Tree Islands: Landforms and Underlying Biotic Feedbacks

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Similar Dynamics - more complex landscape: Everglades freshwater system

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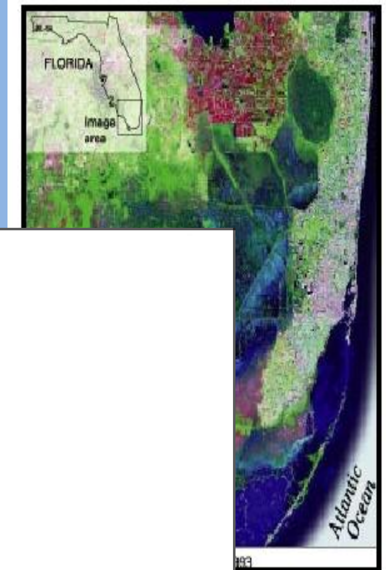
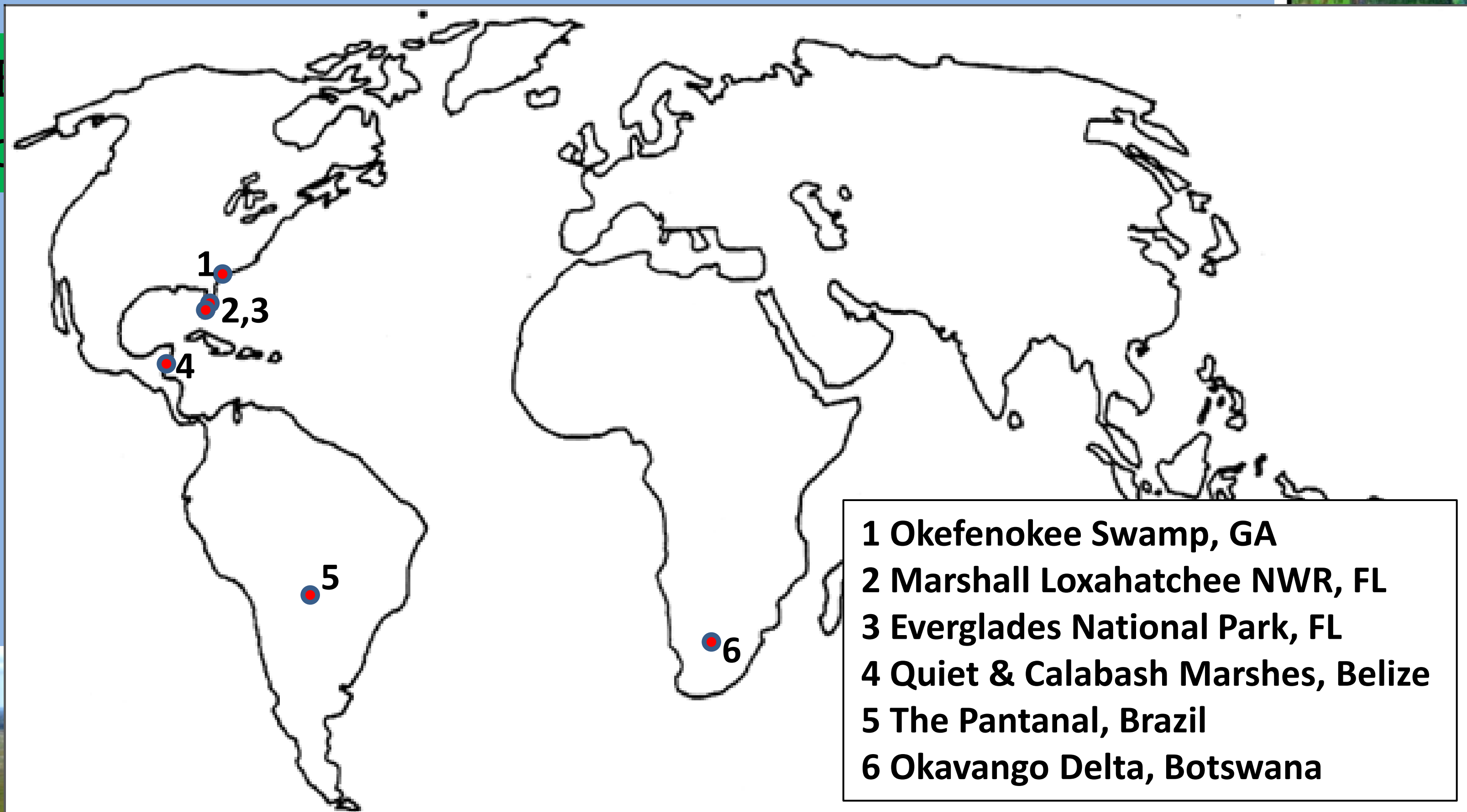
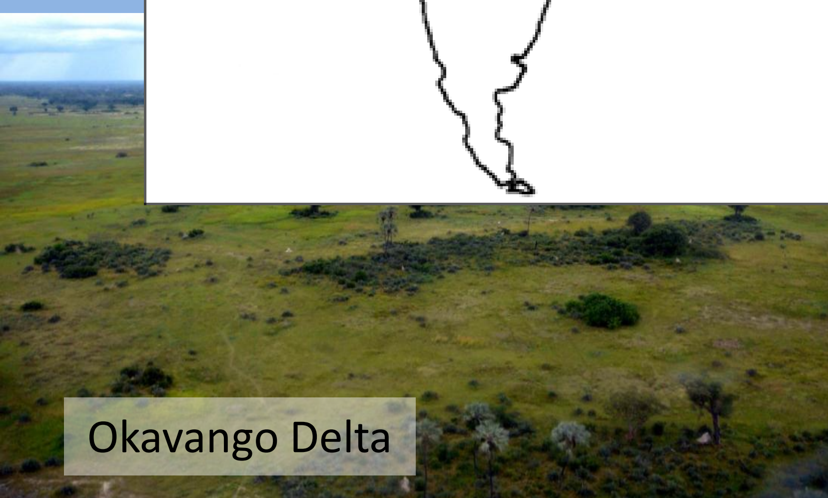
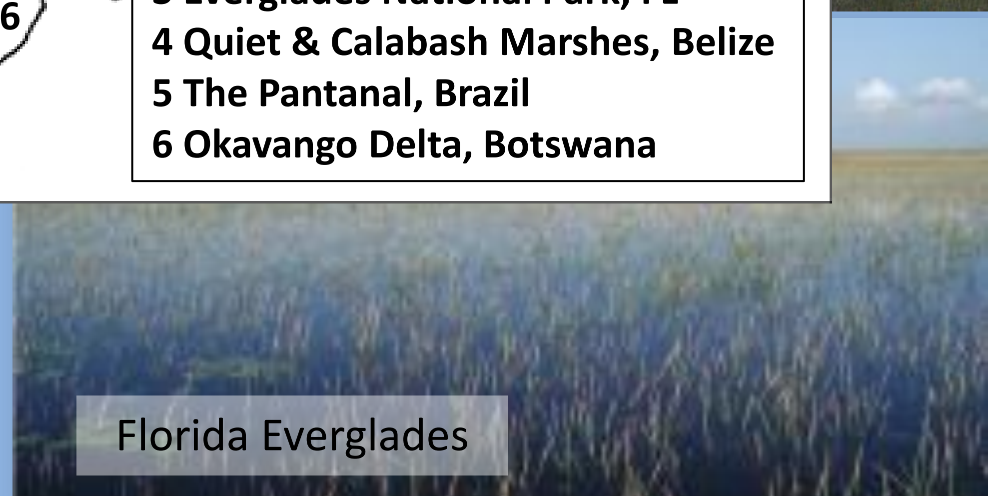
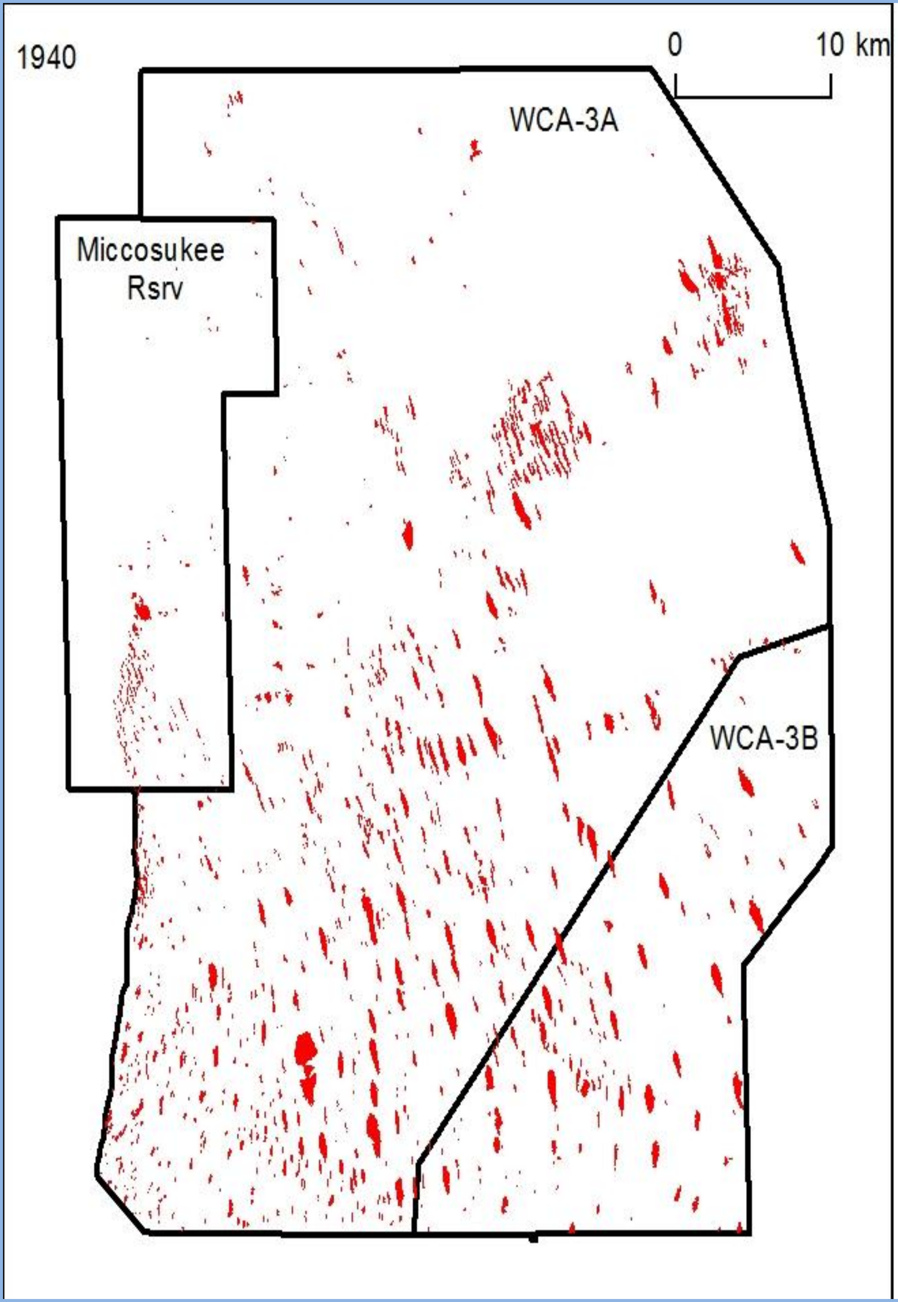
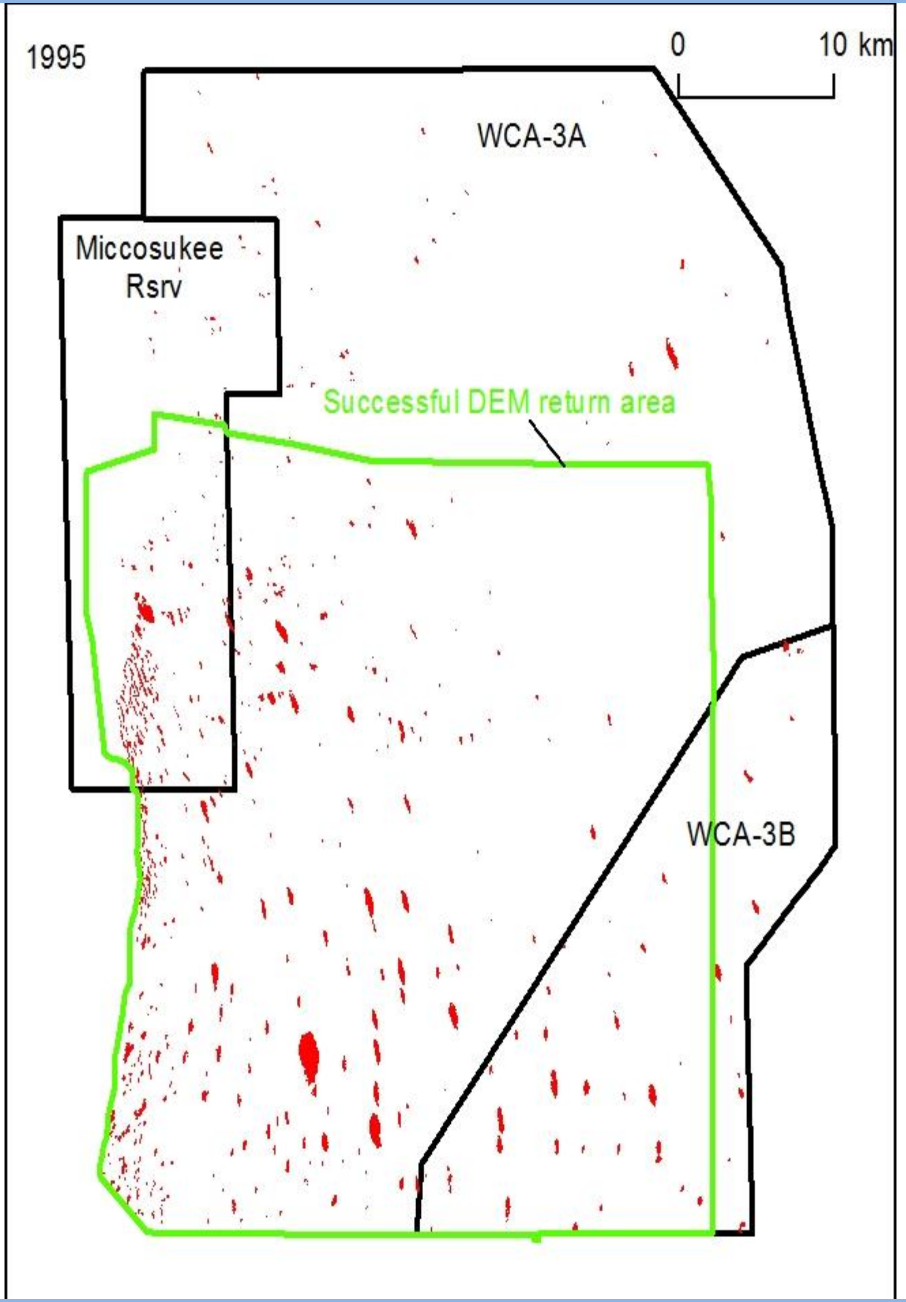




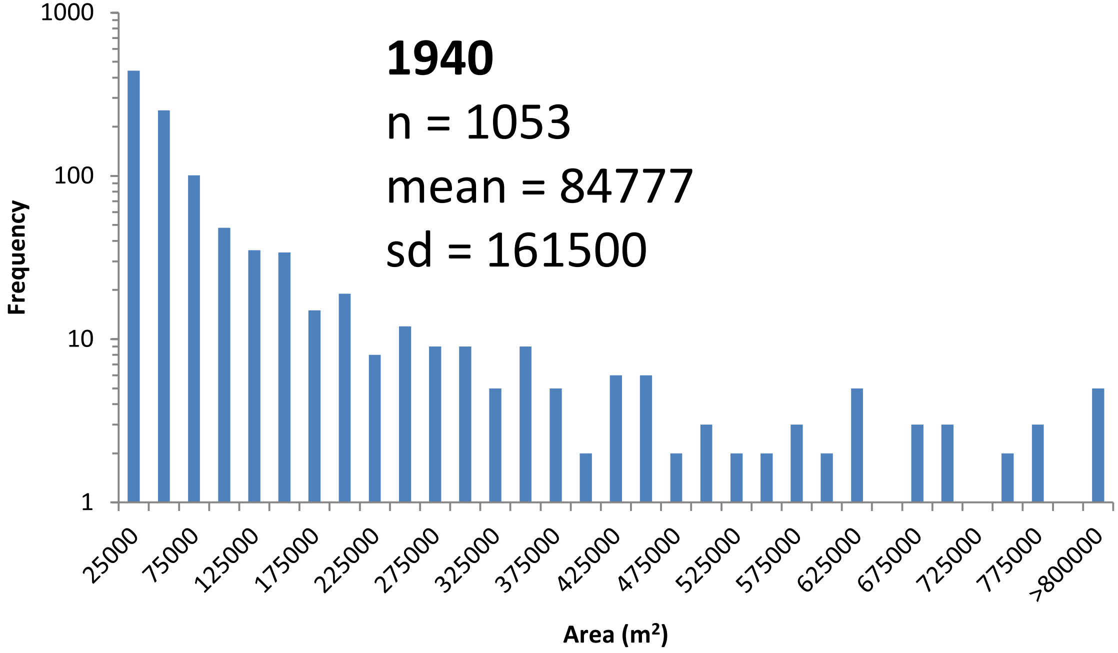


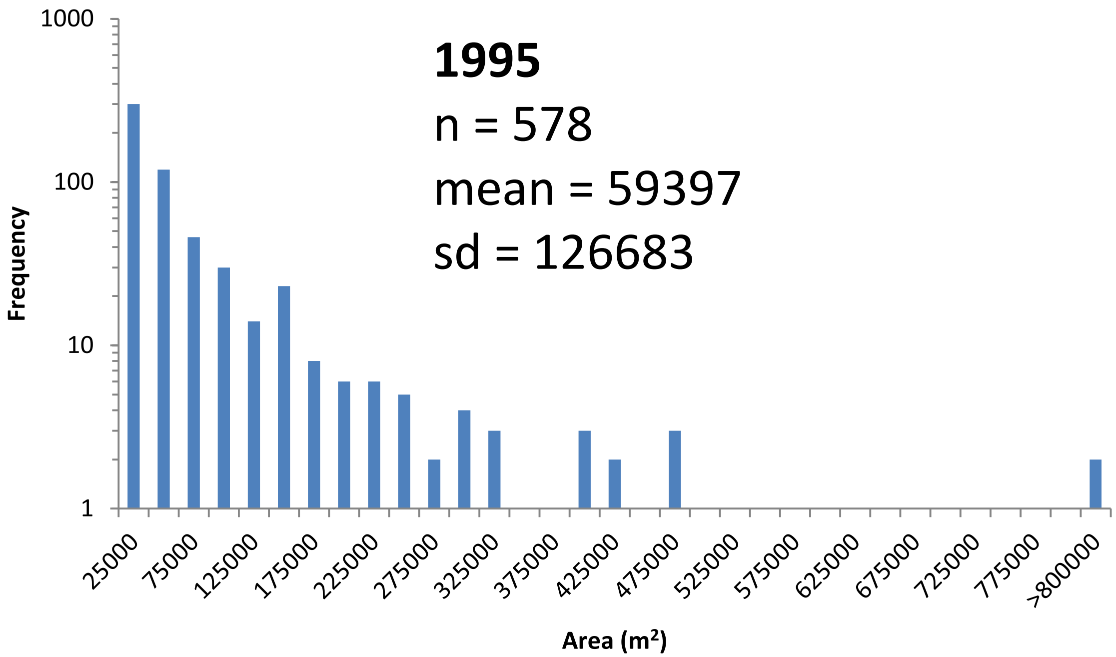



1940
0
10 km
WCA-3A
Miccosukee Rsrv
WCA-3B

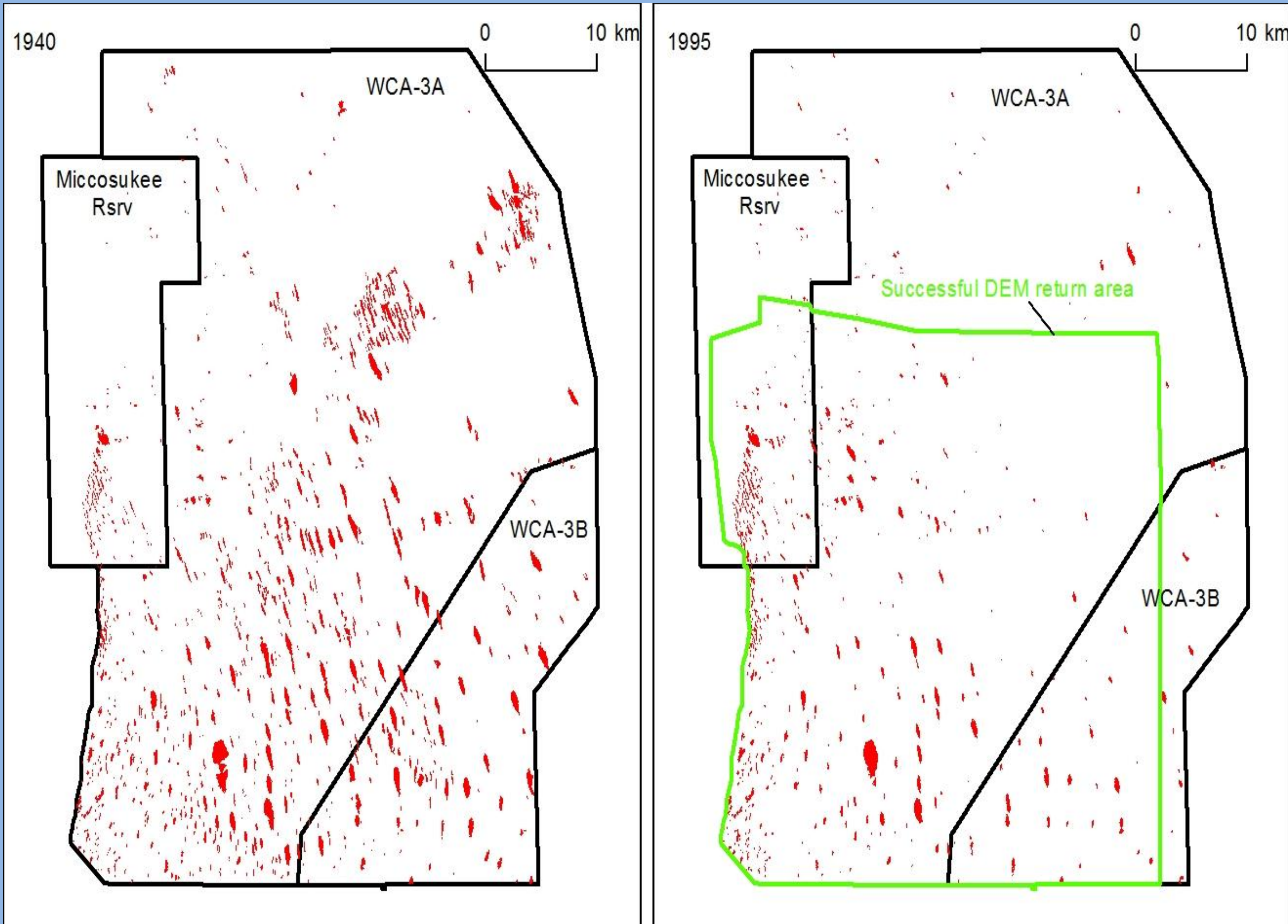

1995
0
10 km
WCA-3A
Miccosukee Rsrv
Successful DEM return area
WCA-3B


1940
0
10 km
WCA-3A
Miccosukee
Rsrv
WCA-3B
1995
0
10 km
WCA-3A
Miccosukee
Rsrv
WCA-3B
Tree island extent per km2
%
100
0





Large change in areal extent in the 55 year period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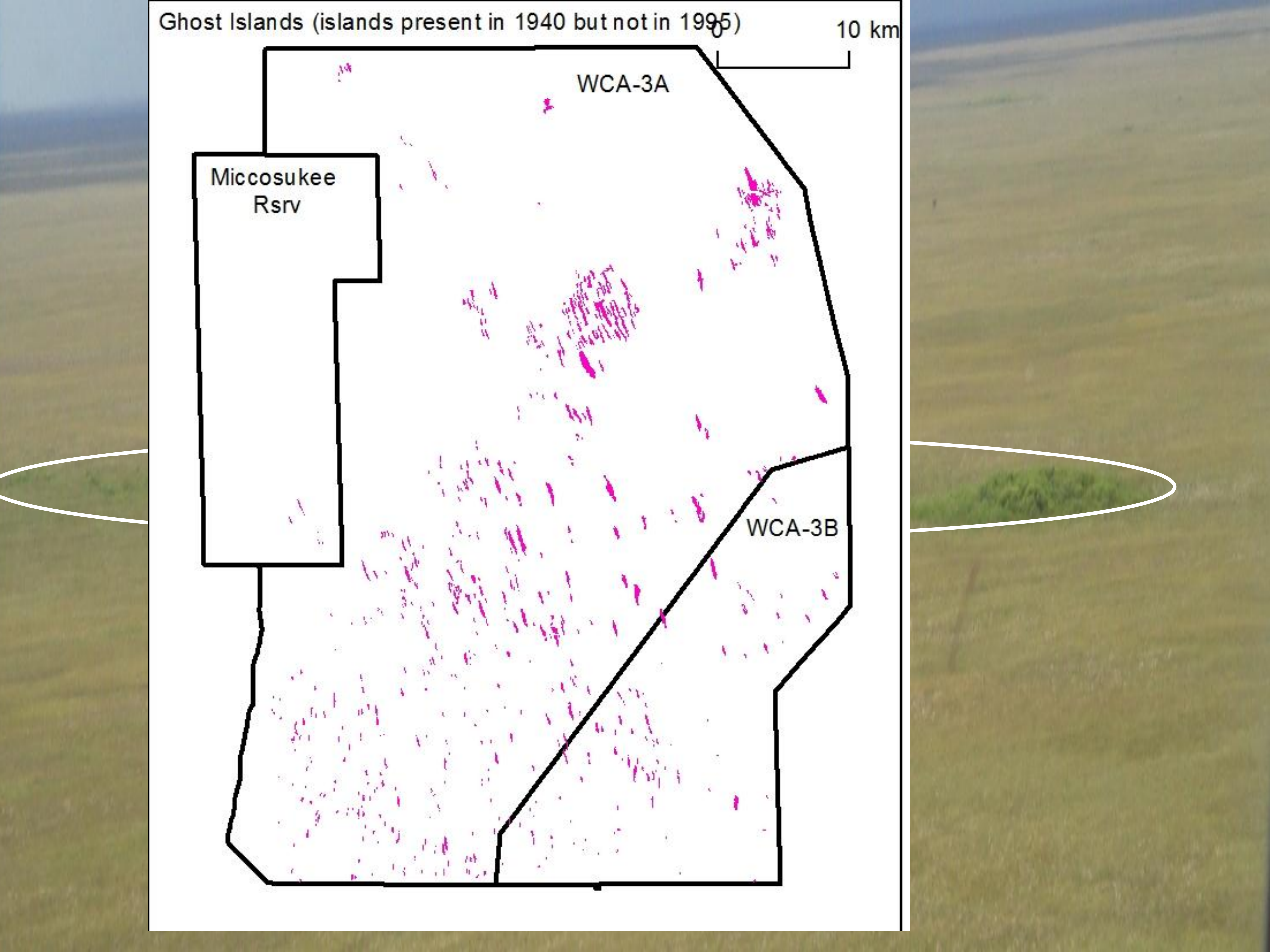
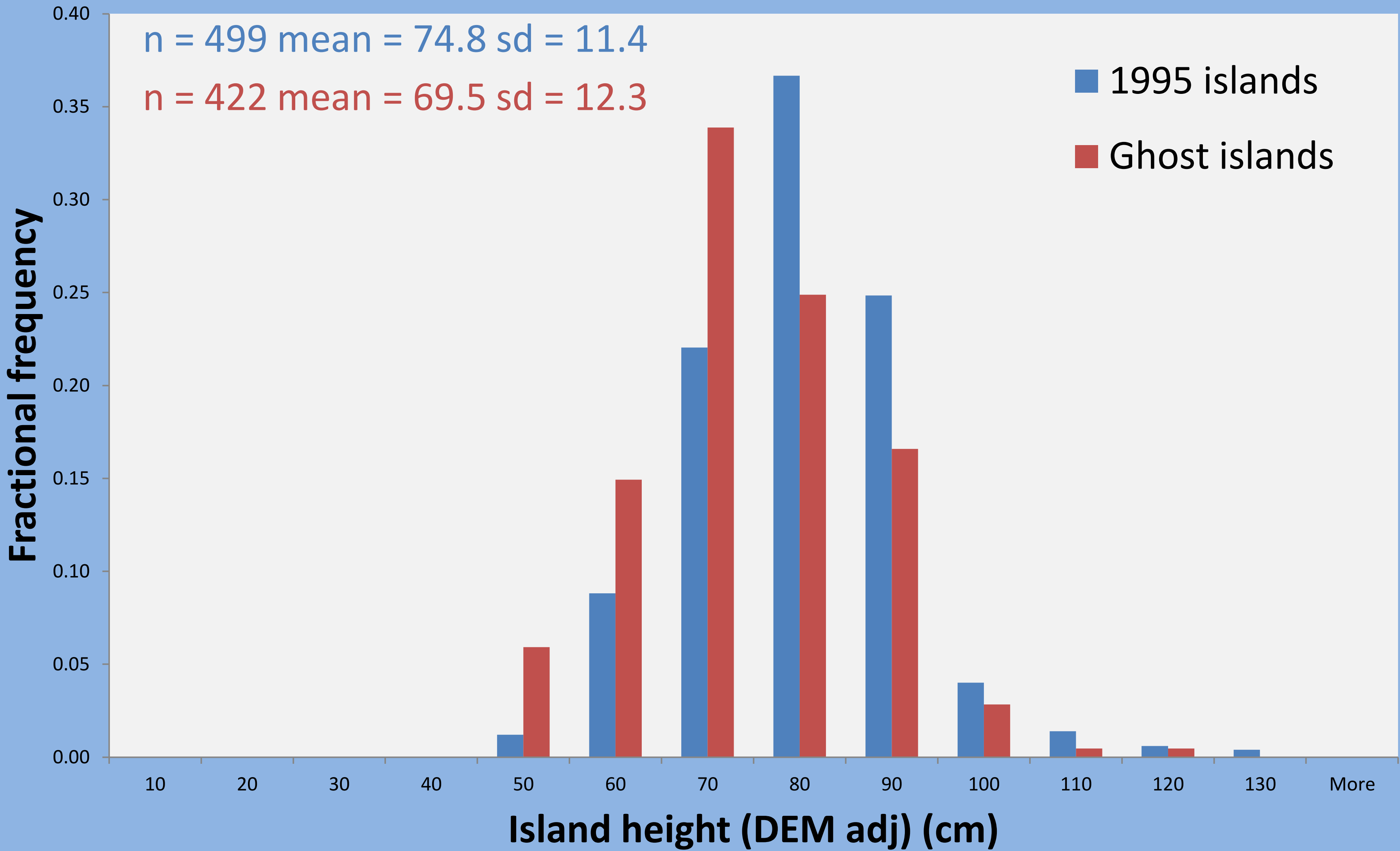

Ghost Islands (islands present in 1940 but not in 1995)
0
10 km
WCA-3A
Miccosukee
Rsrv
WCA-3B

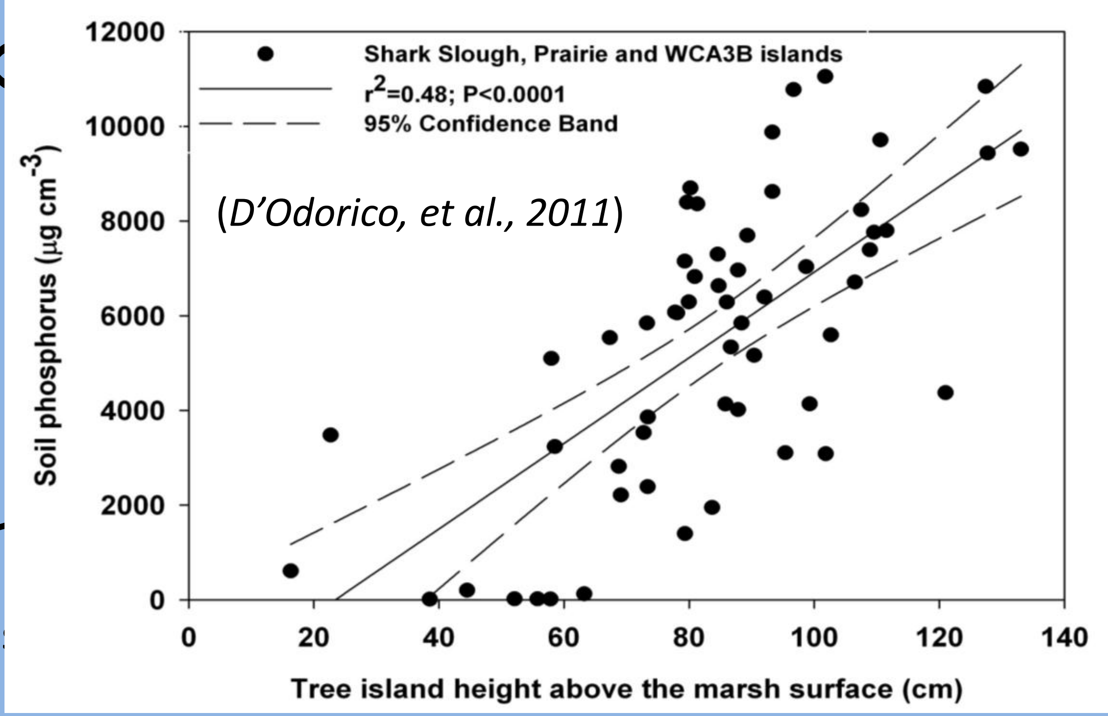
DEM-derived (survey verified) Island Height

(1995 Islands only, and Ghost Island areas)



Two-phase Landscap

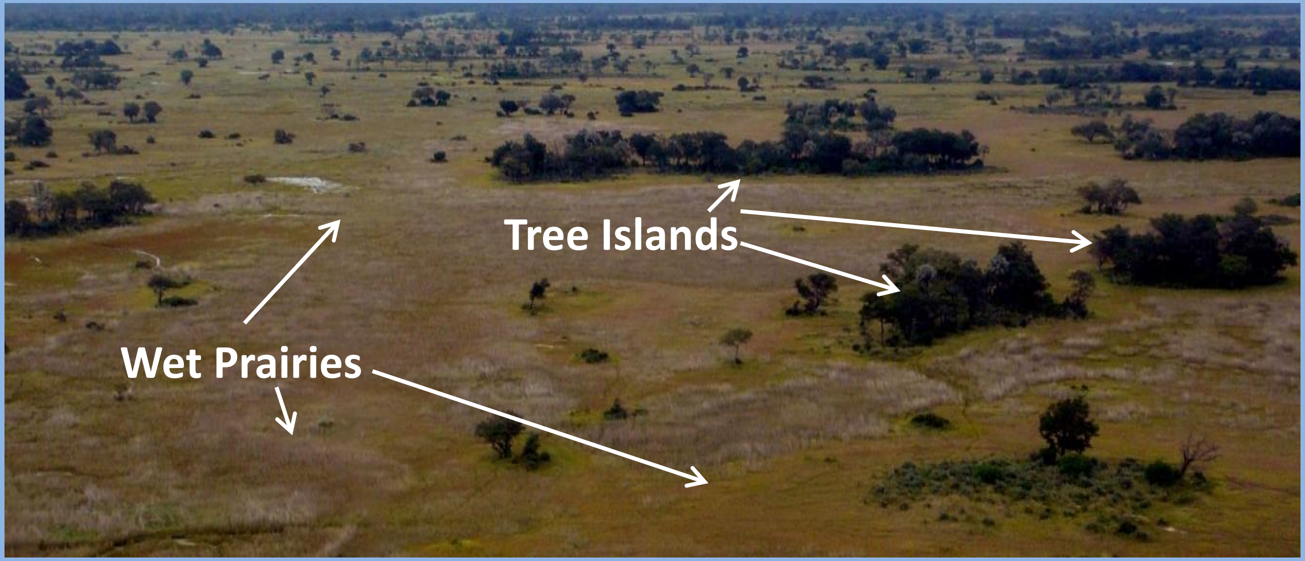
- **Tree islands**:
  - vegetation: trees
  - more elevated→less flooded
  - phosphorus “rich”
- **Marshes/Wet Prairies**:
  - “Herbaceous vegetation”
  - less elevated→more flooded
  - phosphorus “poor”



Tree islands are nutrient rich → “Fertility Islands”
A “Savanna” (*Wetzel et al, 2005*): mosaic of tree and “herbaceous” patches coexisting in the same landscape

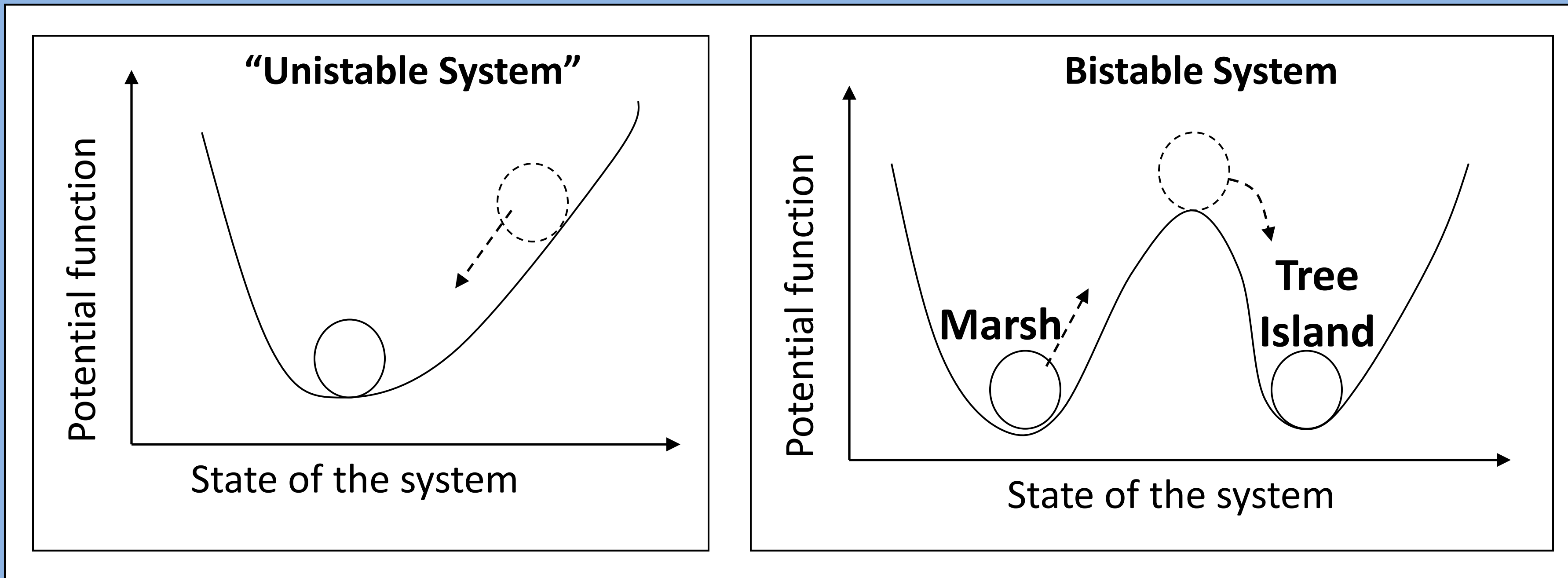
TREE ISLAND DYNAMCS

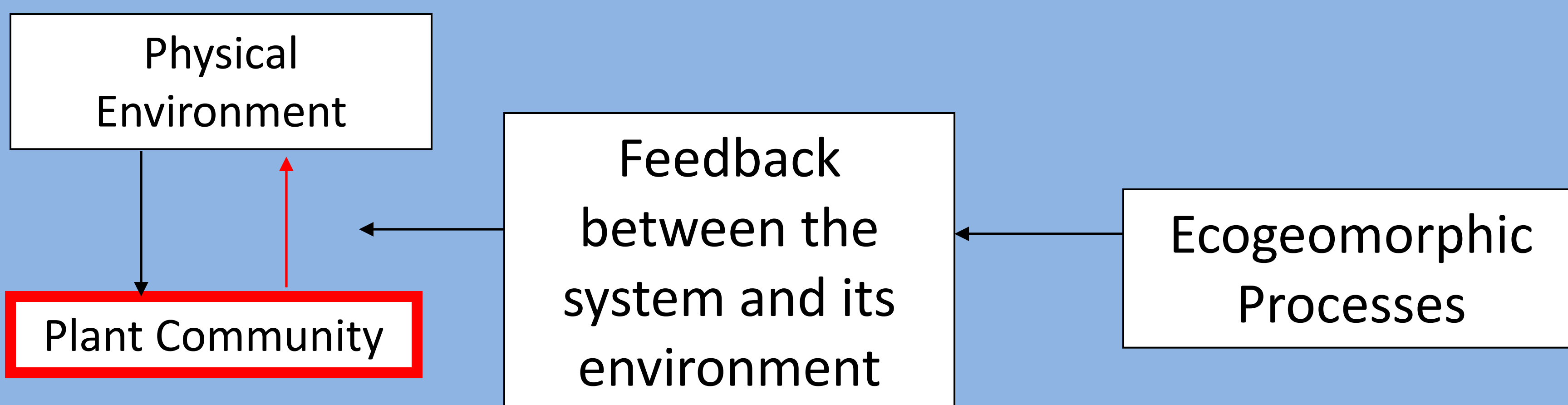
- How do we explain this coexistence?
- Stability & resilience of tree islands
- Impact of changes in tree cover or water level



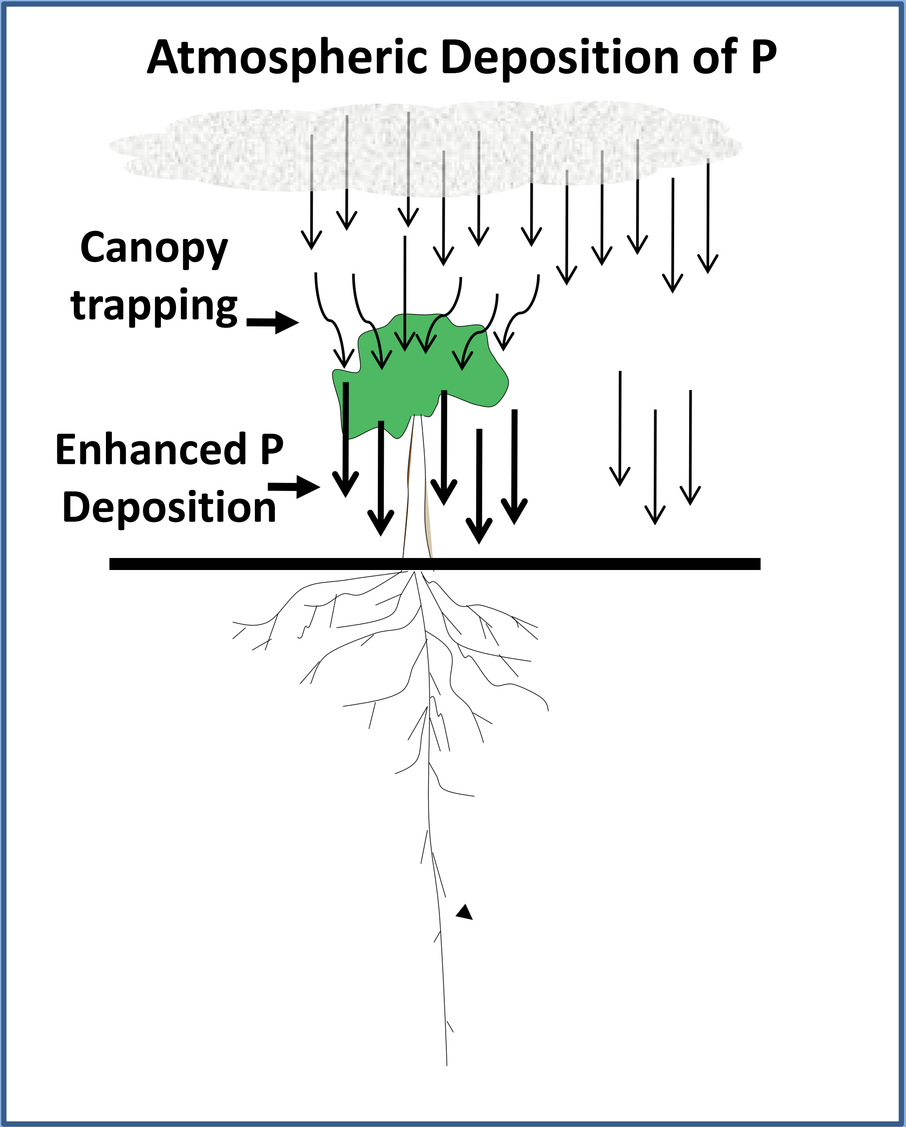
Stable coexistence of two states→ **bistability** → what causes this bistability?

Effects of positive feedbacks on ecosystem dynamics

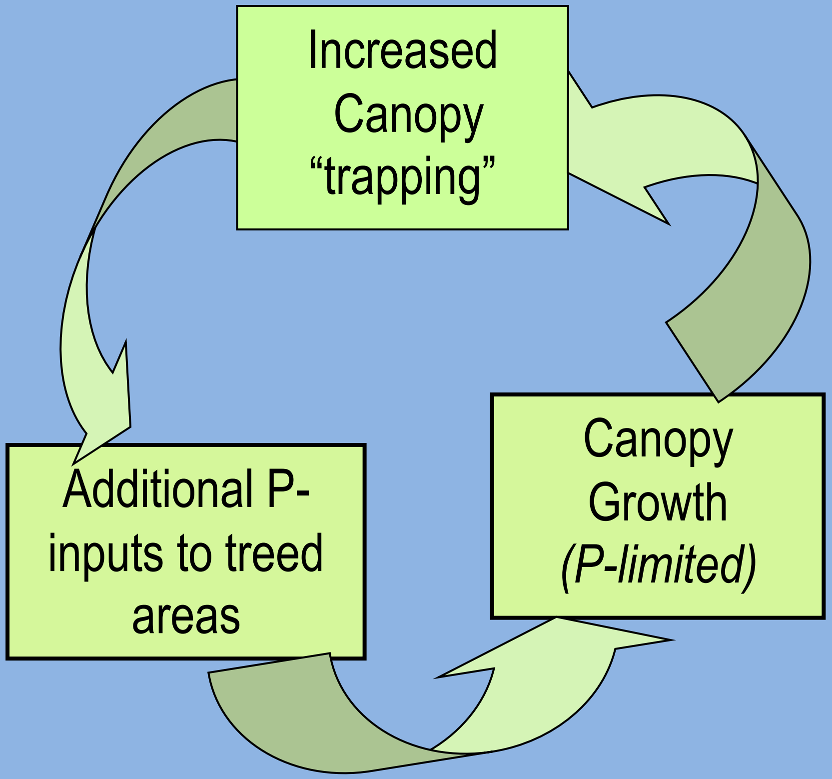




Positive feedbacks: trees create their own "habitat"

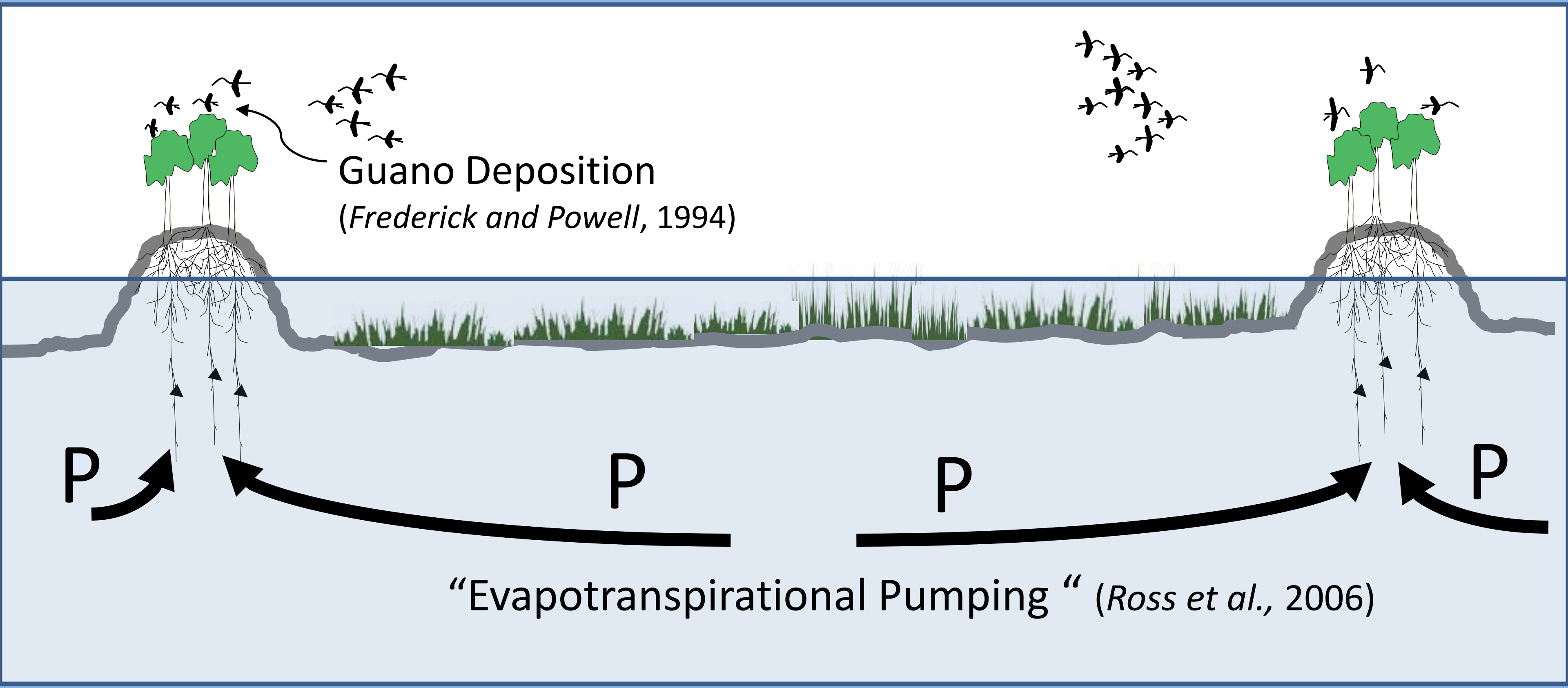


Available Phosphorous: trees enhance P availability



(Wetzel et al., 2005; Lawrence, D'Odorico et al., 2007; DeLonge, D'Odorico et al, 2008)

Other mechanisms of P accumulation in Tree Islands



Other feedbacks: interactions of peat accretion with soil P cycle

Feedbacks ↔ Bistability

Process-based zero-dimensional Model

- Tree growth limited by prolonged waterlogging and P availability
- In the absence of these limitations trees would have competitive advantage over herbaceous vegetation

$$\frac{dT}{dt} = aT\left(T_{cc} - T\right)$$

T → tree biomass

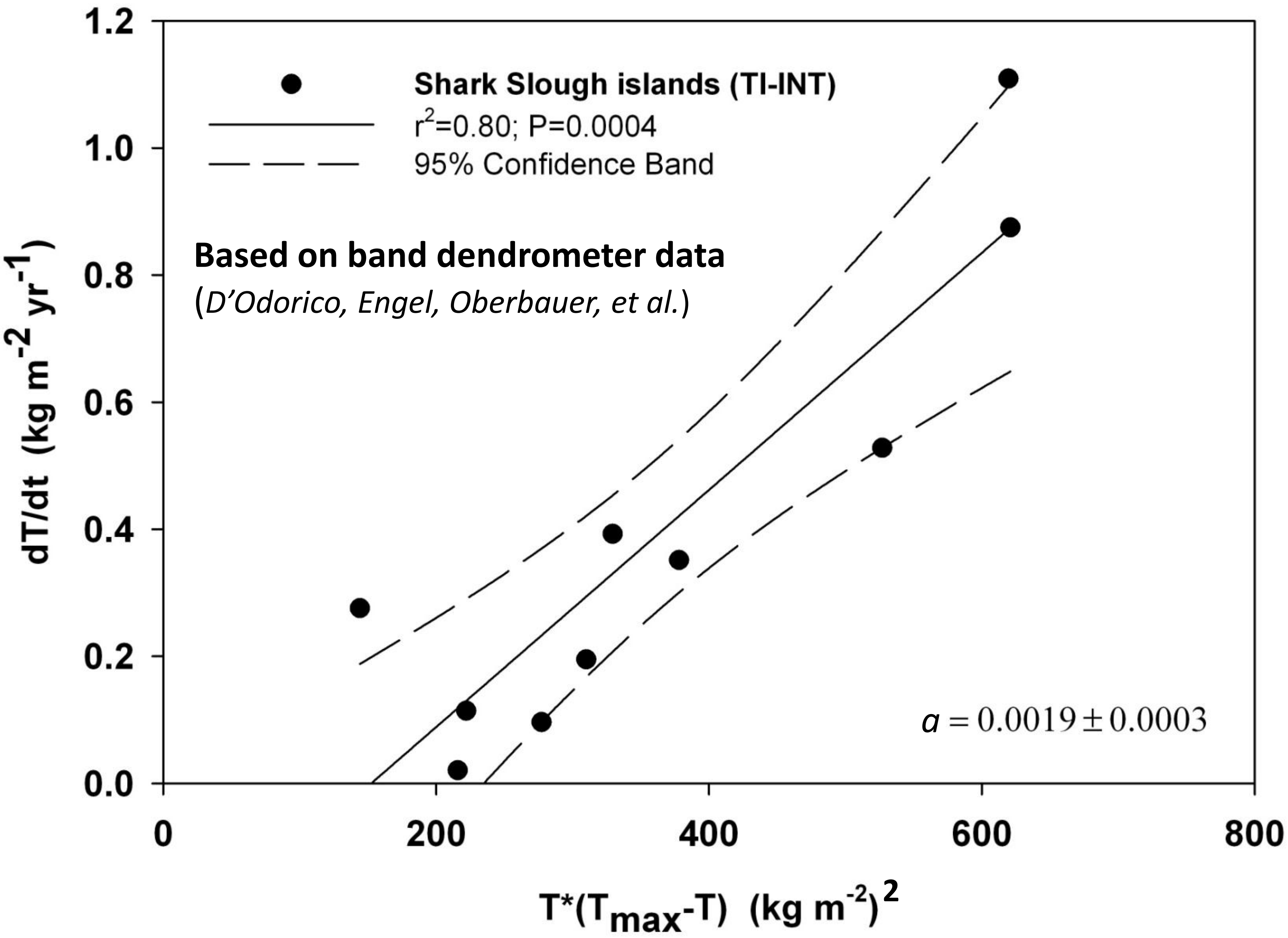
T_{cc} → **Carrying capacity for trees**

$$\frac{dG}{dt} = a_2 G\left(G_{cc} - T - G\right)$$

G → herbaceous biomass

G_{cc} → **Carrying capacity for grasses**

Dynamics of Tree Biomass: $\frac{dT}{dt} = a\,T\left(T_{cc} - T\right)$



Feedbacks ↔ Bistability

Process-based zero-dimensional Model

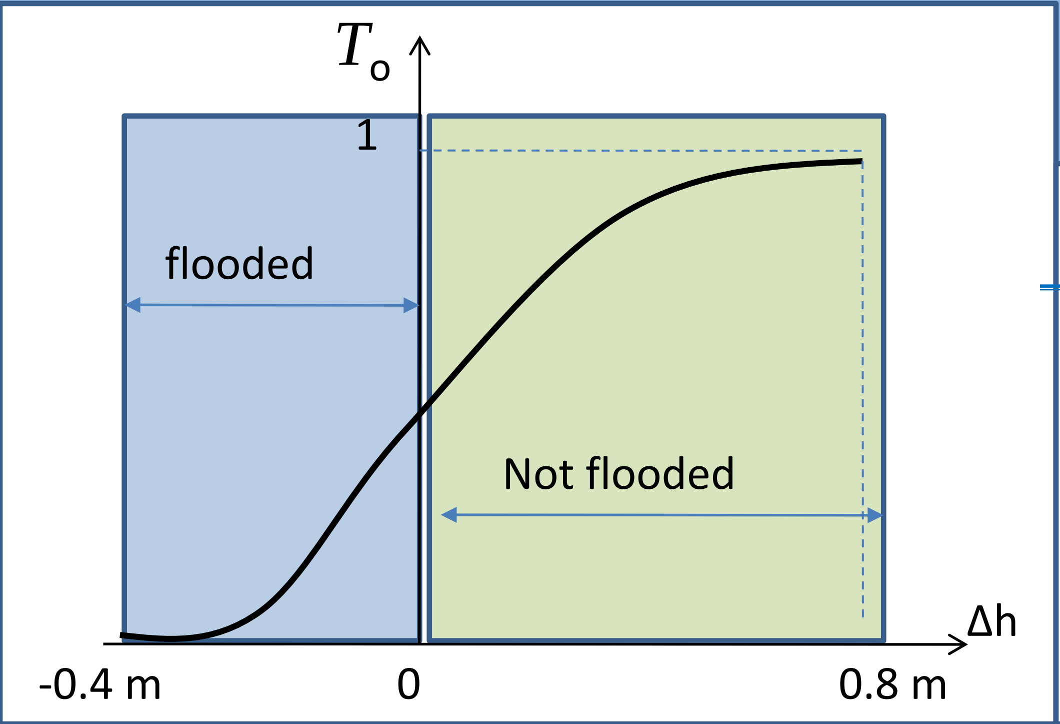
- Tree growth limited by prolonged waterlogging and P

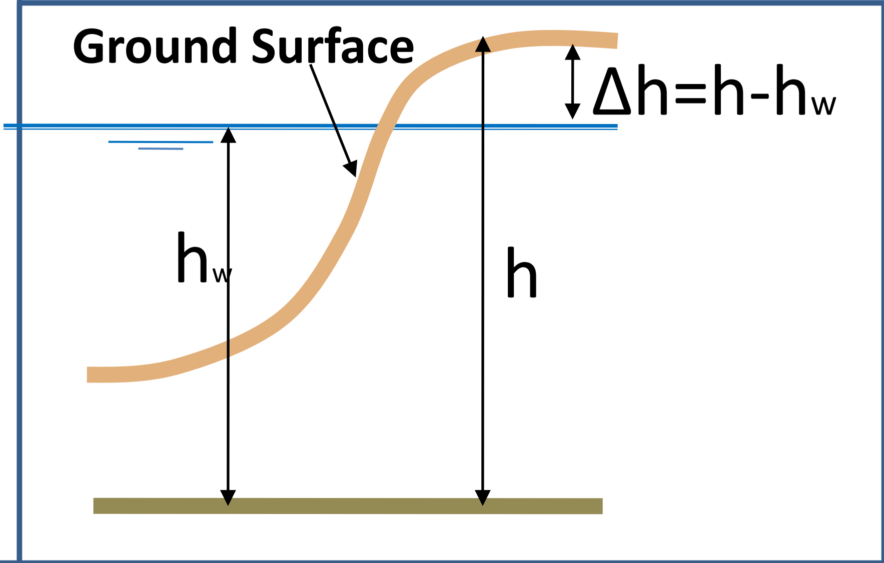
$$\frac{dT}{dt} = aT\left(T_{cc} - T\right)$$

$T \rightarrow$ tree biomass

$T_{cc} = T_0 \, f(P)$

Carrying capacity for trees
(depends on P & hydroperiod)





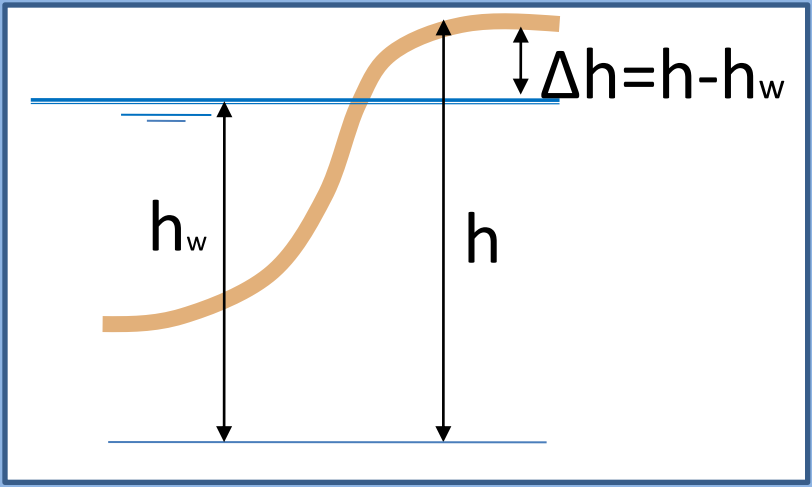
Tree → Soil Accretion

- Depends on tree biomass and hydroperiod

$$\frac{d(\Delta h)}{dt} = Soil\ Accumulation - Soil\ Loss$$

Soil Respiration & Fires

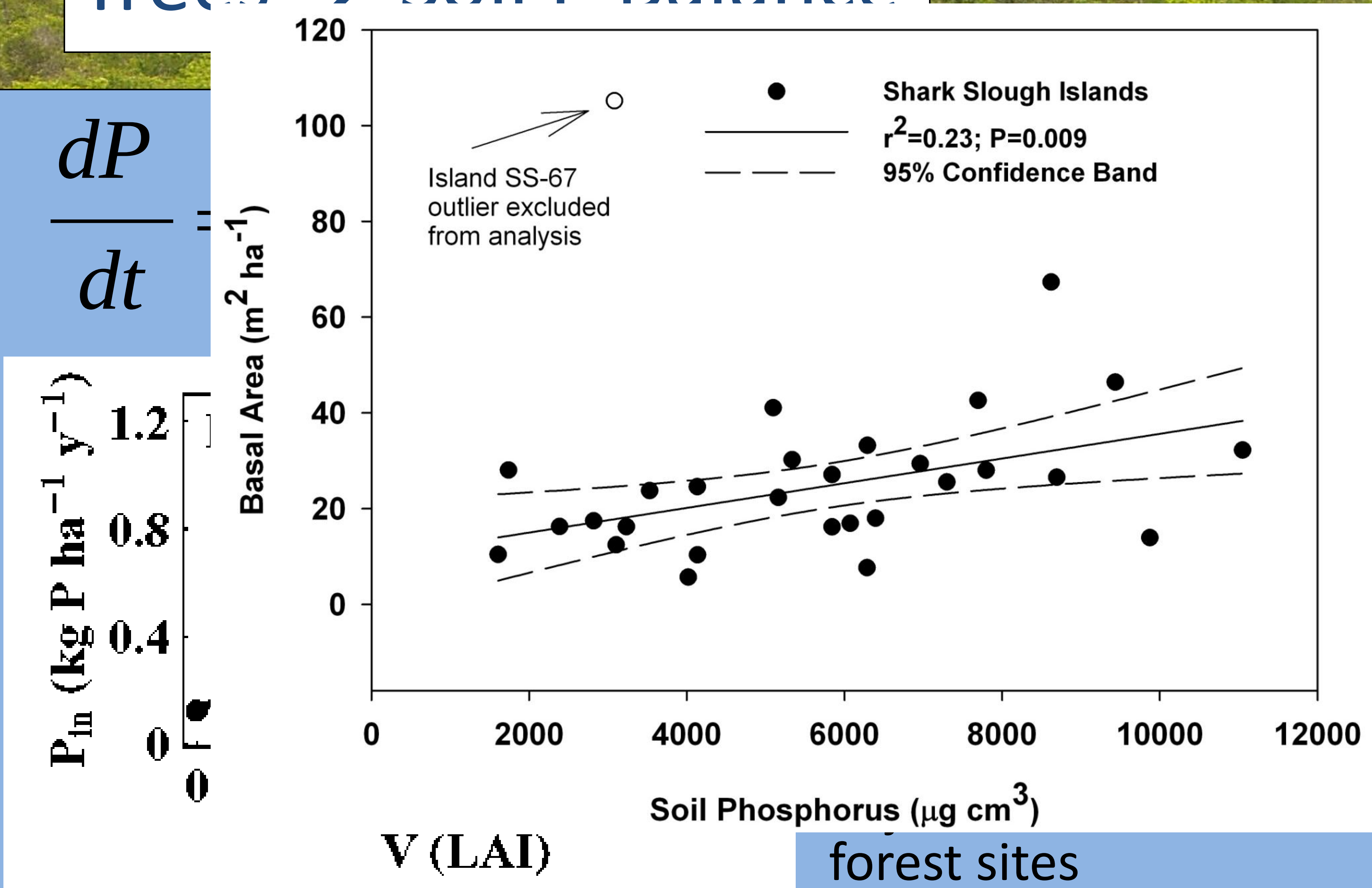
$$\frac{d(\Delta h)}{dt} = \gamma_1 T - \gamma_2 (\Delta h + k)$$



Soil dynamics much slower than vegetation dynamics

Trees → Soil P Balance

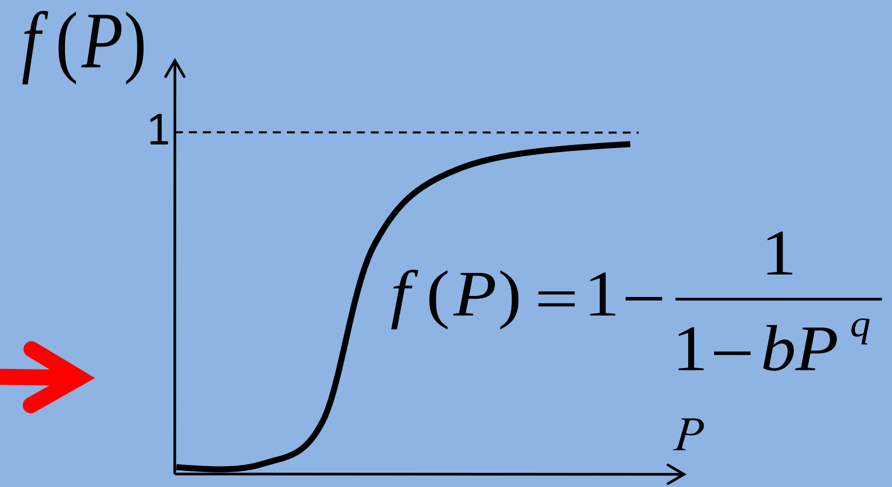
$$\frac{dP}{dt} =$$



forest sites

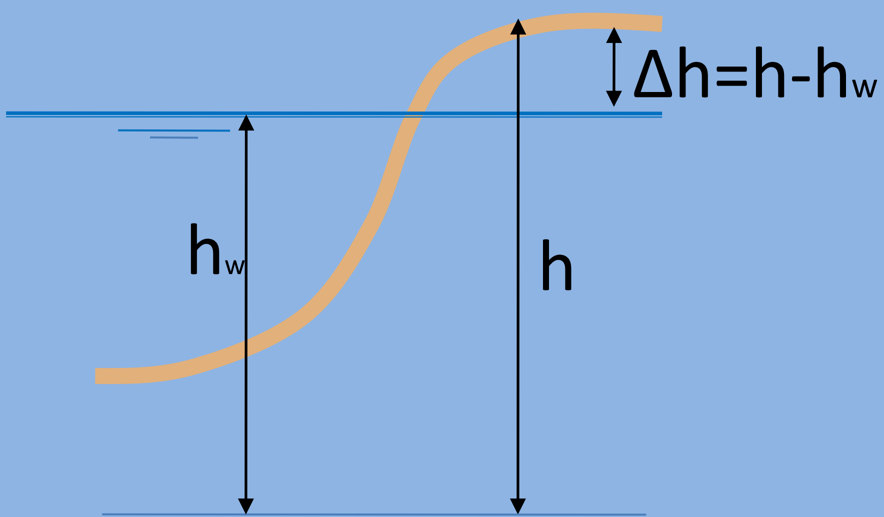
P Availability & Elevation → Tree dynamics

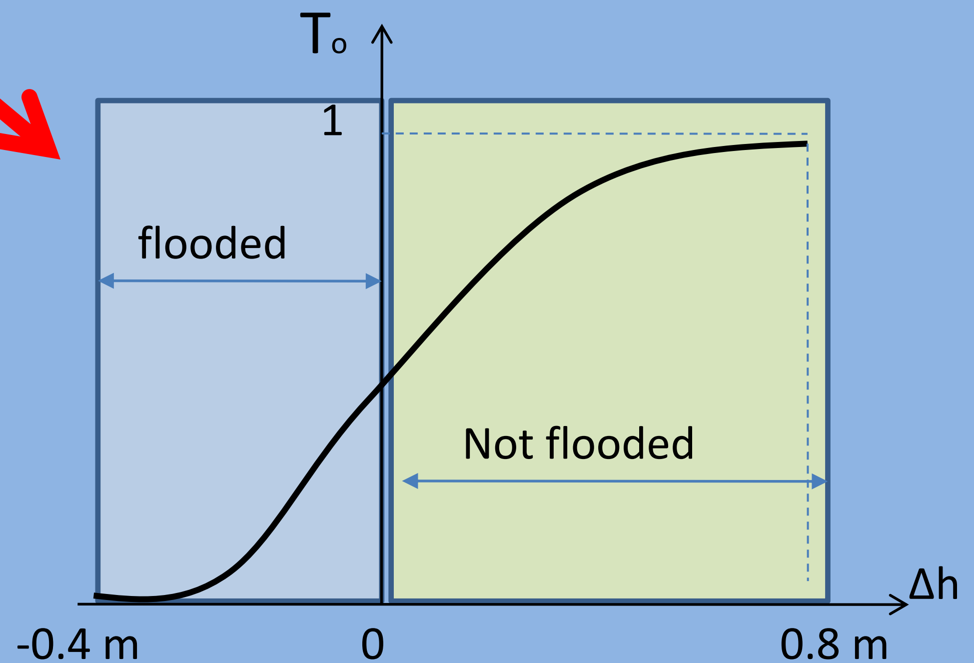
$$T_{cc} = T_0 \, f(P)$$



Dependence of T on P

Dependence of T on Δh





Equilibrium States

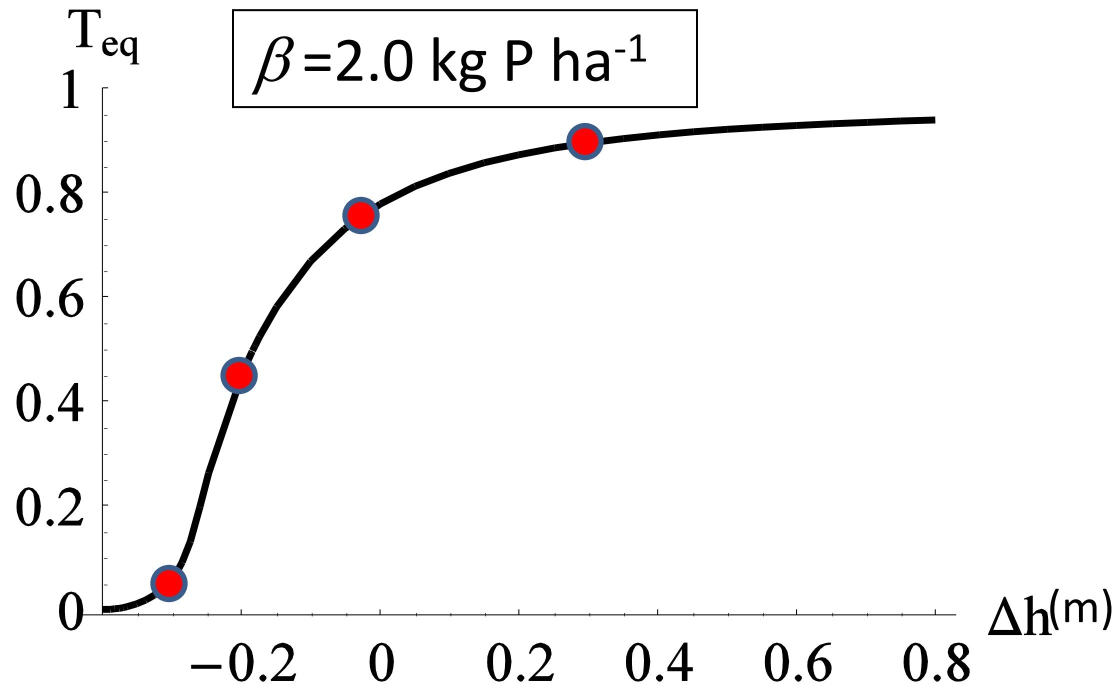
In the short term Δh≈const

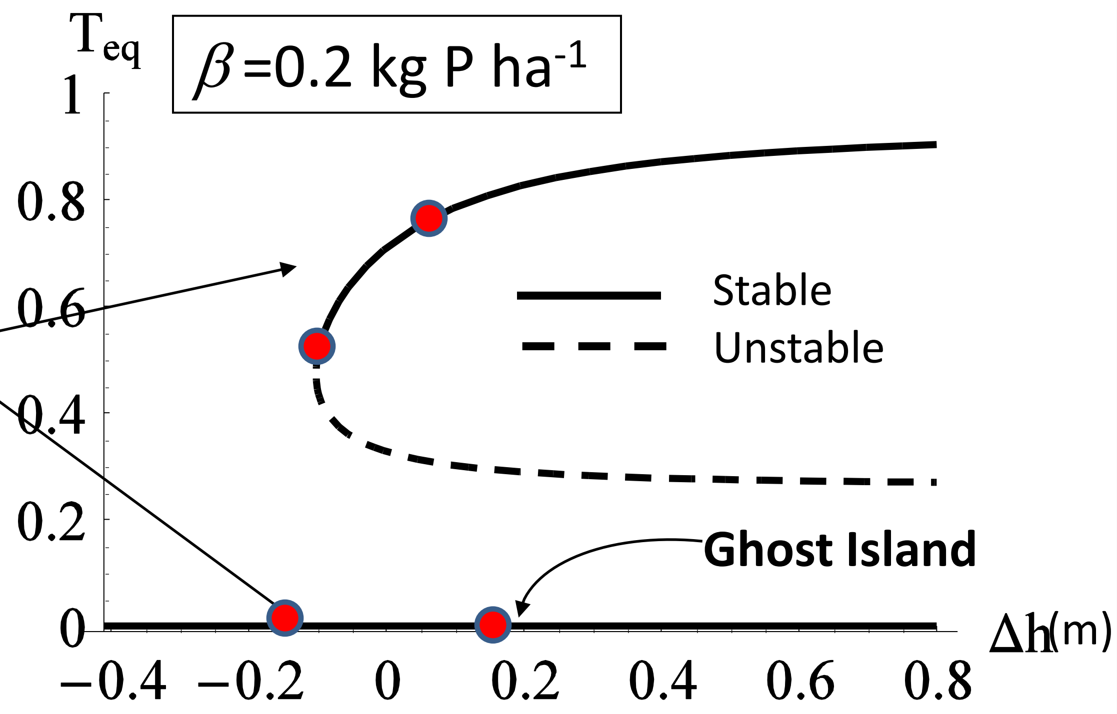
Trees establish in elevated & P-rich areas

P deposition

$$P_{in} = \boldsymbol{\alpha}\, T + \beta$$

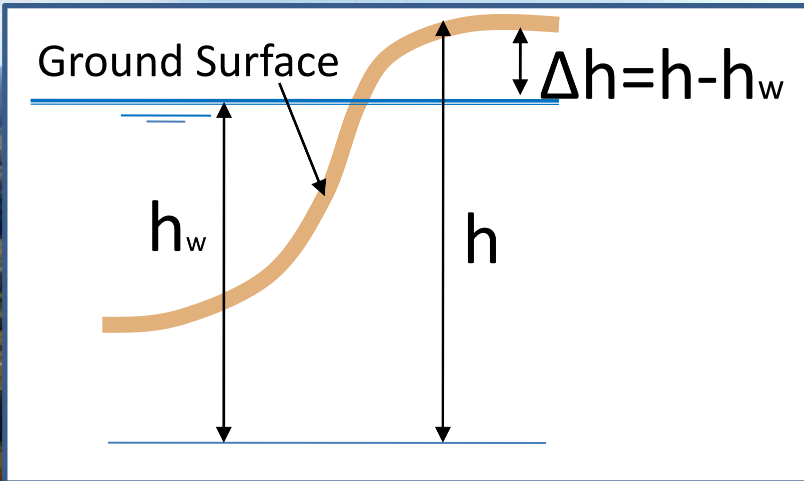
β→Background rate of P deposition





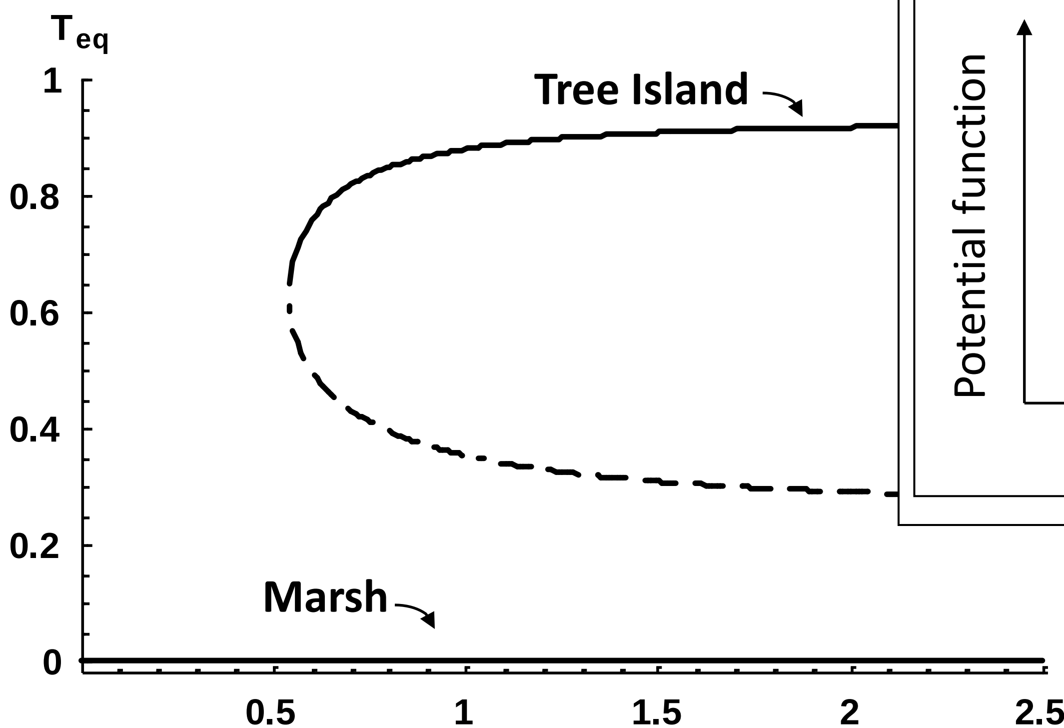
Alternative stable States

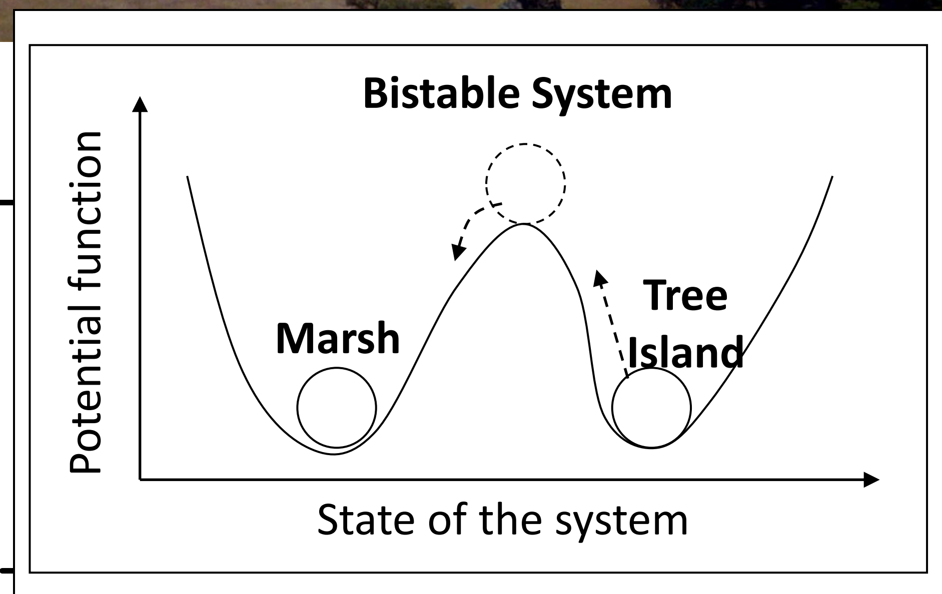
In the long term: dependence on the soil feedback



$$\frac{d(\Delta h)}{dt} = \gamma_1 T - \gamma_2 (\Delta h + k)$$

At Equilibrium: $\Delta h_{eq} = \gamma T_{eq} + k'$





$$\gamma \rightarrow \gamma = \frac{\gamma_1}{\gamma_2} = \frac{soil\ accretion}{soil\ loss}$$

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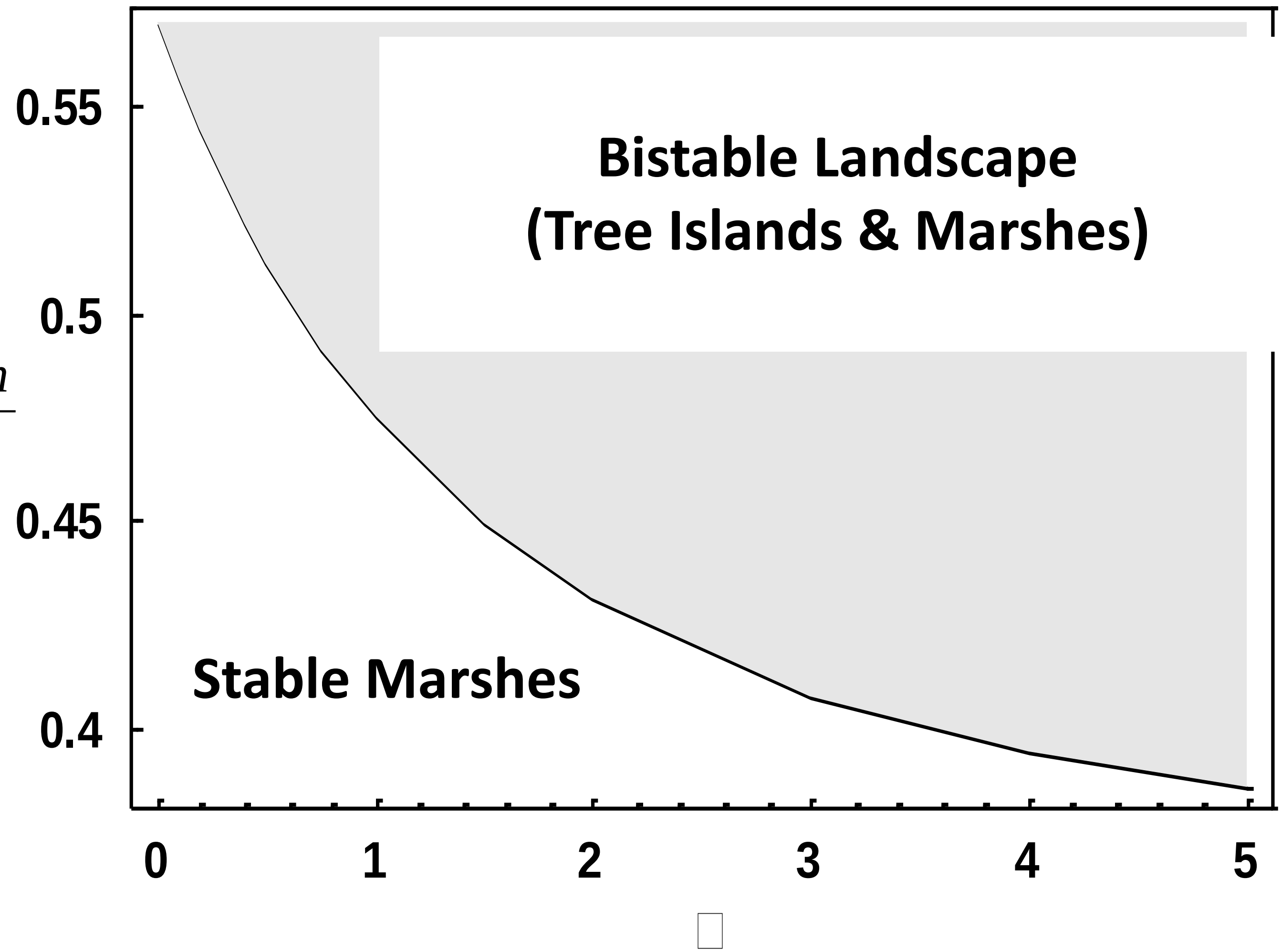


How do tree islands get established?

- Trees colonize marshes/prairies during prolonged droughts
- Rock outcrops provide microsites for tree establishment

Feedbacks ↔ Bistability

Process-based dimensional Model

- Extend the zero point model to incorporate spatial dynamics
- Pattern formation?

$$\frac{d(\Delta h)}{dt} = \gamma_1 T - \gamma_2 (\Delta h + k)$$

$$\frac{dT}{dt} = aT\left(T_{cc} - T\right) + \int_{\Omega} \left[b_1 \exp\left[-\left(\frac{r\left(1+\beta \frac{x-x'}{r}\right)}{d_1} \right)^2 \right] - b_2 \exp\left[-\left(\frac{r\left(1+\beta \frac{x-x'}{r}\right)}{d_2} \right)^2 \right] - b_3 \right] T(x', t)\, dx'$$

T → tree biomass

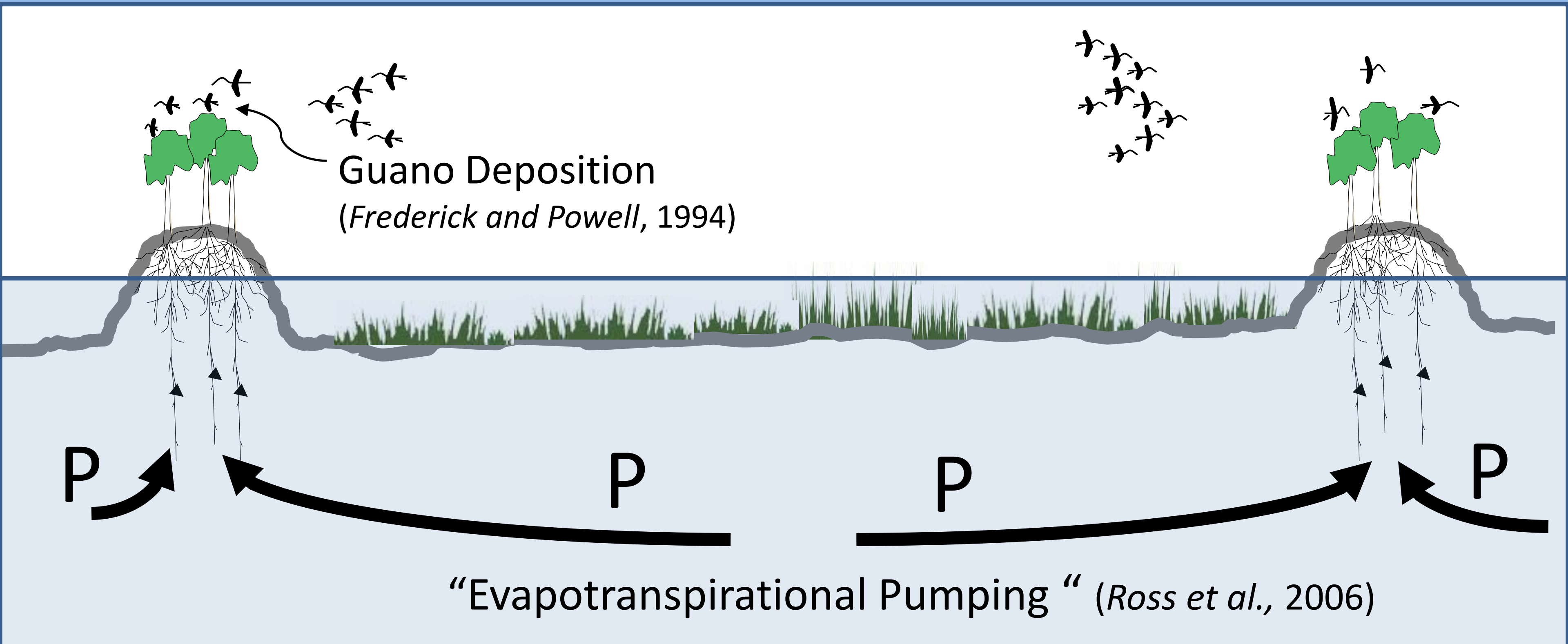
T_{cc} → **Carrying capacity for trees (depends on hydroperiod only)**

Magnitude of facilitation **inhibition**

Limited by atmospheric phosphorus deposition

$$\int_{\Omega}\left[b_1 \exp\left[-\left(\frac{r\left(1+\beta\frac{x-x'}{r}\right)}{d_1} \right)^2 \right] - b_2 \exp\left[-\left(\frac{r\left(1+\beta\frac{x-x'}{r}\right)}{d_2} \right)^2 \right] - b_3 \right] T(x',t)\,dx'$$

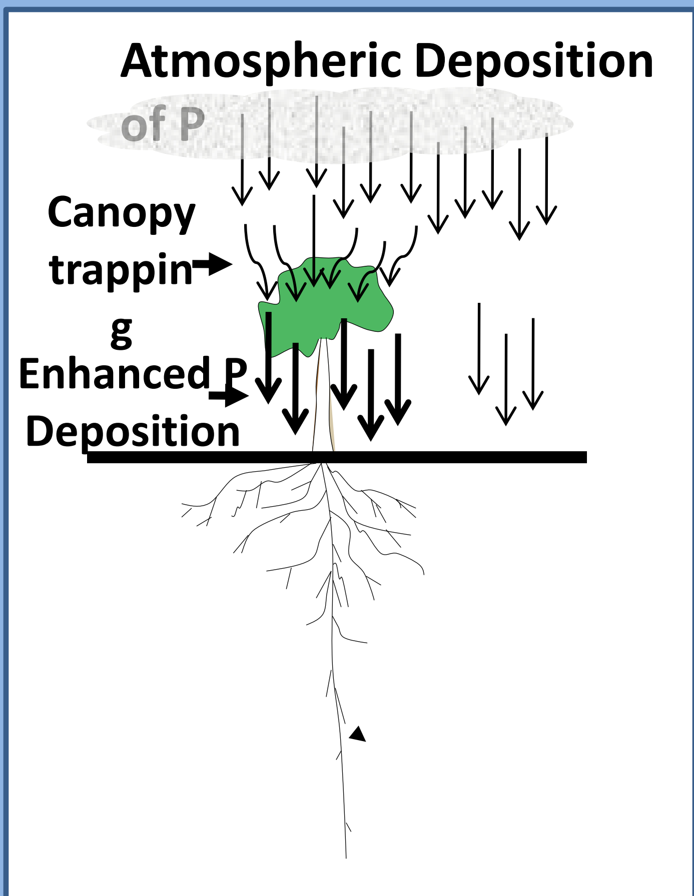
Determine the distance at which maximum inhibition occurs

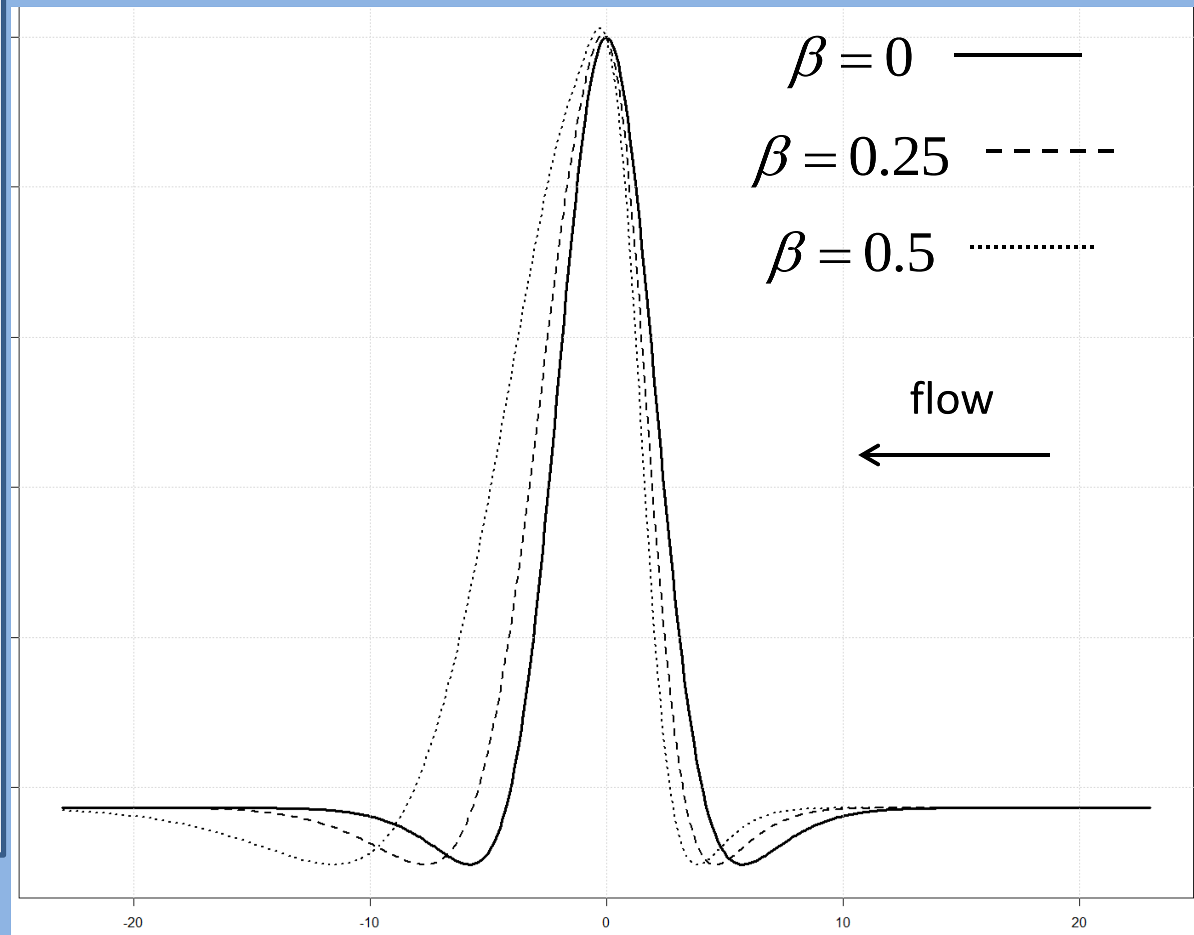


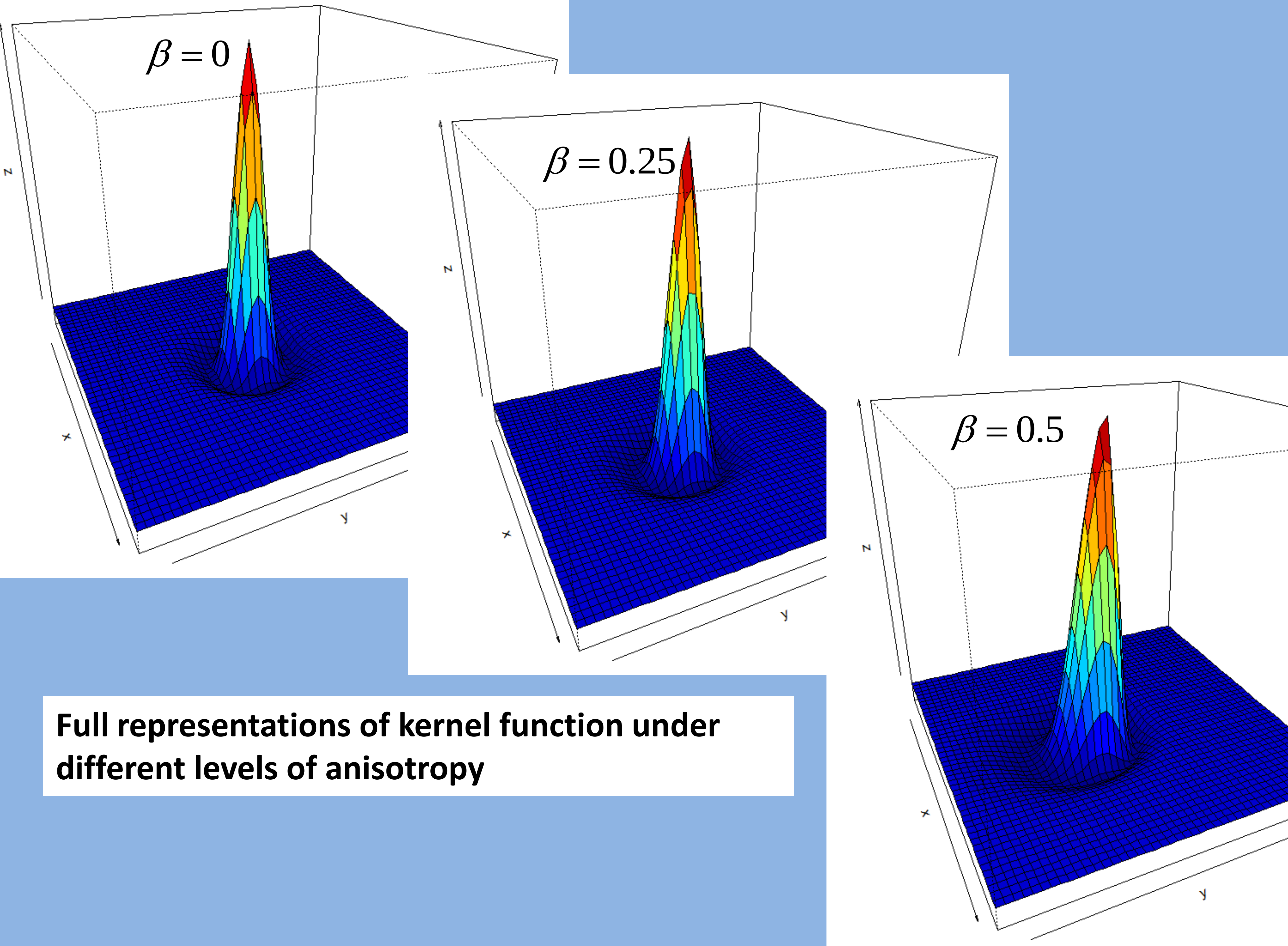
There is also a general hydraulic gradient across the landscape

Advection

$$\int_\Omega \left[b_1 \exp\left[-\left(\frac{r\left(1+\beta\frac{x-x'}{r}\right)}{d_1}\right)^2\right] - b_2 \exp\left[-\left(\frac{r\left(1+\beta\frac{x-x'}{r}\right)}{d_2}\right)^2\right] - b_3\right] T(x',t)dx'$$



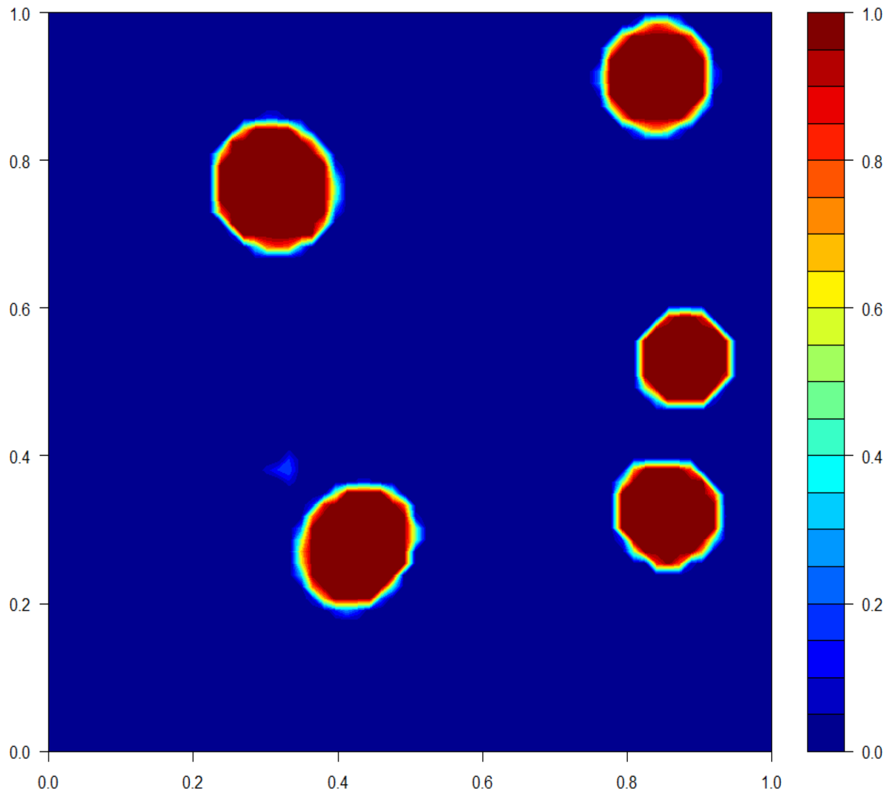


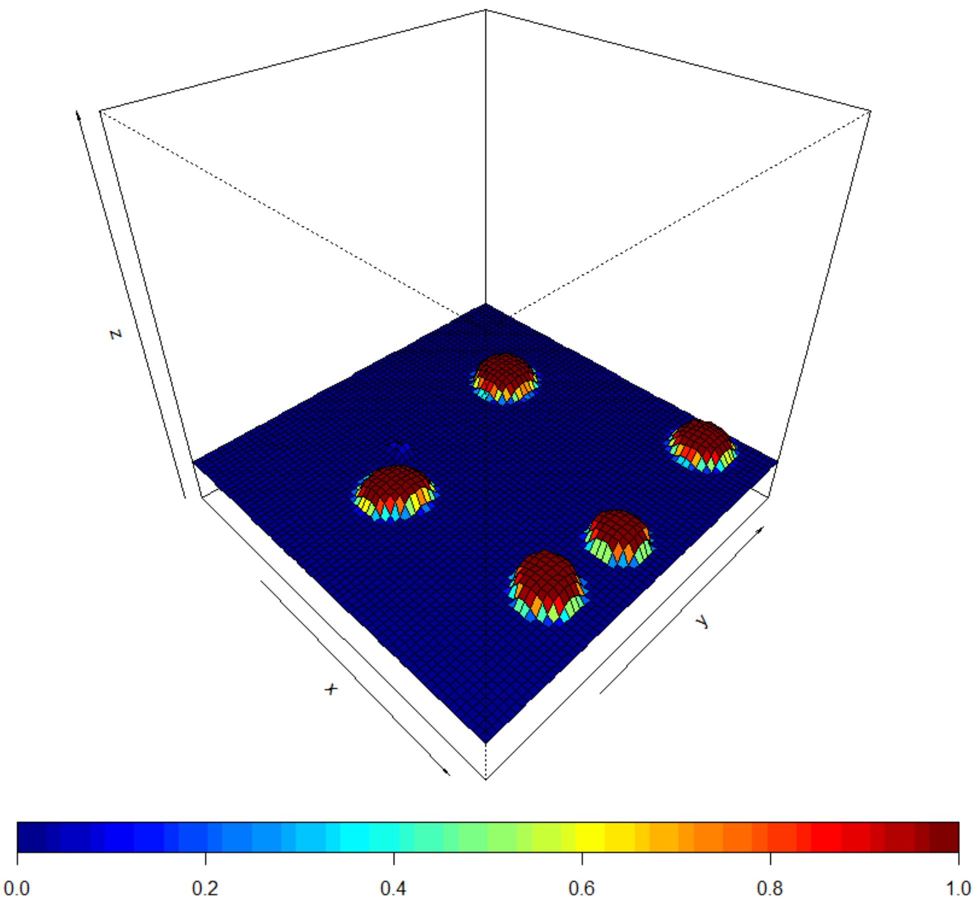


Full representations of kernel function under different levels of anisotropy

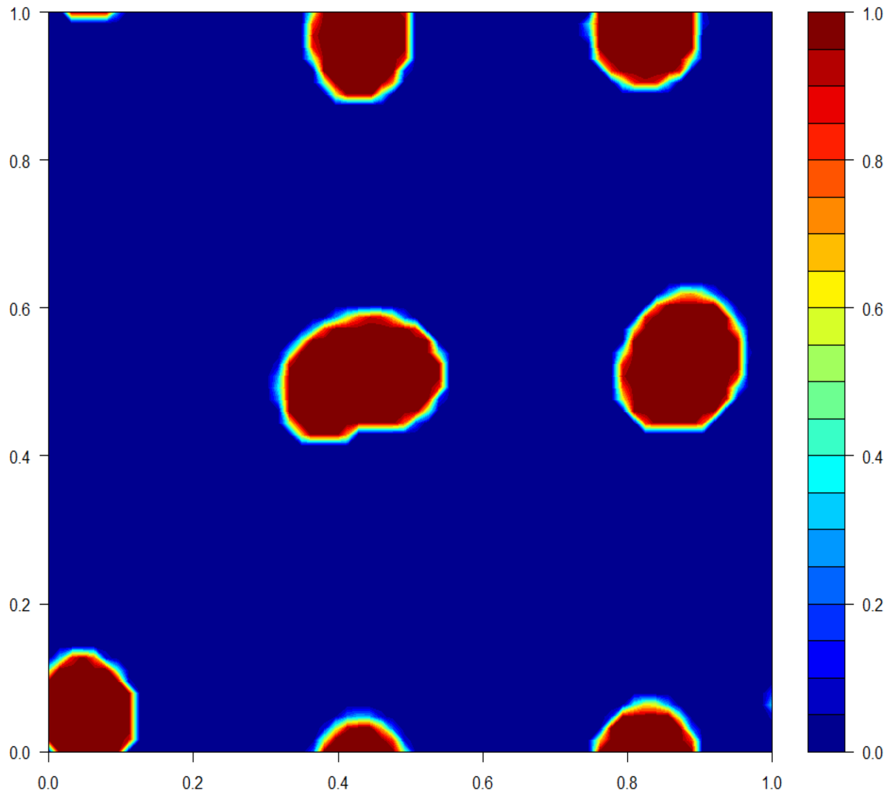
- Changes in soil elevation effectively limit the spreading of trees.
- These mounds are stable in location.

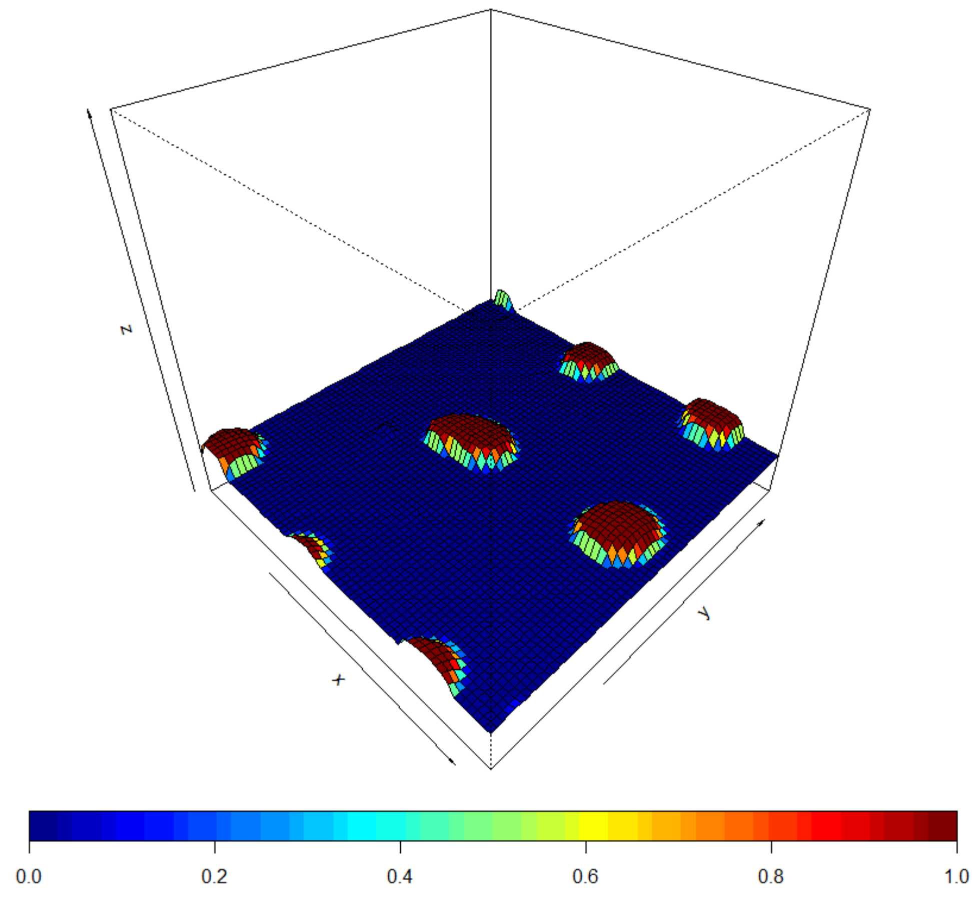
- Small time step and long runs to account for soil feedbacks.
- Patterns often depend on initial distribution of elevation and vegetation.



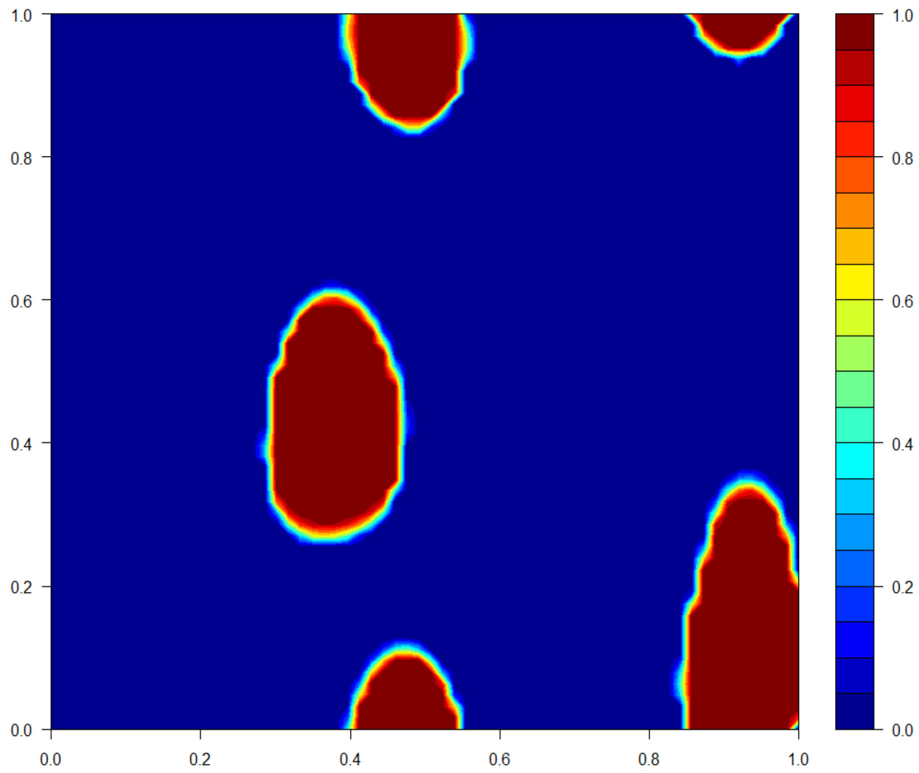


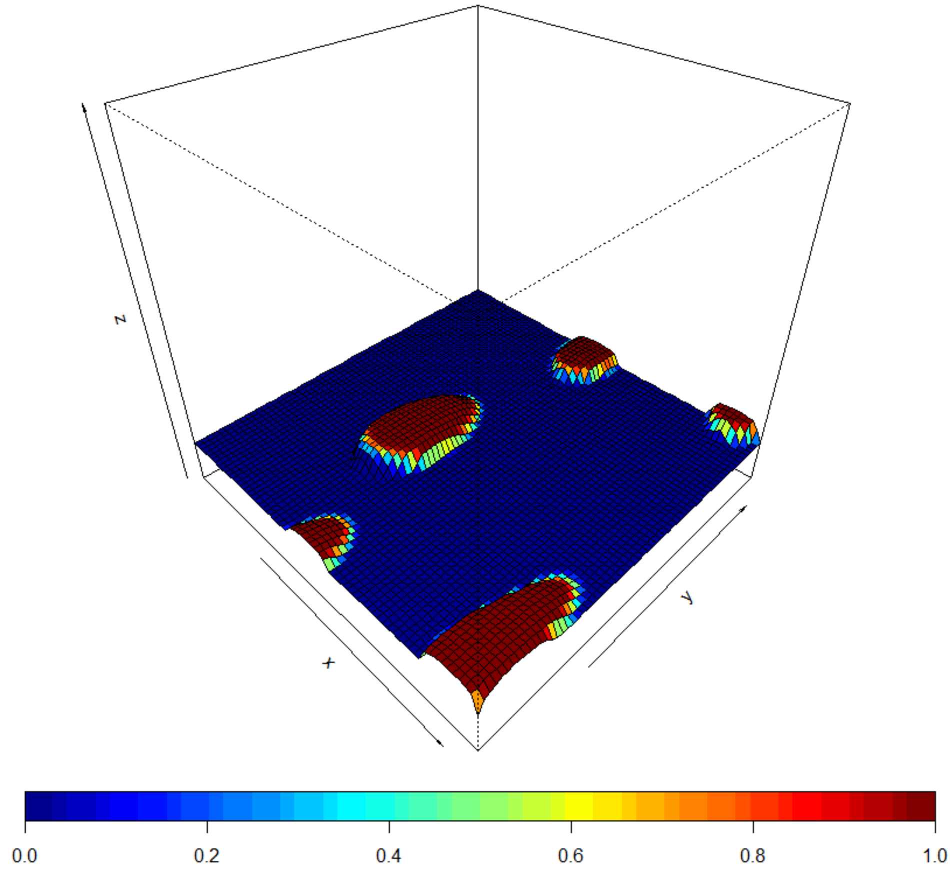
- Under low anisotropic conditions, elliptical islands form
- These islands migrate slowly in the down flow direction.



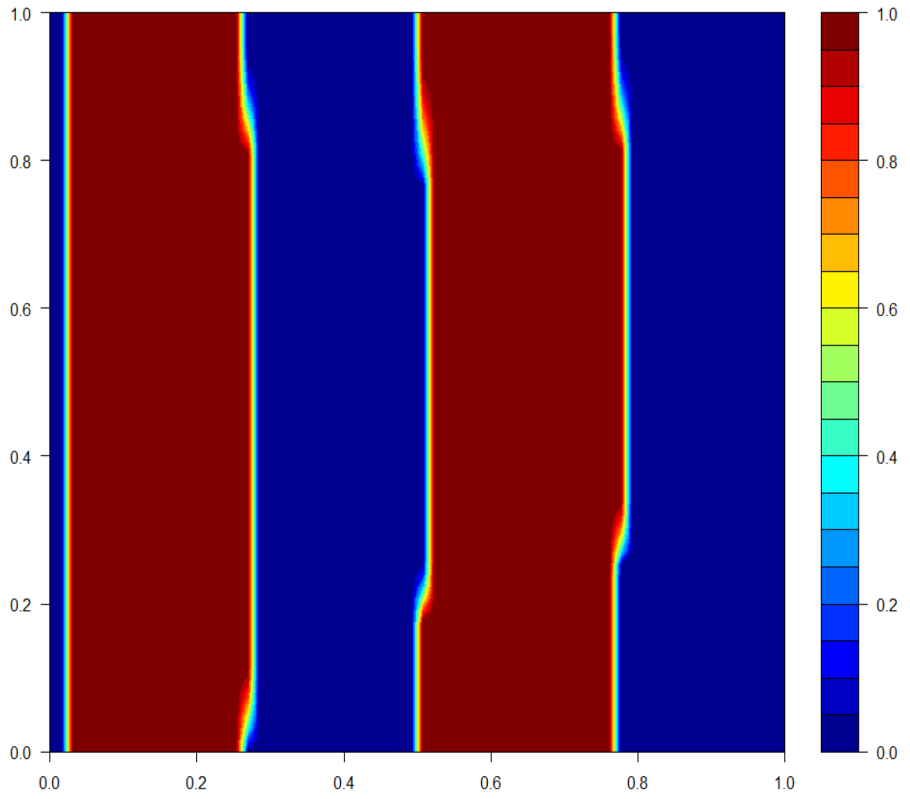


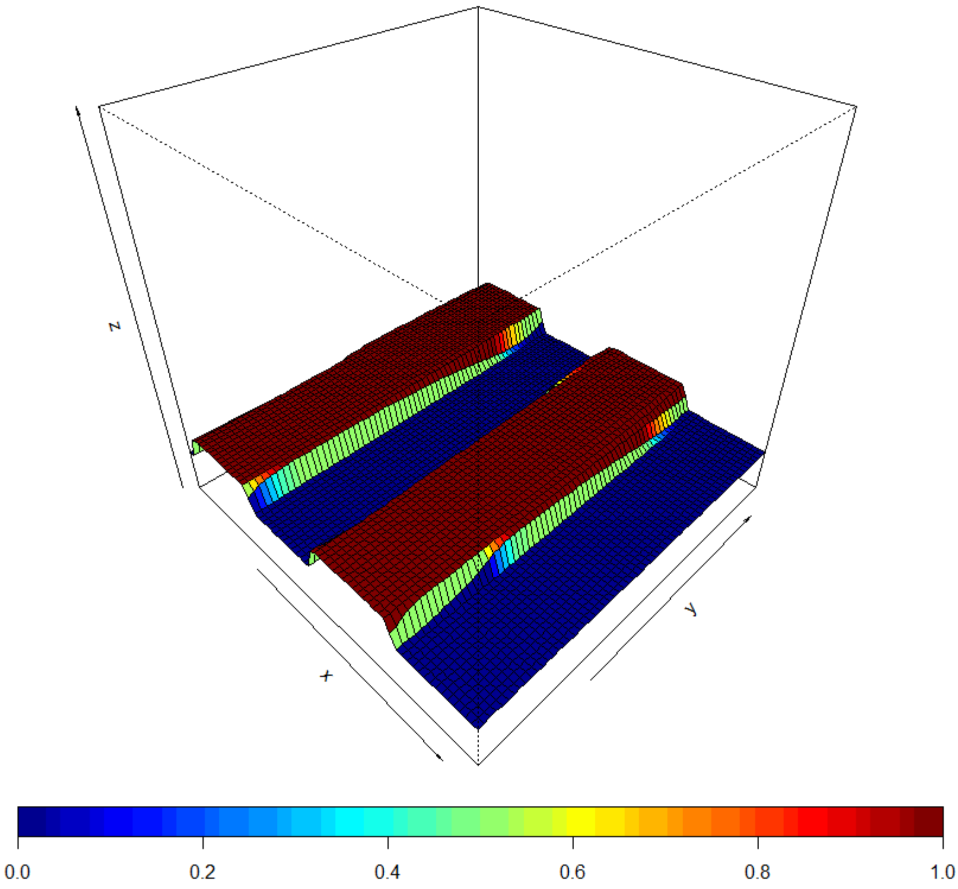
- Under medium anisotropic conditions, elongated islands form
- These islands migrate down flow direction.



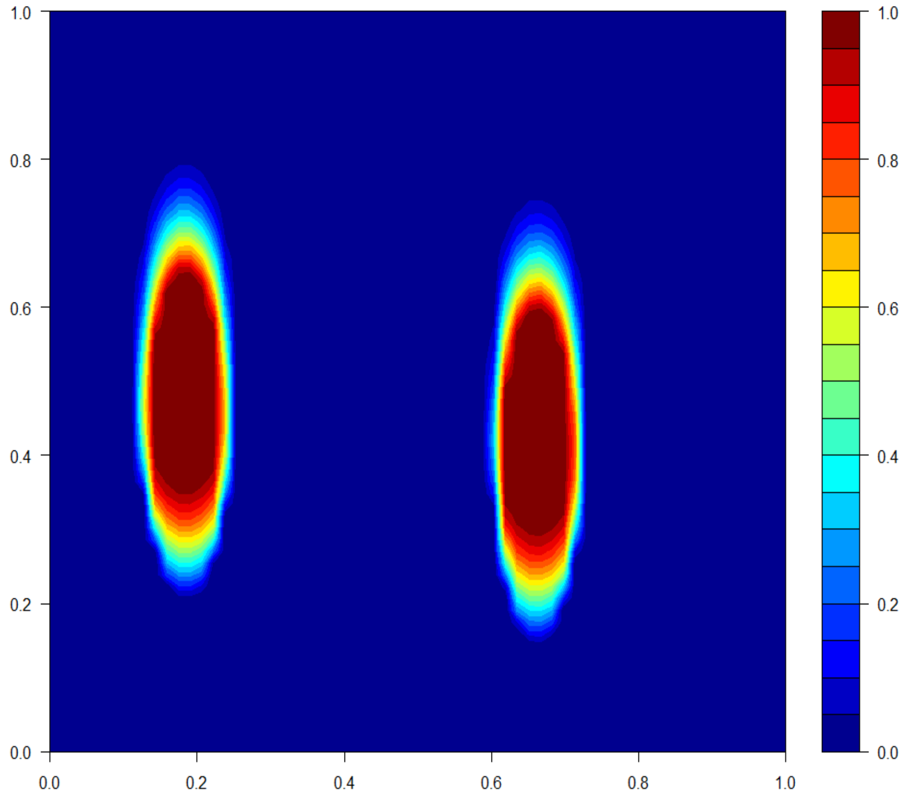


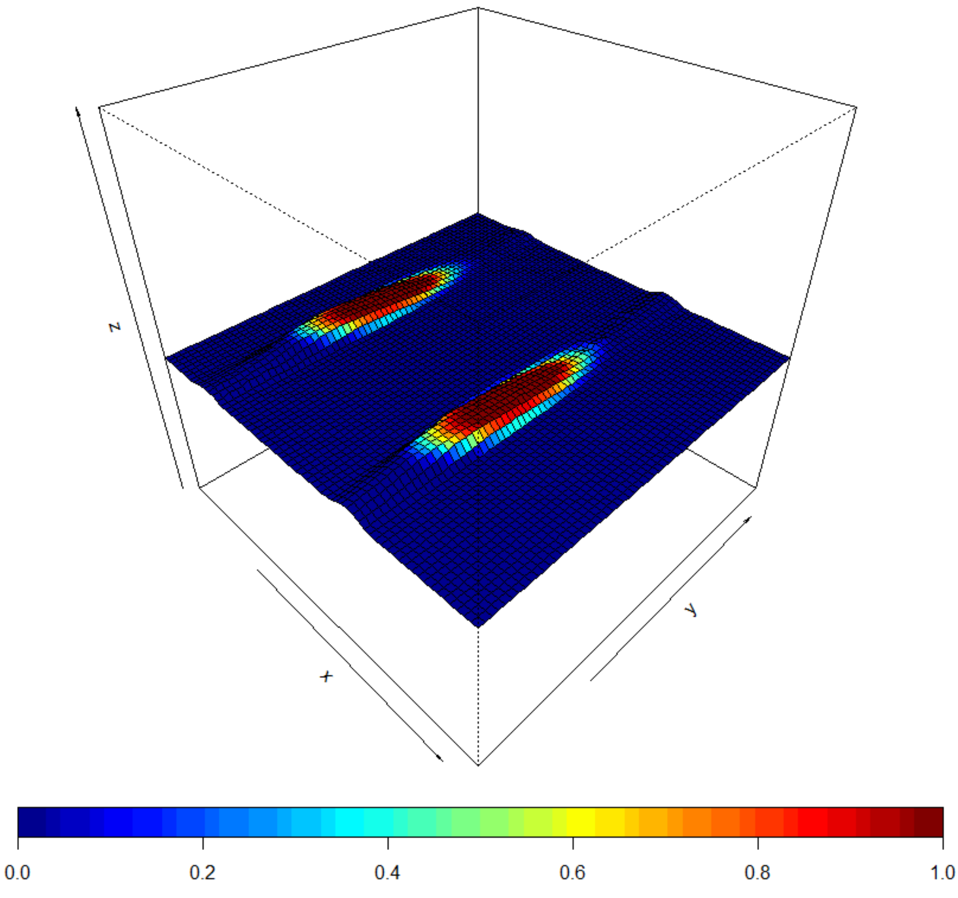
- Under high anisotropic conditions, the islands migrate and extend until the form into full bands, in general here the rate of island migration exceeds the rate of elevation loss.



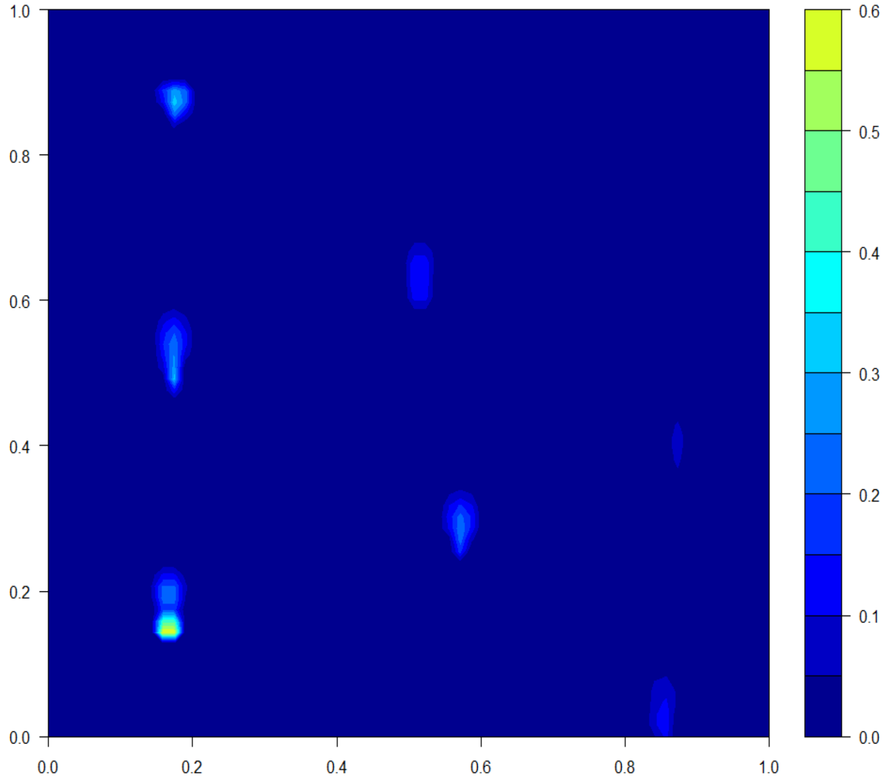


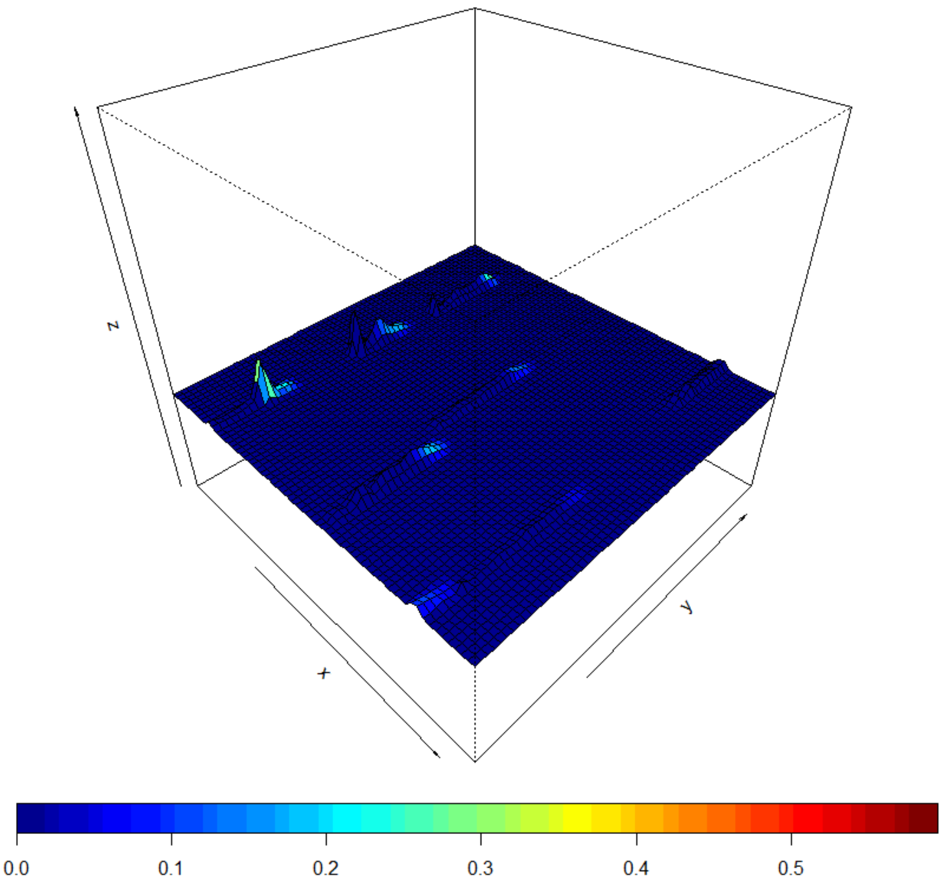
- Under high anisotropic conditions, with moderately low atmospheric phosphorus input the islands migrate and extend but are unable to from full bands.





- Under high anisotropic conditions and low atmospheric P deposition the islands migration "pressure" exceeds the ability of vegetation to stabilize and raised elongated treeless islands form.
- These islands migrate only so long as they have trees, and treeless islands are eventually lost.





Conclusions

- Feedbacks between Trees and P Deposition & Soil Accretion may lead to bistable landscapes
- In the long run Tree Islands and Marshes are alternative equilibria
- The state of elevated island with no trees is a transient (short term) feature
- Tree island are a metastable state → coexisting with the marsh state → only limited resilience

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