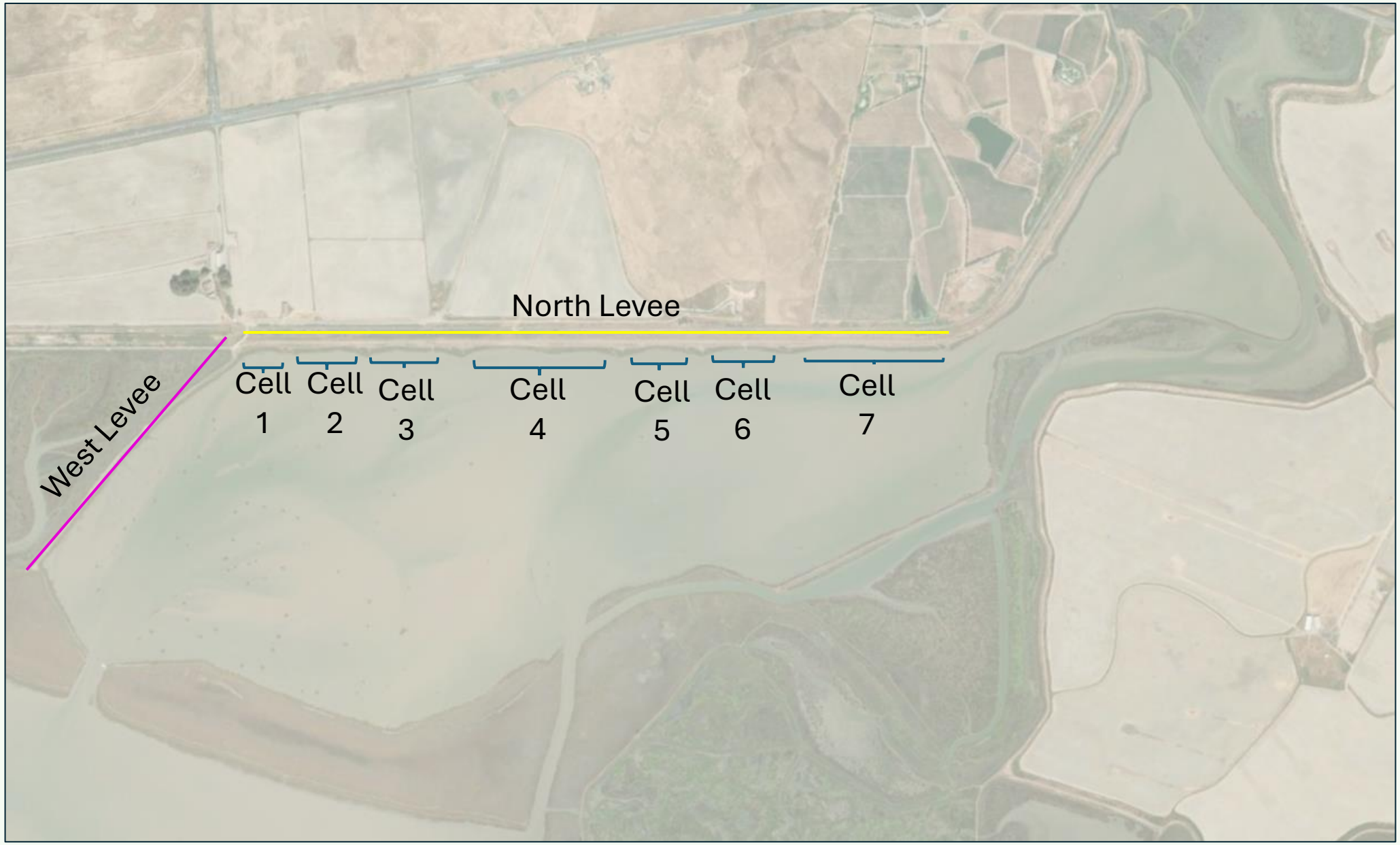
- Second, an increase in vegetation and elevation, greatest in the upper marsh, followed by the middle, and finally the lower marsh.

Methods



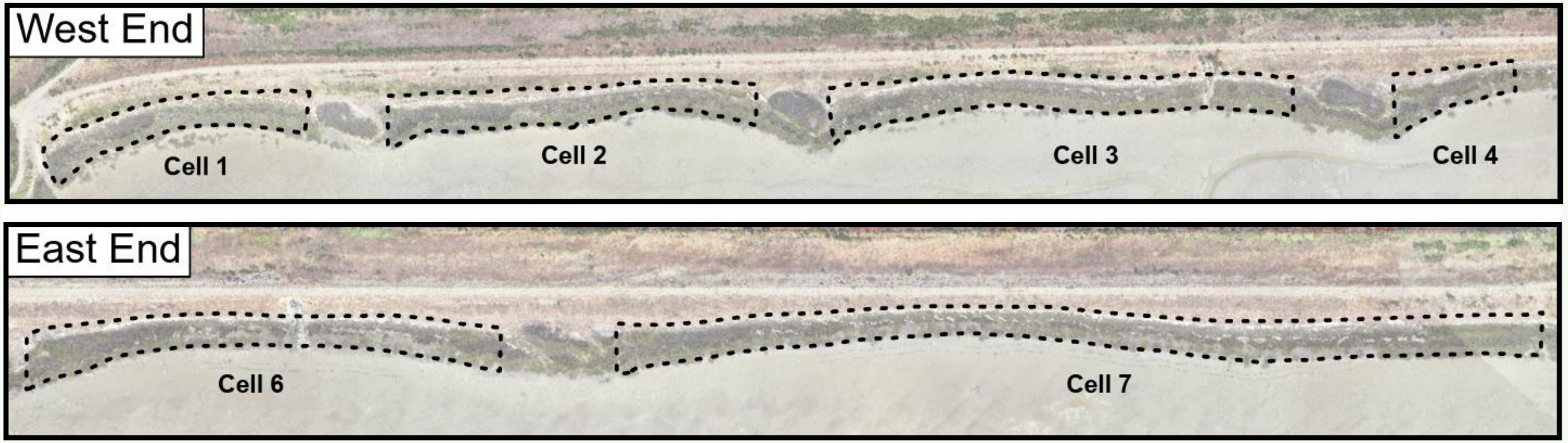


Methods


North Levee
West Levee
Cell 1
Cell 2
Cell 3
Cell 4
Cell 5
Cell 6
Cell 7

Methods

Methods



Thesis Research Extent

Methods

Biological Approach

Method 1: Vegetation Transects

Monthly Transect Surveys

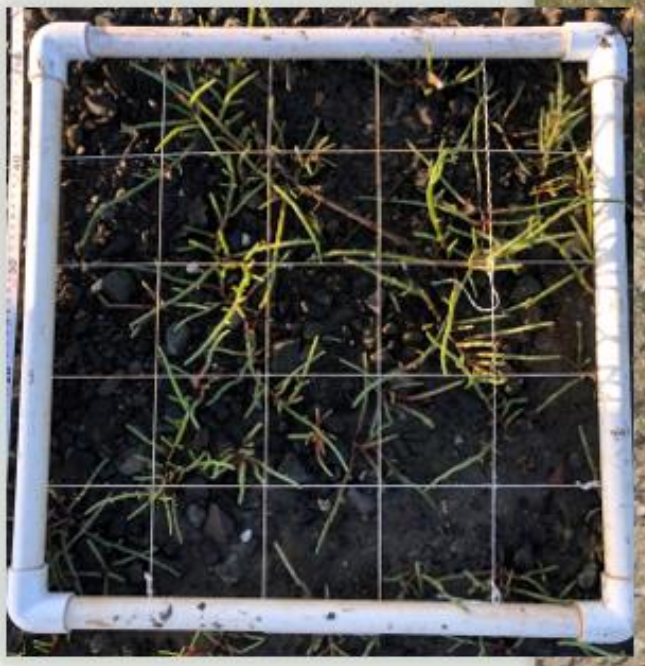
- Two active plant growing seasons (June 2022 to August 2023)

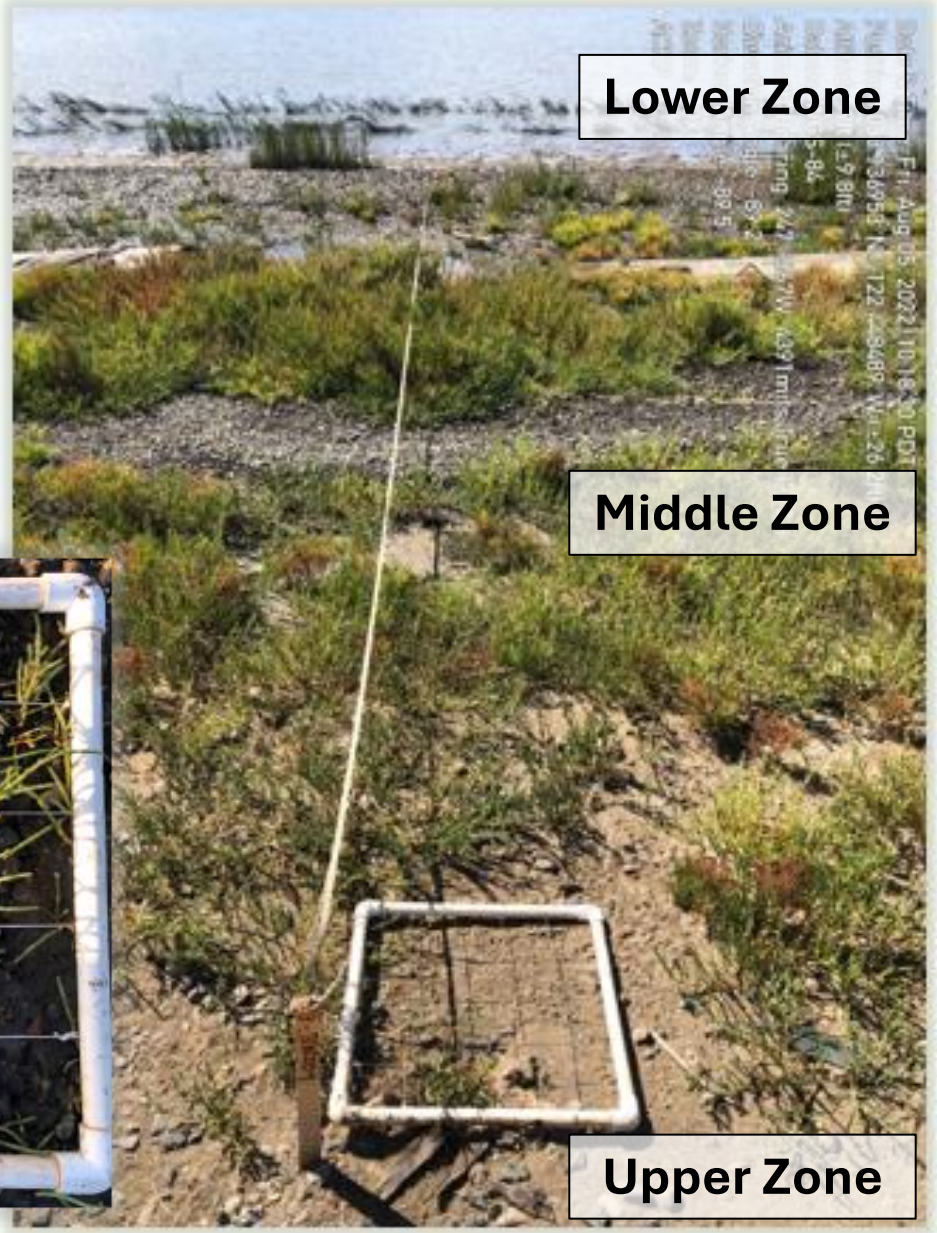
Biological Approach

Method 1: Vegetation Transects

Monthly Transect Surveys

- Two active plant growing seasons (June 2022 to August 2023)
- 60 transects





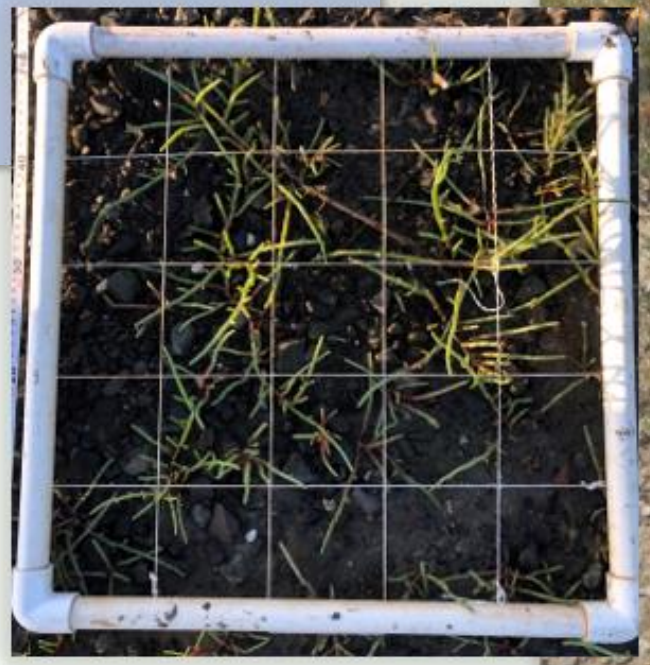
Methods

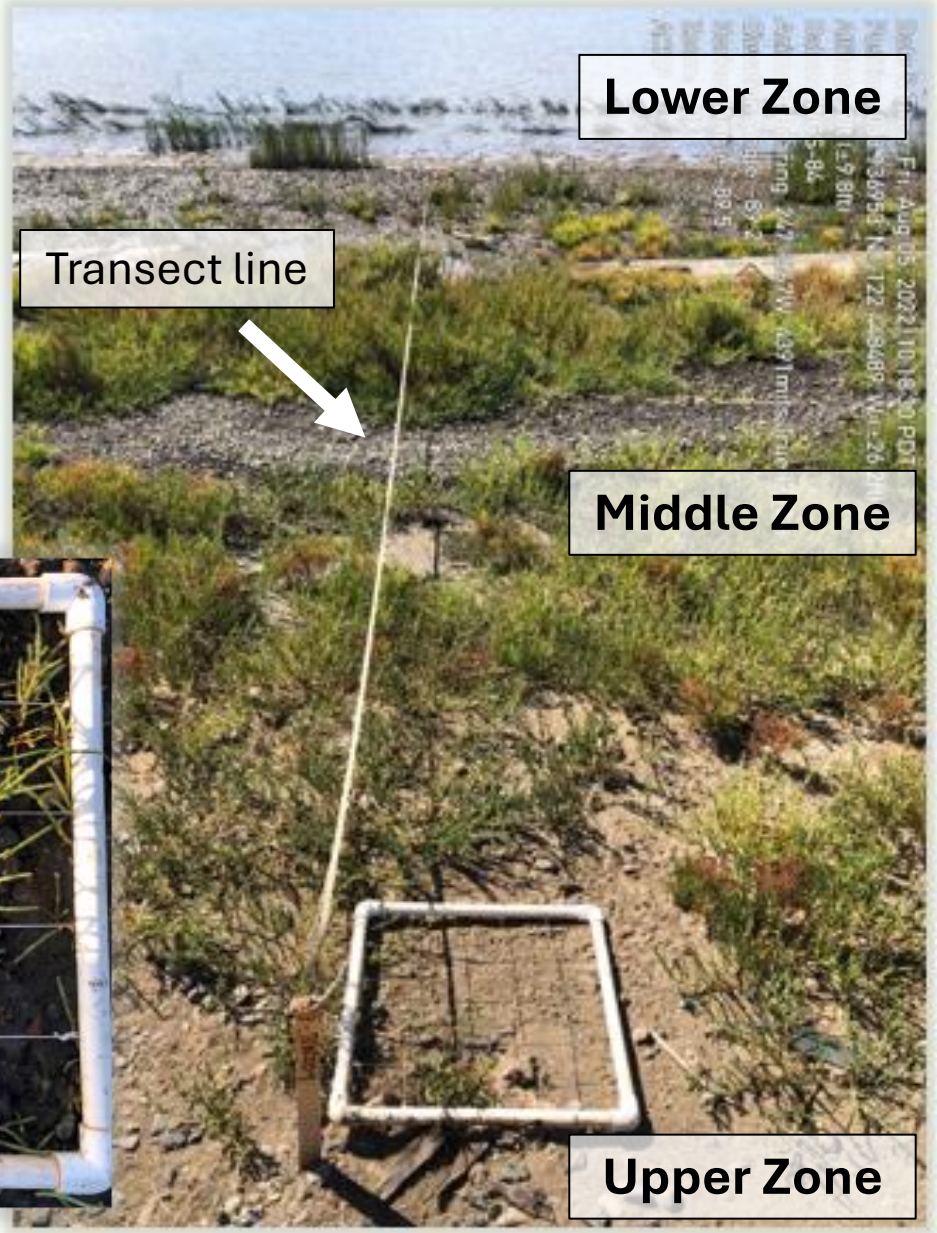
Biological Approach

Method 1: Vegetation Transects

Monthly Transect Surveys

- Two active plant growing seasons (June 2022 to August 2023)
- 60 transects
  - Documented all plants to lowest taxonomic level
  - Percent canopy cover





Methods

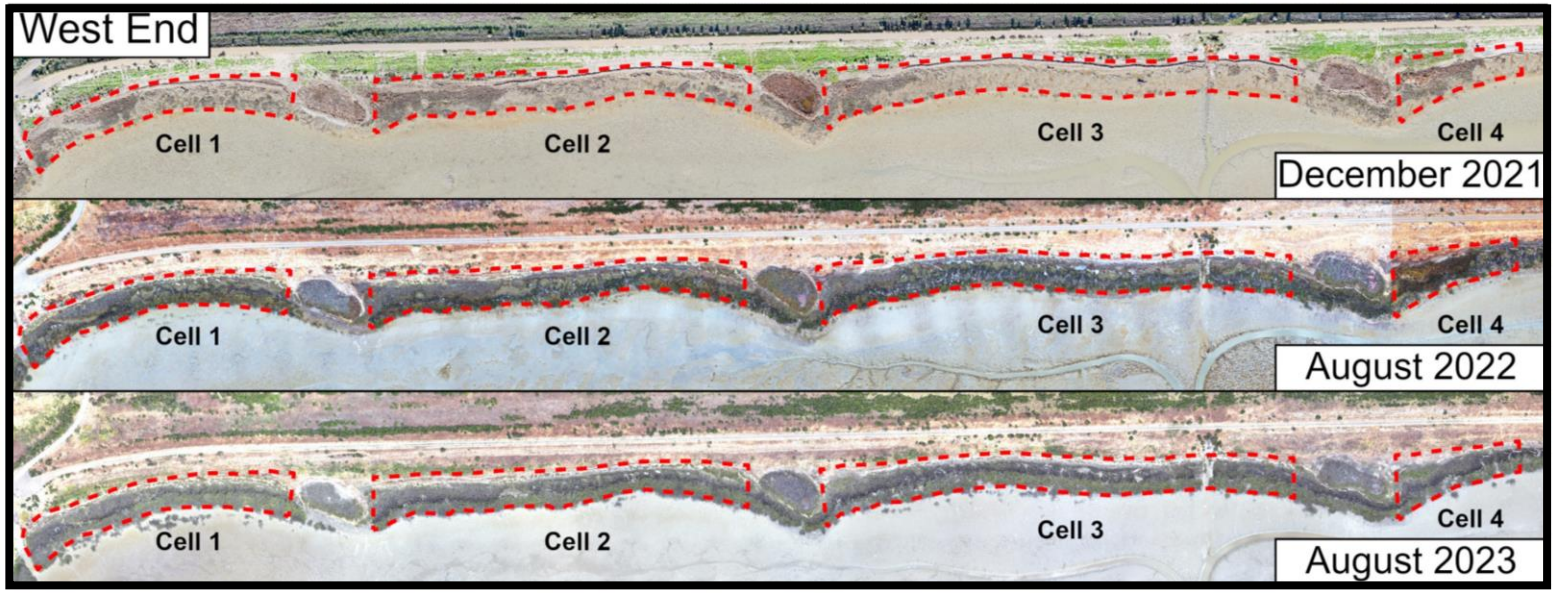
Biological Approach

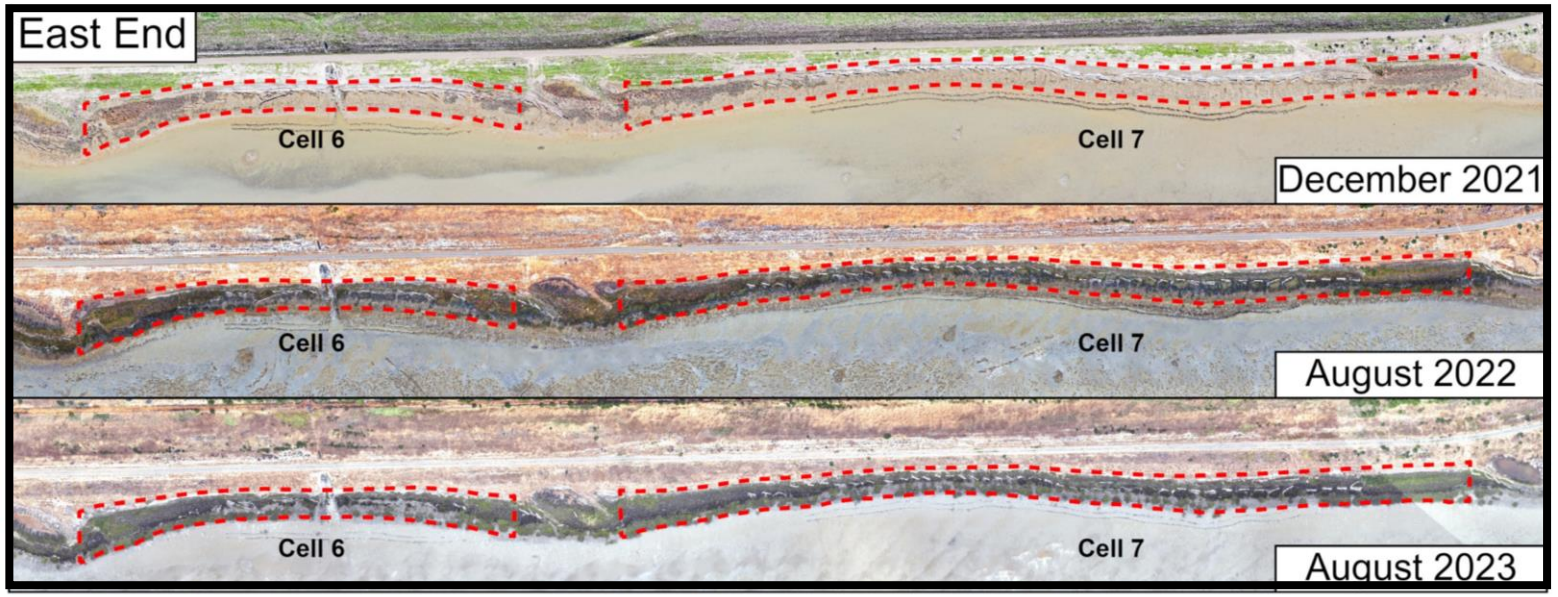
Method 2:
GIS Vegetation Mapping

- UAS aerial imagery - RTK GPS (SFEI and SFSU IGIS)
  - December 2021 (RGB)
  - August 2022 (RGB)
  - August 2023 (NIR & RGB)

*Data held to two control survey points

Research Project Extent





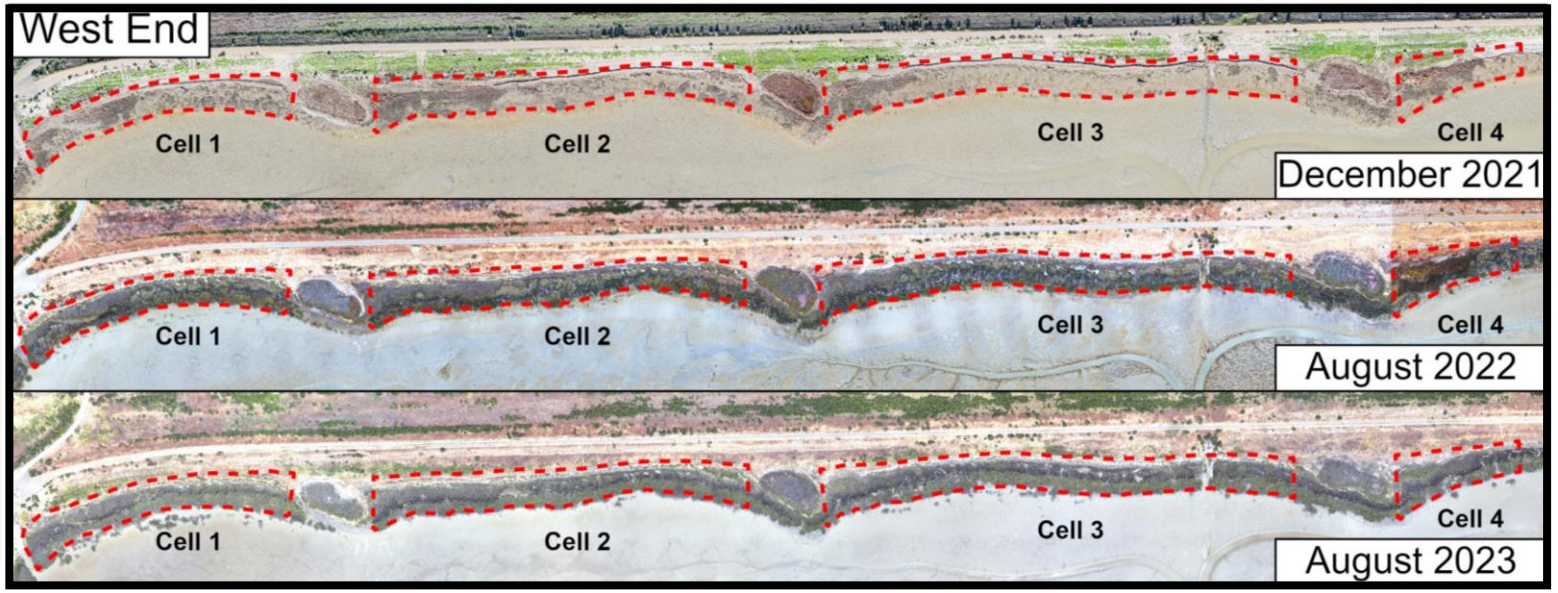
Methods

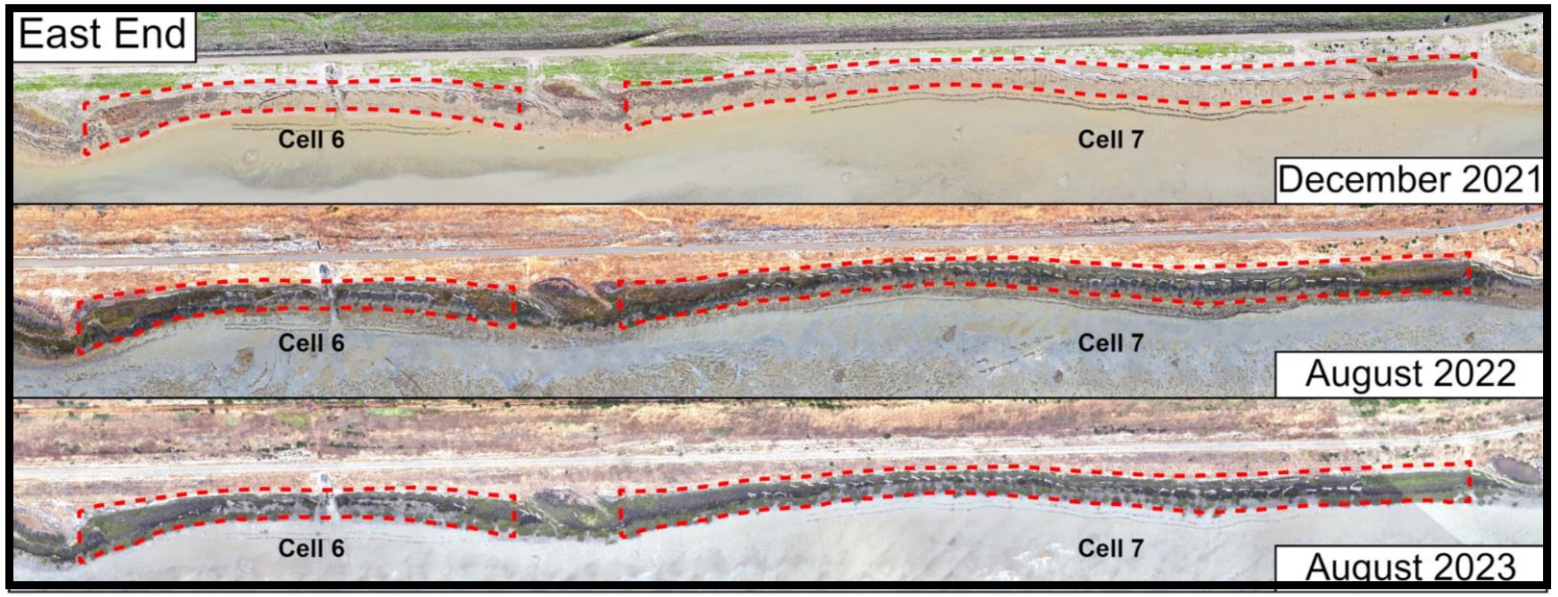
Biological Approach

Research Project Extent

Method 2:
GIS Vegetation Mapping

- Mapped:
  - Vegetation cover
  - Plant Communities
- Derived change





Methods

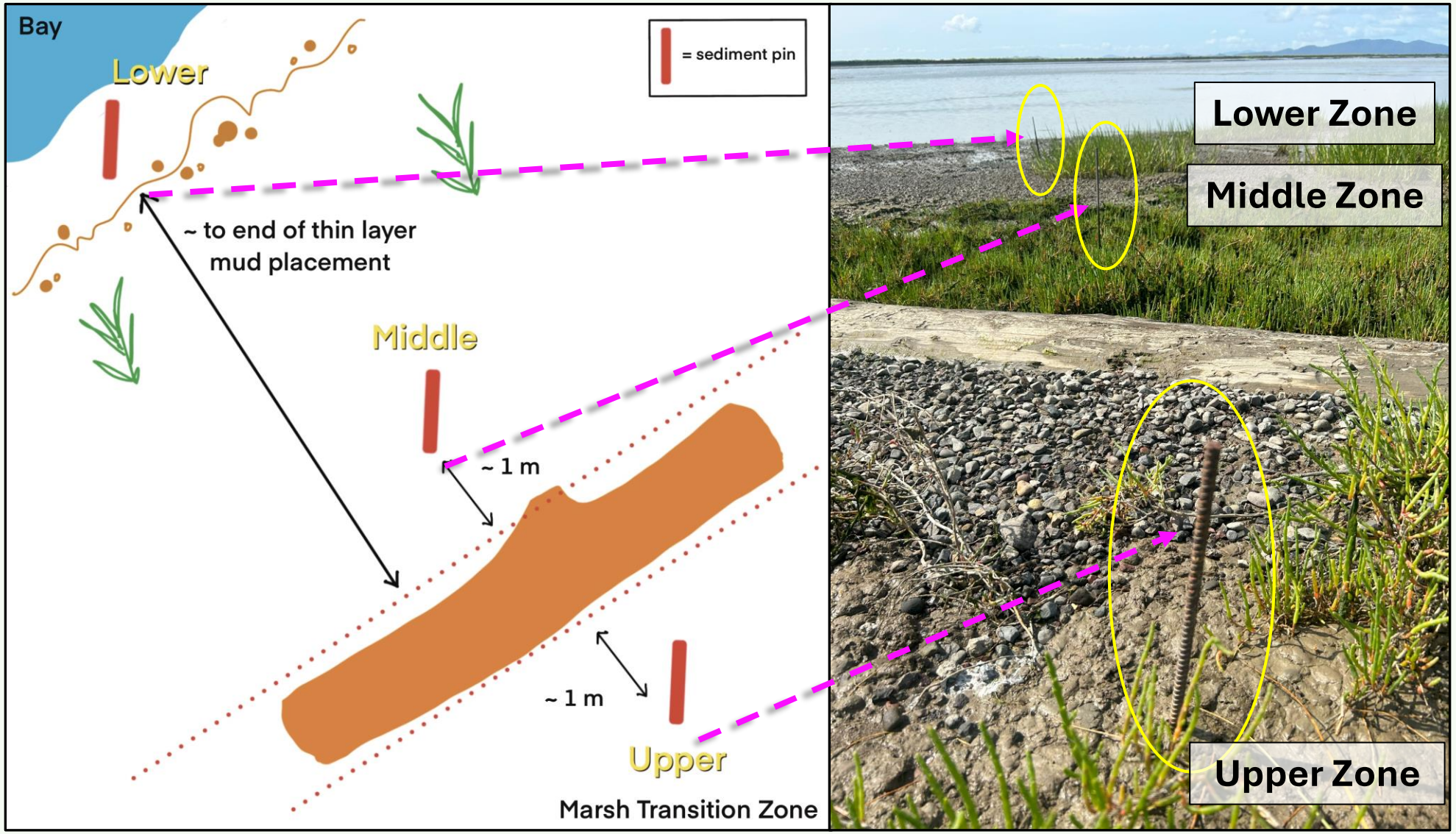
Physical Approach

Method 3: Sediment Pins

- 117 rebar pins
- Surveys:
  - **RTK GPS**
    - Jun 2022 (after installation)
    - Sep 2023 (end of project)
  - **Meter stick**
    - Bimonthly (Jun 2022 – Sep 2023)
- Change in elevation

Physical Approach

Method 3: Sediment Pins

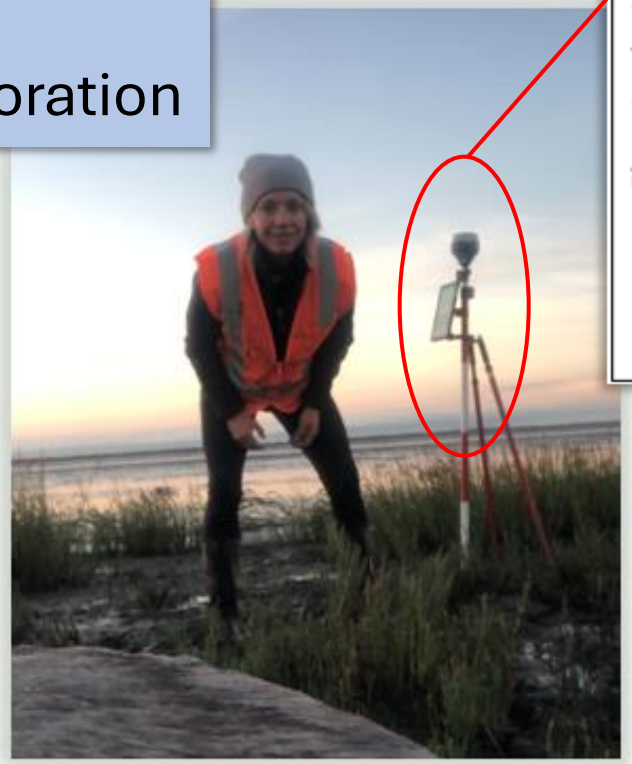


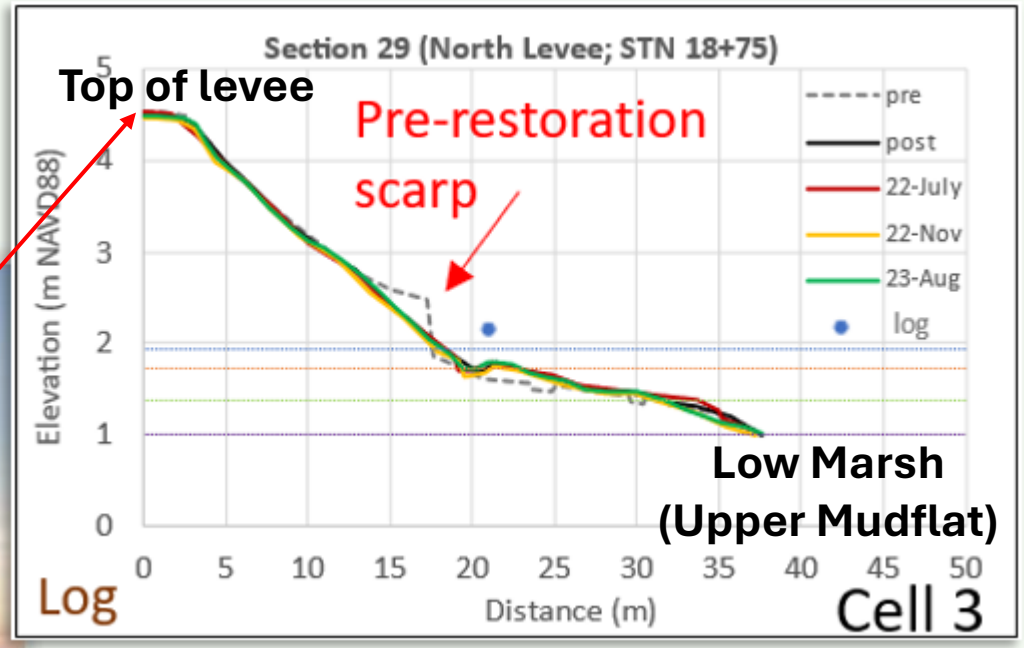
Methods

Physical Approach

Method 4: Topographic Surveys

- 48 transects (22 thesis)
- RTK GPS - collect elevation data
  - July 2022
  - Nov 2022
  - Aug 2023
- Compare to pre/post restoration



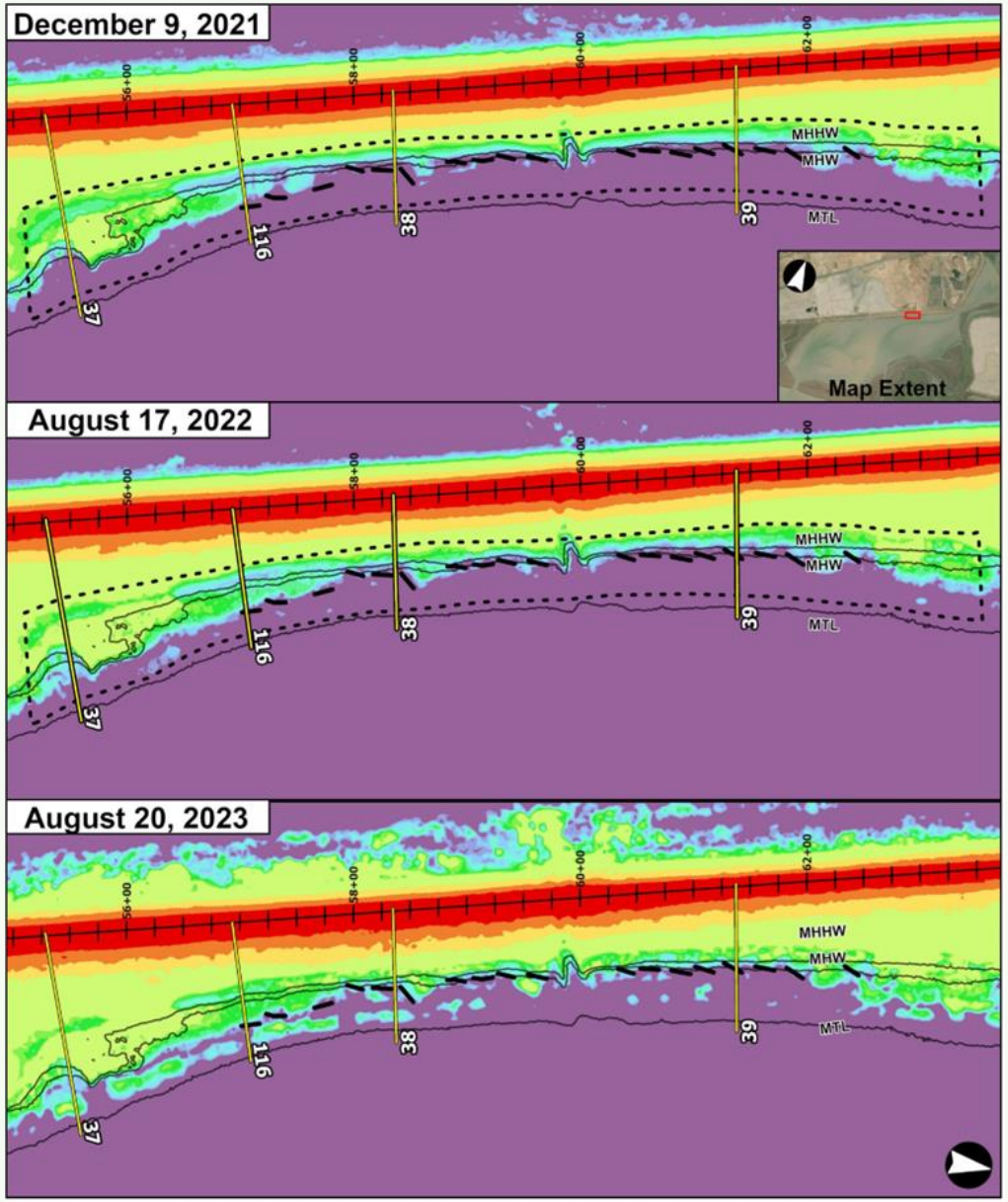


Methods

Physical Approach

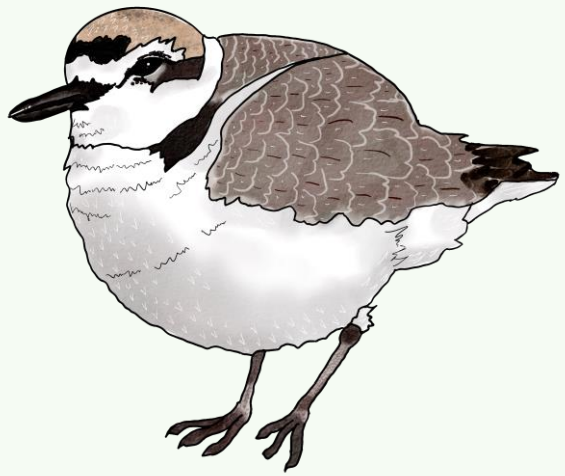
Method 4: Digital Terrain Modeling (DTM)

- Converted UAS aerial imagery
  - Represents surface elevation
  - Identify subtle surface changes



Methods

Results/Discussion



NBS Methods by Shoreline

West End

- Gravel toe berms
  1. Small angular gravel
  2. Pea-sized round gravel
- Logs
- Loose crushed dried bay mud
- Salt marsh planting

East End

- Gravel toe berm
  1. Small angular gravel
  2. Pea-sized round gravel
- Logs
- Loose crushed dried bay mud
- Salt marsh planting

+ Coyote brush fencing
+ Lag gravel armoring

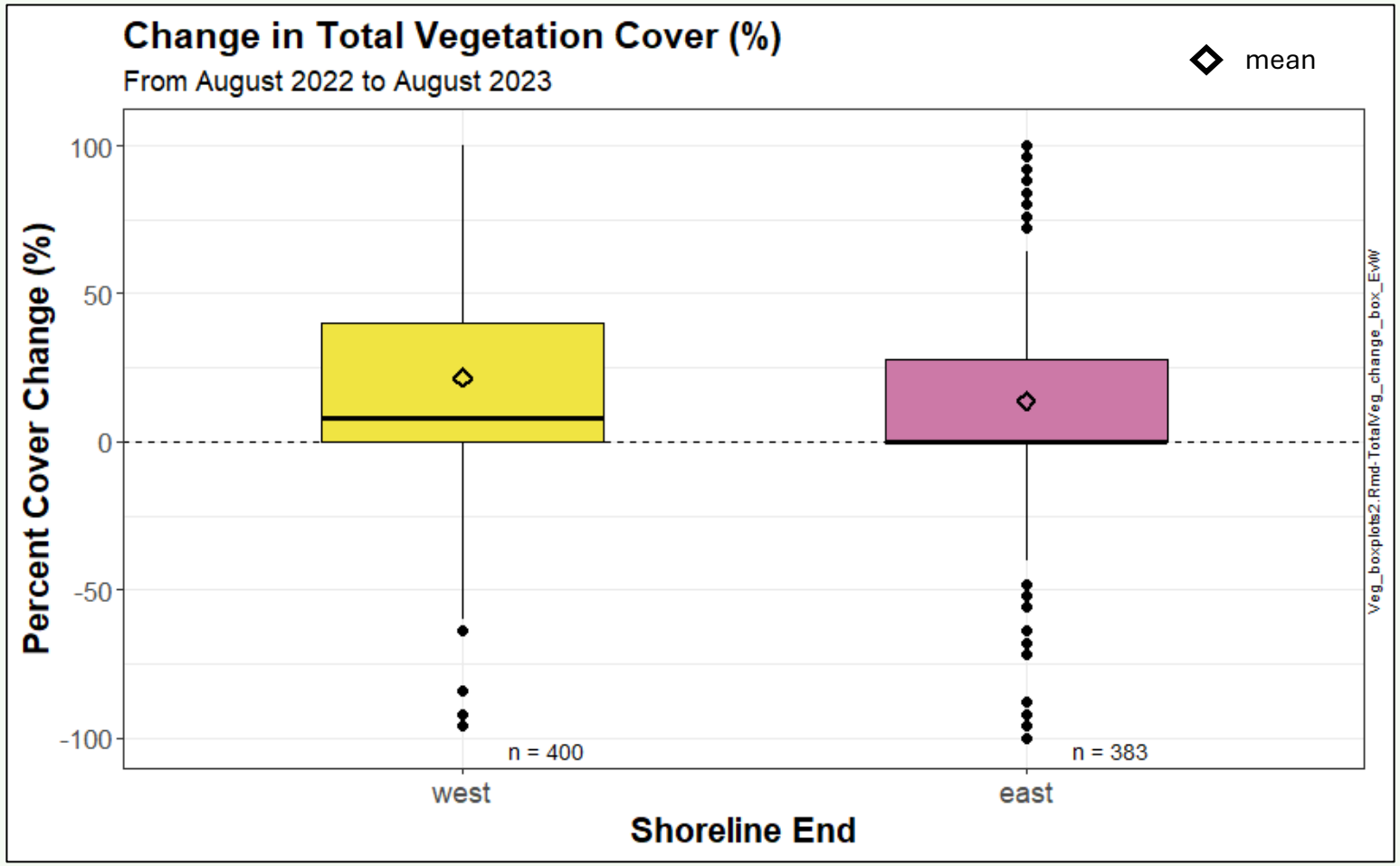
Results/Discussion

Research Questions:
How does vegetation-sedimentation compare…

1. West vs. east
2. Log vs. no-log
3. Between marsh zones: upper, middle, lower

Results/Discussion

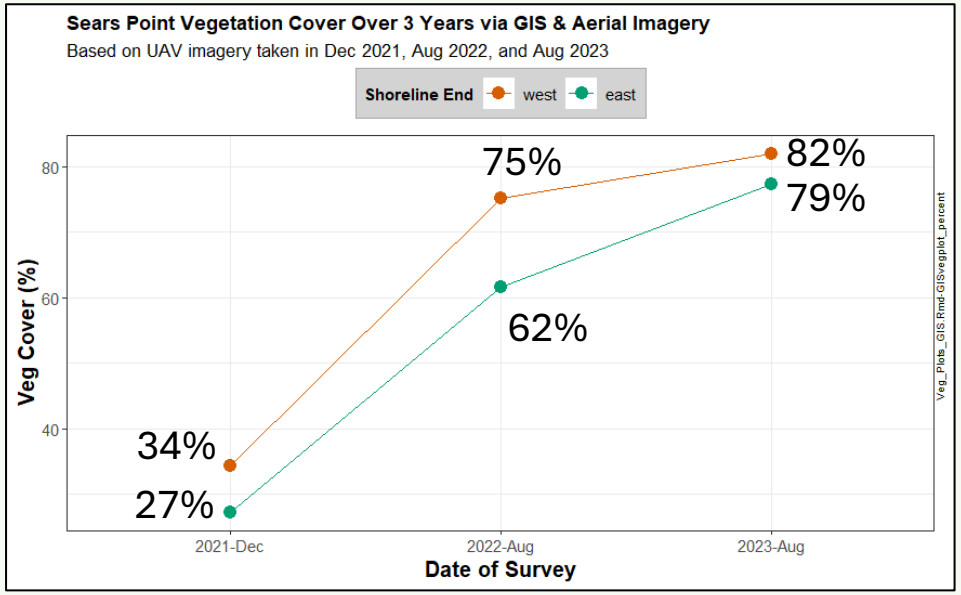
Vegetation Transects

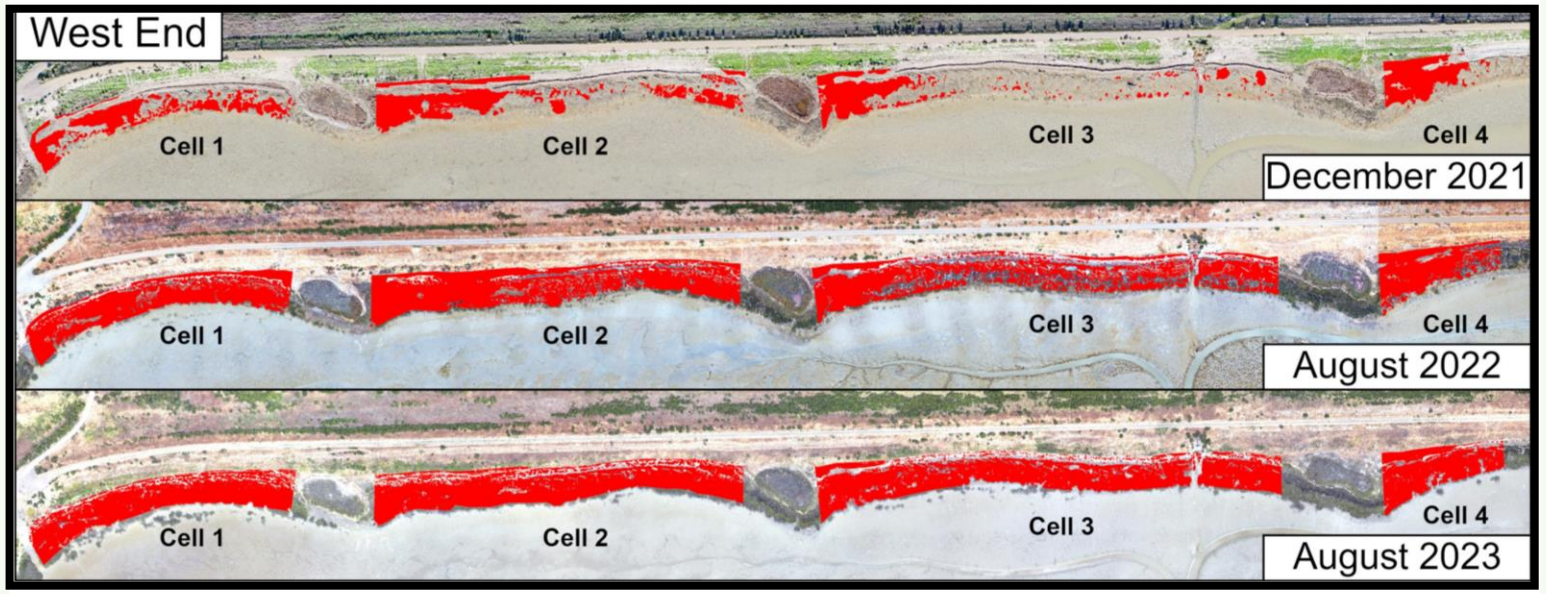


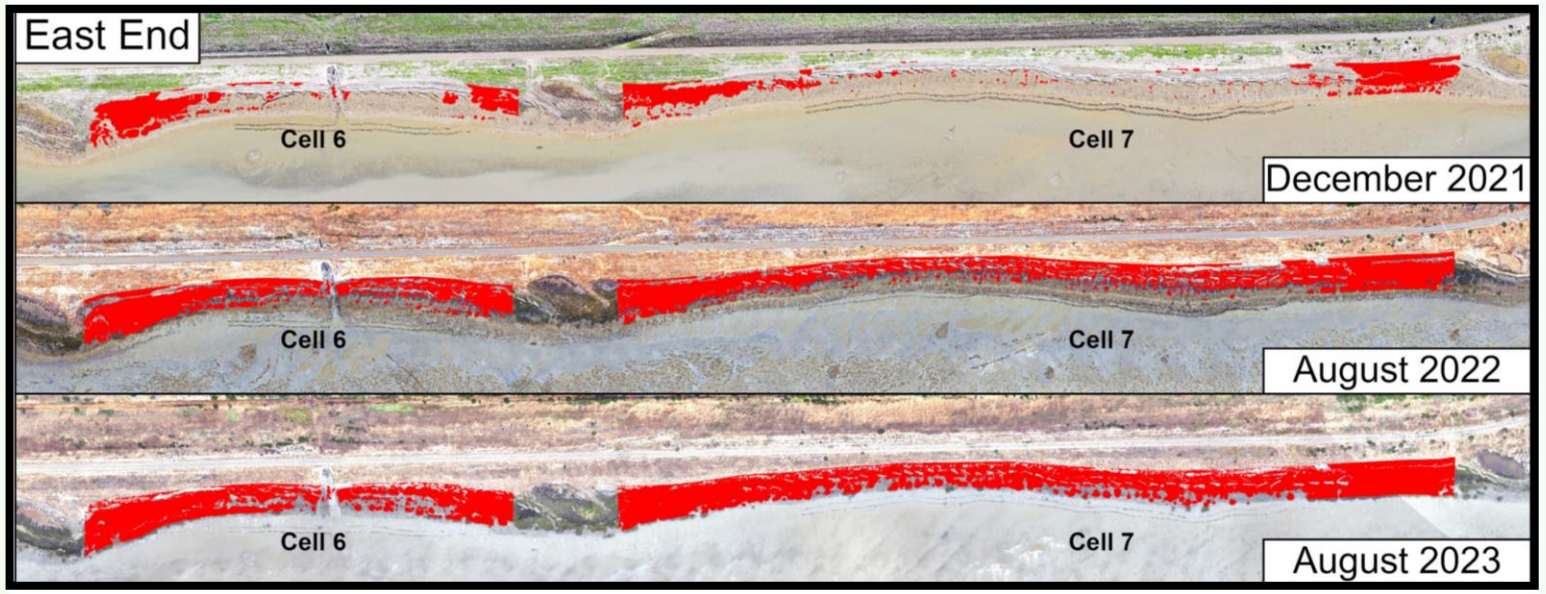
X^2= 7.4233; p = 0.0064

Results/Discussion

GIS Vegetation Mapping





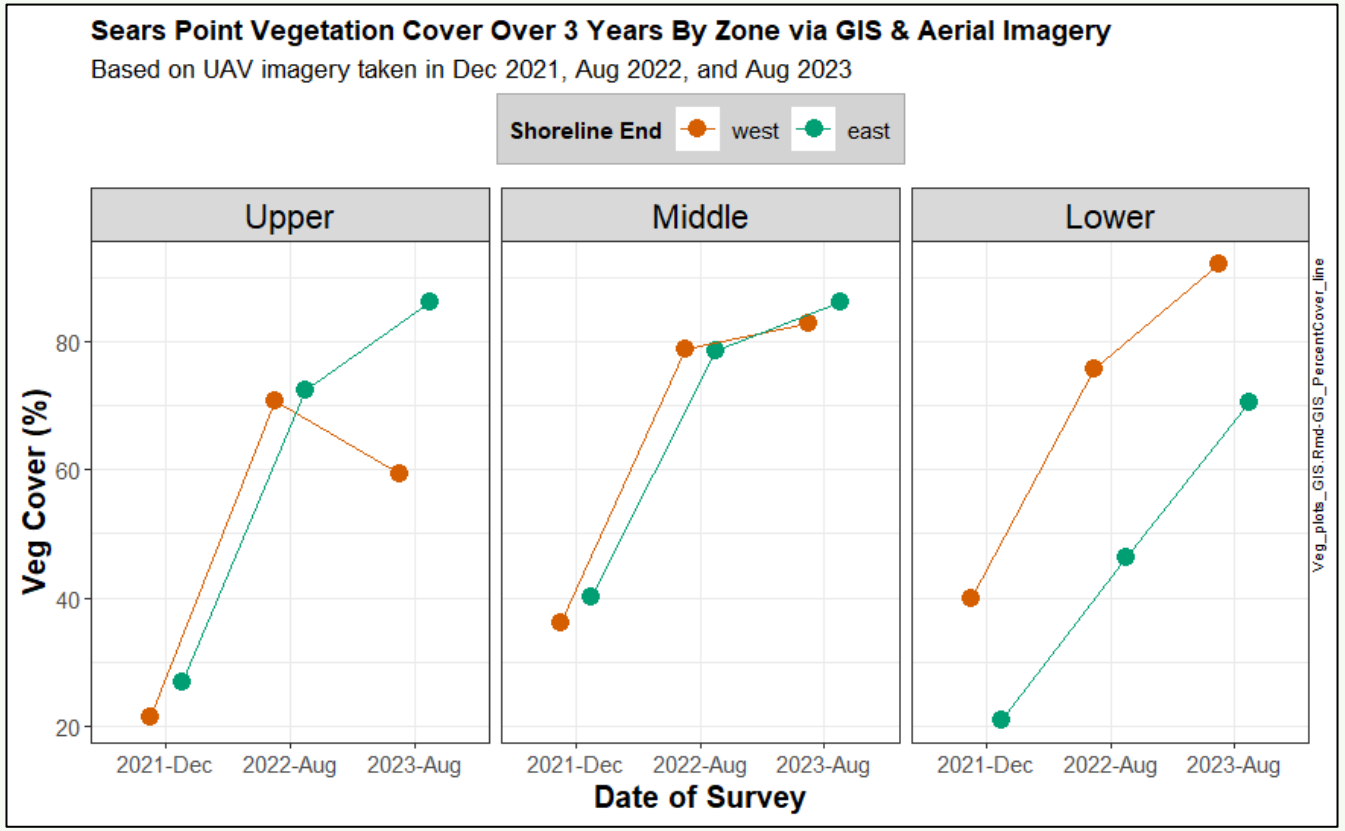


Marsh Vegetation

Shoreline End	Total Area (hectares)	Vegetated Area (hectares) Date		
		Dec-21	Aug-22	Aug-23
West	1.592	0.548	1.197	1.310
East	1.463	0.397	0.902	1.154

Results/Discussion

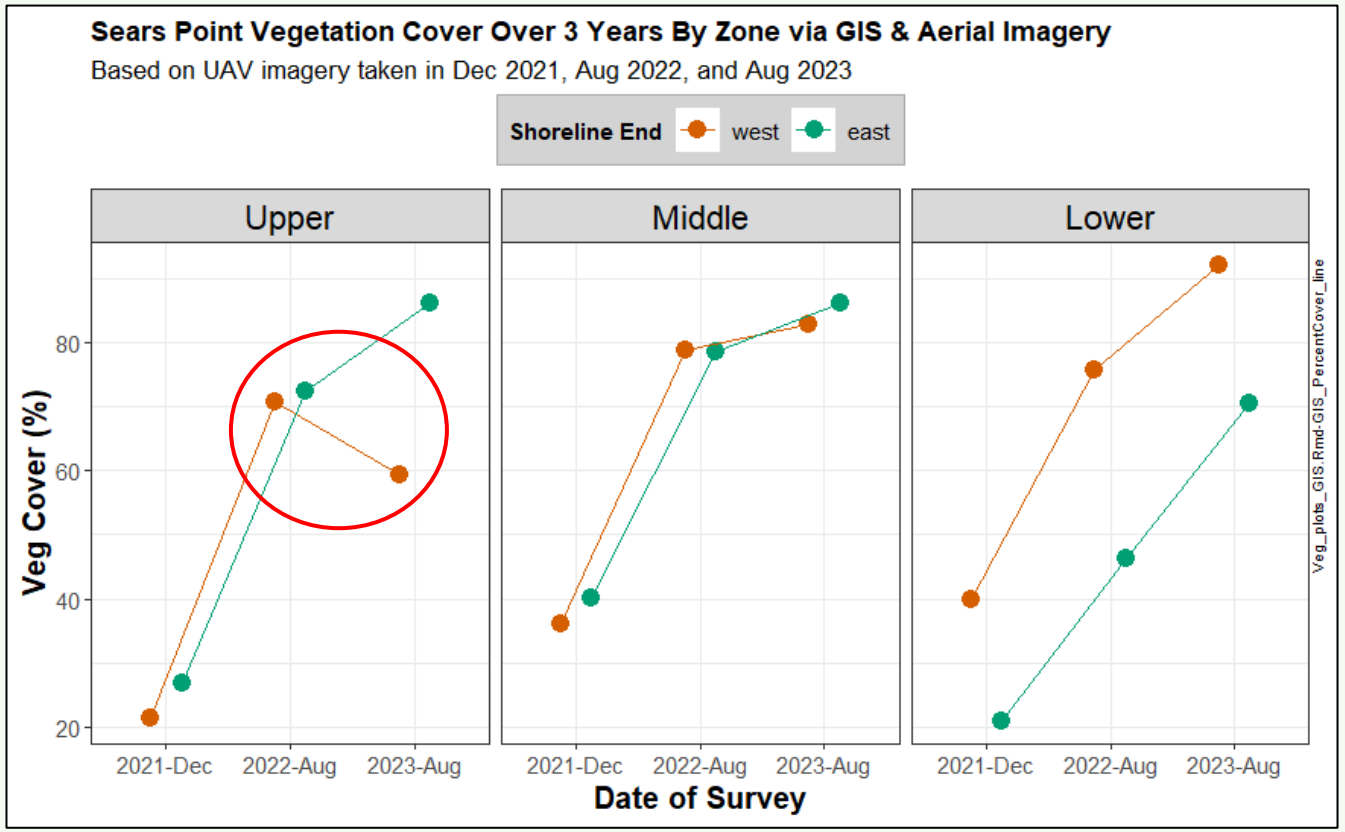
GIS Vegetation Mapping



Shoreline End	Marsh Zone	Total Area of Marsh Zone (hectares)	Vegetated Area (hectares)			Percent Veg Cover			Percent Veg Cover		
			Date			Date			Change		
			Dec-21	Aug-22	Aug-23	Dec-21	Aug-22	Aug-23	Yr 1-2	Yr 2-3	Yr 1-3:
West	Upper	0.396	0.084	0.280	0.235	21.3%	70.8%	59.4%	49.4%	-11.4%	38.0%
	Middle	0.340	0.123	0.268	0.282	36.1%	78.8%	82.9%	42.7%	4.1%	46.8%
	Lower	0.856	0.341	0.649	0.789	39.8%	75.8%	92.2%	36.0%	16.4%	52.4%
East	Upper	0.440	0.118	0.319	0.380	26.8%	72.5%	86.3%	45.7%	13.8%	59.5%
	Middle	0.338	0.135	0.266	0.291	40.1%	78.7%	86.1%	38.6%	7.4%	46.0%
	Lower	0.685	0.144	0.317	0.483	21.0%	46.2%	70.6%	25.2%	24.3%	49.5%

Results/Discussion

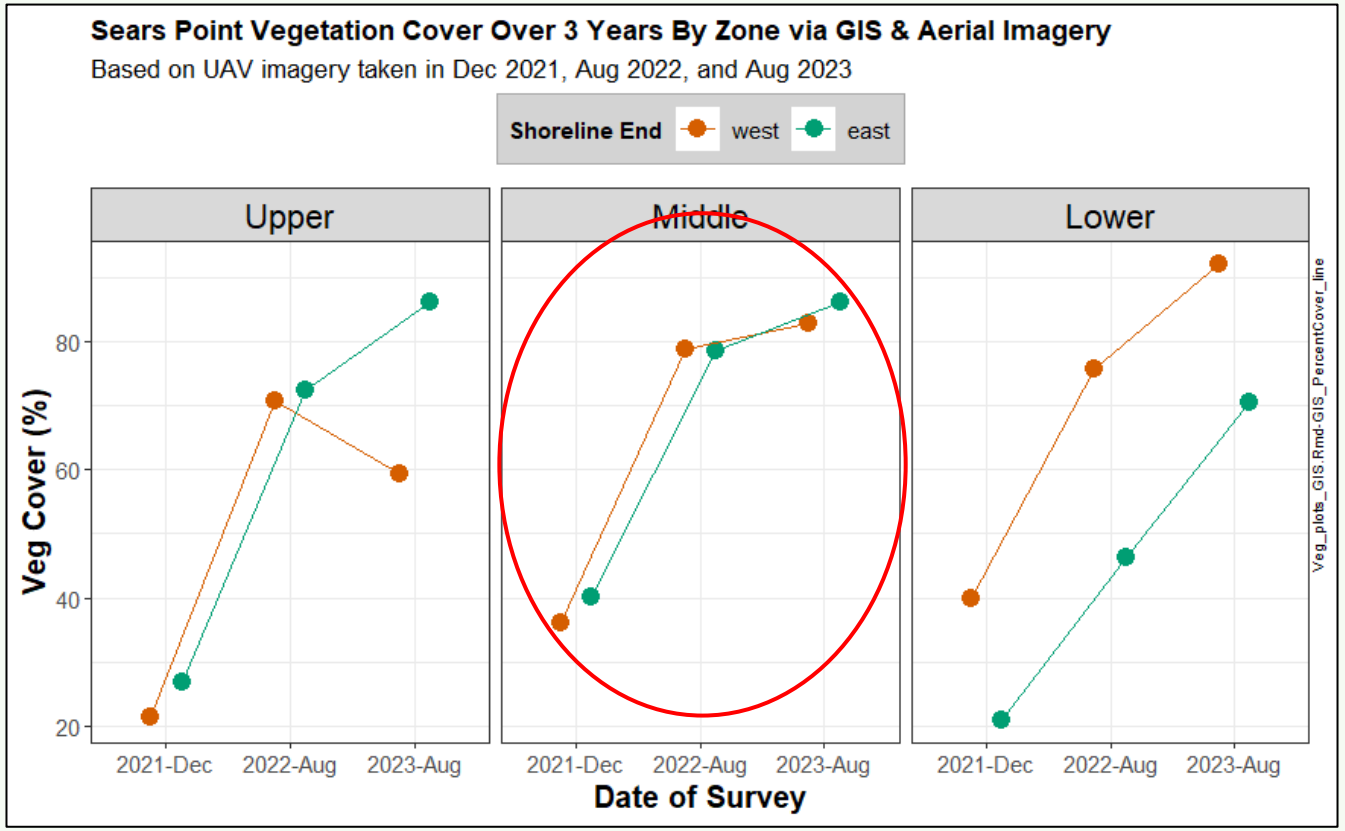
GIS Vegetation Mapping



Shoreline End	Marsh Zone	Total Area of Marsh Zone (hectares)	Vegetated Area (hectares)			Percent Veg Cover			Percent Veg Cover		
			Date			Date			Change		
			Dec-21	Aug-22	Aug-23	Dec-21	Aug-22	Aug-23	Yr 1-2	Yr 2-3	Yr 1-3:
West	Upper	0.396	0.084	0.280	0.235	21.3%	70.8%	59.4%	49.4%	-11.4%	38.0%
	Middle	0.340	0.123	0.268	0.282	36.1%	78.8%	82.9%	42.7%	4.1%	46.8%
	Lower	0.856	0.341	0.649	0.789	39.8%	75.8%	92.2%	36.0%	16.4%	52.4%
East	Upper	0.440	0.118	0.319	0.380	26.8%	72.5%	86.3%	45.7%	13.8%	59.5%
	Middle	0.338	0.135	0.266	0.291	40.1%	78.7%	86.1%	38.6%	7.4%	46.0%
	Lower	0.685	0.144	0.317	0.483	21.0%	46.2%	70.6%	25.2%	24.3%	49.5%

Results/Discussion

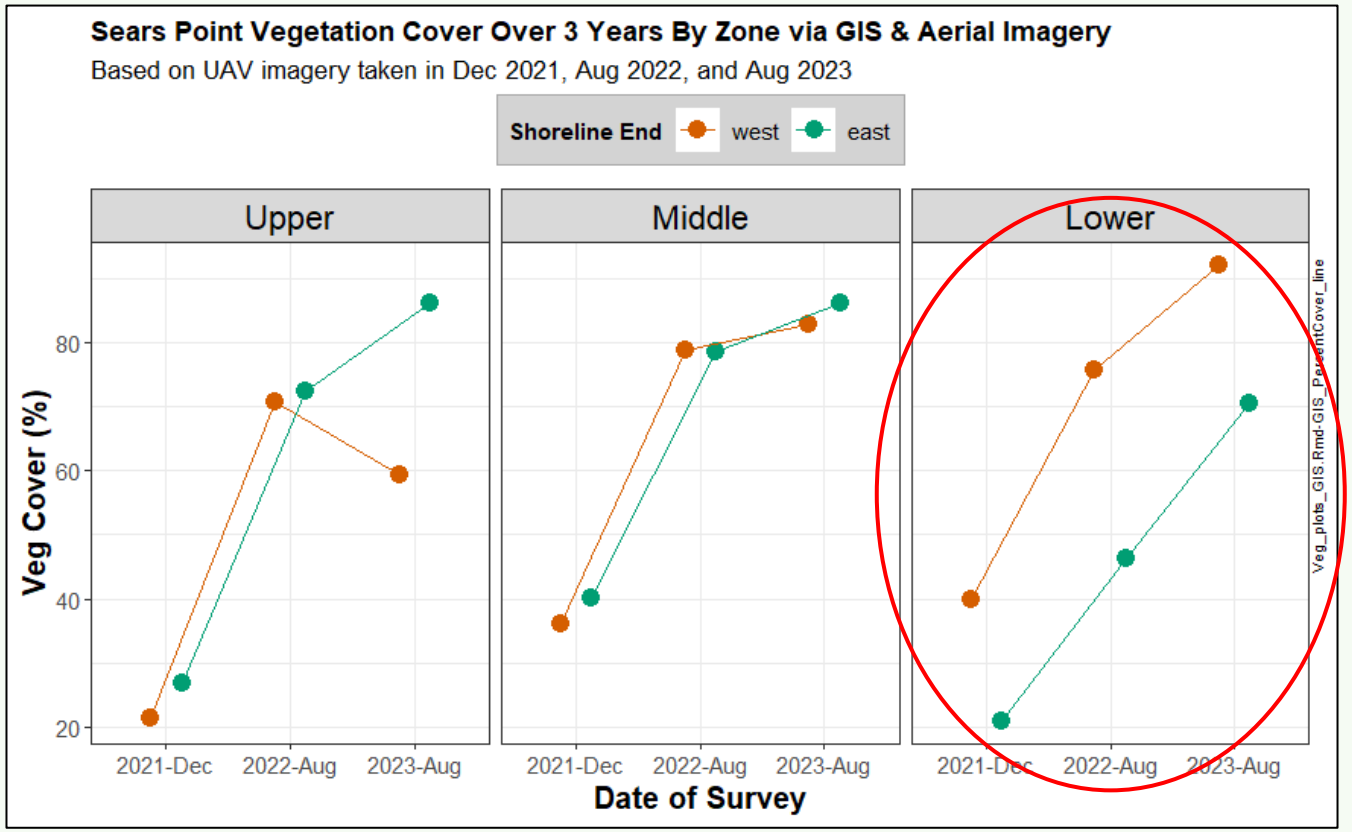
GIS Vegetation Mapping



Shoreline End	Marsh Zone	Total Area of Marsh Zone (hectares)	Vegetated Area (hectares)			Percent Veg Cover			Percent Veg Cover		
			Date			Date			Change		
			Dec-21	Aug-22	Aug-23	Dec-21	Aug-22	Aug-23	Yr 1-2	Yr 2-3	Yr 1-3:
West	Upper	0.396	0.084	0.280	0.235	21.3%	70.8%	59.4%	49.4%	-11.4%	38.0%
	Middle	0.340	0.123	0.268	0.282	36.1%	78.8%	82.9%	42.7%	4.1%	46.8%
	Lower	0.856	0.341	0.649	0.789	39.8%	75.8%	92.2%	36.0%	16.4%	52.4%
East	Upper	0.440	0.118	0.319	0.380	26.8%	72.5%	86.3%	45.7%	13.8%	59.5%
	Middle	0.338	0.135	0.266	0.291	40.1%	78.7%	86.1%	38.6%	7.4%	46.0%
	Lower	0.685	0.144	0.317	0.483	21.0%	46.2%	70.6%	25.2%	24.3%	49.5%

Results/Discussion

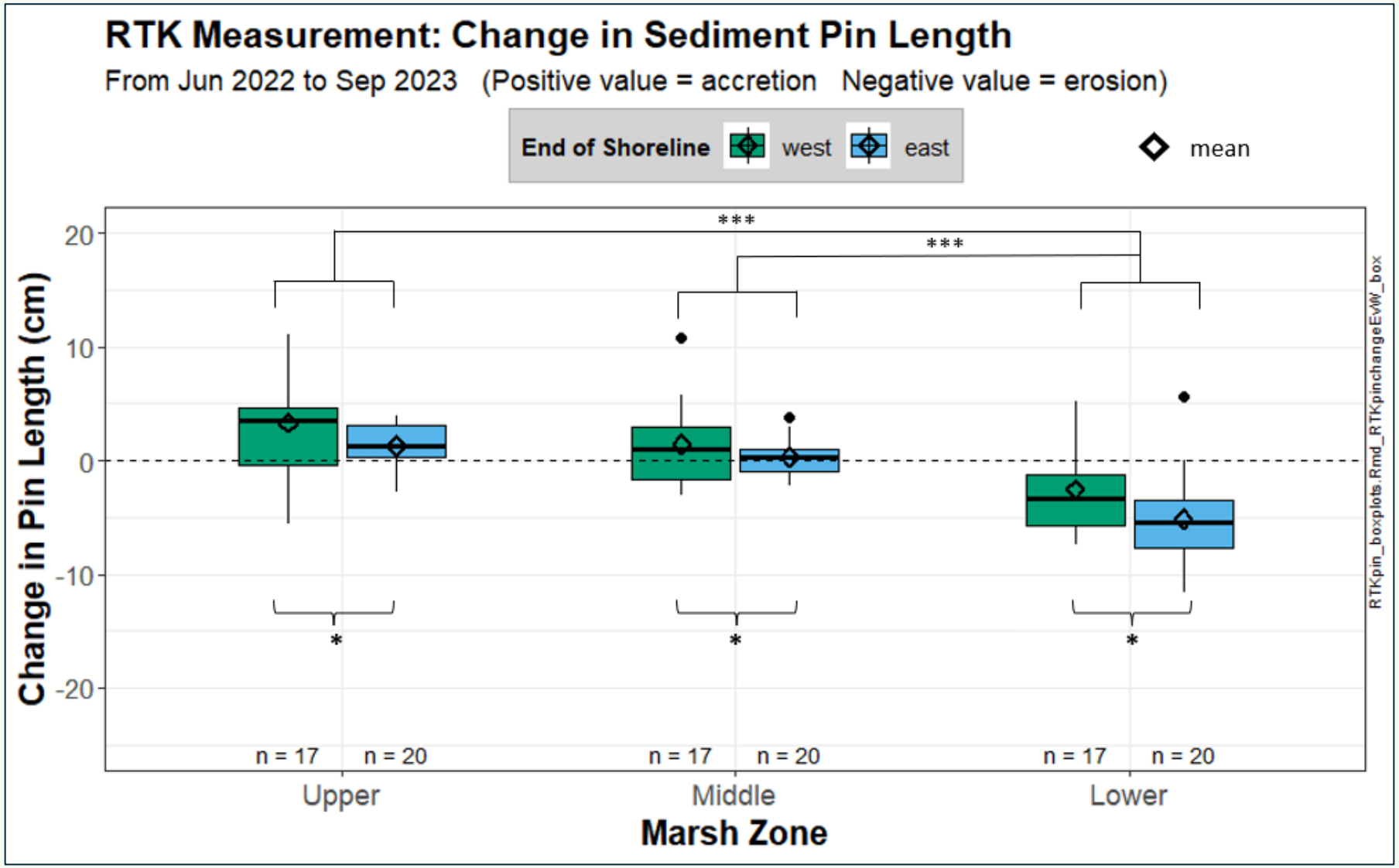
GIS Vegetation Mapping



Shoreline End	Marsh Zone	Total Area of Marsh Zone (hectares)	Vegetated Area (hectares)			Percent Veg Cover			Percent Veg Cover		
			Date			Date			Change		
			Dec-21	Aug-22	Aug-23	Dec-21	Aug-22	Aug-23	Yr 1-2	Yr 2-3	Yr 1-3:
West	Upper	0.396	0.084	0.280	0.235	21.3%	70.8%	59.4%	49.4%	-11.4%	38.0%
	Middle	0.340	0.123	0.268	0.282	36.1%	78.8%	82.9%	42.7%	4.1%	46.8%
	Lower	0.856	0.341	0.649	0.789	39.8%	75.8%	92.2%	36.0%	16.4%	52.4%
East	Upper	0.440	0.118	0.319	0.380	26.8%	72.5%	86.3%	45.7%	13.8%	59.5%
	Middle	0.338	0.135	0.266	0.291	40.1%	78.7%	86.1%	38.6%	7.4%	46.0%
	Lower	0.685	0.144	0.317	0.483	21.0%	46.2%	70.6%	25.2%	24.3%	49.5%

Results/Discussion

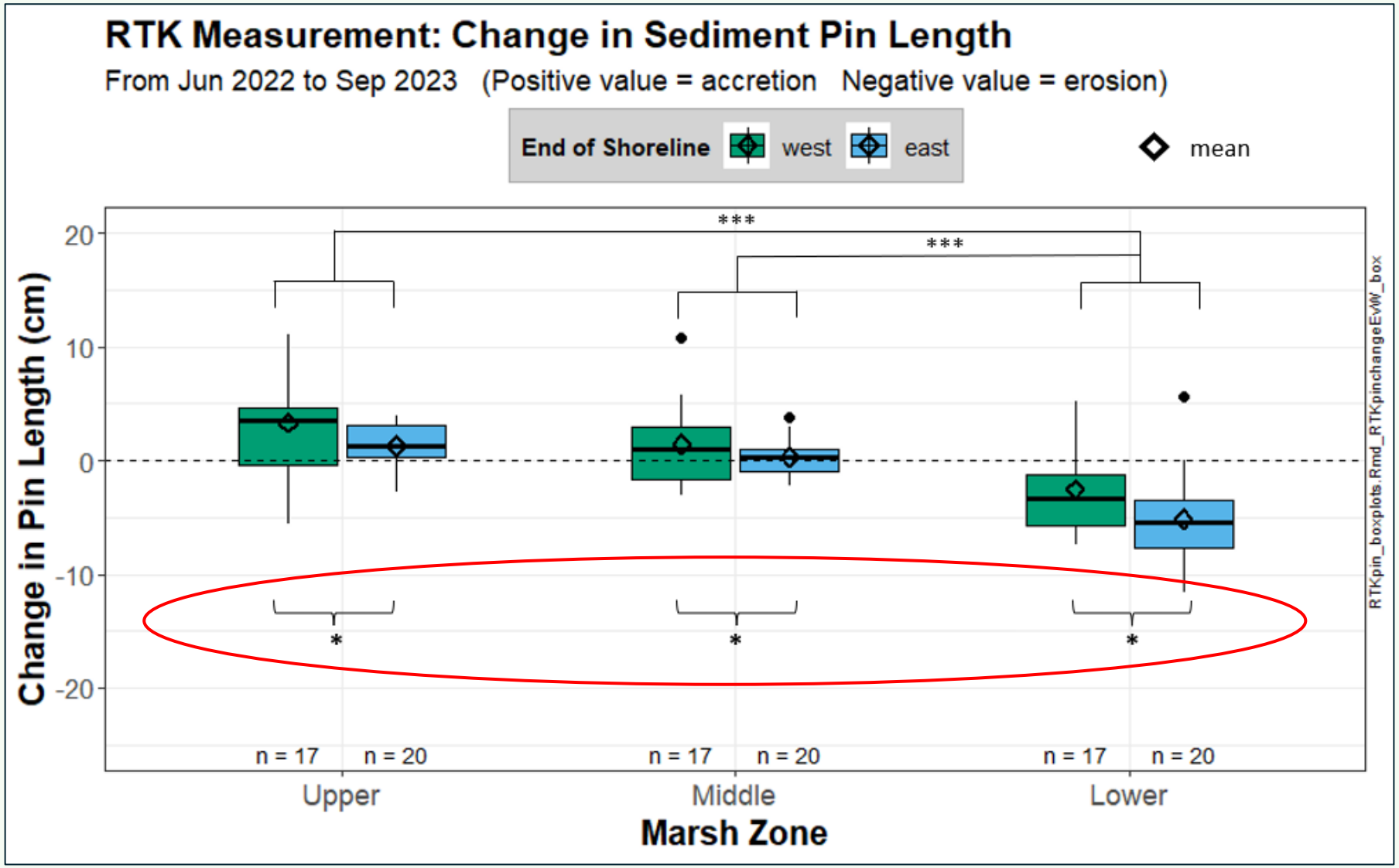
Sediment Pins



Results/ Discussion

Main Effects: Shoreline End: $X^2 = 8.4074$, $p = 0.003737$; Marsh zone: $X^2 = 72.639$, $p < 0.0001$

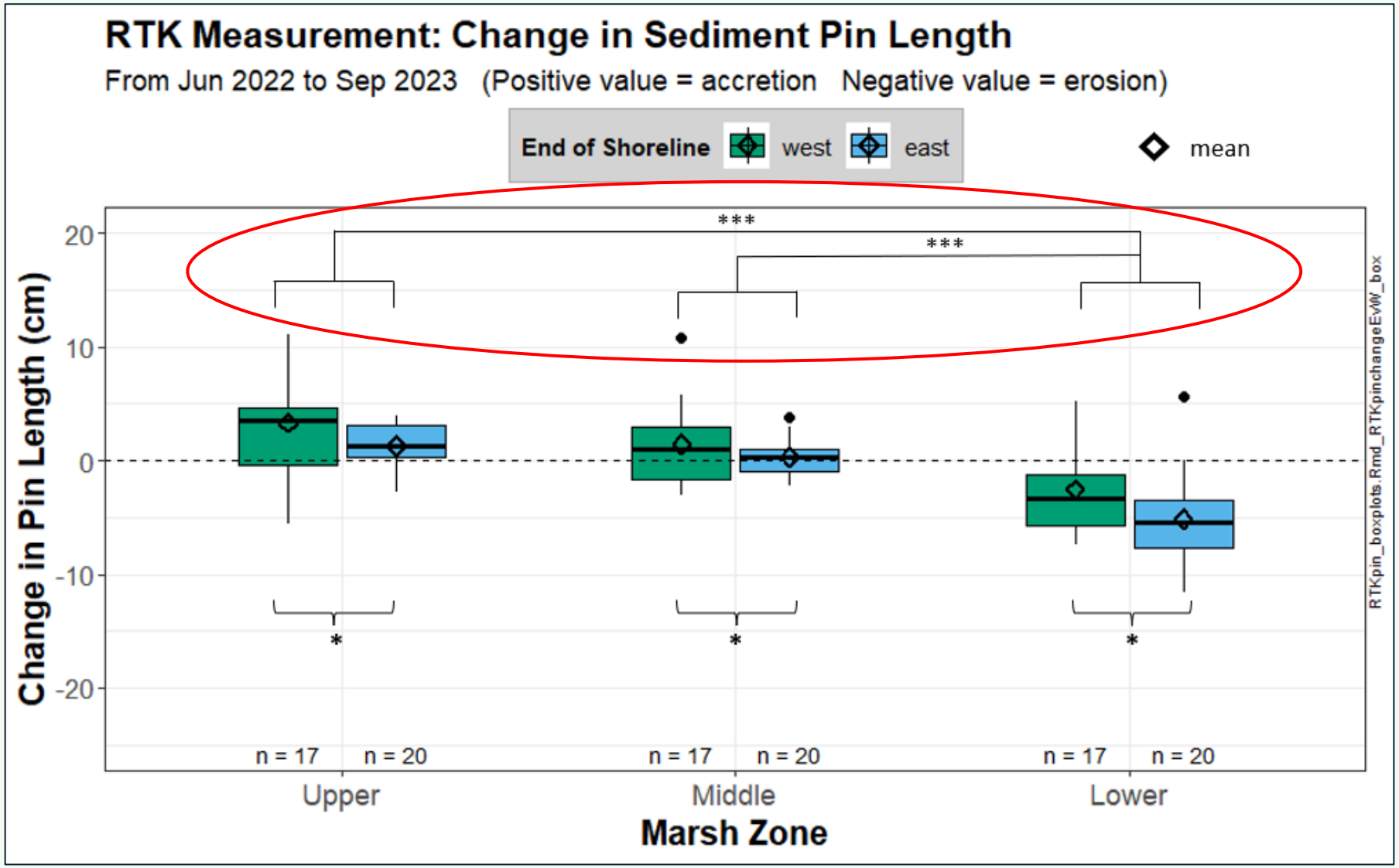
Sediment Pins



Results/ Discussion

Main Effects: Shoreline End: $X^2 = 8.4074$, $p = 0.003737$; Marsh zone: $X^2 = 72.639$, $p < 0.0001$

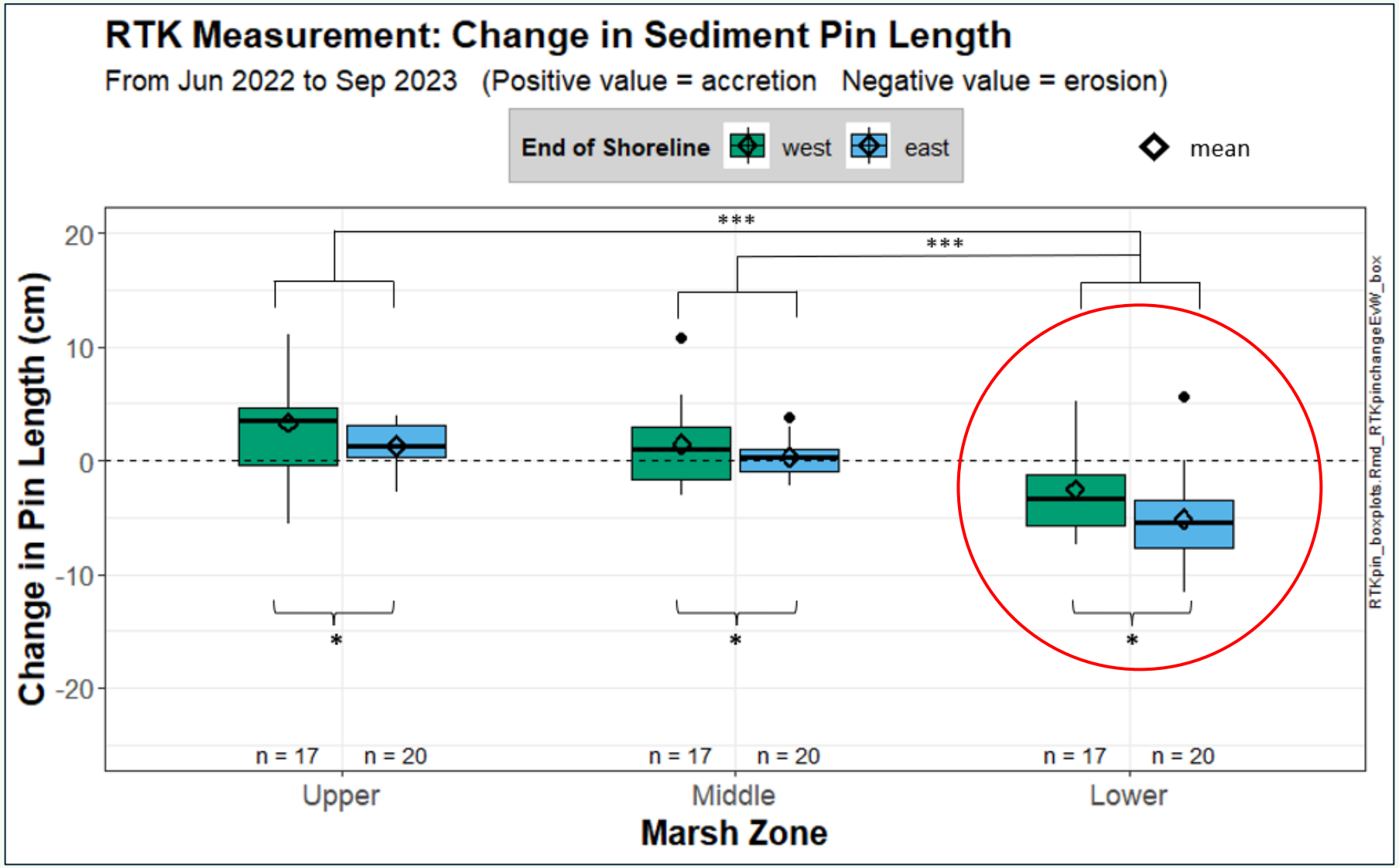
Sediment Pins



Results/ Discussion

Main Effects: Shoreline End: $X^2 = 8.4074$, $p = 0.003737$; Marsh zone: $X^2 = 72.639$, $p < 0.0001$

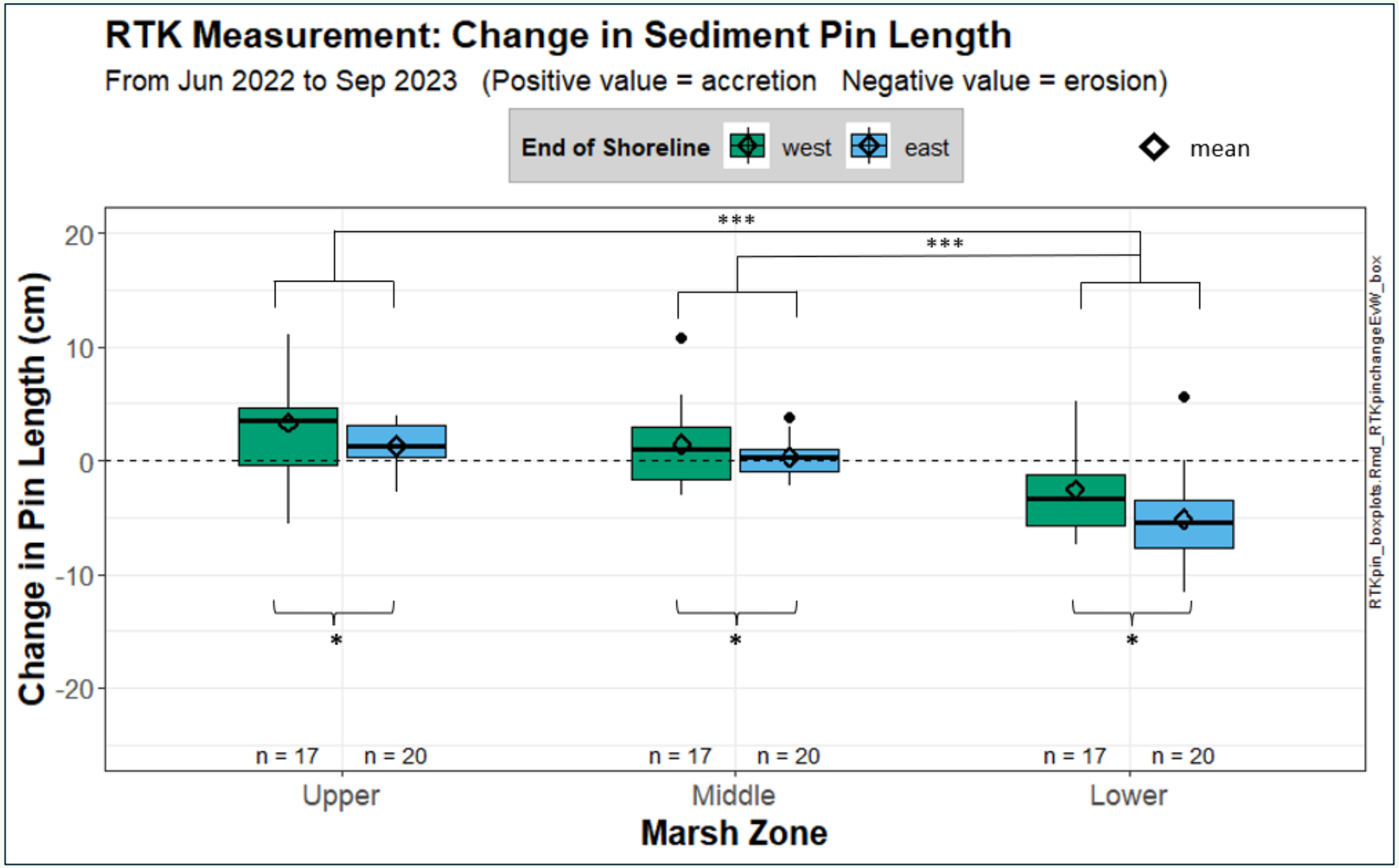
Sediment Pins



Results/ Discussion

Main Effects: Marsh zone: $X^2 = 72.639$, $p < 0.0001$

Sediment Pins

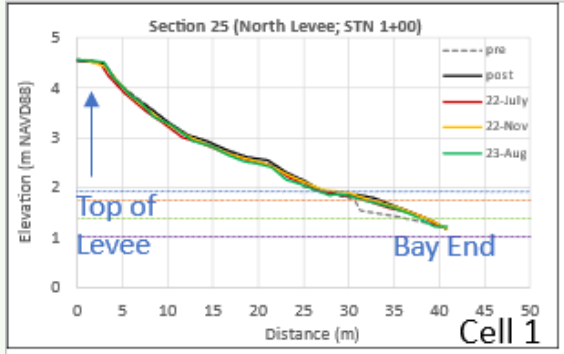


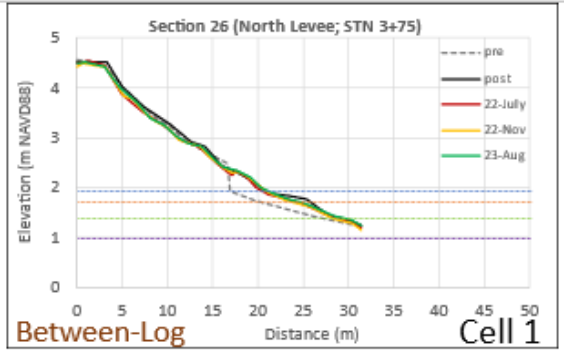
Results/ Discussion

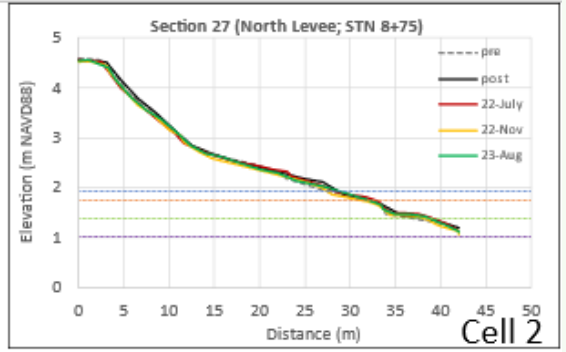
Main Effects: Shoreline End: $X^2 = 8.4074$, $p = 0.003737$

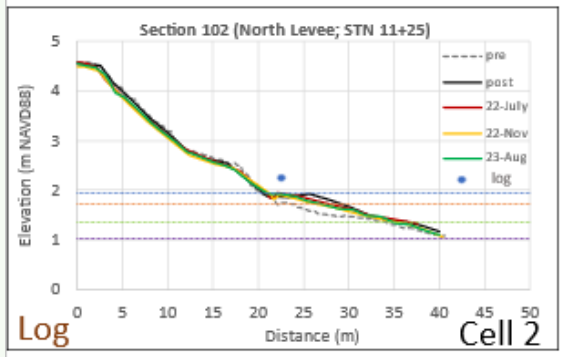
Topographic Transects

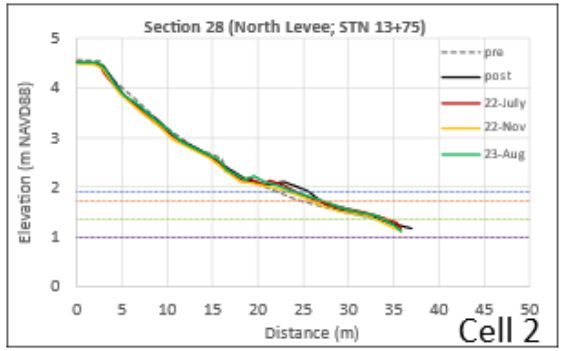
West End

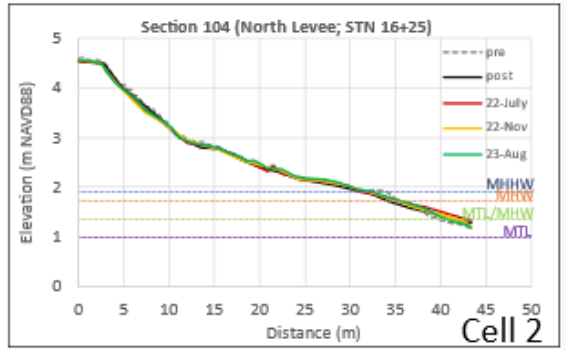


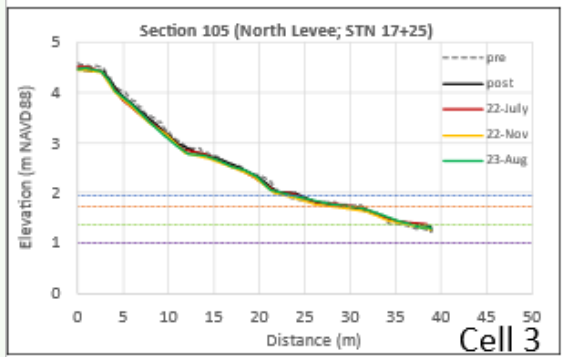


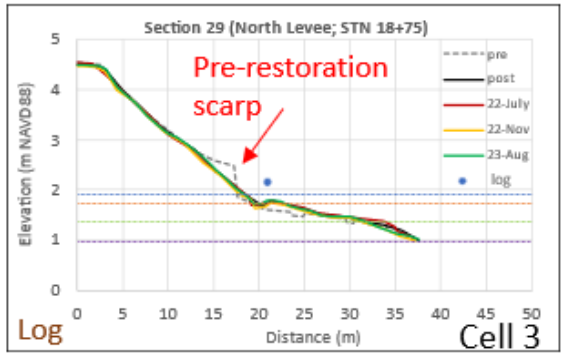


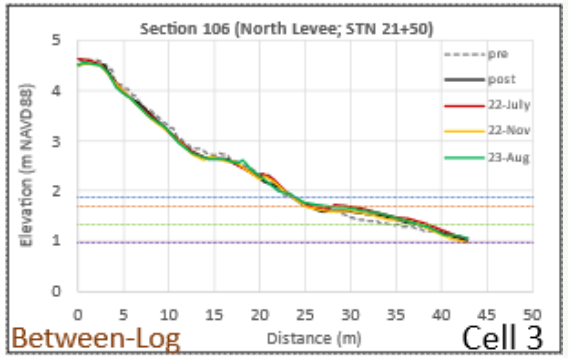


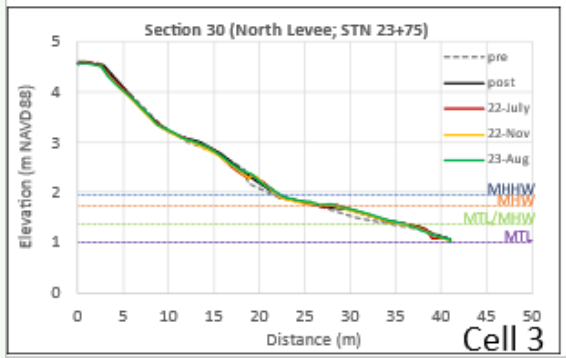


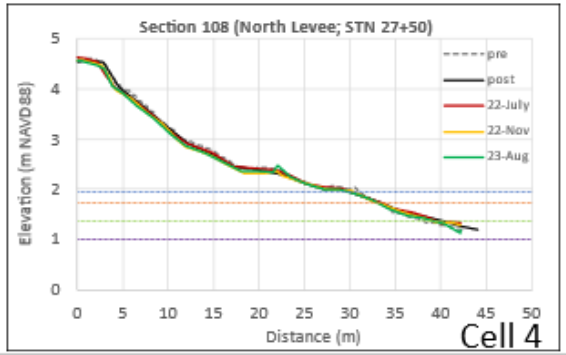


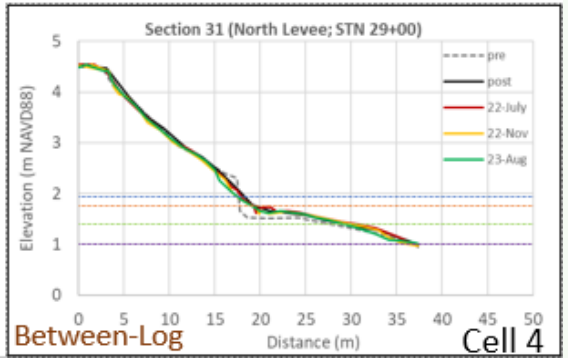












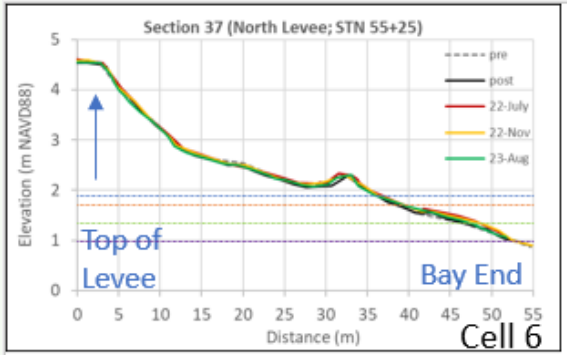
Tidal Datum

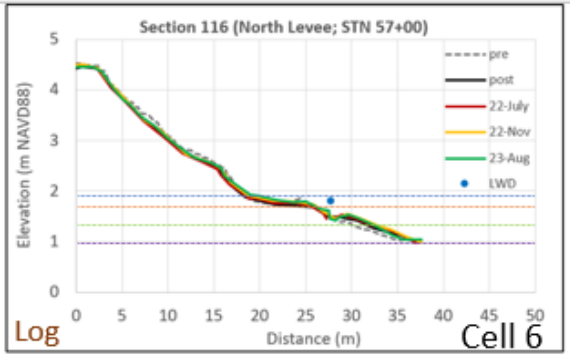
- MHHW (1.95 m)
- MHW (1.77 m)
- MTL/MHW (1.40 m)
- MTL (1.01 m)

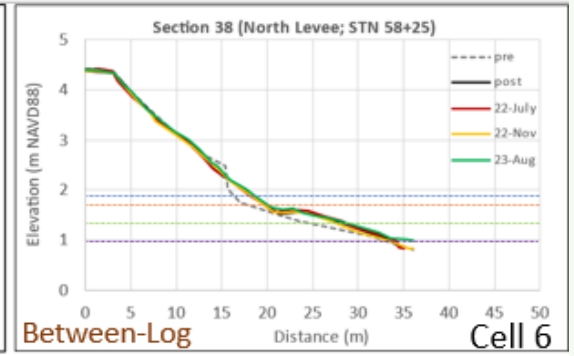
Results/ Discussion

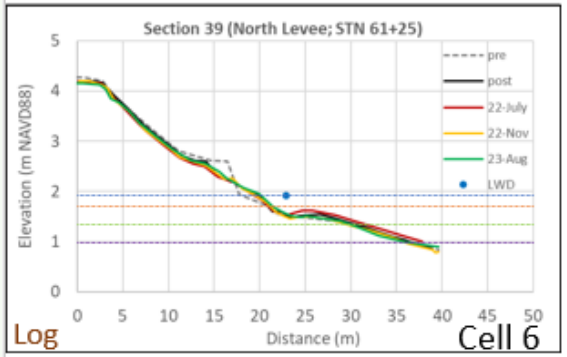
Topographic Transects

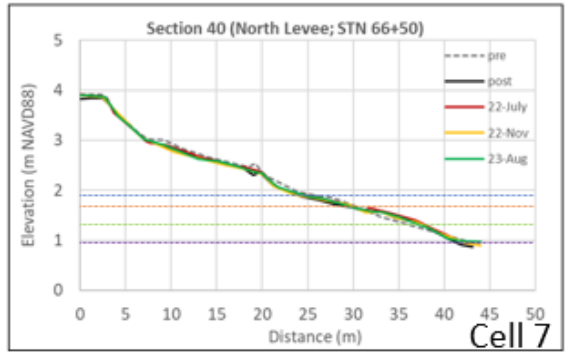
East End

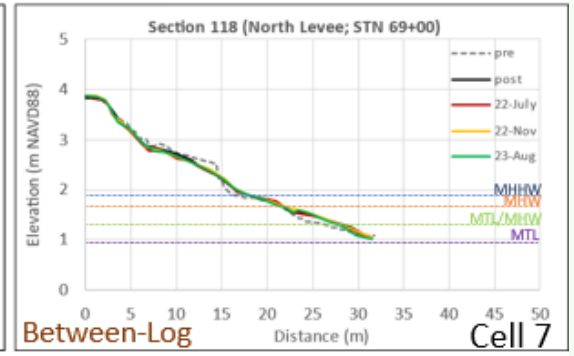


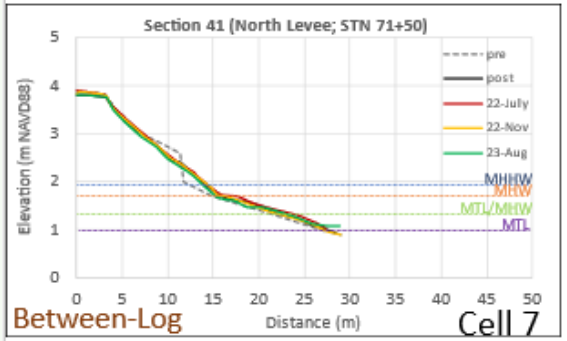


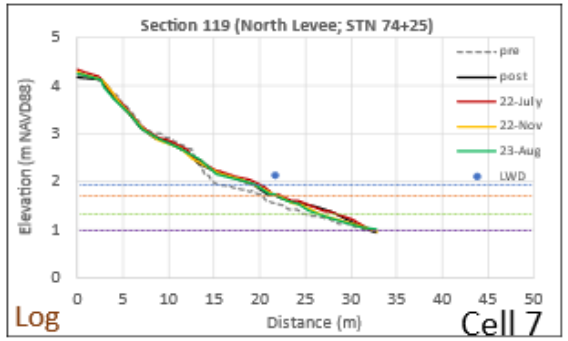


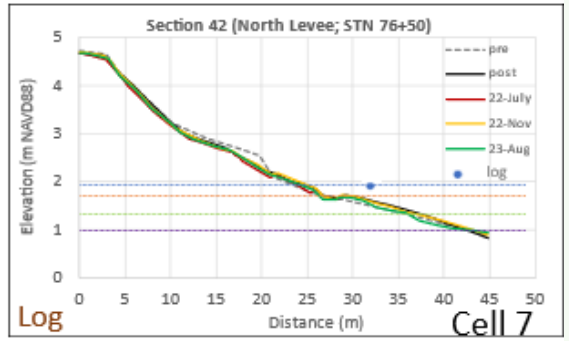


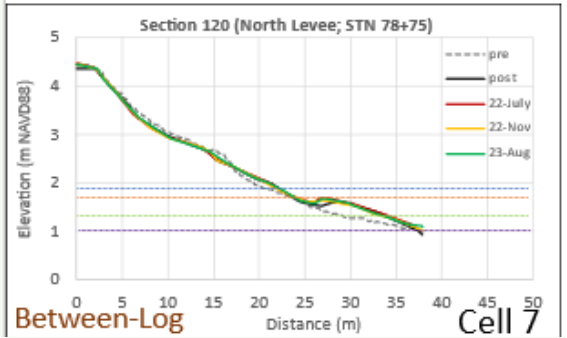


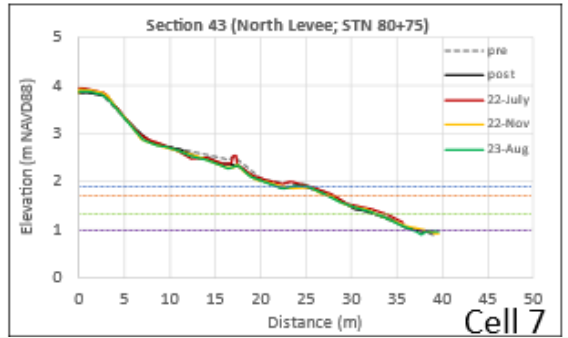












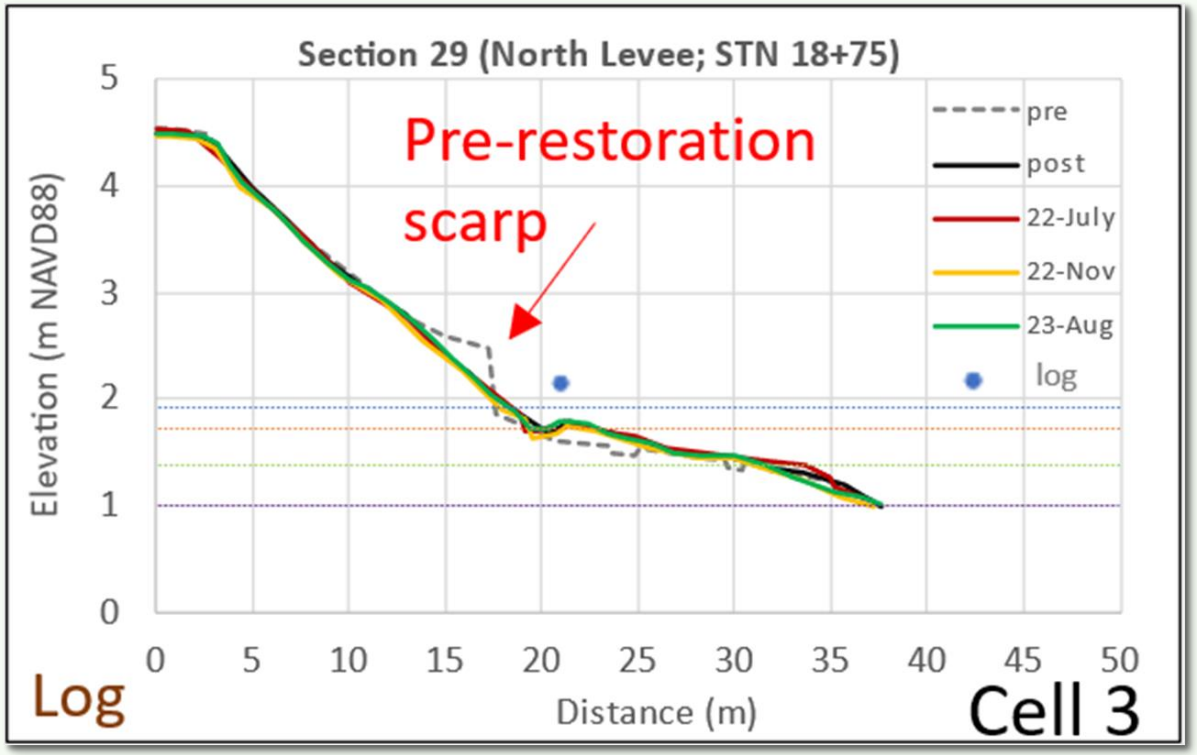
Tidal Datum

- MHHW (1.95 m)
- MHW (1.77 m)
- MTL/MHW (1.40 m)
- MTL (1.01 m)

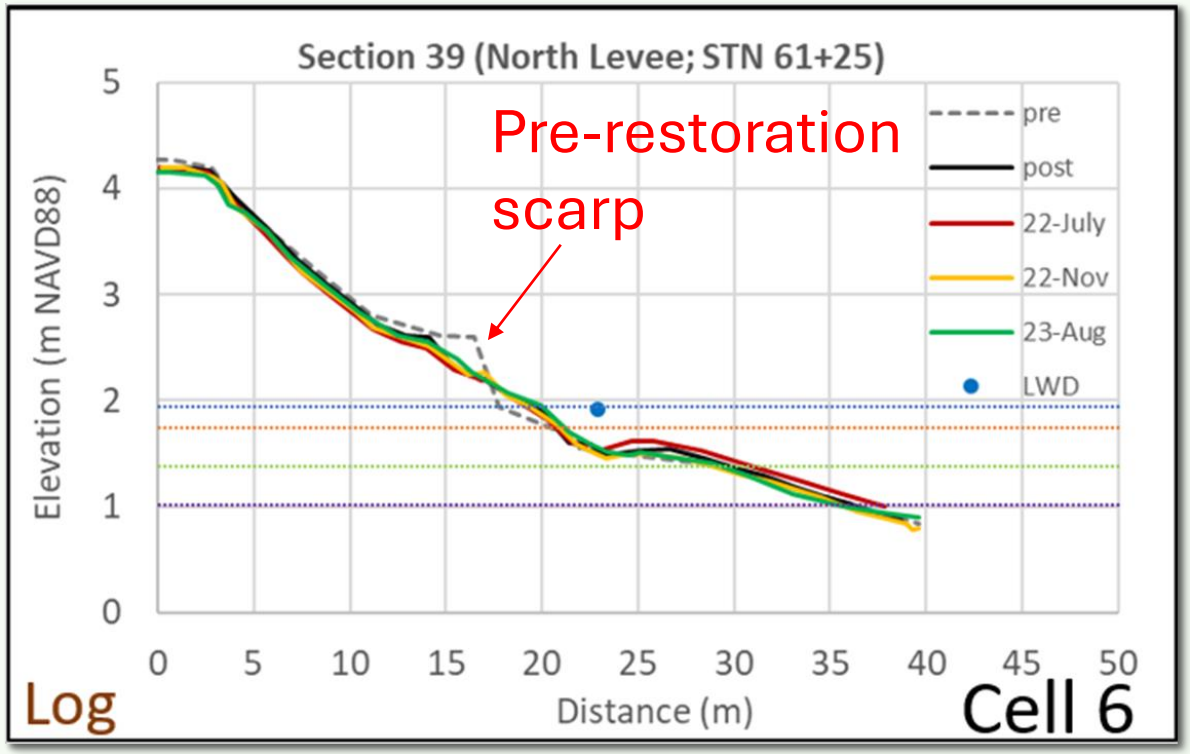
Results/ Discussion

Topographic Transects

West End



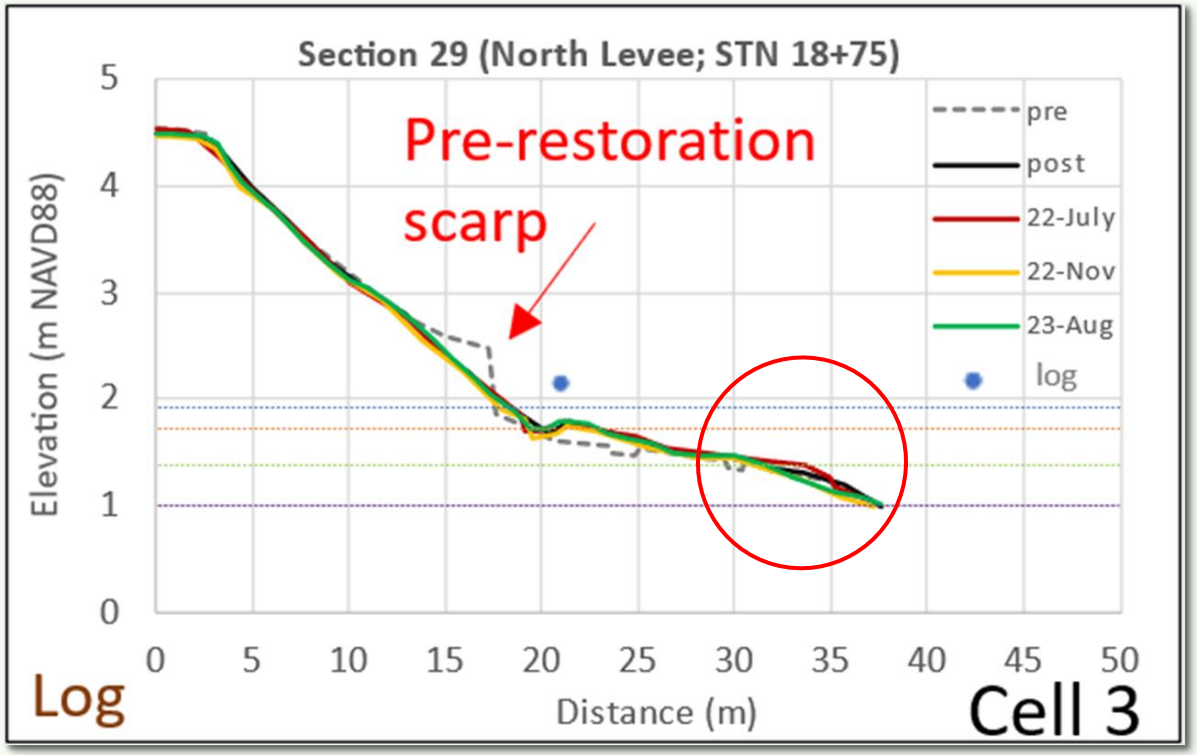
East End



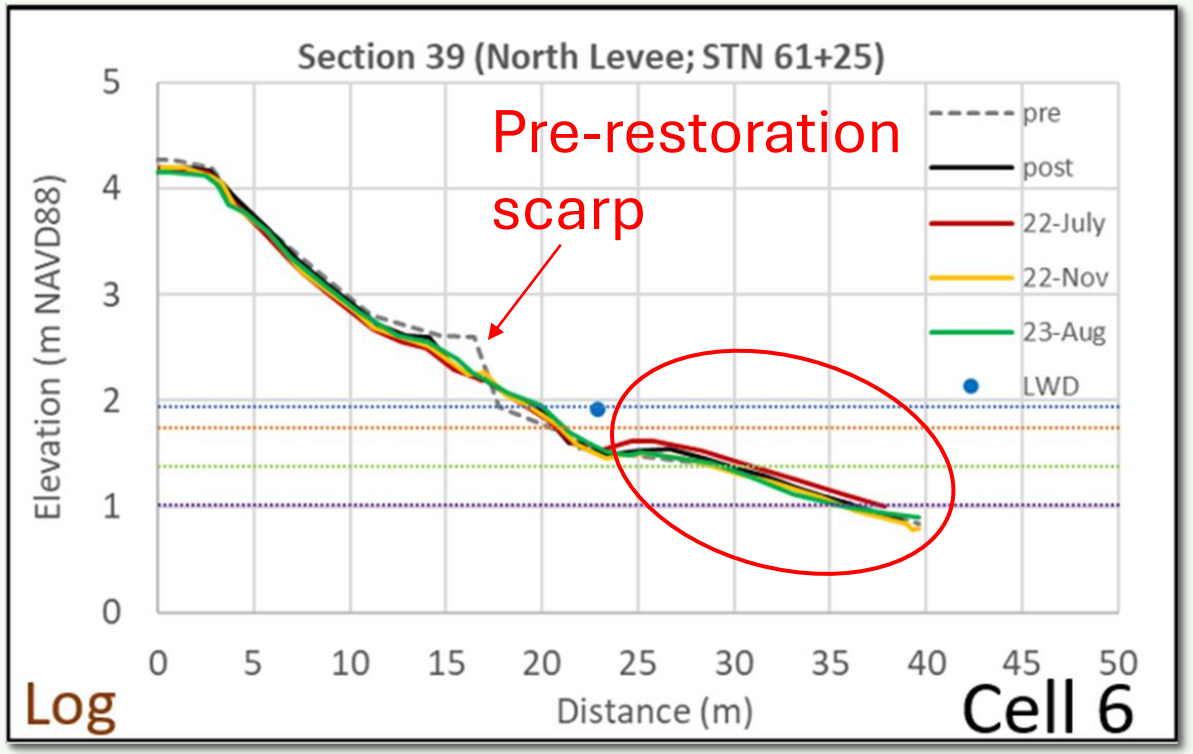
Results/Discussion

Topographic Transects

West End



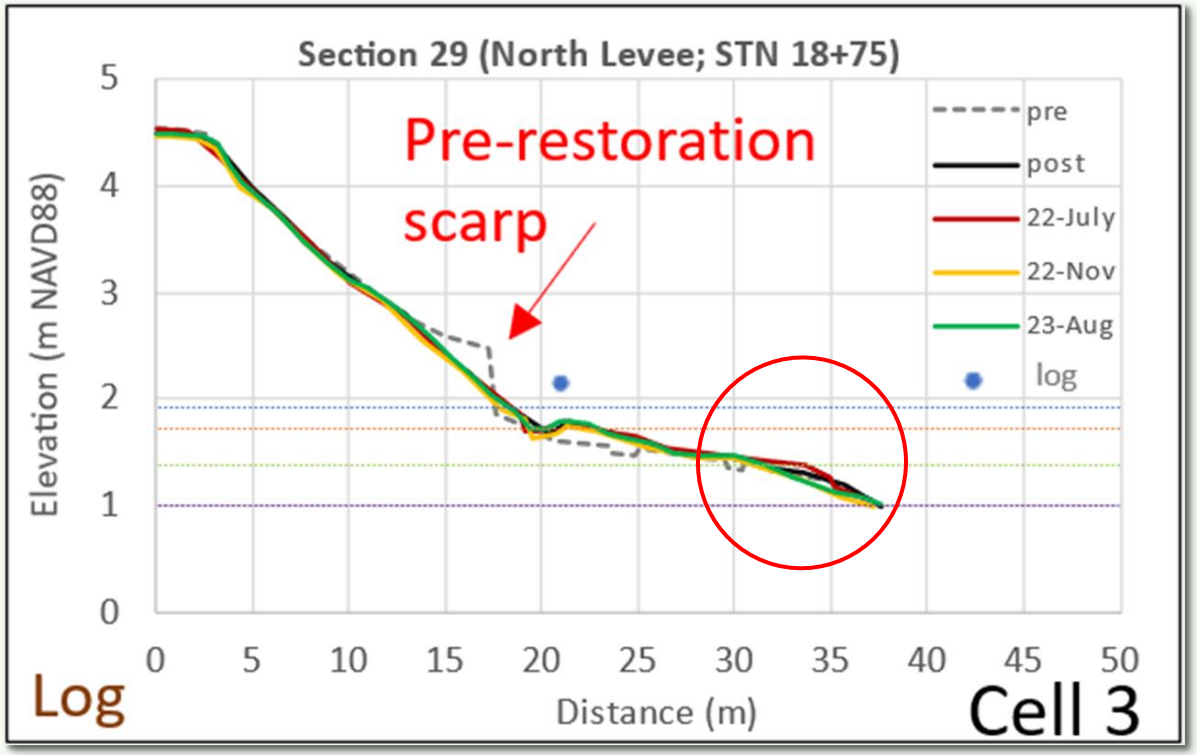
East End



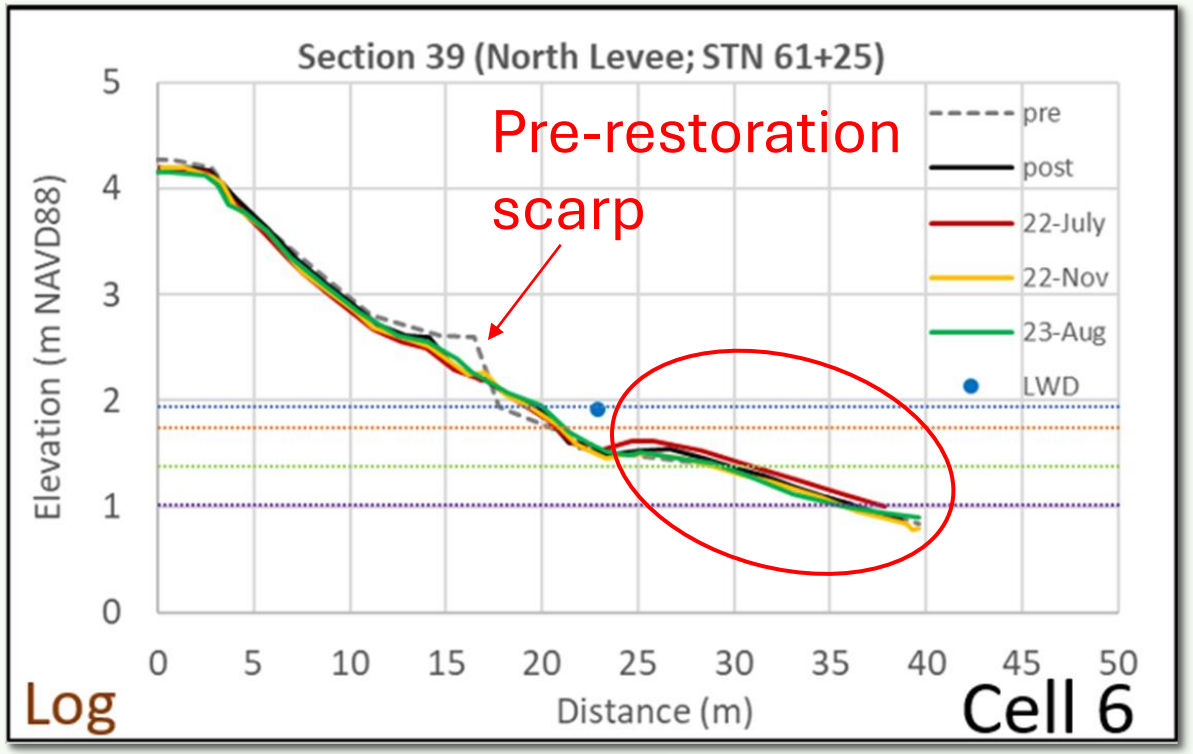
Results/Discussion

Topographic Transects

West End



East End



Results/Discussion

September 2022

June 2023

Image: Sears Point Year 2 Monitoring Report, 2023

Results/Discussion

September 2022

June 2023

Image: Sears Point Year 2 Monitoring Report, 2023

Results/Discussion

September 2022

June 2023

Image: Sears Point Year 2 Monitoring Report, 2023

Results/Discussion

September 2022

June 2023

Image: Sears Point Year 2 Monitoring Report, 2023

Results/Discussion

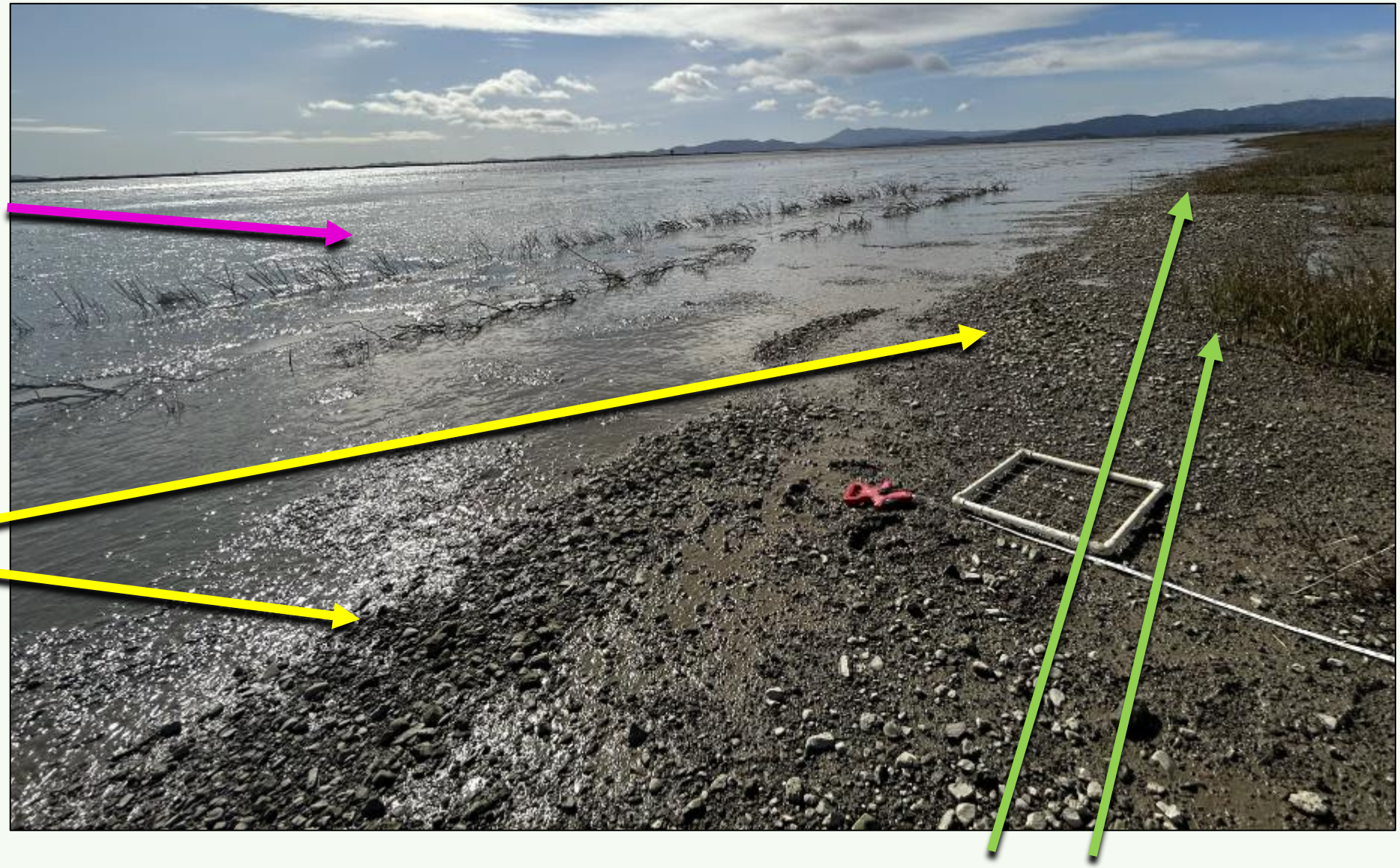
July 2022

Coyote brush fencing

Bay mud still in place

Results/Discussion

February 2023



Results/Discussion

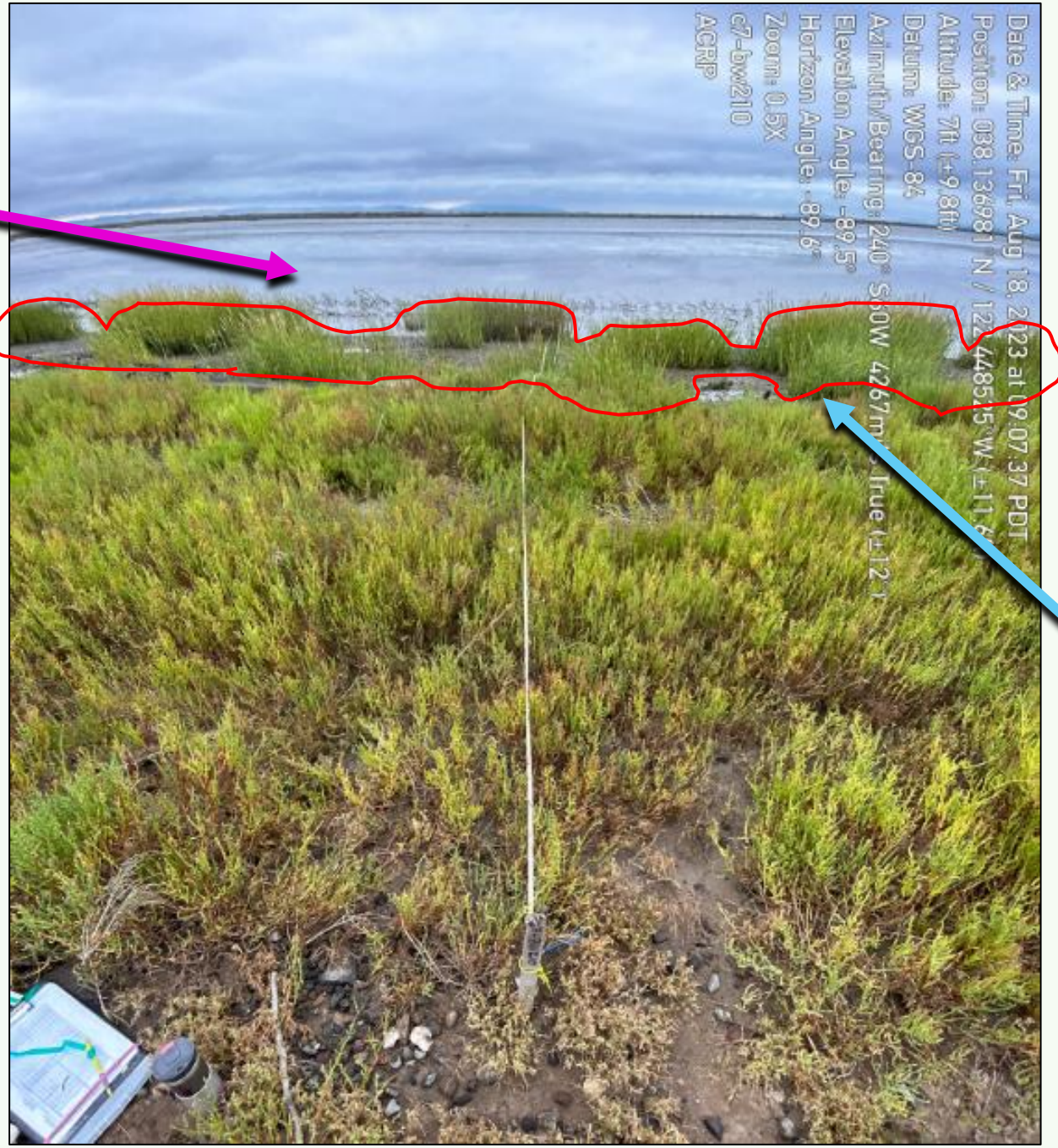
February 2023

Coyote brush fencing

Results/Discussion

February 2023

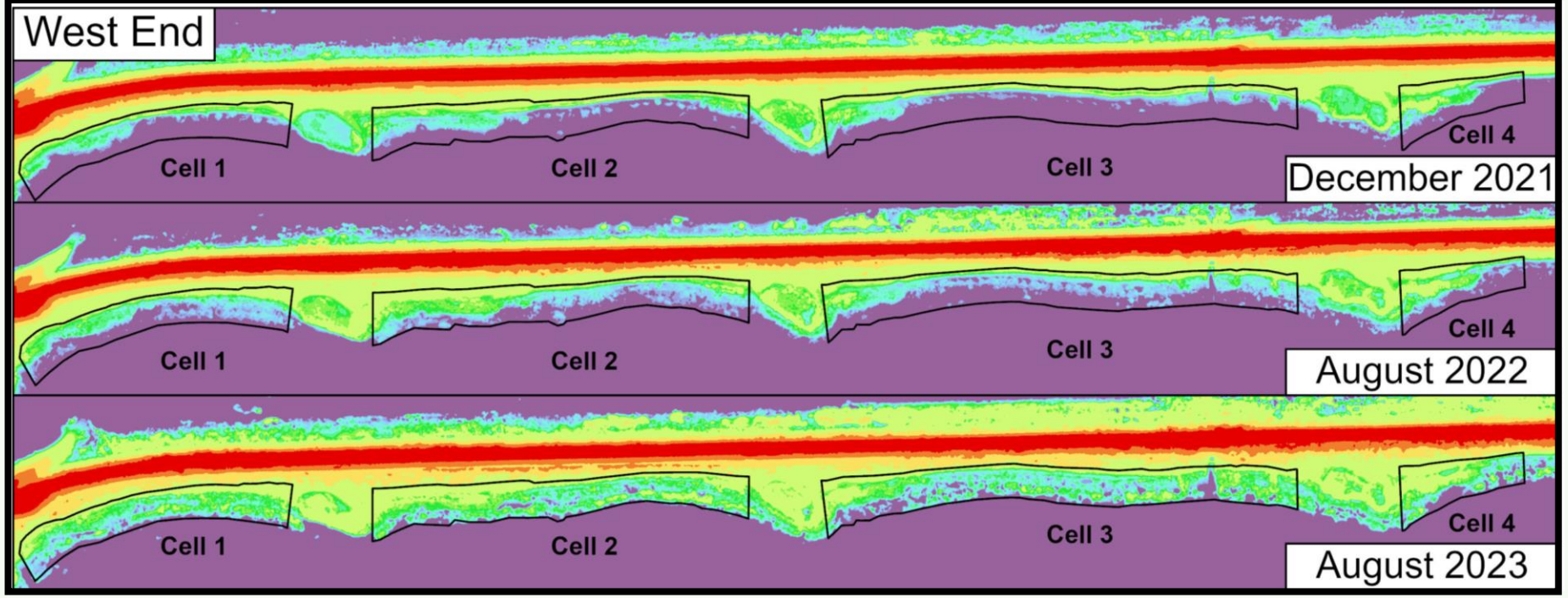
Coyote brush fencing



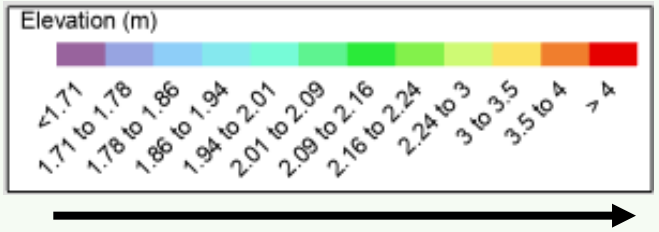
Locked in *Spartina* colonies

Results/Discussion

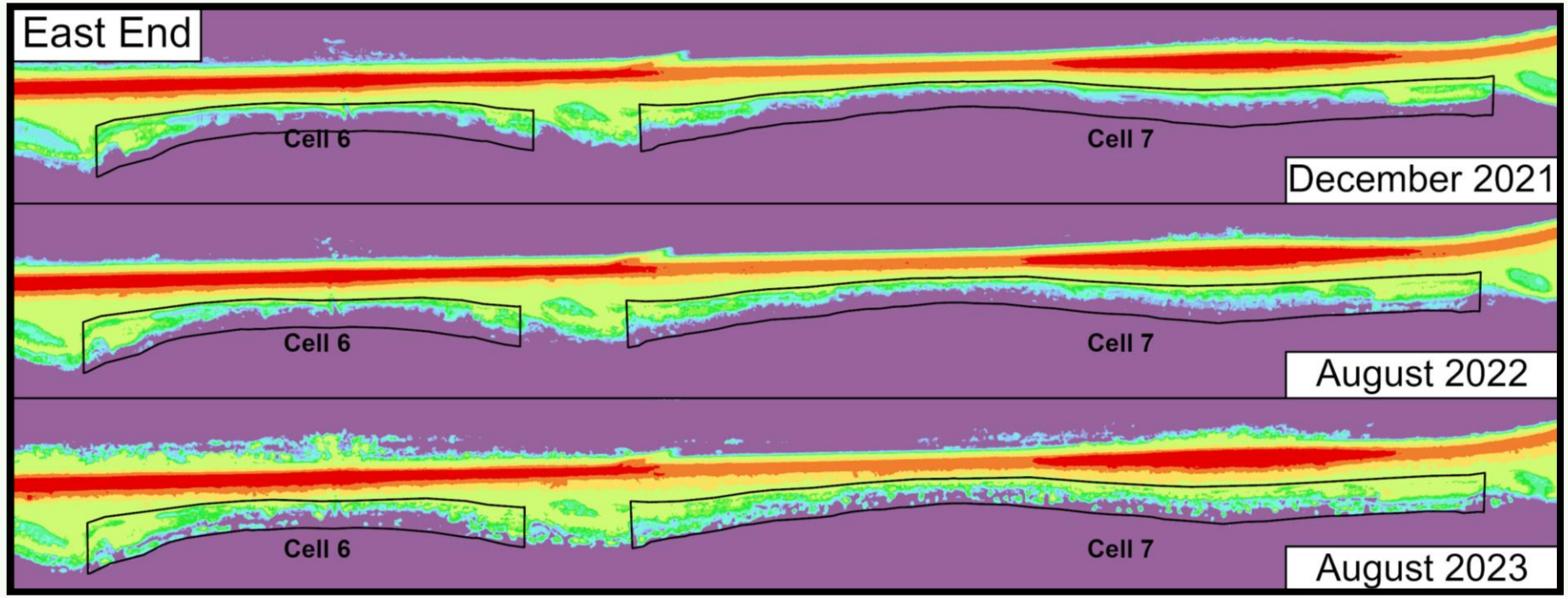
Digital Terrain Modeling



Research Project Extent

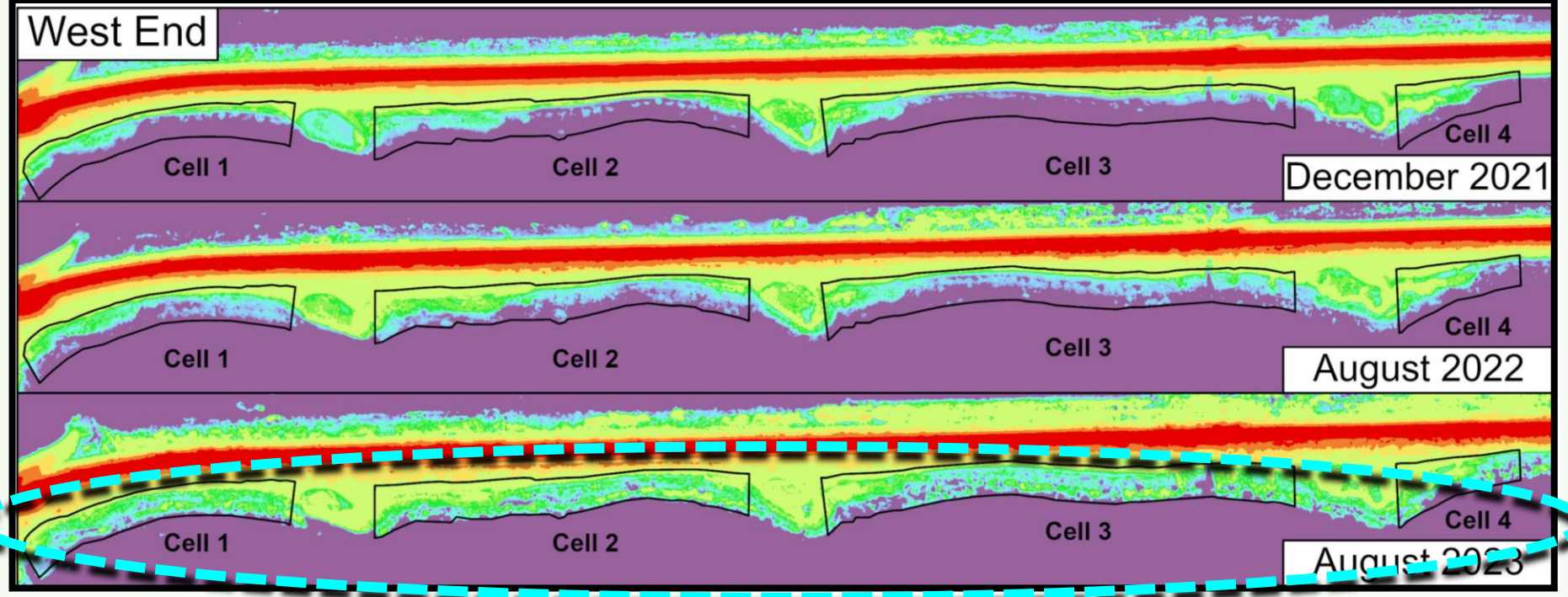


Increase in elevation

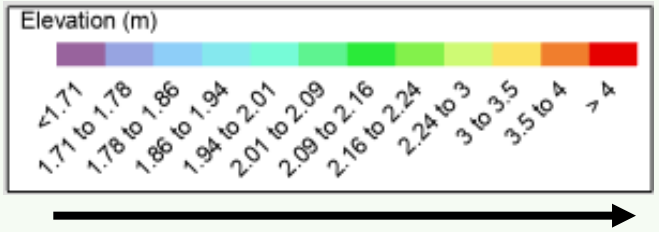


Results/Discussion

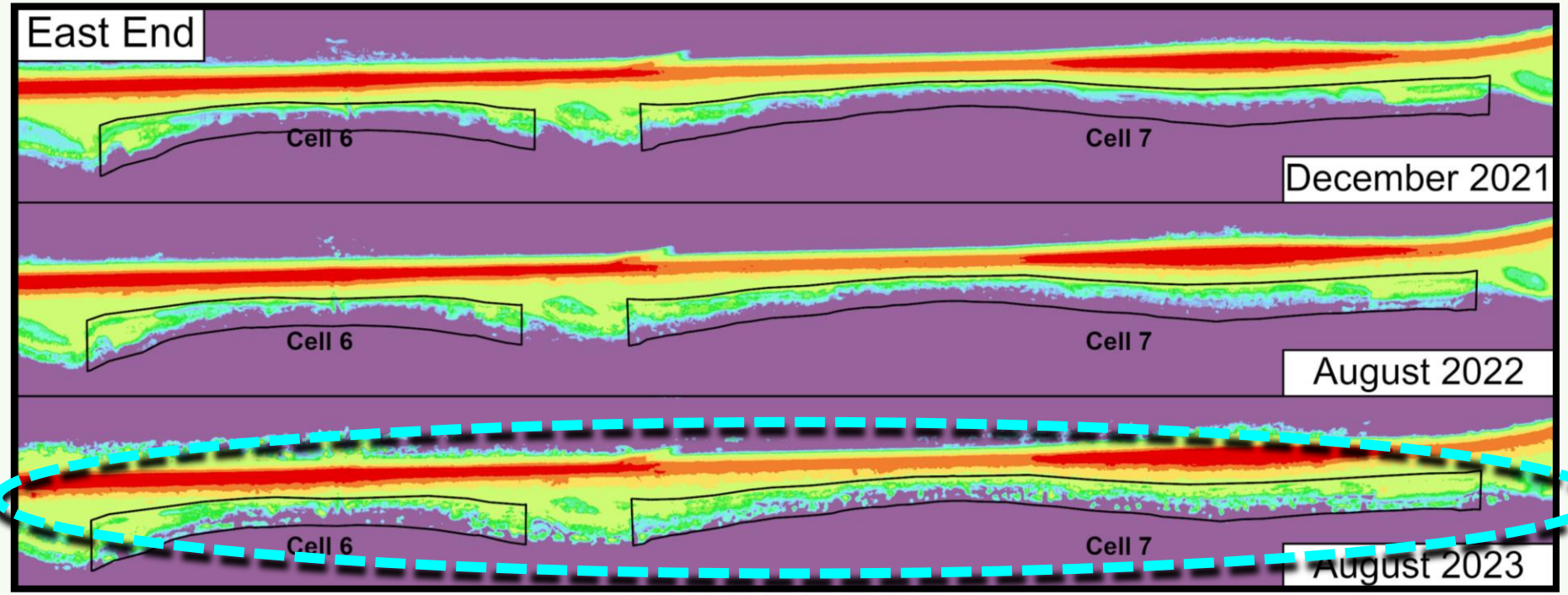
Digital Terrain Modeling



Research Project Extent



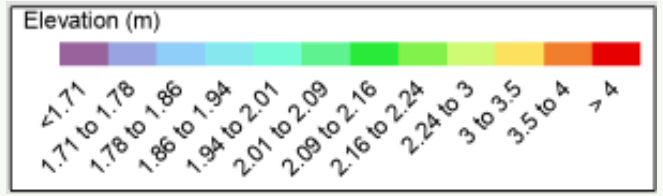
Increase in elevation



Results/Discussion

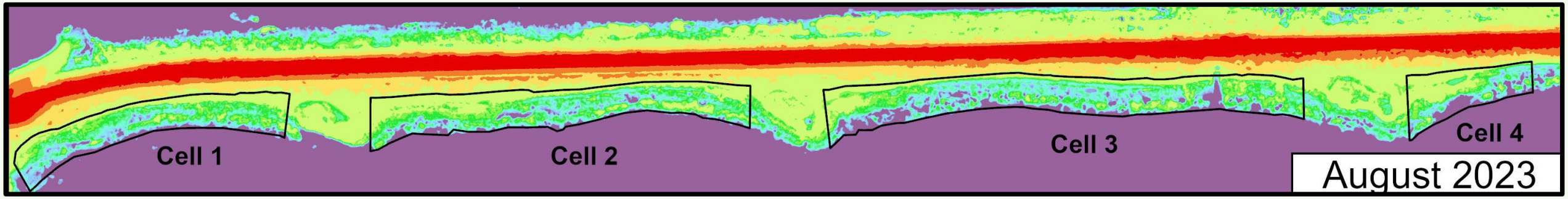
Digital Terrain Modeling

Research Project Extent



Increase in elevation

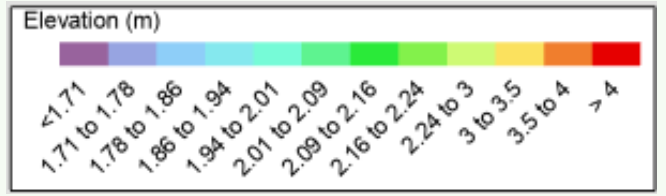
West End



Results/Discussion

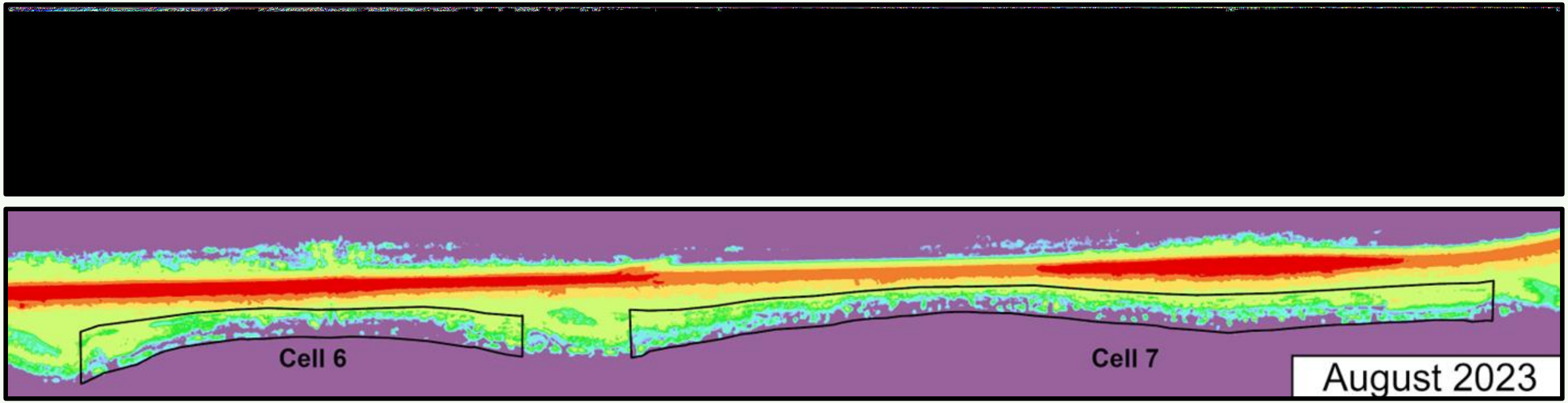
Digital Terrain Modeling

Research Project Extent



Increase in elevation

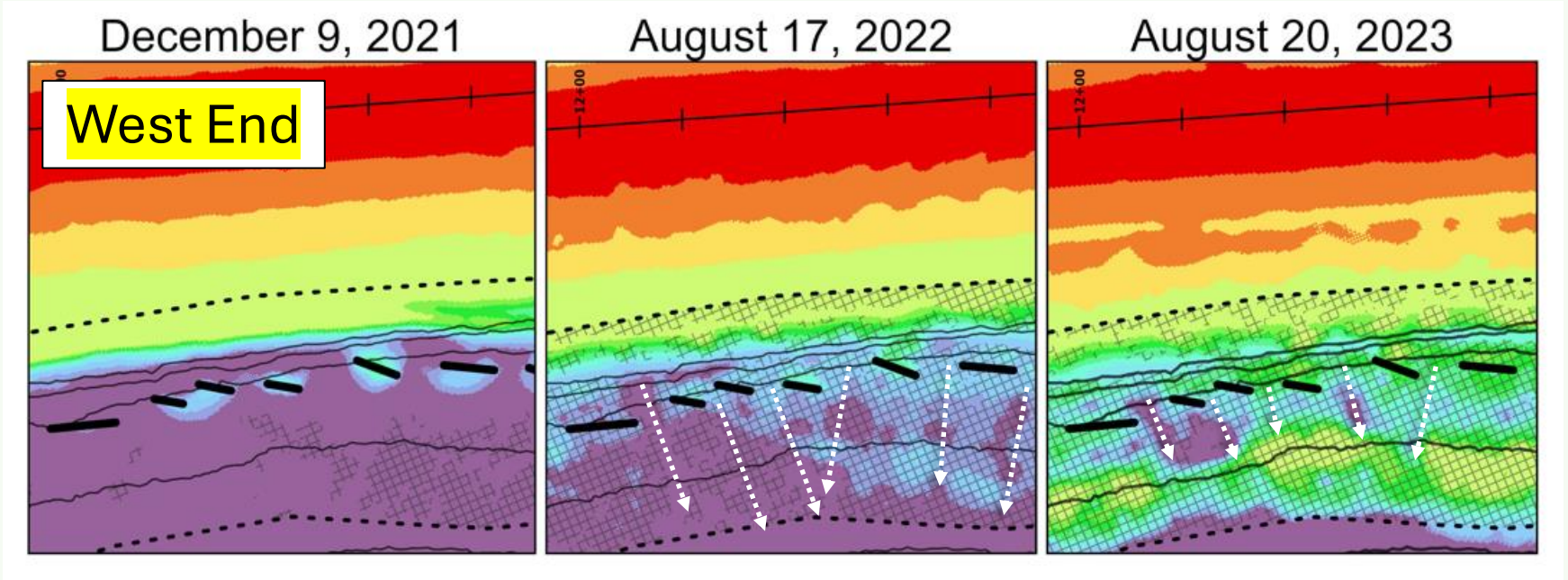
West End

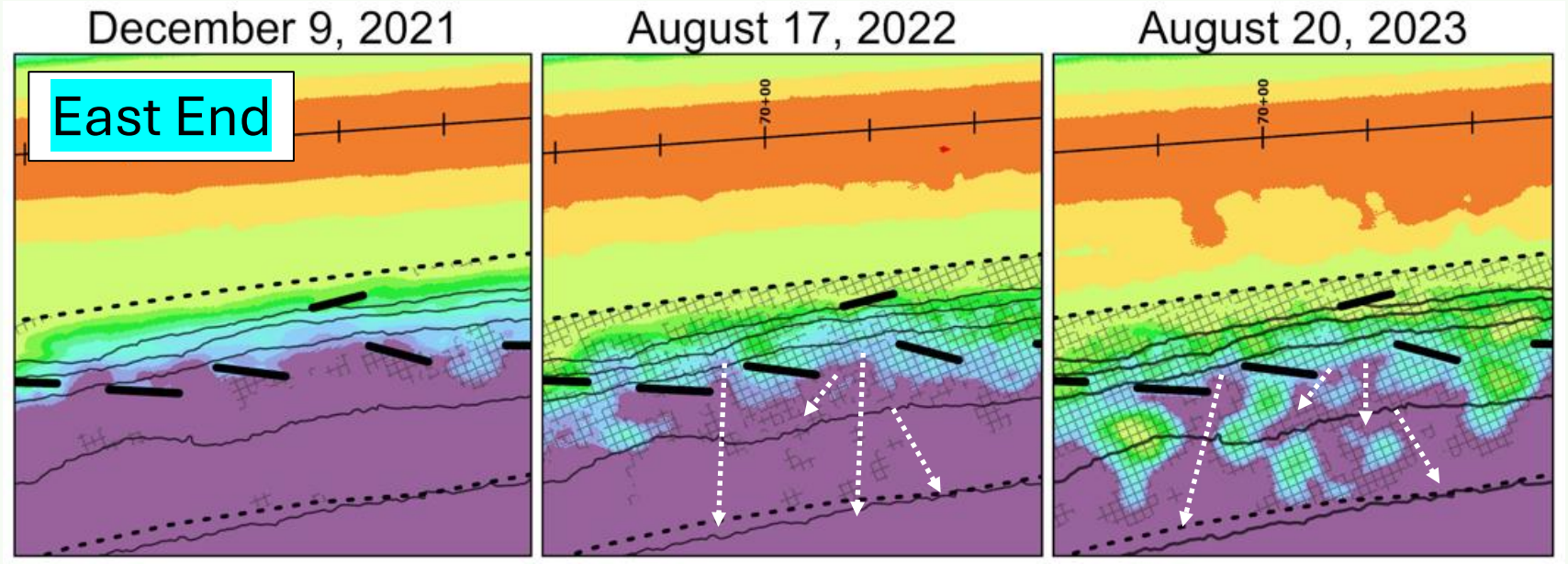


East End

Results/Discussion

Digital Terrain Modeling





SFSU Thesis Research Project Extent

LWD

Vegetation

2018 Datum Contour Lines

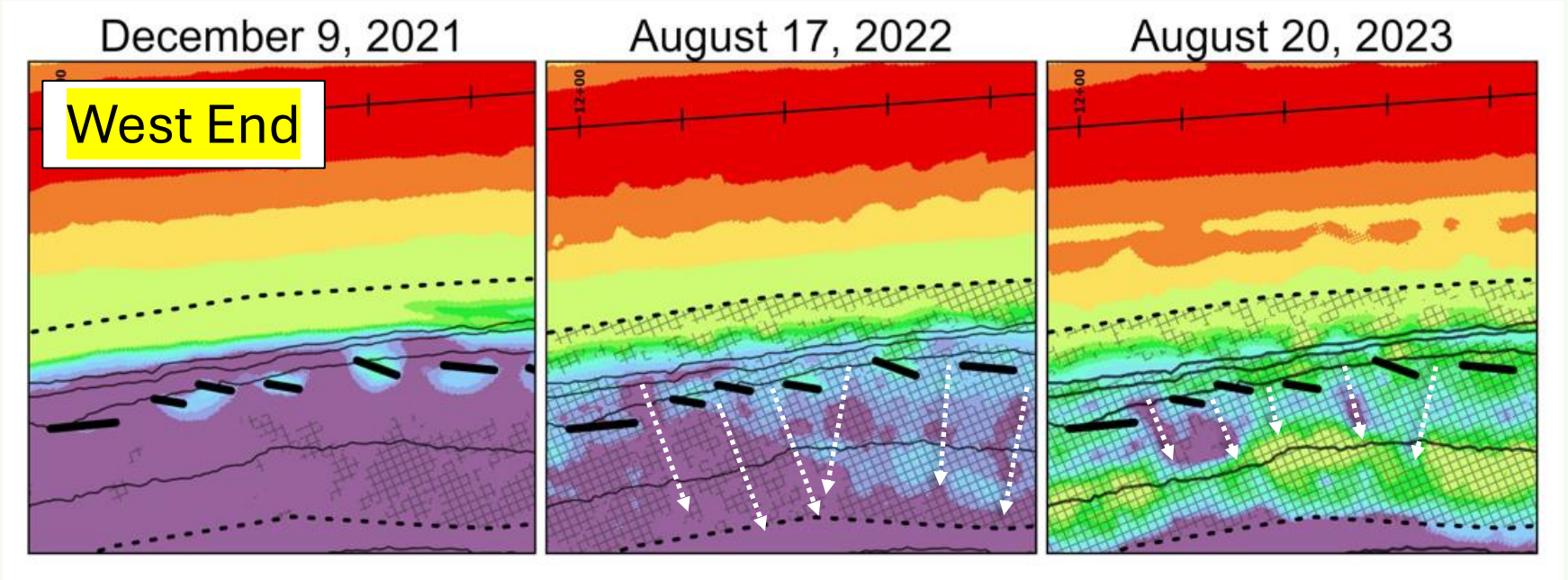
Elevation (m)

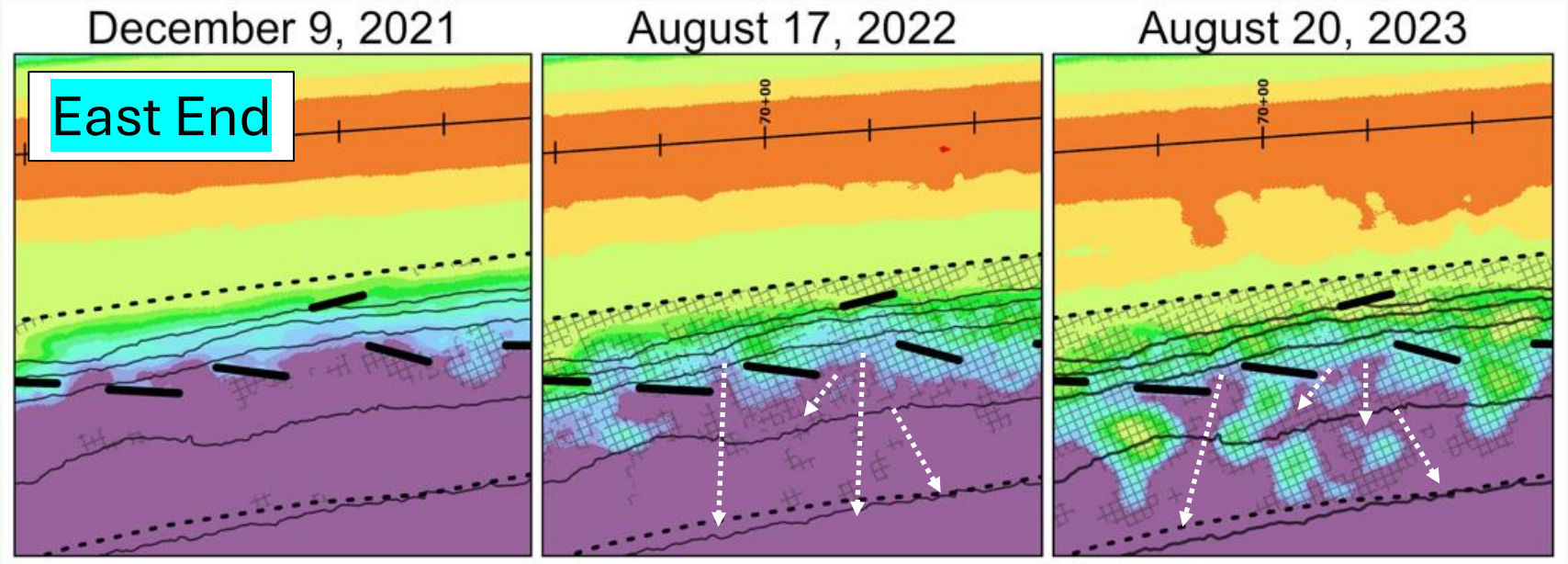
<1.71 | 1.71 to 1.78 | 1.78 to 1.86 | 1.86 to 1.94 | 1.94 to 2.01 | 2.01 to 2.09 | 2.09 to 2.16 | 2.16 to 2.24 | 2.24 to 3 | 3 to 3.5 | 3.5 to 4 | > 4

Increase in elevation

Results/Discussion

Digital Terrain Modeling





SFSU Thesis Research Project Extent

LWD

Vegetation

2018 Datum Contour Lines

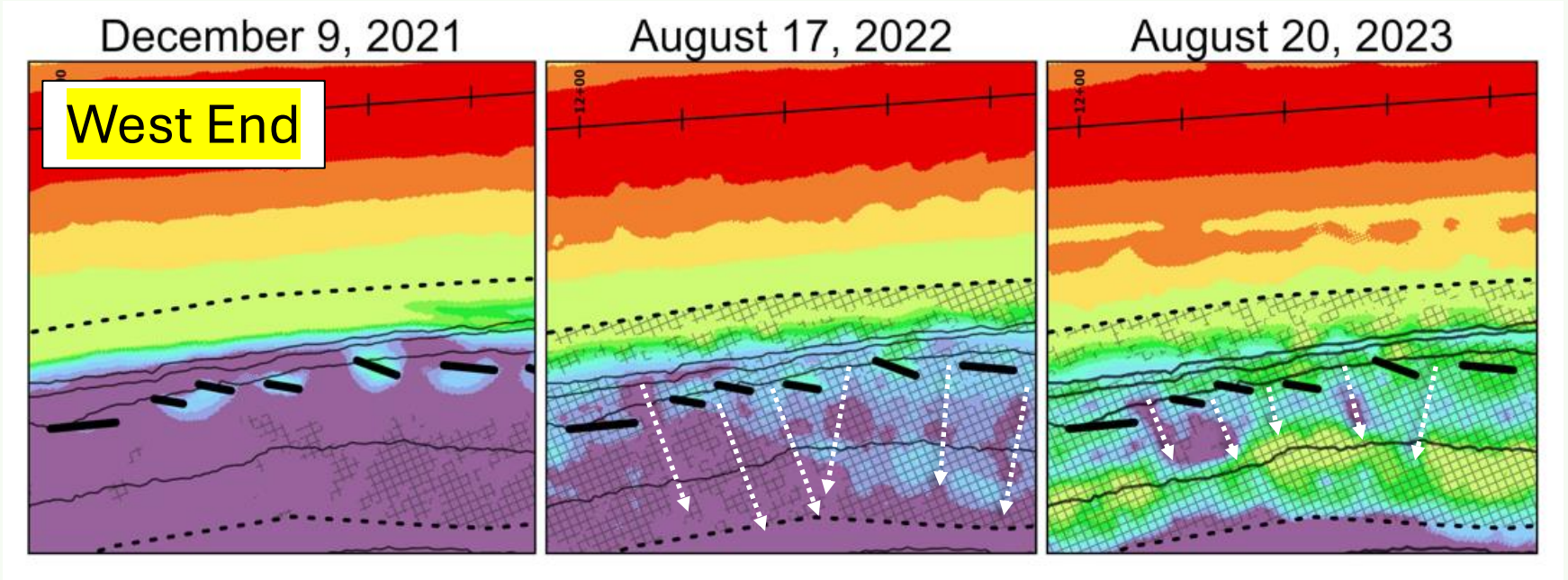
Elevation (m)

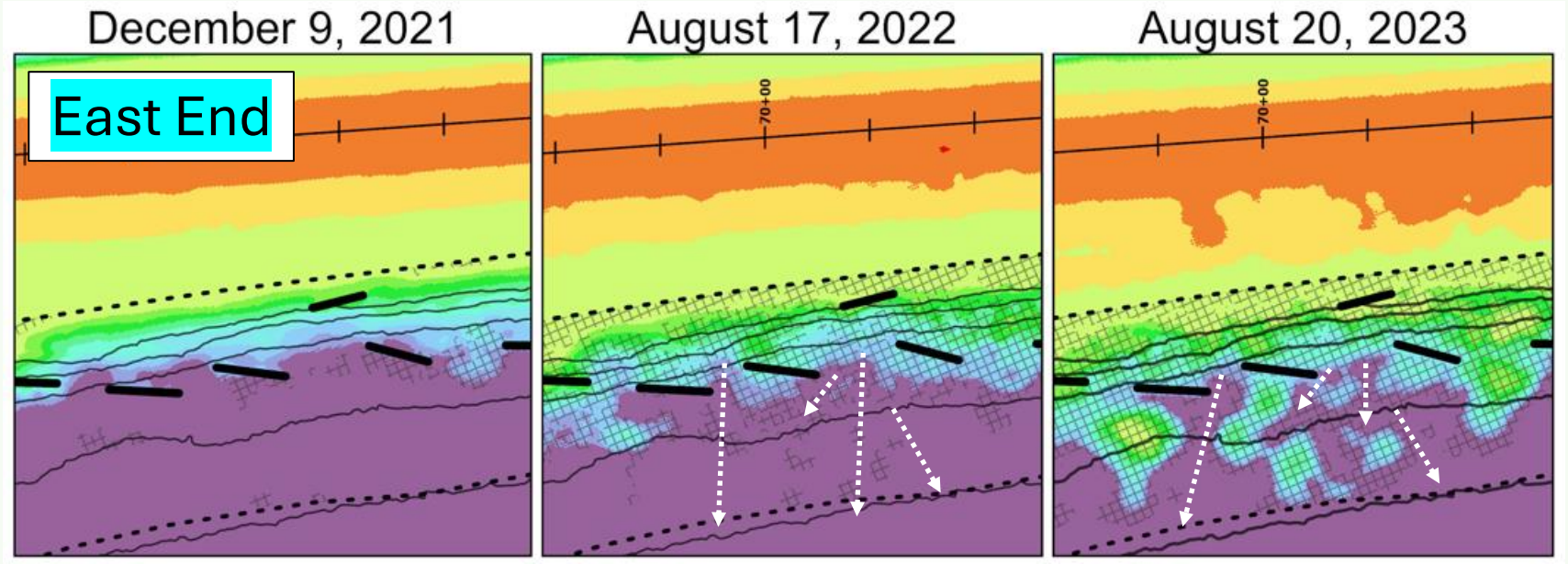
<1.71 | 1.71 to 1.78 | 1.78 to 1.86 | 1.86 to 1.94 | 1.94 to 2.01 | 2.01 to 2.09 | 2.09 to 2.16 | 2.16 to 2.24 | 2.24 to 3 | 3 to 3.5 | 3.5 to 4 | > 4

Increase in elevation

Results/Discussion

Digital Terrain Modeling





SFSU Thesis Research Project Extent

LWD

Vegetation

2018 Datum Contour Lines

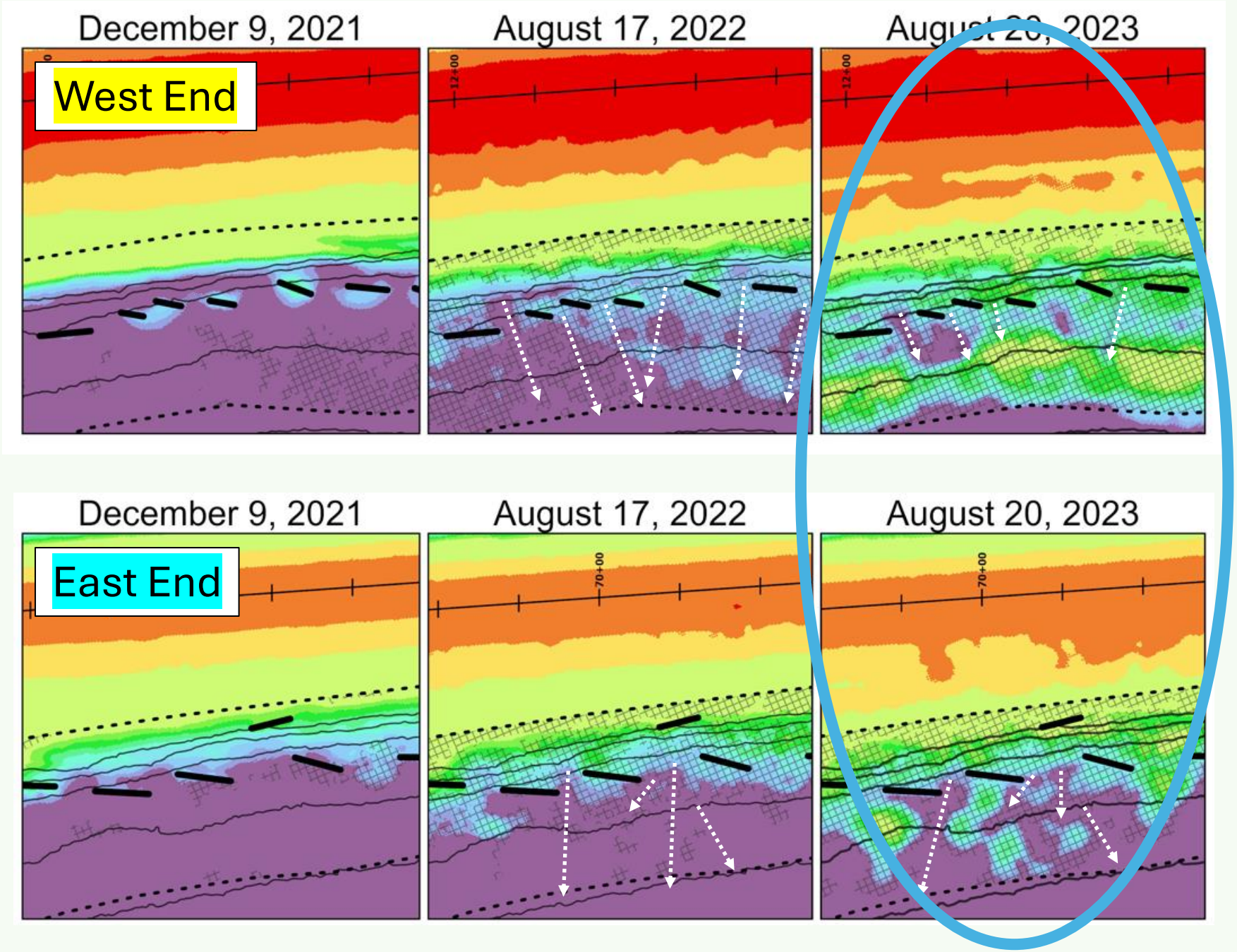
Elevation (m)

<1.71 | 1.71 to 1.78 | 1.78 to 1.86 | 1.86 to 1.94 | 1.94 to 2.01 | 2.01 to 2.09 | 2.09 to 2.16 | 2.16 to 2.24 | 2.24 to 3 | 3 to 3.5 | 3.5 to 4 | > 4

Increase in elevation

Results/Discussion

Digital Terrain Modeling



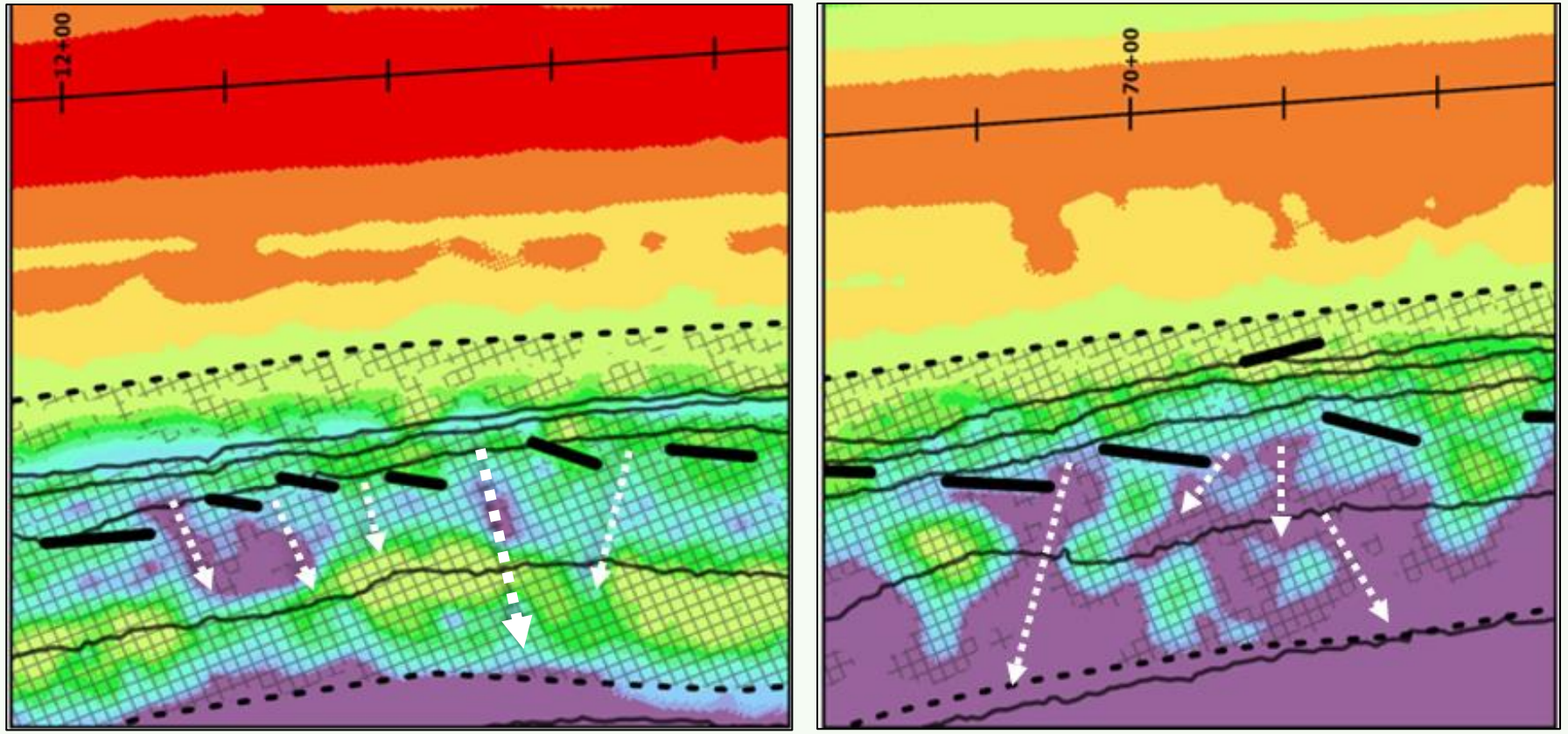
Results/Discussion

Digital Terrain Modeling

August 20, 2023

West End

East End



SFSU Thesis Research Project Extent

LWD

Vegetation

2018 Datum Contour Lines

Elevation (m)

<1.71
1.71 to 1.78
1.78 to 1.86
1.86 to 1.94
1.94 to 2.01
2.01 to 2.09
2.09 to 2.16
2.16 to 2.24
2.24 to 3
3 to 3.5
3.5 to 4
>4

Increase in elevation

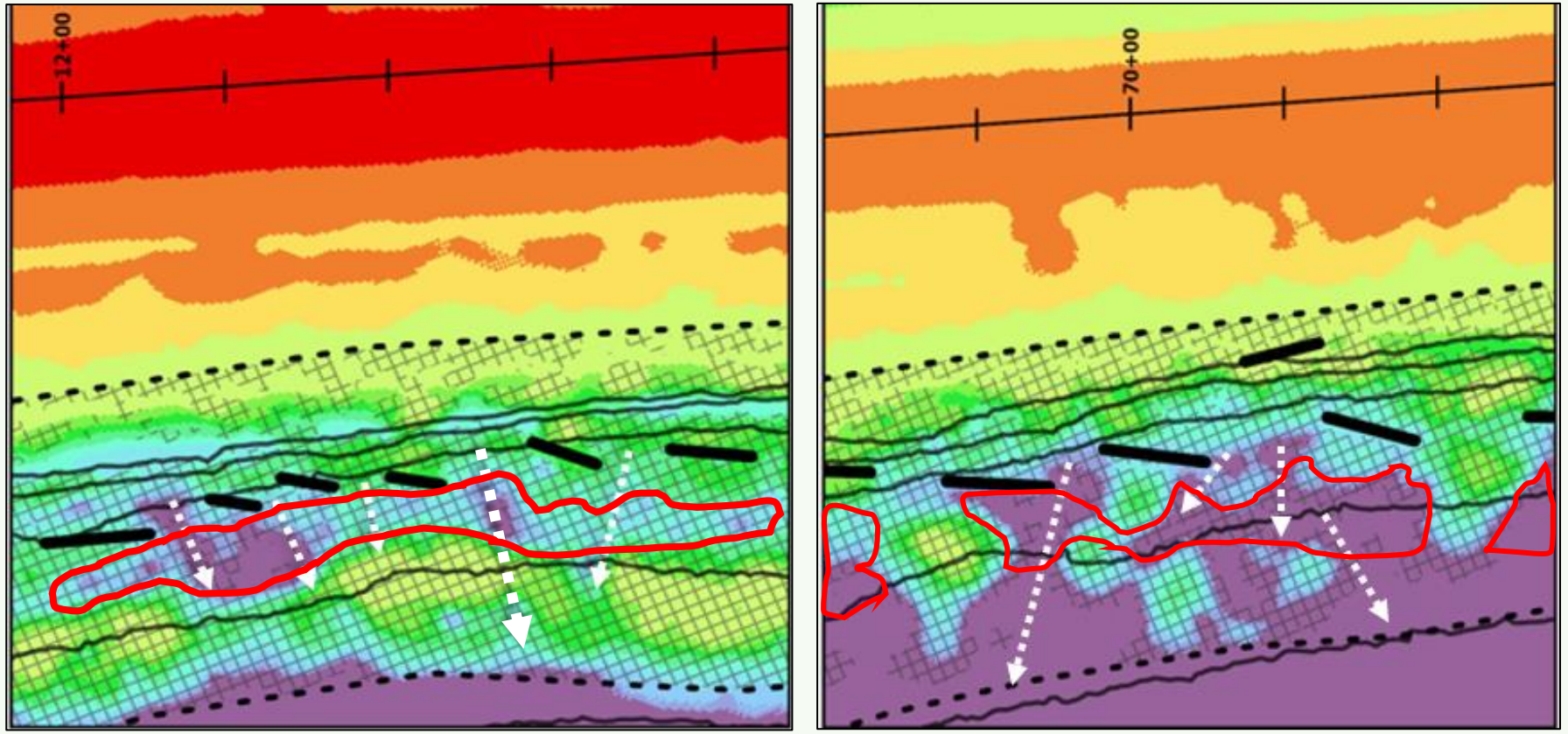
Results/Discussion

Digital Terrain Modeling

August 20, 2023

West End

East End



SFSU Thesis Research Project Extent

LWD

Vegetation

2018 Datum Contour Lines

Elevation (m)

<1.71
1.71 to 1.78
1.78 to 1.86
1.86 to 1.94
1.94 to 2.01
2.01 to 2.09
2.09 to 2.16
2.16 to 2.24
2.24 to 3
3 to 3.5
3.5 to 4
> 4

Increase in elevation

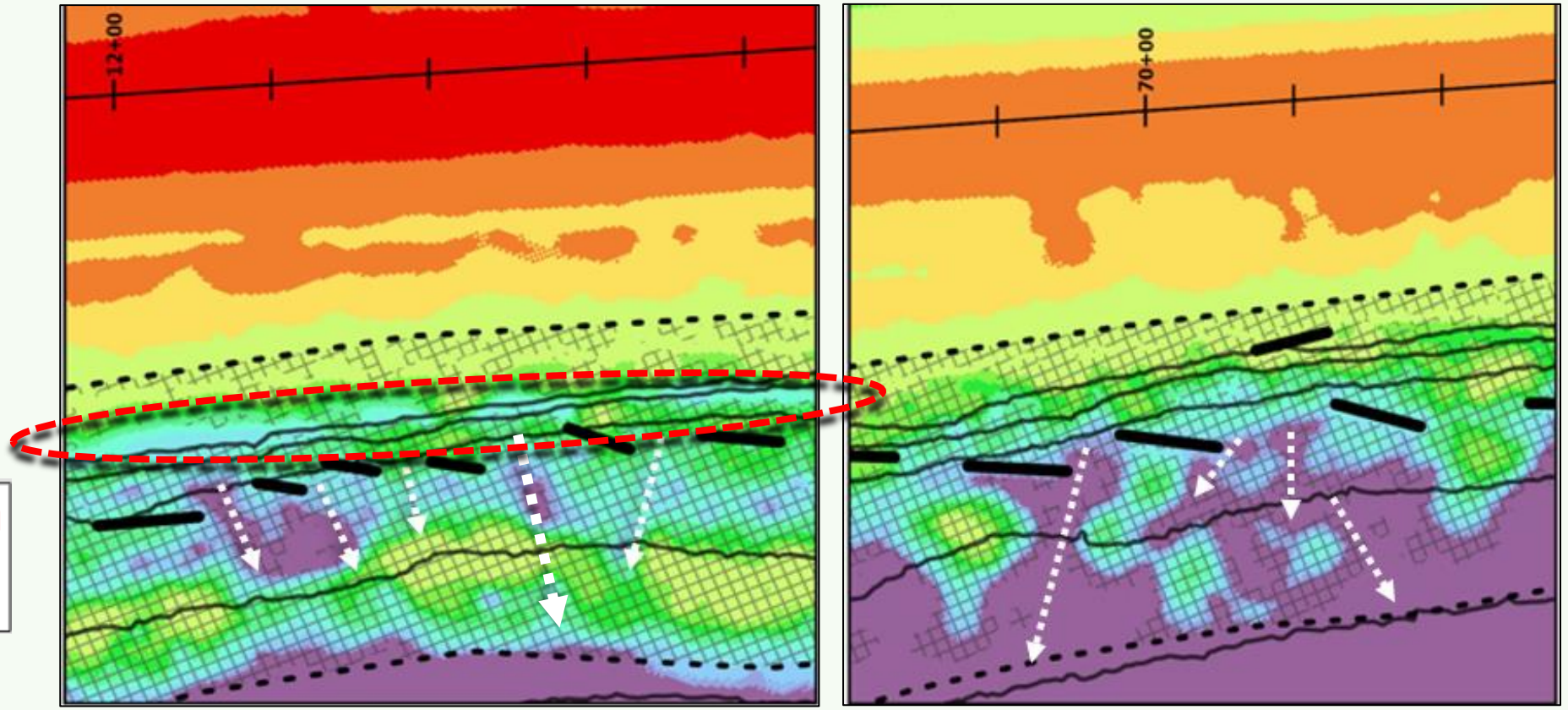
Results/Discussion

Digital Terrain Modeling

August 20, 2023

West End

East End



SFSU Thesis Research Project Extent

LWD

Vegetation

2018 Datum Contour Lines

Elevation (m)

<1.71
1.71 to 1.78
1.78 to 1.86
1.86 to 1.94
1.94 to 2.01
2.01 to 2.09
2.09 to 2.16
2.16 to 2.24
2.24 to 3
3 to 3.5
3.5 to 4
> 4

Increase in elevation

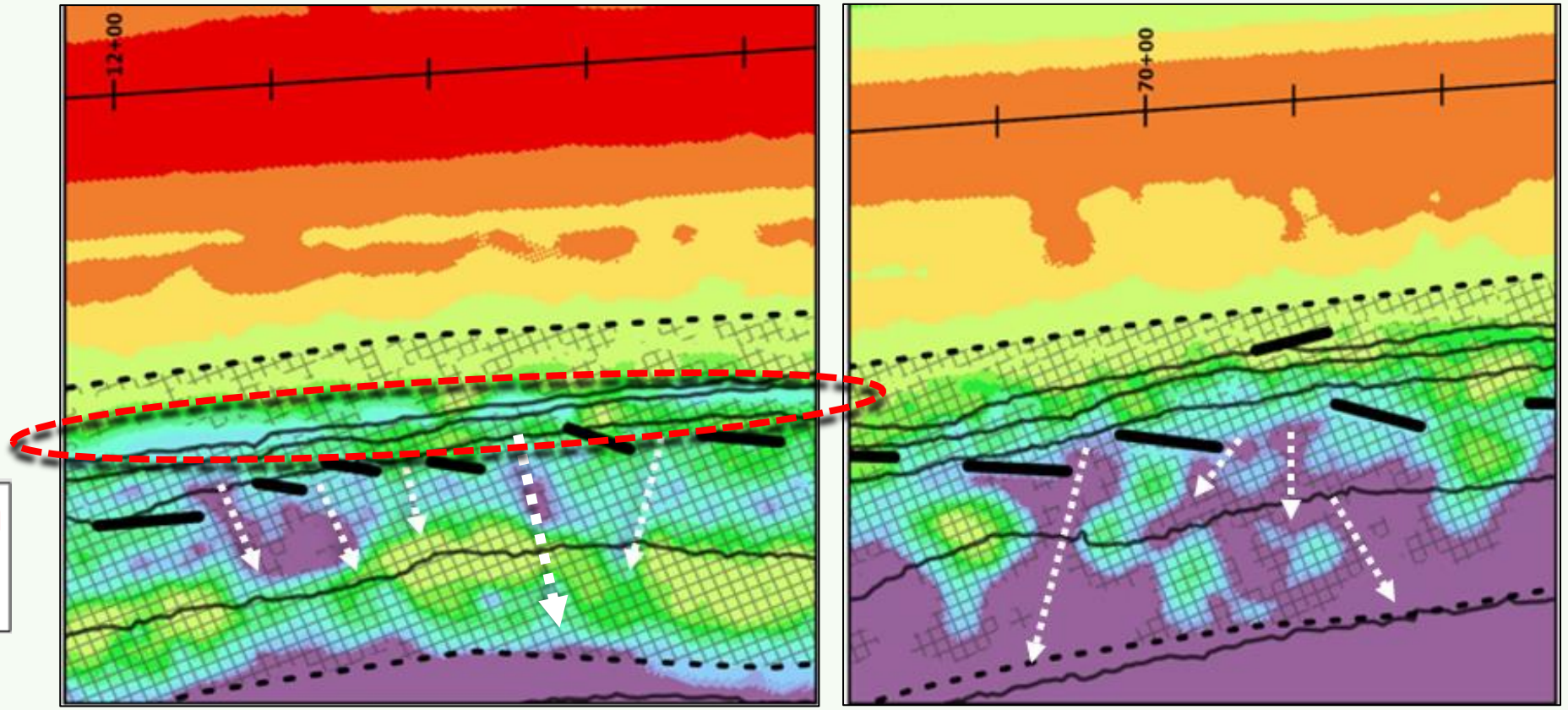
Results/Discussion

Digital Terrain Modeling

August 20, 2023

West End

East End



SFSU Thesis Research Project Extent

LWD

Vegetation

2018 Datum Contour Lines

Elevation (m)

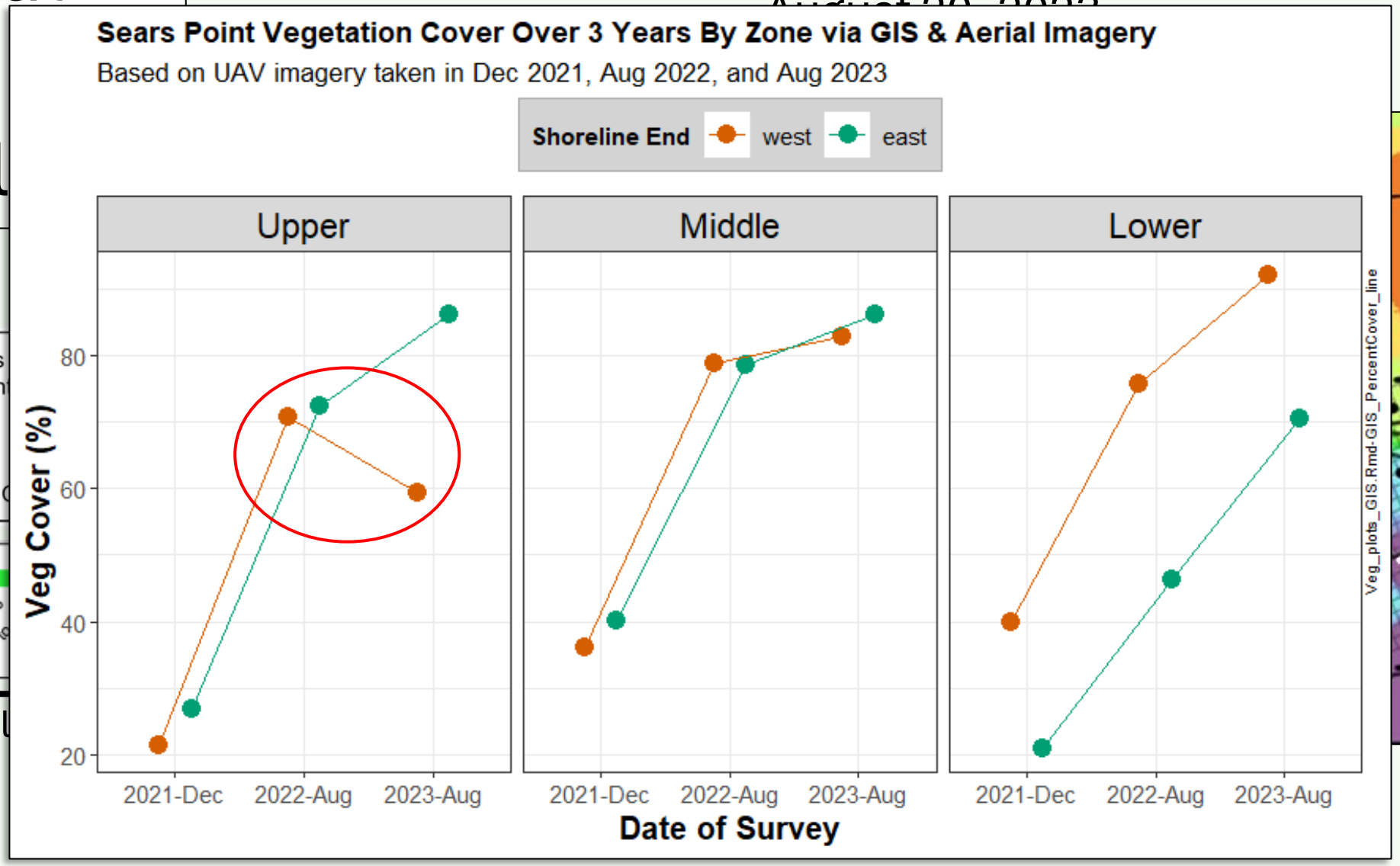
<1.71
1.71 to 1.78
1.78 to 1.86
1.86 to 1.94
1.94 to 2.01
2.01 to 2.09
2.09 to 2.16
2.16 to 2.24
2.24 to 3
3 to 3.5
3.5 to 4
> 4

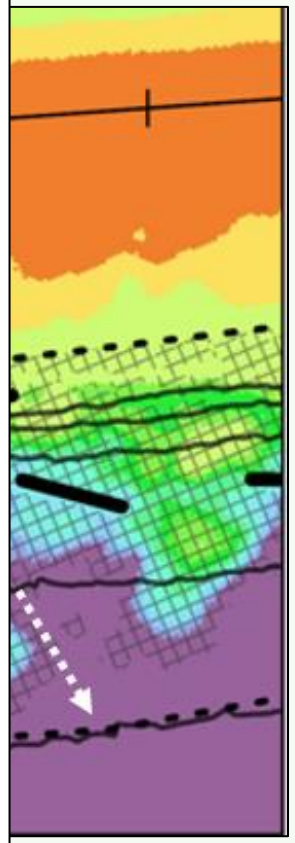
Increase in elevation

Results/Discussion

Digital Terra Model

August 20, 2023





SFSU Thesis Project Extent

LWD

Vegetation

2018 Datum

Elevation (m)

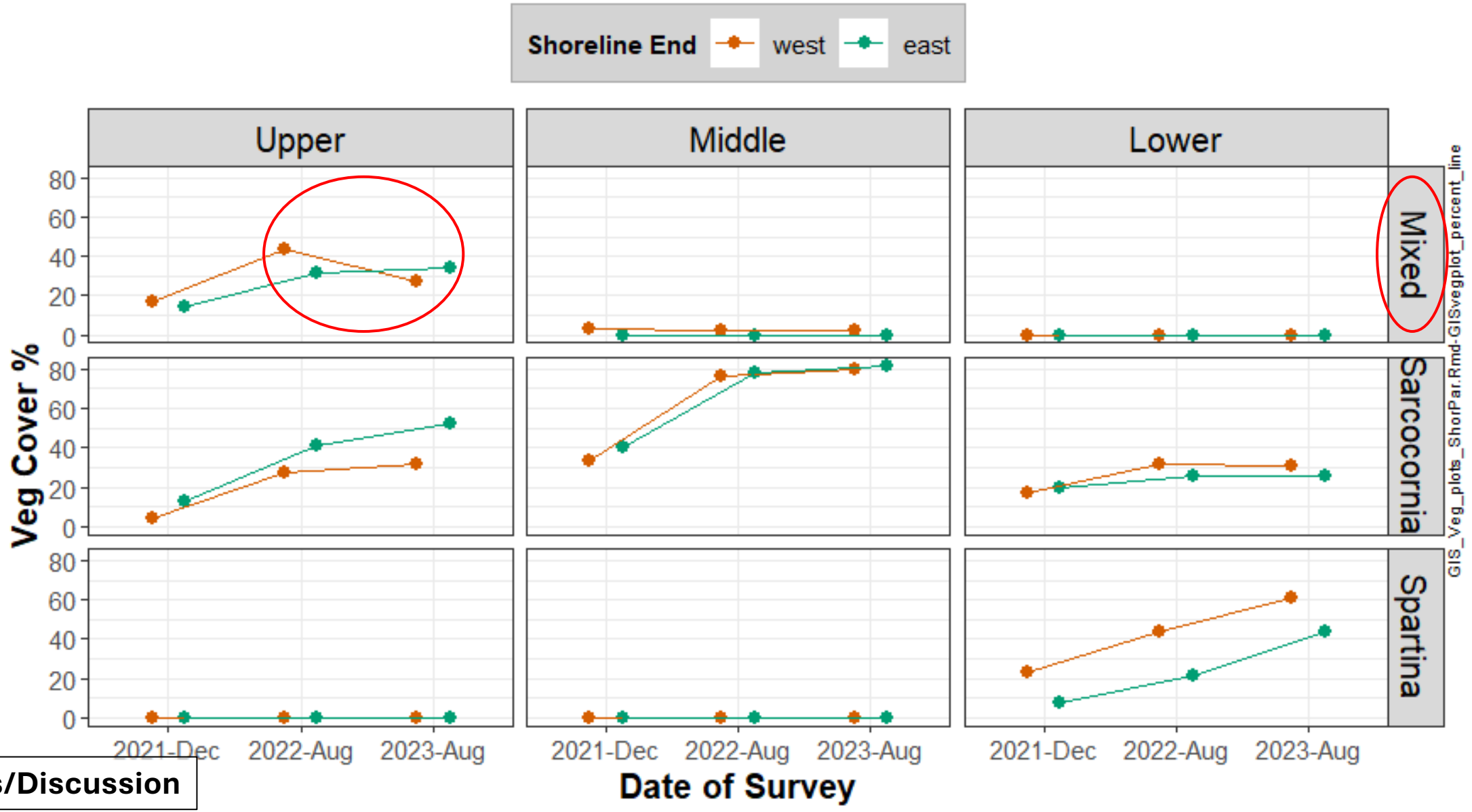
<1.71
1.71 to 1.78
1.78 to 1.86
1.86 to 1.94
1.94 to 2.01
2.01 to 2.09
2.09 to 2.16
2.16 to

Increase in el

Results/Discussion

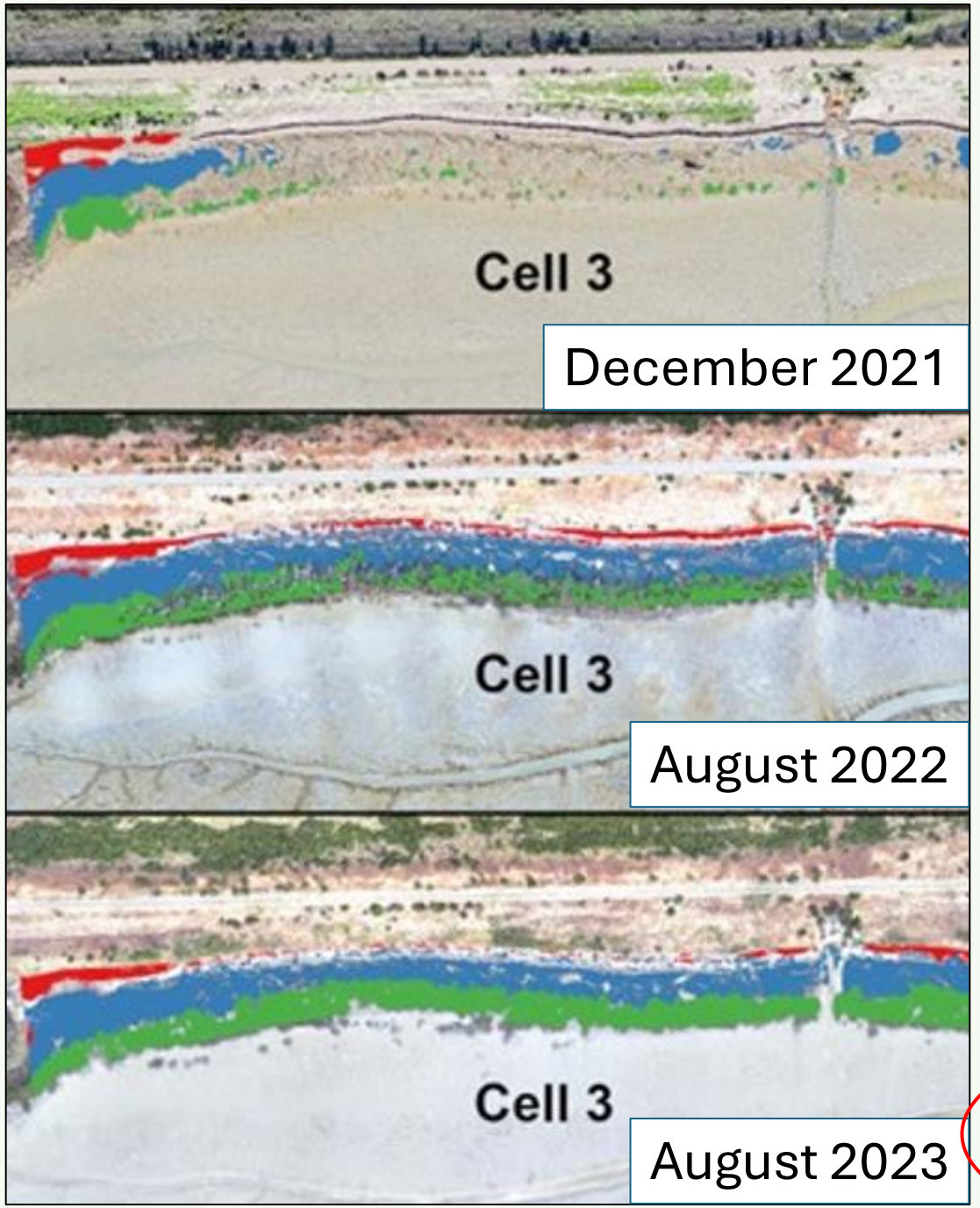
Sears Point Vegetation Cover Over 3 Years By Zone via GIS & Aerial Imagery

Based on UAV imagery taken in Dec 2021, Aug 2022, and Aug 2023

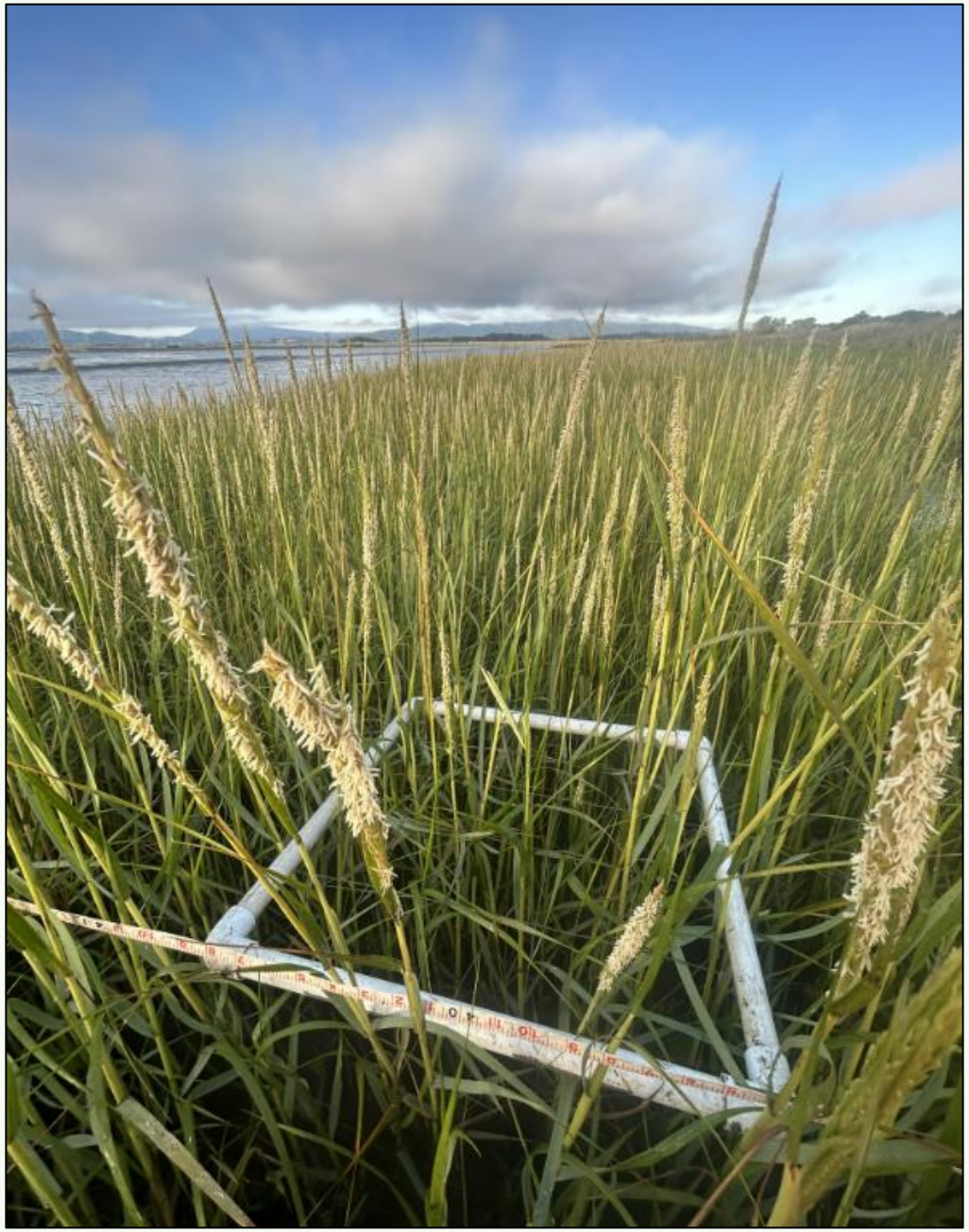


Results/Discussion

Results/Discussion

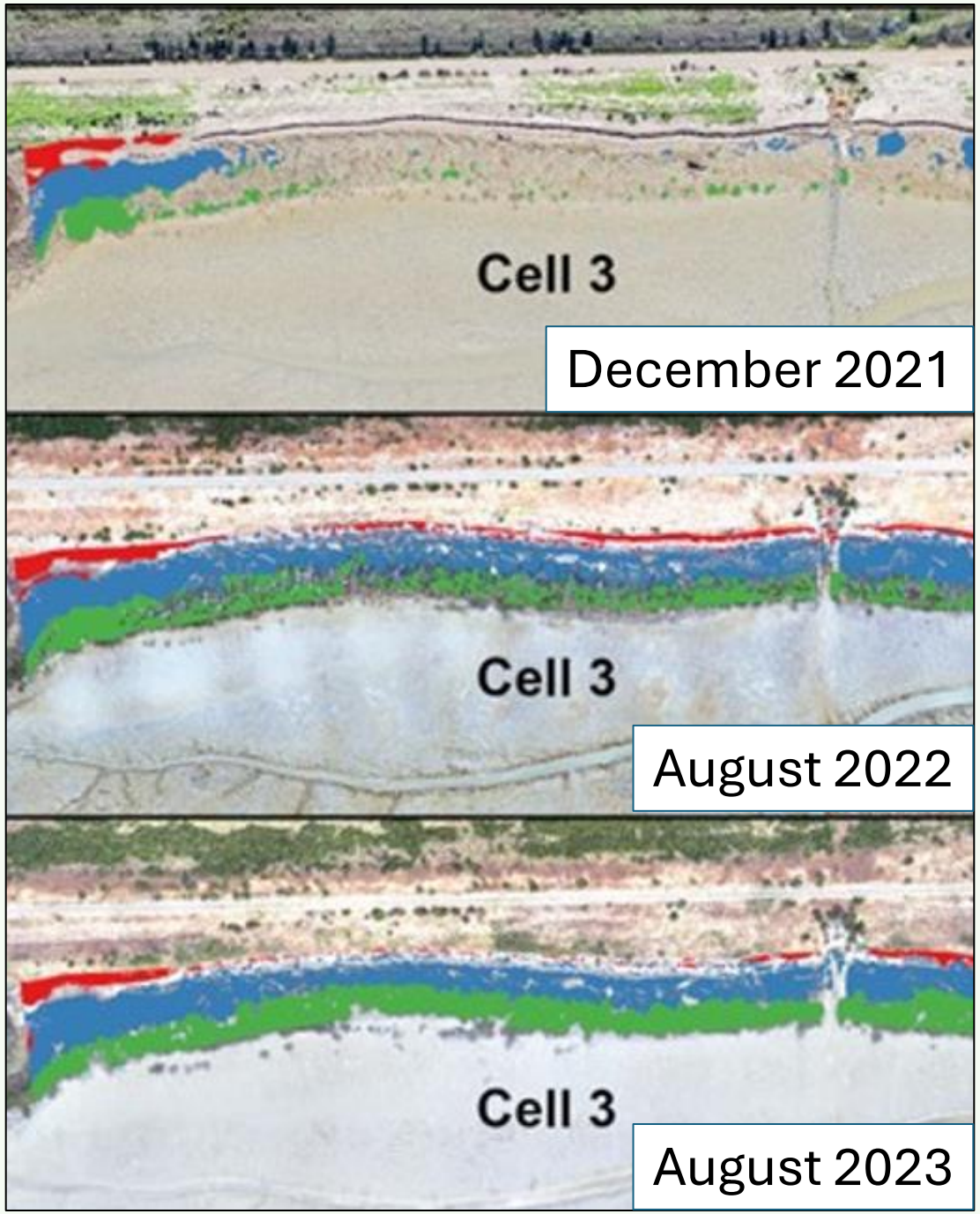


Spartina foliosa
“California cordgrass”



Results/Discussion

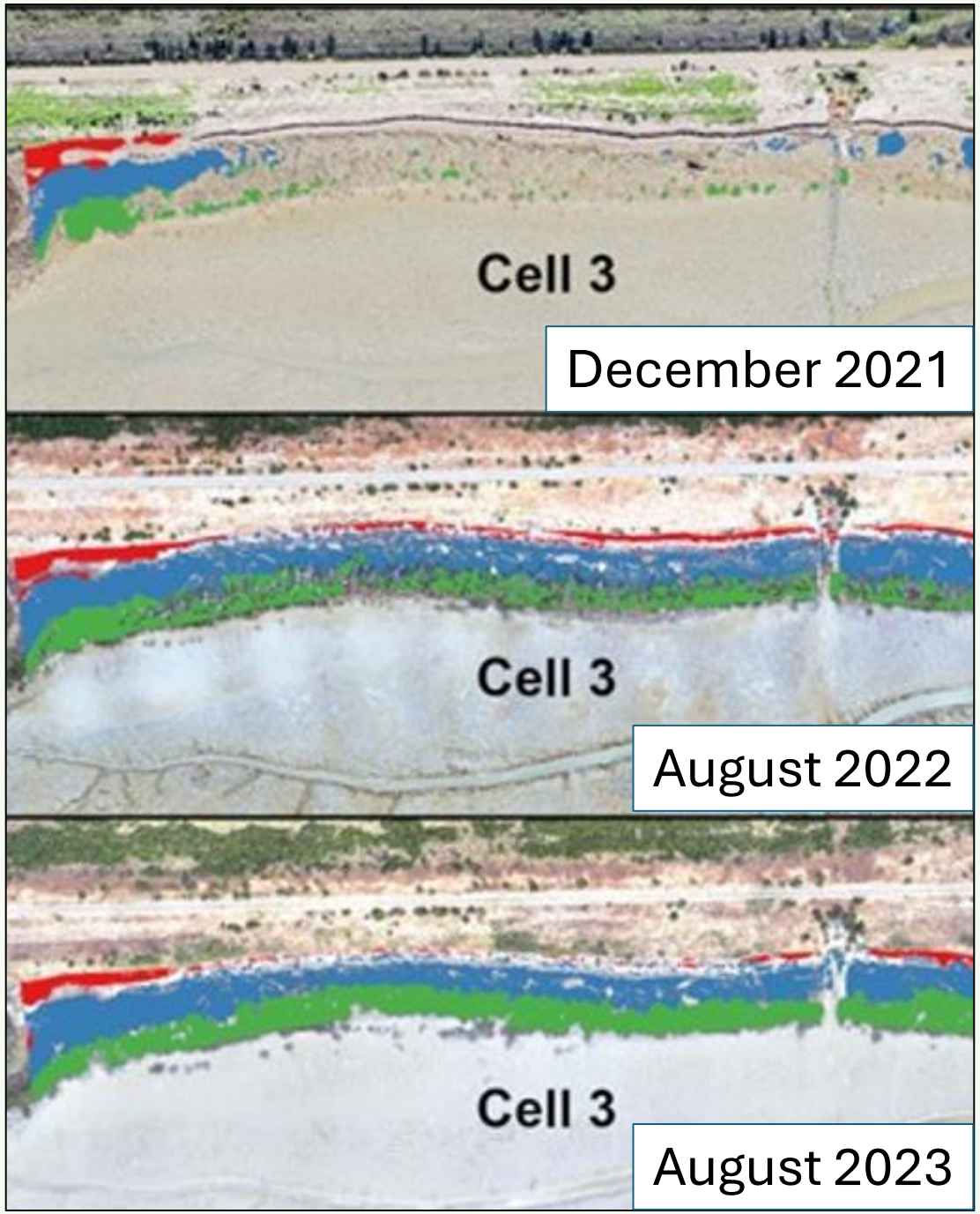
Results/Discussion



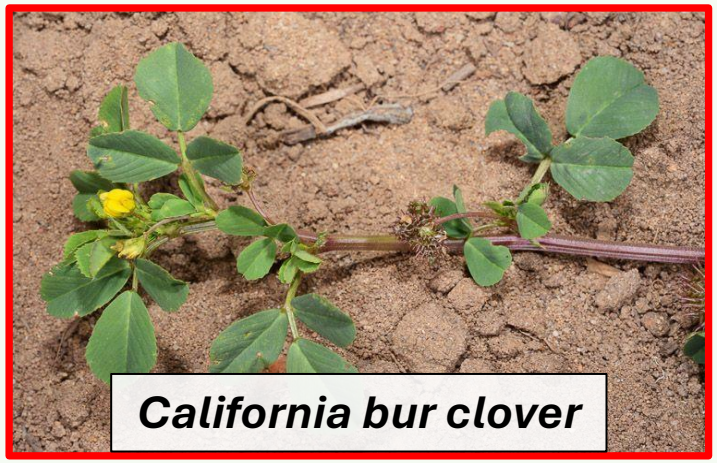
Sarcocornia pacifica
“Perennial pickleweed”

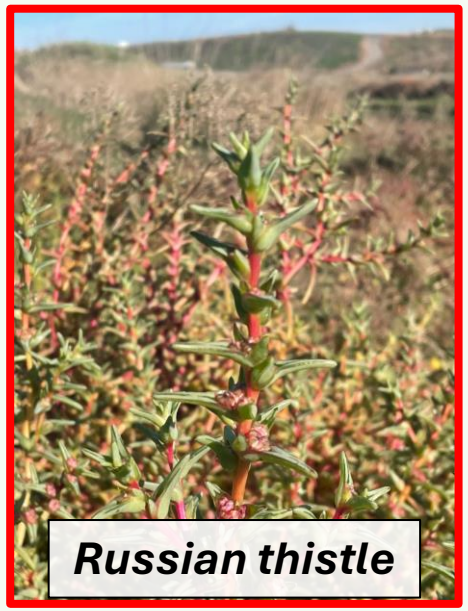
Results/Discussion

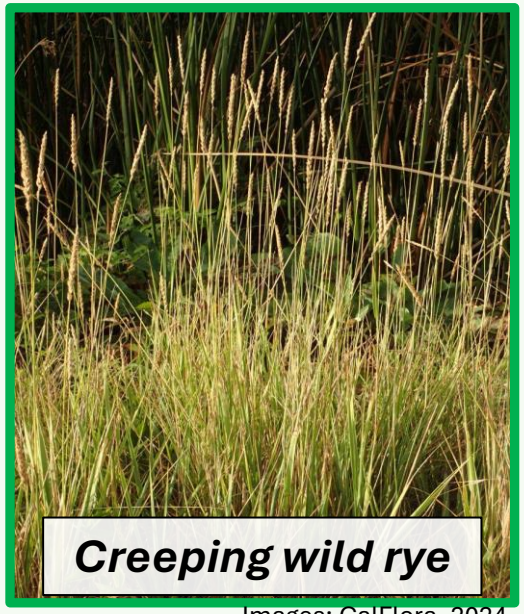
Results/Discussion



Mixed Transitional Vegetation Community





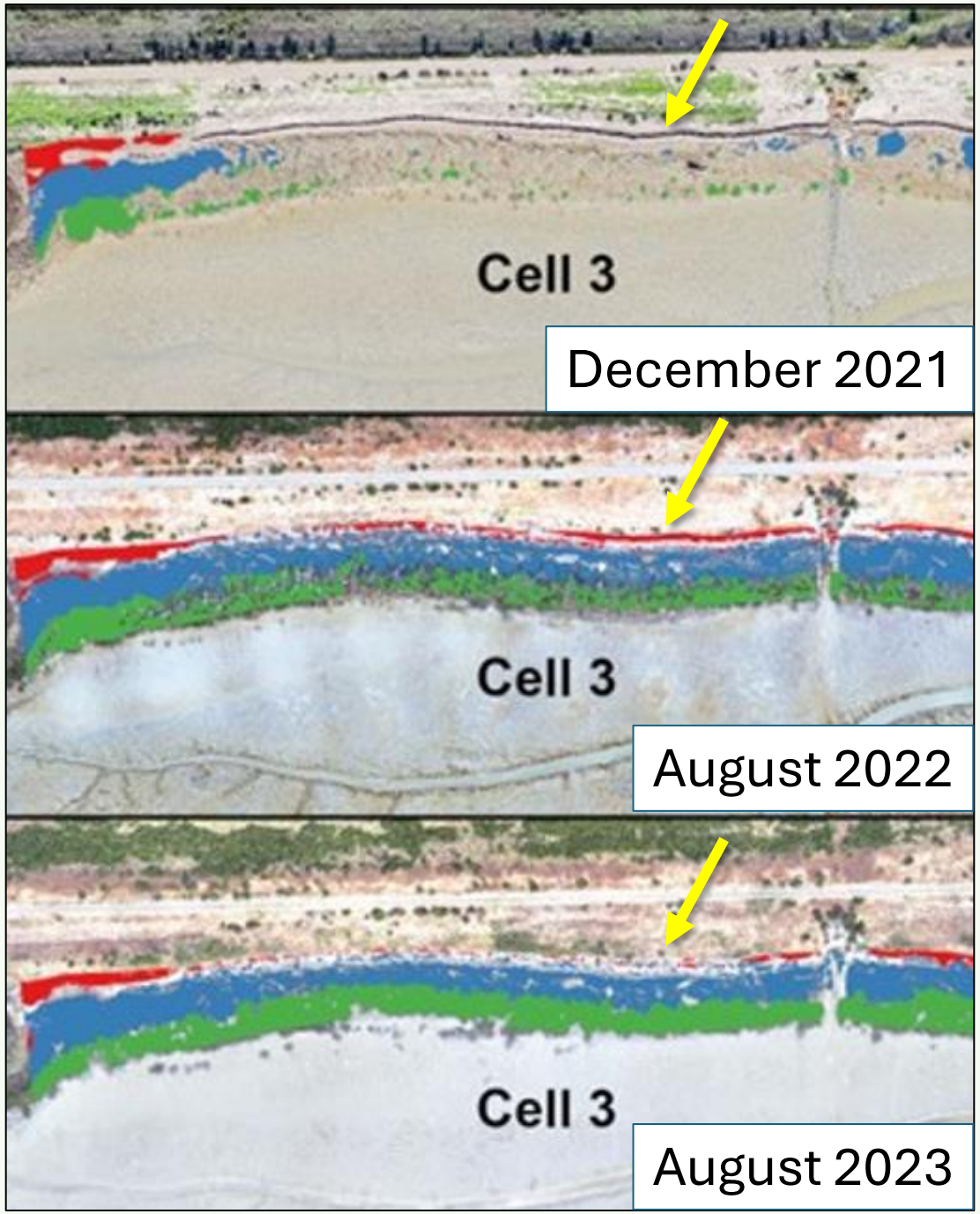


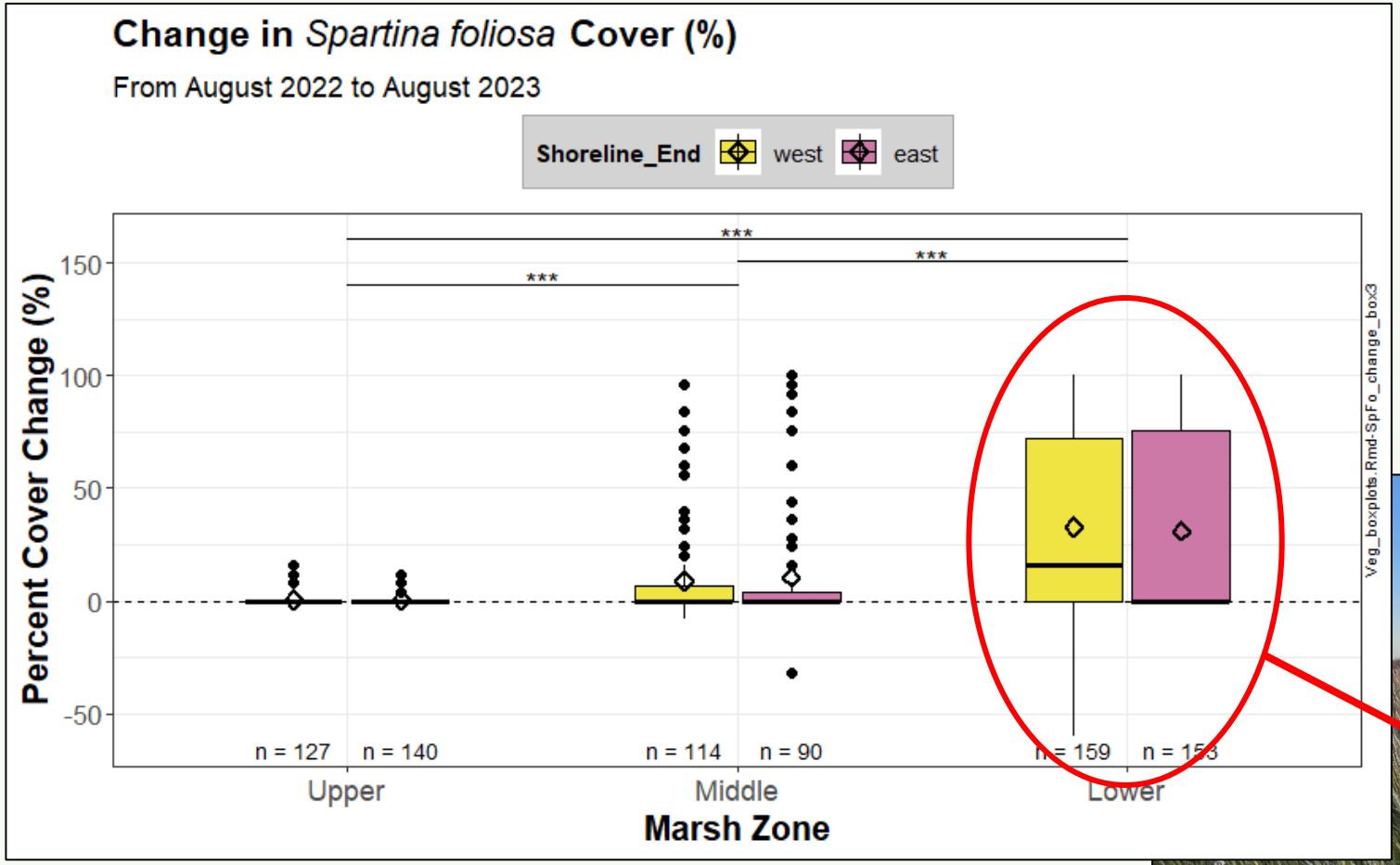
Images: CalFlora, 2024

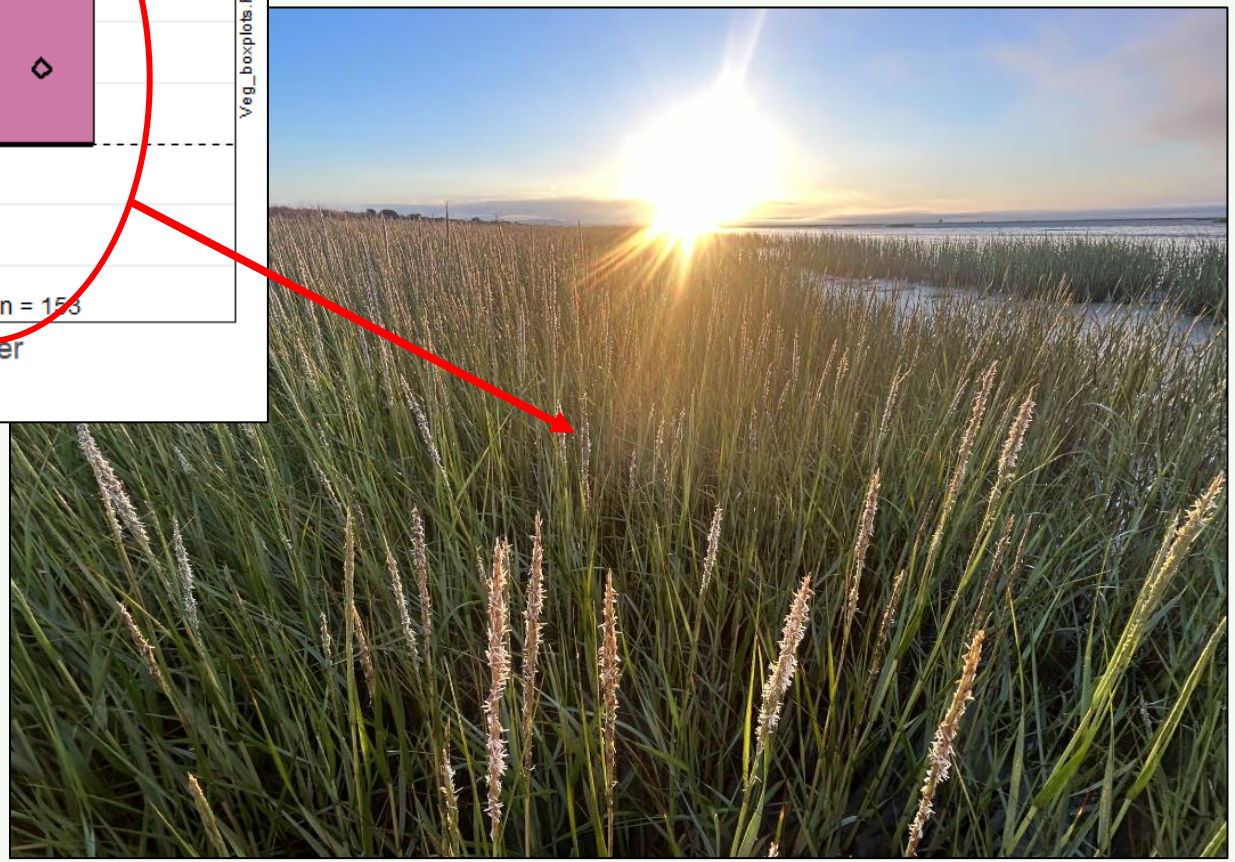
Results/Discussion

= native = invasive non-native

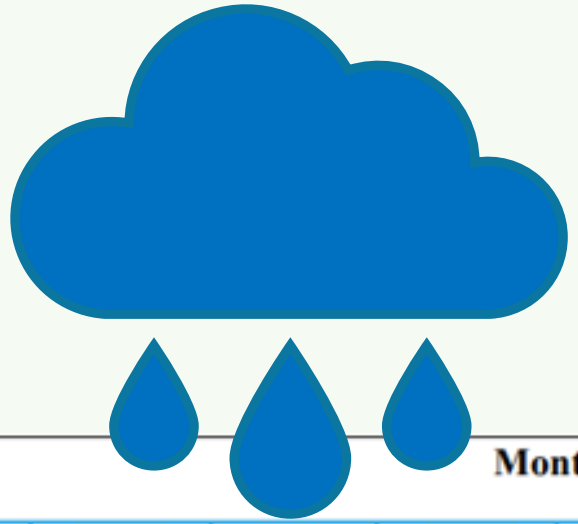
Results/Discussion







Results/Discussion



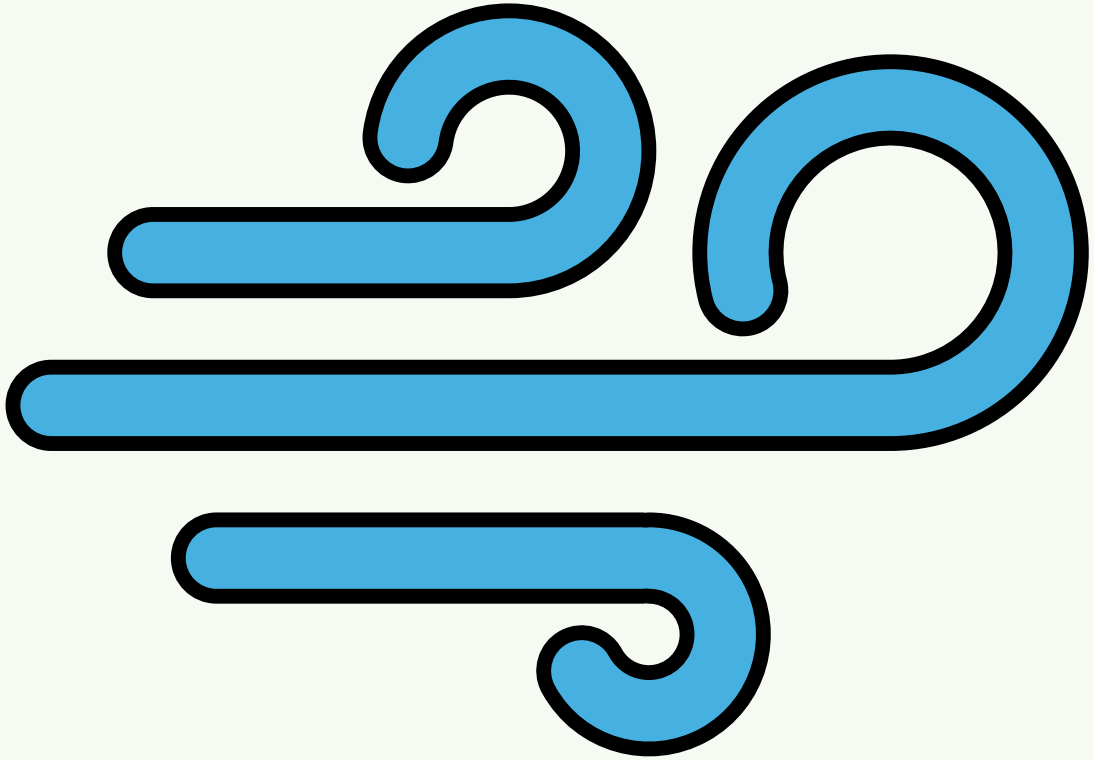
Monthly Total Precipitation for SANTA ROSA SONOMA CO AP, CA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2021	3.89	1.77	2.65	0.09	0.00	T	0.00	T	0.15	10.77	2.93	7.75	30.00
2022	0.61	T	1.30	2.06	0.09	0.66	T	T	0.96	0.01	1.23	9.71	16.63
2023	13.50	3.78	12.84	0.47	0.86	0.03	T	T	0.17	0.65	2.66	8.74	43.70
2024	9.57	9.55	4.57	0.90	0.82	T	M	M	M	M	M	M	M
Mean	6.89	3.78	5.34	0.88	0.44	0.17	T	T	0.43	3.81	2.27	8.73	30.11
Max	13.50 2023	9.55 2024	12.84 2023	2.06 2022	0.86 2023	0.66 2022	T 2023	T 2023	0.96 2022	10.77 2021	2.93 2021	9.71 2022	43.70 2023
Min	0.61 2022	T 2022	1.30 2022	0.09 2021	0.00 2021	T 2024	0.00 2021	T 2023	0.15 2021	0.01 2022	1.23 2022	7.75 2021	16.63 2022

T stands for "Trace," indicating precipitation levels less than 0.01.
M stands for "Missing."

National Weather Service. (2024). Full Weather Glossary. https://www.weather.gov/otx/Full_Weather_Glossary

Results/Discussion



Begin Date	Begin Time	Event Type	Magnitude (kts)	End Date	End Time
12/13/2021	857	Flood		12/13/2021	957
12/13/2021	1300	Strong Wind	29	12/13/2021	1330
12/13/2021	2111	Flood		12/13/2021	2211
1/22/2022	100	High Wind	65	1/22/2022	700
3/4/2022	1200	Strong Wind	37	3/4/2022	1600
4/11/2022	1500	Strong Wind	35	4/11/2022	1600
5/2/2022	1500	Strong Wind	45	5/2/2022	1600
6/10/2022	1500	Heat		6/10/2022	1600
6/21/2022	1500	Heat		6/21/2022	1600
7/11/2022	2000	Coastal Flood		7/11/2022	2300
7/12/2022	2115	Coastal Flood		7/13/2022	15
7/13/2022	2340	Coastal Flood		7/14/2022	300
9/4/2022	1200	Heat		9/8/2022	1800
9/5/2022	1400	Heat		9/5/2022	1600
9/6/2022	1400	Heat		9/6/2022	1600
9/18/2022	1000	Strong Wind	38	9/18/2022	1100
9/18/2022	1100	Strong Wind	40	9/18/2022	1200
9/18/2022	1300	Strong Wind	41	9/18/2022	1400
12/27/2022	30	High Wind	61	12/27/2022	30
12/27/2022	310	High Wind	61	12/27/2022	310
1/4/2023	1715	Strong Wind	22	1/4/2023	1730
1/9/2023	740	Flood		1/9/2023	1000
1/14/2023	1715	Strong Wind	19	1/14/2023	2012
1/21/2023	800	Frost/Freeze		1/21/2023	900
2/21/2023	1330	Strong Wind	26	2/21/2023	1330
2/21/2023	1450	High Wind	57	2/21/2023	1450
2/21/2023	1734	Strong Wind	17	2/21/2023	1734
3/9/2023	2127	High Wind	56	3/9/2023	2127
3/9/2023	2229	Heavy Rain		3/9/2023	2229
3/14/2023	1110	High Wind	64	3/14/2023	1110
3/21/2023	1000	High Wind	51	3/21/2023	1000
3/28/2023	1030	High Wind	54	3/28/2023	1030
7/1/2023	0	Excessive Heat		7/1/2023	2359
7/16/2023	0	Heat		7/16/2023	2359

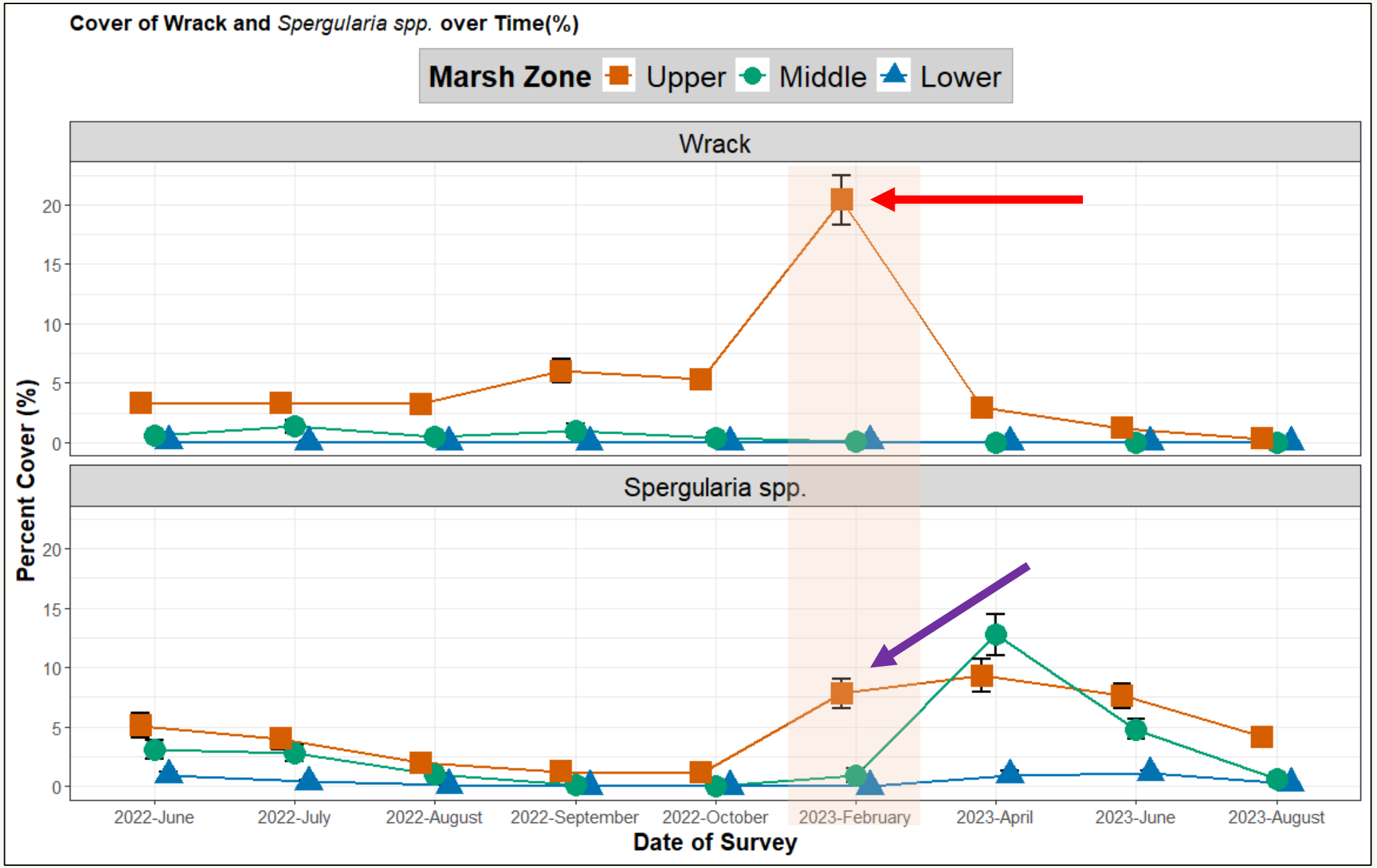
National Centers for Environmental Information. (2023). Storm Events Database: Event data for Sonoma County, CA, December 2021 - August 2023 [Data set]. National Oceanic and Atmospheric Administration.

Results/Discussion

“Sand-spurrey” - *Spergularia spp.*

Results/Discussion

(Hartman *et al.*, 1983;Tolley and Christian, 1999)



Results/Discussion

Synthesis of Results

How effective are the NBS treatments at minimizing erosion, and encouraging emergent marsh establishment along the habitat levee?

The problem:

Cyclical erosion along shoreline, preventing vegetation establishment.

Discussion

How effective are the NBS treatments at minimizing erosion, and encouraging emergent marsh establishment along the habitat levee?

Shoreline Stability:

No new scarp formation was observed along the shoreline*, indicating overall stability.

*Within my research project extent. Some slight scarping observed in a few areas outside (~0.15 – 0.3 m (1/2 -1 ft))

Discussion

How effective are the NBS treatments at minimizing erosion, and encouraging emergent marsh establishment along the habitat levee?

West vs. East Performance:

As hypothesized, the west end showed greater vegetation establishment and sediment accretion compared to the east.

Discussion

How effective are the NBS treatments at minimizing erosion, and encouraging emergent marsh establishment along the habitat levee?

Role of Treatments:

Despite greater accretion on the west, the east end also showed positive results, highlighting the effectiveness of additional treatments in reducing wind wave energy.

Discussion

How effective are the NBS treatments at minimizing erosion, and encouraging emergent marsh establishment along the habitat levee?

Vegetation Loss:

The west end's upper middle zone experienced an 11% vegetation loss from 2022 to 2023, likely due to wrack line formation from *Spartina foliosa* expansion and strong winter storms.

Discussion

How effective are the NBS treatments at minimizing erosion, and encouraging emergent marsh establishment along the habitat levee?

Sediment Dynamics:

Slight sediment loss occurred in middle and lower zones on both ends, but this sediment was designed to move and redistribute, supporting continued accretion and vegetation establishment in the upper areas of the marsh.

Discussion

Limitations

- **Not** set up as an **experimental design**.
- Must rely on trends.

Discussion

Limitations

- Not set up as an experimental design.
- Must rely on **trends**.

Discussion

Limitations

- Not set up as an experimental design.
- Must rely on trends.

!

- **Continued monitoring** and data collection **important**
- Holistic Approach: Vegetation establishment success due to combination of methods, rather than one single approach.

Discussion

Limitations

- Not set up as an experimental design.
- Must rely on trends.

- Continued monitoring and data collection important
- **Holistic Approach**: Vegetation establishment success due to **combination of methods**, rather than one single approach.

Broader Implications

Nature-based strategies work to prevent erosion and increase habitat at a landscape scale – **especially adding treatment in high energy areas, in this project lag gravel armoring**.

Discussion

Broader Implications

Using **natural elements saves money and time**, simultaneously **providing habitat, recreational opportunities, and aesthetic beauty**.

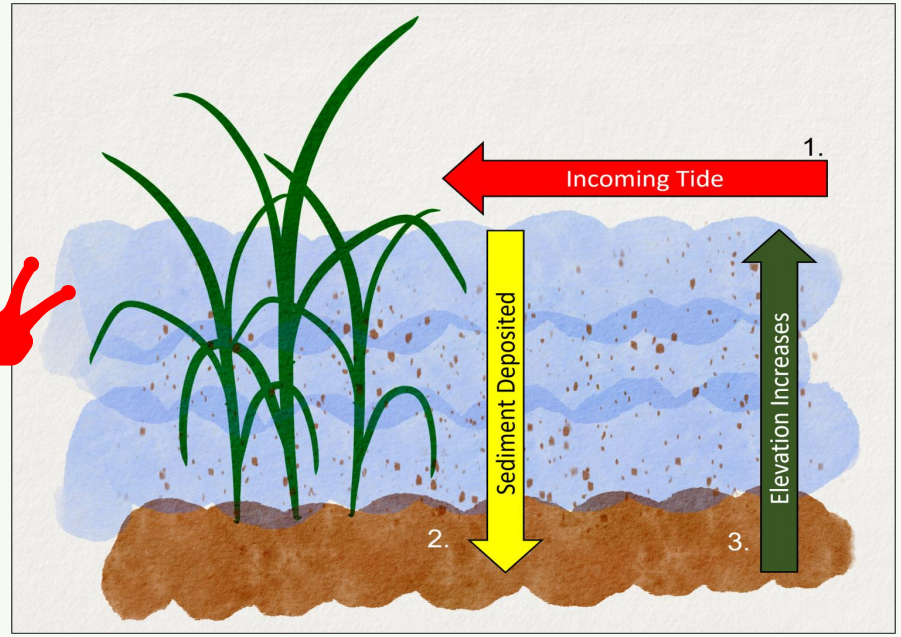
Narayan *et al., 2016*

Discussion

Broader Implications

Vertical accretion alone is slow –
Transport and redistribution of bay mud/gravel is fast.

Vertical Accretion



Wave Deposition

Discussion

Broader Implications

No tidal action until all restoration elements are in place!

Discussion

Prospects for Future Progress

This analysis is a model for future projects:

- **Incorporates physical and biological data from:**
  - Vegetation and topographic surveys
  - Sediment pin measurements
  - And high resolution DTM's

Discussion

Prospects for Future Progress

Continued monitoring at Sears Point very necessary – future storms and drought conditions

Discussion

Prospects for Future Progress

Critical need for similar research in other locations with:

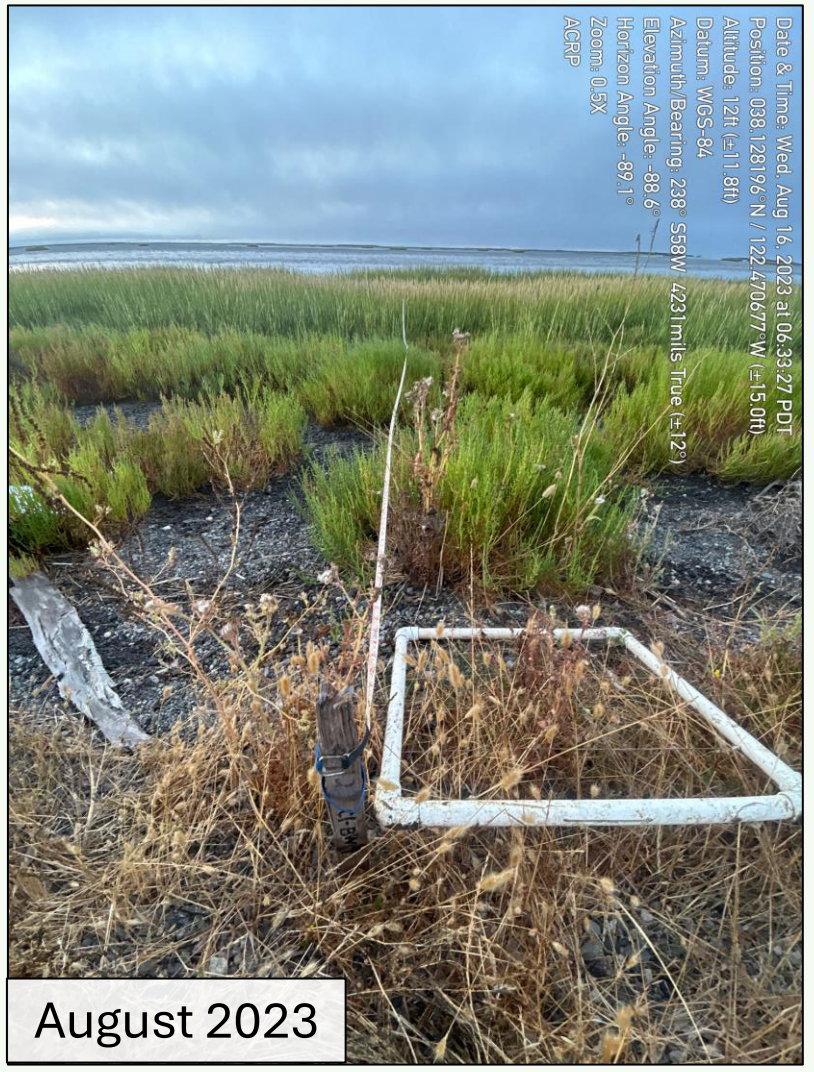
- Different sediment supply
- Wind-wave energy gradients
- Tidal inundation
- Freshwater inputs

Discussion

West End, Cell 1

June 2022

August 2022



August 2023

Time

Transect C1-BW6

East End, Cell 7

Time

Transect C7-BW209


October 2023


August 2024

Acknowledgements

Committee:

- Dr. Stuart Siegel, Dr. Katharyn Boyer, and Dr. Peter Baye

Lab Managers/Techs:

- Margot, Jessie, Kate, Sebastian, Christian, Jeremiah, and Anna

Boyer Lab Buddies:

- Tessa, Natalie, Jivan, Amy, Angelo, Emily, Josie, and Neil

Statistical Wizards:

- Julie Gonzalez, Margot Buchbinder, Wim Kimmerer, Michelle and Sean Jungbluth

GIS Wizard: Dan Gillenwater

Everyone else at EOS – Brita, Facilities Crew

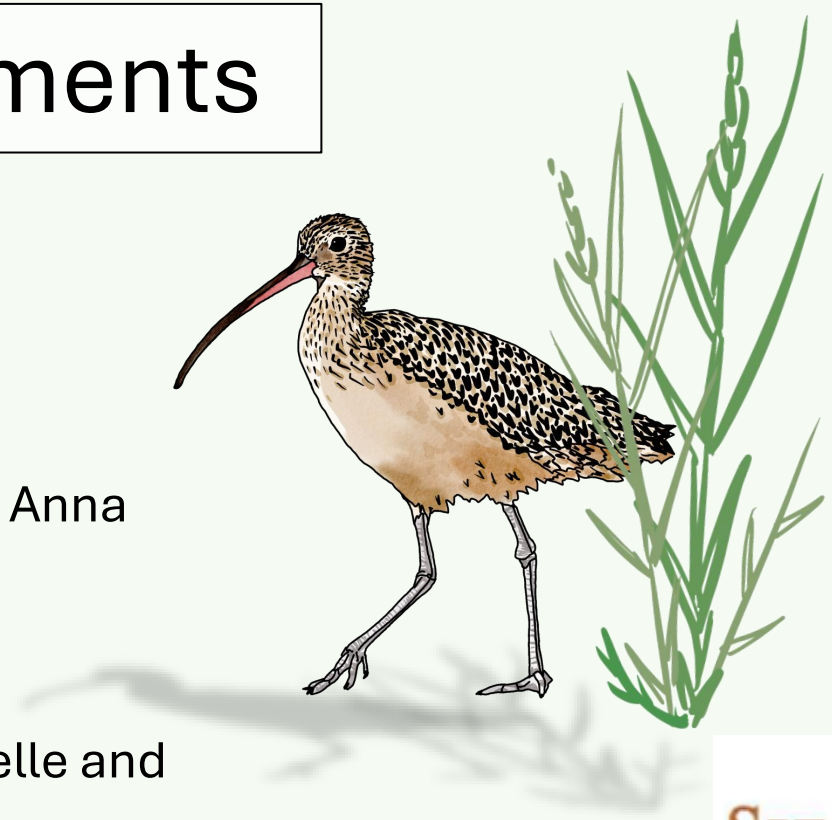
Cohort 5 Buddies:

- Danielle, Erick, and Dagny

Mike Vasey

Friends and Family Near and Far

Jeremyn Horsley



Funding:

San Francisco State University
Estuary & Ocean Science Center
At the Romberg Tiburon Campus

Siegel Environmental

COAST

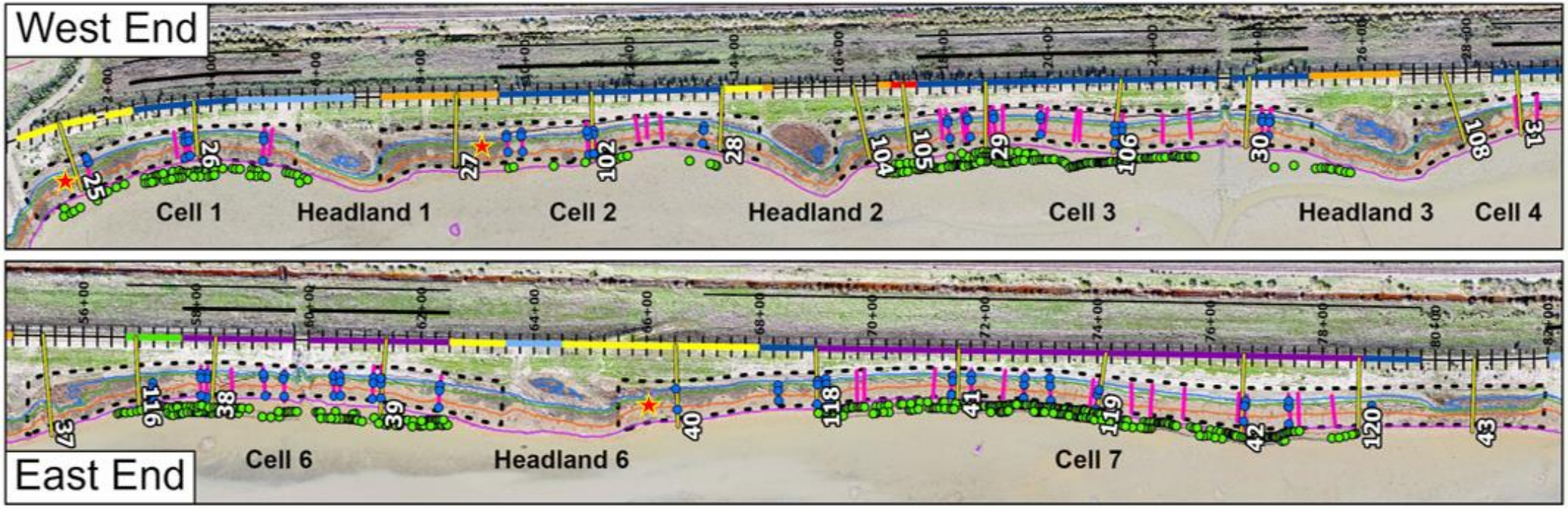
Sonoma Land Trust

San Francisco Bay National Estuarine Research Reserve

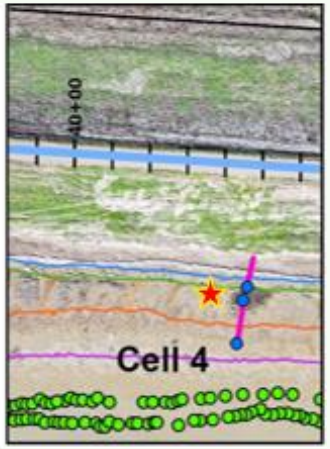
National Estuarine Research Reserve System Science Collaborative

Maxwell | Hanrahan Foundation

Questions



SFSU Thesis Project Extent
Vegetation Transect
Topographic Transect and ID
Sediment Pin
Cordgrass Plug
Reference Transects
(Not included in stats)



Nature Based Treatment Map with Transects

Design Treatments

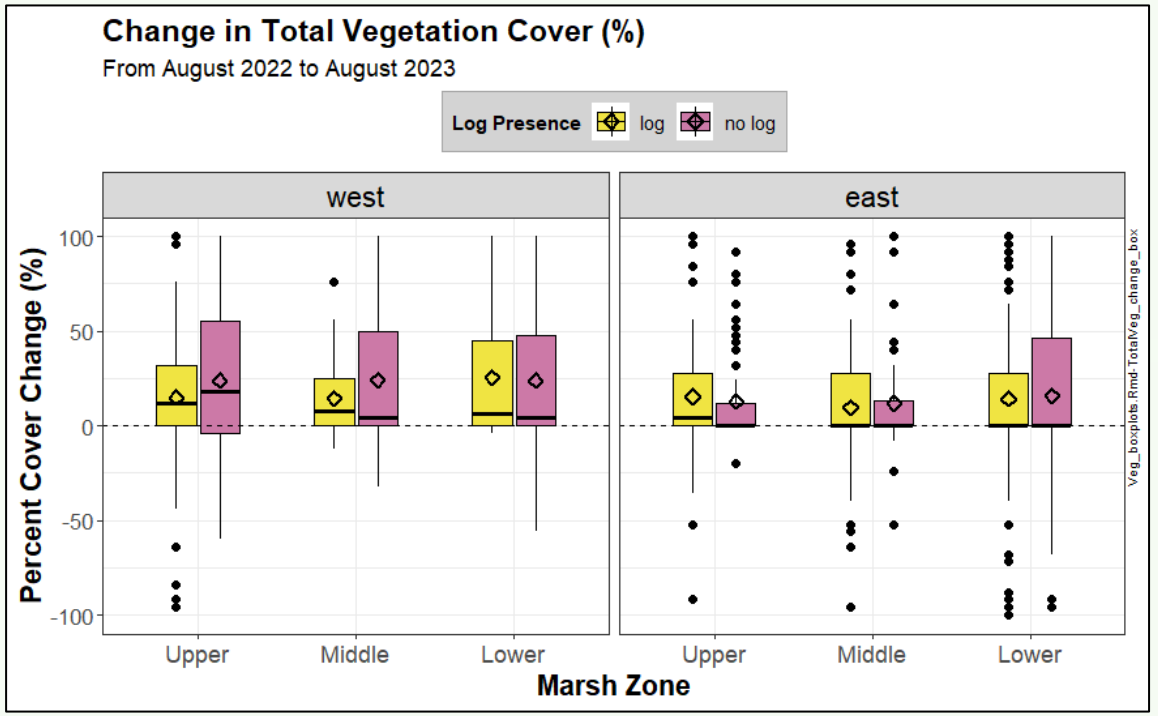
		Scarp Grading	LWD Placement	Mud Placement	Brush Fence	Veneer (lower)
No Color	Approach A		NO TREATMENT			
	Approach B	■				
	Approach C		■			
	Approach D			■		
	Approach E	■	■			
	Approach F		■	■		
	Approach G	■	■	■		
	Approach H	■	■	■	■	■
	Approach I	■		■		

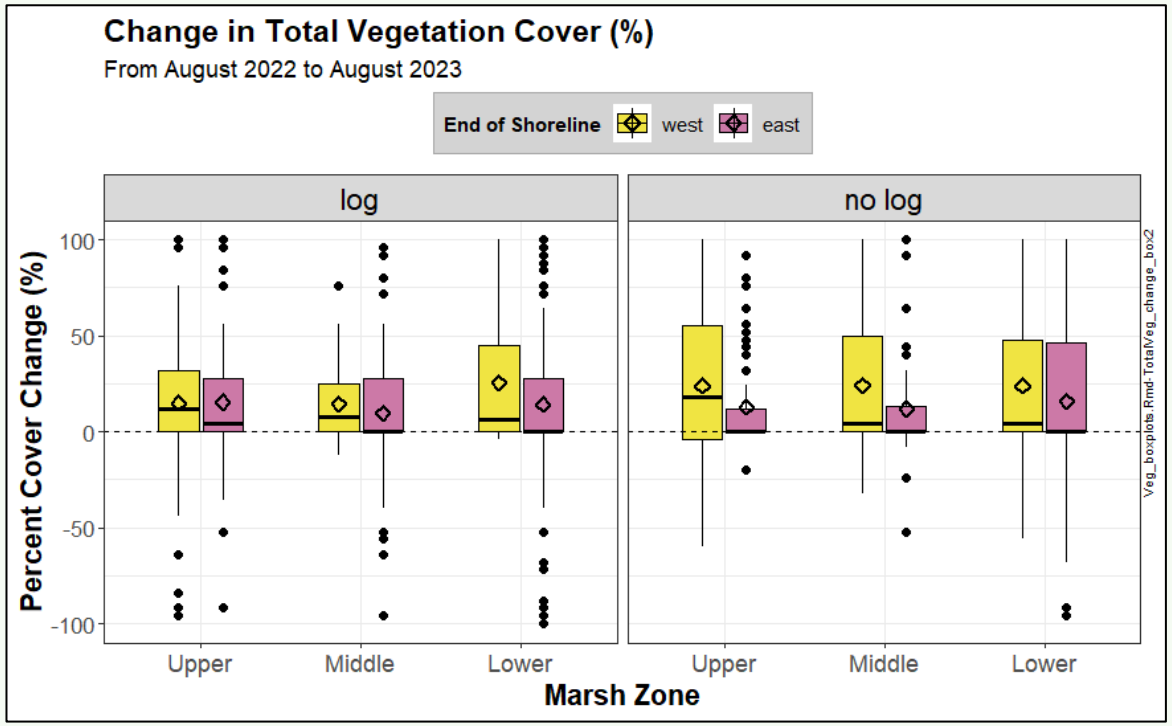
Field Added Treatments

- Mud Placement (above MHHW)
- Gravel Toe Berm (above MHHW)
- Gravel Veneer (above MHHW)

datum

- MHHW
- MHW
- MTL
- MTL/MHW


Change in Total Vegetation Cover (%)
From August 2022 to August 2023
Log Presence
log
no log
west
east
Percent Cover Change (%)
100
50
0
-50
-100
Upper
Middle
Lower
Marsh Zone

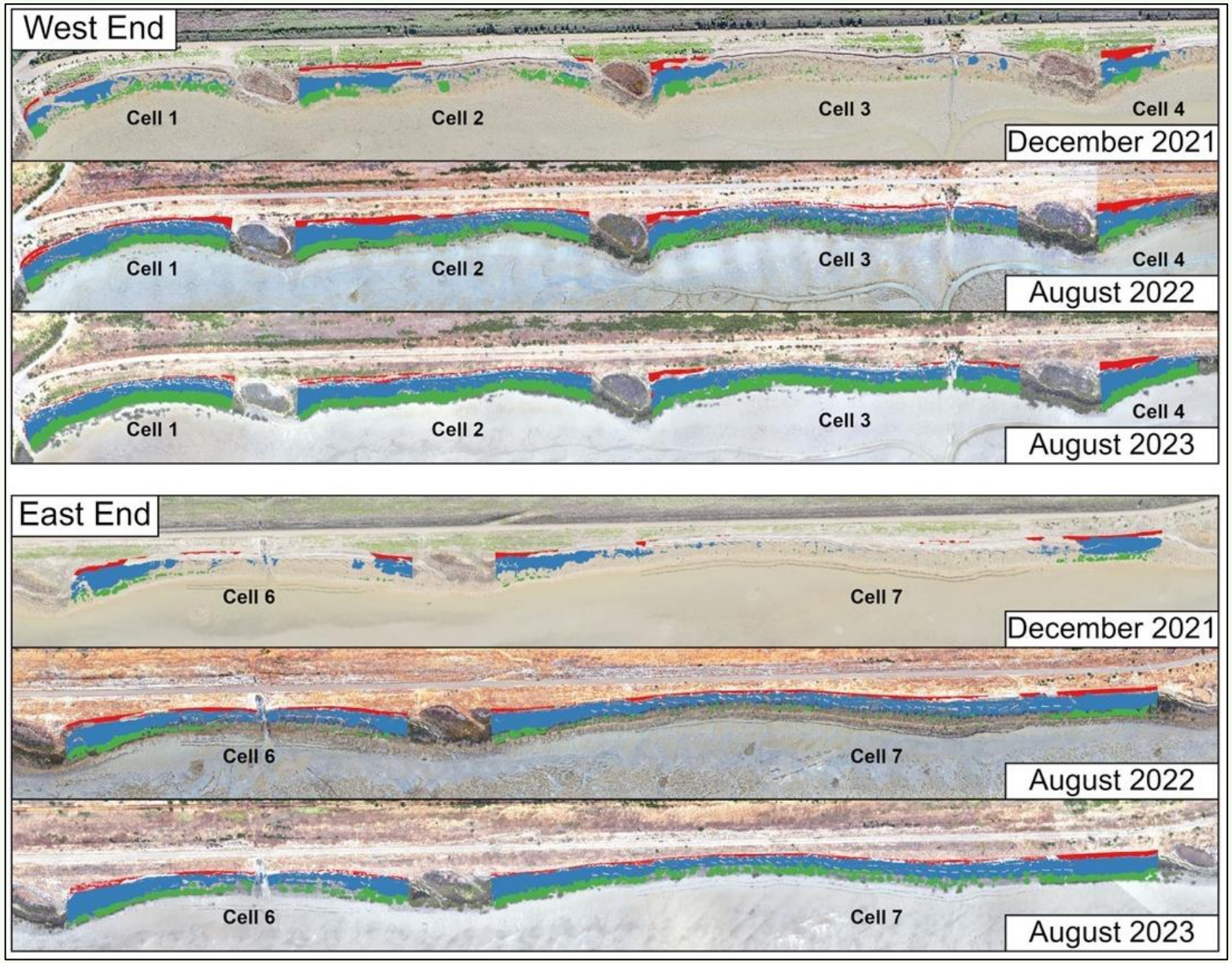

Change in Total Vegetation Cover (%)
From August 2022 to August 2023
End of Shoreline
west
east
log
no log
Percent Cover Change (%)
100
50
0
-50
-100
Upper
Middle
Lower
Marsh Zone

Results: GIS Vegetation Mapping

Dominant Veg Community Zones

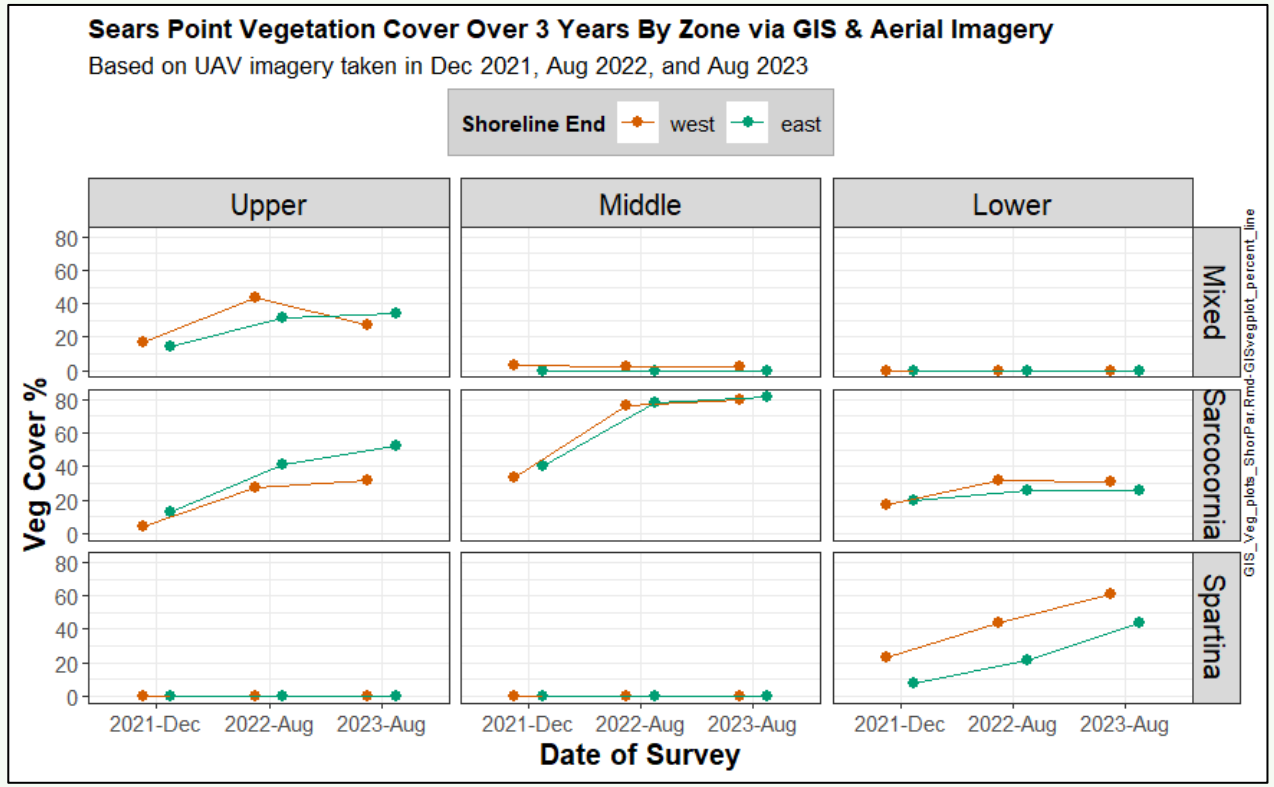
Mixed Transitional
Sarcocornia
Spartina

Shoreline End	Veg Zone	Vegetated Area (hectares) Date Dec-21	Aug-22	Aug-23
West	Mixed	0.076	0.181	0.112
	Salicornia	0.278	0.620	0.666
	Spartina	0.194	0.376	0.525
East	Mixed	0.061	0.141	0.316
	Salicornia	0.283	0.640	0.687
	Spartina	0.053	0.141	0.316



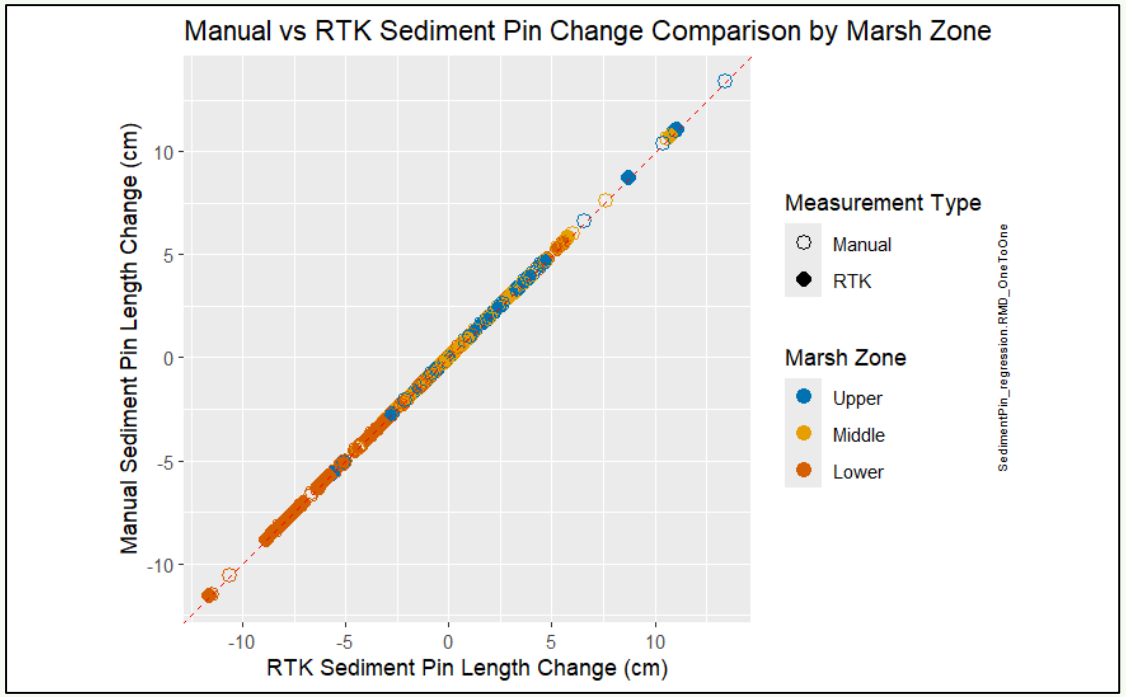
Results

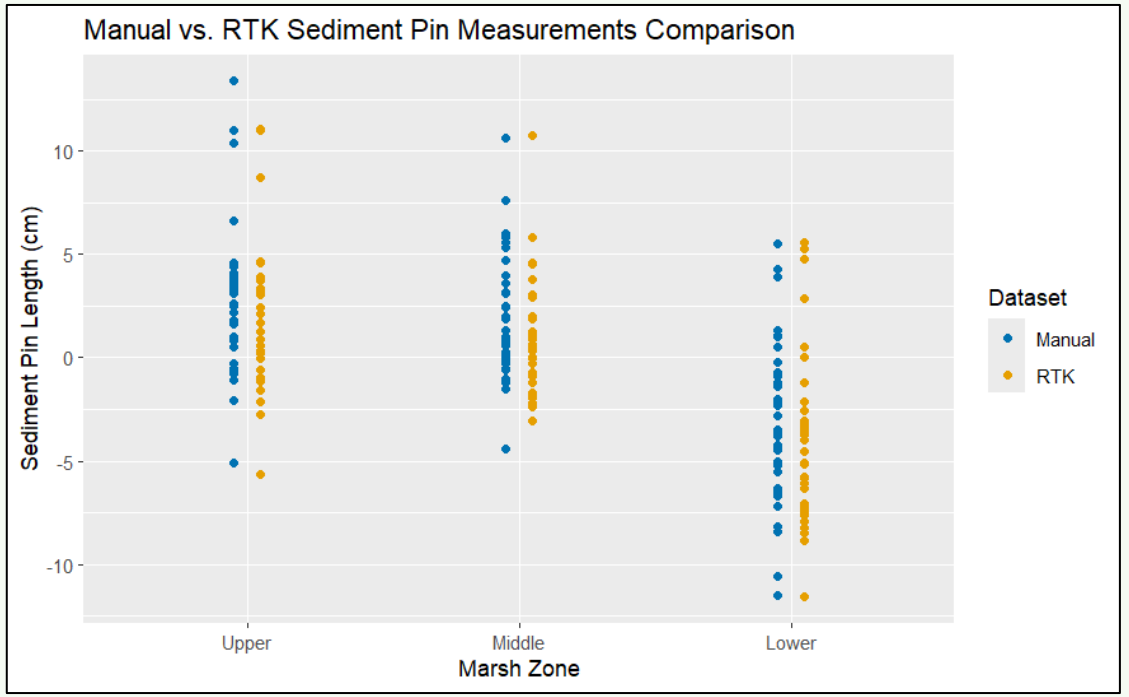
Results: GIS Vegetation Mapping

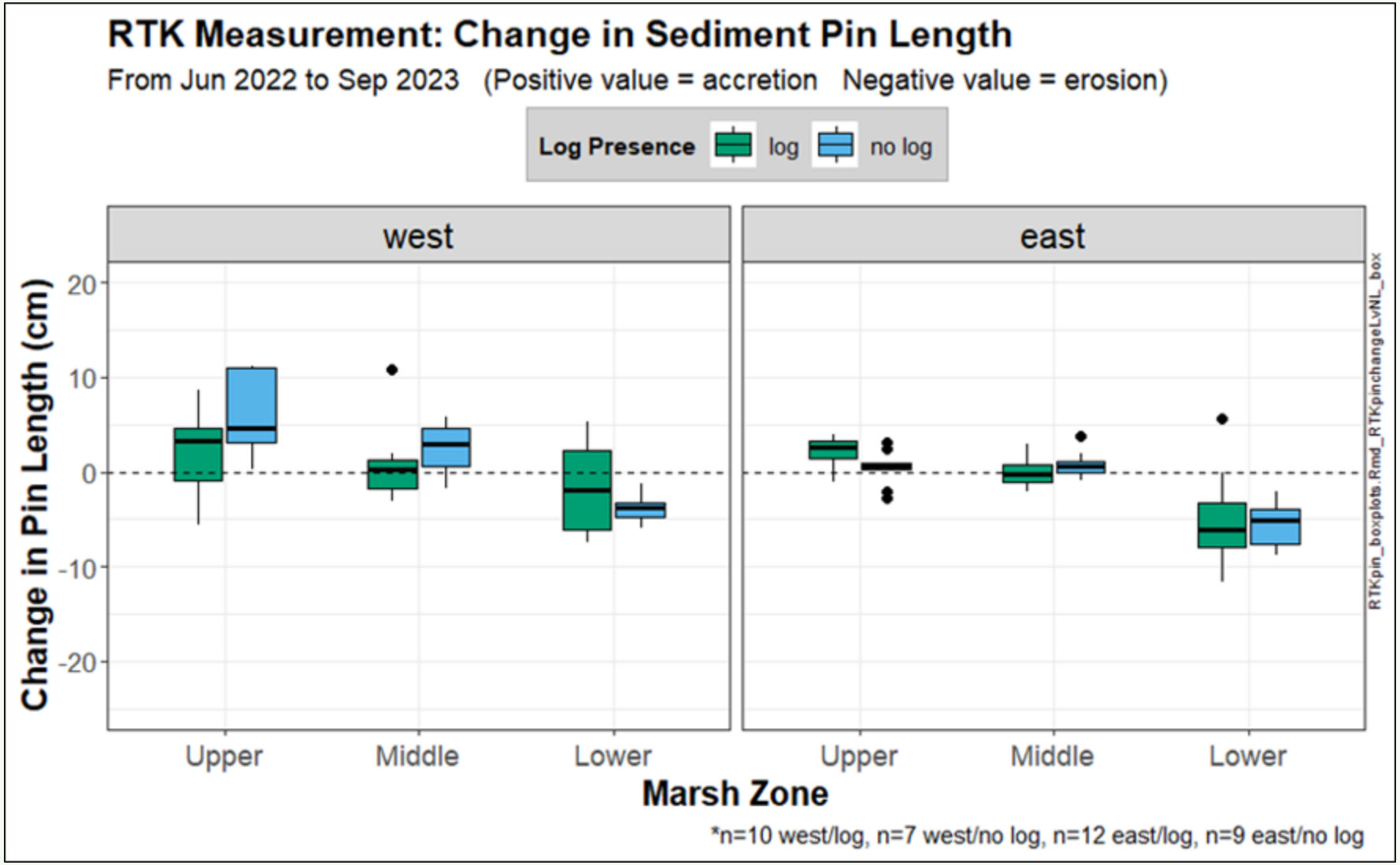


Shoreline End	Veg Zone	Marsh Zone	Total Area of Marsh Zone (hectares)	Vegetated Area (hectares) Date			Percent Veg Cover Date			Percent Veg Cover Change		
				Dec-21	Aug-22	Aug-23	Dec-21	Aug-22	Aug-23	Yr 1-2	Yr 2-3	Yr 1-3:
West	Mixed	Upper	0.396	0.067	0.173	0.112	16.8%	43.6%	28.3%	26.8%	-15.3%	11.5%
		Middle	0.340	0.010	0.008	0.007	2.8%	2.4%	2.1%	-0.4%	-0.3%	-0.7%
		Lower	0.856	0.000	0.000	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Salicornia	Upper	0.396	0.018	0.107	0.128	4.5%	27.2%	32.2%	22.7%	5.1%	27.8%
		Middle	0.340	0.113	0.260	0.274	33.3%	76.3%	80.4%	43.0%	4.1%	47.1%
		Lower	0.856	0.147	0.273	0.264	17.2%	31.8%	30.9%	14.7%	-1.0%	13.7%
	Spartina	Upper	0.396	0.000	0.000	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Middle	0.340	0.000	0.000	0.000	0.00%	0.00%	0.00%	0.0%	0.0%	0.0%
		Lower	0.856	0.194	0.376	0.524	22.6%	43.9%	61.2%	21.3%	17.3%	38.6%
East	Mixed	Upper	0.440	0.059	0.140	0.150	13.4%	31.9%	34.0%	18.5%	2.1%	20.6%
		Middle	0.338	0.000	0.000	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Lower	0.685	0.000	0.000	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Salicornia	Upper	0.440	0.058	0.179	0.230	13.3%	40.6%	52.3%	27.4%	11.7%	39.0%
		Middle	0.338	0.134	0.265	0.278	39.8%	78.4%	82.5%	38.7%	4.0%	42.7%
		Lower	0.685	0.091	0.176	0.179	13.2%	25.7%	26.1%	12.5%	0.4%	12.9%
	Spartina	Upper	0.440	0.000	0.000	0.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Middle	0.338	0.000	0.000	0.000	0.00%	0.00%	0%	0.0%	0.0%	0.0%
		Lower	0.685	0.053	0.141	0.305	7.8%	20.5%	44.5%	12.7%	24.0%	36.7%

Results


Manual vs RTK Sediment Pin Change Comparison by Marsh Zone
Manual Sediment Pin Length Change (cm)
RTK Sediment Pin Length Change (cm)
10
5
0
-5
-10
-10
-5
0
5
10
Measurement Type
Manual
RTK
Marsh Zone
Upper
Middle
Lower
SedimentPin_regression.RMD_OneToOne


Manual vs. RTK Sediment Pin Measurements Comparison
Sediment Pin Length (cm)
10
5
0
-5
-10
Upper
Middle
Lower
Marsh Zone
Dataset
Manual
RTK


RTK Measurement: Change in Sediment Pin Length
From Jun 2022 to Sep 2023 (Positive value = accretion Negative value = erosion)
Log Presence
log
no log
west
east
Change in Pin Length (cm)
20
10
0
-10
-20
Upper
Middle
Lower
Upper
Middle
Lower
Marsh Zone
*n=10 west/log, n=7 west/no log, n=12 east/log, n=9 east/no log
RTKpin_boxplots.Rmd_RTKpinchangeLvNL_box