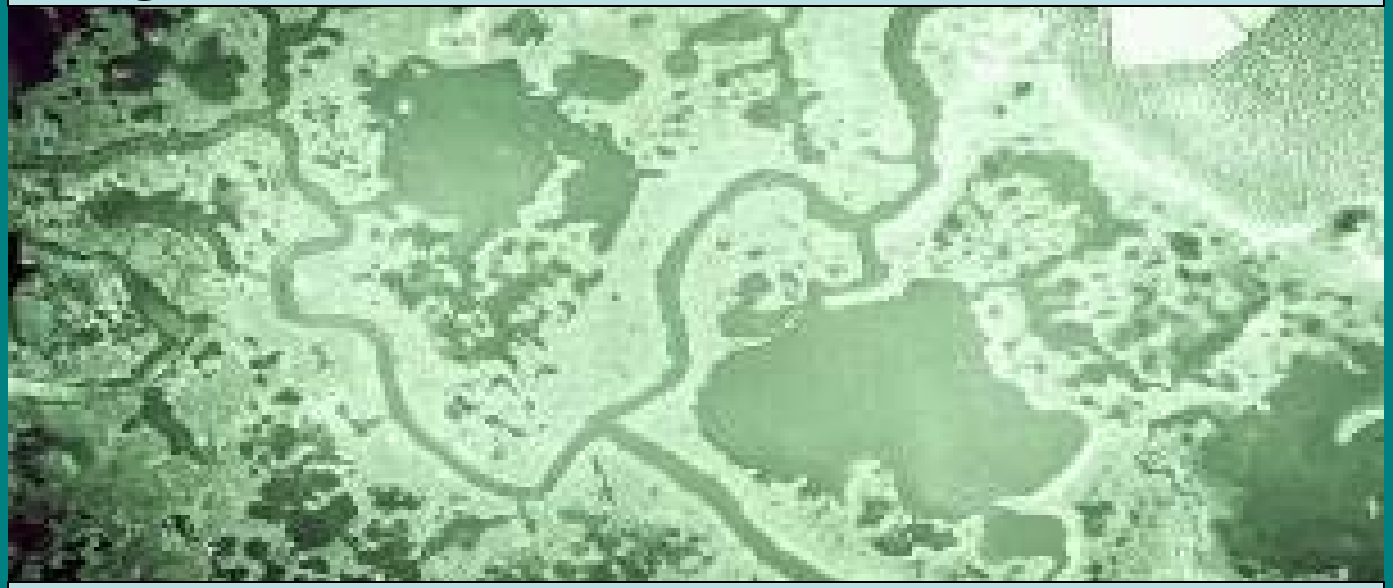
Sea-Level Rise Impacts on Salt Marsh Processes in the Northeast Region



Donald R. Cahoon, US Geological Survey

Sea-Level Rise and Salt Marsh Restoration Workshop, NOAA Restoration Center, Gloucester, MA, September 14, 2010

U.S. Department of the Interior
U.S. Geological Survey

Ideas & Concepts

Glenn Guntenspergen, USGS

Charles Roman, NPS

Jim Morris, University of South Carolina

Denise Reed, University of New Orleans

Mark Brinson, East Carolina University

Jim Lynch, USGS

Philippe Hensel, NGS

Tom Spencer, Cambridge University

Neil Saintilan, NSW, Australia

Mike Kearney, University of Maryland

Court Stevenson, University of Maryland

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Outline

- Marsh formation dynamics
- Factors influencing coastal wetland elevation and survival relative to sea level
- Steps you can take to address your concerns
- Summary and implications; need for models

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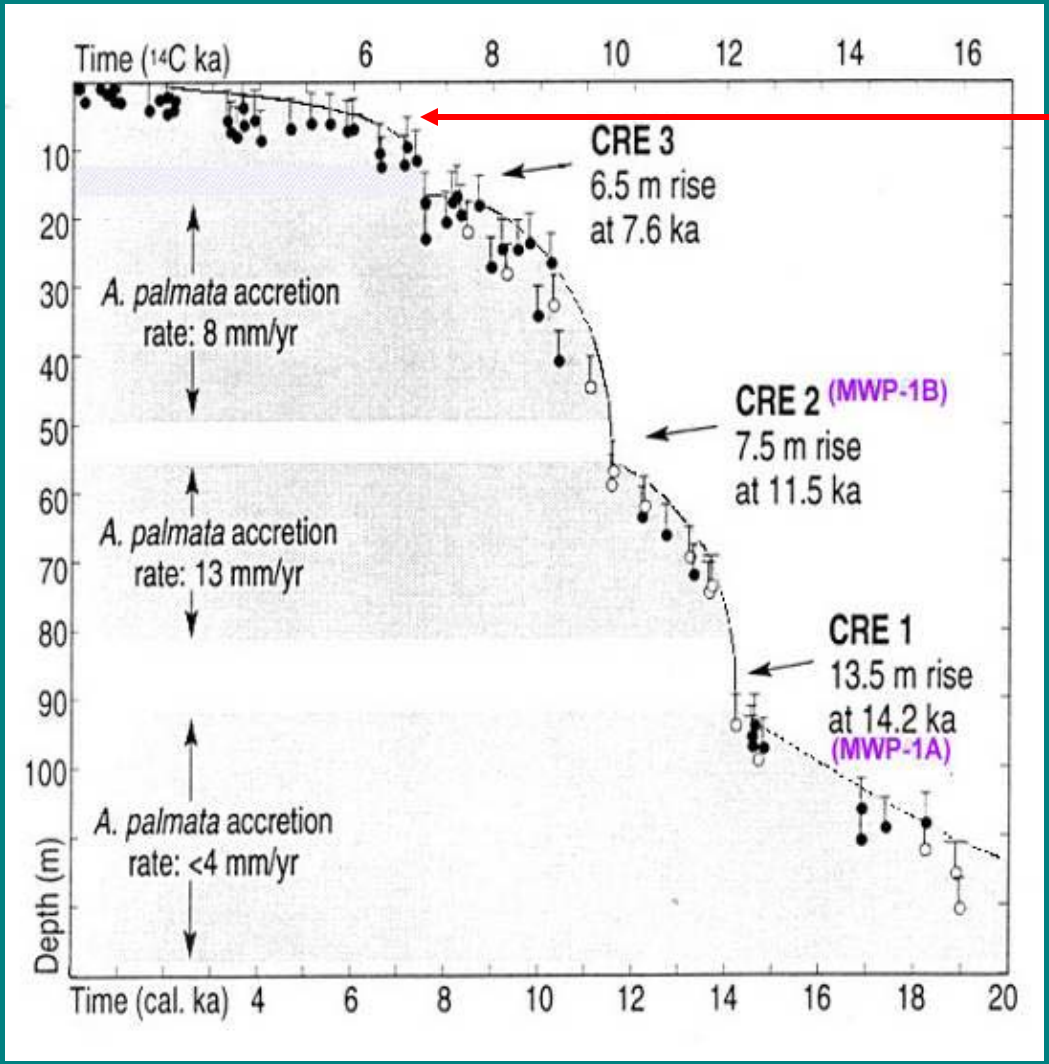
Global sea-level rise over the past 20,000 years

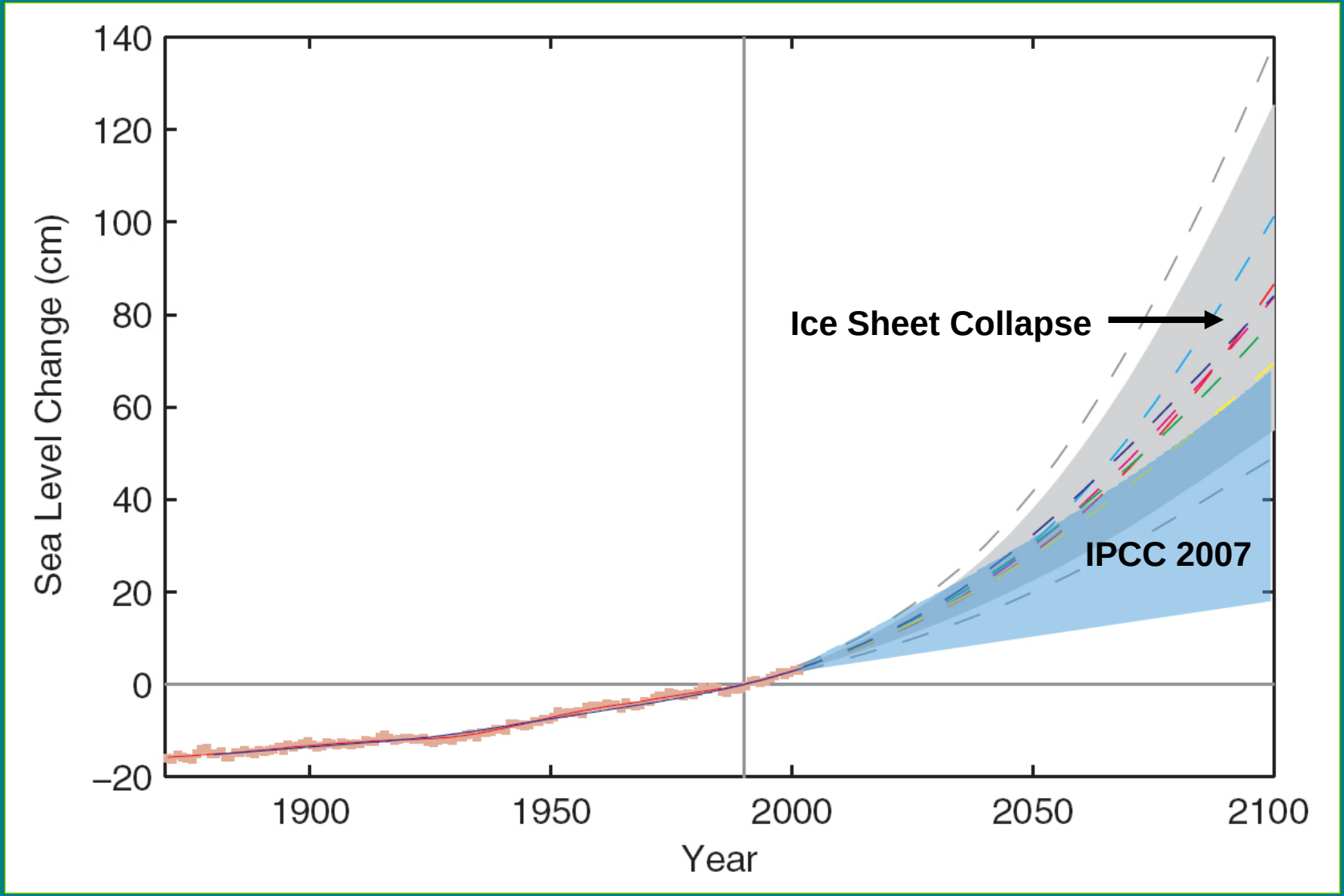


Around the world deltas form and wetlands develop 6,500 to 7,000 years ago

> 110 meters below present level

Blanchon and Shaw (1995)

Past, Current and Projected Sea-level Rise



(modified after Bindoff, 2007; Rahmstorf, 2007)

Graphic presentation prepared by E. R. Thieler

Coastal Wetlands & Sea-Level Rise

Tidal marsh survival depends on a balance between the forces leading to their creation (mineral and organic sediment accumulation) and the forces leading to their deterioration (sea-level rise, subsidence and wave erosion).

The critical factor controlling wetland sustainability is the rate of vertical development compared to the local relative sea-level rise rate.

Relative sea-level rise is the combination of the change in sea level and the change in land level.

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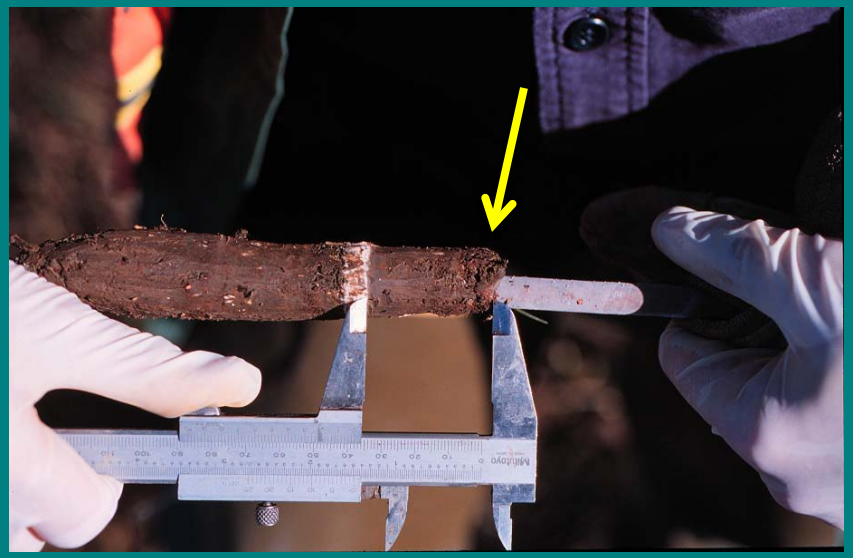
Wetland Vertical Development

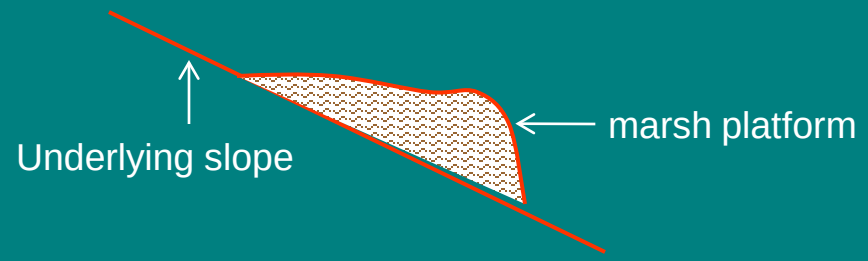
Mineral Sediment Deposition

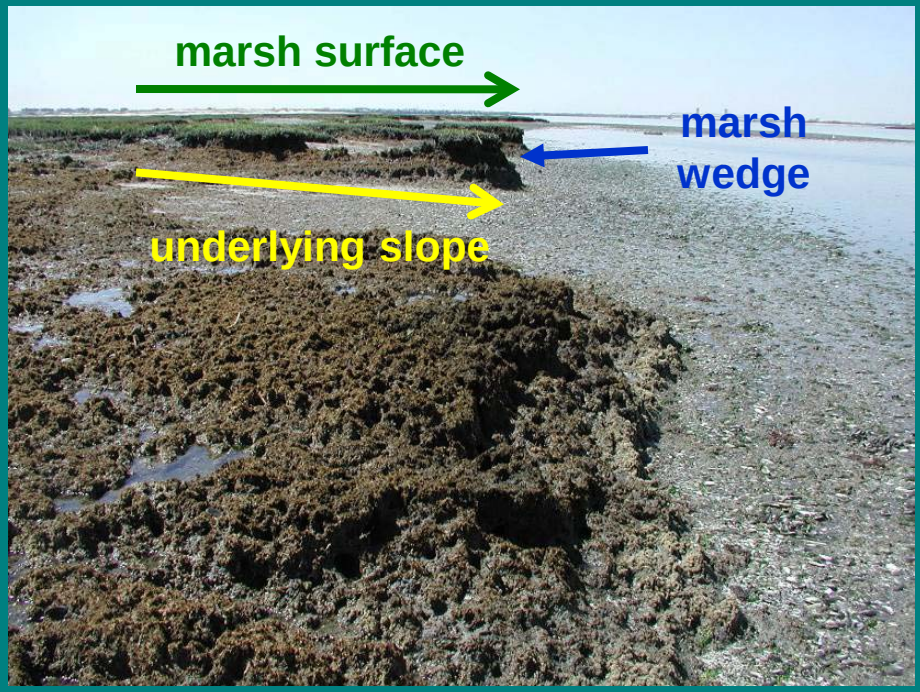


Plant matter accumulation in the soil
[< 10 % to > 90 %]
(root production:decomposition)

Marshes Keeping Pace with Sea-Level Rise

When marsh elevation keeps pace with sea-level rise through vertical development, a wedge-shaped marsh platform develops over the underlying substrate.





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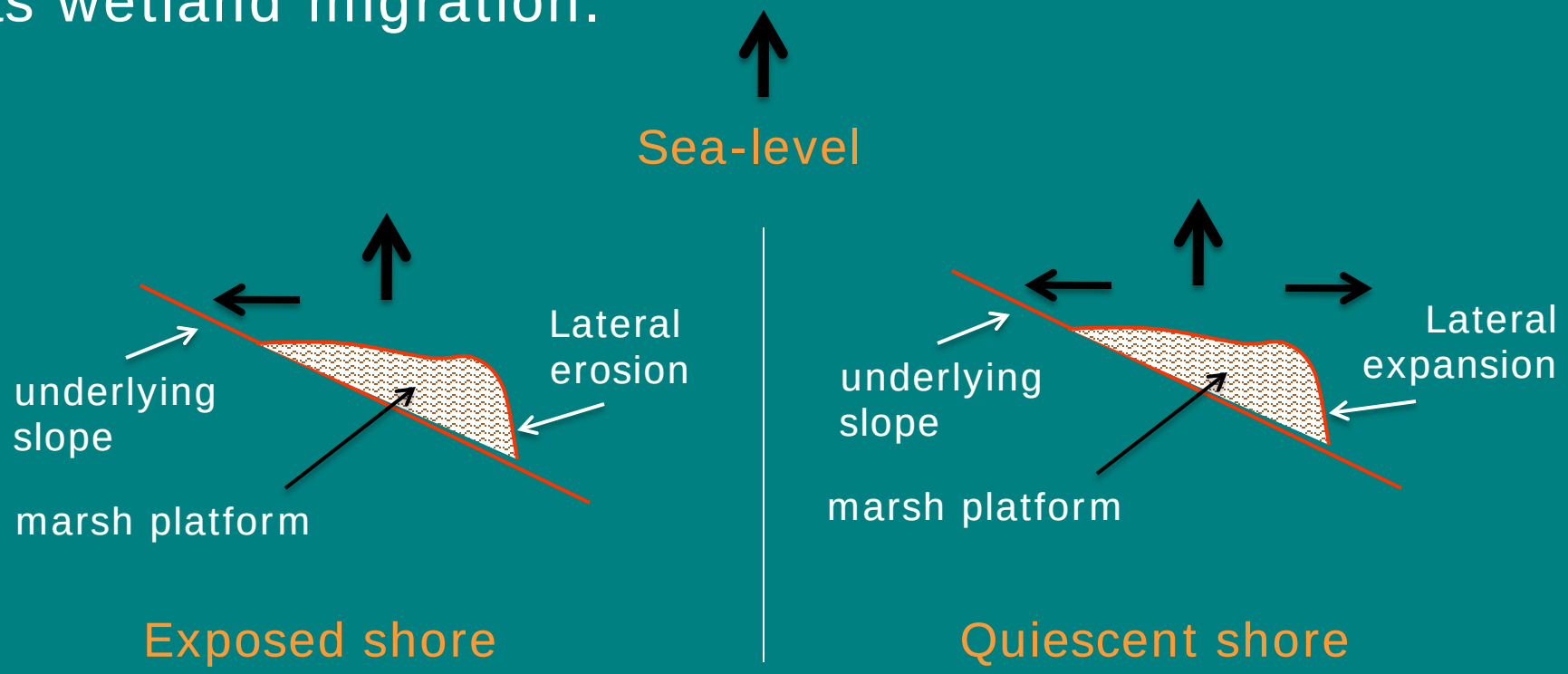
Marshes Keeping Pace with Sea-Level Rise: wetland migration

Vertical development in response to sea-level rise can lead to horizontal expansion, or what is known as wetland migration.



Wetland Migration

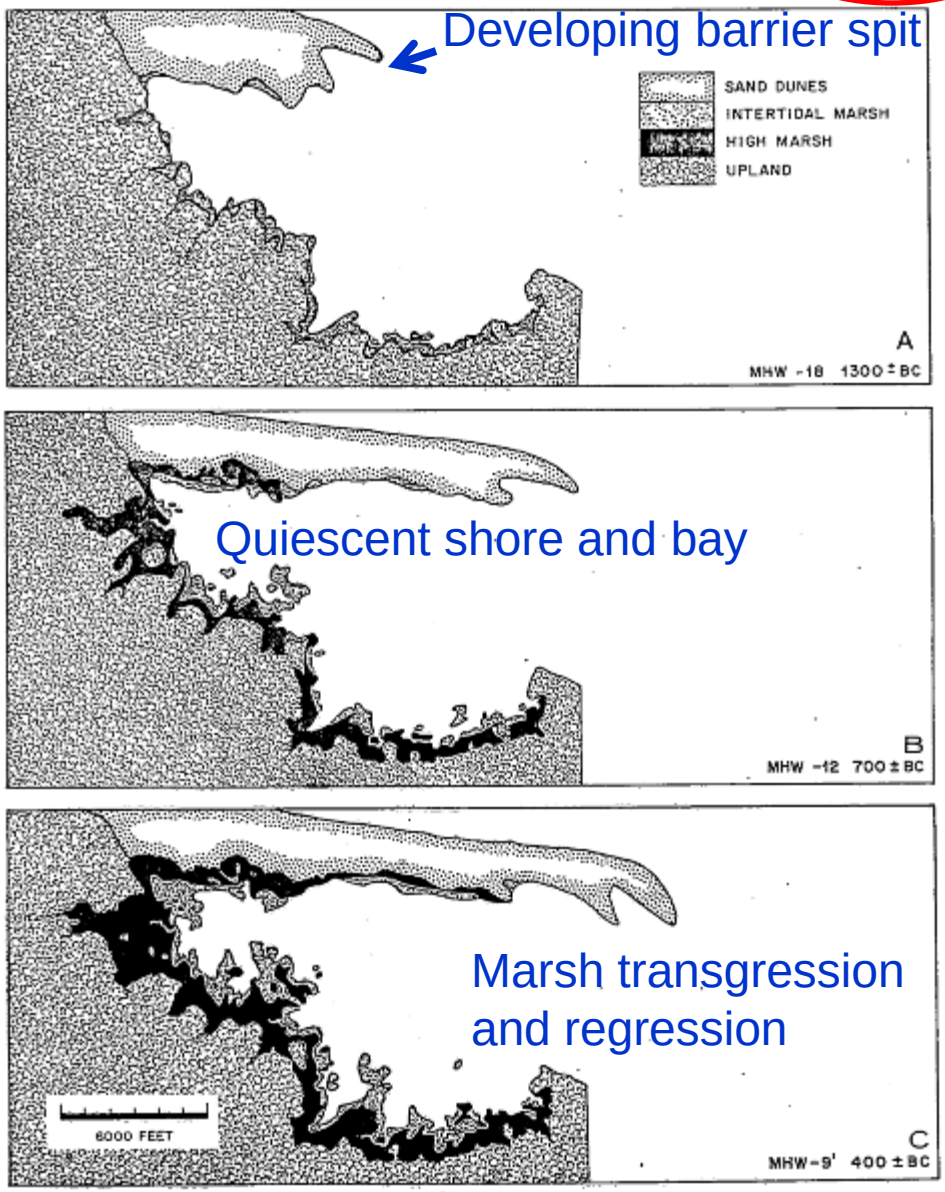


FIG. 10. Reconstruction of the history of the Barnstable Marsh. The date and contemporary elevation of mean high water, relative to the present elevation, are indicated in the lower right-hand corner of each reconstruction. After Redfield (1965*a*):

Wetland Migration

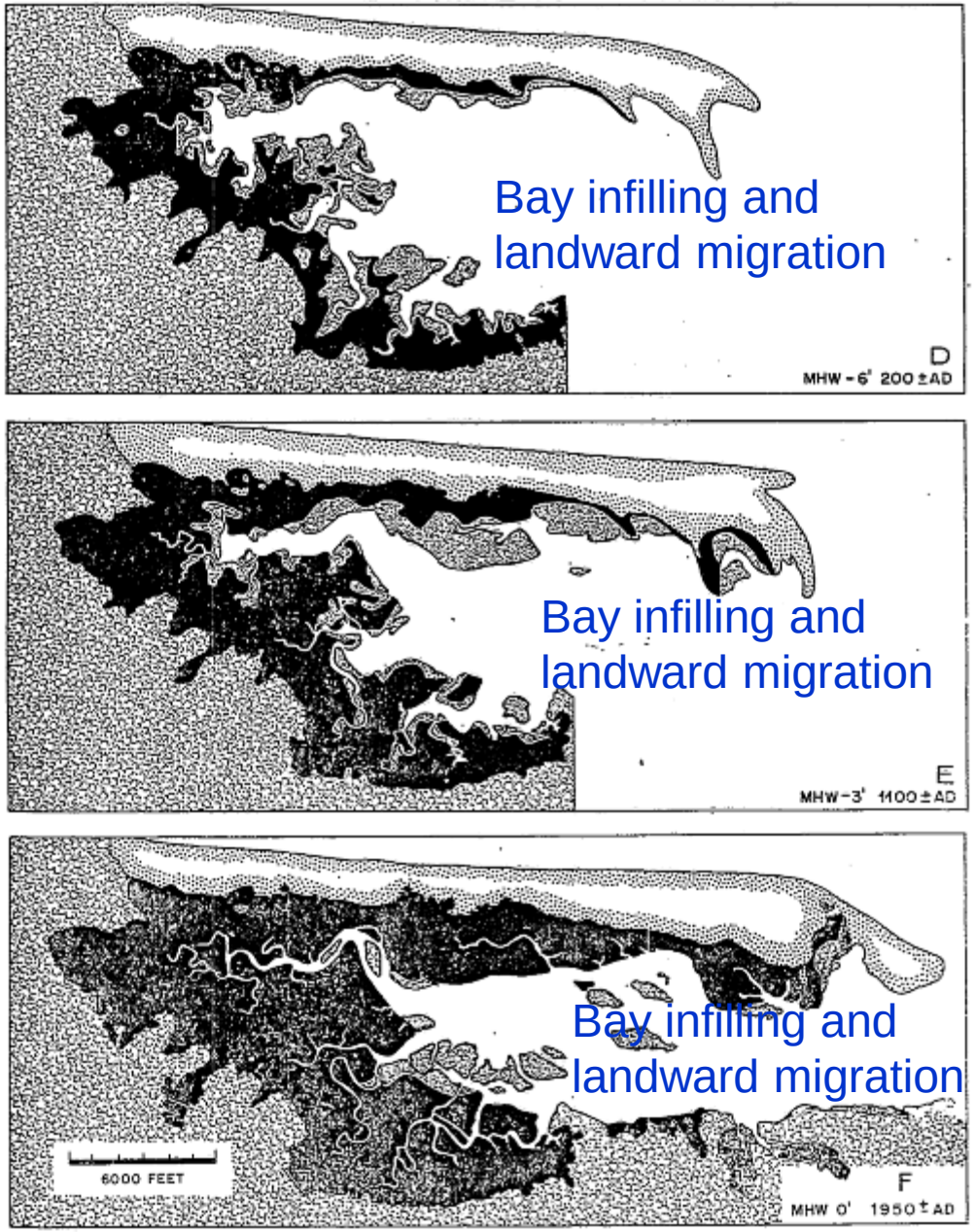


FIG. 10 (continued). Reconstruction of the history of the Barnstable Marsh.

Marshes keeping pace with sea-level rise migrate or build in place if there is a barrier to migration

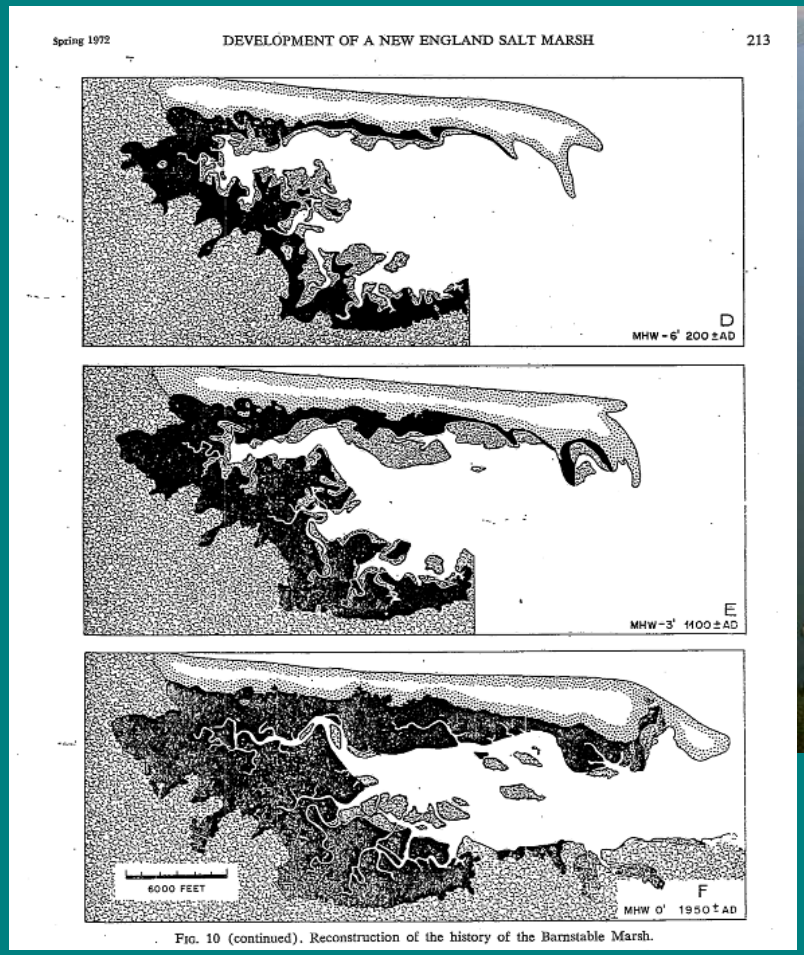


FIG. 10 (continued). Reconstruction of the history of the Barnstable Marsh.

A Manager's Concerns

- Are my wetlands keeping pace with current sea-level rise?
- What are the processes controlling wetland elevation change in my wetlands?
- Will my wetlands keep pace with future accelerated sea-level rise?

Assessing wetland vulnerability to sea-level rise: 4-step process

- Elevation Capital (your starting point)
- Elevation Trends (compare to RSLR)
- Processes Controlling Elevation Trends
- Forecast Future Vulnerability (models)

Cahoon & Guntenspergen 2010

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Assessing wetland vulnerability to sea-level rise:

STEP #1: GEOSPATIAL FRAMEWORK:

Determine the elevation of your marsh relative to local sea level.

Tie marsh elevation and sea level to common datum

Starting Point or Elevation Capital:
Is your marsh located high or low within its growth range?

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1. Growth Range ~ Tidal Range
2. Elevation Capital

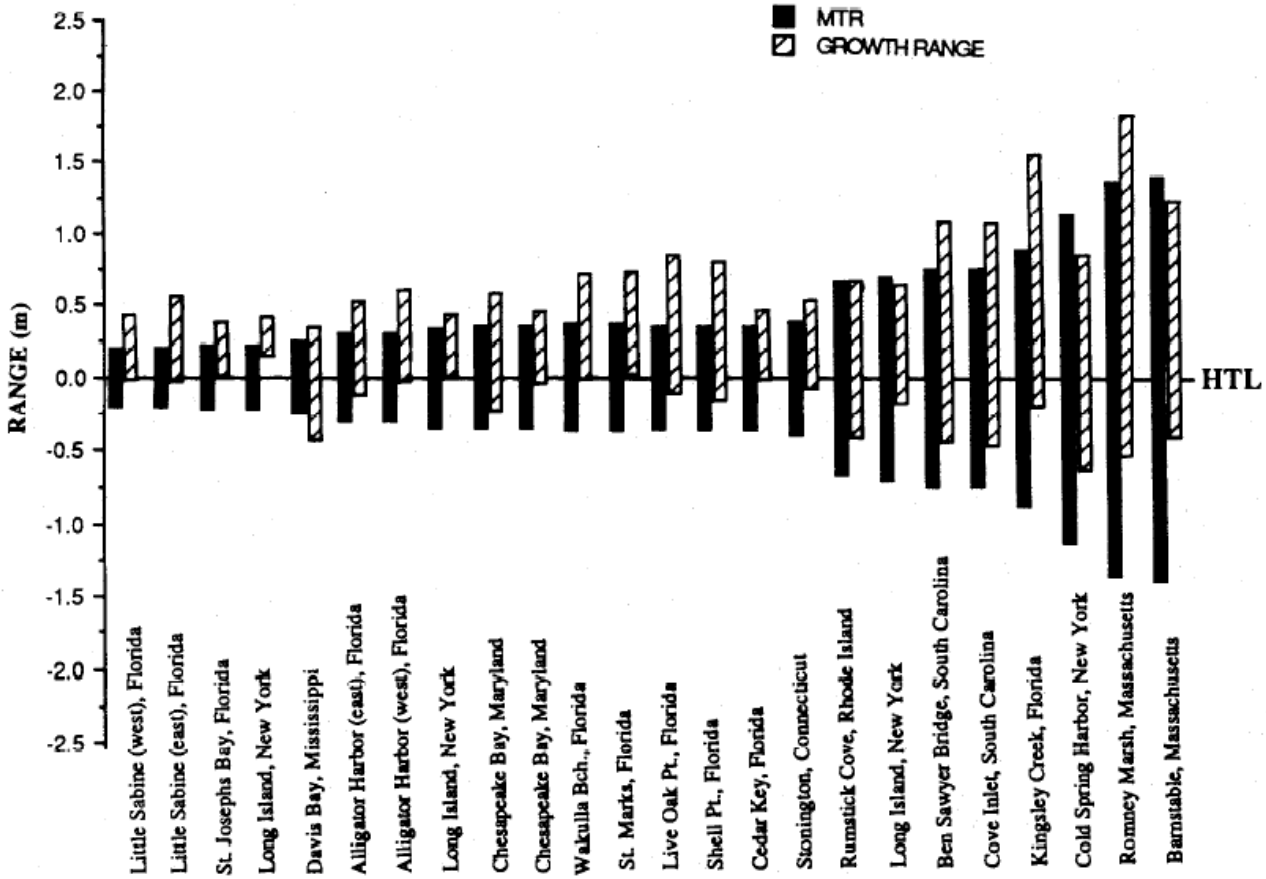


Fig. 2. The elevational range of growth of *Spartina alterniflora* relative to mean tide range (MTR) at selected locations along the Atlantic and Gulf coasts (arranged in order of increasing tidal amplitude). The half tide level (HTL) is the plane midway between mean high water (MHW) and mean low water (MLW).

McKee, K. L. & W. H. Patrick, Jr. 1988. The relationship of smooth cordgrass (Spartina alterniflora) to tidal datums: a review. Estuaries 11:143-151

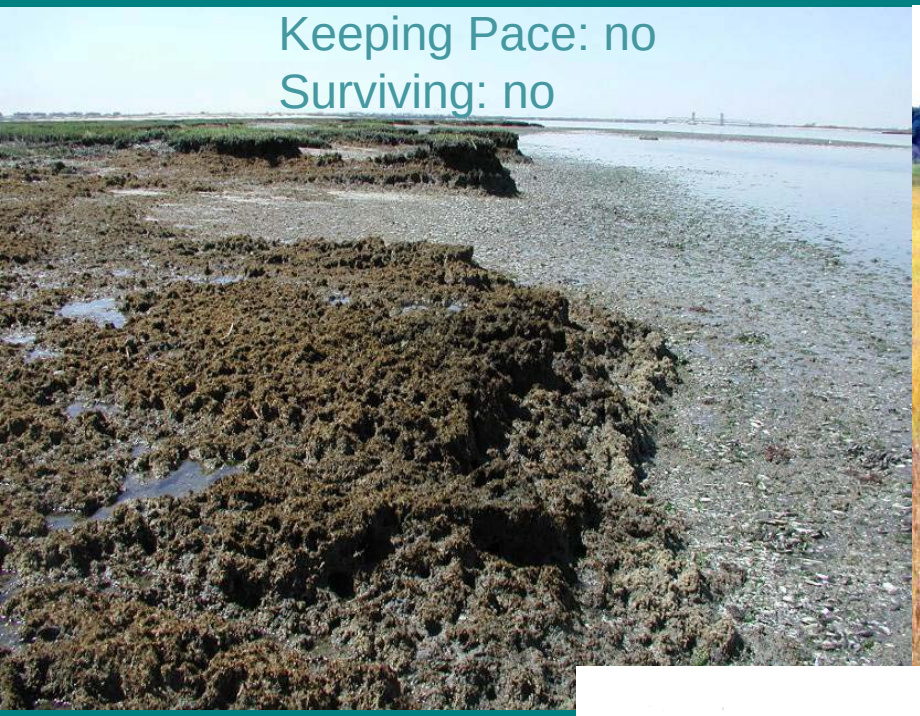
Surveying elevation of the marsh at Blackwater NWR

Assessing wetland vulnerability to sea-level rise:

STEP #2: RATES - determine the trend in elevation change of your marsh relative to local sea level.

Is your marsh keeping pace with the local rate of sea-level rise or is it experiencing an elevation deficit?

Keeping Pace vs. Surviving



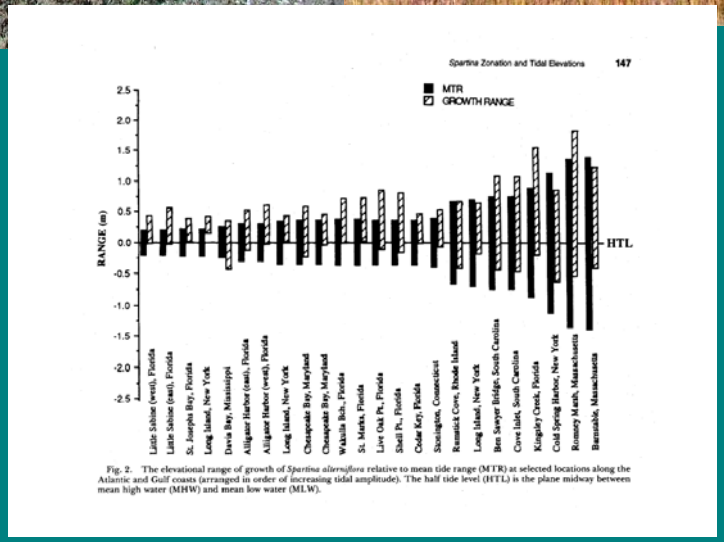


Fig. 2. The elevational range of growth of *Spartina alterniflora* relative to mean tide range (MTR) at selected locations along the Atlantic and Gulf coasts (arranged in order of increasing tidal amplitude). The half tide level (HTL) is the plane midway between mean high water (MHW) and mean low water (MLW).

Even though this marsh appears healthy, it could be experiencing an elevation deficit, and is surviving on its elevation capital

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Surface Elevation Table (SET)

The surface elevation table method provides high resolution measures of elevation change

Cahoon, D., Reed, D., Day, J. 1995. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Barghoorn revisited. Marine Geology 128:1-9.

Elevation Deficit

Develops when elevation gain lags behind sea-level rise

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Elevation Deficit Relative to Sea-Level Rise

Marsh elevation gradually gets lower within the growth range, which leads to increased hydroperiod (frequency, depth and duration of flooding).

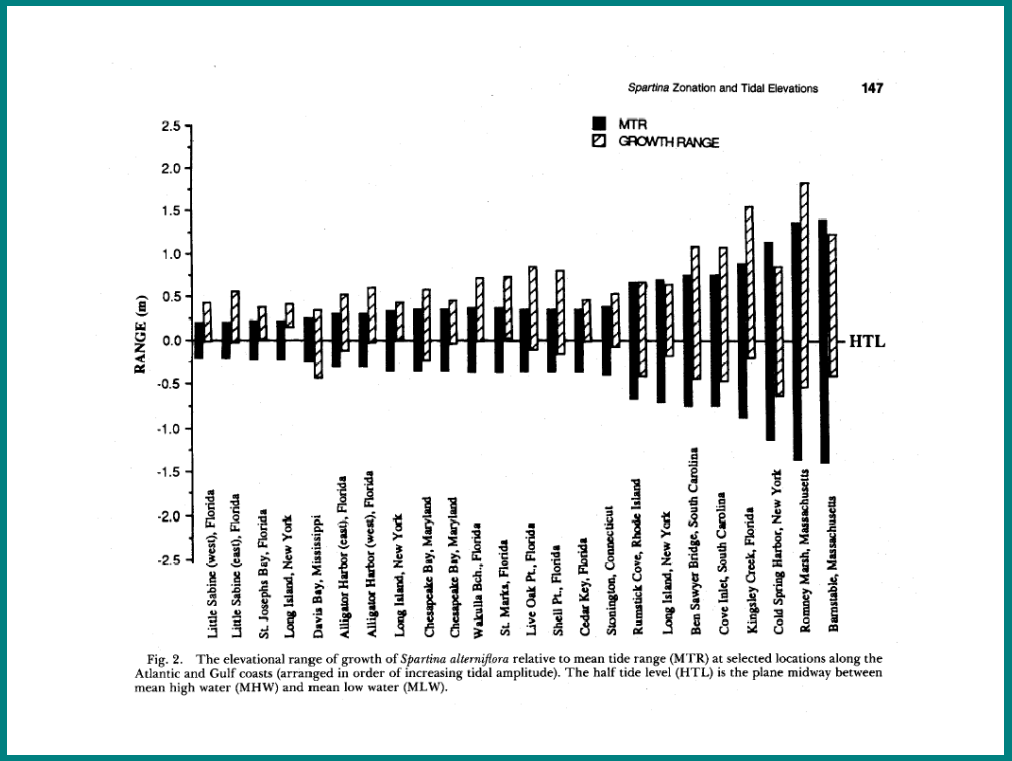

Fig. 2. The elevational range of growth of *Spartina alterniflora* relative to mean tide range (MTR) at selected locations along the Atlantic and Gulf coasts (arranged in order of increasing tidal amplitude). The half tide level (HTL) is the plane midway between mean high water (MHW) and mean low water (MLW).

Elevation Deficit Relative to Sea-Level Rise

Marsh elevation gradually gets lower within the growth range, which leads to increased hydroperiod (frequency, depth and duration of flooding).

Eventually marsh elevation falls below optimum growth range, the plants die, and marsh habitat converts to intertidal mudflat or subtidal open water.

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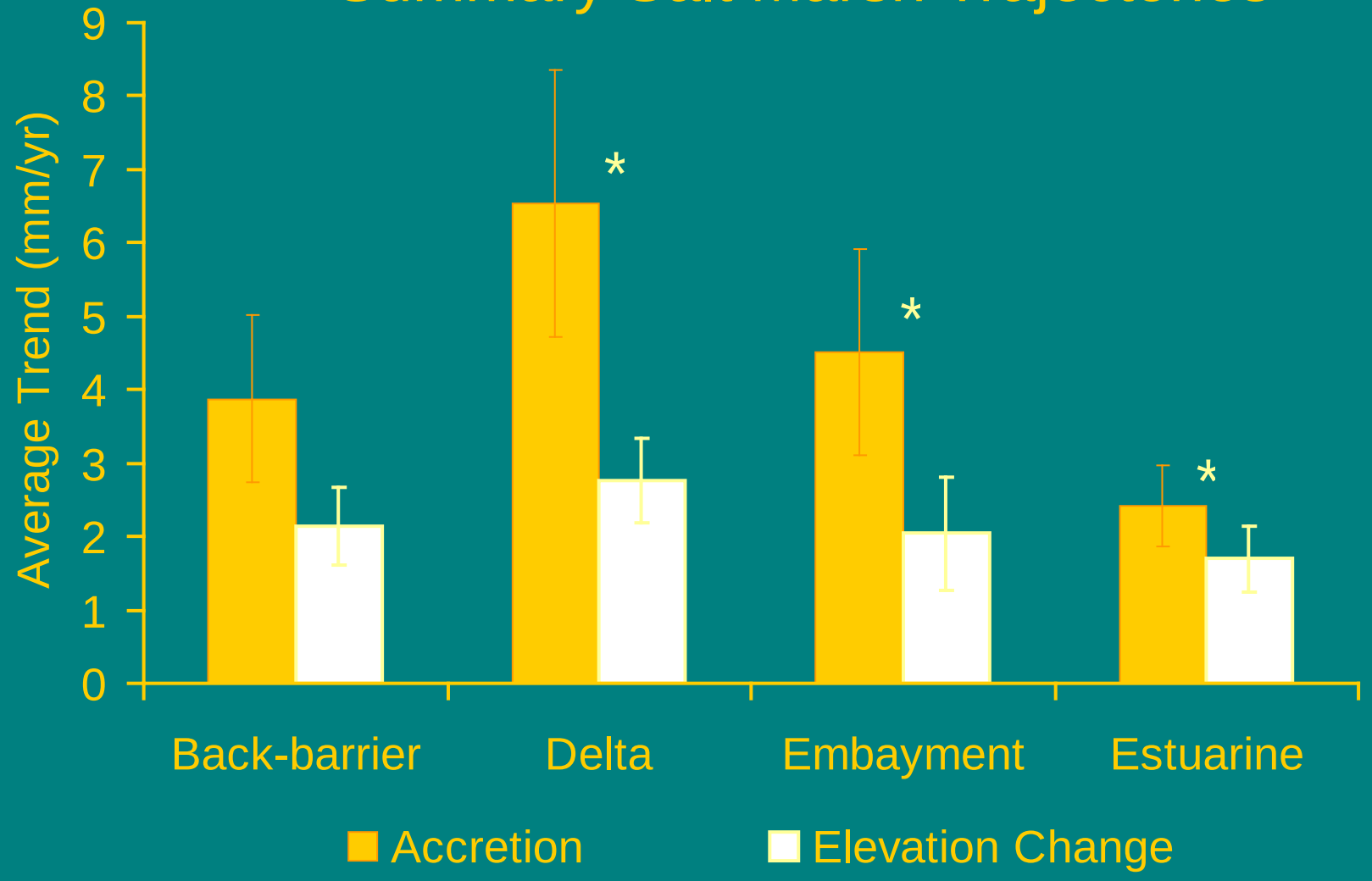
Summary Salt Marsh Trajectories

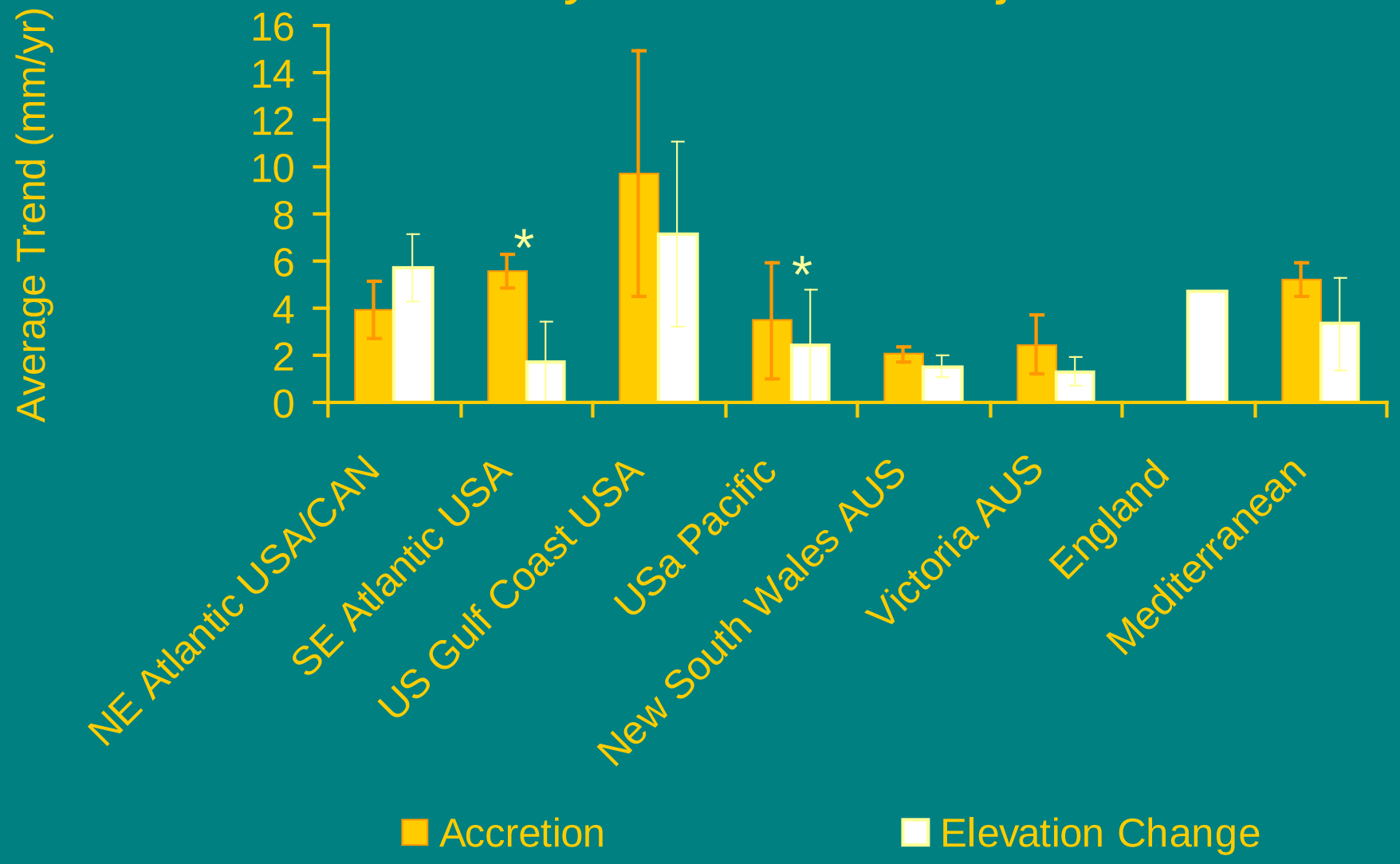


* Significant Shallow Subsidence at the P ≤ 0.10 level

Cahoon et al 2006

Salt Marsh

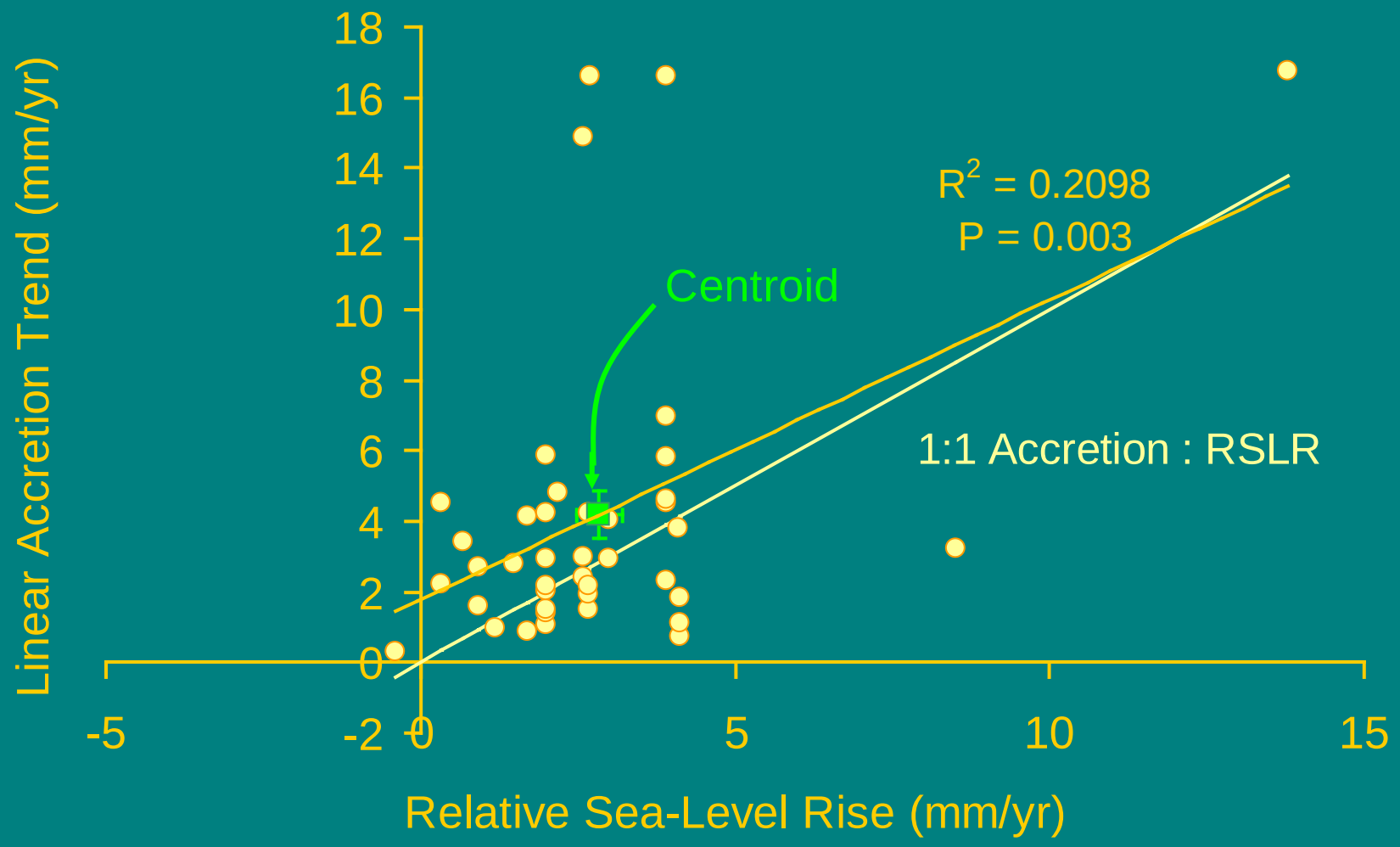
Summary Salt Marsh Trajectories



* Significant Shallow Subsidence at the P ≤ 0.10 level

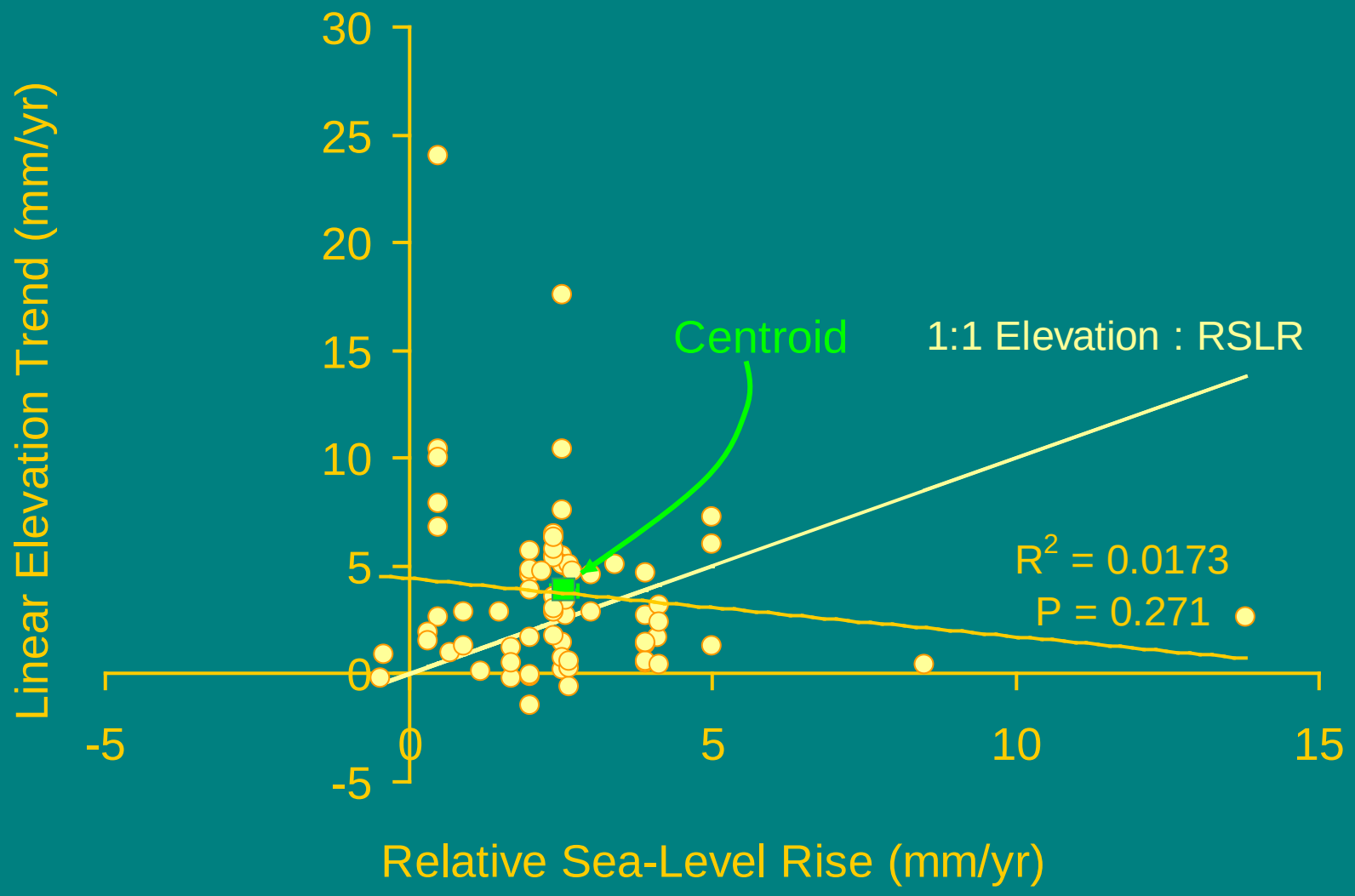
Cahoon et al 2006

Salt Marsh Accretion Trajectories vs. RSLR



Cahoon et al 2006

Salt Marsh Elevation Trajectories vs. RSLR



Cahoon et al 2006

Assessing wetland vulnerability to sea-level rise:

STEP #3: PROCESSES - Determine the factors controlling elevation change (i.e., vertical development) in your marsh.

Which environmental drivers and surface and subsurface processes most control elevation change in your marsh?

Improve your ability to manage your marsh to survive future climate change!

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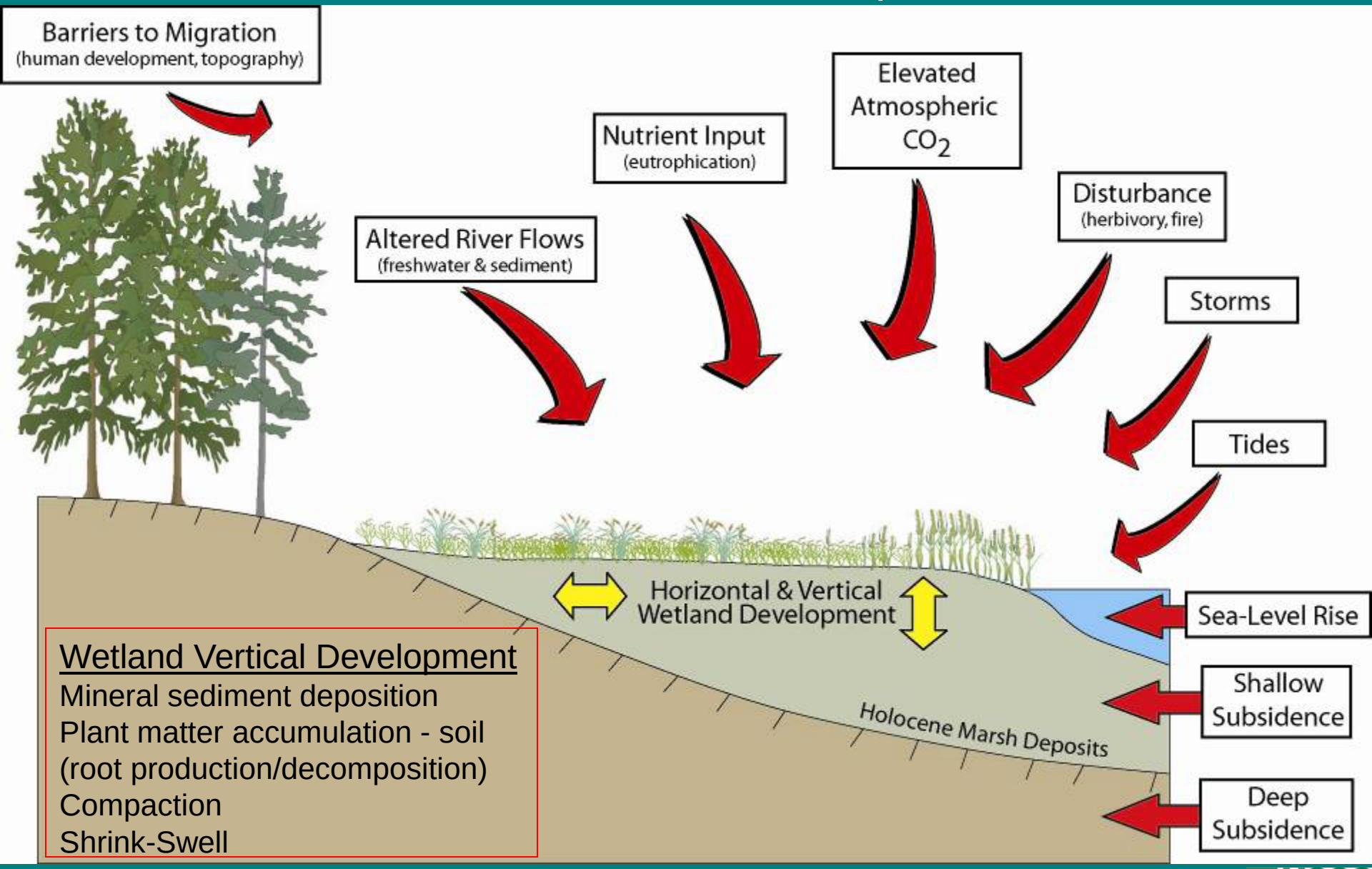
Environmental Drivers Influencing Vertical and Horizontal Wetland Development



Wetland Vertical Development

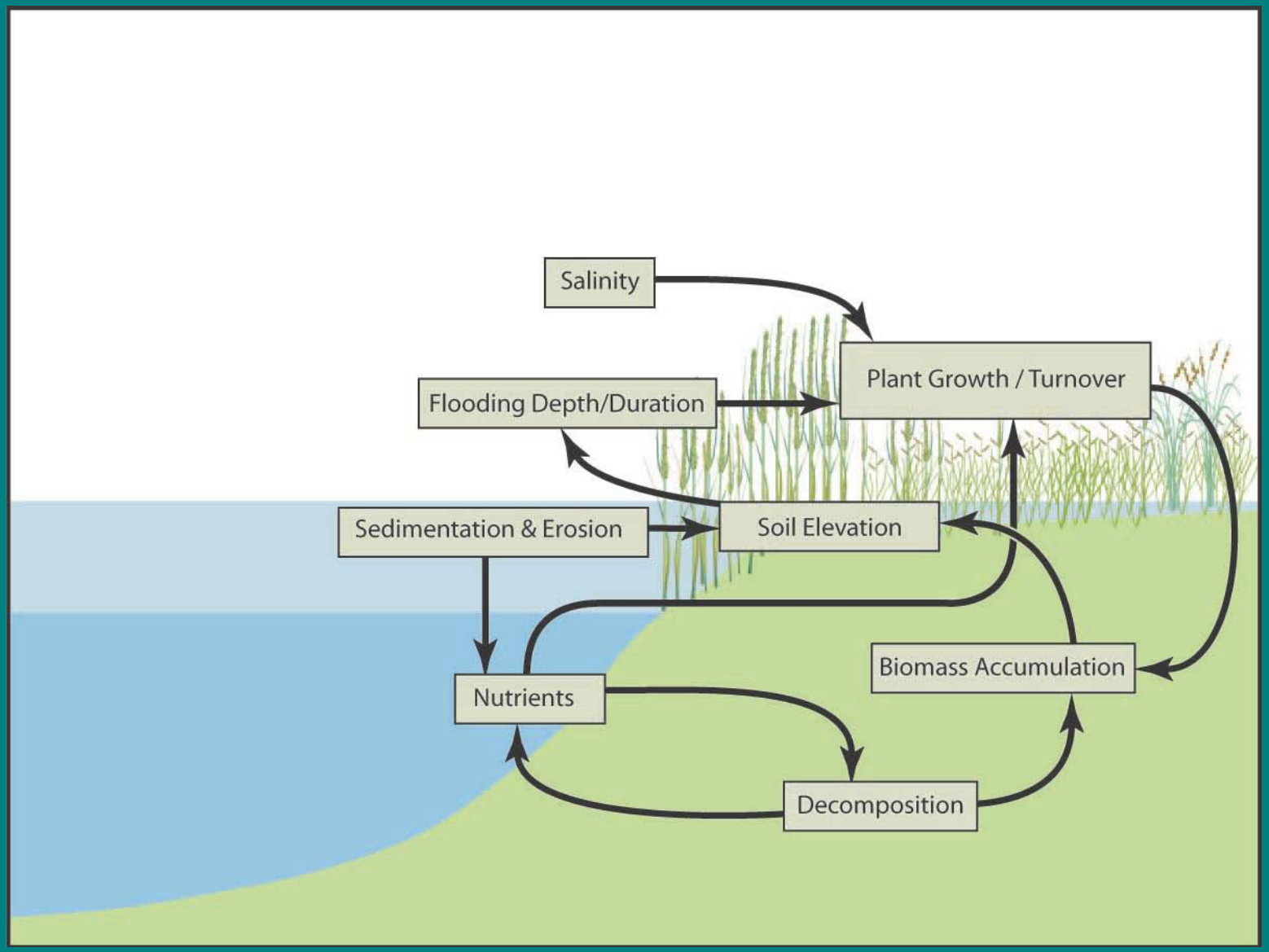
Mineral sediment deposition
Plant matter accumulation - soil (root production/decomposition)
Compaction
Shrink-Swell

Cahoon et al. 2009. CCSP SAP 4.1

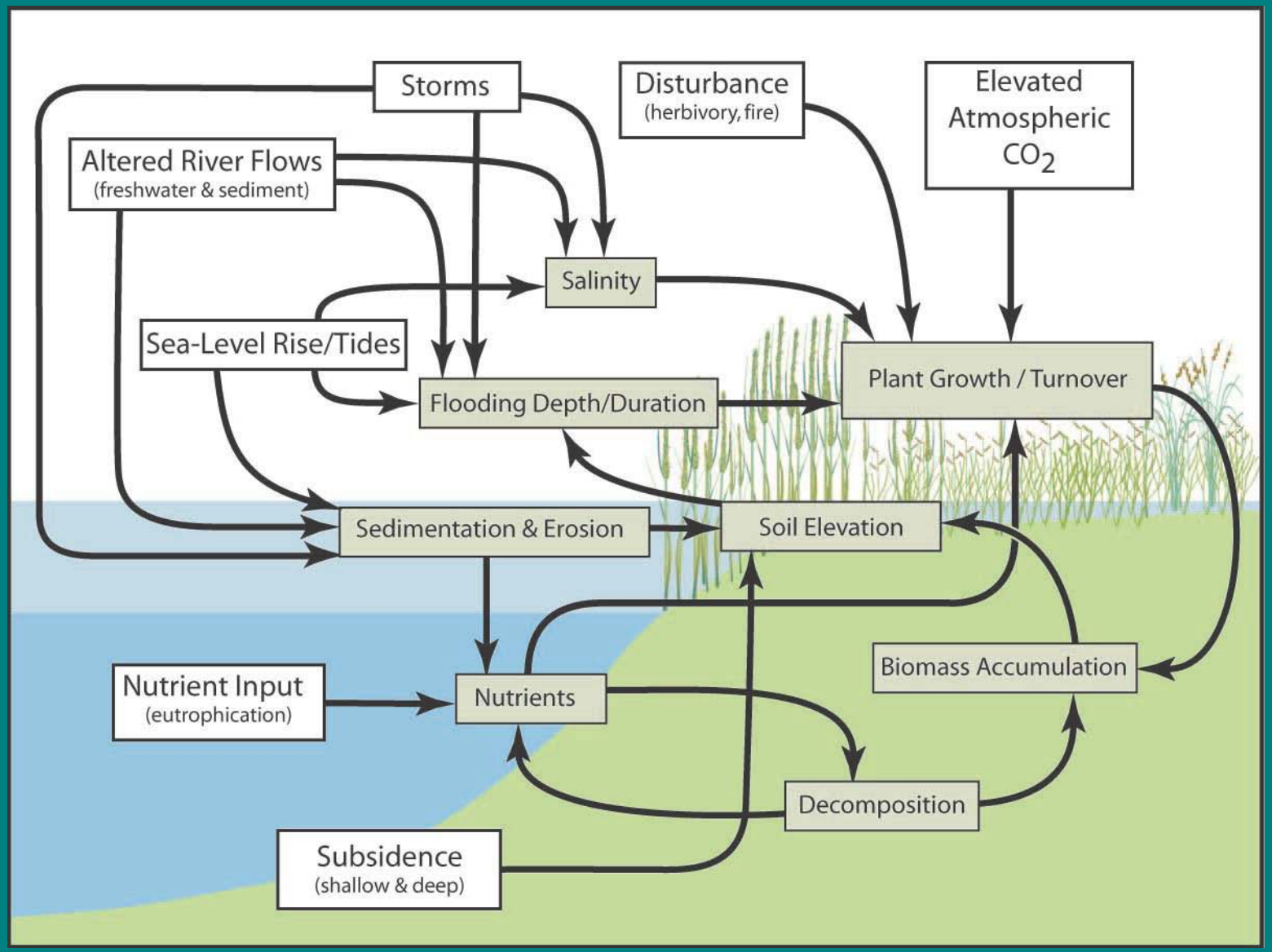
Interactive Effects

How do other environmental drivers interact with sea-level rise to influence the processes controlling wetland vertical development?

Processes and Feedbacks Within the Marsh Influence Soil Elevation



Environmental Drivers Interact with Processes and Feedbacks to Influence Marsh Elevation



Cahoon et al. 2009. CCSP SAP 4.1

SET- MH Method

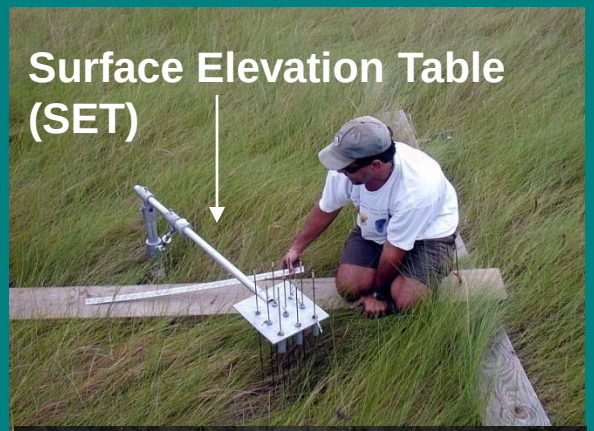
The surface elevation table – marker horizon method provides high resolution measures of

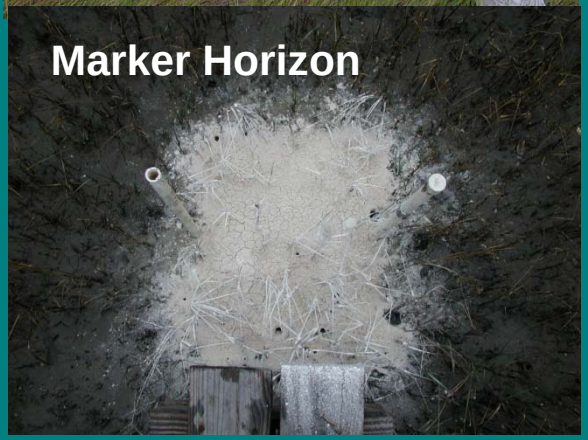
vertical accretion,

elevation change, and

shallow subsidence

such that the separate influence of surface and subsurface processes (0 – 25 m depth) on elevation can be determined





Cahoon, D., Reed, D., Day, J. 1995. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Barghoorn revisited. Marine Geology 128:1-9.

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Subsurface Influences

The influence of subsurface processes on marsh elevation are calculated as:

Accretion – Elevation

If A > E, then shallow subsidence occurs

If A < E, then shallow expansion occurs

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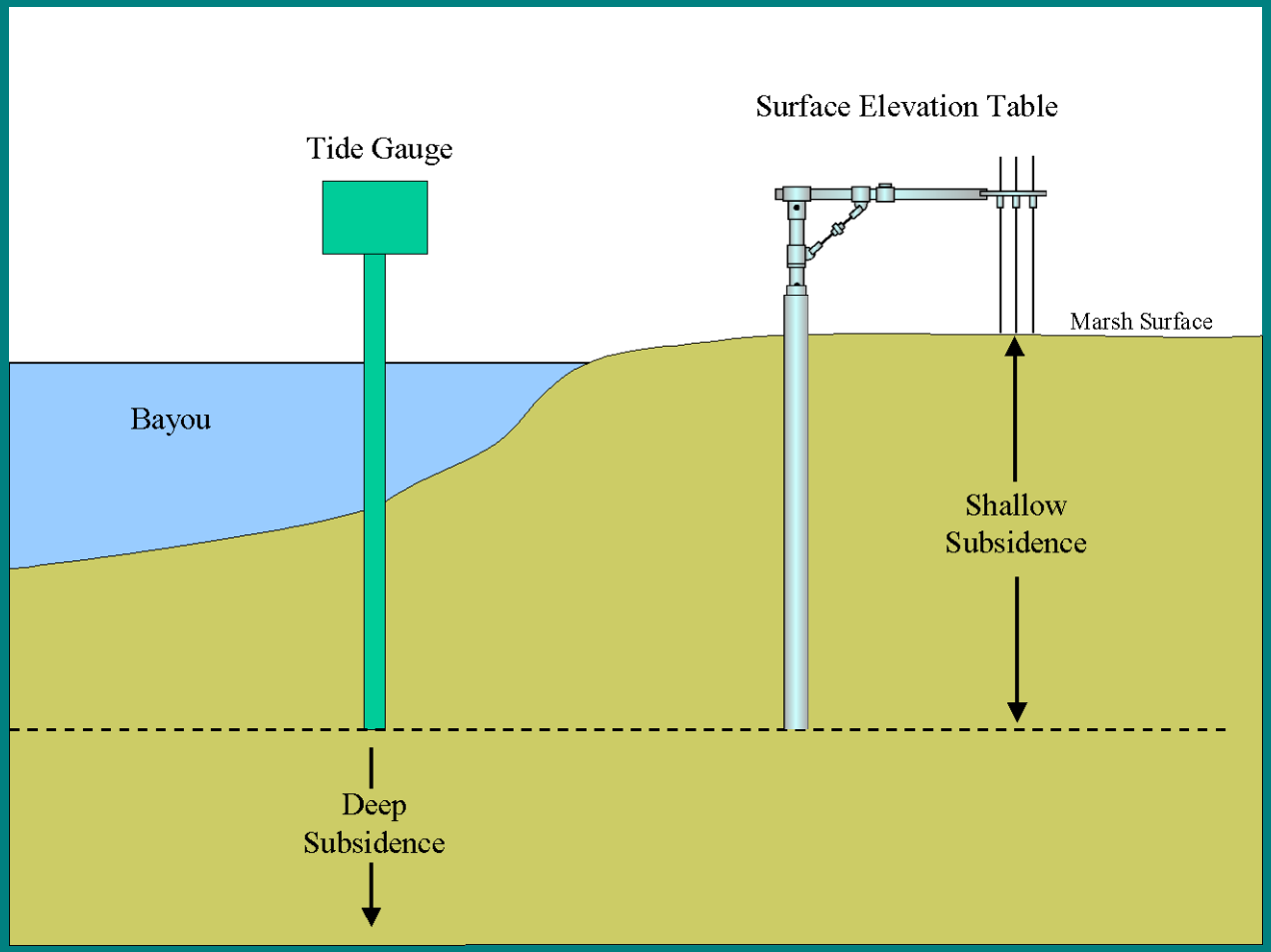
Revised Relative Sea-Level Rise

Revised RSLR = eustatic SLR + deep subsidence + shallow subsidence or expansion



Assessing wetland vulnerability to sea-level rise:

STEP #4: MODELS - Estimate the ability of your marsh to build vertically under future sea-level rise and global change scenarios using models developed with the information acquired in Steps 1-3

Improve your ability to manage your marsh to survive future climate change!

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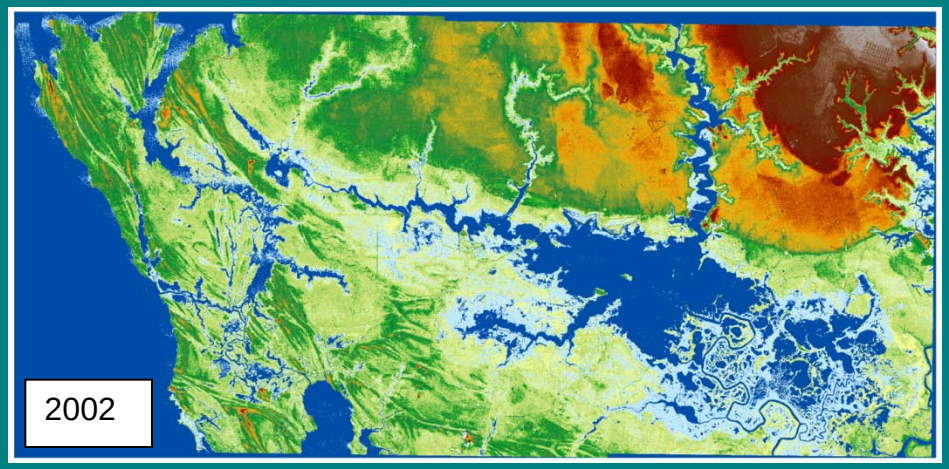
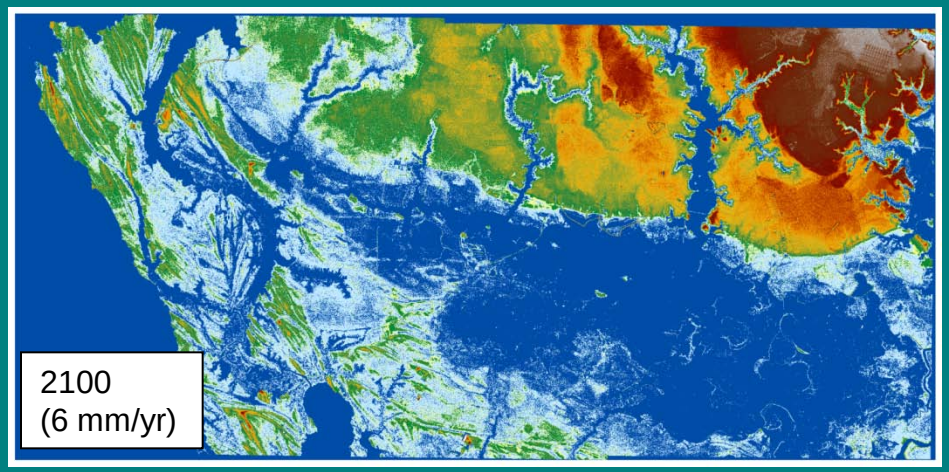
Blackwater Inundation Model





Digital elevation model (DEM) based on LiDAR showing the area of open water (dark blue), low marsh (pale blue), high marsh (pale yellow), and upland (all other colors) in the vicinity of Blackwater NWR in 2002, and 2100 assuming a 60 cm rise over 100 years or a 6 mm/y rise in sea level.

(Larsen, Clark, Guntenspergen, Cahoon, Caruso, Hupp, Yanofsky 2004)

Static Model: given the high rates of shallow subsidence and low to negative elevation trends, this static model output = the best case scenario

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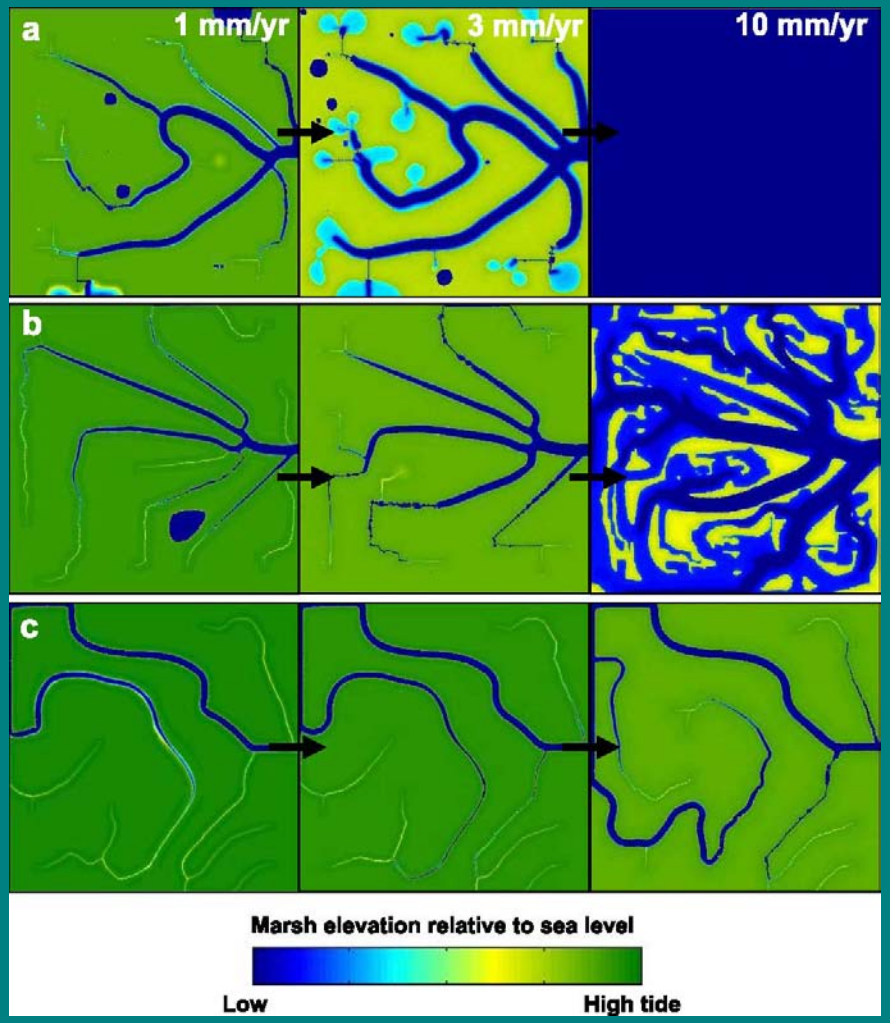
Effect of tidal range on marsh platform response to sea level change

Annual rate of sea-level rise



0.4 m tidal range

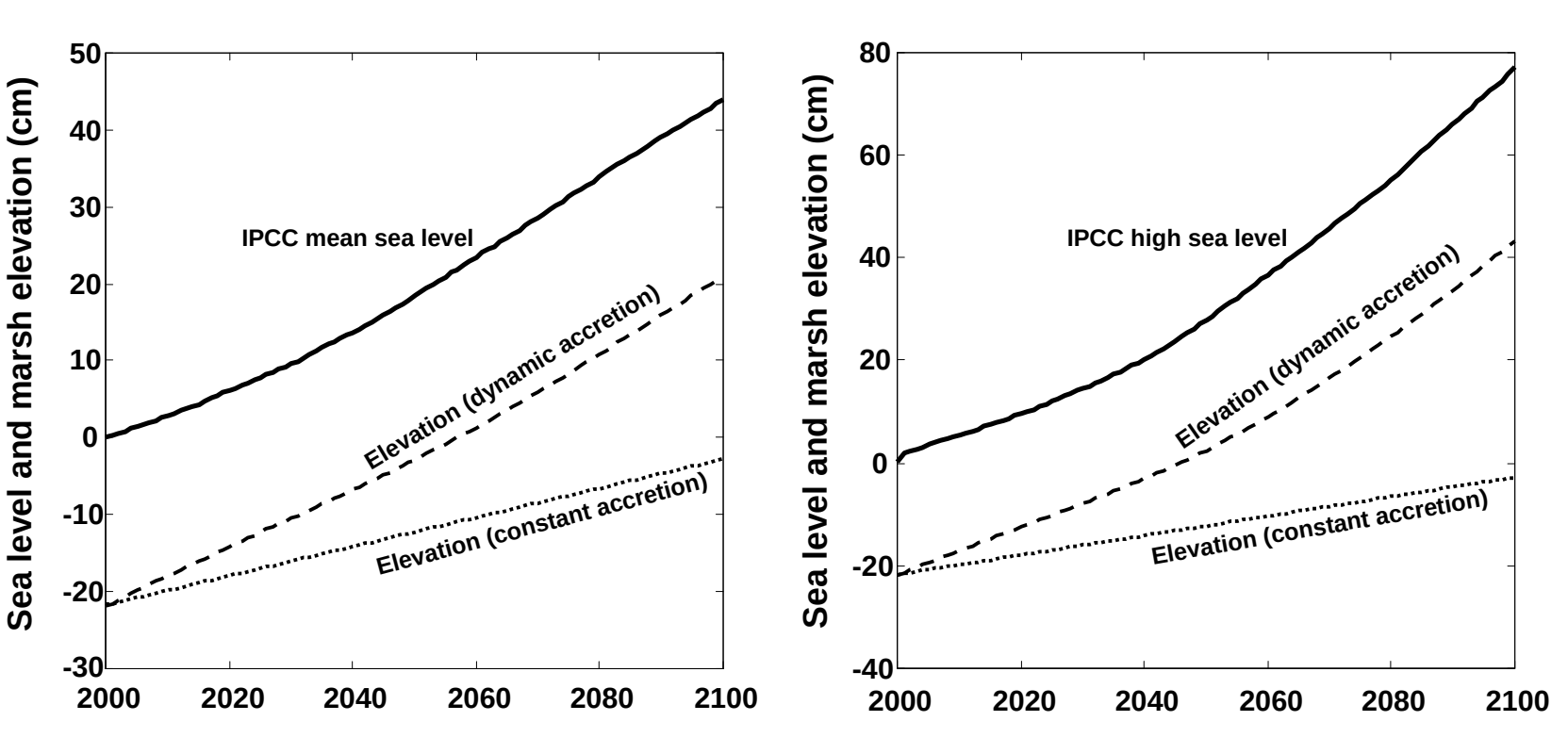
1.0 m tidal range

4.0 m tidal range

For a given suspended sediment concentration, a macrotidal marsh can survive higher sea level rise rates than a microtidal marsh

(Kirwan & Guntenspergen, 2010 Journal of Geophysical Research)

Response of salt marsh elevation to sea-level



Positive feedbacks between inundation and accretion reduce the predictive inundation of the marsh surface by about one-half compared to simple models that do not use this feedback process

Kirwan and Guntenspergen, Frontiers In Ecology, 2009

Recommendations for Assessing Wetland Vulnerability to Climate Change

Elevation Capital – determine for all wetlands, not just deteriorating wetlands

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Elevation Trajectories – are your wetlands keeping pace with Relative Sea-Level Rise (RSLR)?

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Beyond RSLR – evaluate effects of other climate and environmental drivers on wetland vertical development

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Adaptation/Management – adapt management practices to maximize wetland vertical development (interactions among RSLR and other drivers)

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Elevation Data – Better quality data will improve regional model assessments

Recommendations for Assessing Wetland Vulnerability to Climate Change

Elevation Capital – determine for all wetlands, not just deteriorating wetlands

Elevation Trajectories – are your wetlands keeping pace with Relative Sea-Level Rise (RSLR)?

Revised RSLR – correct RSLR rates from tide gauges with local estimates of shallow subsidence/expansion

Beyond RSLR – evaluate effects of other climate and environmental drivers on wetland vertical development

Adaptation/Management – adapt management practices to maximize wetland vertical development (interactions among RSLR and other drivers)

Elevation Data – Better quality data will improve regional model assessments

Models – Improve models, both site-specific and regional

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