Modeling the Effects of Sea Level Rise and Storm Surges on Coastal Everglades Vegetation

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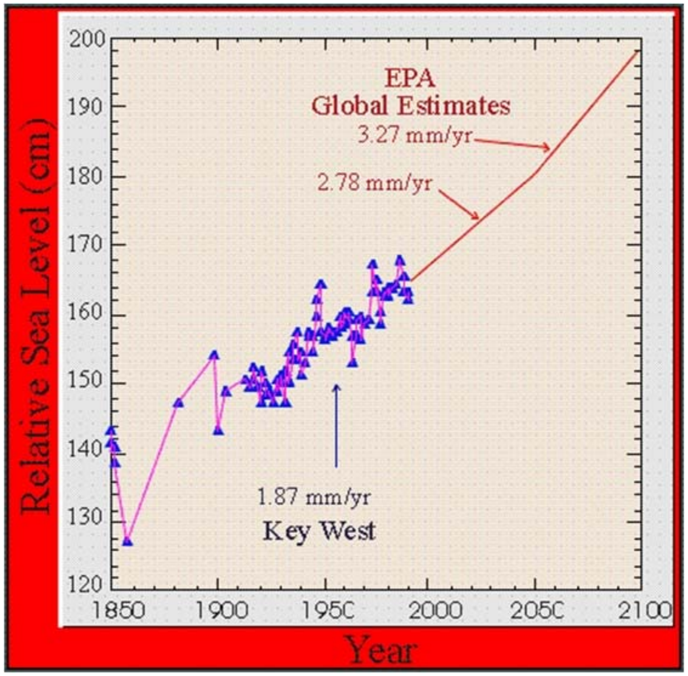
Photo: jasoncdukes.files.wordpress.com

Purpose of Work

Project the effects of sea level rise and storm surges on the ecotone between coastal halophytic vegetation and salinity-intolerant vegetation.

Problem: Both the gradual rise in sea level and the transport of large pulses of seawater from storm surges can result in vegetation shifts on coasts.



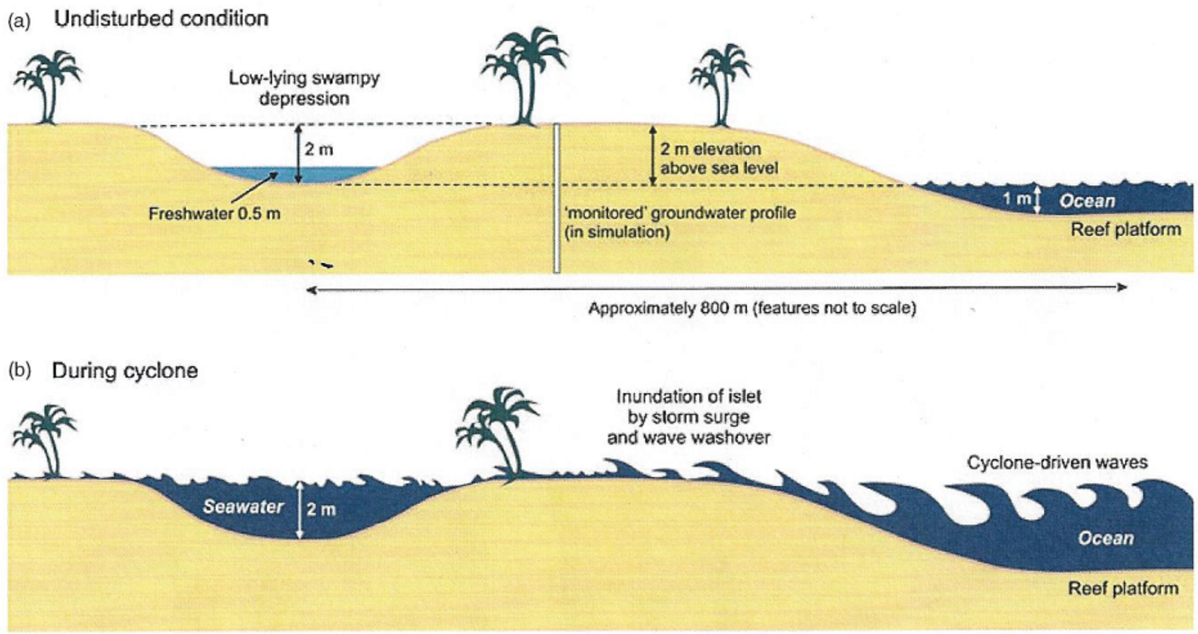


Figure from Chui and Terry. 2012. Groundwater 50(3):412-420

Our previous work:
focused on ecotone between salinity tolerant mangroves (halophytes) and salinity-intolerant hardwood hammock trees (glycophytes)

Mangroves (halophytic)

Hardwood Hammock (glycophytic)

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Everglades mangroves form extremely sharp (~ 1m) ecotones with freshwater vegetation types such as hardwood hammocks or freshwater marsh.

- "Ecotone"– a zone of relatively rapid change between two communities.

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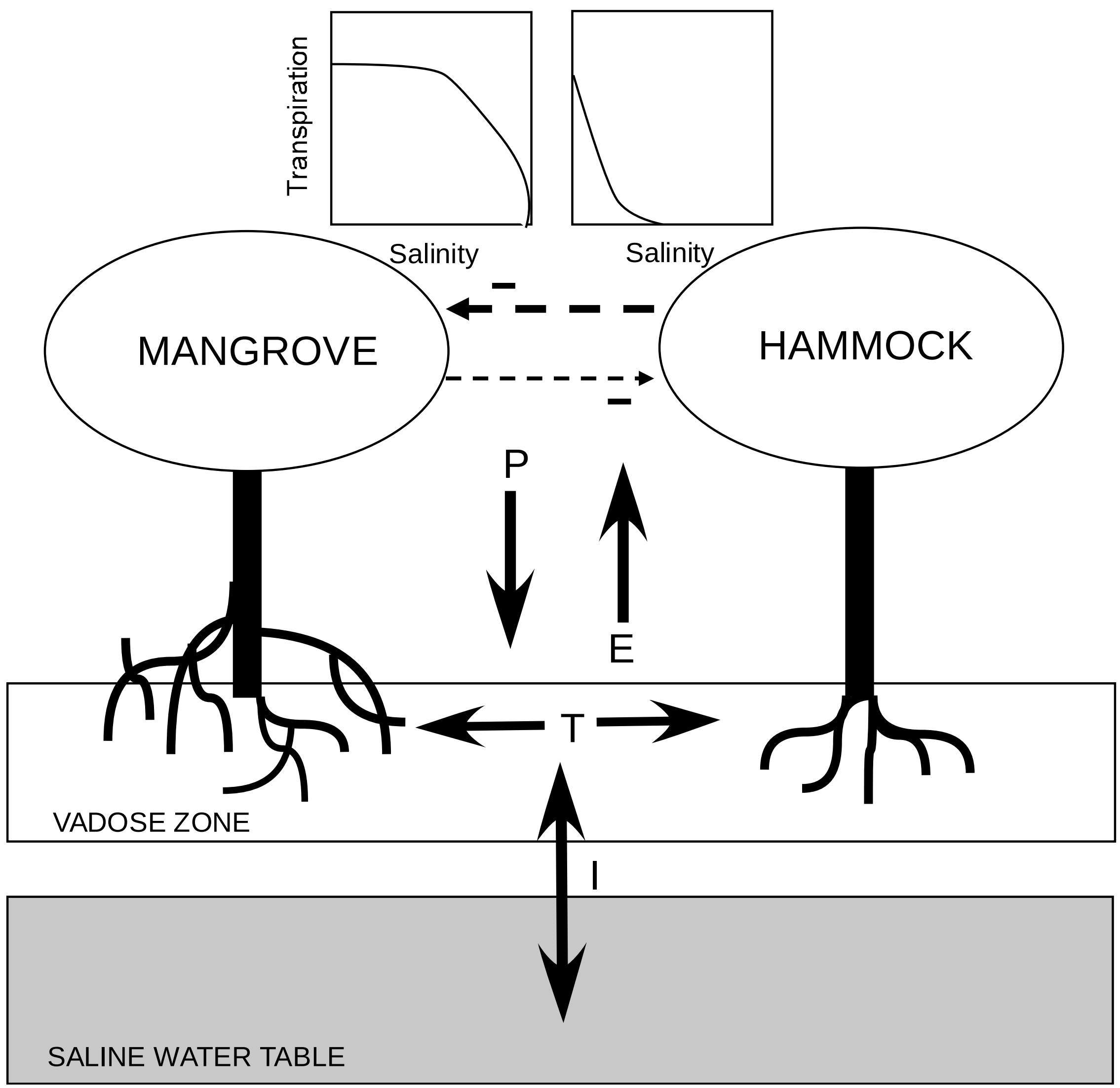
The model MANHAM was developed to simulate competition between mangroves and tropical hardwood hammock trees on landscape, including hydrologic and salinity processes in the vadose zone (unsaturated zone).



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Results of Previous Work

MANHAM a spatially explicit simulation model:

- Explained the sharpening of halophyte/glycophyte ecotone through positive feedback with soil salinity.
- Showed the existence of a bistable region along a salinity gradient, over which alternative stable states of halophytic or glycophytic vegetation could exist.
- Showed that along the bistable region, regime shifts could result from a storm surge under certain conditions.

Current Work: Methods

The current work revises the MANHAM model by combining it with the USGS's SUTRA model, in order to improve the accuracy.

Developers of MANTRA

Assoc. Prof. Su Yean Teh
Universiti Sains Malaysia

Michael Turtora, Water Resources Division, USGS

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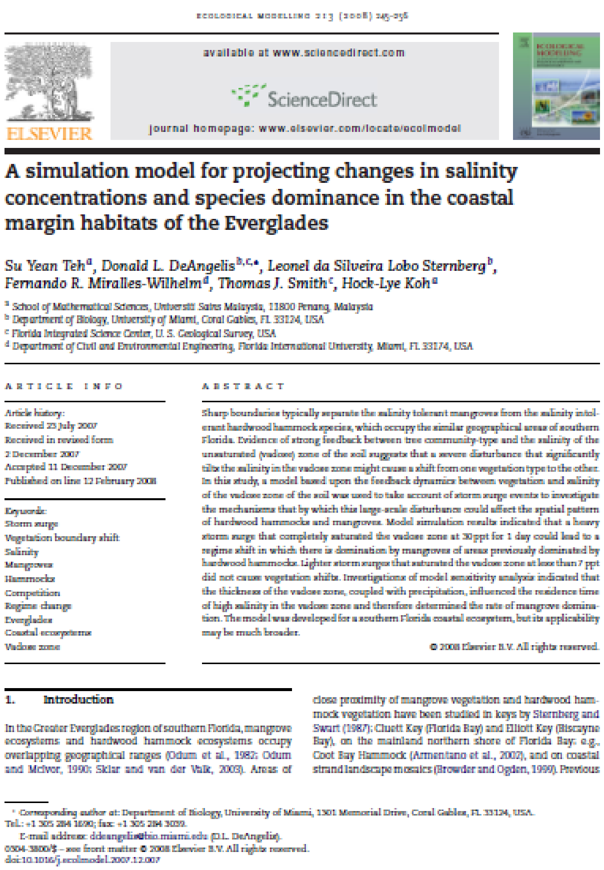
MANHAM + SUTRA = MANTRA

- MANHAM: MANgrove and Hardwood HAMmock Competition Model
- SUTRA: Model for saturated-unsaturated variable-density ground-water flow with solute and energy transport



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A simulation model for projecting changes in salinity concentrations and species dominance in the coastal margin habitats of the Everglades

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ABSTRACT

Sharp boundaries typically separate the salinity tolerant mangroves from the salinity intolerant hardwood hammock species, which occupy the similar geographical areas of southern Florida. Evidence of strong feedback between tree community-type and the salinity of the unsaturated (vadose) zone of the soil suggests that a severe disturbance that significantly tilts the salinity in the vadose zone might cause a shift from one vegetation type to the other. In this study, a model based upon the feedback dynamics between vegetation and salinity of the vadose zone of the soil was used to take account of storm surge events to investigate the mechanisms that by which this large-scale disturbance could affect the spatial pattern of hardwood hammocks and mangroves. Model simulation results indicated that a heavy storm surge that completely saturated the vadose zone at 30 ppt for 1 day could lead to a regime shift in which there is domination by mangroves of areas previously dominated by hardwood hammocks. Lighter storm surges that saturated the vadose zone at less than 7 ppt did not cause vegetation shifts. Investigations of model sensitivity analysis indicated that the thickness of the vadose zone, coupled with precipitation, influenced the residence time of high salinity in the vadose zone and therefore determined the rate of mangrove domination. The model was developed for a southern Florida coastal ecosystem, but its applicability may be much broader.

1. Introduction

In the Greater Everglades region of southern Florida, mangrove ecosystems and hardwood hammock ecosystems occupy overlapping geographical ranges (Odum et al., 1982; Odum and McIvor, 1990; Sklar and van der Valk, 2003). Areas of close proximity of mangrove vegetation and hardwood hammock vegetation have been studied in keys by Sternberg and Swart (1987): Cluett Key (Florida Bay) and Elliott Key (Biscayne Bay), on the mainland northern shore of Florida Bay: e.g., Coot Bay Hammock (Armentano et al., 2002), and on coastal strand landscape mosaics (Browder and Ogden, 1999). Previous

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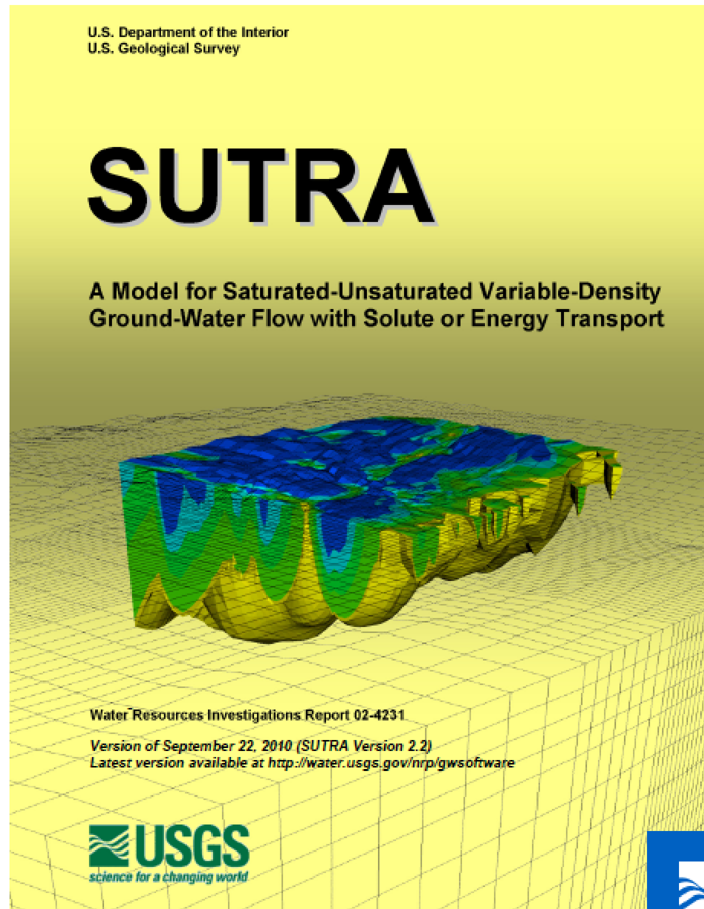

MANHAM

- Describes plant growth per unit time
  = Productivity – Respiration – Litterfall
- Productivity depends on:
  - Water uptake efficiency (salinity-dependent).
  - Competition for light.
  - Intra- and inter-species competition.

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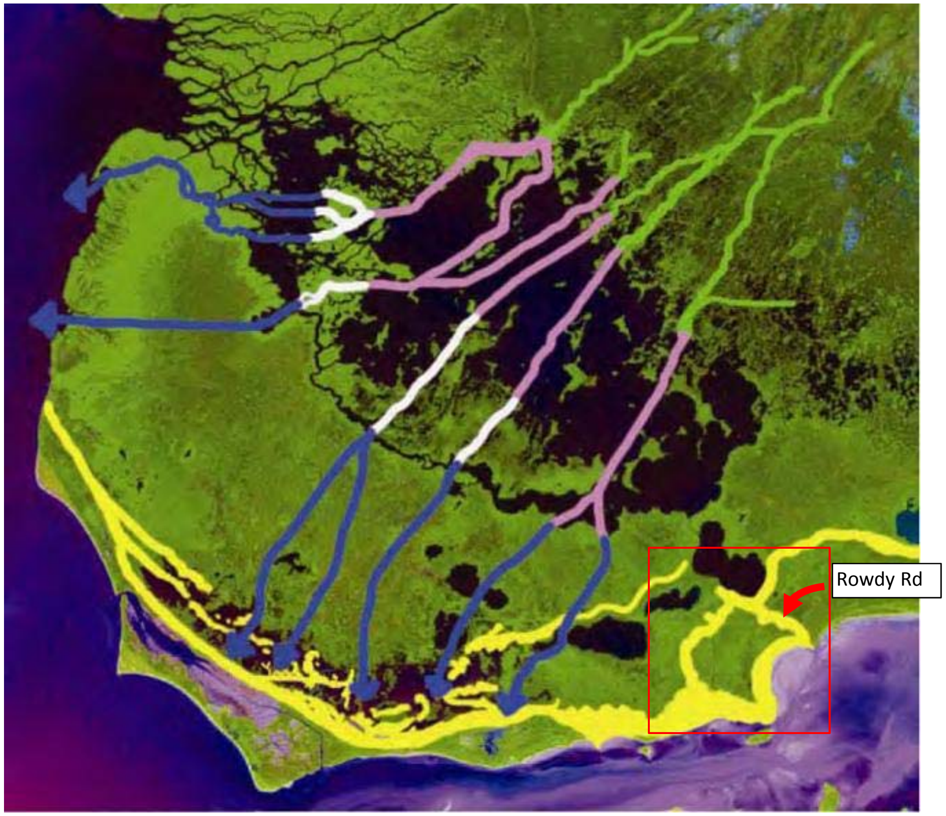
Specific Application

We describe an application to an area of the coastal Everglades.

Cape Sable vicinity ridges and paleo channels, Wanless (2005)



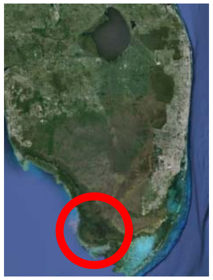
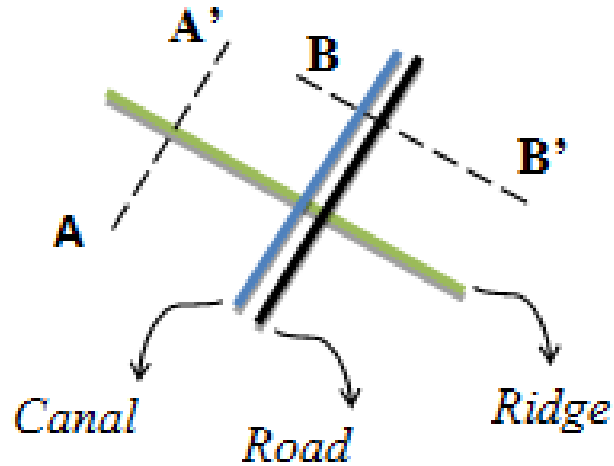
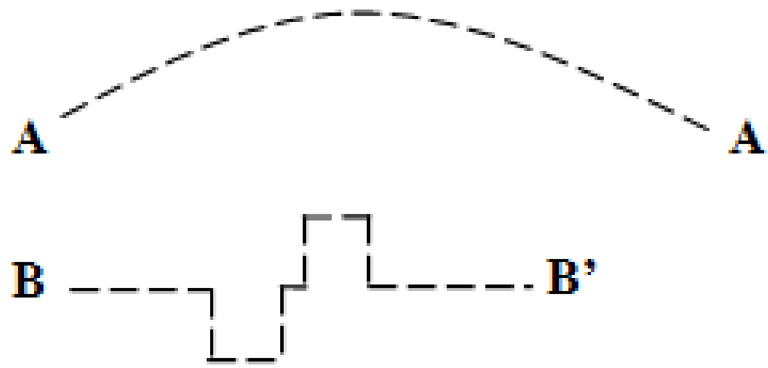


FIGURE 4. Top – Satellite image map of Cape Sable, Whitewater Bay and the lower Everglades. Bottom – Map with interpreted Paleo-Everglades drainage shown from lower Everglades, across Whitewater Bay and through Cape Sable. Yellow are a sequence of Emergent Marl Ridges that formed following 2,400 years before present, eventually blocking the paleo-Everglades outflow paths (Base map provided by USGS).

Wanless, Harold. R., Brigitte M. Vlaswinkel (2005). Coastal landscape and channel evolution affecting critical habitats at Cape Sable, Everglades National Park, Florida. Final Report to ENP.


11/12/2007
Coot Bay
Mud Lake
Image USDA Farm Service Agency


A'
B
B'
A
Canal
Road
Ridge


A
A'
B
B'

West-to-east transect of about 400 m across the Coot Bay Hammock showing the sharp gradations between vegetation types

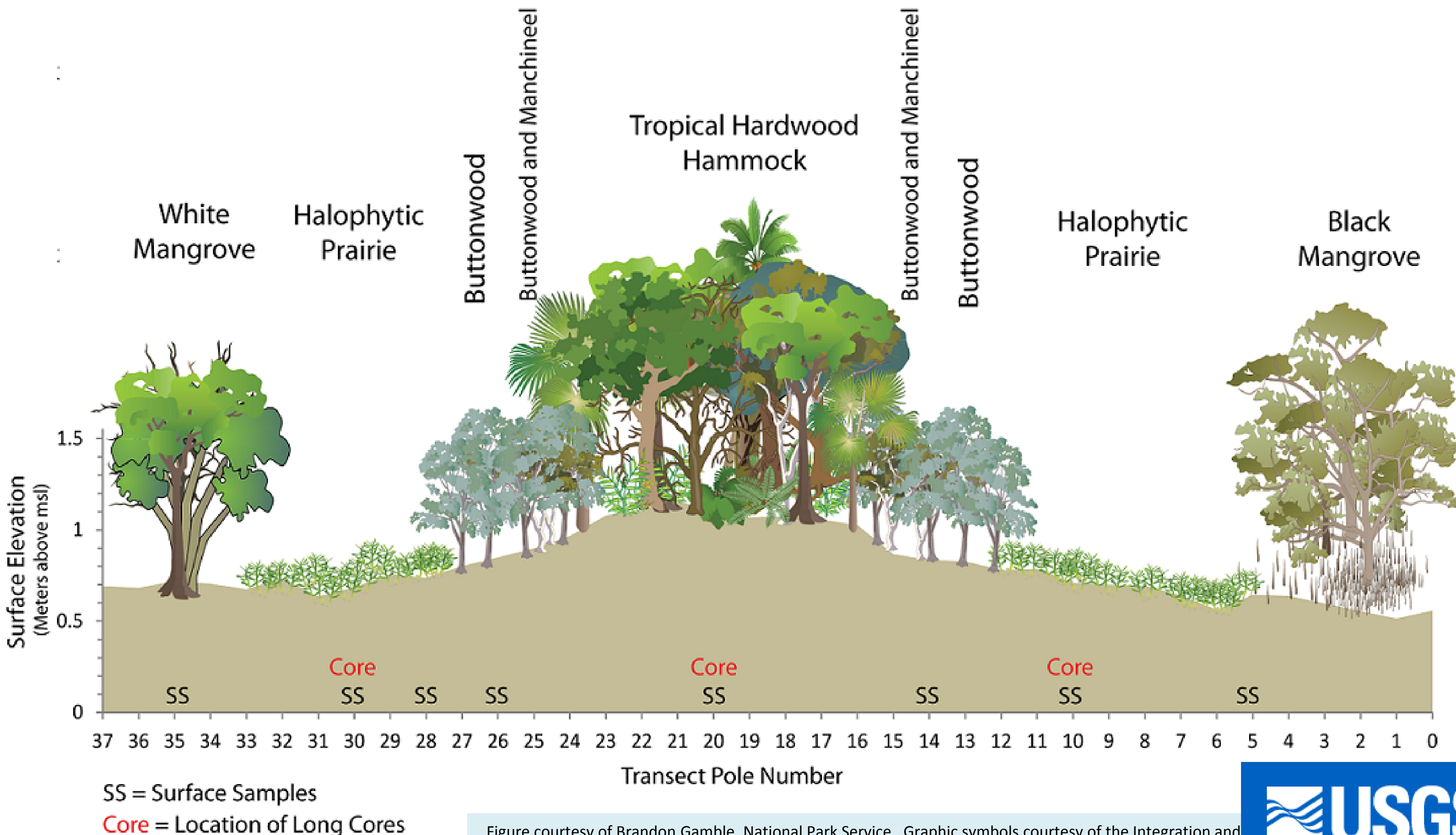


Figure courtesy of Brandon Gamble, National Park Service. Graphic symbols courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces/symbols/).

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Needed Parameters

- Data on groundwater hydrology at study site:
  - Permeability
  - Groundwater and soil salinity (water table)
  - Precipitation
  - Porosity
  - Dispersivity
  - Topography
  - Tidal height
- Data on plant water uptake amount/rate.
- Data on plant growth and physiological parameters.

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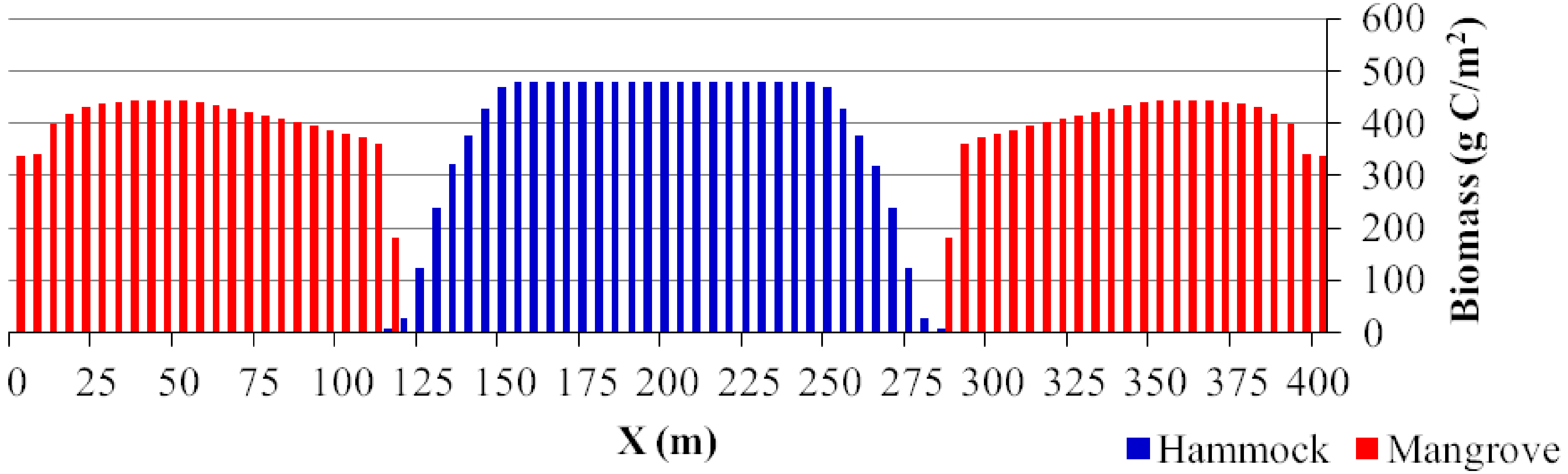
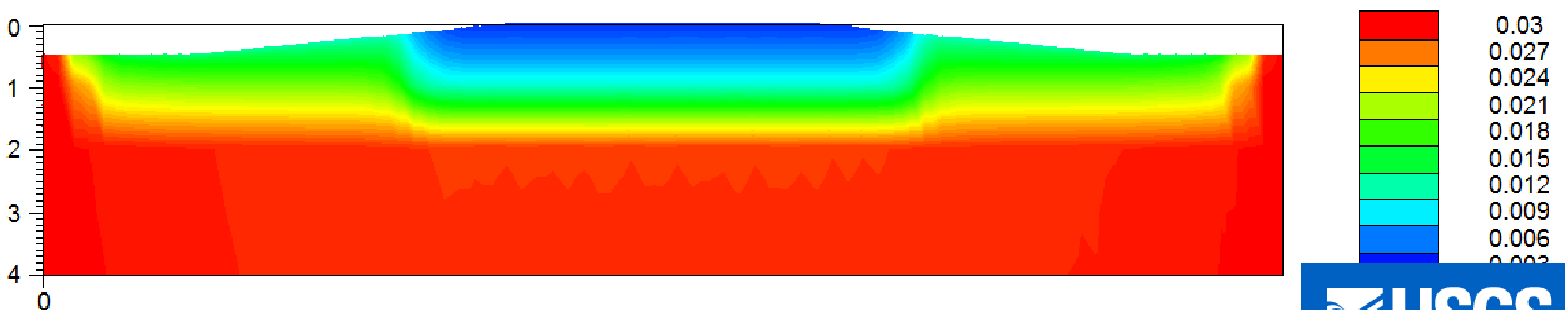
Existing Conditions



Simulated Salinity (kg/kg) Profile for Rowdy Bend



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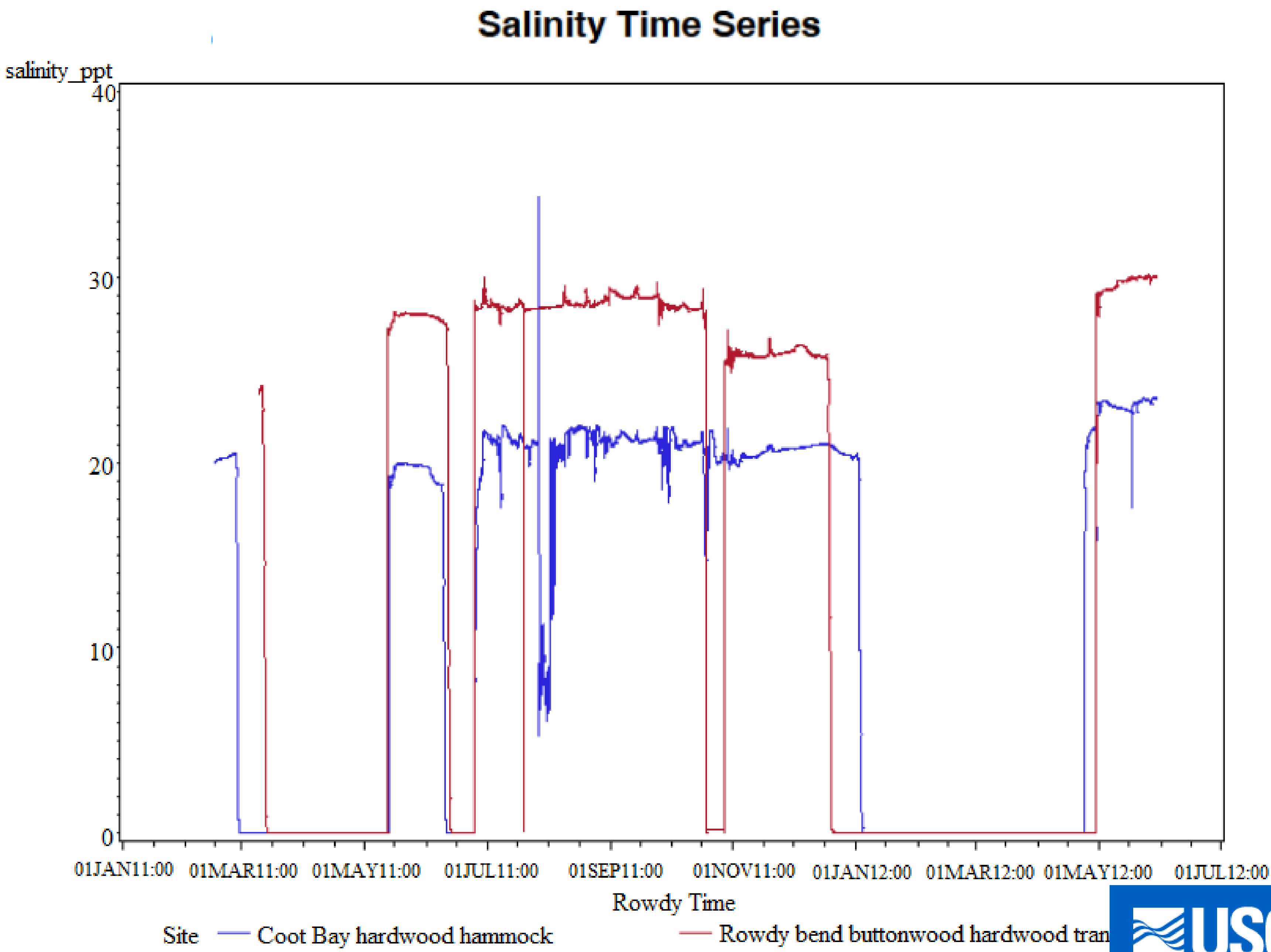
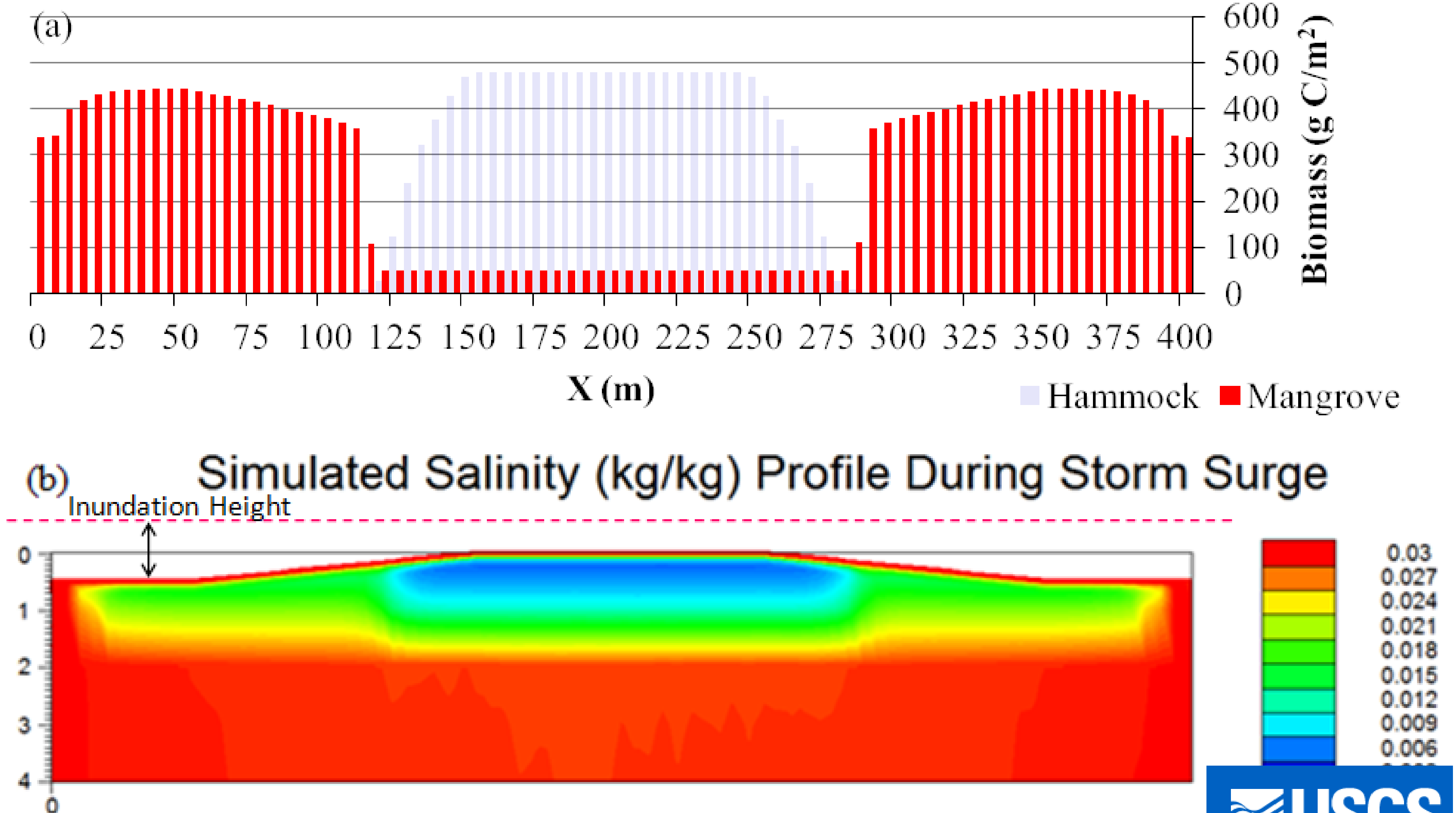

Salinity Time Series
salinity_ppt
40
30
20
10
0
01JAN11:00
01MAR11:00
01MAY11:00
01JUL11:00
01SEP11:00
01NOV11:00
01JAN12:00
01MAR12:00
01MAY12:00
01JUL12:00
Rowdy Time
Site
Coot Bay hardwood hammock
Rowdy bend buttonwood hardwood tran

Storm Surge



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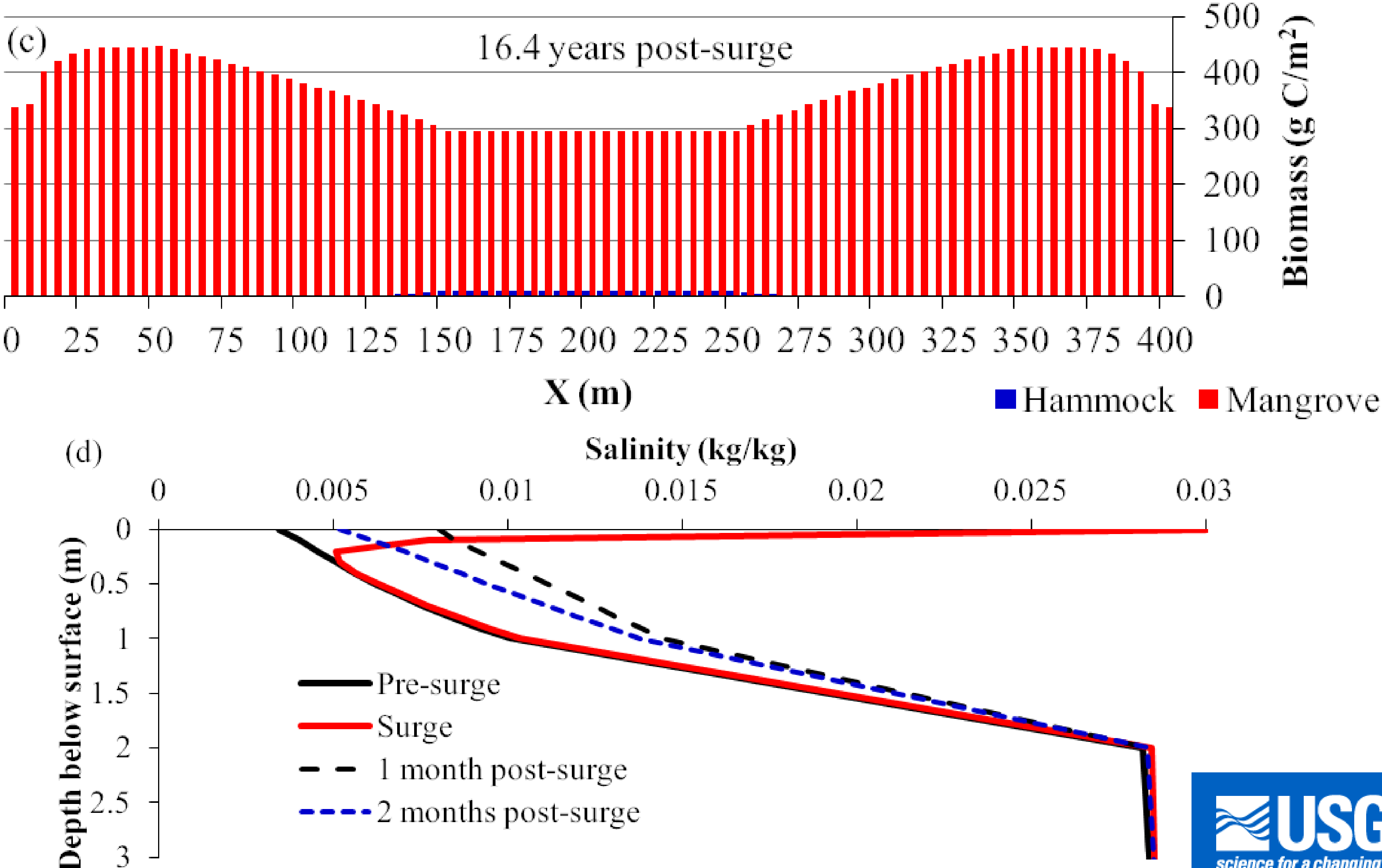
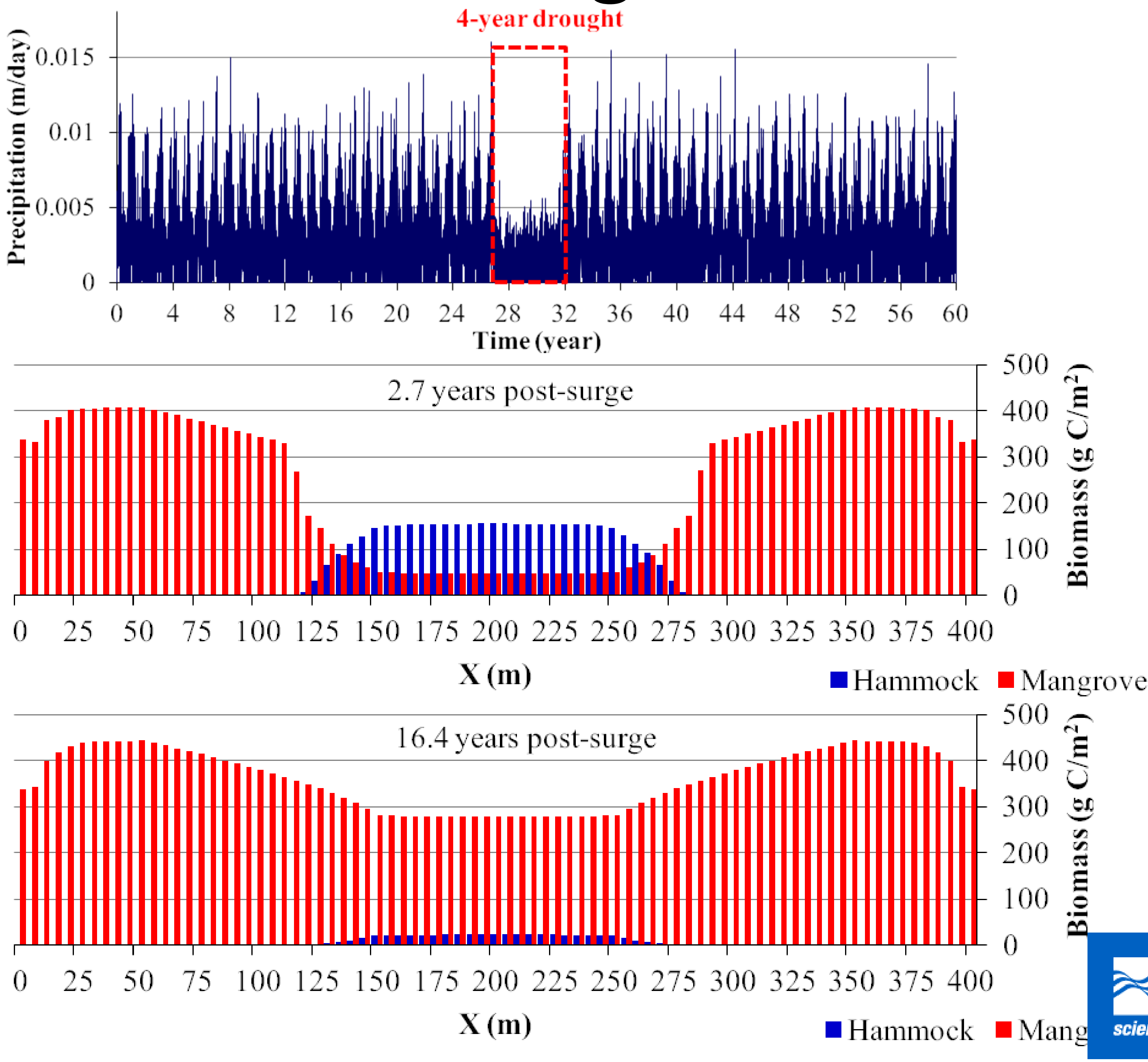
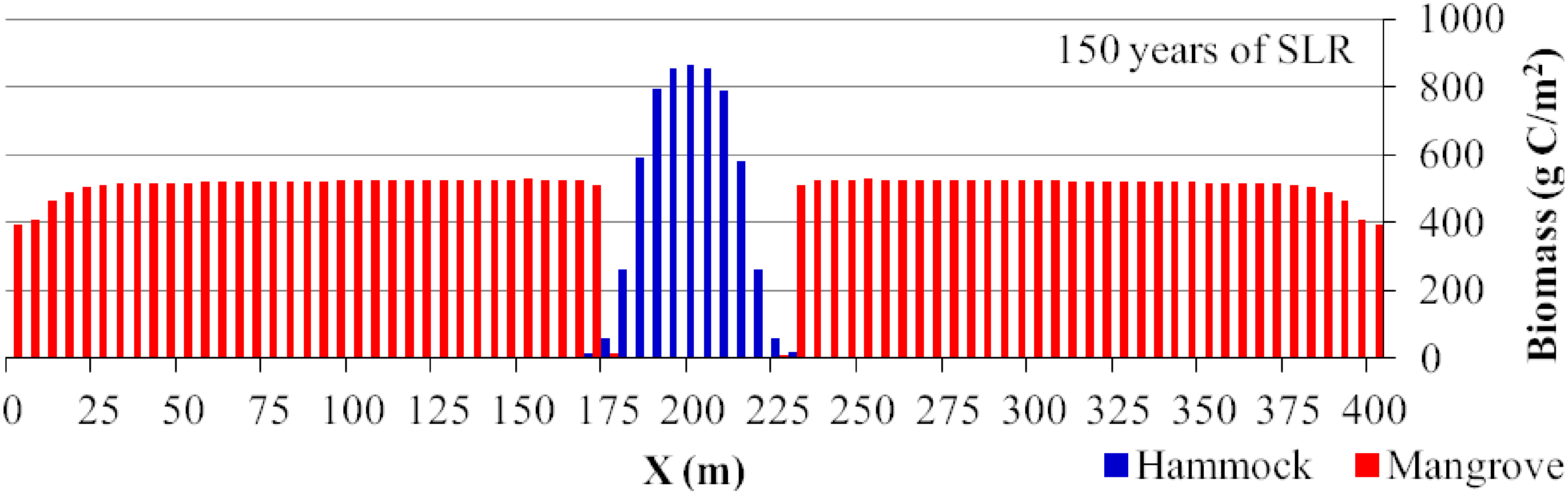
Storm Surge

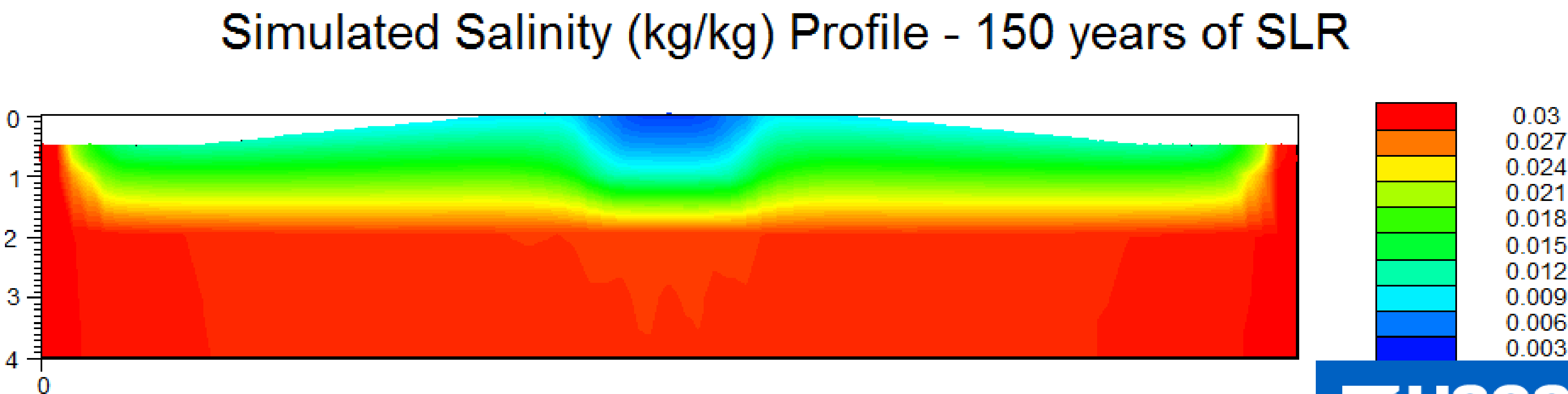

(c)
16.4 years post-surge
500
400
300
200
100
0
Biomass (g C/m²)
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400
X (m)
Hammock
Mangrove
(d)
Salinity (kg/kg)
0 0.005 0.01 0.015 0.02 0.025 0.03
0 0.5 1 1.5 2 2.5 3
Depth below surface (m)
Pre-surge
Surge
1 month post-surge
2 months post-surge

Drought


4-year drought
Precipitation (m/day)
0.015
0.01
0.005
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
Time (year)
2.7 years post-surge
500
400
300
200
100
0
Biomass (g C/m²)
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400
X (m)
Hammock
Mangrove
16.4 years post-surge
500
400
300
200
100
0
Biomass (g C/m²)
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400
X (m)
Hammock

Sea Level Rise





Conclusions

Combining hydrologic models with modeling of competition of vegetation types allows one to project future vegetation changes.

Future Plans

- Get better information on transpiration of mangroves and hardwood hammock trees, as well as other growth and physiological parameters.
- Extend the model to include a buttonwood zone between the mangroves and hardwood hammocks.
- Inclusion of stable isotope, ^{18}O, in water, in the model.
- Extension of model to Waccamaw National Wildlife Refuge, SC.

Acknowledgments

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USGS Greater Everglades Priority Ecosystem Science Program

Assessing the past and potential future impacts of salt water intrusion on tidal swamp habitat along the south Atlantic coast (LLC under Kenneth Krauss)

Past and Future Impacts of Climate Change on Coastal Habitats and Species in the Everglades – An Integrated Modeling Approach (FISCHS). PIs. C. A. Langtimm et al.

Help in Field: Jimi Saddle, Sonali Saha, Kristie Wendelberger

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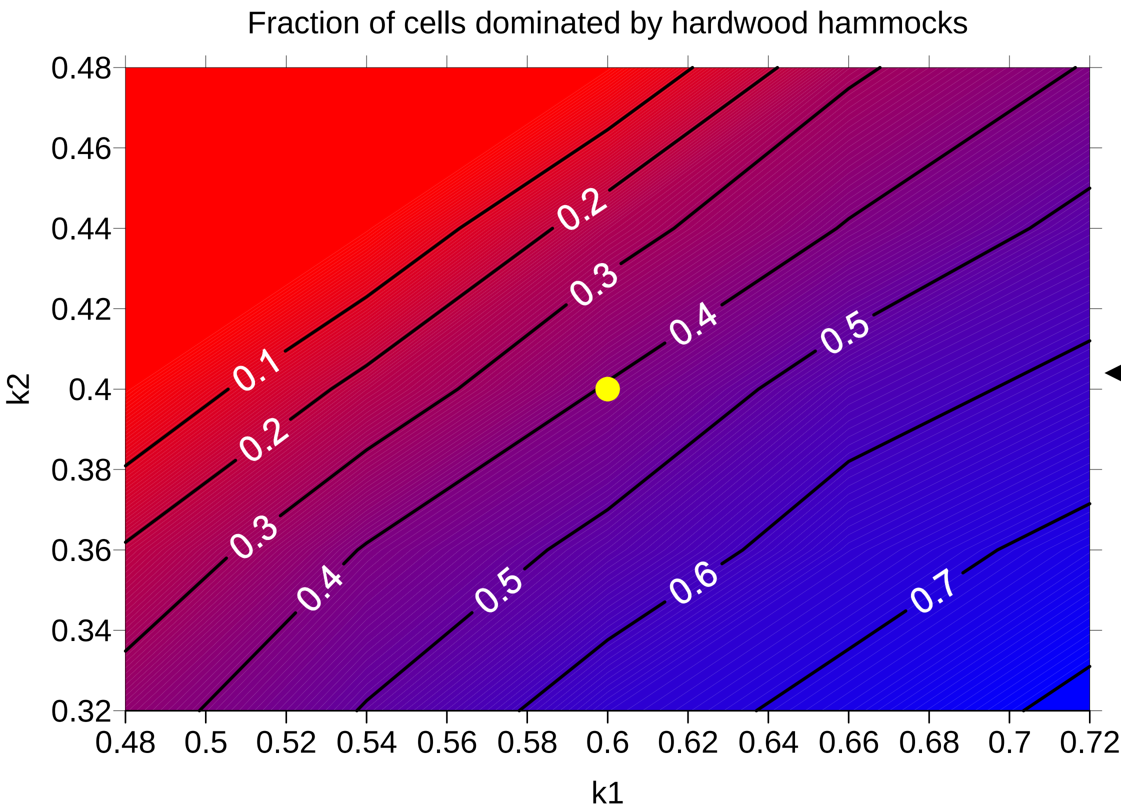
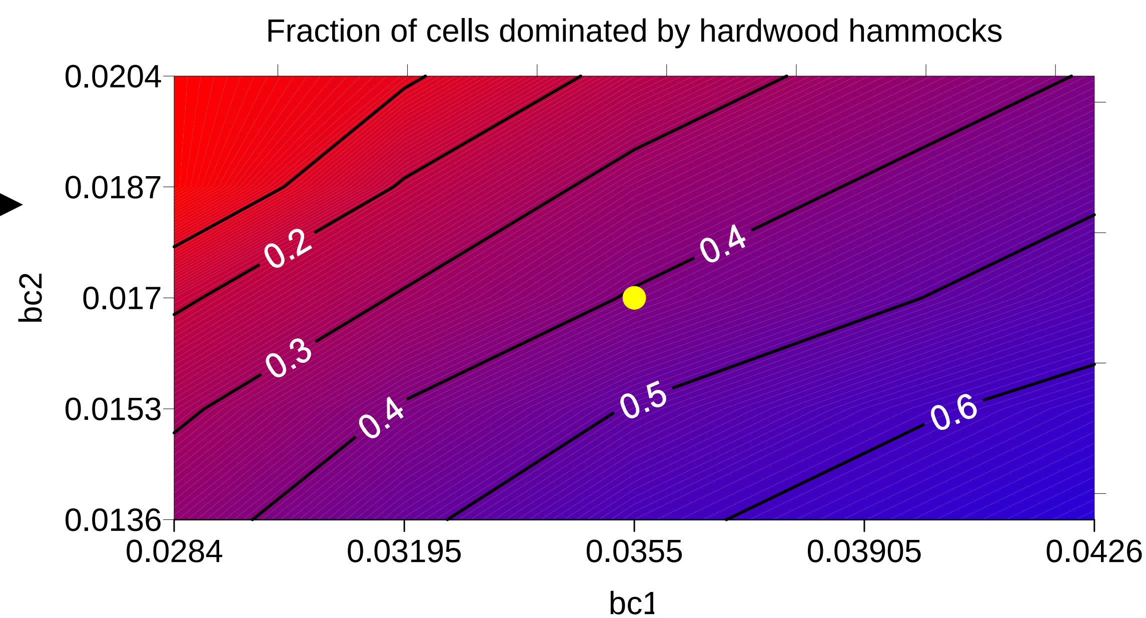
The next figures may be added, but will probably be left out.



Fraction of cells dominated by hardwood hammocks for various values of light extinction coefficients of hardwood hammock (k_1) and mangrove (k_2)

Fraction of cells dominated by hardwood hammocks for various values of leaf area per unit carbon of hardwood hammock (bc_1) and mangrove (bc_2).



MANTRA

Two of our key assumptions in getting a separation of mangroves and hardwood hammocks by a sharp boundary are the following:

- The light extinction coefficient of the hardwood hammocks is effectively greater than that of the mangroves (i.e., hammock trees shade mangroves greater than vice versa).
- Leaf area index is proportional to water uptake rate, $Q_i(S_v)$, not just active tissue carbon, B_{Ai}.

$$Sc_i = bc_i B_{Ai} \cdot Q_i\left(S_v\right)$$

MANTRA Algorithm

1. Read input for MANHAM and SUTRA.
2. Calculate fluid mass available for plant uptake.
3. Calculate plant growth.
4. Calculate source of fluid from random precipitation.
5. Add sink term (2) to the global vector for flow equation.
6. Add source term (3) to the global vector for flow equation and to the global matrix for transport equation.
7. Solve flow and transport equations via SUTRA module.

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