

STATE OF THE BAY: MULTIPLE STRESSOR CHALLENGES AND THEIR IMPACTS ON GALVESTON BAY REGION AND ITS ECOSYSTEMS

IMPACTS ON WATER AND SEDIMENT QUALITY

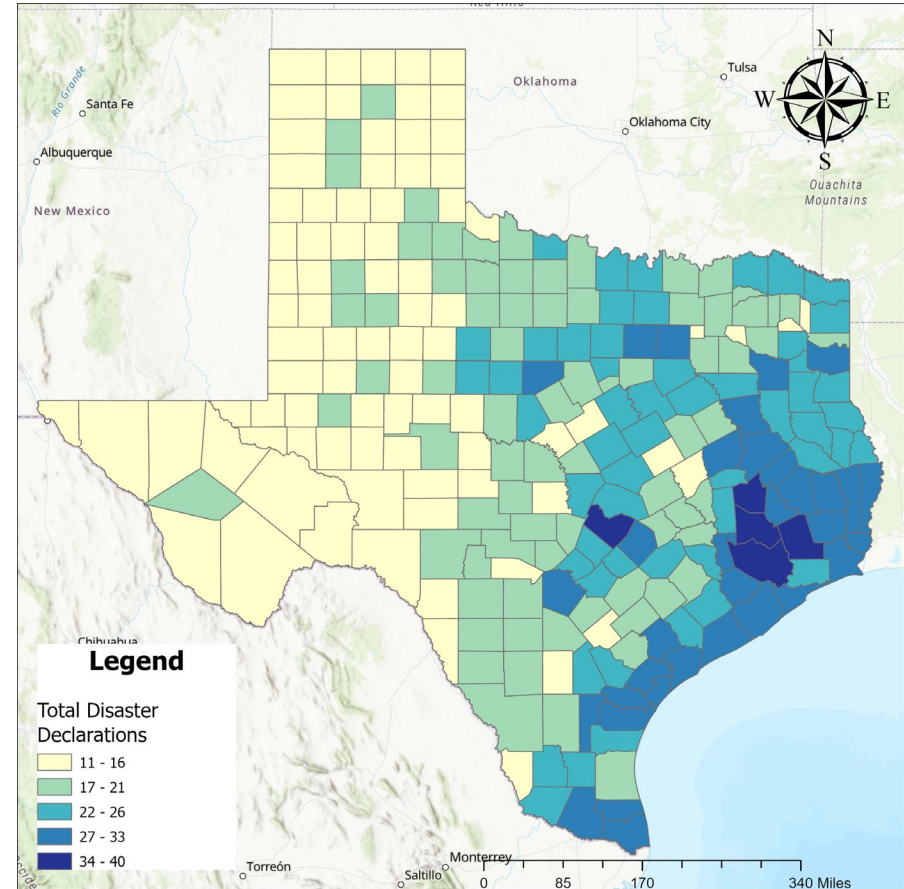
**Hanadi S. Rifai, PhD, PE, Fellow
ASCE
Civil and Environmental
Engineering
University of Houston**

**2026 State of The Bay Symposium
February 24-25, 2026**



Texas Disasters: 1953-2024

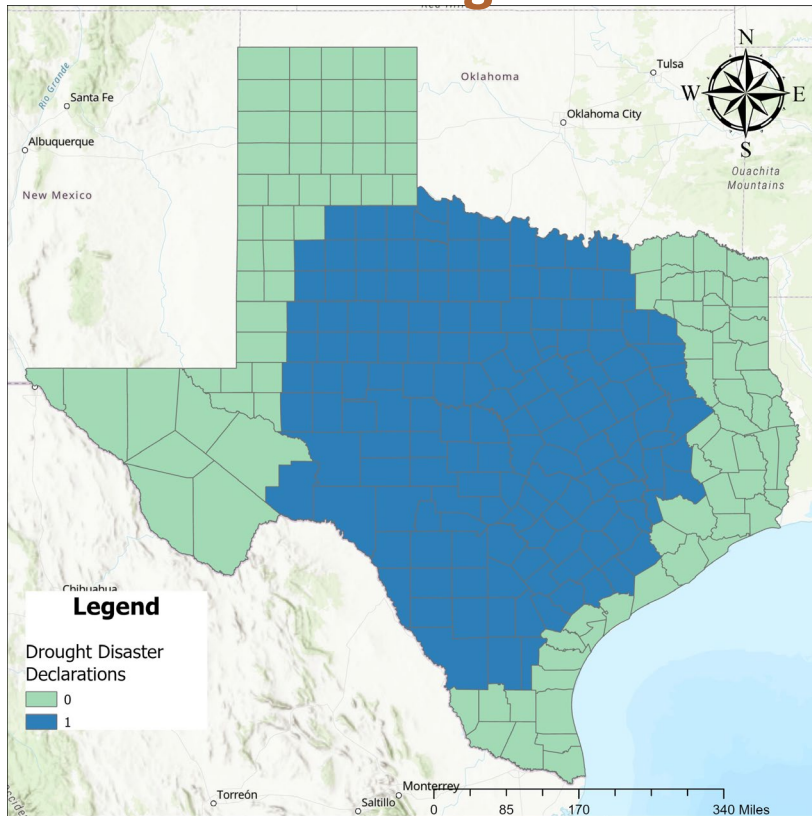
- Declared Disasters include Drought, Fire, Tornado, Flood, Hurricane, and Coastal Storms
- Coastal region has experienced more disasters than rest of the state
- Disasters are centered around population centers



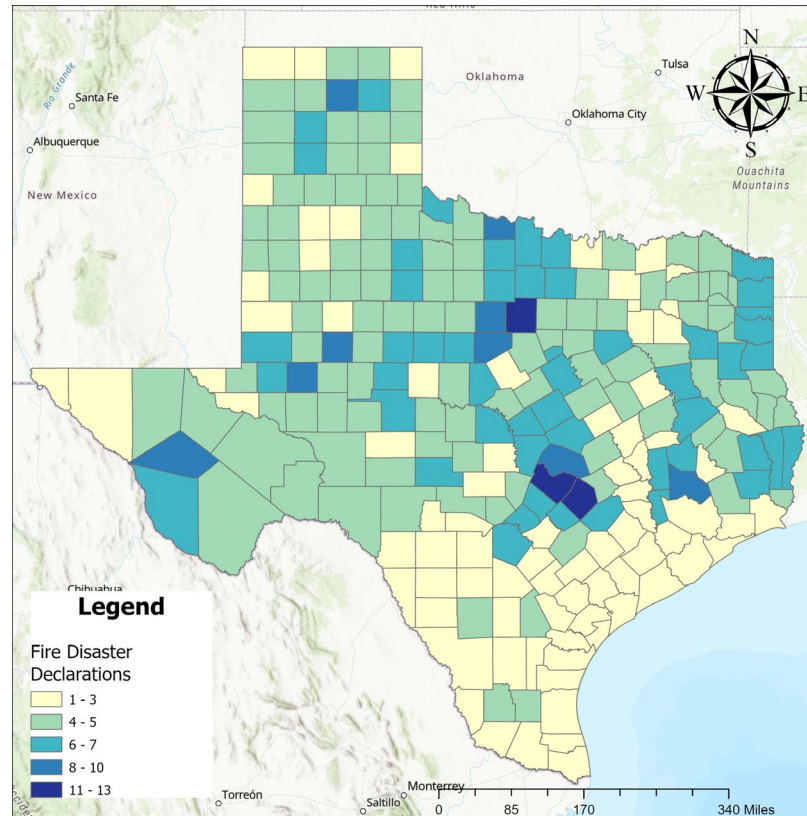
Source: FEMA Disaster Declarations Summaries Dataset

Texas Disasters: 1953-2024

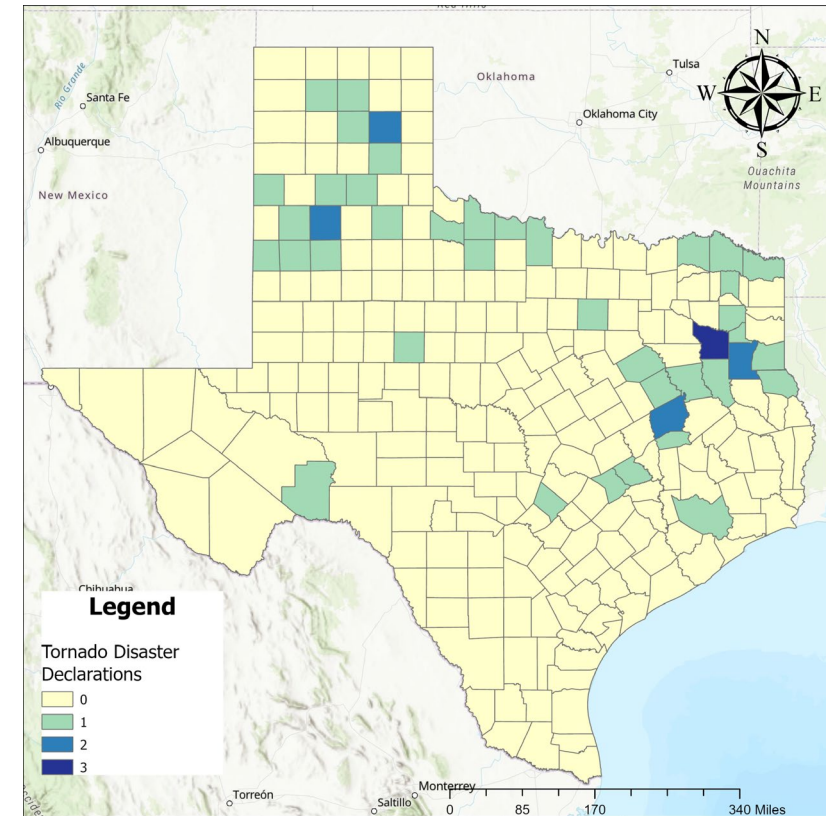
Drought



Fire



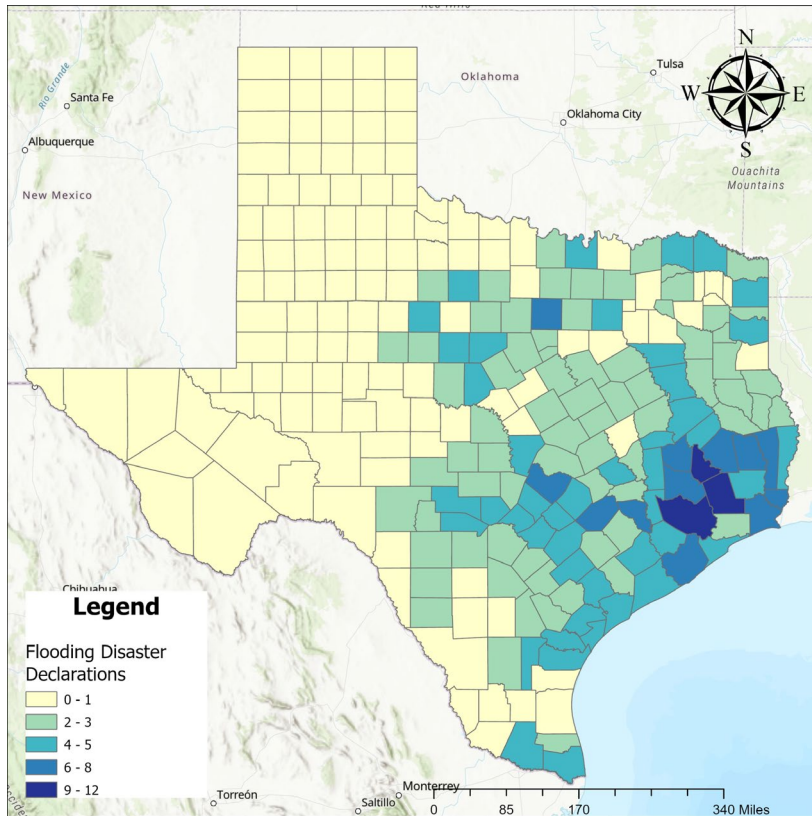
Tornado



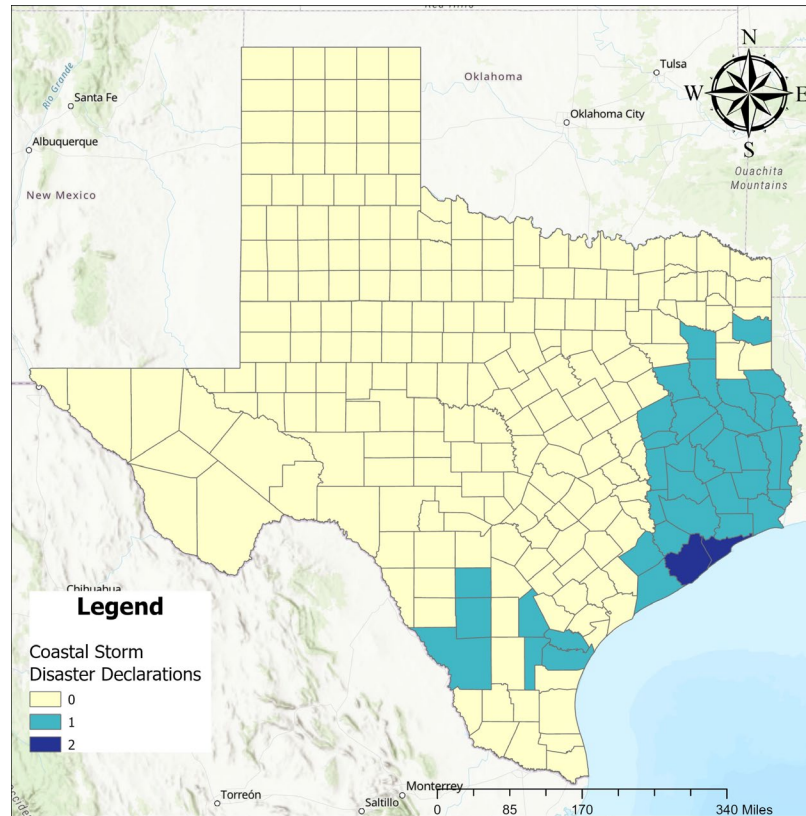
Source: FEMA Disaster Declarations Summaries Dataset

Texas Disasters: 1953-2024

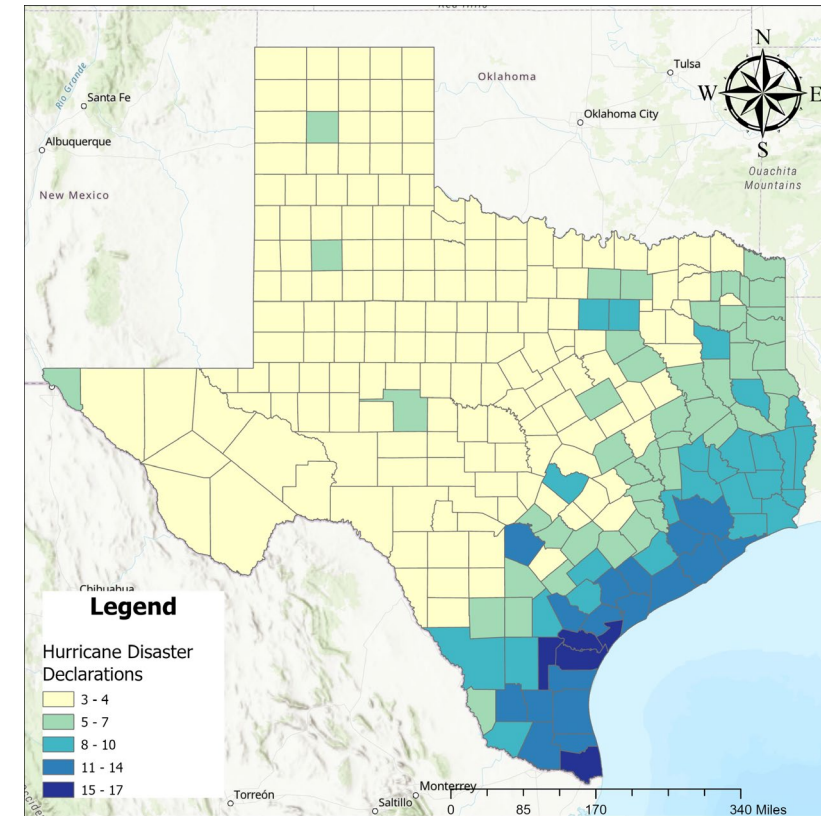
Flood



Coastal Storms

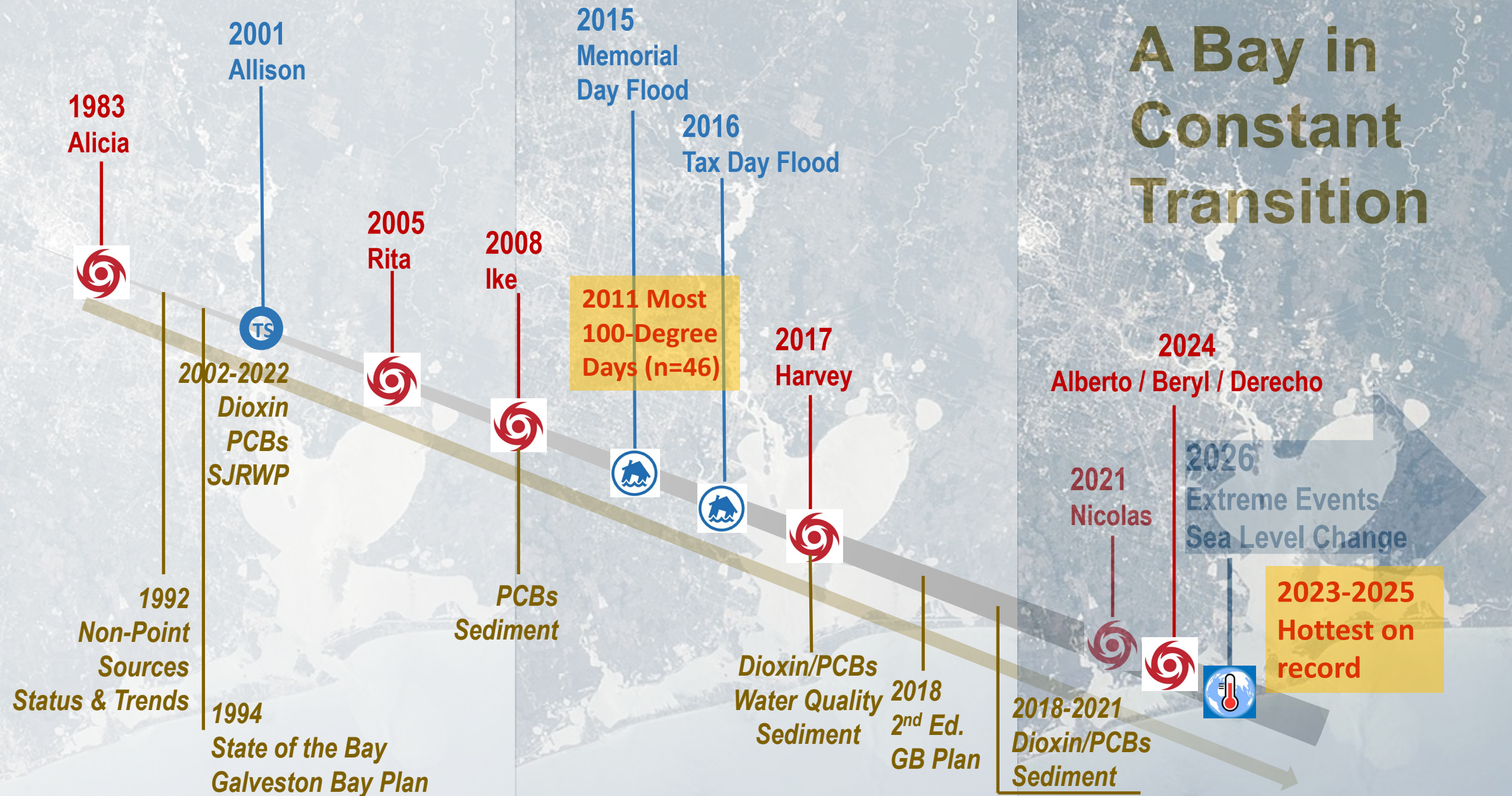


Hurricanes



Source: FEMA Disaster Declarations Summaries Dataset

A Bay in Constant Transition



Extreme Heat Impacts on Sediment and Water Quality

Direct:

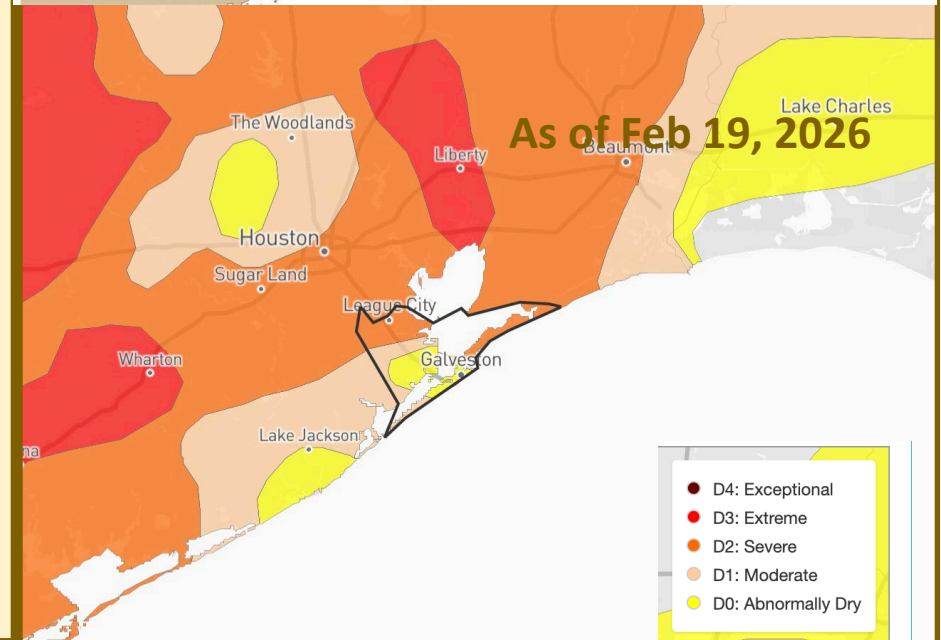
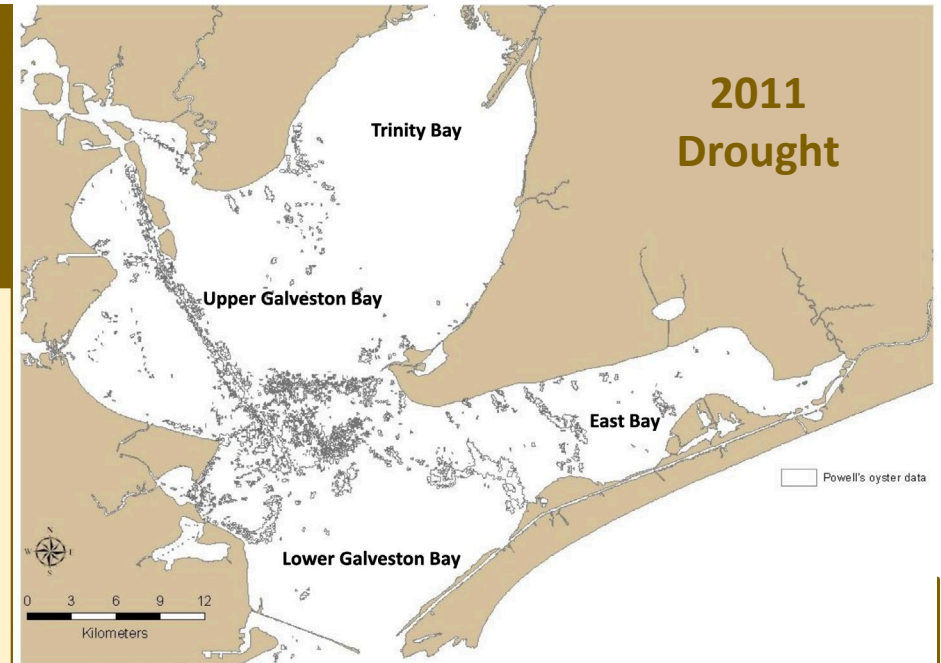
- Changes in chemistry and biology
 - Accelerated decomposition processes
 - Metal mobilization
 - Nutrient mineralization
- Reduced oxygen levels
- Microbial activity changes
- Degraded water quality

Indirect:

- Altered hydrology
 - Drought co-occurrence
 - Lower streamflow and sediment transport
- Changes in ecosystem processes
 - Stress benthic organisms
 - Promote eutrophication
 - Reduced biodiversity
 - Altered food webs
 - Increased Fish kills

Drought

- More dramatic and complex impacts on sediment and water quality
 - Sediment drying and oxidation
 - Organic matter accumulation
 - Reduced sediment supply
- Salinity intrusion upstream
- Greater hypoxia risk in deeper zones
- Increased shellfish contamination
- Stratification & depleted oxygen in dredged channels



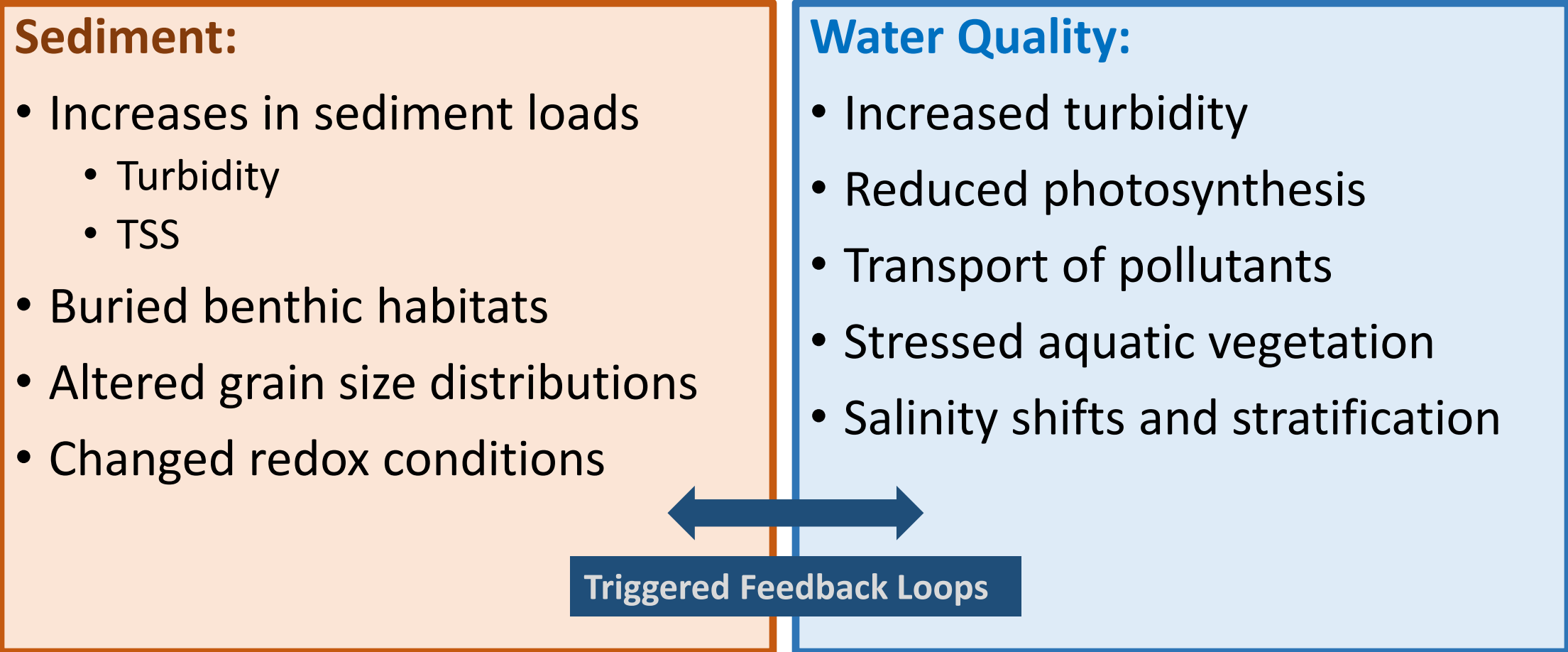
Extreme Rainfall Impacts on Sediment and Water Quality [short and long term]

Sediment:

- Increases in sediment loads
 - Turbidity
 - TSS
- Buried benthic habitats
- Altered grain size distributions
- Changed redox conditions

Water Quality:

- Increased turbidity
- Reduced photosynthesis
- Transport of pollutants
- Stressed aquatic vegetation
- Salinity shifts and stratification



Triggered Feedback Loops

Cascading Impacts of Extreme Events

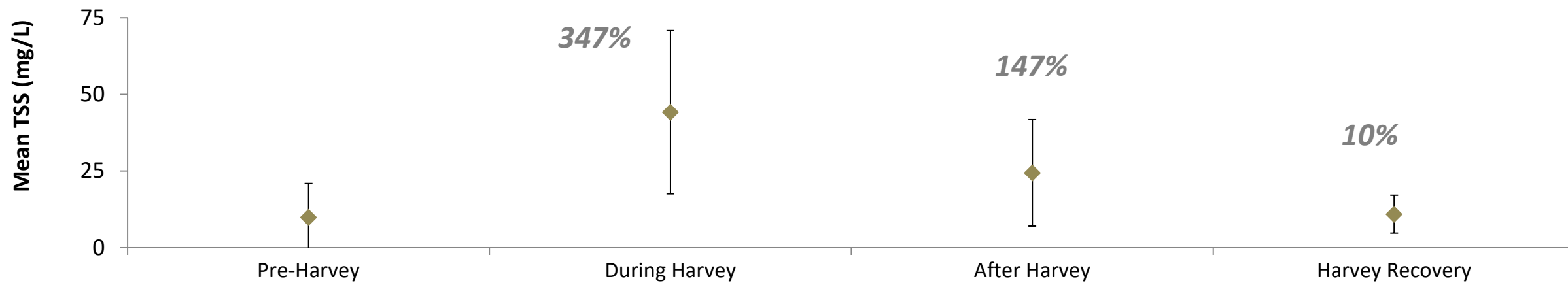
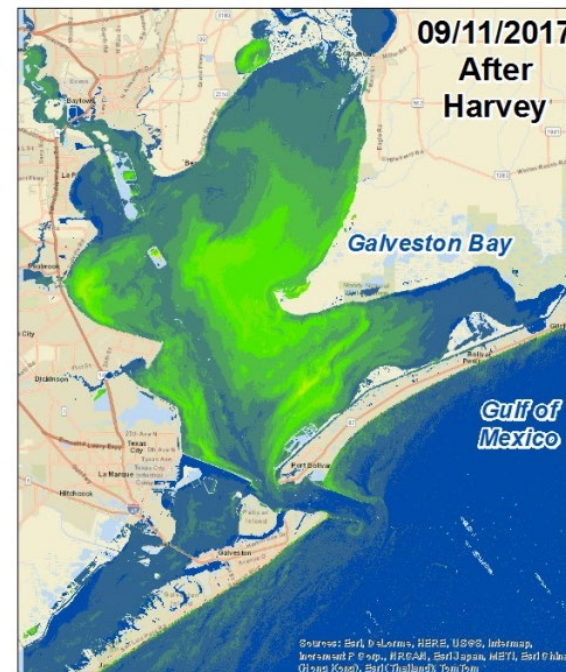
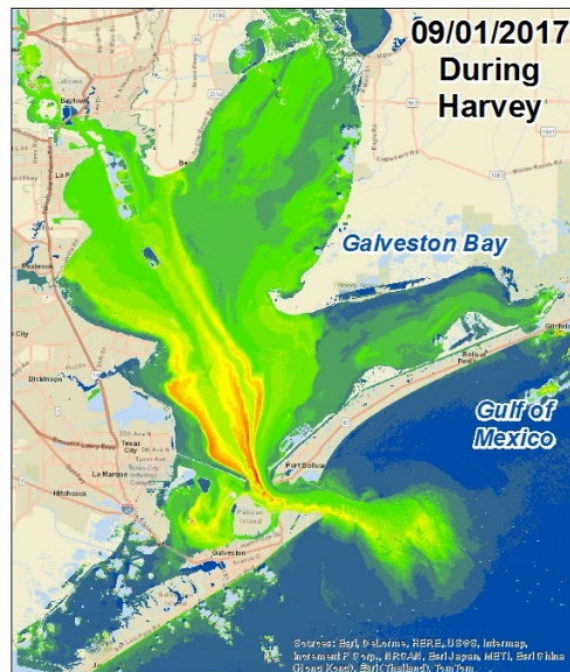
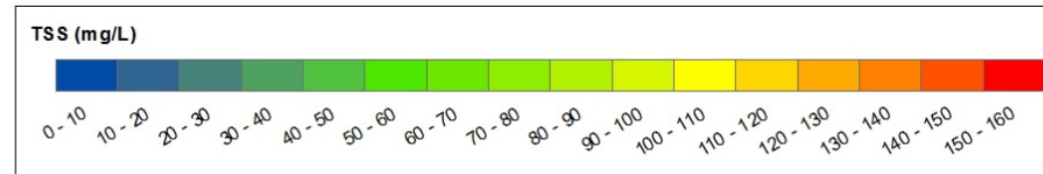
- Severe changes in water quality
- Sediment transport
- Leaks and spills from Industrial and Environmental Infrastructure
- Human exposure
- Degradation of aquatic life



<http://swamplot.com/a-photo-tour-of-the-brand-new-beaches-along-buffalo-bayou/2017-09-18>

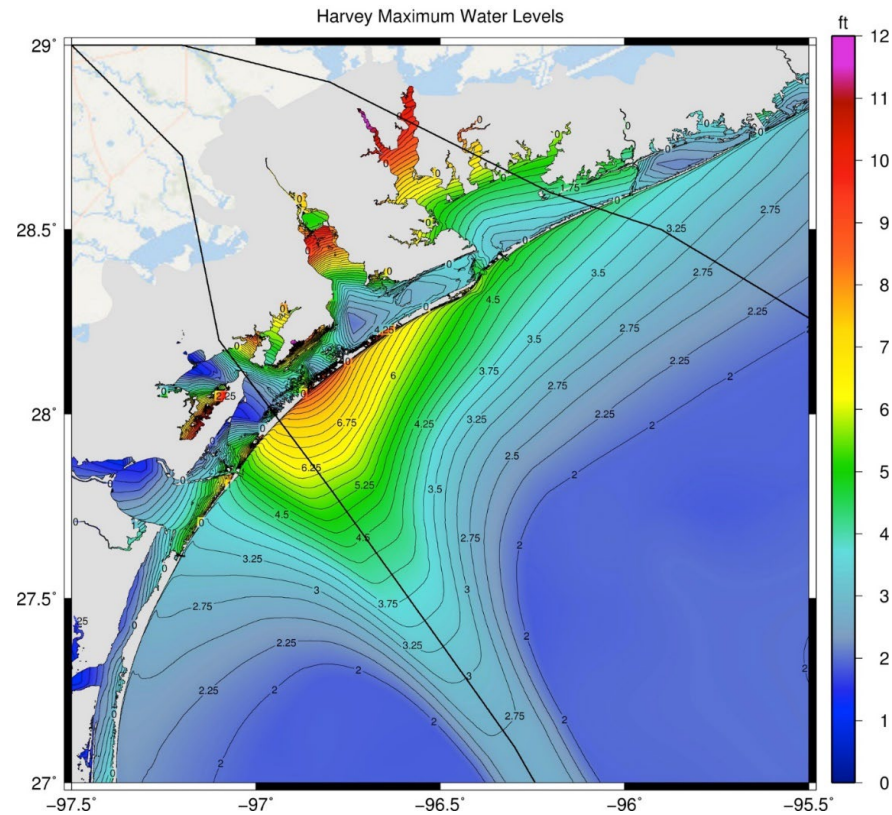


TSS Concentration

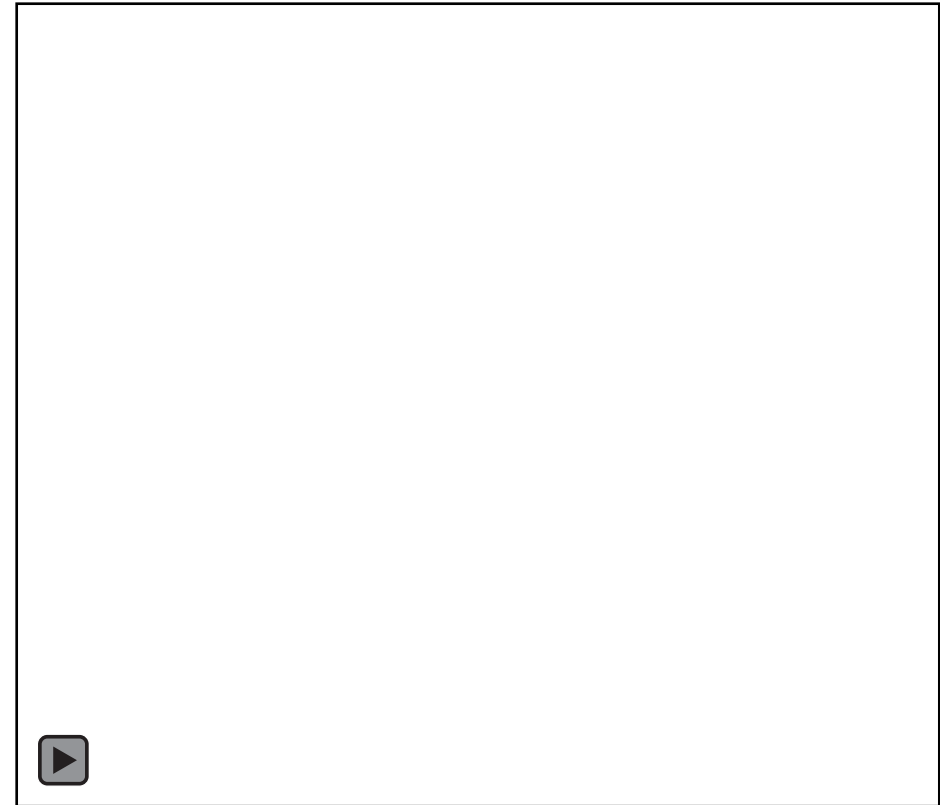


Bay Salinity Changes during Extreme Events

Hurricane Harvey Max. Water Levels (Best Track)

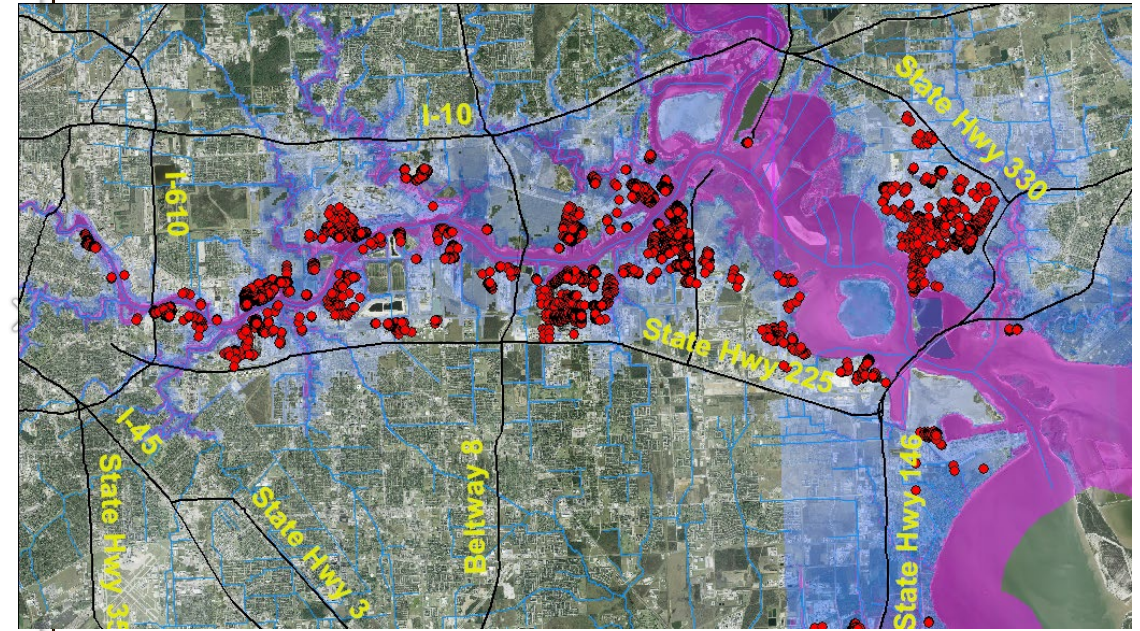
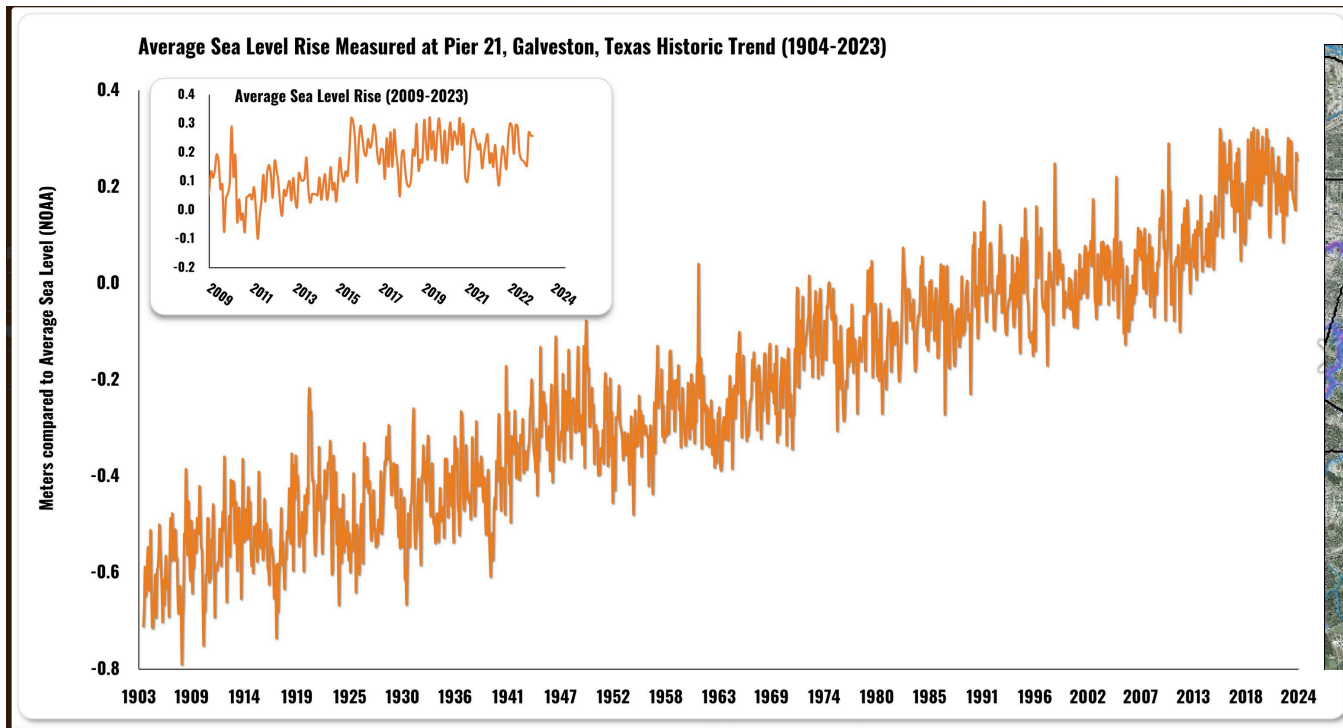


Changes in salinity during Hurricane Harvey (2017)



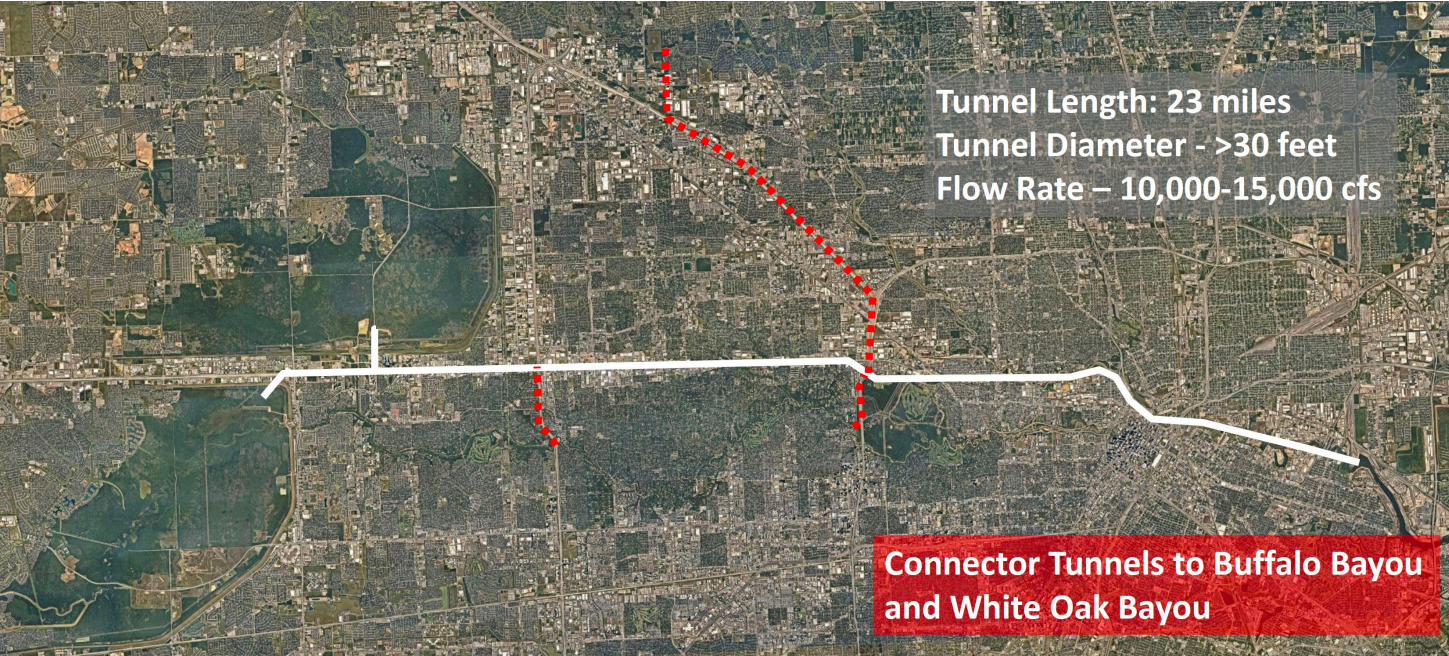
Sea Level Impacts

- Increased salinity and water intrusion
- Salinity regimes move inland
- Groundwater + wetland impacts
- Infrastructure corrosion + exacerbated flooding
- Increased vibrio and other pathogen indicators
- Altered erosion and deposition



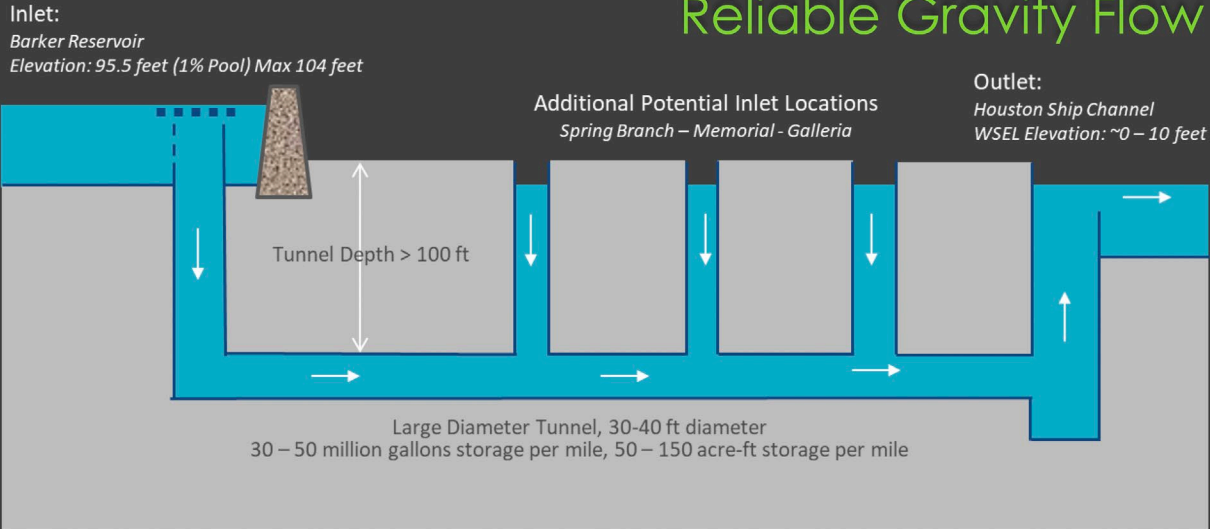
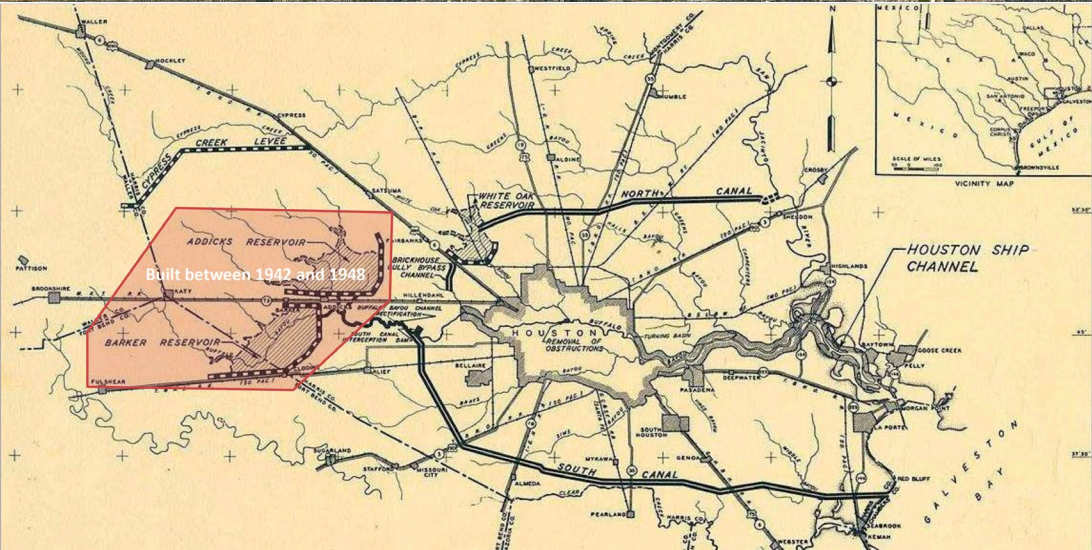
Inundation at 25 ft Storm Surge

Mitigation in Houston and Harris County

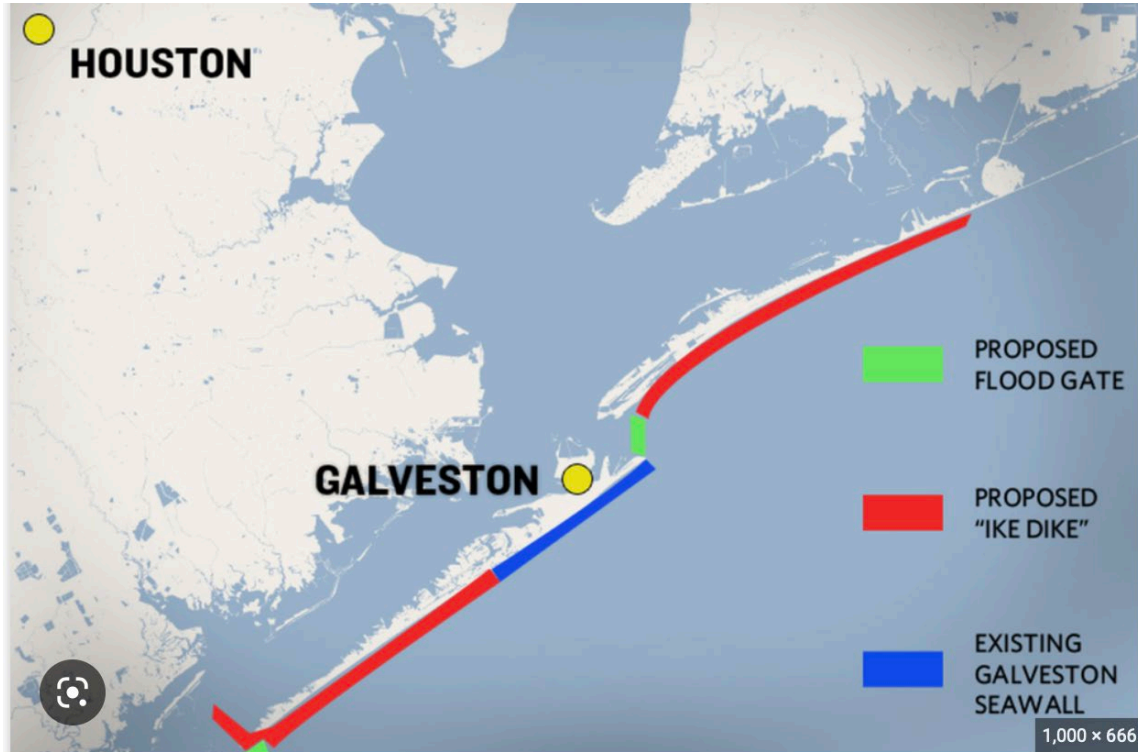


Additional Reservoirs

\$\$\$\$\$\$\$\$\$\$\$\$



Mitigation Along the Coast – Storm Surge



U.S. House approves massive \$31 billion "Ike Dike" project to protect Texas coast from hurricanes – Houston Public Media

[Visit](#)



Rice University says it has a cheap plan to guard the Texas coast | The Texas Tribune

[Visit](#)

Engineered Solutions: Costly • Less Adaptable • Harden Coastlines • May not soften environmental impacts

MULTIPLE STRESSOR CHALLENGES AND THEIR IMPACTS ON GALVESTON BAY REGION AND ITS ECOSYSTEMS – CONCLUDING REMARKS

- Consider stressor frequency and severity over the long term via scenario analysis
- Examine proposed mitigation measures and their corresponding water and sediment quality impacts
- How do we co-produce with communities towards resilience to multiple stressors
- Evaluate where do mitigation and adaptation intersect, overlap and diverge in this context?



Acknowledgements



GK-12 &
RAPID Grant



NATIONAL
ACADEMIES
GULF Research

HOUSTON
ENDOWMENT



TEXAS COMMISSION
ON ENVIRONMENTAL QUALITY



National Institutes
of Health



GALVESTON BAY
FOUNDATION





GALVESTON BAY FOUNDATION

PROTECT TODAY. PRESERVE TOMORROW.

Ecosystem Protection and Preservation

President, Bob Stokes



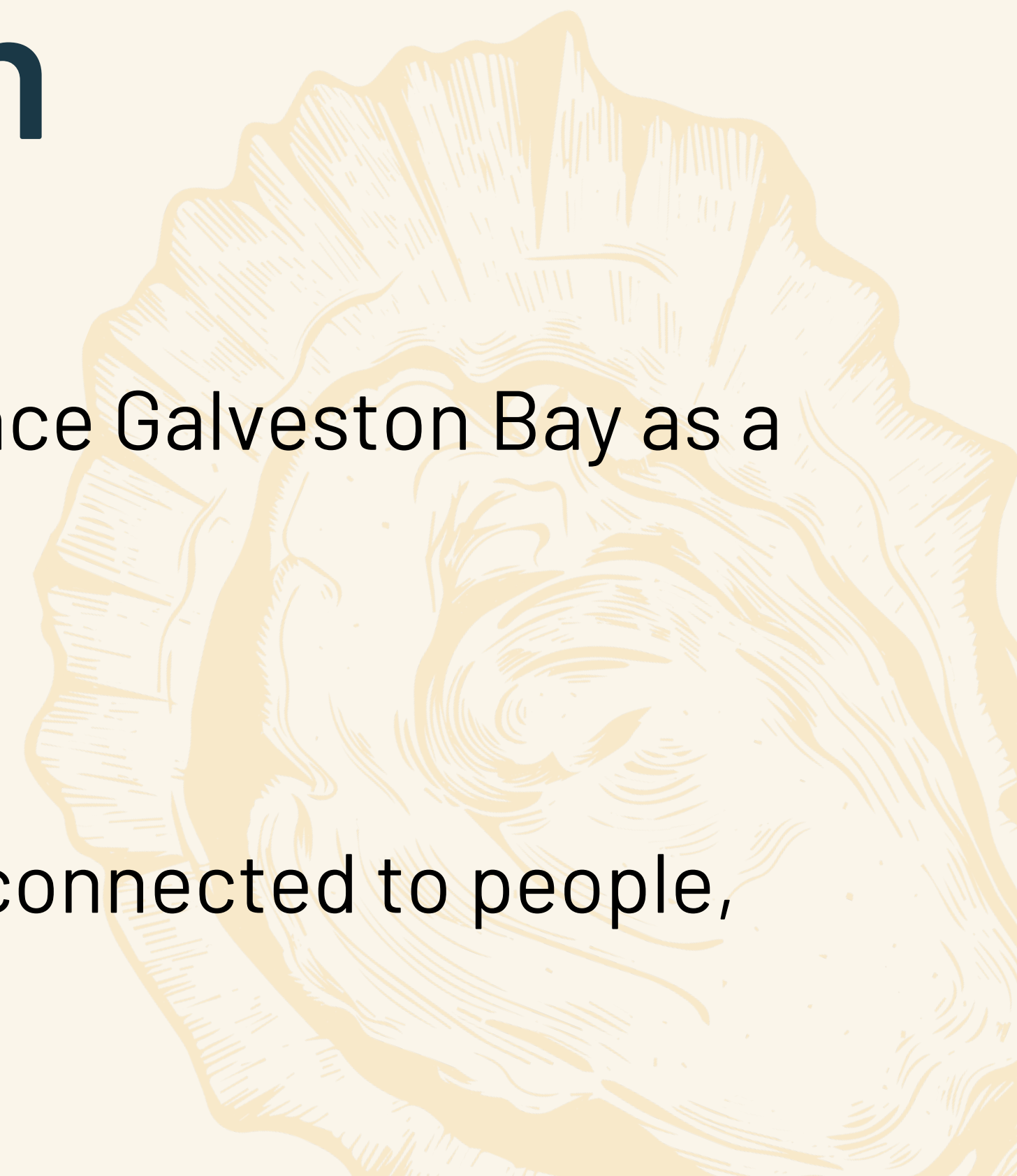
Our Mission & Vision

Mission

The mission of Galveston Bay Foundation is to preserve and enhance Galveston Bay as a healthy and productive place for generations to come.

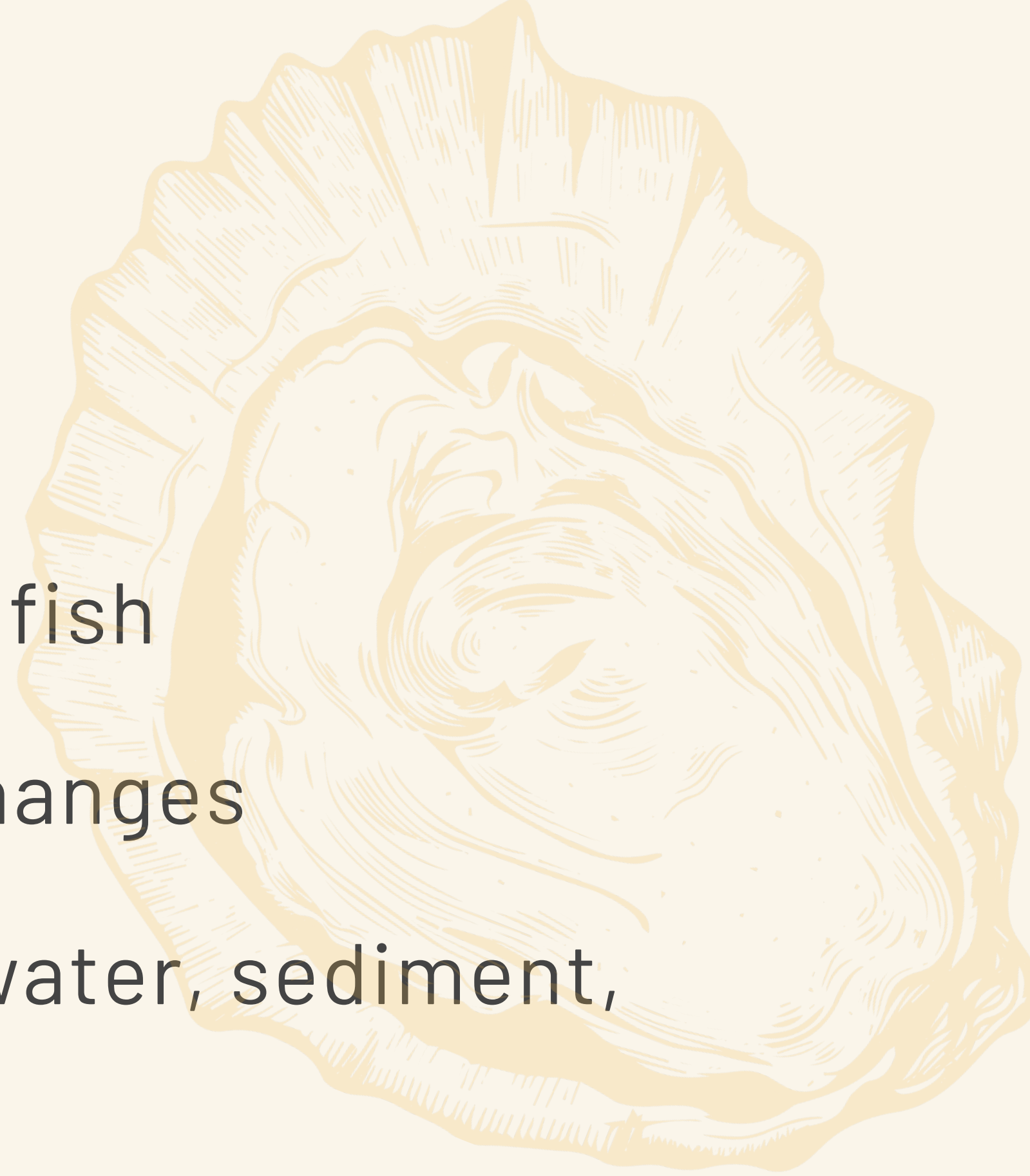
Vision

We envision a future Galveston Bay that is brimming with vitality, connected to people, and contributing to the community in every possible way.



Top Issues We Face

- Loss and degradation of coastal habitats
- Reductions in wildlife populations, particularly shellfish
- Insufficient freshwater inflows and other coastal changes
- Human health risks, such as bacteria and toxics in water, sediment, and seafood
- Lack of awareness of the importance of Galveston Bay



Stressor Challenges

- Relative Sea Level Rise
- Population Growth and Land Fragmentation
- Extreme Weather
- Water Temperature Changes





Program Areas



Education



Habitat Restoration



Land Conservation



Water Protection



Research



Advocacy

Solutions

- Complex Policy Issues
- Build Resiliency
- What'd Old is New Again





Land Conservation



-
- Sound Finances
 - Ethical Conduct
 - Responsible Governance
 - Lasting Stewardship
-

Total Land Conserved 19,179 acres

Fee Simple Preserves 9,340 acres

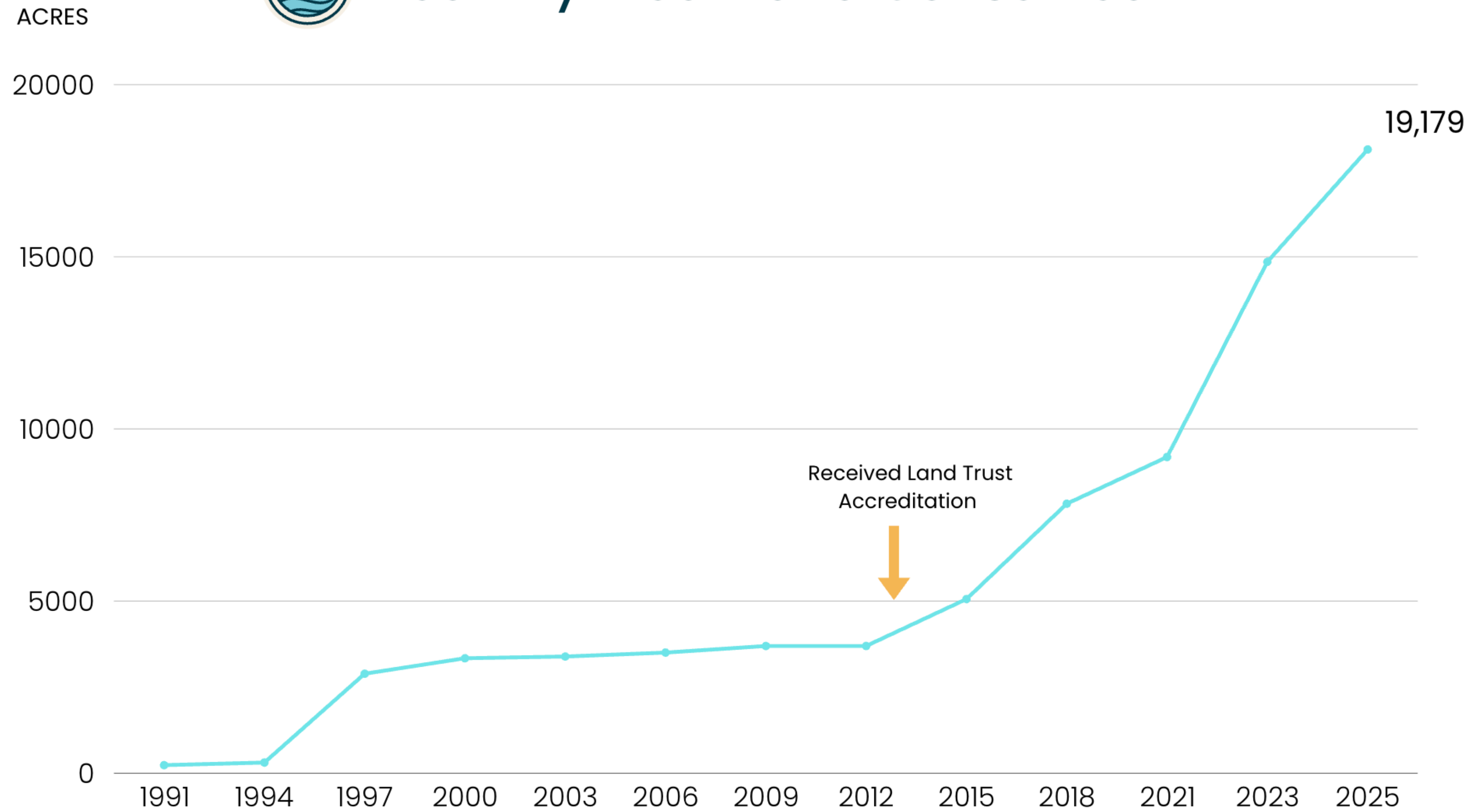
Conservation Easements 7,668 acres

Lands Transferred to Partner 2,019 acres





Year-By-Year Land Conserved



Habitat Restoration

- Shoreline protection
- Salt Marsh, coastal prairie, oyster reef, and bird rookery restoration
- Invasive species control
- Marine debris removal



Restoring Intertidal Marsh



Before & After

Dickinson Bay Island Restoration

2005



2011



Before & After

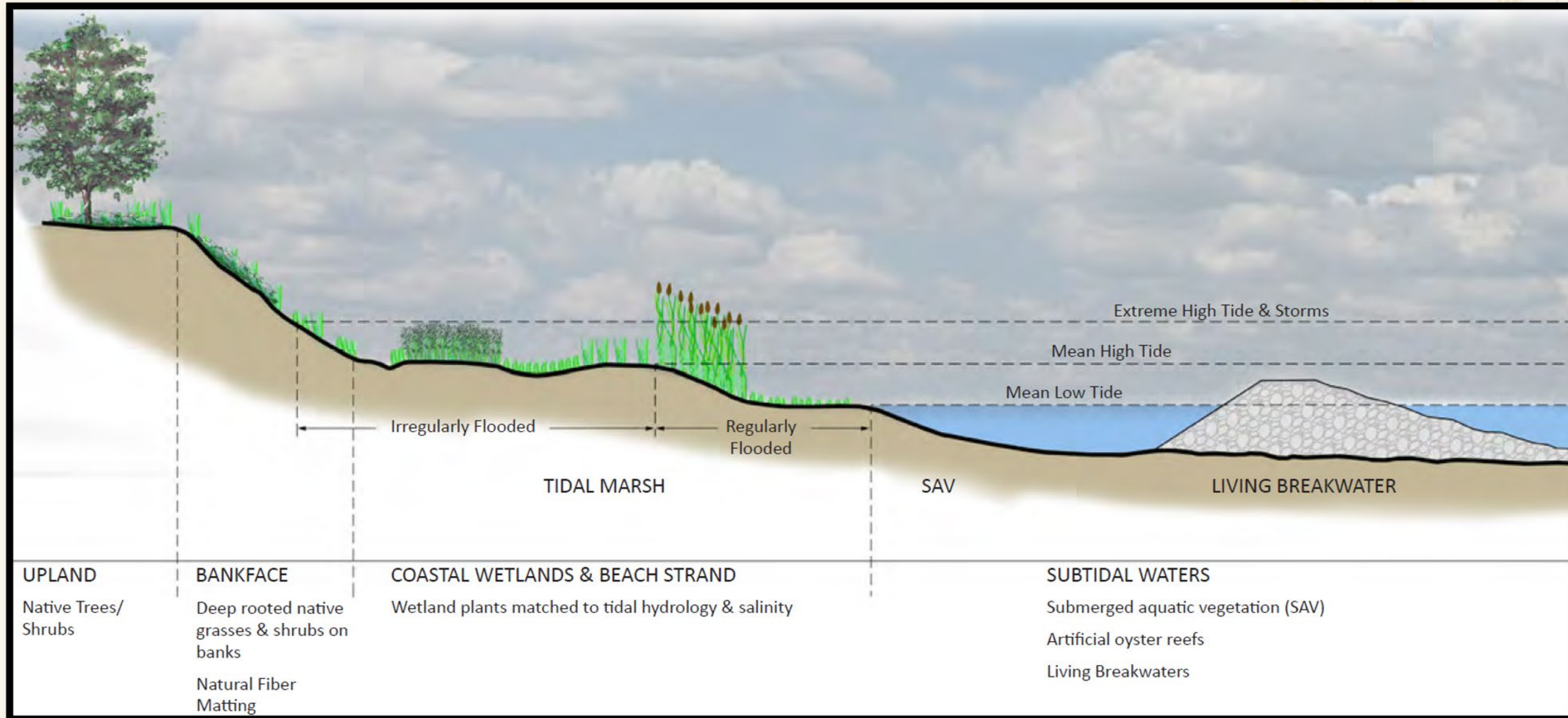
Burnet Bay Wetlands Restoration



Shoreline Protection



Living Shorelines



Bulkhead



Living Shoreline



Before & After

Lake Forest Park Living Shoreline

2011



2012



2019



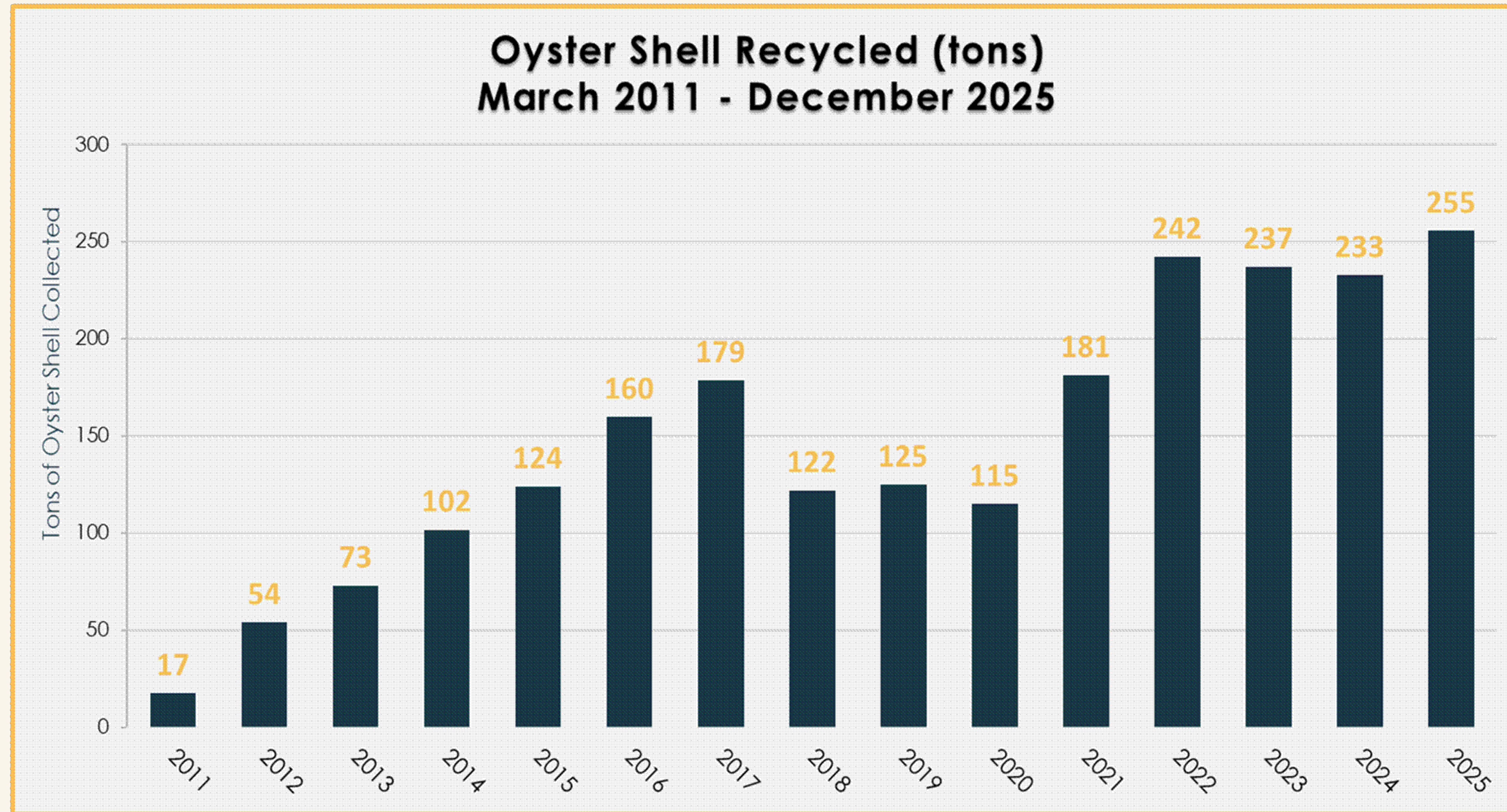
2023



Restoring Native Oyster Habitat

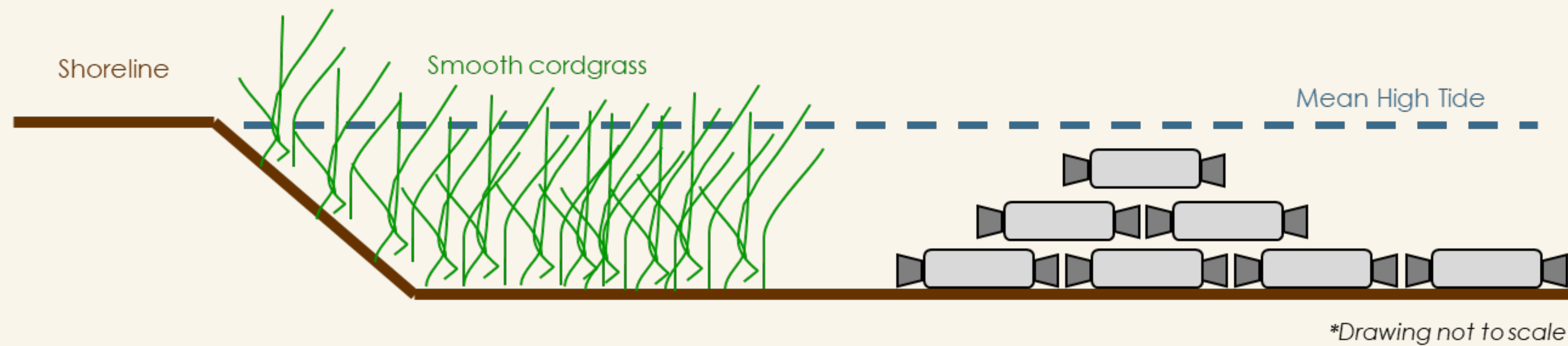


Reclaimed **2,219 tons** of oyster shell since 2011 thanks to the participation of **37 recycling partners!**





Oyster Shell Breakwater





Oyster Shell Reef Mounds



www.galvbay.org

Bob Stokes, President

bstokes@galvbay.org

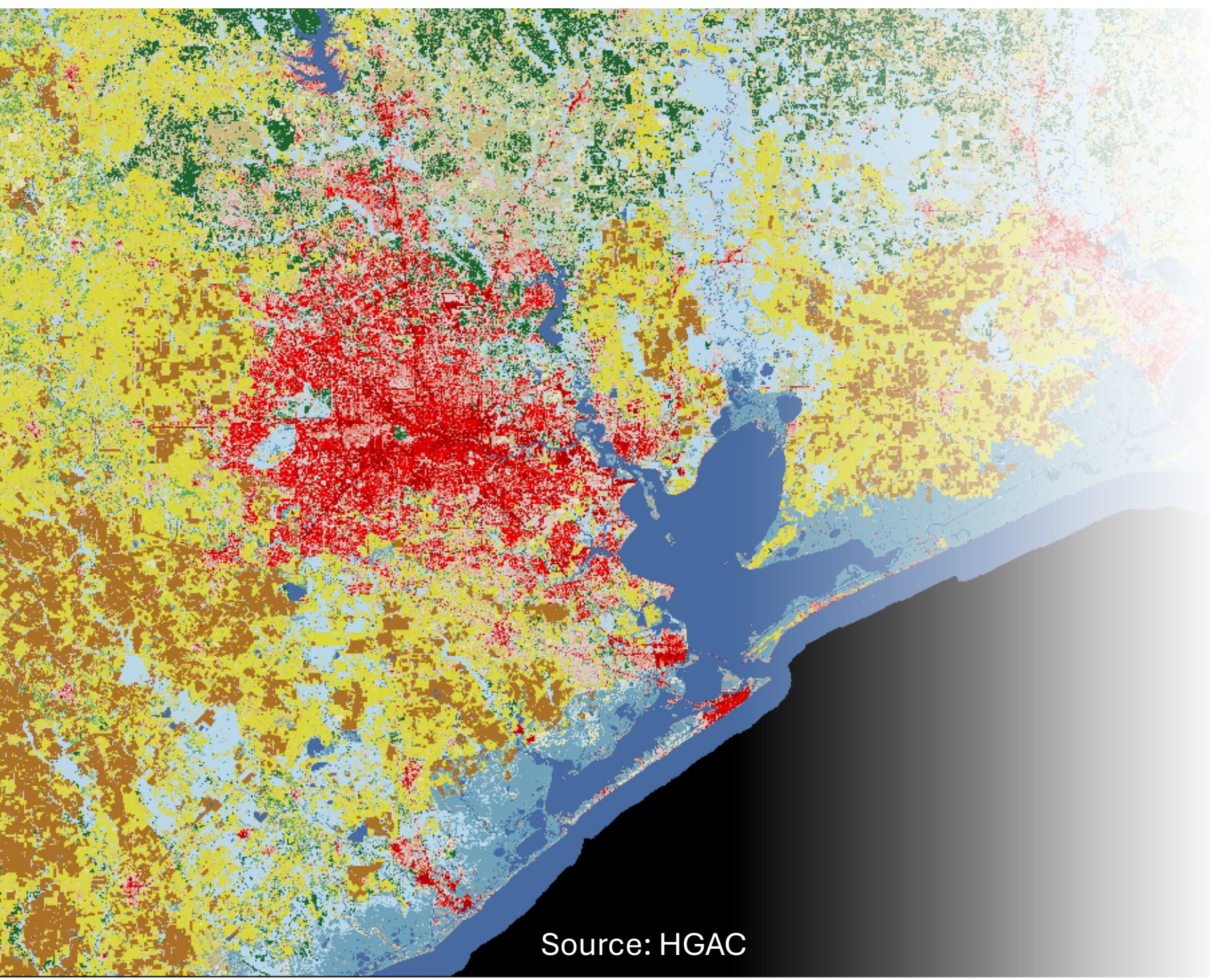
832-536-2253

Galveston Bay Foundation

1725 Highway 156

Kemah, TX 77565





Impacts on Ecosystems

Dr. Antoinetta Quigg,
Texas A&M University
Galveston

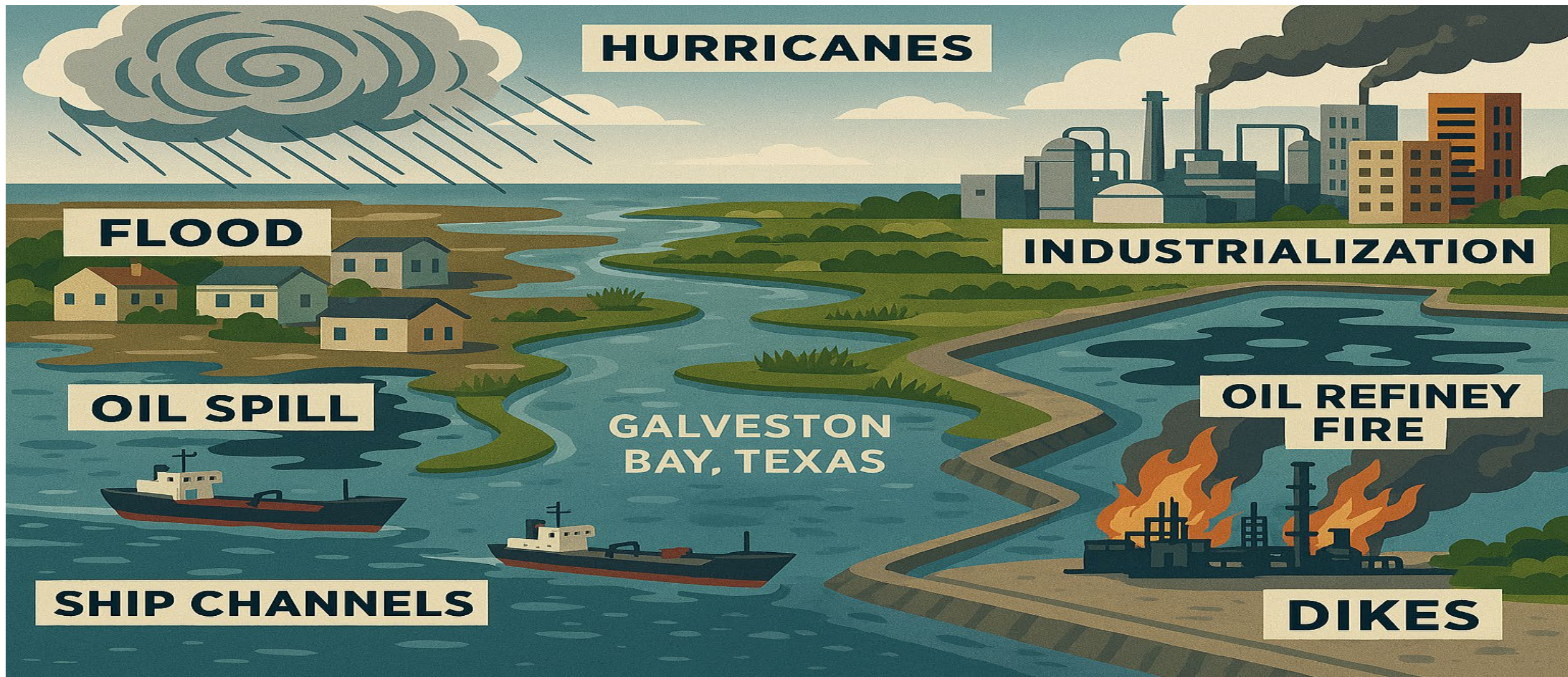


Source: HGAC

Acknowledgements



Amazing crew of students, postdoctoral fellows, colleagues and peers !



Impacts on Ecosystems

What is unique about Galveston Bay?

Ecological Significance:

As the seventh-largest estuary in the United States, and largest estuary in the Gulf of Mexico, it provides critical nurseries for shrimp, crabs, and oysters, fueling a massive fishing industry.

Industrial Coexistence: The bay hosts the Houston Ship Channel, making it a unique mix of high-intensity industrial activity, shipping, and natural habitats.

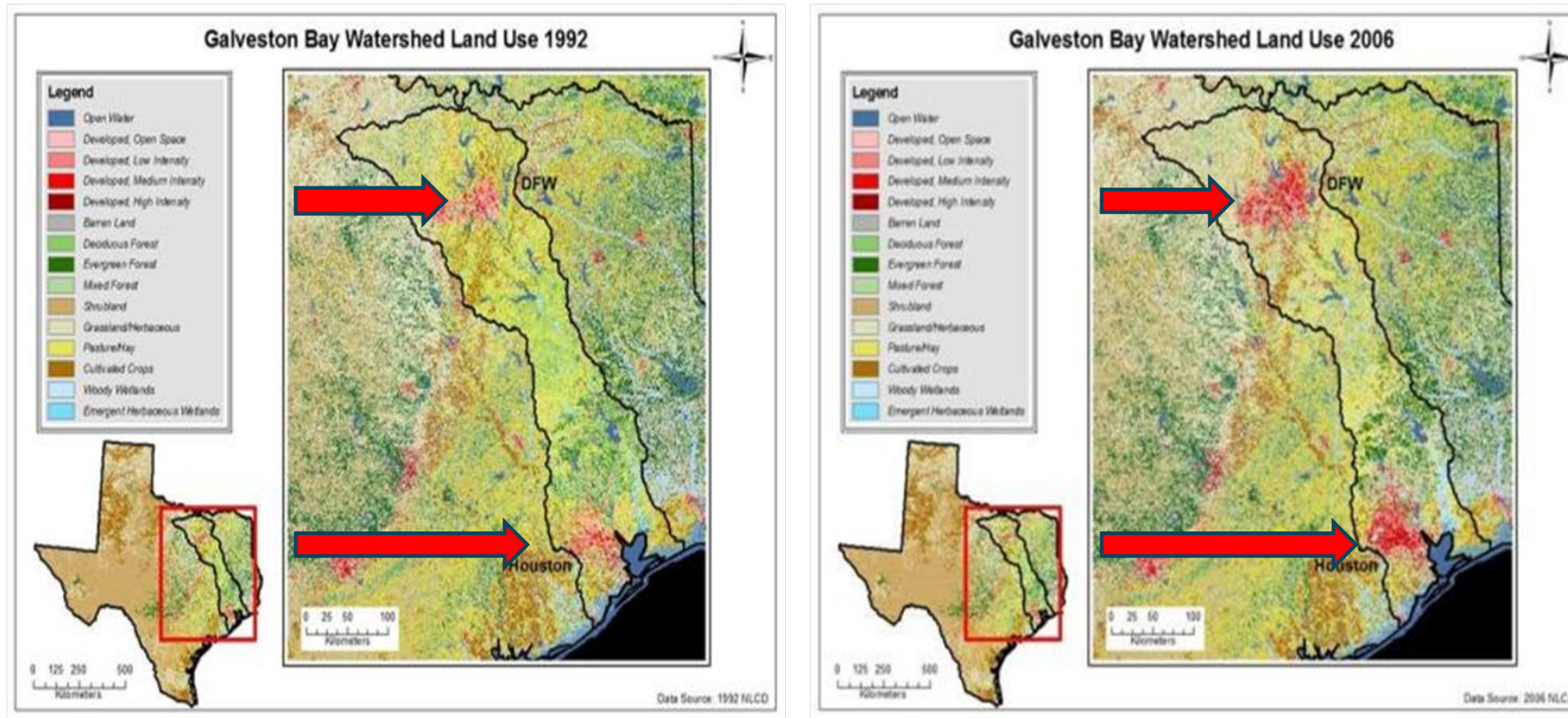
Diverse Habitats: The ecosystem includes salt/brackish marshes, seagrass beds, and unique prairie pothole complexes that act as water quality buffers.

Shallow Structure: Unlike many deep bays, its average depth is only about 6 feet, with a maximum of around 10 feet.



- Houston is the fourth-largest city in the United States, with ~ 2.39 million people
- The Greater Houston metropolitan area has a population > 7.8 million

Changes in land use land cover



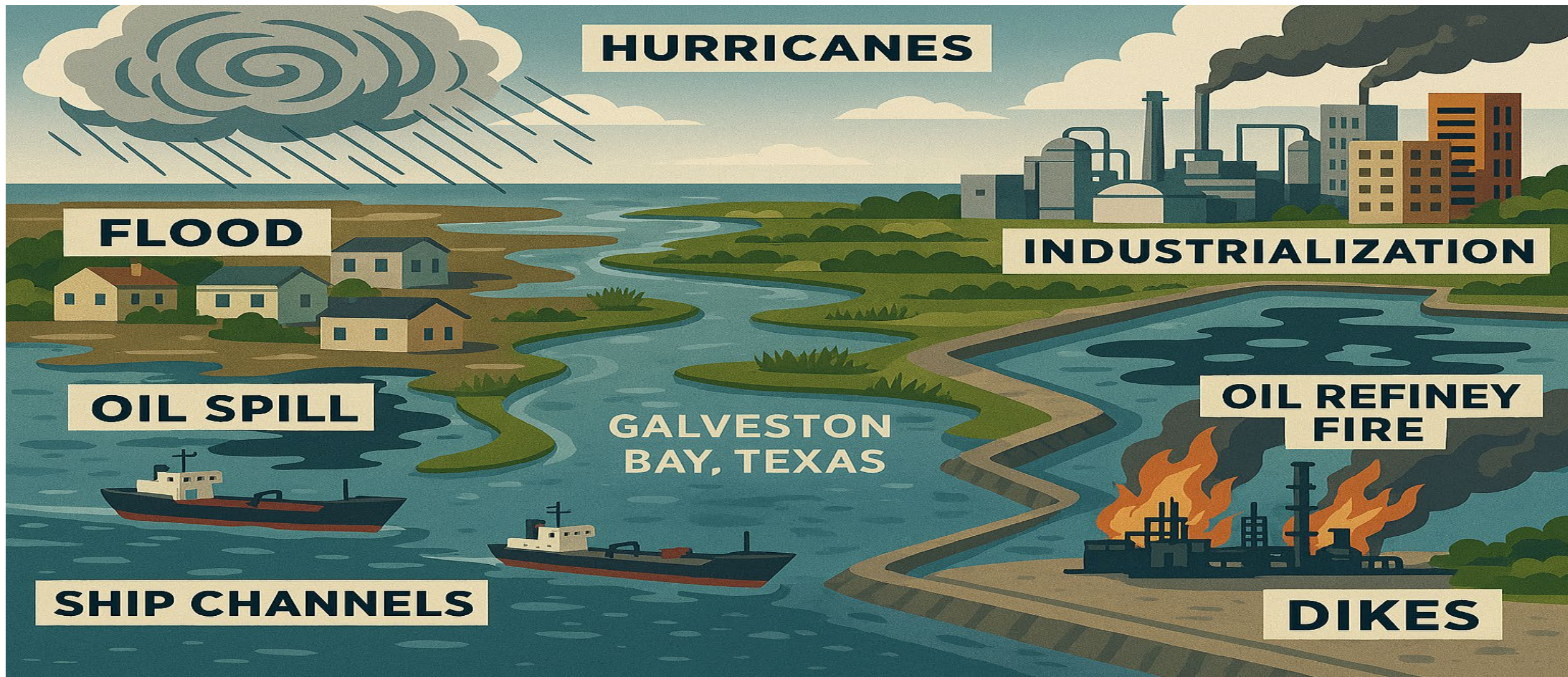
- i. forest land cover experienced the **greatest loss**, primarily due to **development (urbanization)**
- ii. forests were also lost to grasslands and more shrubs; agricultural (cultivated) lands and wetlands
- iii. wetlands were converted into developed lands, to shrubs and grasslands associated with urban community centers connected to waterways

Estuaries and Coasts (2019) 42:1821–1838
<https://doi.org/10.1007/s12237-019-00597-z>

Impacts of Urbanization and Development on Estuarine Ecosystems and Water Quality



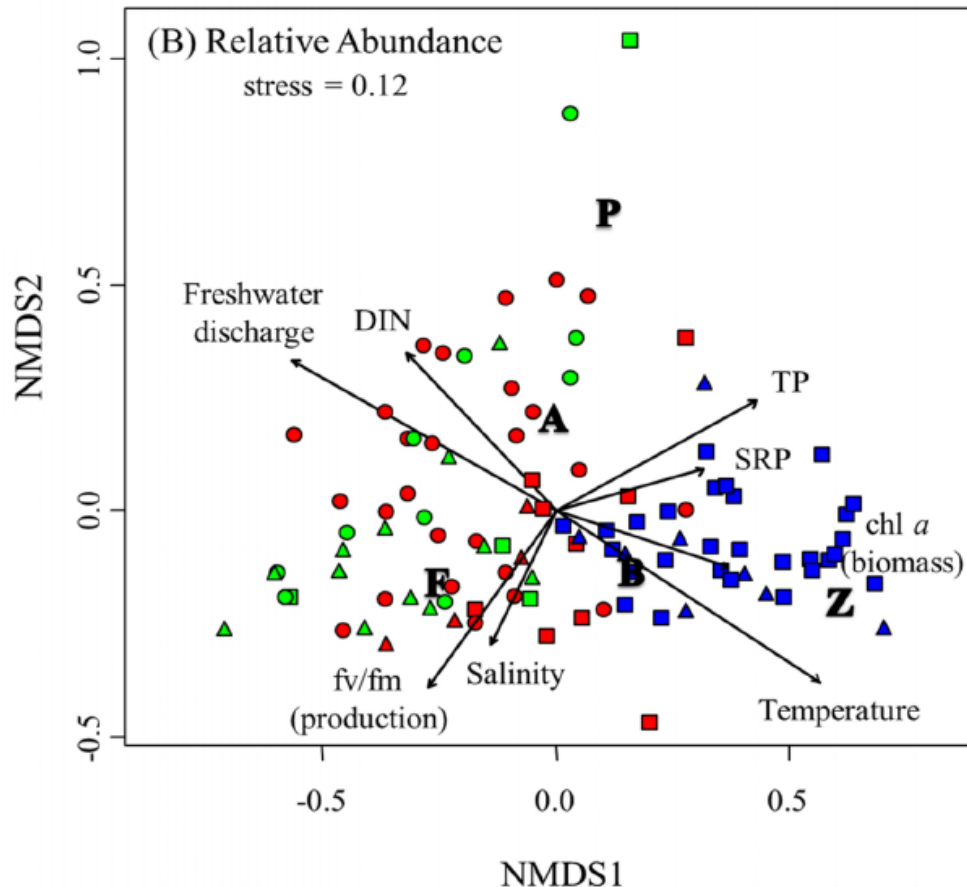
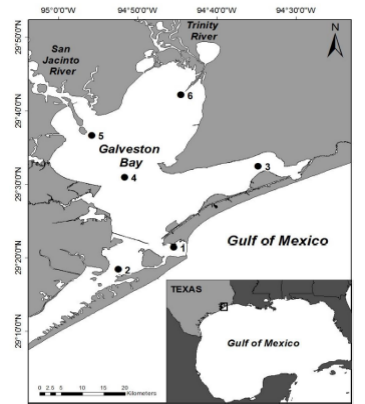
Lauren A. Freeman¹ • D. Reide Corbett² • Allison M. Fitzgerald³ • Daniel A. Lemley⁴ • Antonietta Quigg⁵ • Cecily N. Steppe⁶



What do these impacts have in common?

- alter phytoplankton communities, and therefore important ecosystem services
- introduce and/or reintroduce pollutants to water column

What do we know about phytoplankton in Galveston Bay?



Colors reflect major phytoplankton groups

- Temporally, they are sensitive to seasons
- Spatially, phytoplankton biomass and community composition responded to nutrient loading from the major rivers
- **San Jacinto River** - nutrient limitation primary driver
- **Trinity River** - hydraulic displacement (and perhaps other processes)
- The influence of freshwater inflows on phytoplankton diminishes along a north to south gradient in the bay

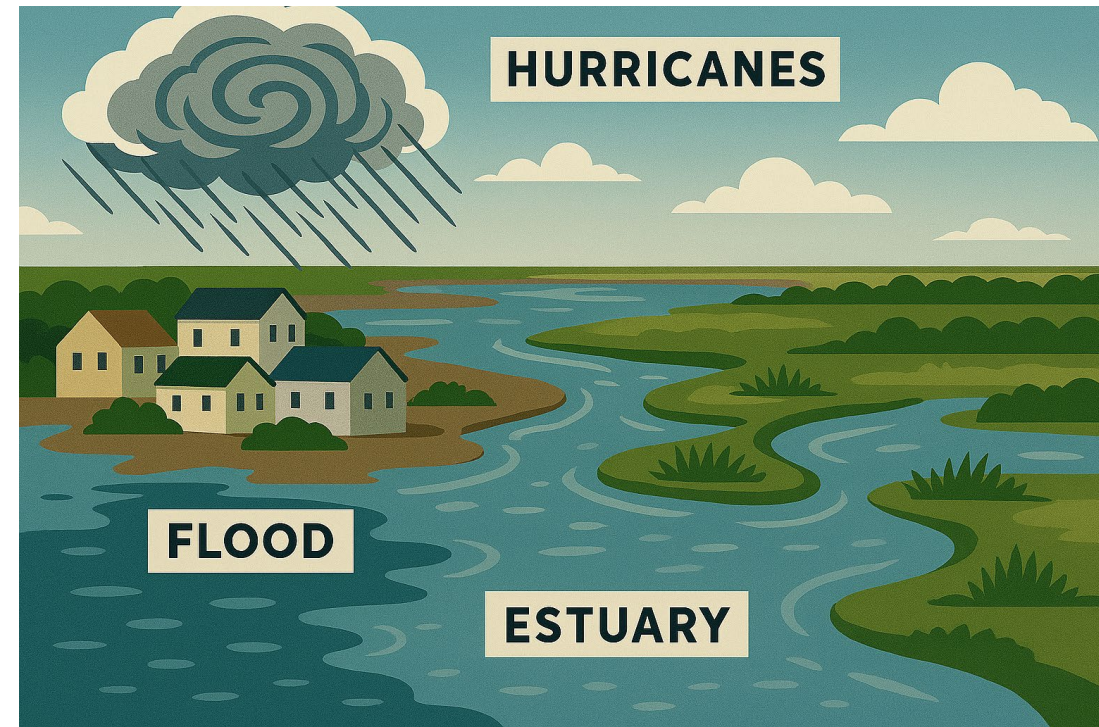
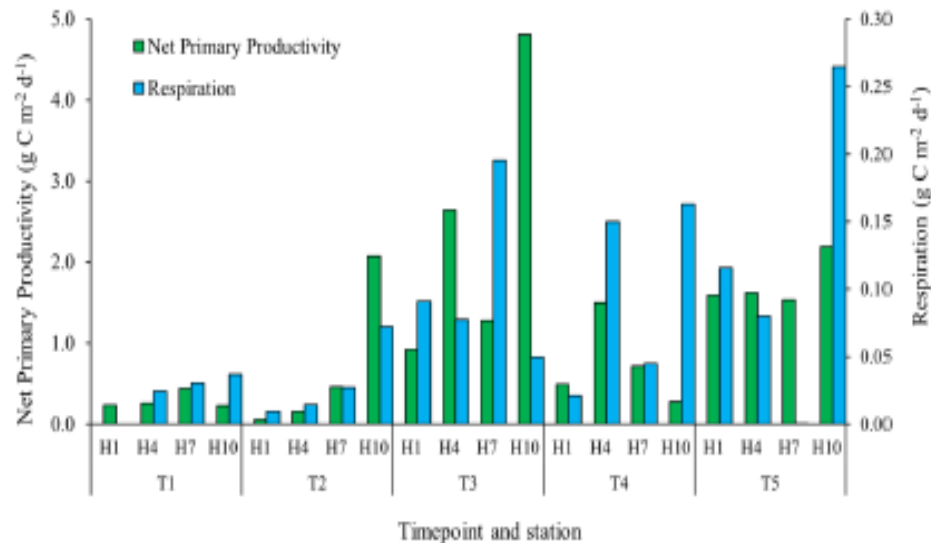
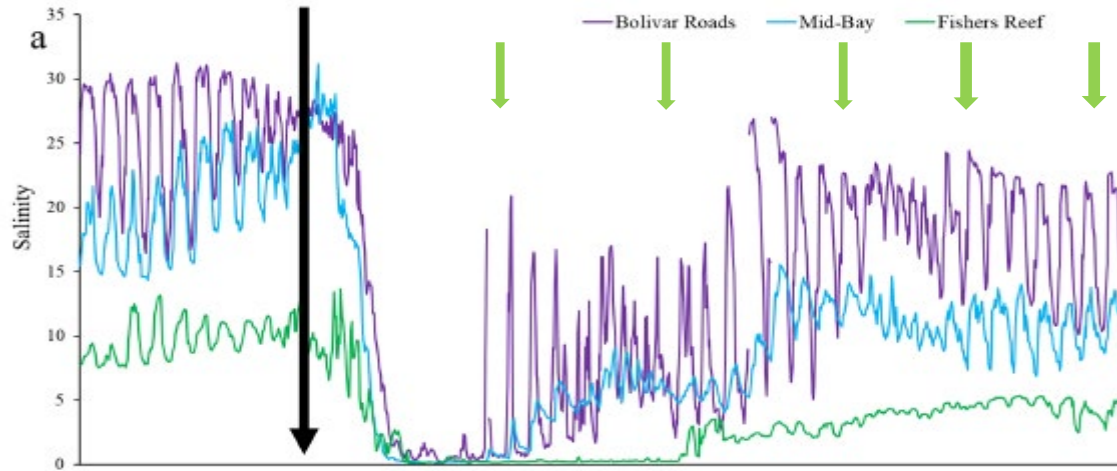


RESEARCH ARTICLE

Towards an Understanding of the Interactions between Freshwater Inflows and Phytoplankton Communities in a Subtropical Estuary in the Gulf of Mexico

Samuel Dorado¹, Tyra Booe¹, Jamie Steichen^{1,2}, Allison S. McInnes^{2*}, Rachel Windham¹, Alicia Shepard², Allyson E. B. Lucchese², Hannah Preischel², James L. Pinckney^{3,4}, Stephen E. Davis^{5,6}, Daniel L. Roelke^{2,5}, Antonietta Quigg^{1,2*}

Hurricane Harvey



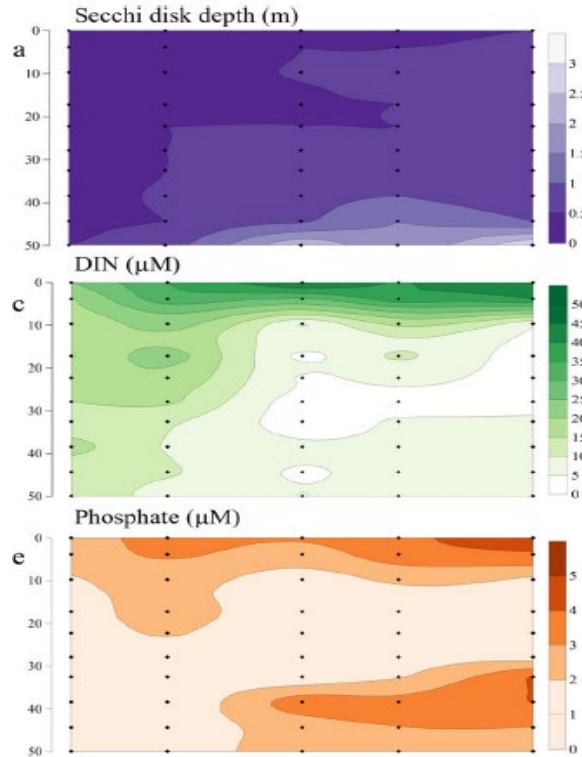
- After initially being flushed out of the bay, primary productivity increased back to pre-storm levels over several weeks

Estuaries and Coasts
<https://doi.org/10.1007/s12237-024-01352-9>

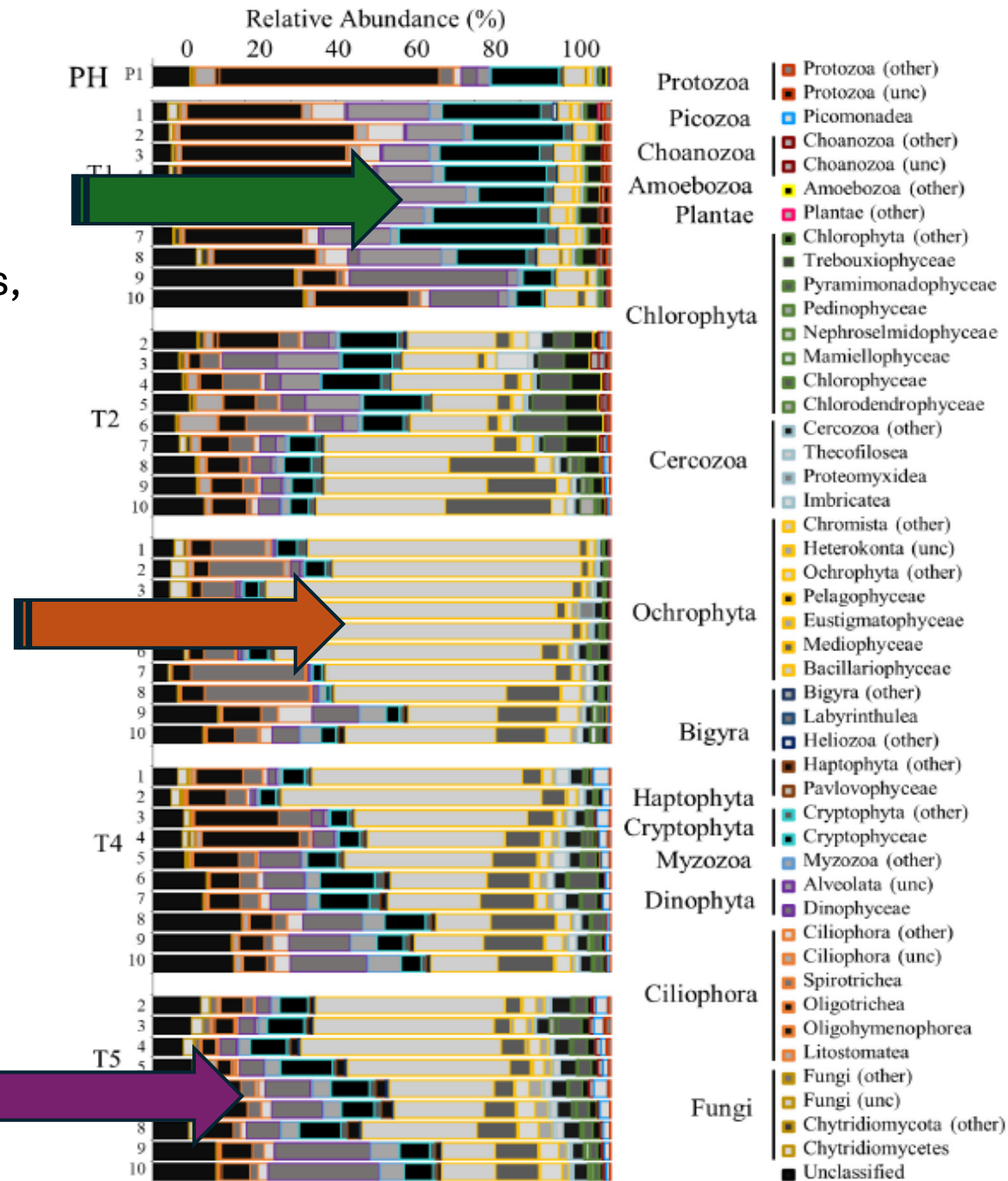
Response of a Phytoplankton Community in a Subtropical Estuary to a Pulse Disturbance Driven by a Combo Hurricane and Extreme Rainfall Event

Antonietta Quigg¹ · Noah Clafflin¹ · Manoj Kamalanathan^{1,2} · Jessica M. Labonté¹ · Jamie L. Steichen¹

Hurricane Harvey

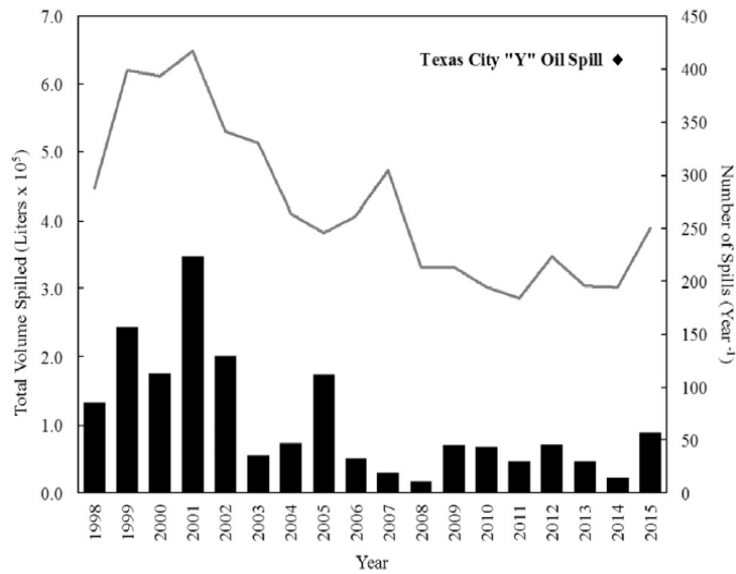


- Along with lower salinities, there was significant higher turbidity
- Elevated nutrients were added to the bay
- Successive blooms of **Chlorophyta** (green algae), **diatoms** and **dinoflagellates**

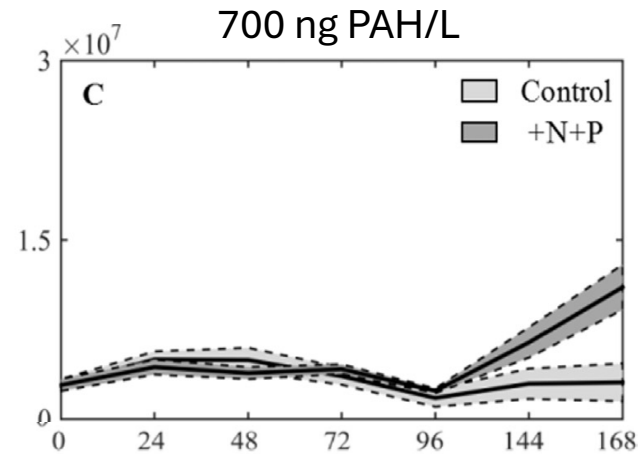
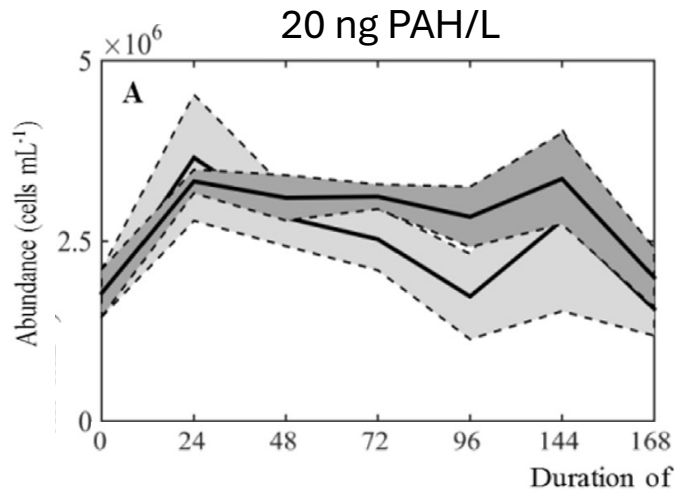
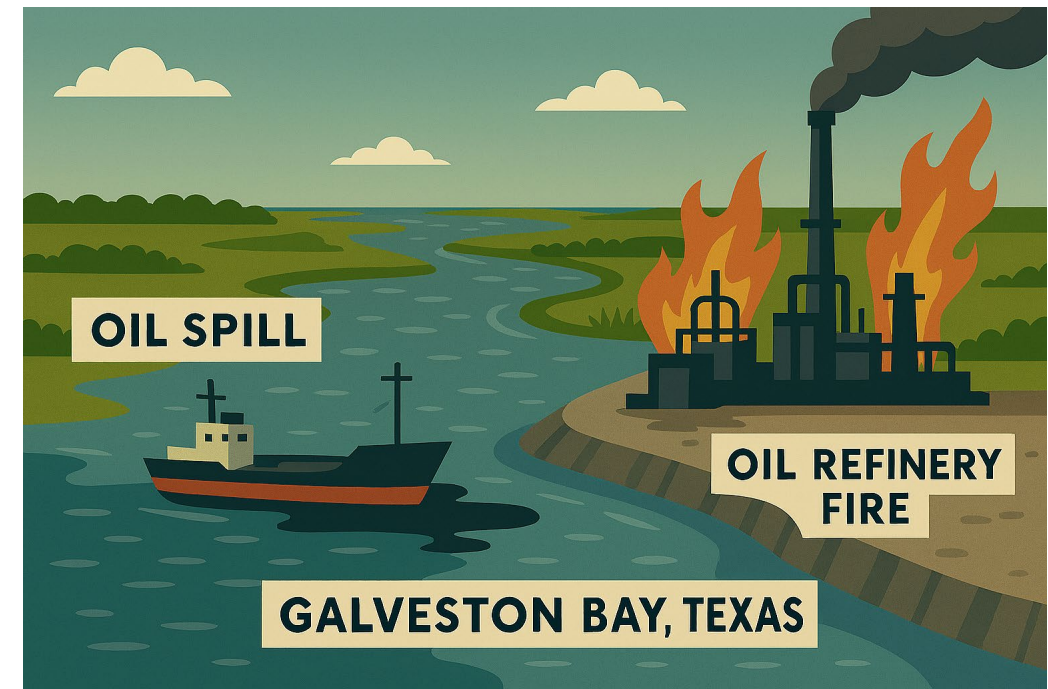


Microbial, Physical, and Chemical Changes in Galveston Bay Following an Extreme Flooding Event, Hurricane Harvey

Jamie L. Steichen^{1*}, Jessica M. Labonté¹, Rachel Windham¹, David Hala¹, Karl Kaiser^{2,3}, Samantha Setta¹, Patricia C. Faulkner¹, Hernando Bacosa¹, Ge Yan², Manoj Kamalanathan¹ and Antonietta Quigg^{1,3}



**Not a matter of if,
but rather a matter
of when, where and
how much !**



- Phytoplankton growth initially inhibited by oil, concentration dependent
- Recovers faster in presence of ample N+P



Marine Pollution Bulletin 121 (2017) 32–44



Contents lists available at ScienceDirect

Marine Pollution Bulletin

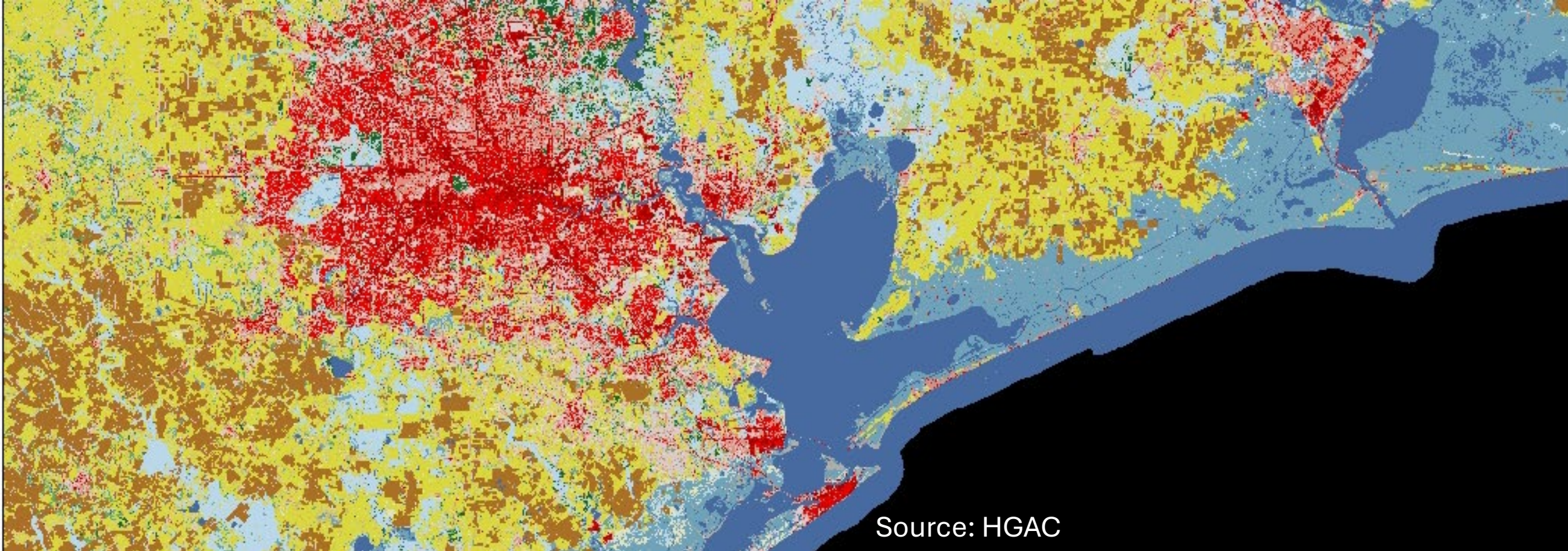
journal homepage: www.elsevier.com/locate/marpolbul



The impact of dissolved inorganic nitrogen and phosphorous on responses of microbial plankton to the Texas City “Y” oil spill in Galveston Bay, Texas (USA)

Alicia K. Williams^{a,b,*}, Hernando P. Bacosa^{a,c}, Antonietta Quigg^{a,b}



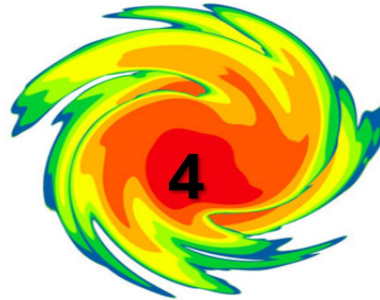


Do Galveston Bay phytoplankton respond in the same way to every impact?

2016 Tax Day Flood



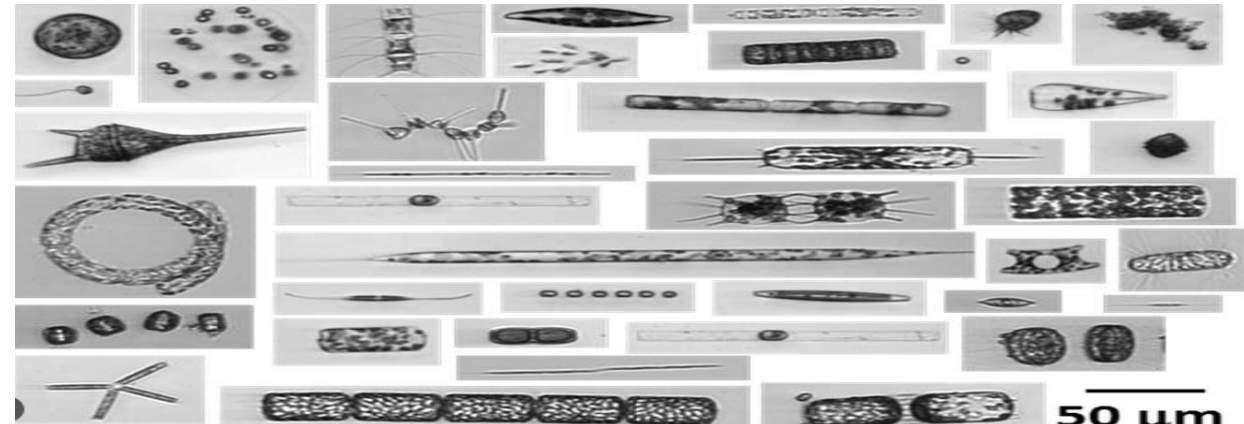
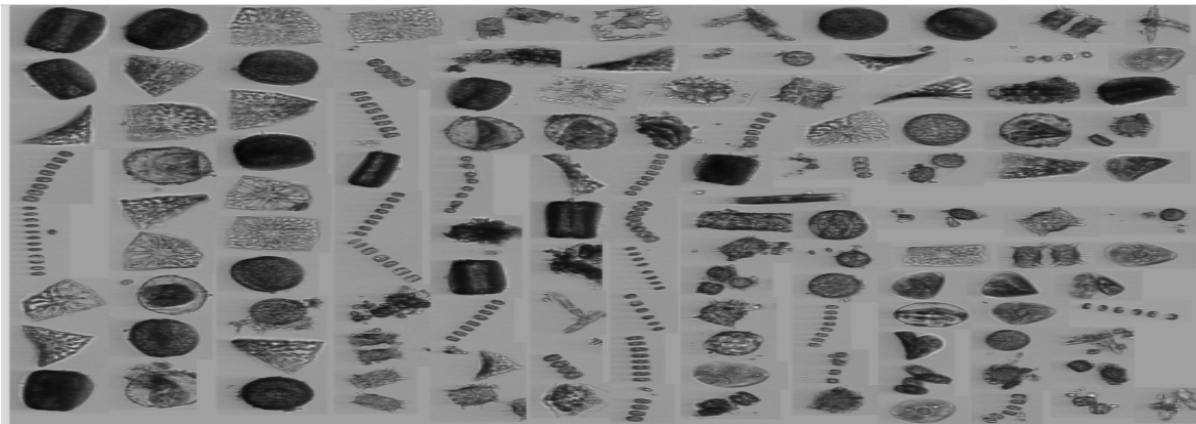
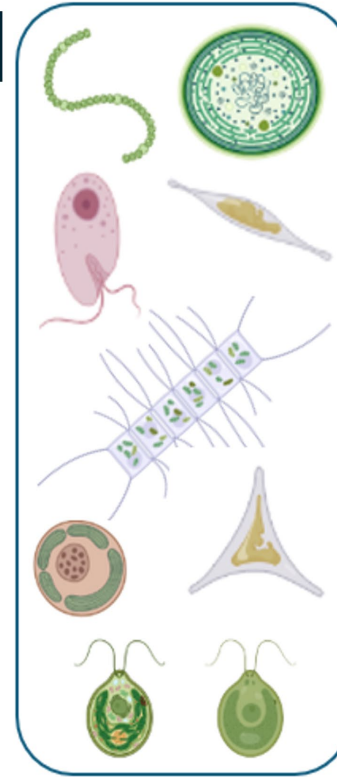
2017 Hurricane Harvey



2019 Tropical Storm Imelda



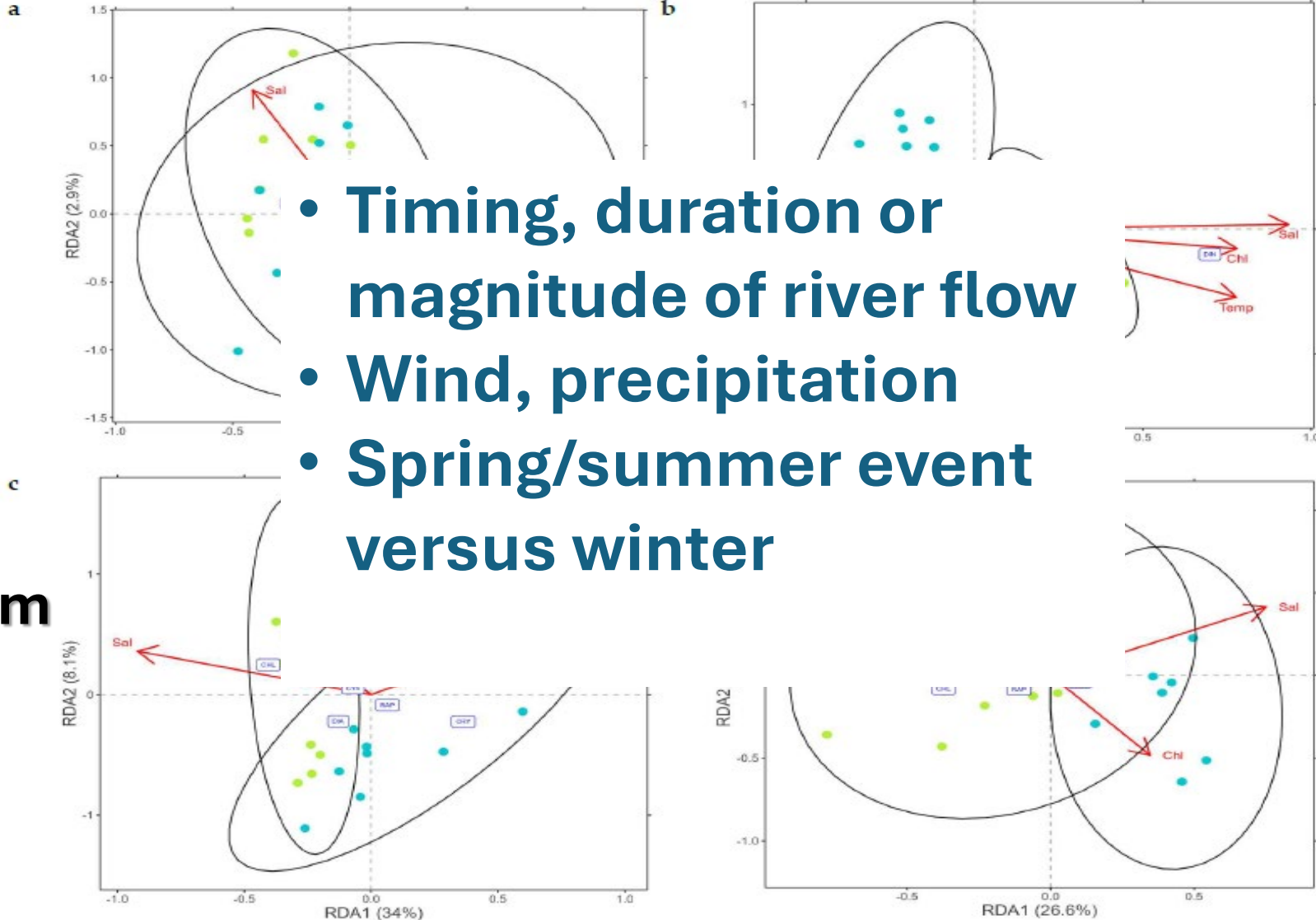
2021 Winter Storm Uri



pre- (green) and post- (blue) storm

**Tax Day
Flood in
2016**

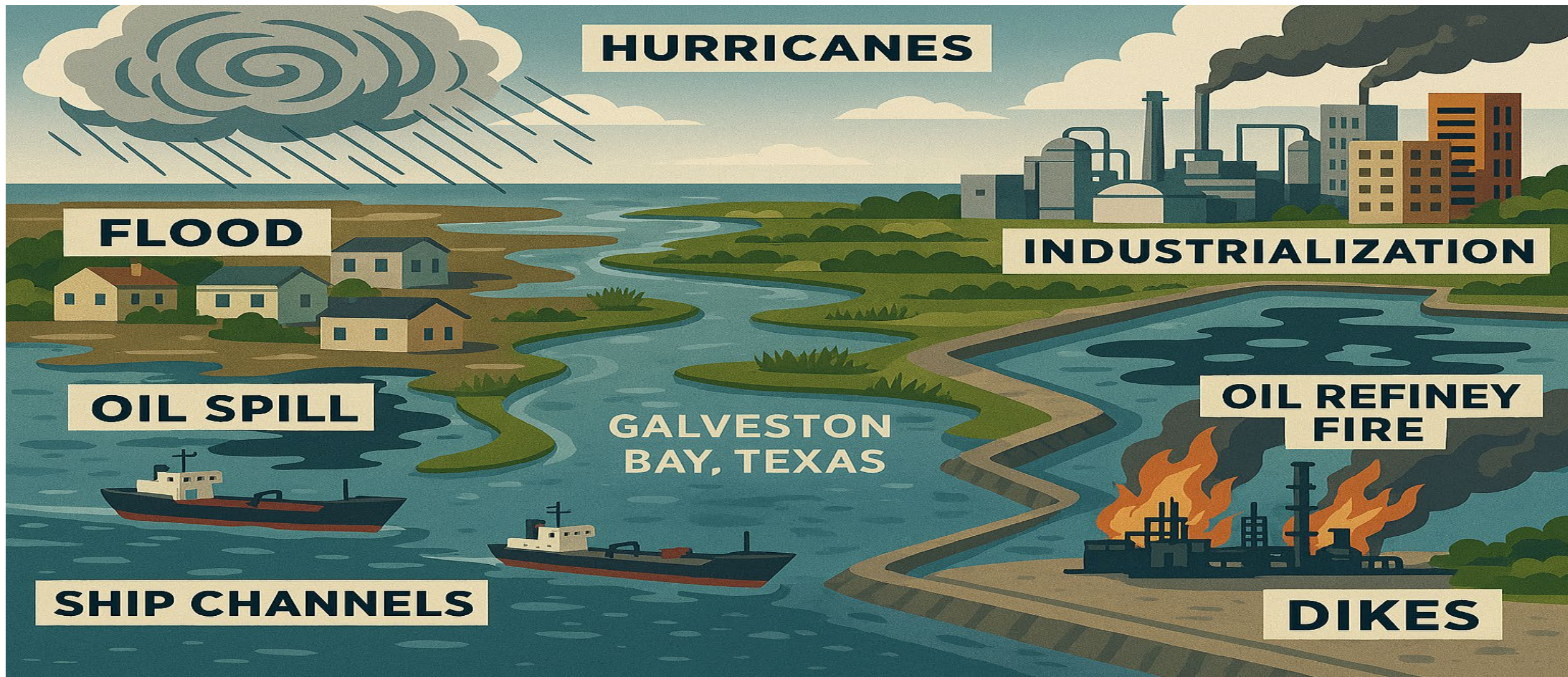
**Hurricane
Harvey in
2017**



**Tropical Storm
Imelda
in 2019**

**Winter
Storm Uri
in 2021**

> Diversity in community > ellipsoid size



Do these impacts on the ecosystem have long term effects?

Investigating *Rangia cuneata* Clams as Ecological Response Bioindicators to Three Decades of Variable Freshwater Inflows

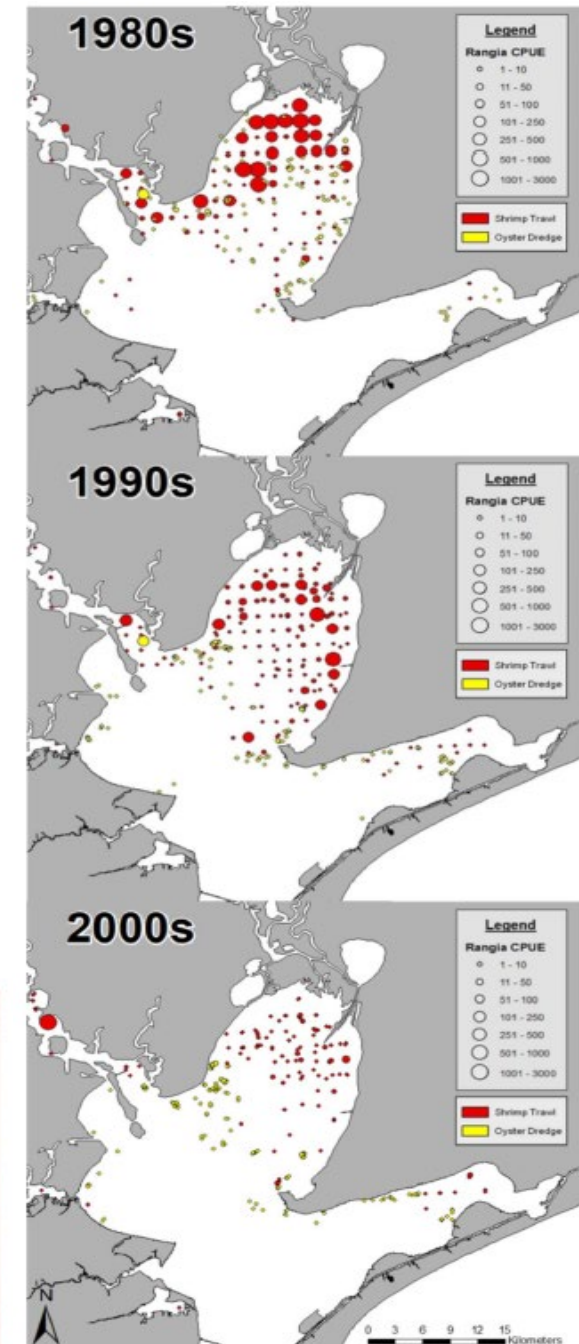
Rachel Windham*, Allison P. Nunnally**, and Antonietta Quigg

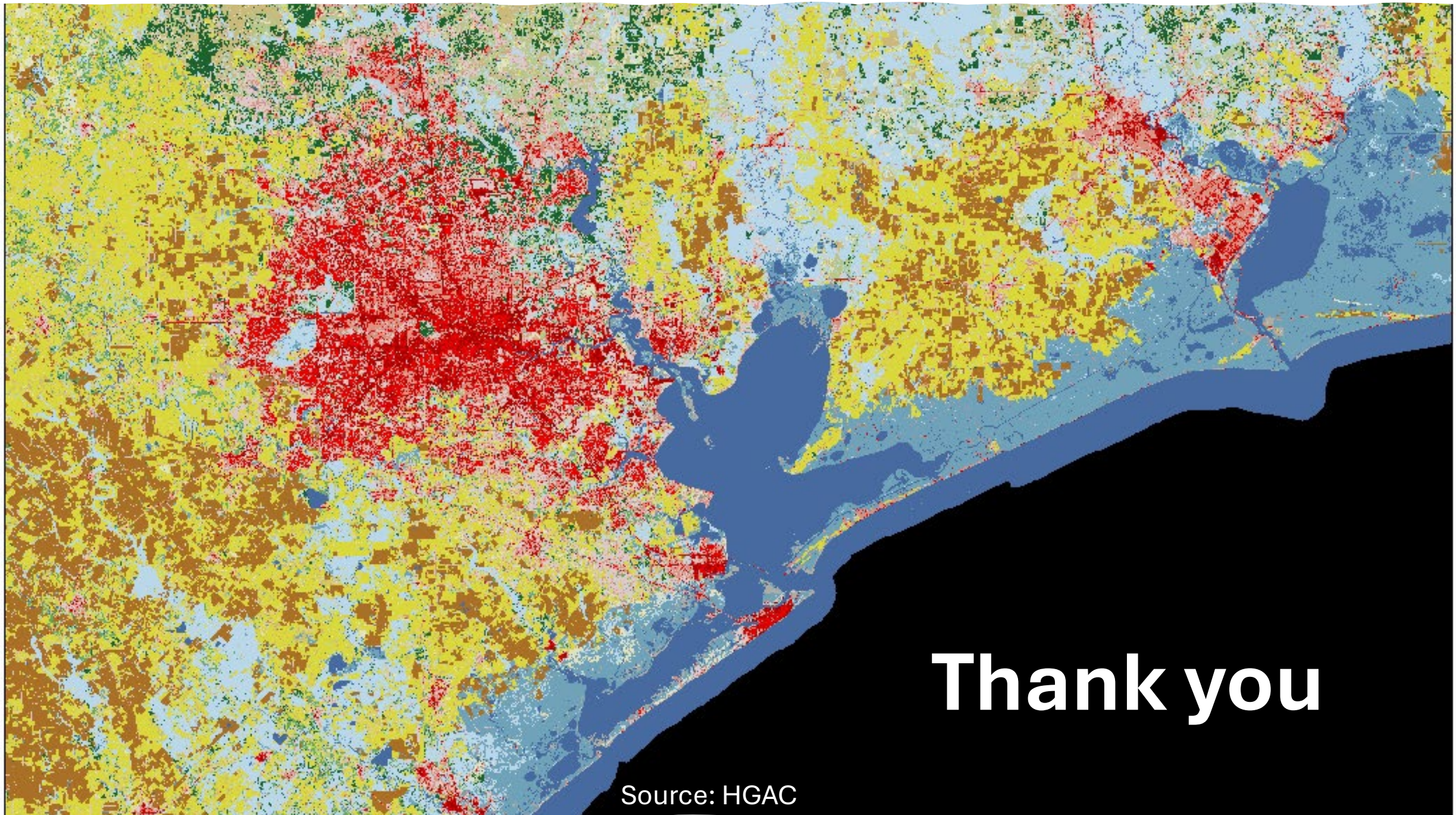
Department of Marine Biology
Texas A&M University at Galveston
Galveston, TX 77554, U.S.A.



www.cerf-jcr.org

- *Rangia* clams **do** prefer areas which receive frequent freshwater inputs such as Trinity Bay
- We **could not** relate clam distributions, size, meat index, or other measurements to freshwater inflows
- What we do see are long term declines which are reflective of the ongoing impacts on this ecosystem





Thank you

Source: HGAC



Nature-Based Solutions to Flood Control and Flood Resilience

Jonathan Holley, CPESC, CPSWQ
Environmental Services Department Manager
Harris County Flood Control District

Overview

Introduction and Background

Flood Damage Reduction Tools and Terminology

- Environmental Enhancements and Nature-Based Solutions
-

Harris County Flood Resilience Plan

- Interagency Review Team
-

Questions

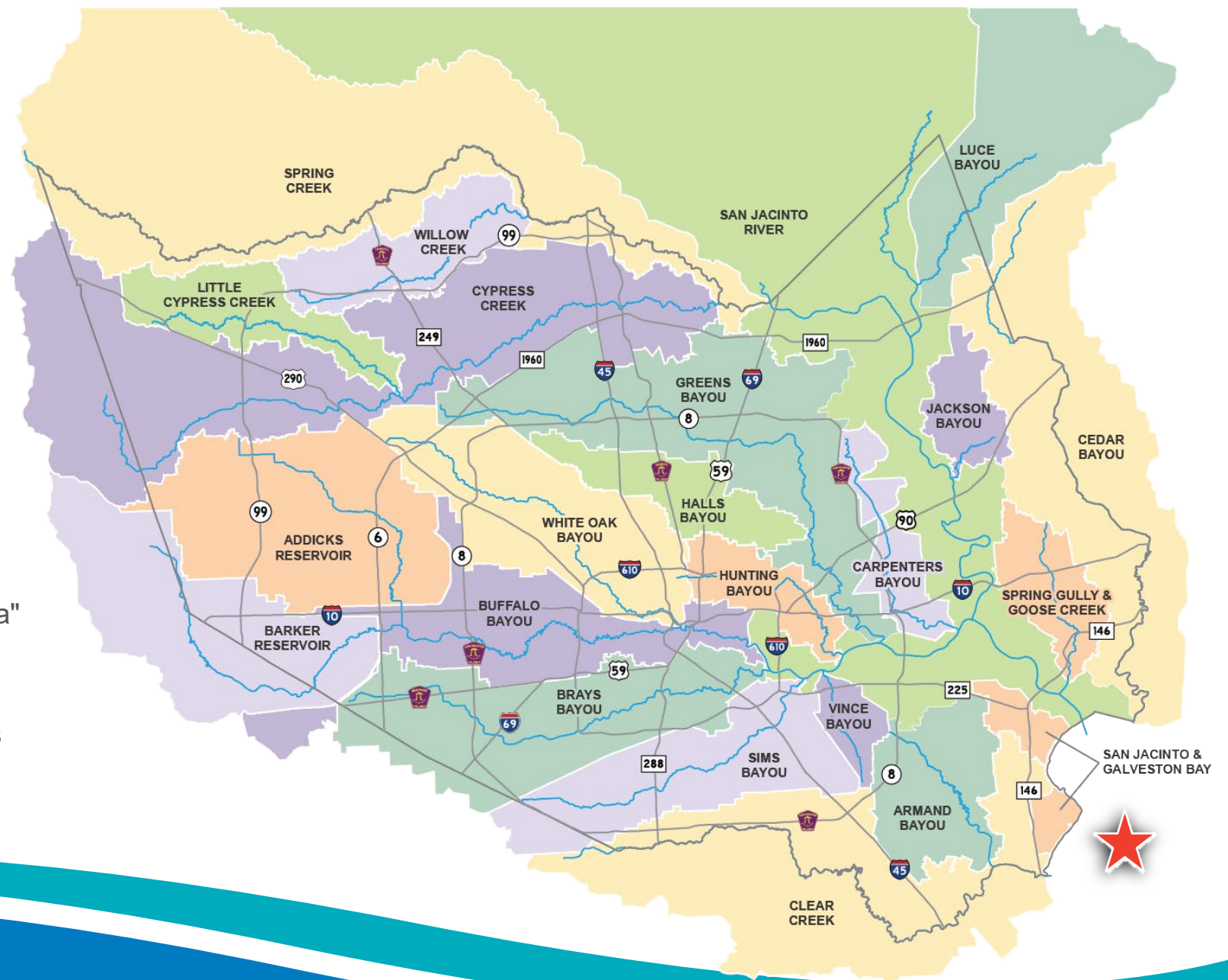
Harris County Flood Control District

- Special purpose district created in 1937 by the Texas Legislature in response to floods that devastated the Houston-area in 1929 and 1935
- Governed by the Harris County Commissioners Court
- Work closely with other regional entities
- Serves as a local partner to leverage federal dollars for flood damage reduction efforts

Harris County Watersheds

What is a watershed?

A geographical region of land or "drainage area" that drains to a common channel or outlet, mostly creeks and bayous in Harris County. Drainage of the land can occur directly into a bayou or creek, or through a series of systems that may include storm sewers, roadside ditches, and/or tributary channels.



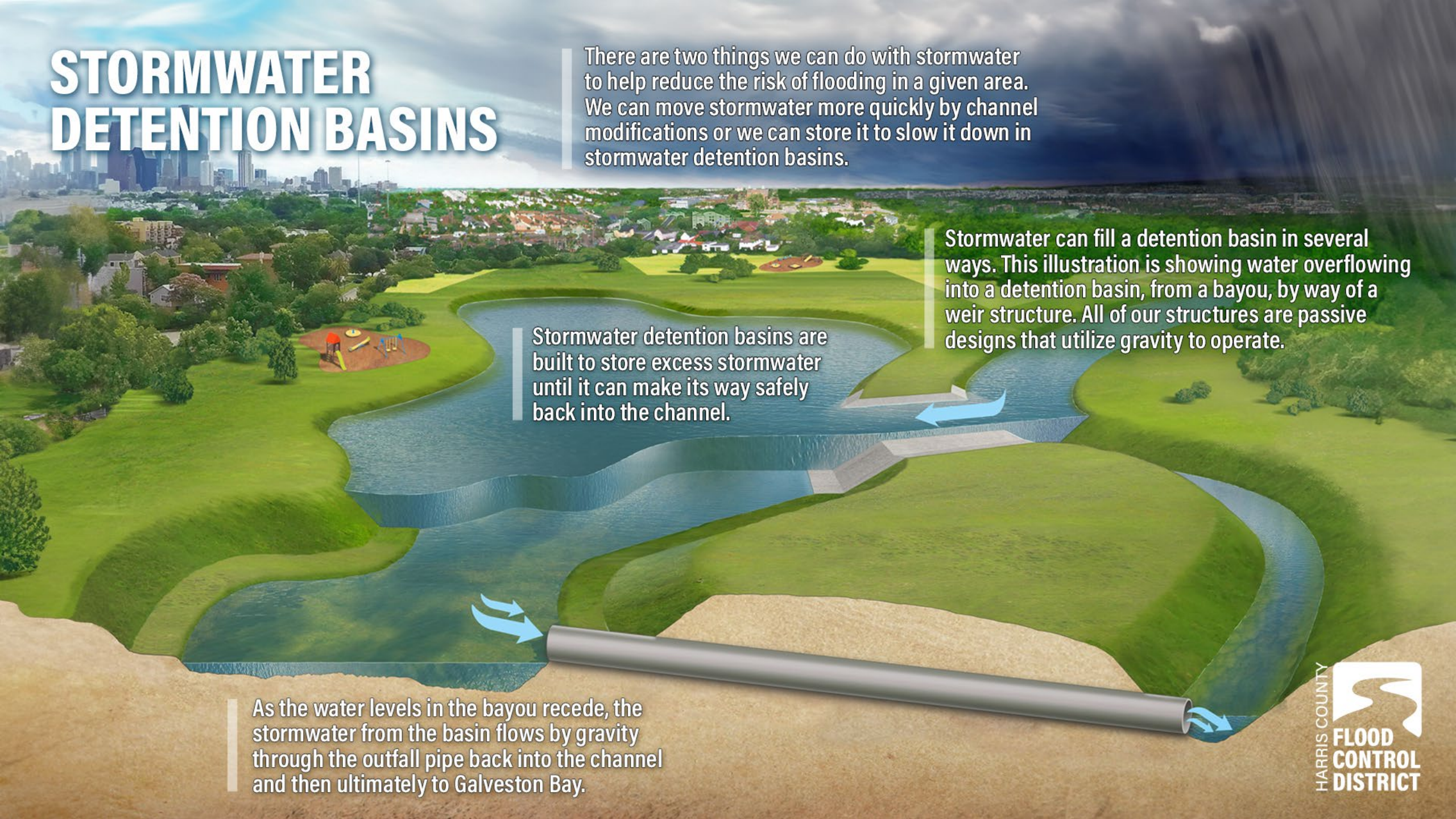
Flood Damage Reduction Tools

Channel Conveyance Improvements

- Designed to help move stormwater more efficiently out of an area by increasing channel capacity
- This can be accomplished by:
 - Widening and/or deepening the channel
 - Reducing the friction by removing vegetation
 - Adding concrete lining (on occasion)



STORMWATER DETENTION BASINS

An aerial illustration of a stormwater detention basin. The basin is a large, irregularly shaped pond with a blue water surface, surrounded by green grass and trees. In the background, a suburban neighborhood with houses and a city skyline are visible under a cloudy sky. The basin is connected to a channel on the right by a weir structure. A large grey outfall pipe runs along the bottom of the basin, leading to a smaller channel on the right. Blue arrows indicate the flow of water from the basin into the outfall pipe and then into the channel.

There are two things we can do with stormwater to help reduce the risk of flooding in a given area. We can move stormwater more quickly by channel modifications or we can store it to slow it down in stormwater detention basins.

Stormwater detention basins are built to store excess stormwater until it can make its way safely back into the channel.

Stormwater can fill a detention basin in several ways. This illustration is showing water overflowing into a detention basin, from a bayou, by way of a weir structure. All of our structures are passive designs that utilize gravity to operate.

As the water levels in the bayou recede, the stormwater from the basin flows by gravity through the outfall pipe back into the channel and then ultimately to Galveston Bay.

Protect and Restore Floodplains



Floodplain Preservation



Voluntary Home Buyout

Environmental Enhancements

Not limited to this...



White Oak Bayou

Keith Weiss Stormwater Detention Basin





Hollister Stormwater Detention Basin

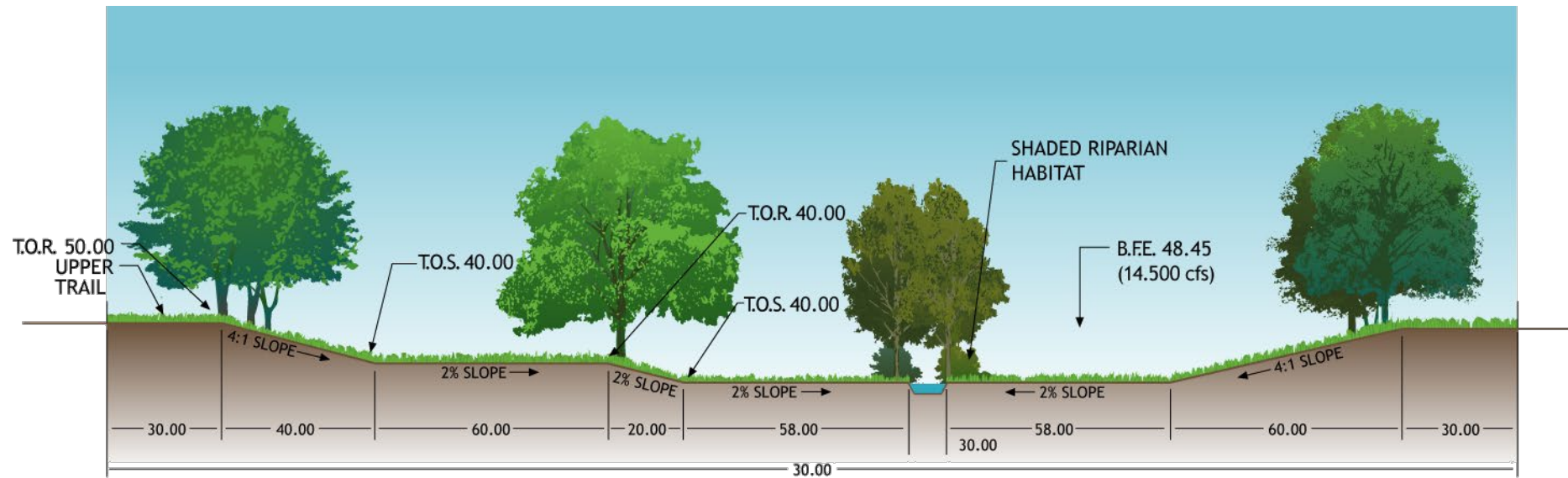


Basin Filled With Stormwater

Basin When Empty

As shown in this cutaway, stormwater detention basins can hold millions of gallons of stormwater.

Wetland plants help filter pollutants from stormwater runoff.



BASE CHANNEL WITH FLOOD BENCH



Stormwater Quality

Stormwater Quality

- Plant nutrient uptake and filtration
- Extended detention
 - Sediment settling
 - UV breakdown
- Shading of water
- Re-establishment of ecosystem services



Wetland Planting



Bretshire Detention Basin



Harris County Flood Resilience Plan

Flood Resilience Planning

- Harris County's first comprehensive county-wide plan
- Designed to safeguard physical, social, and economic hardships of flooding
- Actionable Plan with clear recommendations
- Multi-Departmental (Interagency Review Team)
- Expected completion February 2027

<https://www.readyharris.org/Harris-County-Flood-Resilience-Plan>



Jonathan Holley, CPESC, CPSWQ
Environmental Services Department Manager
Harris County Flood Control District



Ecosystem service provisioning in restored salt marshes: changes over time

**Anna R. Armitage, Ansley Levine,
Jamie Brinkley, Jackson Akin,
Jessica O'Connell**

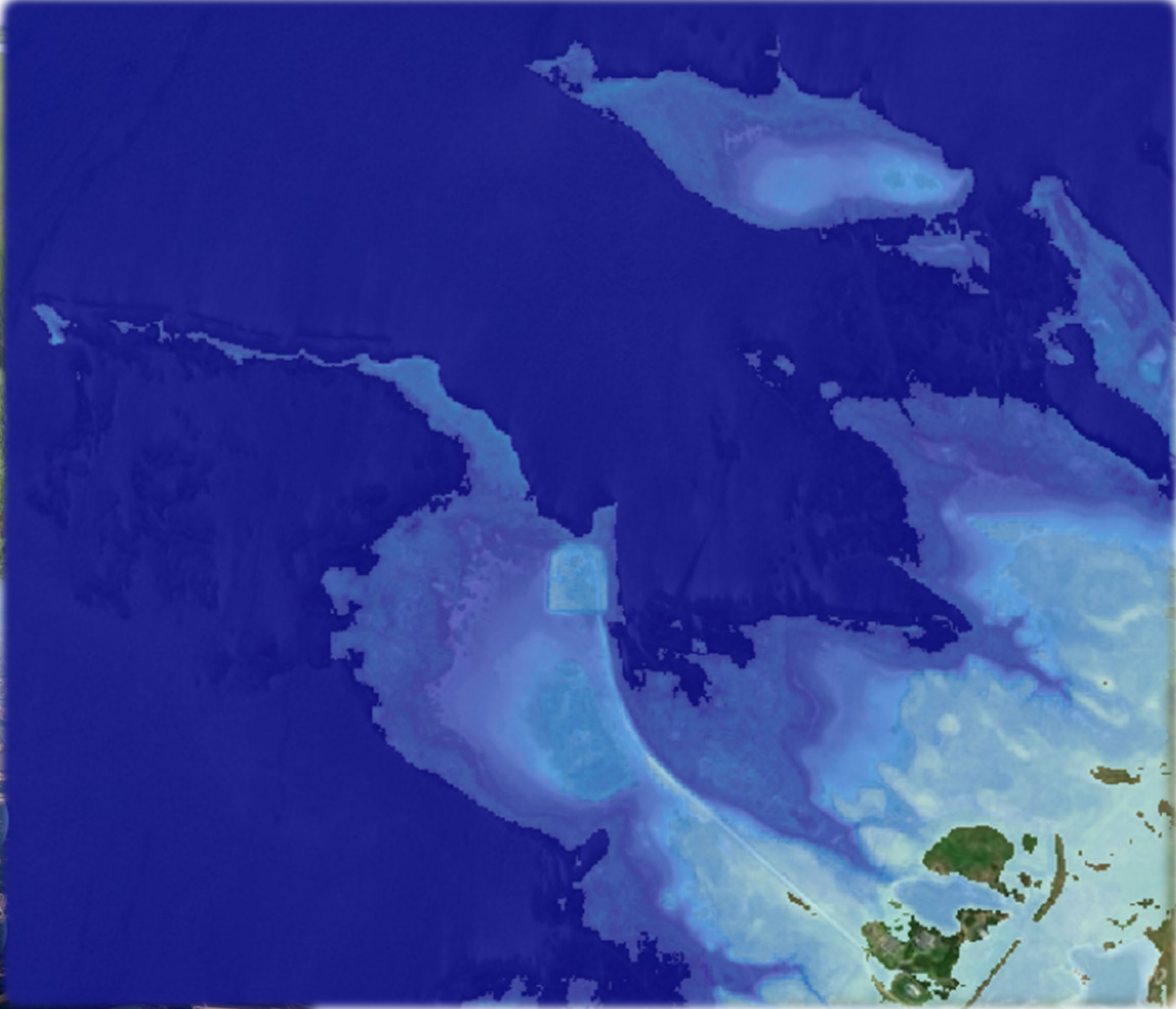


TEXAS A&M
UNIVERSITY

GALVESTON CAMPUS®



COLORADO STATE
UNIVERSITY



The “Field of Dreams” approach in restoration



If you build it, they will come

Inverts

Diversity

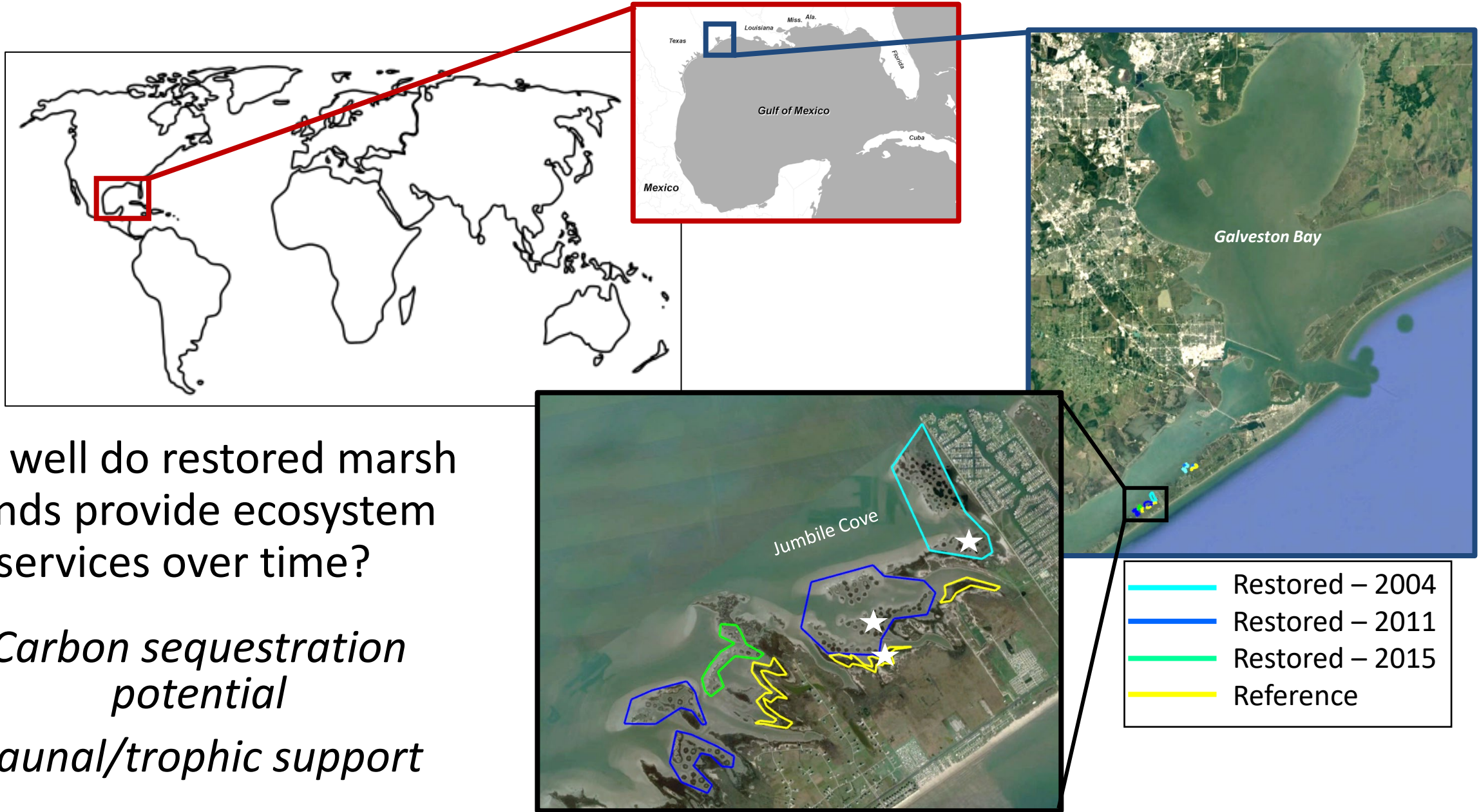
Soils

Carbon
sequestration

Variations in wetland restoration design

- Placement within a larger landscape matrix of wetland habitat
 - Isolated
 - Near reference site
- Planting strategy
 - Active
 - Passive
- Construction technique
 - Formations
 - Beneficial uses

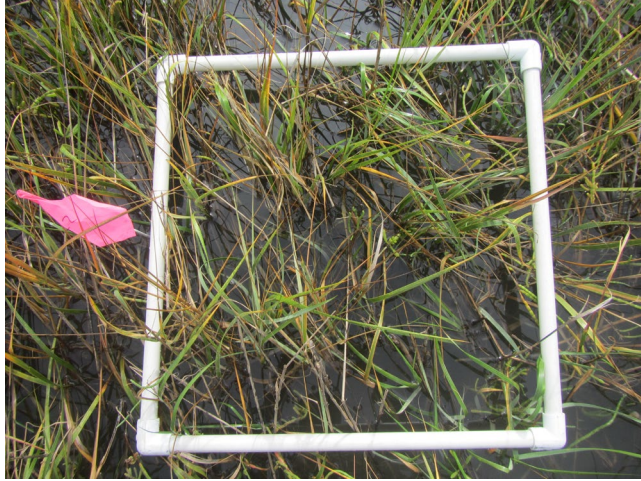




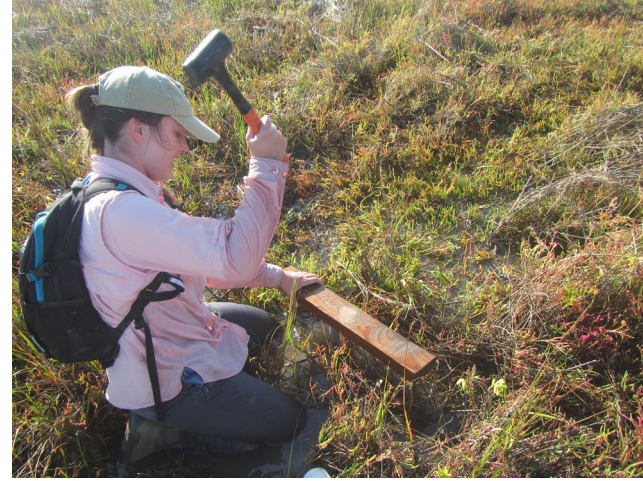
How well do restored marsh islands provide ecosystem services over time?

- *Carbon sequestration potential*
- *Faunal/trophic support*

Visual estimates of percent cover



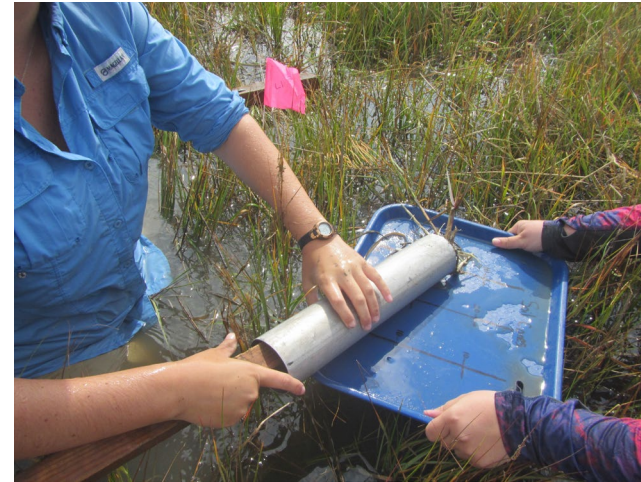
Extracting belowground biomass cores



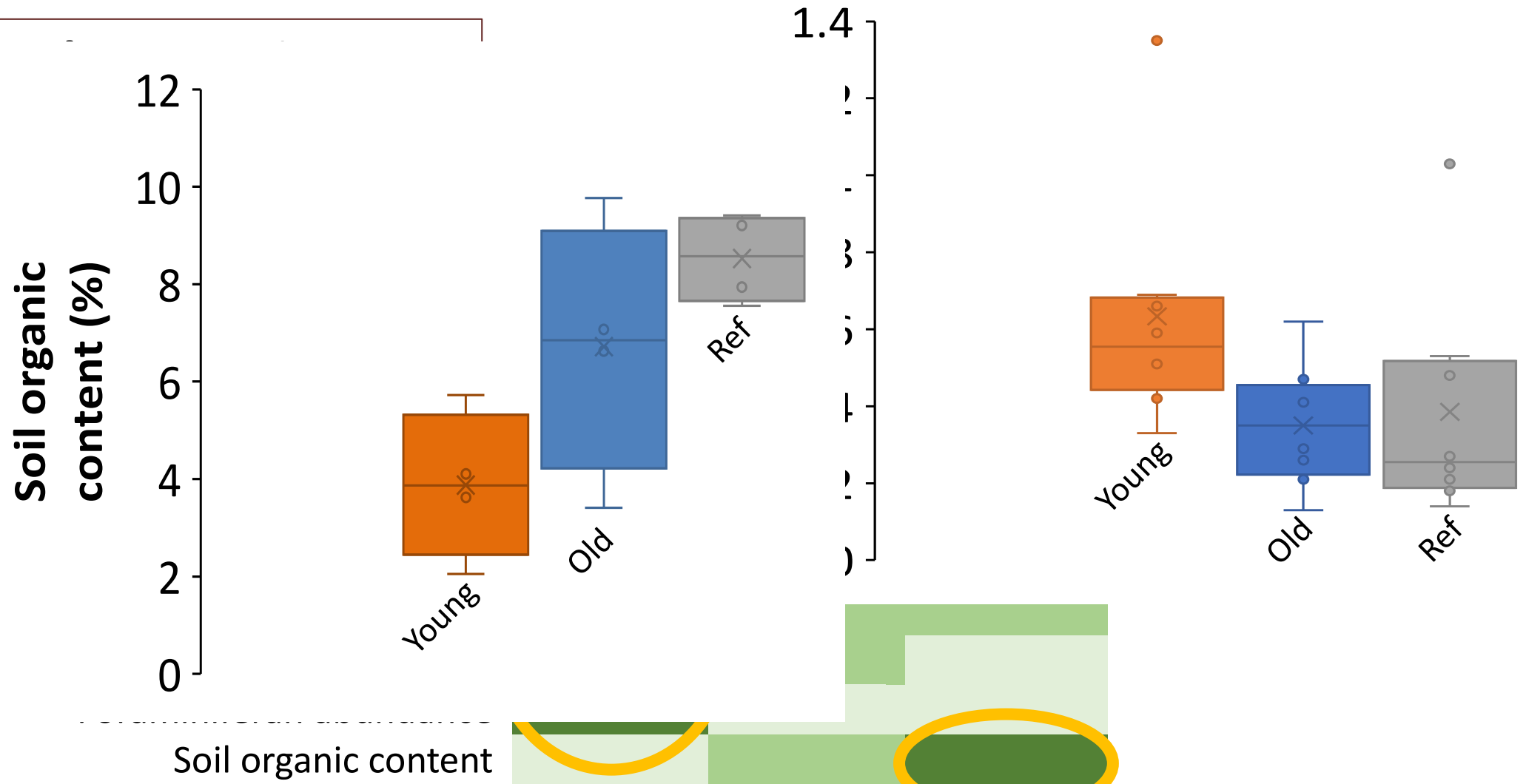
Using a bbe BenthosTorch to record benthic microalgal biomass



Extracting soil & infauna cores



Som approach



Trophic support diverged

Carbon storage targets not met

Some islands decrease in size over time

2004



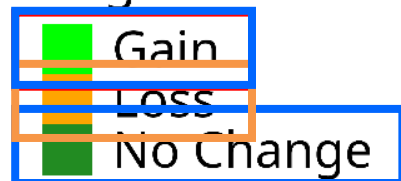
2012



2022



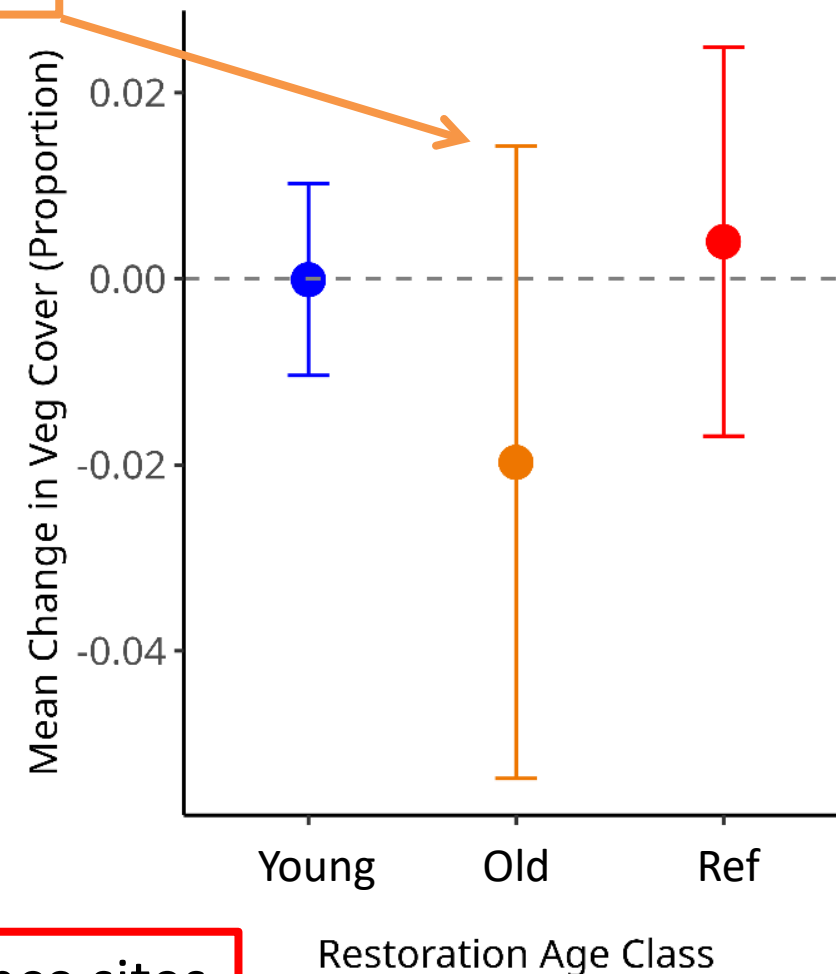
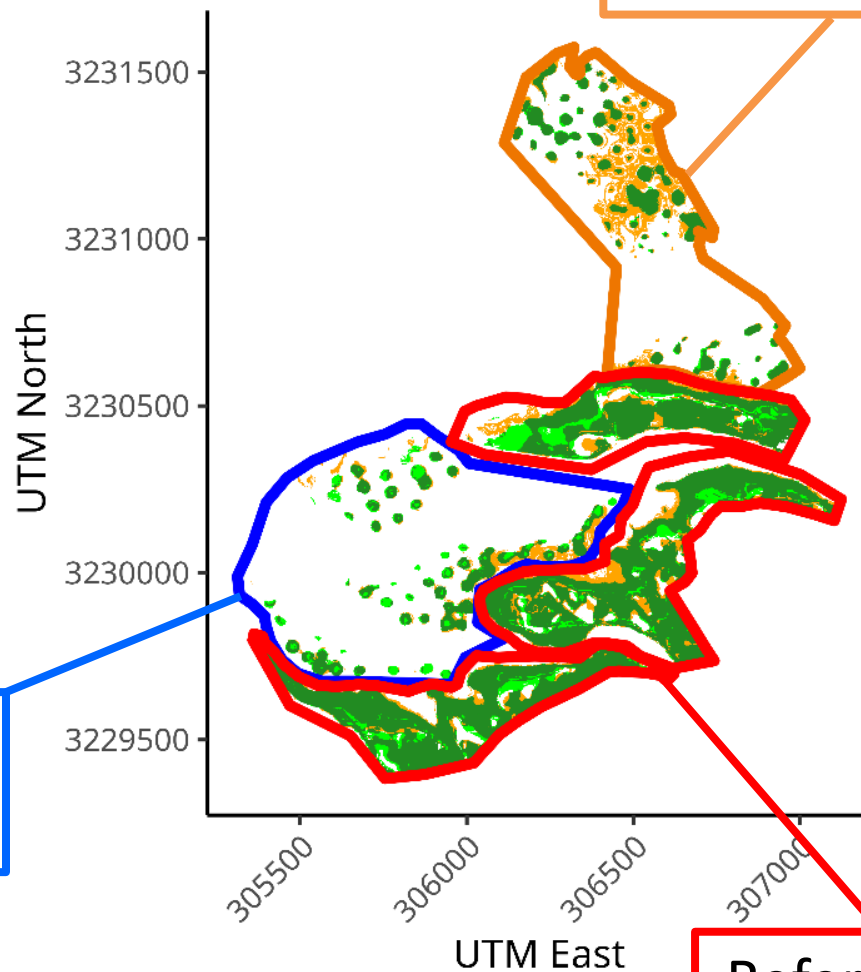
Vegetation Change



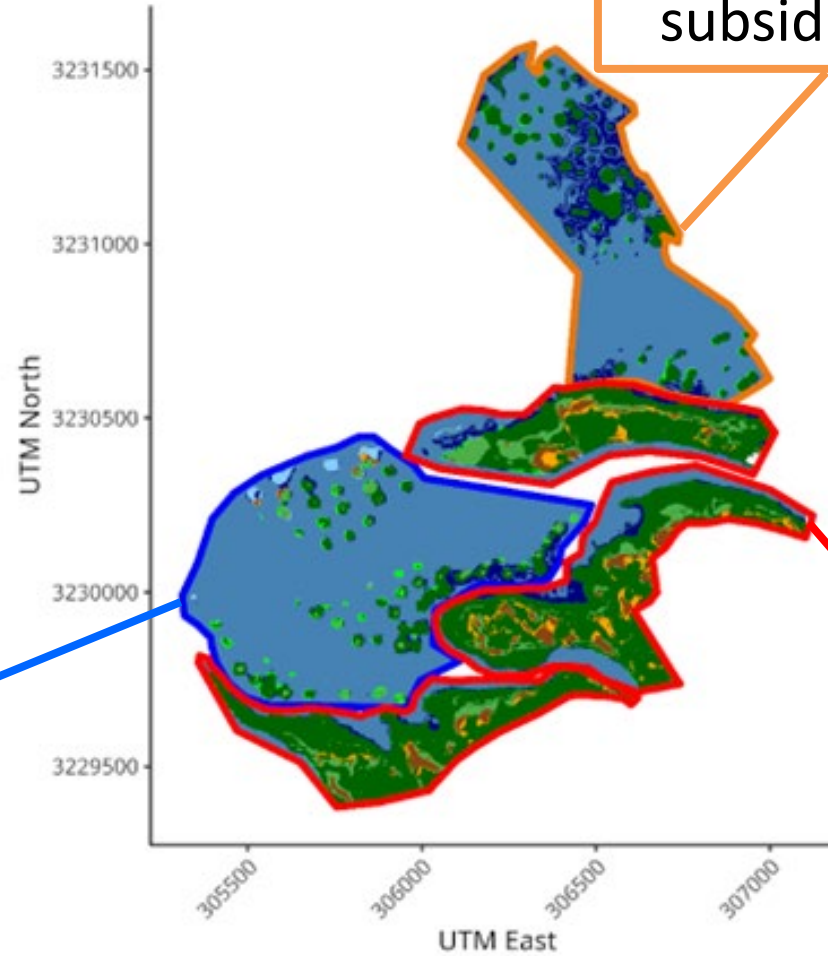
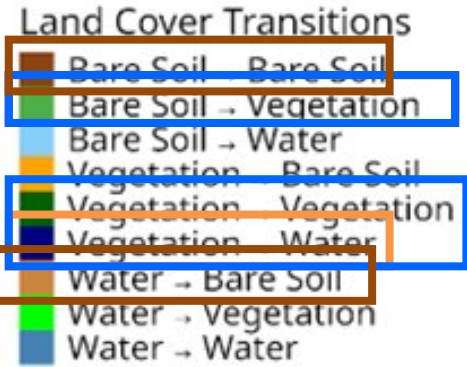
Young sites
stable

Old sites
losing area

Reference sites
gain vegetation



A



Old sites
subsiding

Young sites
stable

Reference sites
migrating

***Minimal mudflat area**

As restored islands subsided, high marsh plant community became more homogeneous over time

Young: low density,
high diversity



Old: High density, low
diversity, lower elevation



Reference: High density,
high diversity



→ Restored islands are not migrating

Lessons learned

Long term monitoring revealed divergence from reference conditions

- Cover metrics suggest restoration success

But...

- Ecosystem service metrics varied among marsh ages
 - Carbon sequestration potential
 - Trophic support
- Older restored sites were not necessarily approaching reference targets
- Island configurations were vulnerable to subsidence and sea level rise
- The inclusion of migration refuges/upland connectivity will boost sustainable restoration design on long (20+ year) time scales
- Other mitigation measures...?

Thanks!

- Many fearless wetland field warriors, including Jackson Akin, Melissa Ciesielski, Chelsea Crosby, Marissa Palmer, Alizia Rhodes, Jamie Thompson, Brooke Torjman, Jamie Brinkley, Briana Sebastian, Ansley Levine
- Texas Parks & Wildlife Department



Funded by Ducks Unlimited

