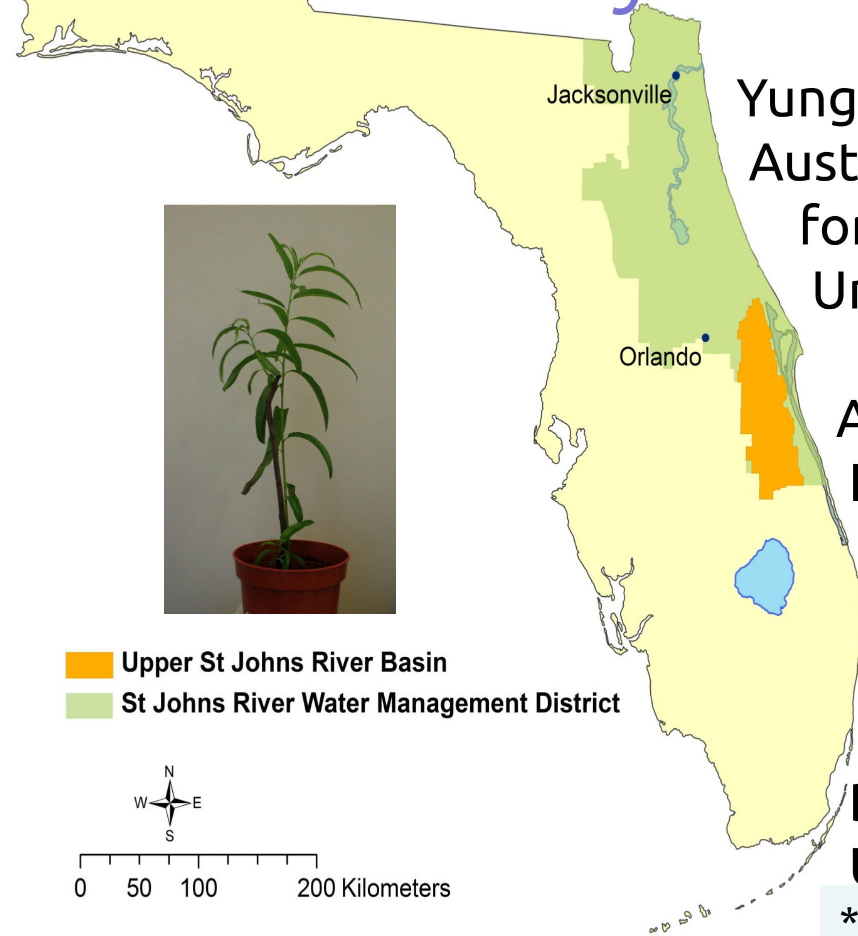
Modelling spatial and temporal changes with Bayesian Networks: an approach combining GIS, spatial and dynamic Bayesian Networks



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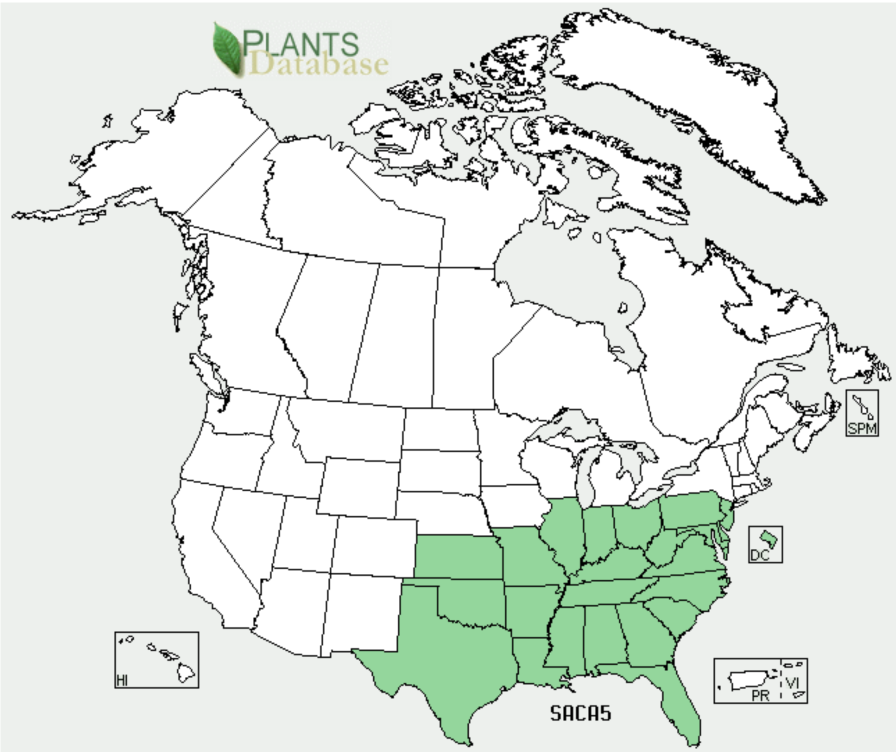
Overview

- The application background: managing willows
- Re-formulation of ST-DBN as OOBN
- Adding a spatial component
- Preliminary results

Willow: ***Salix caroliniana*** Michx..



Native to the south-eastern United States, Mexico and parts of Central America and the Caribbean.

Woody plant
Dioecious (dʌɪˈiːʃəs)
Flowers in Spring
Obligate wetland

St. John’s River, Florida, USA

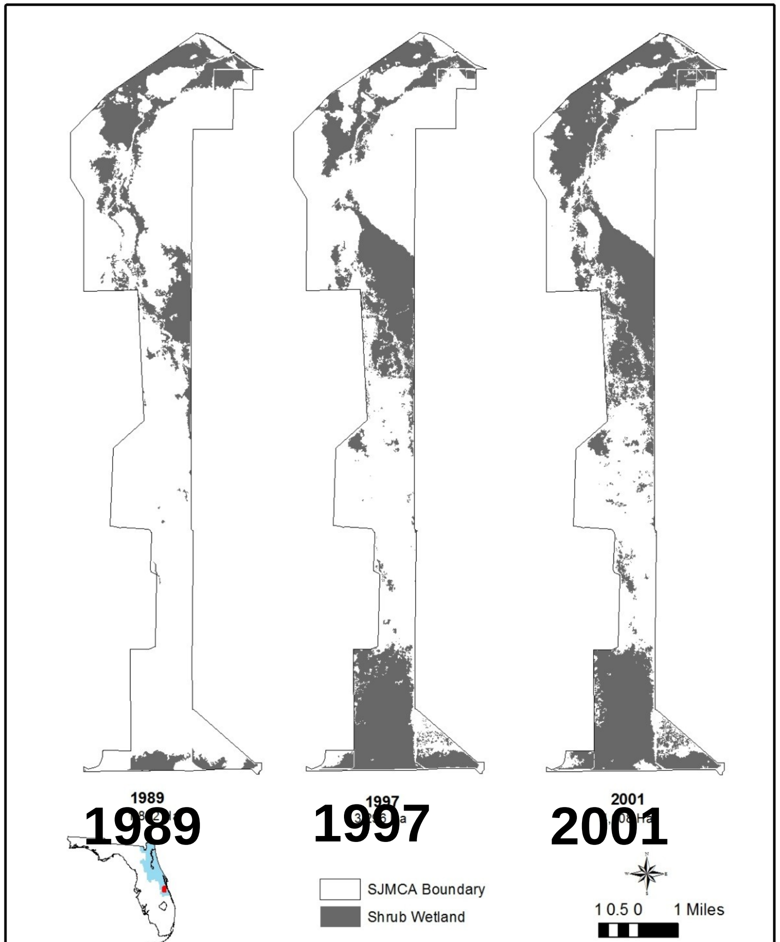


Figure 2. Expansion of shrub wetland communities in the St. Johns Marsh Conservation Area for 1989, 1997, and 2001.

S. caroliniana can convert herbaceous wetlands to forested wetlands.

Managing Willows

Management Objectives:

- control overall extent of willows
- control rate of expansion into extant wetland types
- control encroachment into newly restored areas

Addressing this requires:

- spatially explicit data on ***willow occupancy*** (is it there? What life-history stage is it in?)
- an understanding of ***dispersal*** mechanisms (what's the probability an unoccupied area will be colonised?)
- knowledge of how the various life-history stages of willow respond to environmental factors and management interventions

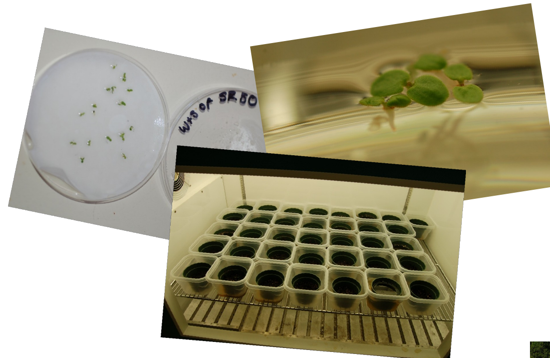
Managing Willows

Management Considerations:

- Different interventions have different spatial, environmental & operational constraints (e.g. Mechanical clearing requires appropriate substrate)
- These induce different effects depending on life-stage & level of cover

Experimental research program 2009-2011

Evaluating germination



Artificial Islands

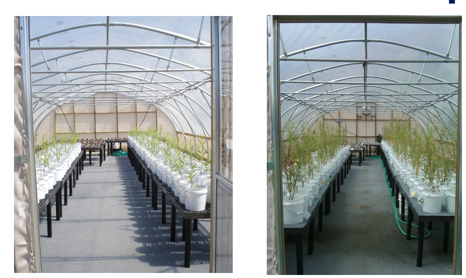
Plant and seed collection

Artificial Ponds

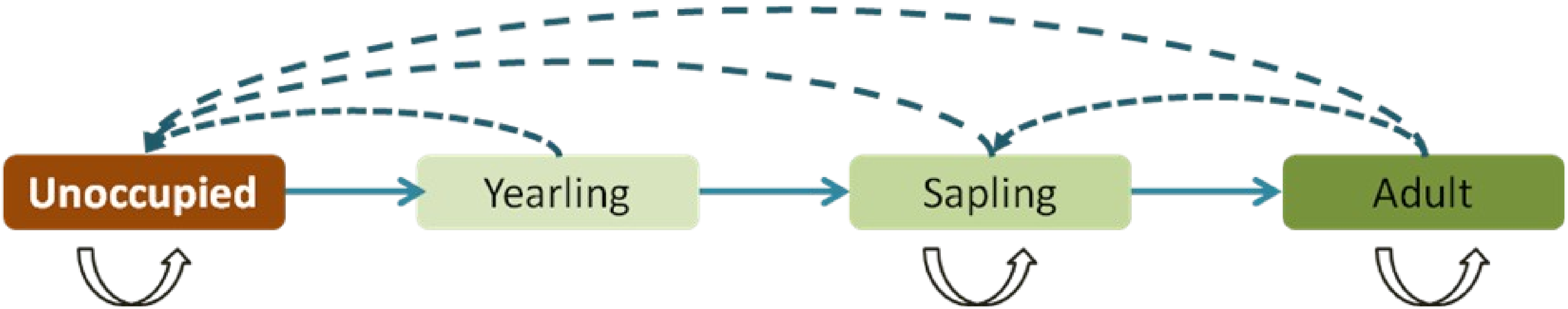
Transplanting

Changes in water depth

Greenhouse expts



Willow Lifecycle



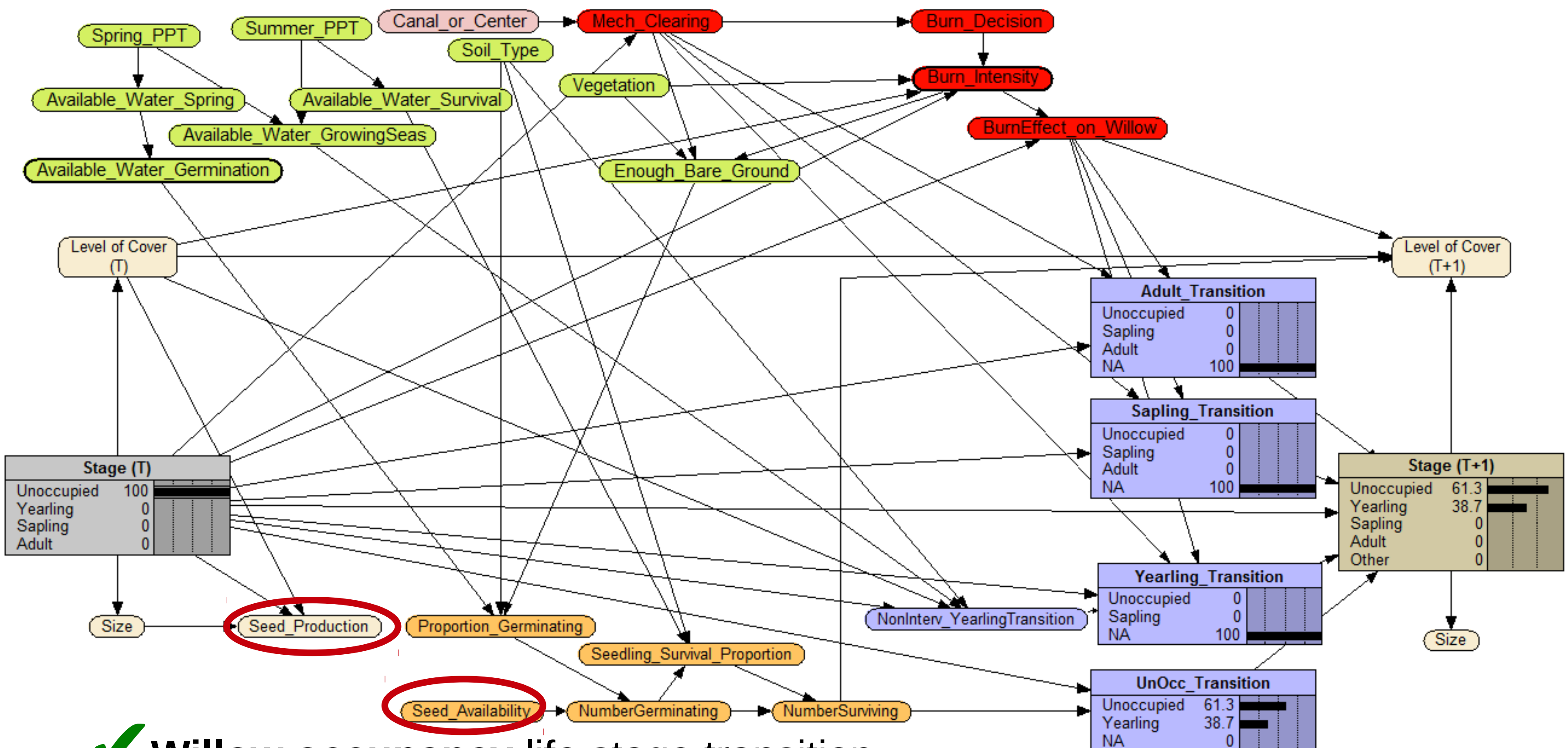
Some Choices and Assumptions

Conceptual Framework: To represent key willow life-history stages: we use State and Transition Models

Spatial Scale: To guide thinking about processes & GIS data → 1 hectare (100mx100m)

Temporal Scale: Time step of 1 year

Previous model



✔ **Willow occupancy** life stage transition

✘ **Seed Dispersal mechanism**

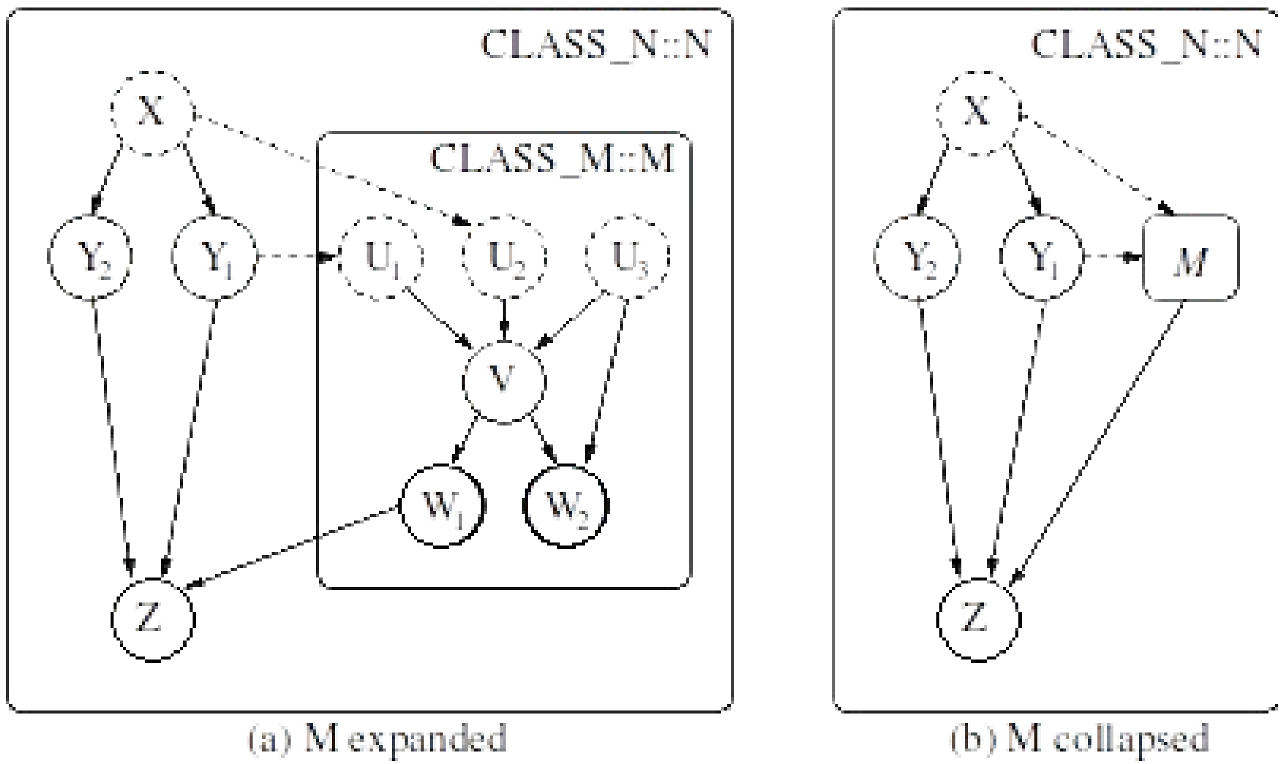
Nicholson, A., Chee, Y., Quintana-Ascencio, P., 2012. A state-transition DBN for management of willows in an american heritage river catchment, in: Nicholson, A., Agosta, J.M., Flores, J. (Eds.), Ninth Bayesian Modeling Applications Workshop at the Conference of Uncertainty in Artificial Intelligence, Catalina Island, CA, USA, http://ceur-ws.org/Vol-962/paper07.pdf.

Step 1: Re-formulate as an Object-Oriented BN

In the first instance interested in:

- Hiding details
- Concentrating on interfaces

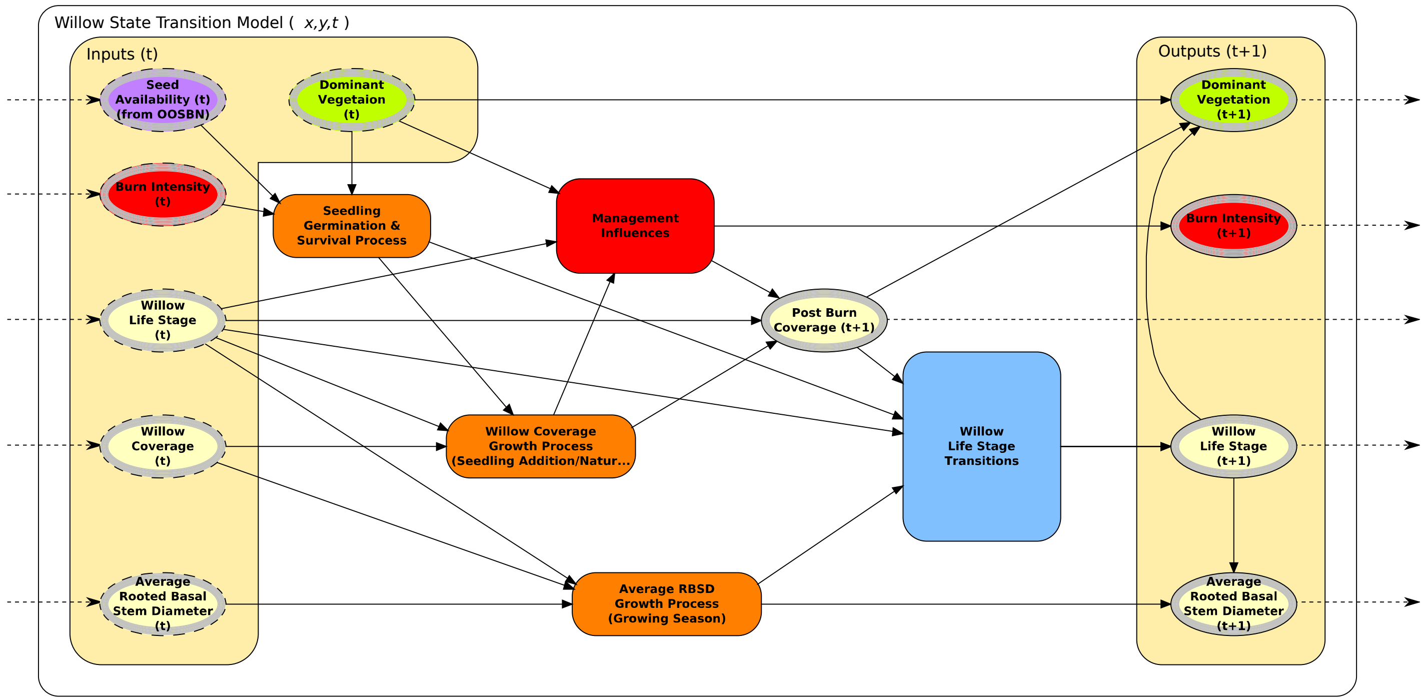
Step 1: Re-formulate as an Object-Oriented BN



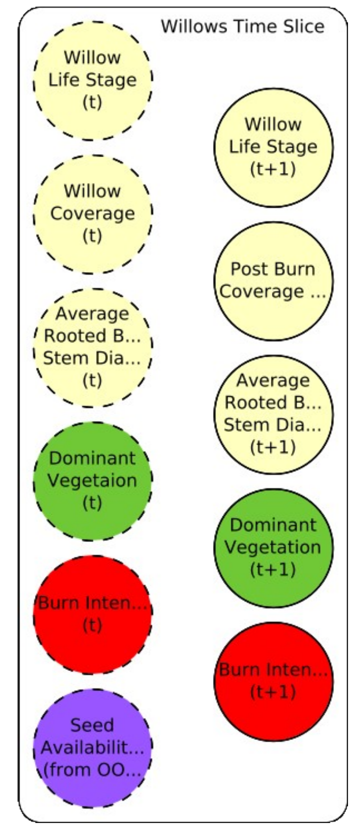
Korb and Nicholson 2010, FIGURE 4.17: A simple OOBN example.

Korb, K.B., Nicholson, A., 2010. Bayesian artificial intelligence. 2nd ed., Chapman&Hall/CRC, Boca Raton, FL.

Step 1: Re-formulate as an Object-Oriented BN

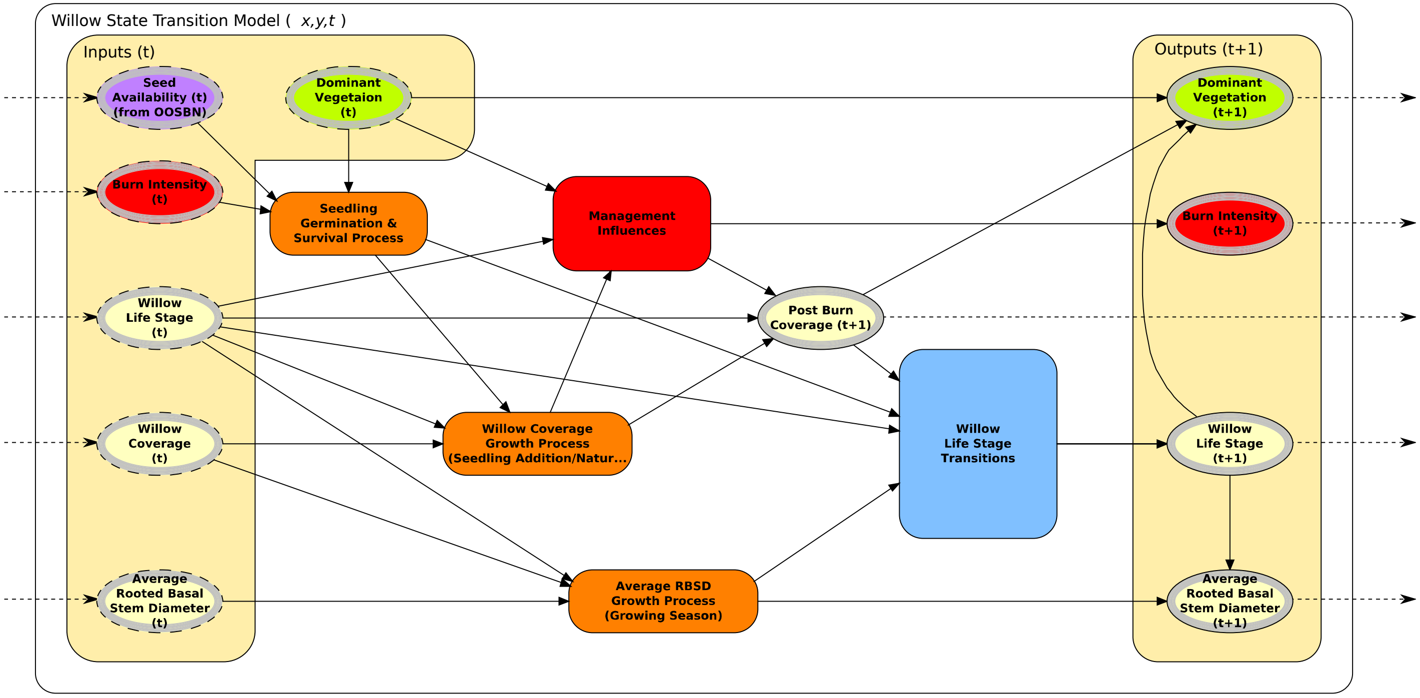


Collapsed



Expanded

Step 1: Re-formulate as an Object-Oriented BN



Expanded

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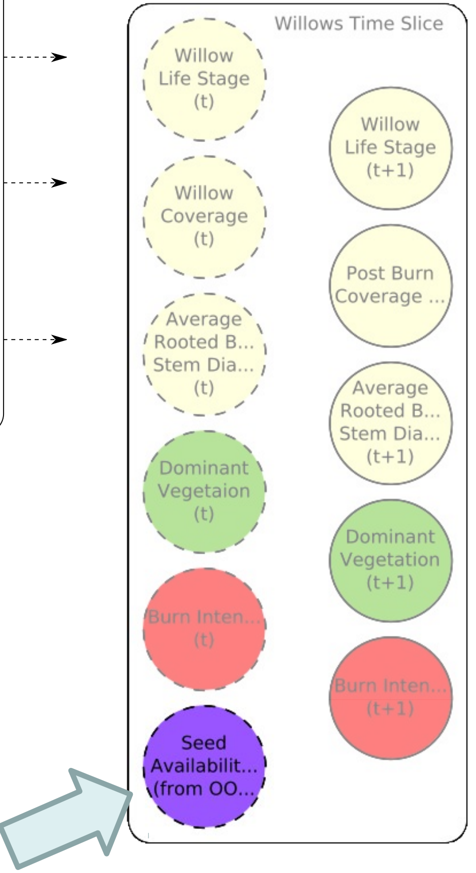
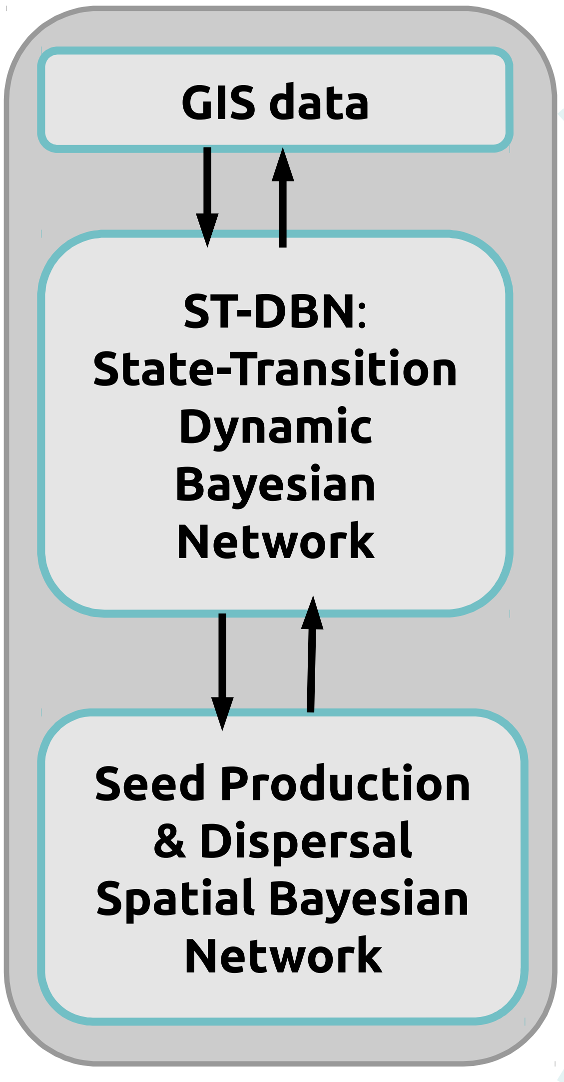
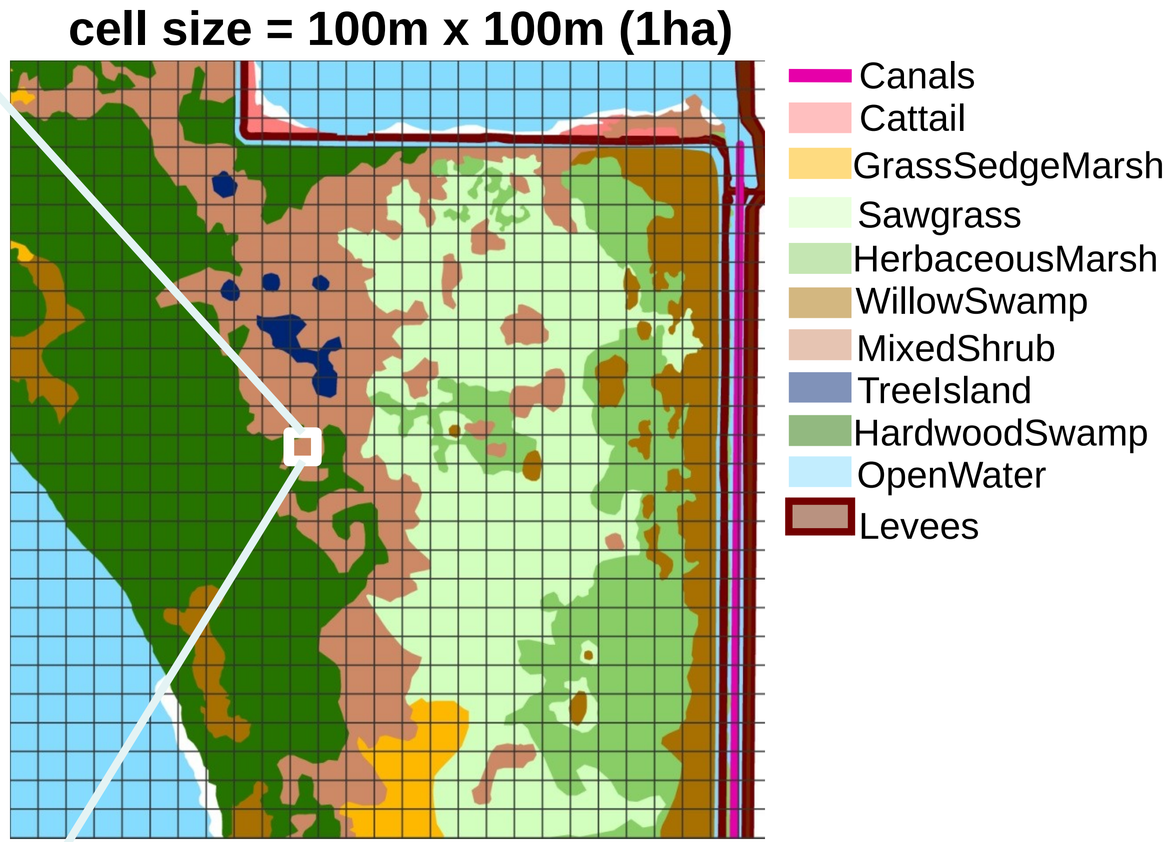


If it wasn't for seed availability that would be the end of the story.

Step 2: Revise Architecture to do seed dispersal in BN



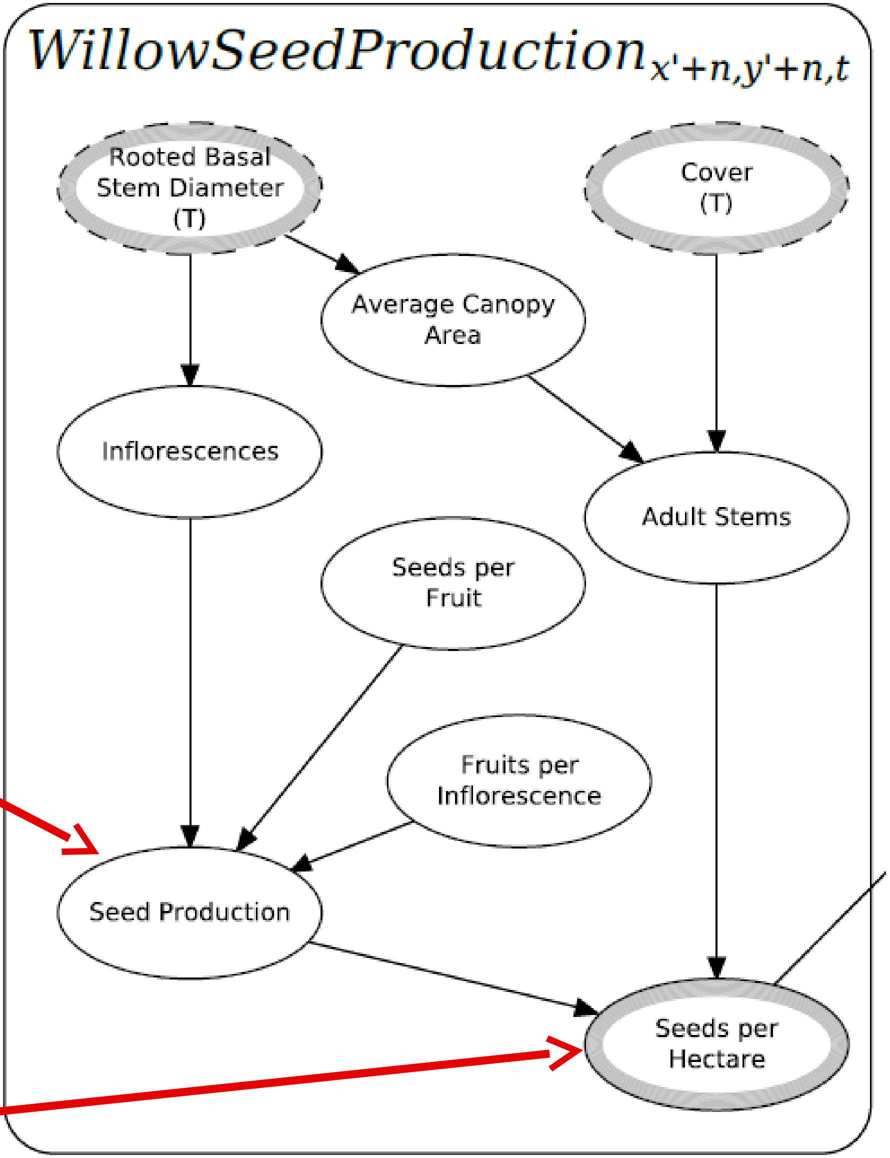


Step 3: Modelling Seed Production & Dispersal

- key drivers of willow spread
- single adult can produce ~660,000/yr!
- dispersed by wind & water

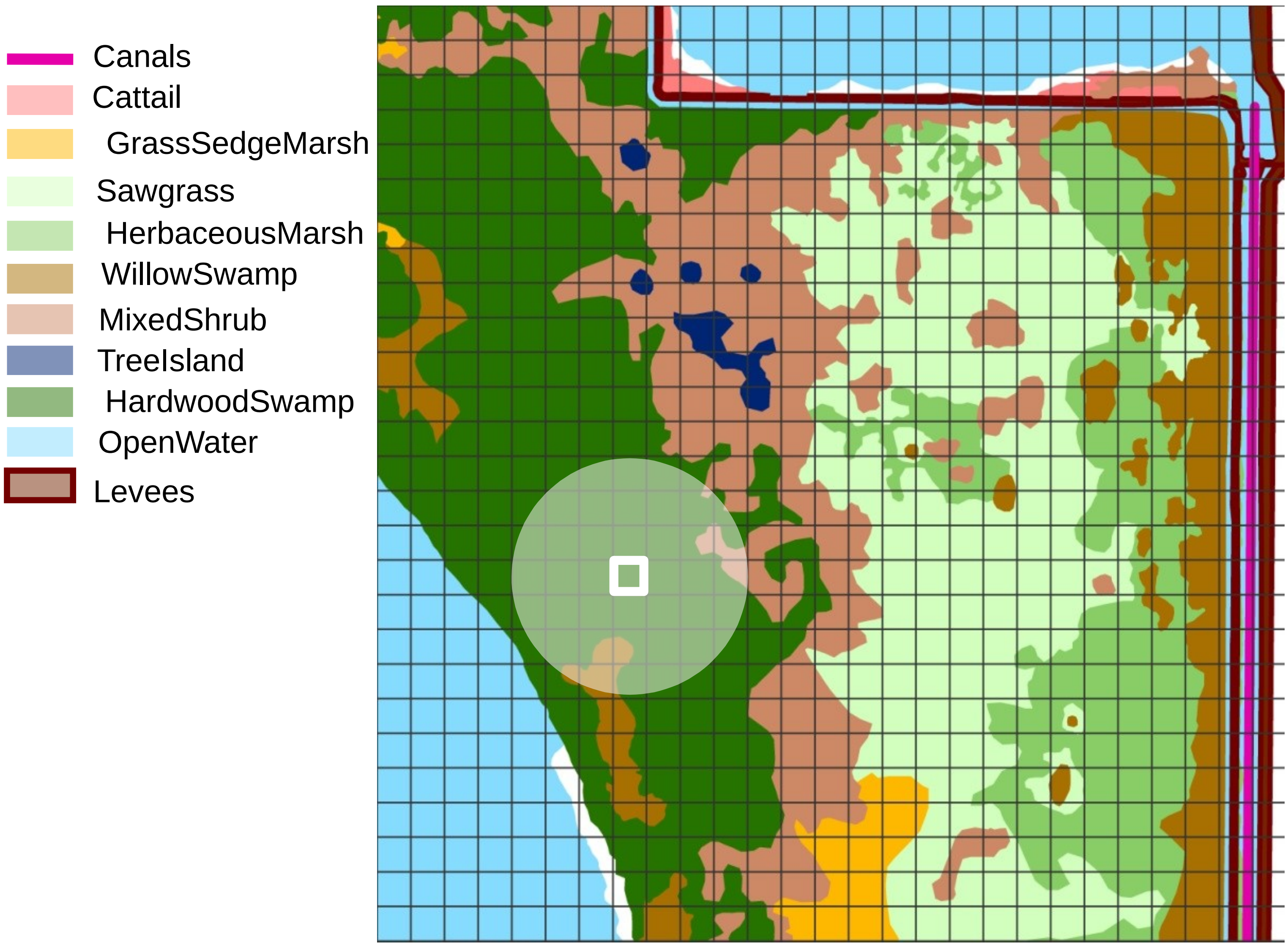
Modelling Seed Production

SeedsPerStem = I * F * S
where
- **I** = # of ***inflorescences***
- **F** = # ***fruits per inflorescence***
- **S** = # ***seeds per fruit***



SeedsPerHA = SeedsPerStem * NumberOfStemsPerHA

Modelling Seed Dispersal by Wind



Modelling Seed Dispersal by Wind

$$SD_{x,y}^{x',y'} = SP_{x',y'} \times \frac{1}{2\pi\alpha^2} e^{-(\frac{d}{\alpha})}$$

number of seeds dispersed to cell (x, y) from those produced at cell (x', y')

number of seeds produced at cell (x', y')

exponential dispersal kernel where d is the distance between cells (x,y) & (x', y') and α is a distance parameter

Clark, J. S., Silman, M., Kern, R., Macklin, E. & Hille Ris Lambers, J. (1999) Seed dispersal near and far: patterns across temperate and tropical forests. *Ecology* 80, 1475-1494.
Fox, J. C., Buckley, Y. M., Panetta, F. D., Bourgoin, J. & Pullar, D. (2009) Surveillance protocols for management of invasive plants: modelling Chilean needle grass (Nassella neesiana) in Australia. *Diversity and Distributions* 15, 577-589.

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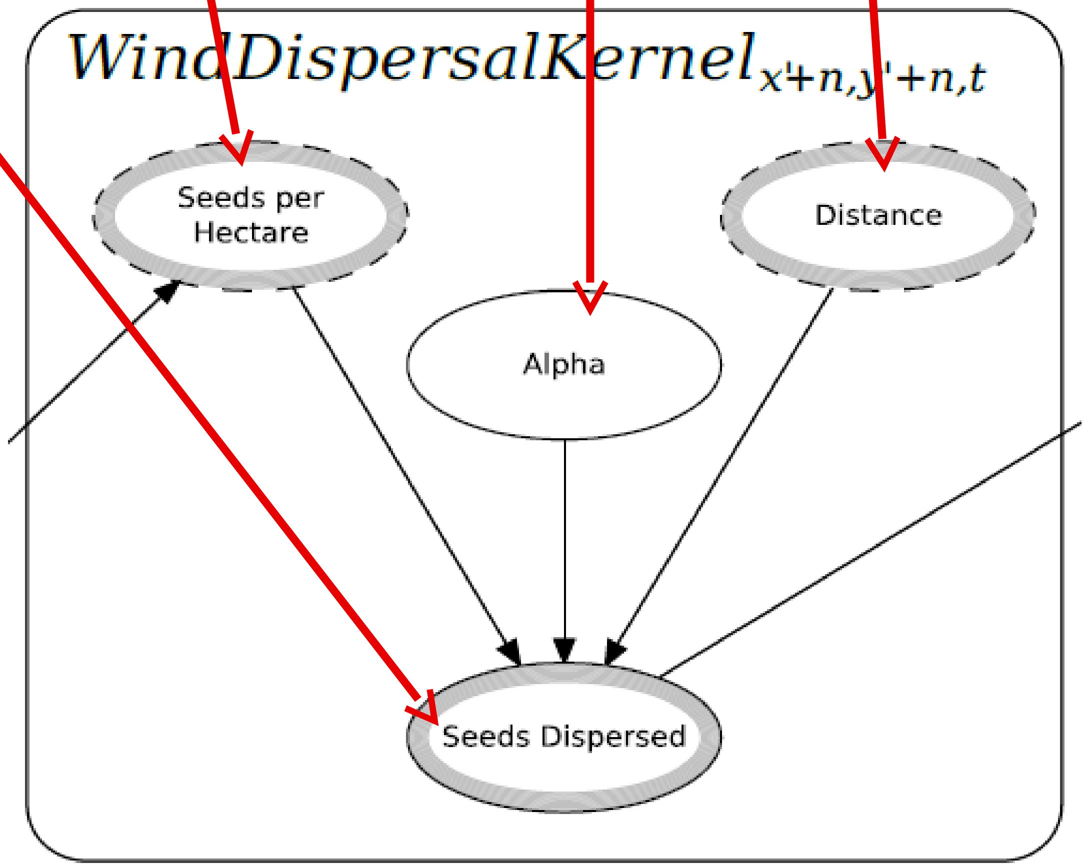


Modelling Seed Dispersal by Wind

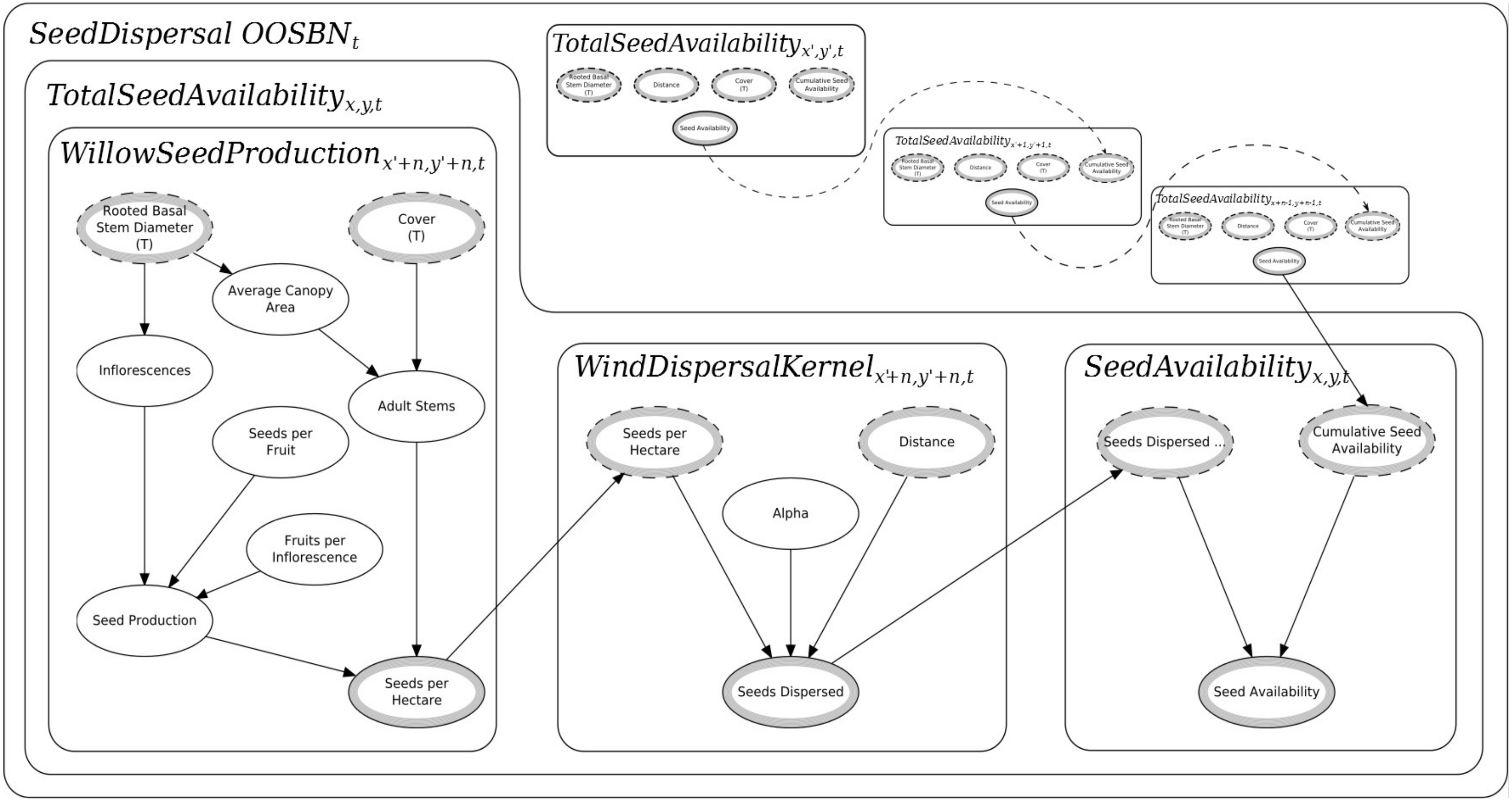
$$SD_{x,y}^{x',y'} = SP_{x',y'} \times \frac{1}{2\pi\alpha^2} e^{-(\frac{d}{\alpha})}$$

$$SA_{x,y} = \sum_{x',y' \in Area} SD_{x,y}^{x',y'}$$

Total Seed Available at cell (x, y)

sum up all seeds dispersed to cell (x, y) from those produced at ALL other cells (x', y') across the Area of interest

Modelling Seed Dispersal by Wind



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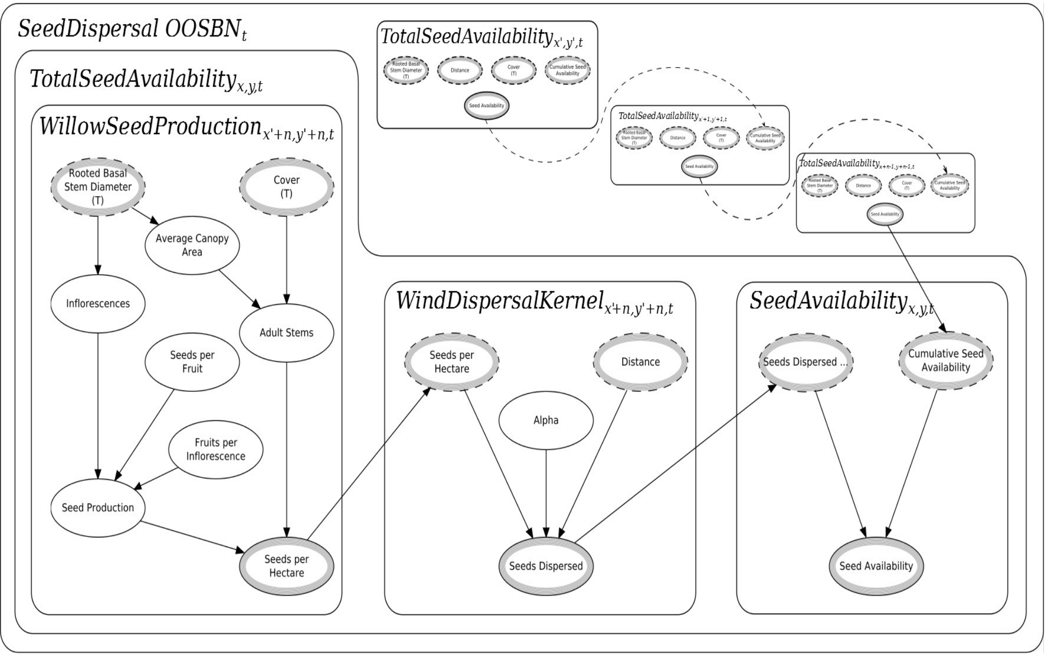

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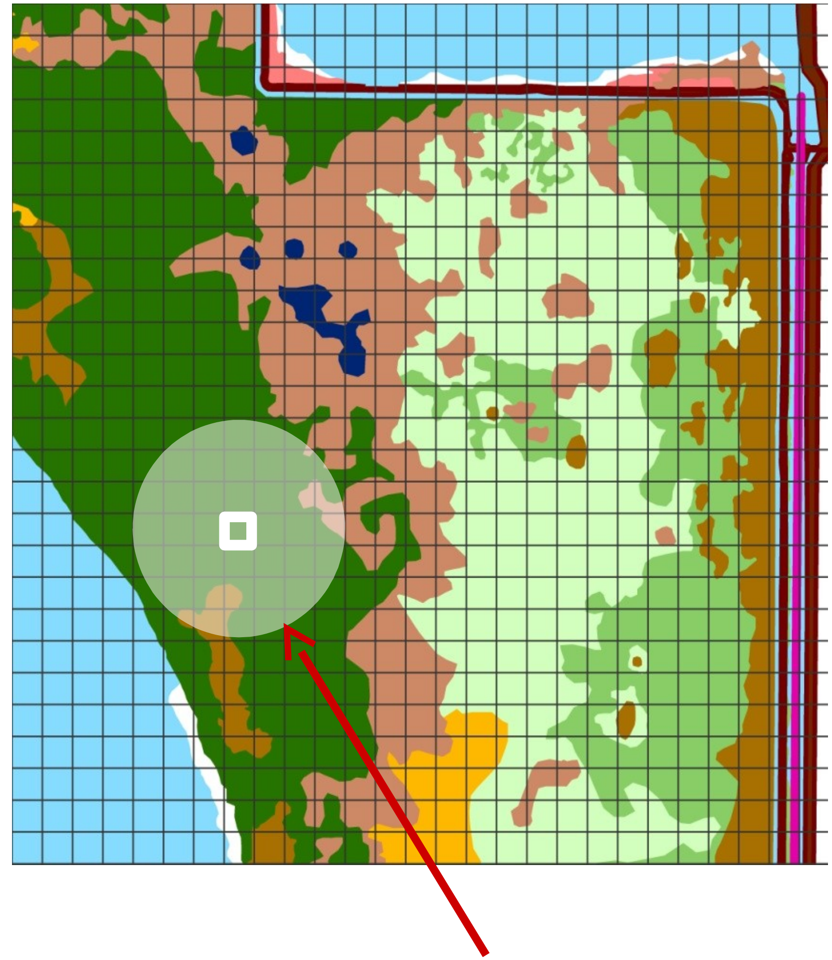
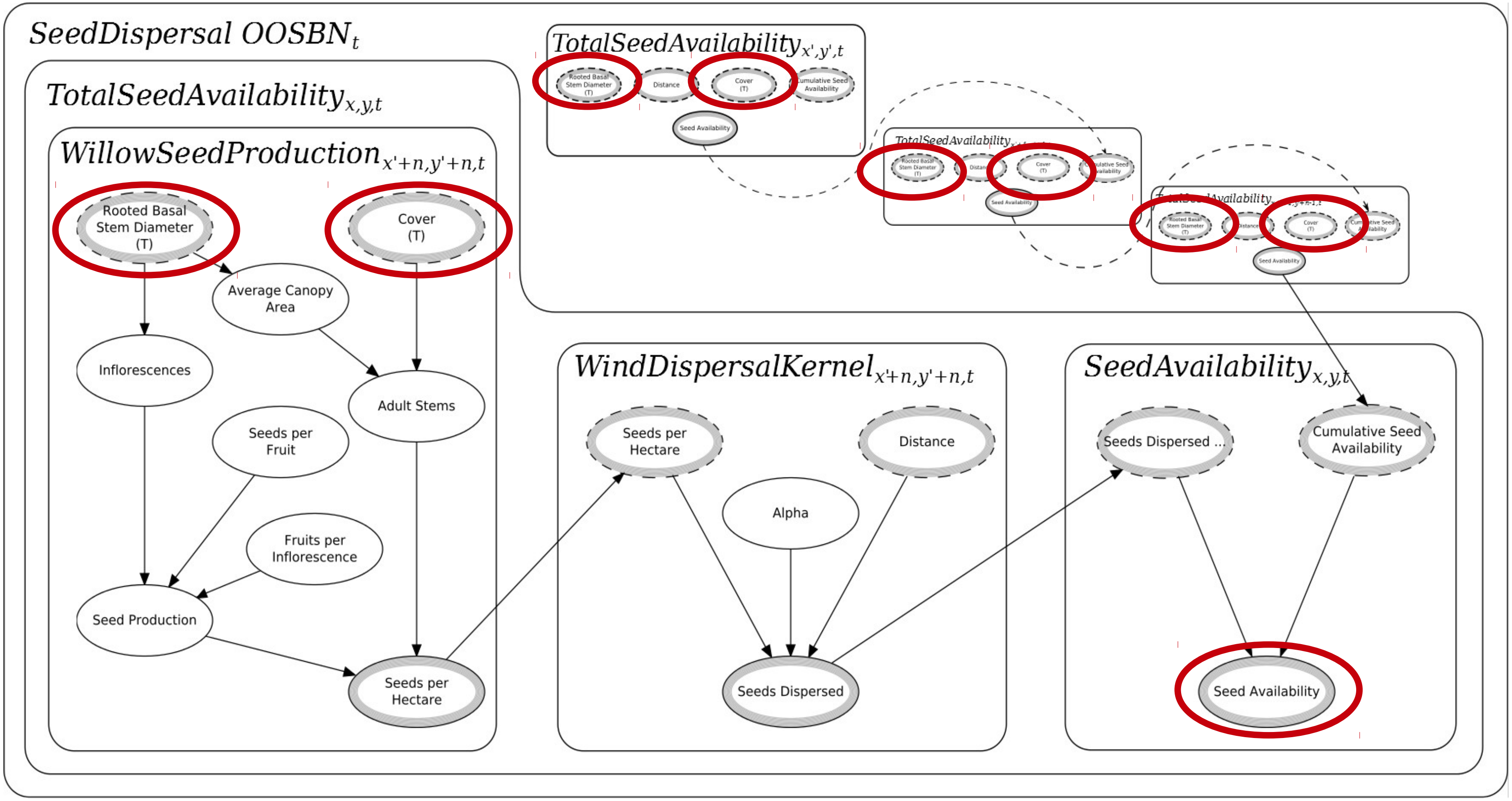


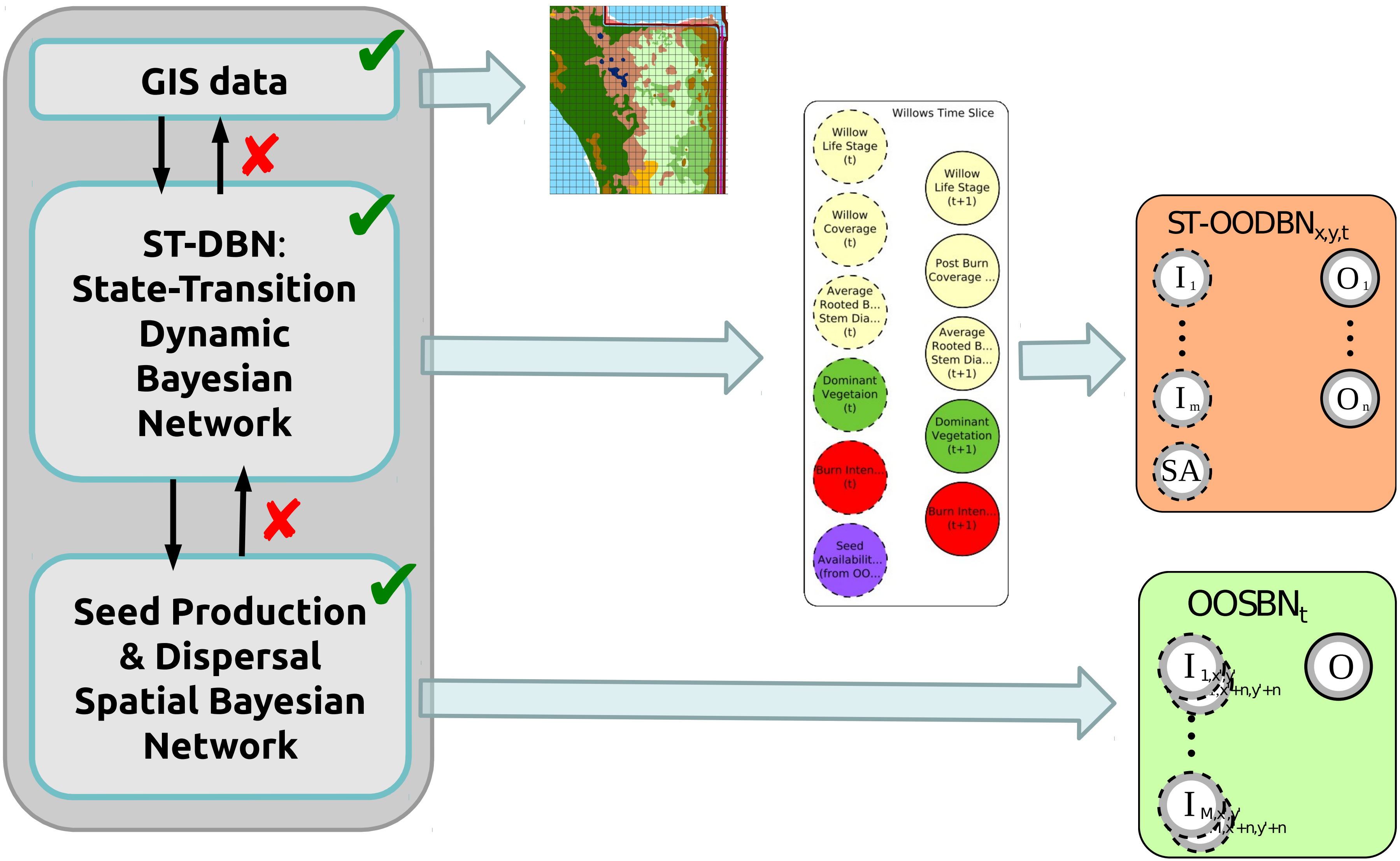
Dispersal mask

Modelling Seed Dispersal by Wind



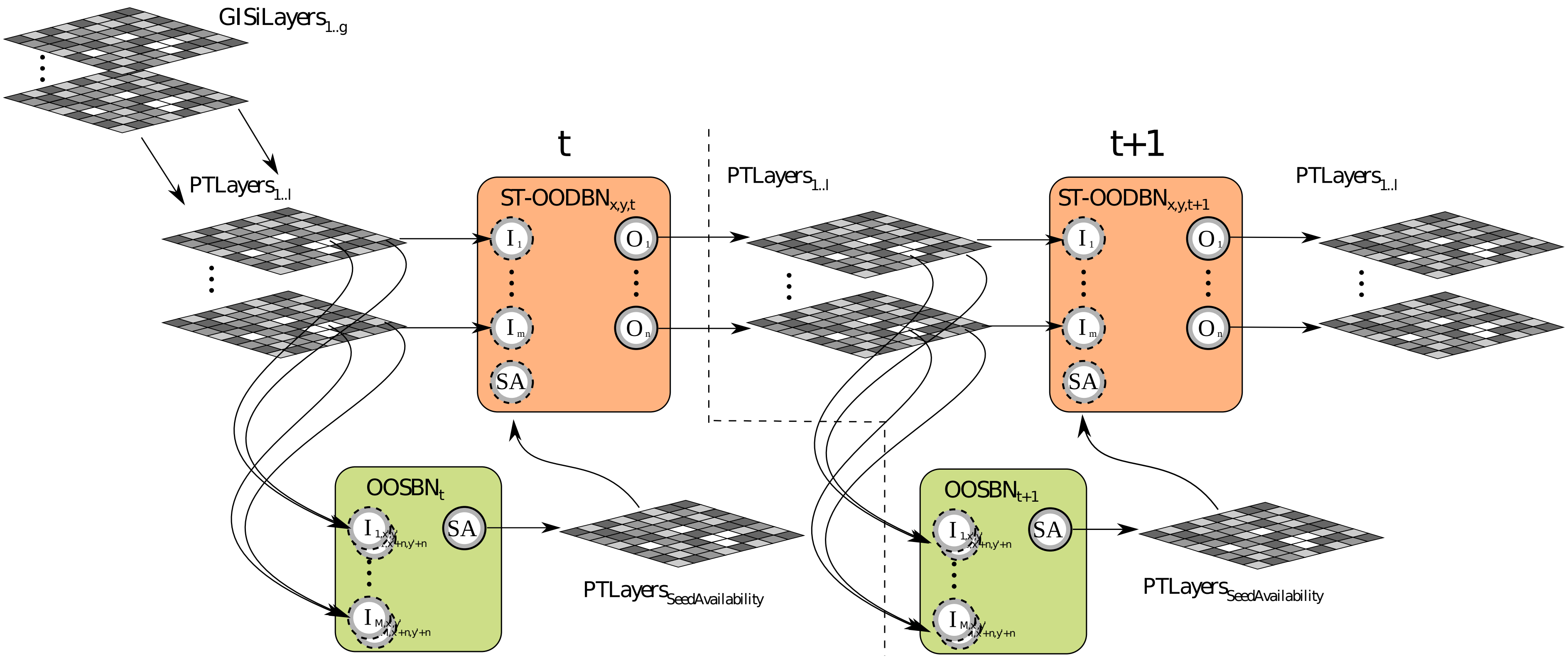
2 inputs (from each source cell) → 1 output (to each target cell)

Step 4: Integration



2 inputs (from each source cell) → 1 output (to each target cell)

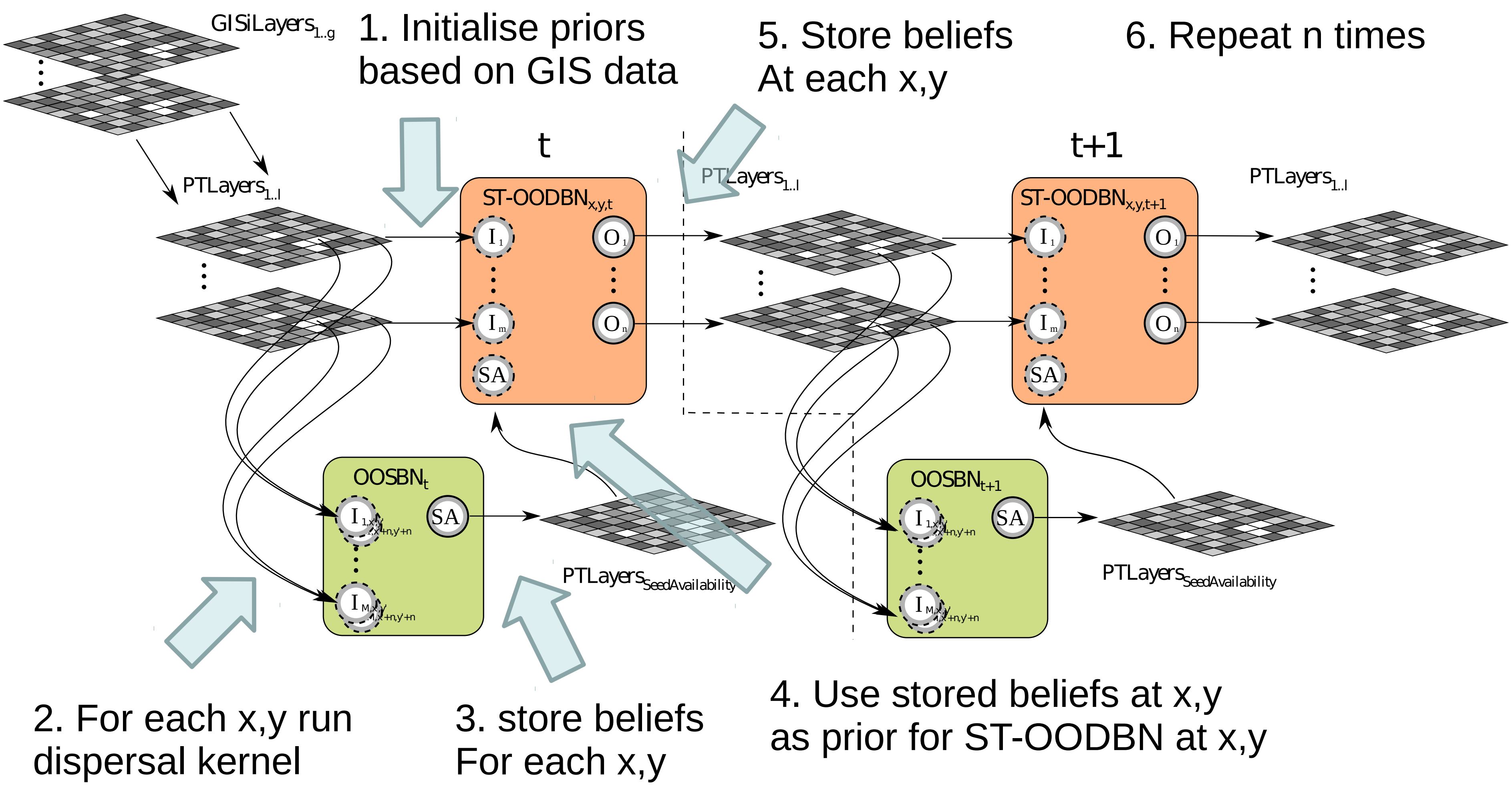
Integrating GIS data, Willow State-Transitions model (ST-OODBN) & Seed Dispersal model (OOSBN)



PTLayer = compact representation of **probability distribution** for each node at each x,y location in the area of interest.

(Another way to represent this would be as a CPT with a third dimension indexed by location)

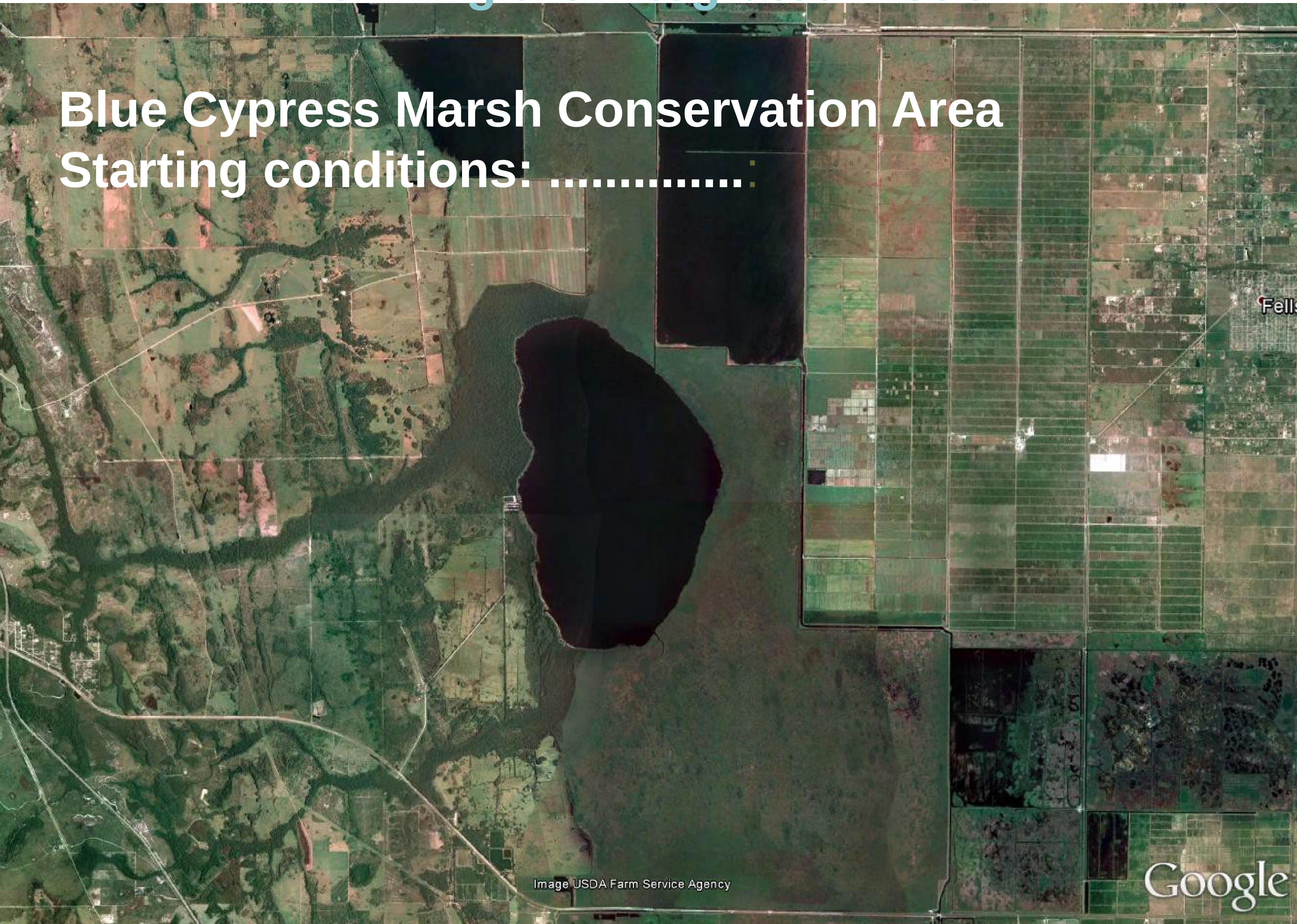
Integrating GIS data, Willow State-Transitions model (ST-OODBN) & Seed Dispersal model (OOSBN)

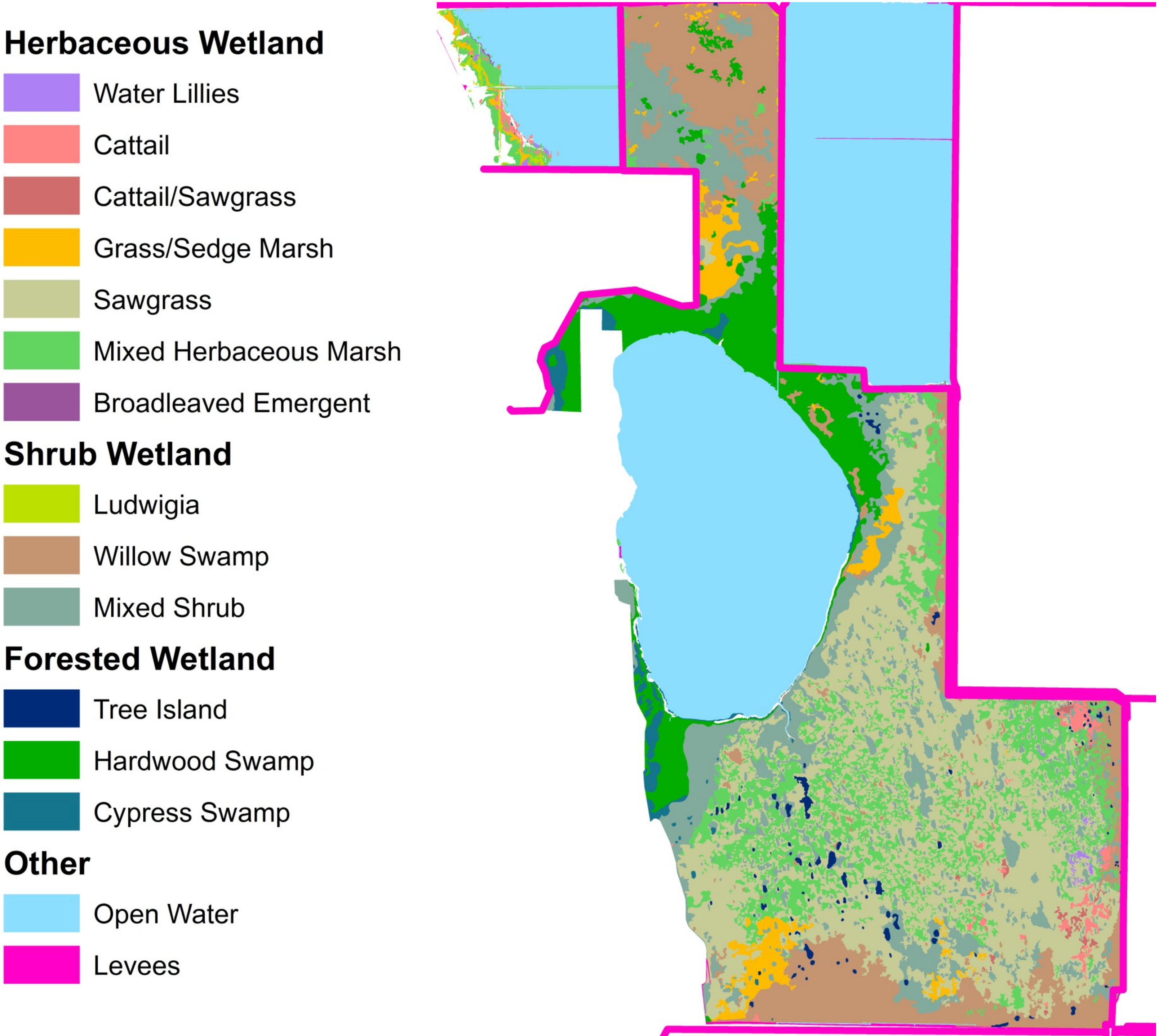


Running the Integrated Model

Blue Cypress Marsh Conservation Area

Starting conditions: ....

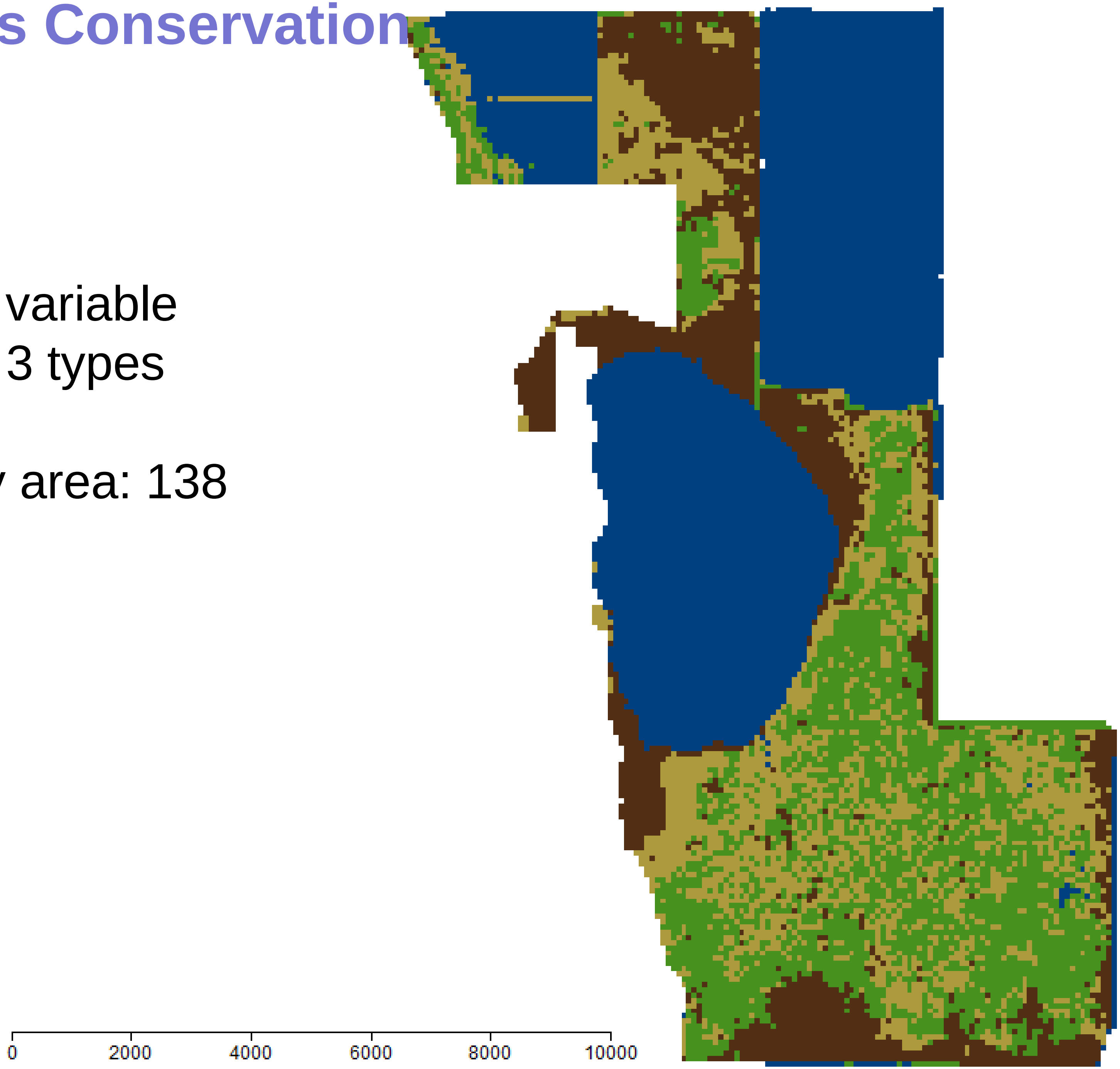




Herbaceous Wetland
Water Lillies
Cattail
Cattail/Sawgrass
Grass/Sedge Marsh
Sawgrass
Mixed Herbaceous Marsh
Broadleaved Emergent
Shrub Wetland
Ludwigia
Willow Swamp
Mixed Shrub
Forested Wetland
Tree Island
Hardwood Swamp
Cypress Swamp
Other
Open Water
Levees

Blue Cypress Conservation Case Study

- Vegetation variable reduced to 3 types
- Case study area: 138 x 205 cells



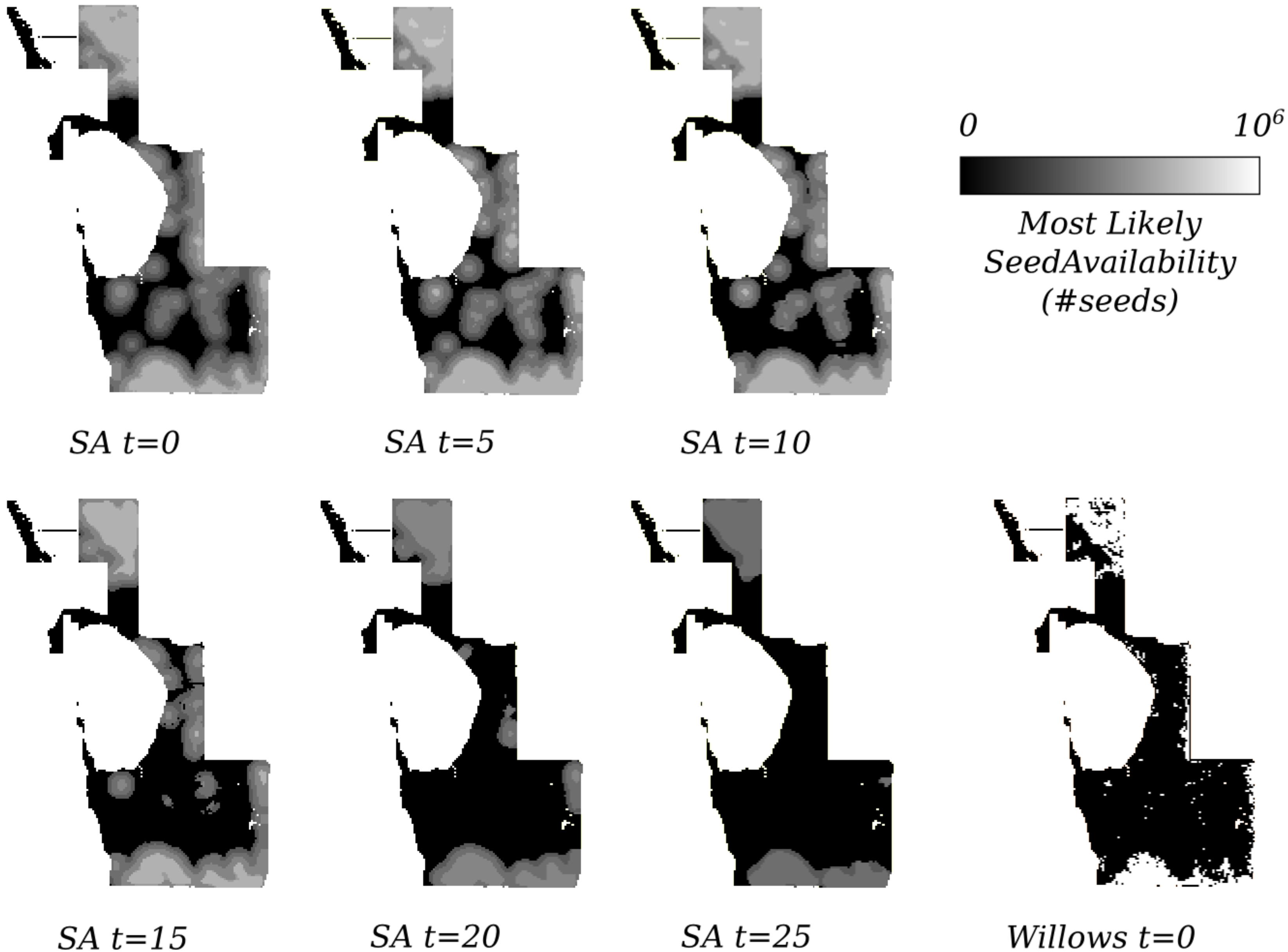
Preliminary Results

- Simple (simplistic) management scenario:

if a cell is next to a canal, mechanical clearing is carried out, otherwise (for landlocked cells), burning is prescribed (with prob=0.1).

- Maps of willow cover and seed production were generated at yearly intervals for a 25 year prediction window.
- Computation time: ~8 hours (64bit, 2.8GHz)

Preliminary Results



Conclusions

- We now have a combined spatial and temporal model for willows management
- Algorithms for propagating beliefs forward in both time and space
- Next:
  - Explore more realistic management scenarios
  - Continue calibrating model parameters