# Effects of Sea Level Rise and Storm Surge Events on Coastal Vegetation Communities


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: Photo: jasoncdukes.files.wordpress.com

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# Subject of talk:

- USGS project on the potential effects of sea level rise on the coastal habitats of southern Florida.

- Aspect discussed here: Possible effects of storm surges on changes in coastal vegetation.

- Collaboration of USGS, University of Miami, Universiti Sains Malaysia

# Sea level is rising at an increasing rate…

- … which is causing a gradual inland movement of the boundary zone between salt-tolerant species (e.g., mangroves) and freshwater species (e.g., sawgrass, freshwater woody vegetation).

- But this rise will also extend farther inland potential effects of discrete disturbances, such as overwash of freshwater vegetation by seawater from storm surge events.

# Overwash events have been implicated in cases of change in coastal terrestrial vegetation

- **Experiment:** Baldwin and Mendelssohn (1998) studied the effects of salinity and inundation coupled with clipping of aboveground vegetation on two adjoining plant communities, *Spartina patens* and *Sagittaria lancifolia*. The study concluded that the vegetation might shift to a salt-tolerant or flood-tolerant species, depending on the level of flooding and salinity at the time of disturbance.

- **Hurricane:** Hurricanes Katrina and Rita (2005), which affected the coastal areas of Louisiana, created large storm surges. Subsequent changes in the vegetation have been identified in both freshwater and brackish communities, as studied by Steyer et al. (2010).

- **Tsunami:** "By far the worst effect on soils was the extent to which the tsunami deposited salt from seawater. The change in soil composition impacted local vegetation and agricultural productivity and home food gardening…" (MALDIVES Post-Tsunami Environmental Assessment. United Nations Environment Programme)

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… and it is possible that salinity inundation is damaging forests in Florida, possibly leading to vegetation shifts.


Slide from Mike Ross

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The possibility of permanent vegetation change over large overwash areas is of special concern.

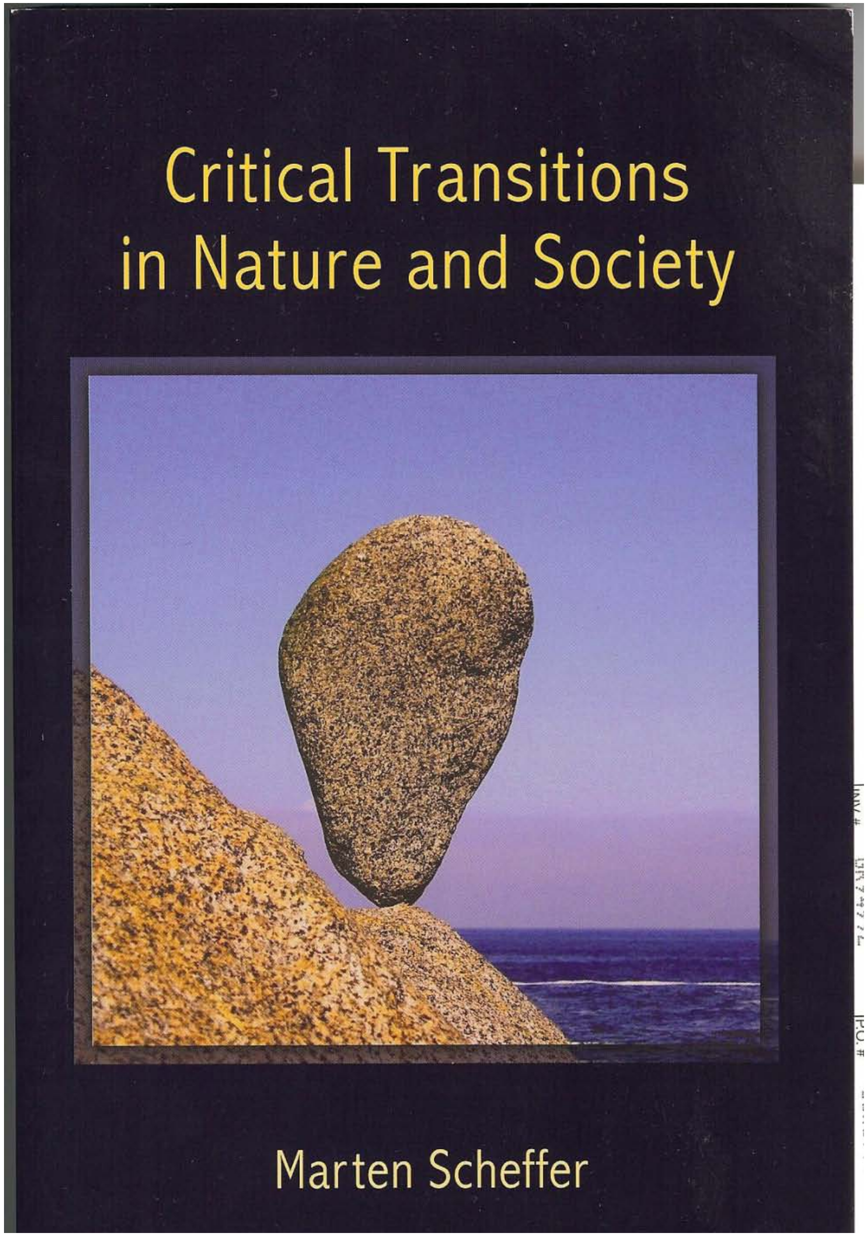
When such vegetation changes due to disturbance are permanent ones, through self-reinforcing processes, they can constitute 'ecological regime shifts'.

## Regime shifts

“Regime shift – a relatively sharp change from one regime to a contrasting one, where a regime is a dynamic ‘state’ of a system” Scheffer 2009

Large perturbations can shift some systems from one regime to another.

A regime shift is typically permanent, or at least very hard to reverse (hysteresis).




This book describes the mathematical theory of regime shifts

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Can a storm surge cause a massive regime shift of vegetation in the coastal Greater Everglades or other regions?

Work so far is the beginning of an attempt to understand how a storm surge of this sort might cause a major regime change.

This is part of our larger current project…

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Project: "Past and Future Impacts of Climate Change on the Coastal Habitats and Species in the Everglades – An Integrated Modeling Approach" USGS Global Climate Program.

PIs: **Catherine Langtimm**, Thomas J. Smith, Dennis Krohn, Brad Stith, Eric Swain, Donald L. DeAngelis, USGS.

Collaborators: Hock-Lye Koh and Su-Yean Teh, Universiti Sains Malaysia, Leo Sternberg, University of Miami

# FISCHS

## SLR Integrated Models

### Current

FTLOADDS hydrology models

Observed data for period of record

Hurricane Wilma

**Vegetation & land elevation change mechanisms**

Output for HIS, SESI and other models

### Hindcast

Modified BISECT hydrology model

Observed & interpolated climate & SLR data

Historical hurricanes

Validate output against historic vegetation charts & photos

### Forecast

New core model from Hindcast

Downscaled climate & SLR data

Management-specified scenarios

Output appropriate for HSI, SESI and other models

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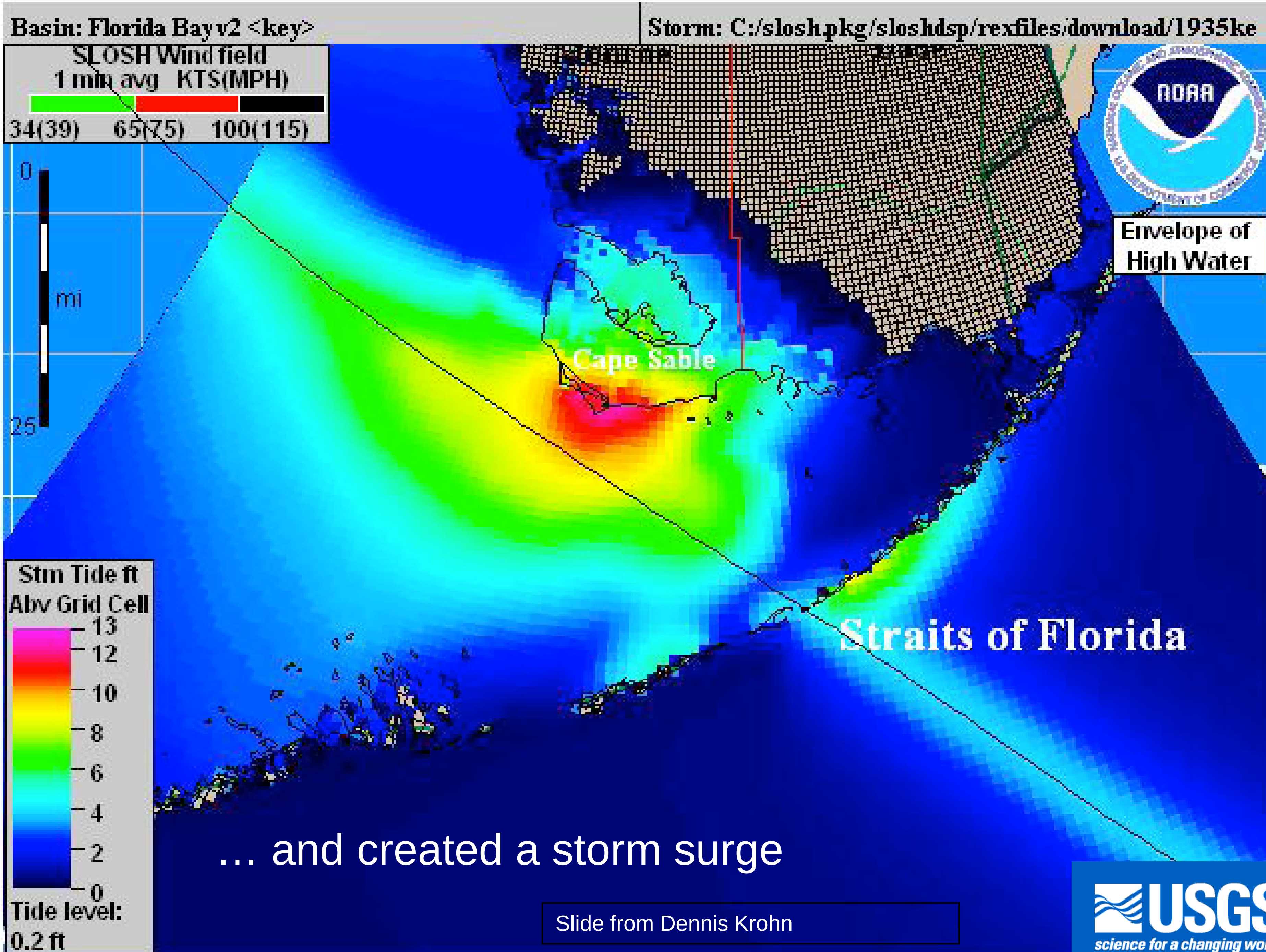
# Example of storm surge: The 1935 “Labor Day” hurricane passed close to Cape Sable.


Slide from Dennis Krohn




… and created a storm surge

Slide from Dennis Krohn

So far our work has been to try to understand the mechanisms maintaining the boundaries between glycophytic (freshwater) and halophytic (salt-water tolerant) vegetation types - and how these mechanisms might be overcome by a disturbance.

Some of this work has been published…

Teh, S. Y., D. L. DeAngelis, L. S. L. Sternberg, F. R. Miralles-Wilhelm, T. J. Smith, and H.-L. Koh. 2008. A simulation model for projecting changes in salinity concentrations and species dominance in the coastal margin habitats of the Everglades. *Ecological Modelling* 213:245-256.

Sternberg, L. da S. L, S.-Y. Teh, S. Ewe, F. Miralles-Wilhelm, and D. L. DeAngelis. 2007. Competition of hardwood hammock and mangrove vegetation. *Ecosystems* 10:648-660.

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Mangrove and tropical hardwood hammocks are two types of Everglades vegetation that overlap in geographic area, though generally hardwoods occupy slightly higher elevation.

Mangroves (halophytic)

Hardwood Hammock (glychophytic)

# Empirical Observations

Typically, mangrove and hardwood hammock trees are not interspersed. Sharp ‘ecotones’ (transition zones) typically separate the salinity tolerant mangroves from the salinity intolerant hardwood hammock species, which occupy the similar geographical areas of southern Florida.

(Snyder et al., in *Ecosystems of Florida, 1990;* Sternberg et al., *Ecosystems* 10:648-660, 2006)

Mangrove-Hardwood Hammock Boundary – Key Largo


**This sharp boundary is maintained despite only a tiny elevation gradient**

# Mechanisms of Boundary Stability

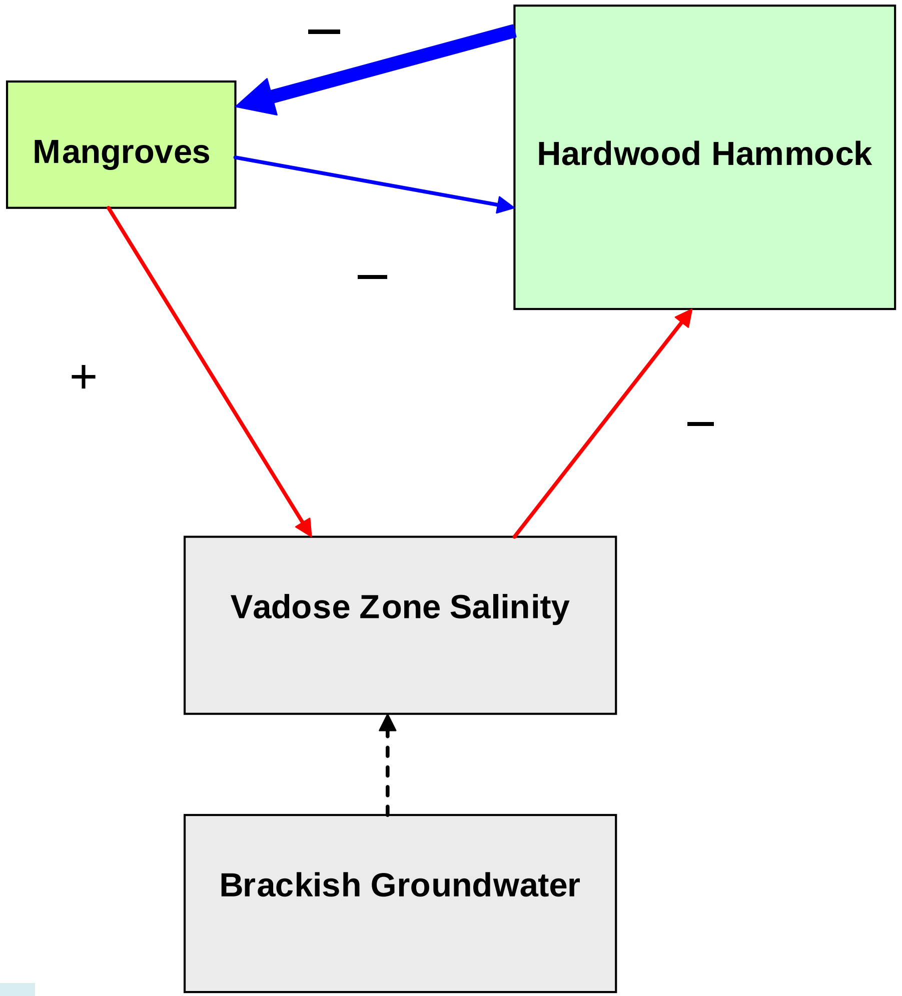
The following mechanisms underlie both the normal stability of the ecotone and possibility of a shift in the ecotone.

Both mangroves and hammock species obtain their water from the vadose zone (unsaturated soil zone). In coastal areas this vadose zone is underlain by highly brackish ground water, so that evapotranspiration, by depleting water in the vadose zone during the dry season, can lead to infiltration by more saline ground water.

Although hardwood hammock trees tend to decrease their evapotranspiration when vadose zone salinities begin to increase, thus limiting the salinization of the vadose zone, mangroves can continue to transpire at relatively high salinities.  Thus, each vegetation type tends to promote local salinity conditions that favor itself in competition, which helps explain the stability of sharp boundaries between the types.

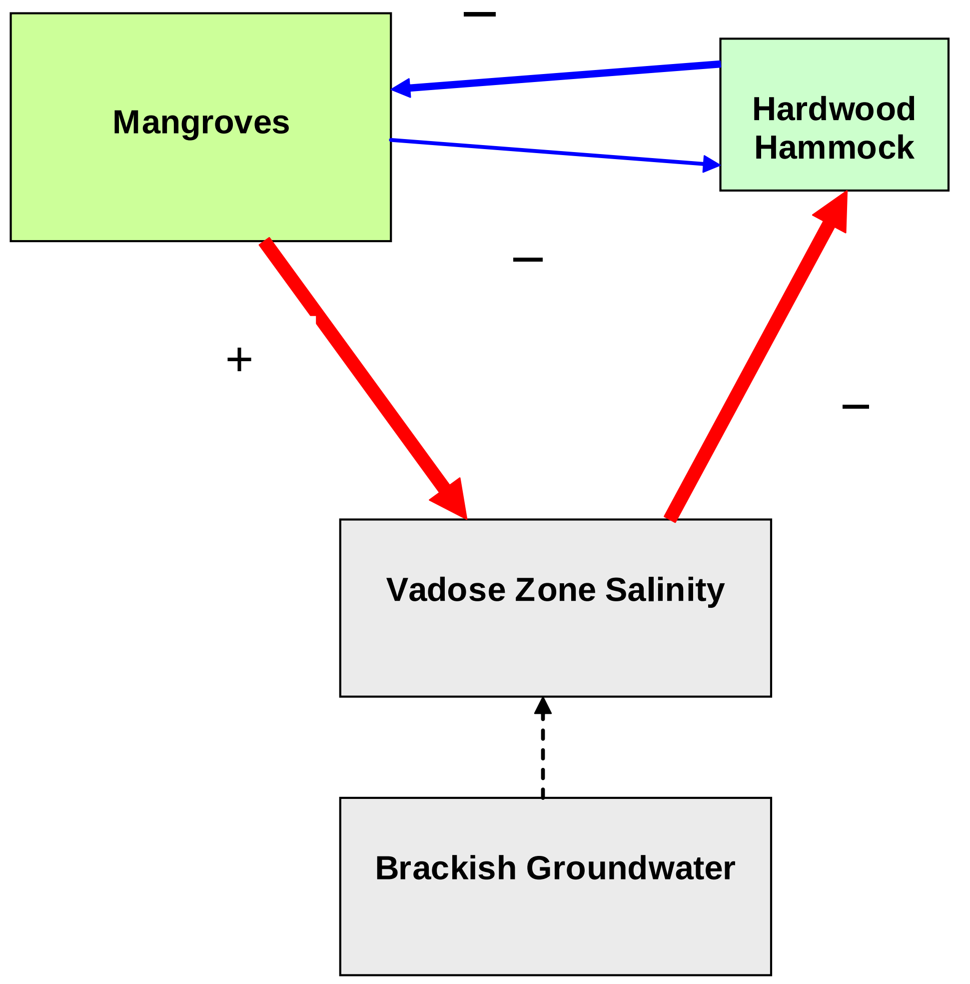
At low initial salinities and small mangrove densities, hammock trees outcompete mangroves.

The low mangrove density has only a weak indirect negative effect on hammock trees through a positive effect on vadose zone salinity.



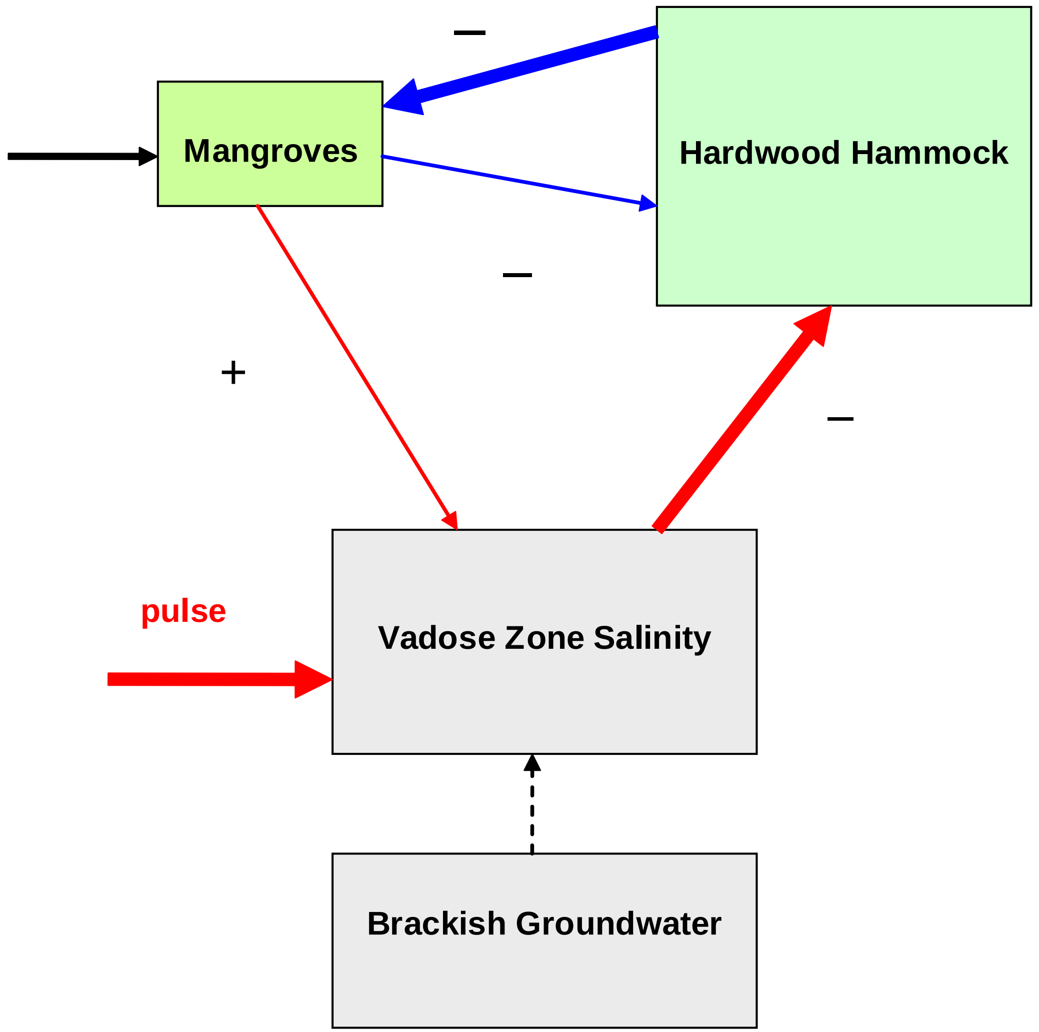

So hammock trees dominate.

At higher initial densities, mangroves have enough indirect negative effect on hammock trees to overcome the more direct competitive effects.




So mangroves dominate.

But, in initially hammock-dominated areas, a temporary increase in salinity may (if accompanied by mangrove propagules) provide enough of a push to trigger the feedback loop operating against hammock trees and for mangroves and overcome the hammock's competitive advantage.



# Possibility of a sudden large-scale mangrove-hardwood boundary shift

This suggests that sharp upward salinity perturbation of an area initially dominated by hardwood hammock, by reducing hardwood tree growth and favoring invasion by a few mangroves, may lead to a positive feedback cycle of increasing salinity and increasing mangrove invasion.

This could lead to rapid large scale shifts in vegetation.

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# Quantitative Model: MANHAM Code

(S.-Y. Teh et al.)

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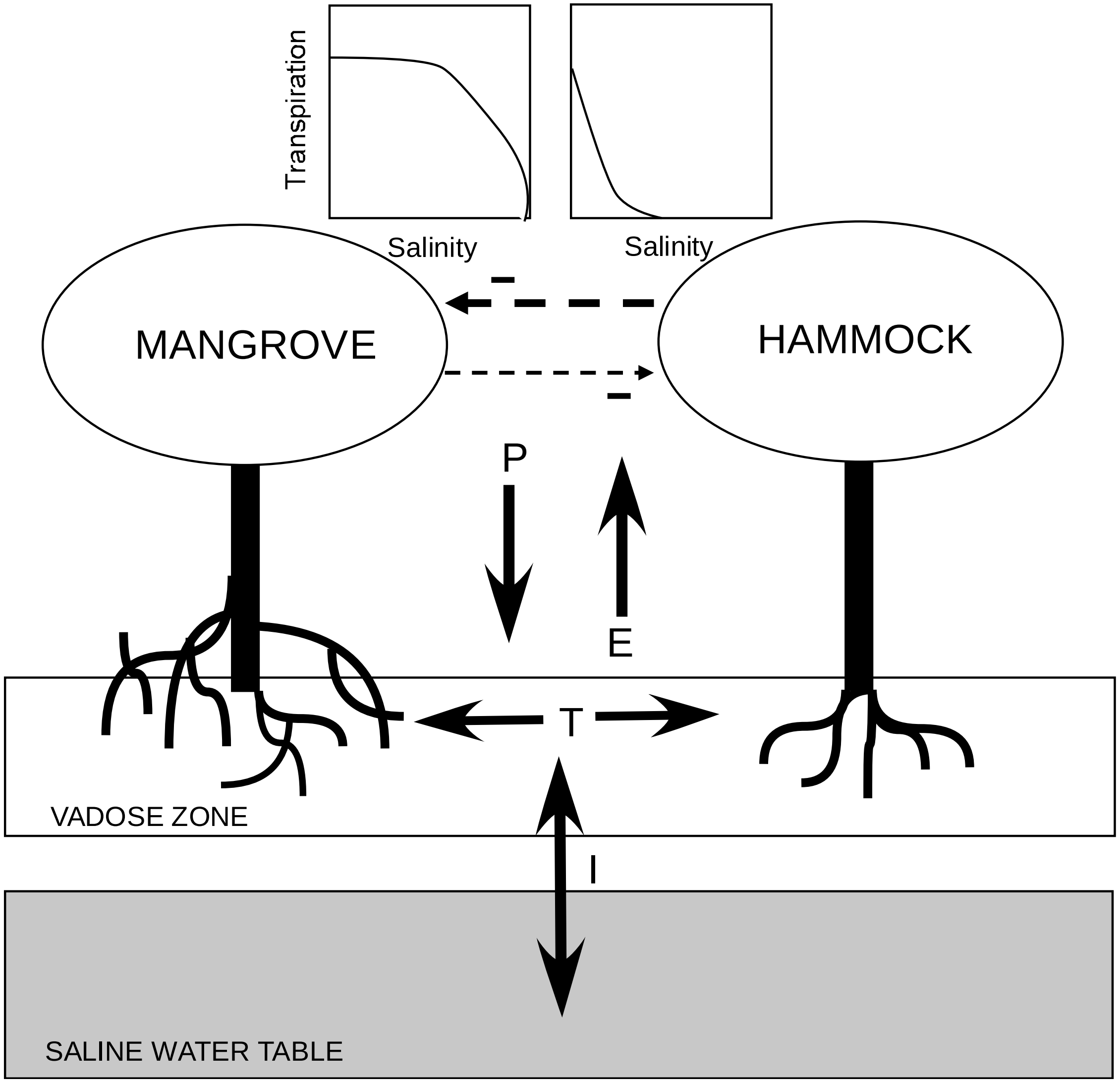
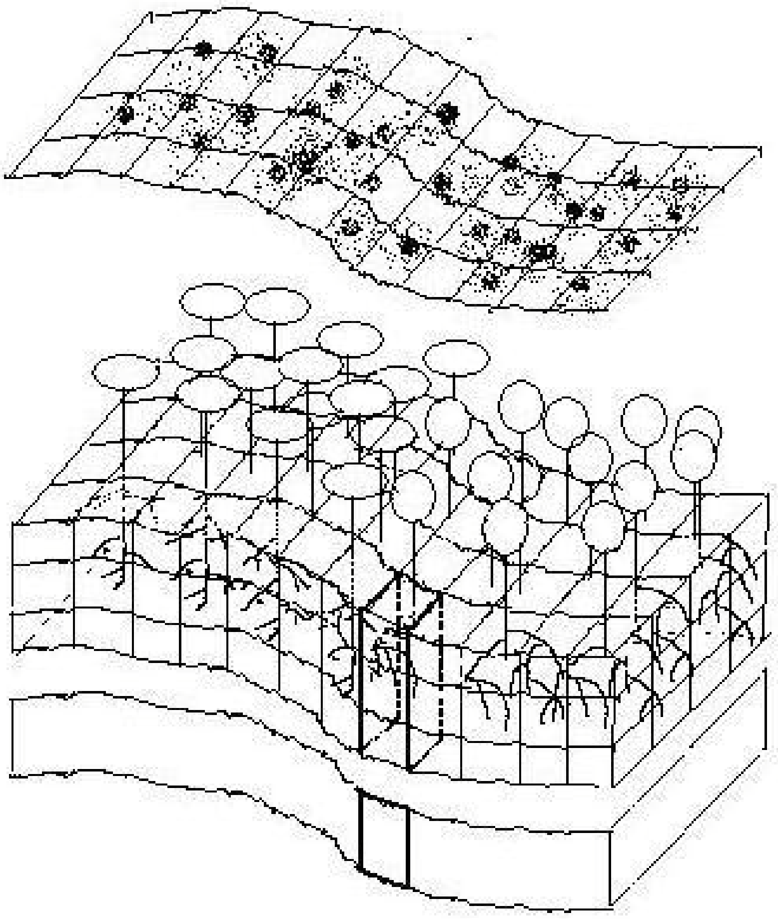
**The model simulates competition between mangroves and tropical hardwood hammock trees on a landscape, including hydrologic and salinity processes in the vadose zone (unsaturated zone, roughly the rooting zone).**



# Model overview

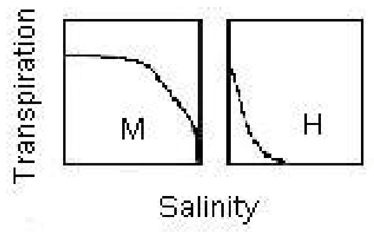


- Vegetation dynamics was simulated in a two-dimensional continuous coordinate system.

- Hydrodynamics was modeled in a grid-based three-dimensional soil space using several stacked layers

# Submodels
# ---Soil water and salinity dynamics

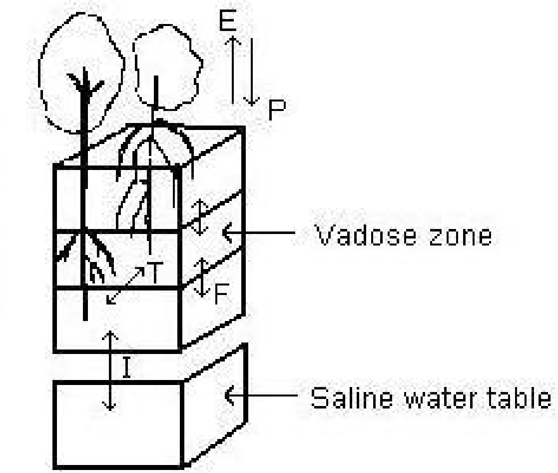
- Soil water fluxes were simulated by Darcy's equation




$$\theta \frac{\partial Sv}{\partial t} = TSv - F \frac{\partial Sv}{\partial z}$$

salinity increase due to uptake of water by roots

salinity change due to water fluxes



# Submodels
# ---Vegetation growth module

- Use classic gap model (FORET) as basic framework.

- Three factors were modeled as multiplier

  *light*: the fraction of available light captured

  *neib*: shading competition from neighboring trees

  *sal*: depression in growth due to salinity in the vadose zone

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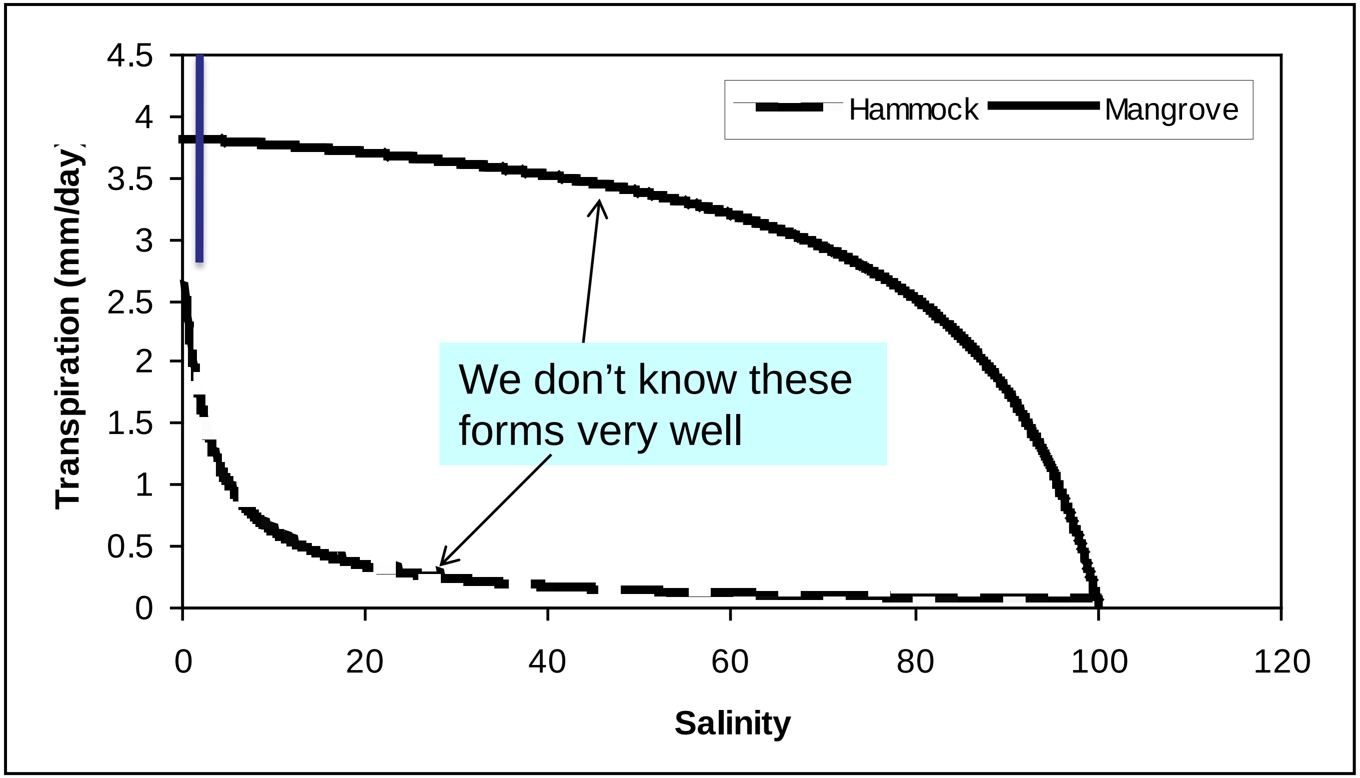
# Transpiration (mm/day) of mangrove vegetation and by freshwater hammocks as a function of vadose pore water salinity.



# Abiotic Processes

- The salinity in a given spatial cell is determined first of all by the difference between the precipitation, *P*, which brings in fresh water to the top of the vadose zone, and the evaporation, *E*, and plant uptake of water

- Tidal effects were imposed on a daily basis on all spatial cells at elevations low enough to be affected. Daily tidal height was generated from NOAA data on monthly means and standard deviations.

- Horizontal diffusion of salinity between spatial cells was based on literature data.

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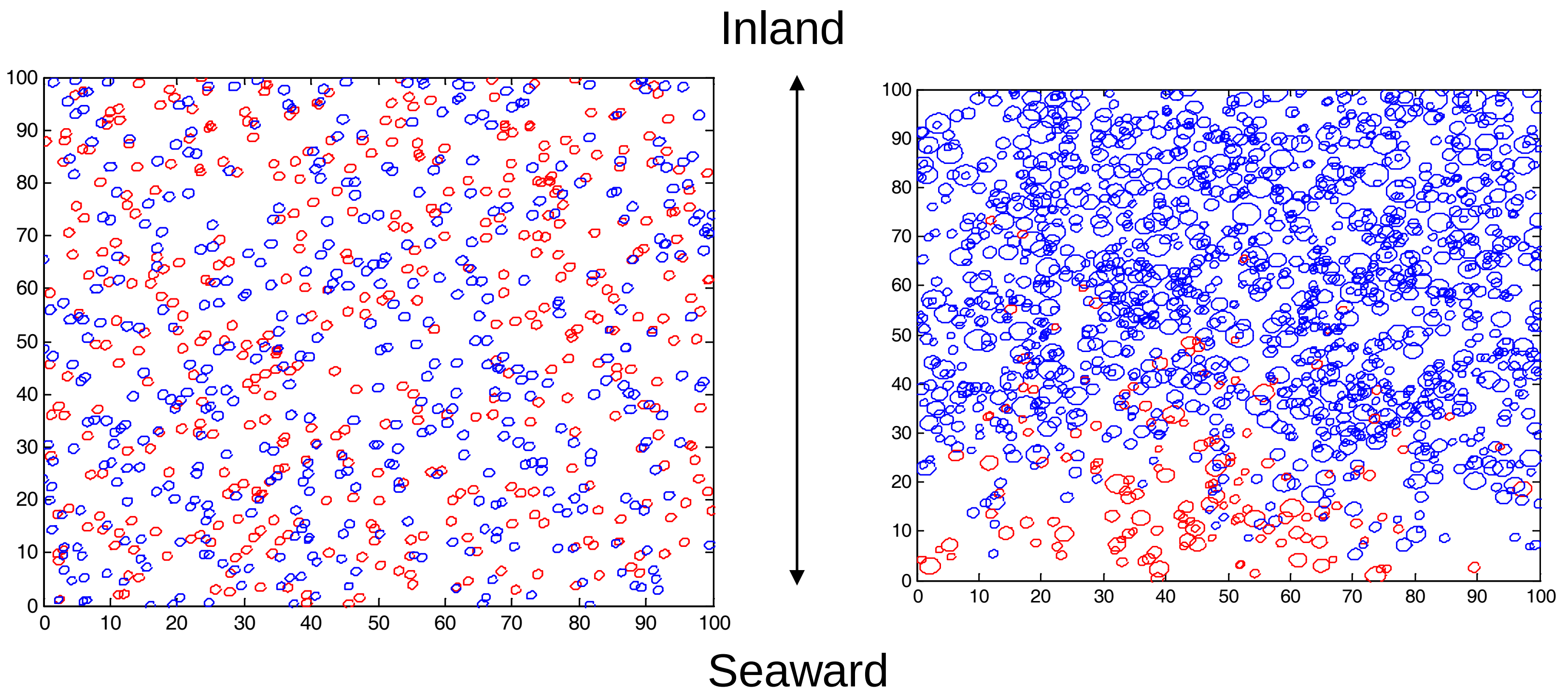
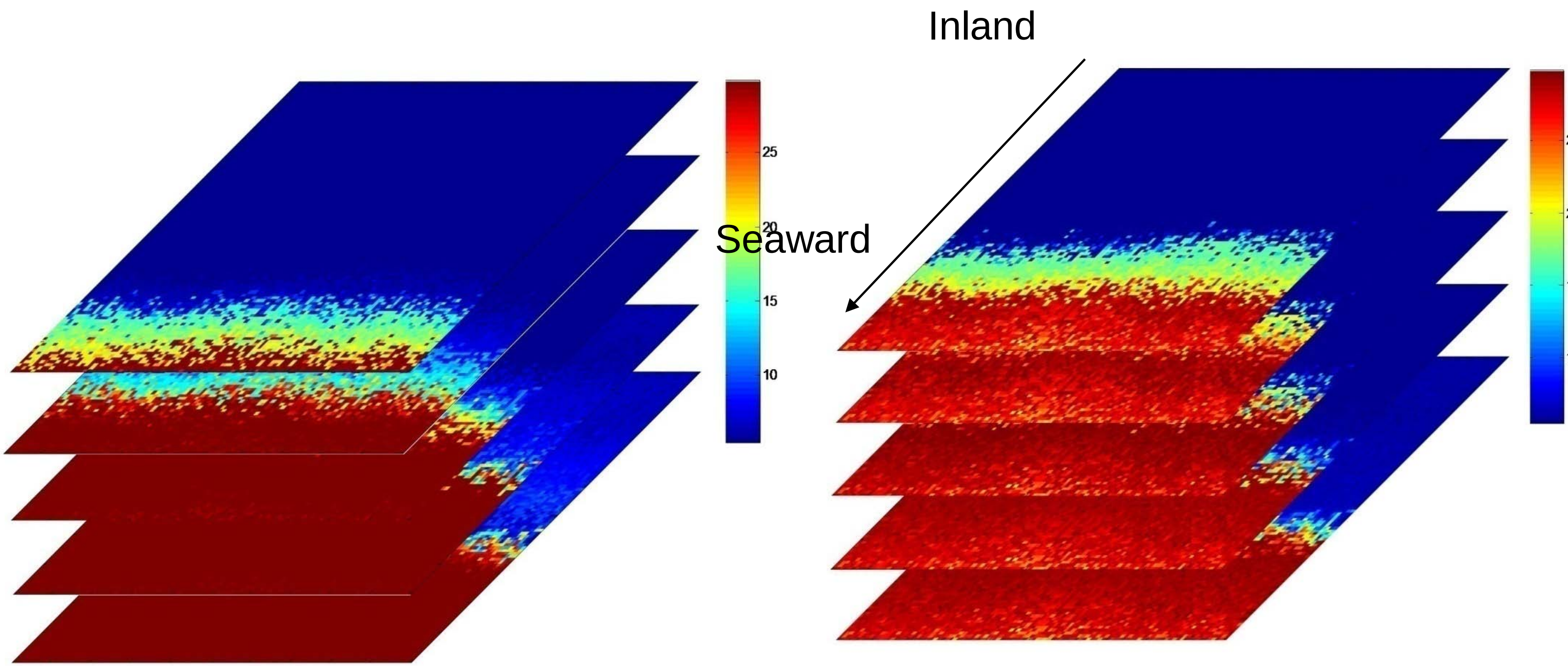
## Results: If we start with an initially random distribution of mangroves and hammock trees, we always get boundary formation of trees…




Hardwood hammock (blue) and mangrove (red), with random initial distribution (left) and 50 years' simulation (right). After 50 years hammock retreat to inland side. The boundary is self-reinforcing and leads to a sharp salinity gradient in the vadose zone.

# … and a sharp salinity gradient form at each depth within the vadose zone.




Dry Season

Wet Season

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# Now we ask the question...

What happens if there is a brief overwash event from a storm surge?

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# Method of Performing Simulations

We simulated this system over 50 years (18,250 days).

The storm surge was assumed to take place after 10,000 days (27.4 years), flooding the entire study domain for one day at 30 ppt.

After the inundation, processes of precipitation, tides, and evapotranspiration acted on each cell and vegetation was allowed to undergo succession.  The simulation was continued for an additional 23 years.

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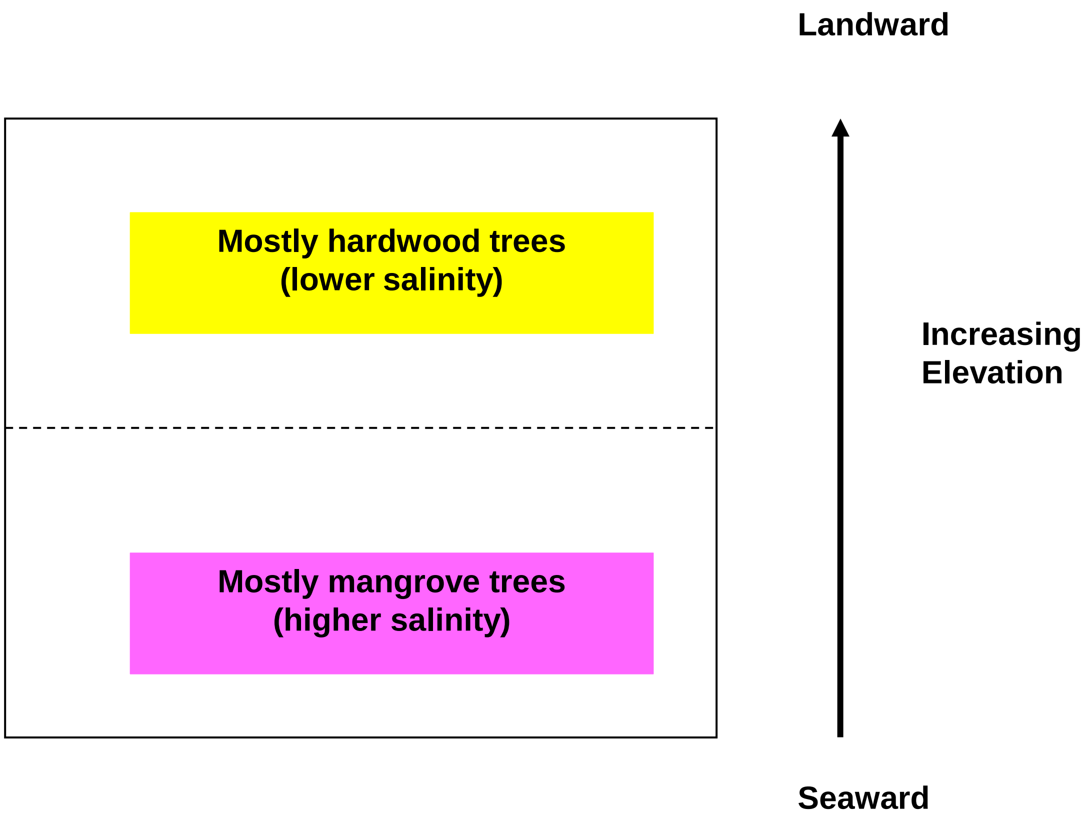
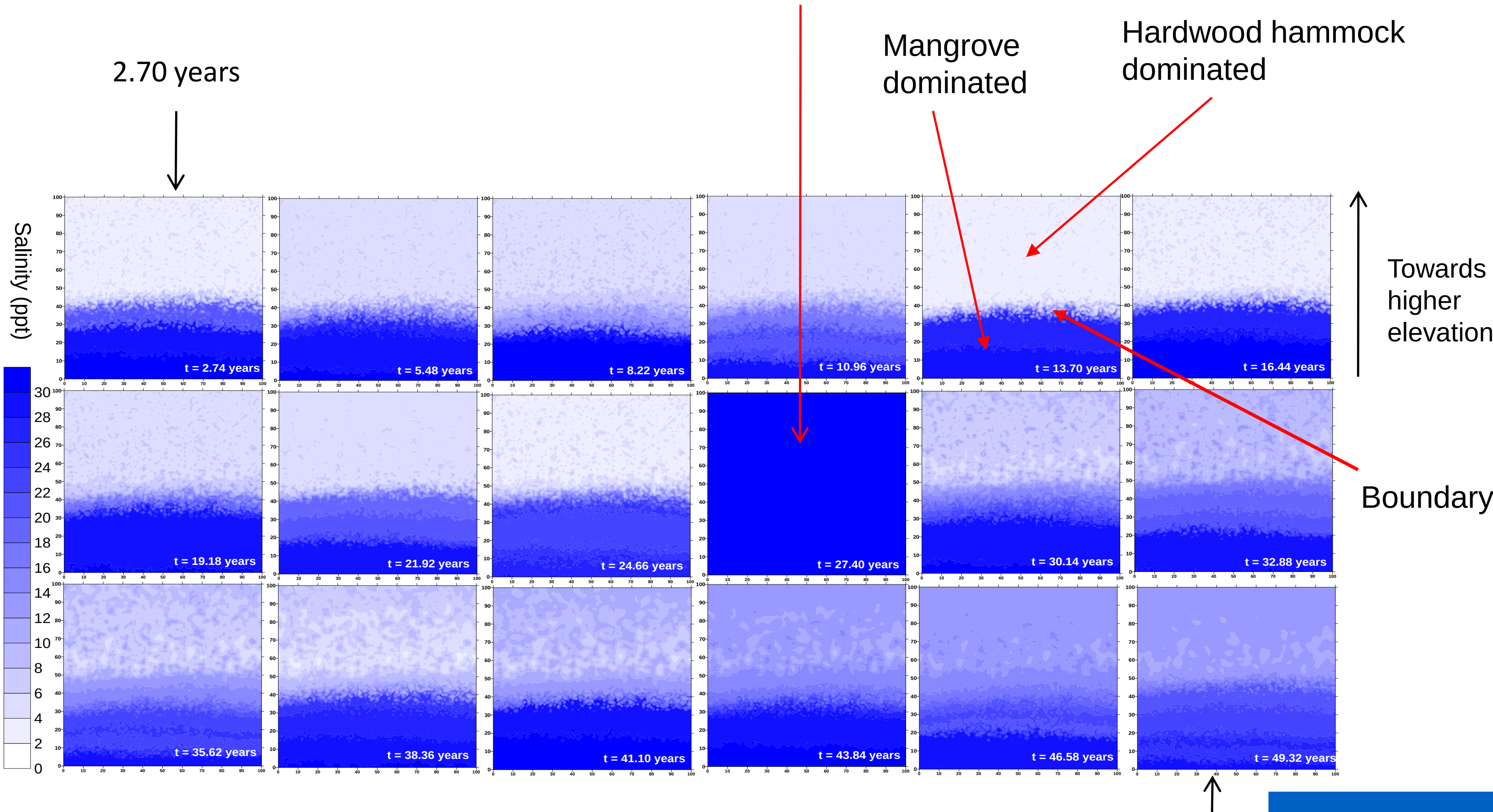
**We start a model simulation with an area of land initially dominated by mangroves at its lower elevations and by hardwood trees at the higher elevations. All spatial cells could be settled by propagules of each vegetation type.**



Snapshots of soil salinity (ppt) across the landscape at time intervals of 2.74 years. Darker colors indicate higher salinity. Frame 10 shows the day on which the entire area was inundated by the storm surge.




Darker blue is higher salinity

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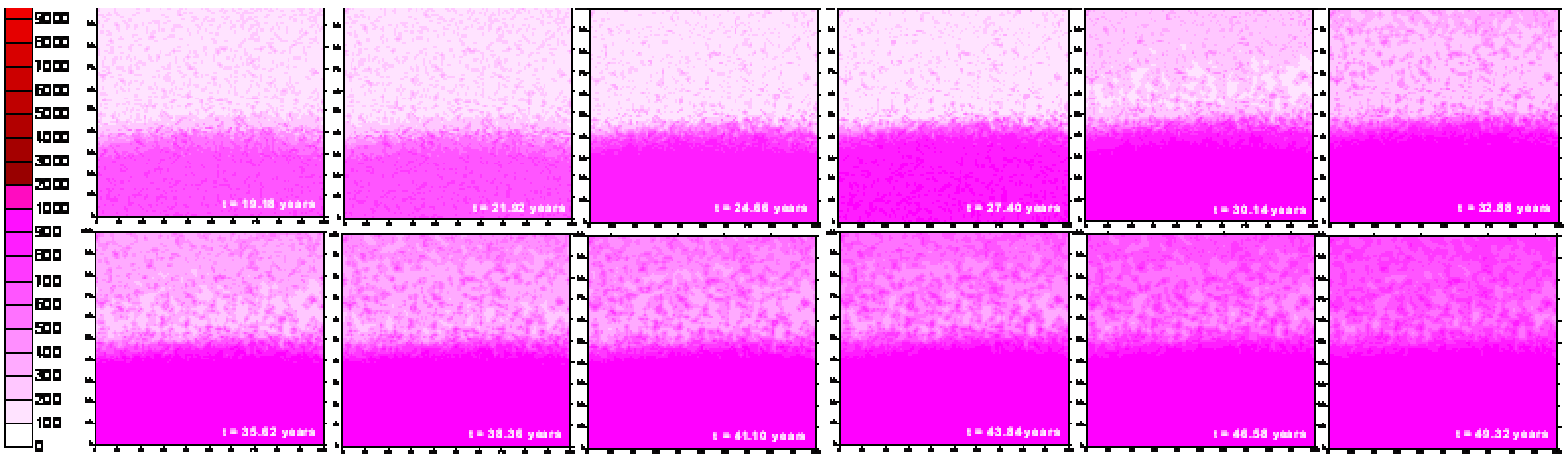
Distribution of mangroves across the landscape at intervals at intervals of 2.74 years during the heavy storm surge (left to right then down).

**19.18 years**

**27.4 years ; storm surge**




Darker magenta is higher mangrove density

**50 ye**

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# Conclusion

The model suggests that sudden intense inundations on saline water (from storm surges) can cause major shifts in coastal ecosystems..

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# Future work

Extend model to different vegetation types.

Combine with remote sensing methodologies to detect early signs of impending regimes shifts in vegetation.

Thank you

Questions?

Slide from Hal Wanless