Competition Model

- Species A
  - $d\text{species}_A / dt = (r_A * (1\text{-species}_A / K_A)*)\ \text{species}_A - \alpha_{AB} * \text{speciesA} * \text{speciesB}$
- Species B
  - $d\text{species}_B / dt = (r_B * (1\text{-species}_B / K_B)*)\ \text{species}_B - \alpha_{BA} * \text{speciesA} * \text{speciesB}$

Similar to predictor - prey models - building on logistic growth

Types of Models:

Conceptual.....Mathematical

Static……Dynamic :*TIME*

Lumped.....Spatially Distributed: *SPACE*

Stochastic.....Deterministic

Abstract……Physically/Process Based

but biggest differences may often be the degree specific processes/parameters are accounted for

STEPS: Modeling for Problem Solving in ES

1. **Clearly define your goal (question you want to answer, hypothesis you want to test, prediction you want to make) - as precisely as possible**
2. Design or Select your model
3. Implement the model
4. Evaluate the model and quantify uncertainty
5. Apply the model to the goal
6. Communicate model results

Some common "Eco-Hydrology" goals that can use models

How do changes in water supply and demand impact vegetation productivity and sensitivity to disturbance (fire, disease, and drought related mortality) and nutrient cycling?

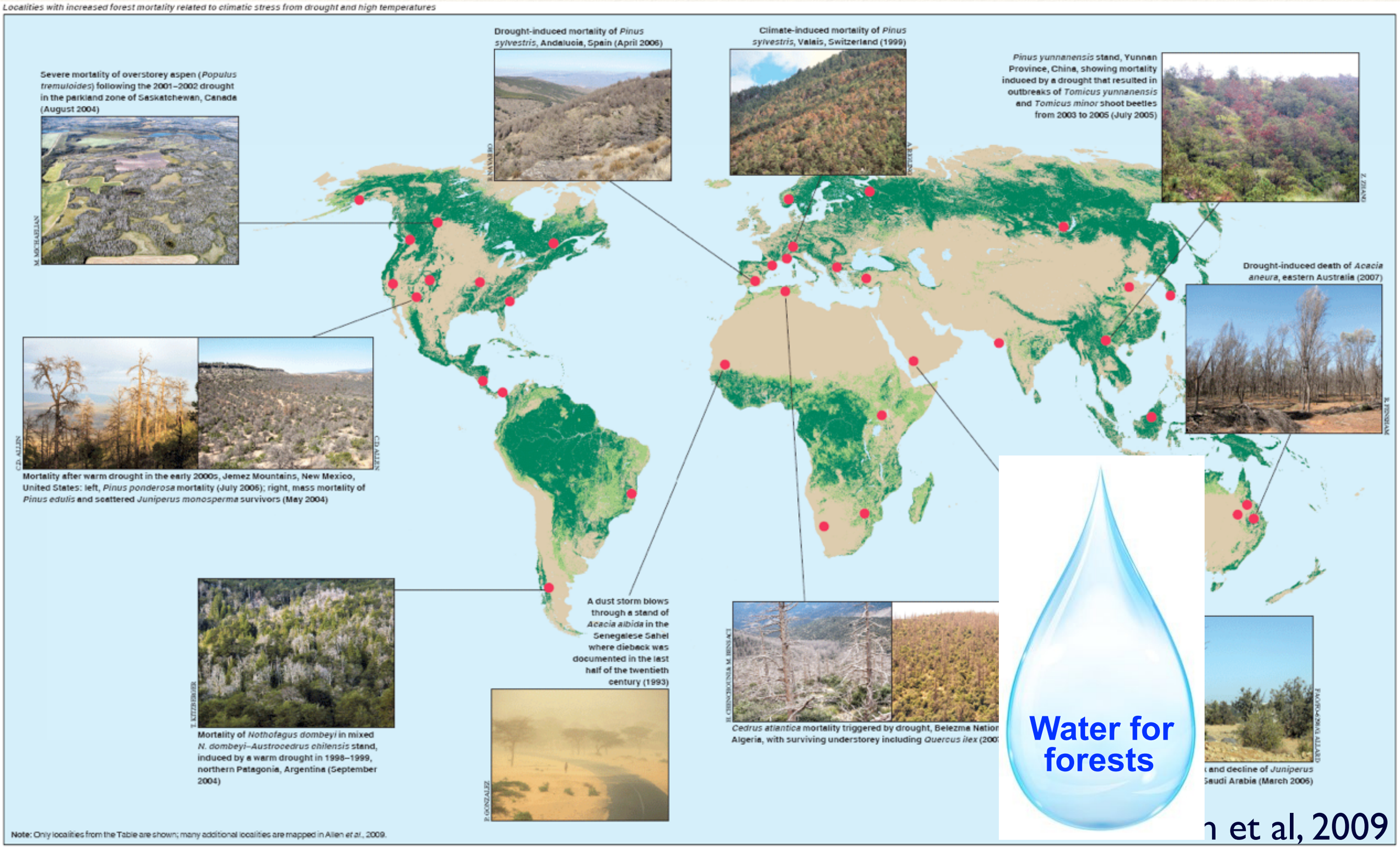
Do these changes have implications for

- streamflow timing and magnitude?
- for water quality?

How do changes in forest structure (intentional or otherwise) influence these relationships?

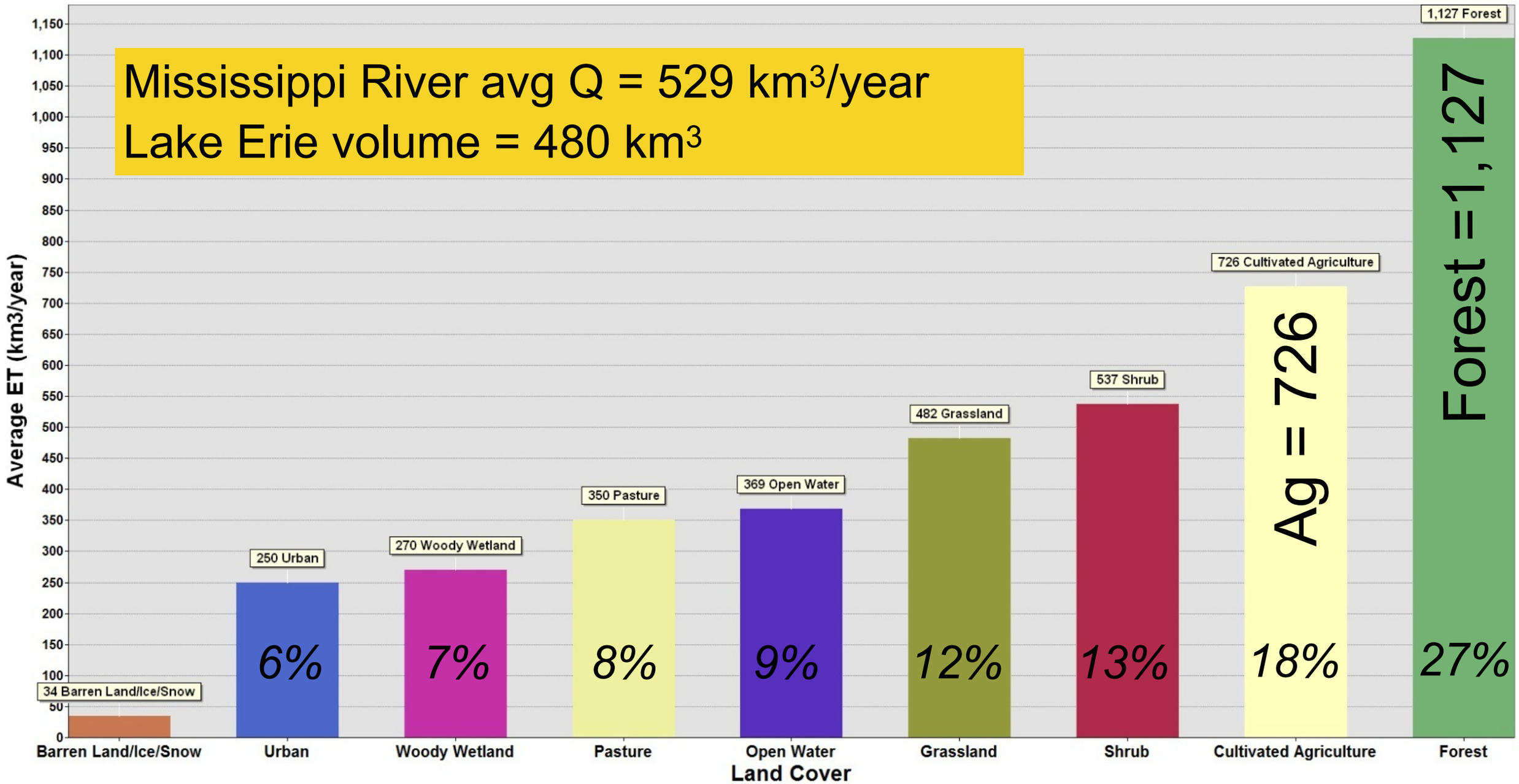
Forests also need water - and increasing warmer temperatures & drought have been linked to

large-scale episodic forest dieback events



n et al, 2009

Forests use a lot of water!
But how much varies with many forest characteristics:
Some of which we can manage



Percent ET by land cover

So how much water do forests use?

Empirical Evidence of Changing Forest Structure and Streamflow

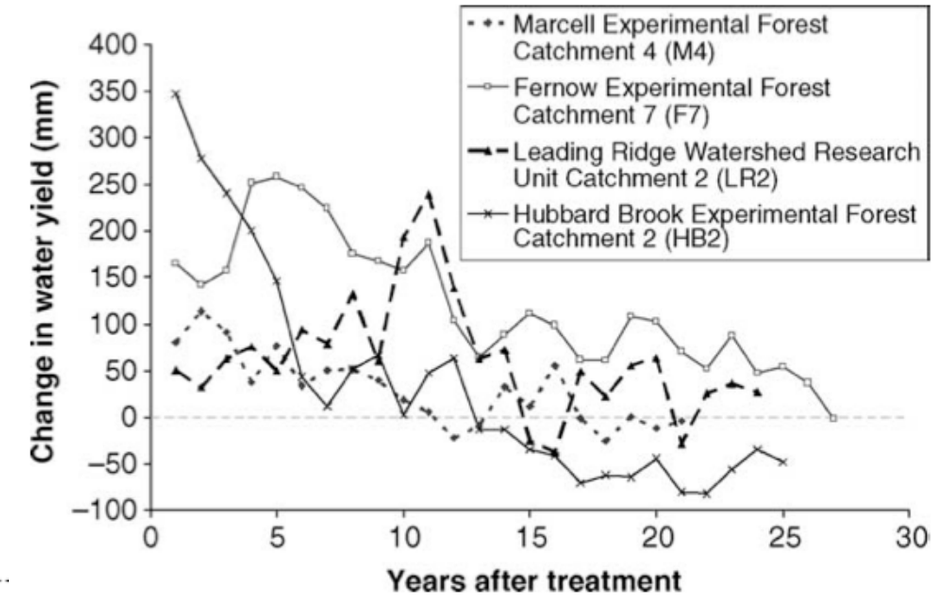


Fig. 5. Change in annual water yield for four paired catchment studies in the USA. M4—100% Basal area cut. F7, Upper half clear-cut (year 0), herbicides on upper half (2-7), lower half cut (year 4), herbicide on entire catchment (5-7). LR2—Lower 24% clear cut (year 0), mid slope 27% clear-cut (years 4-5), herbicide on lower and mid slope (year 7) 40% Upper slope clear-cut (year 8-9), herbicide all catchment (year 10). HB2—100% clear felled (year 0), herbicide on entire catchment (years 2-4). After Hornbeck et al. (1993).

Brown et al. (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation, *J. of Hydrology* 310: 28-61.

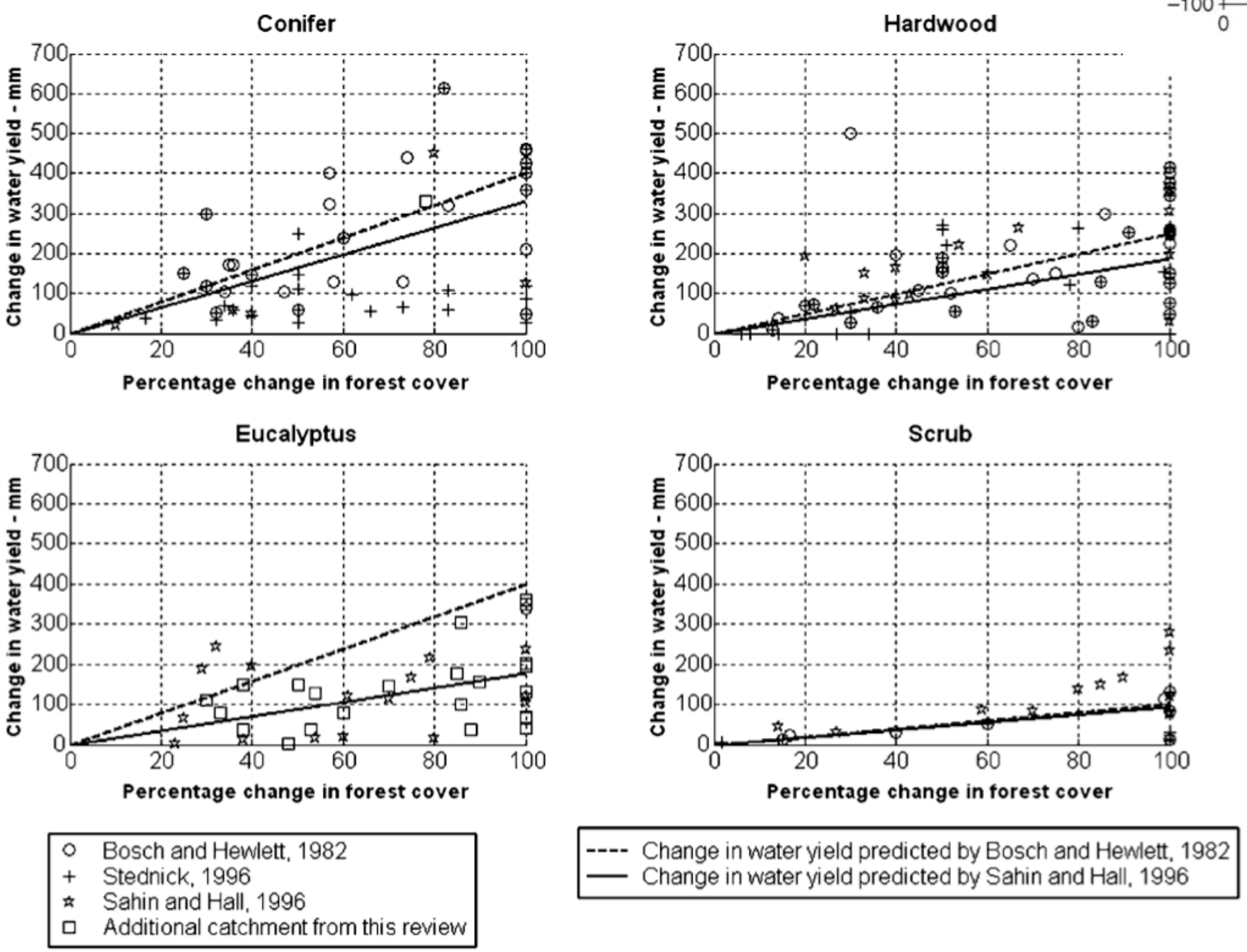
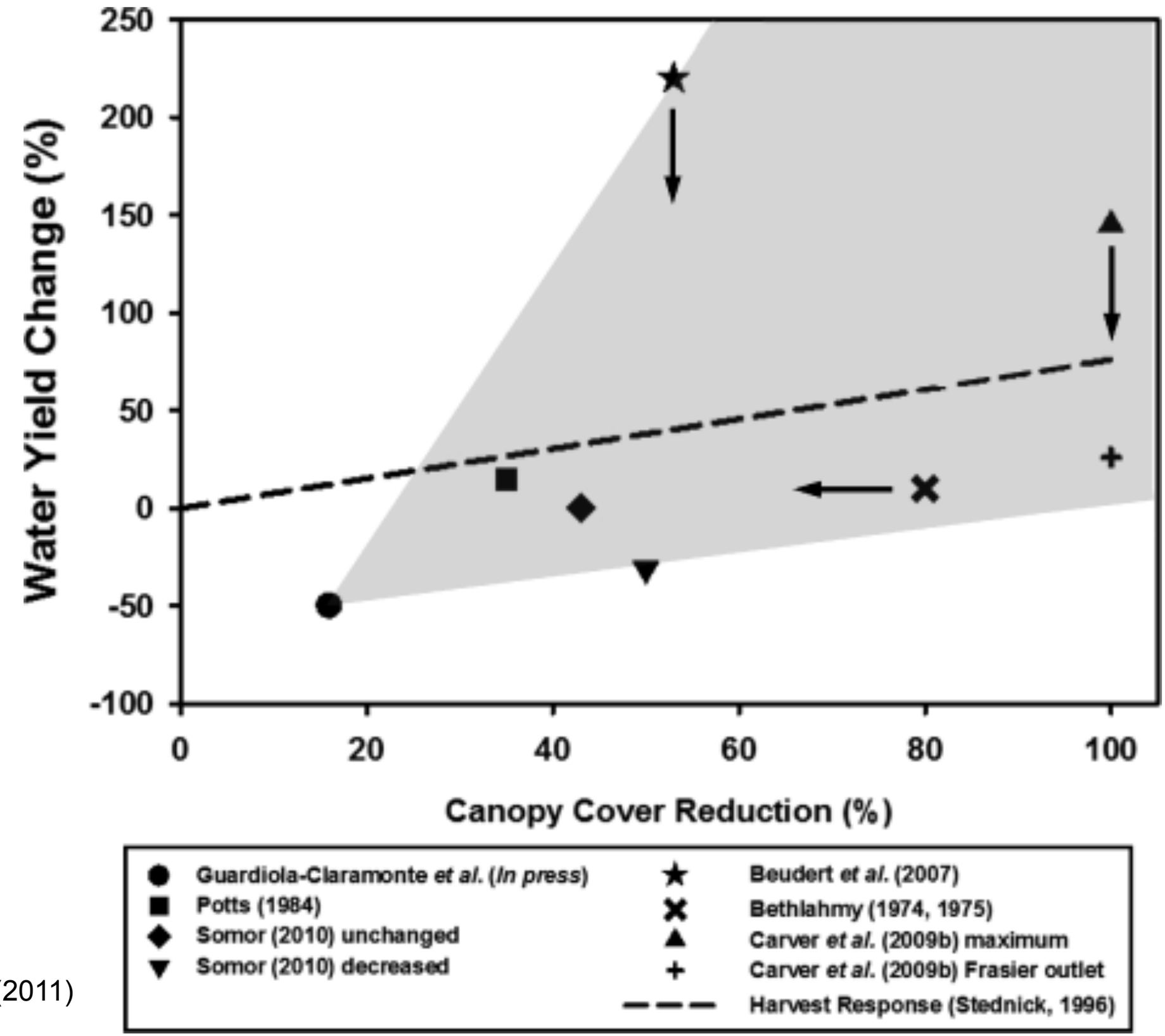


Fig. 1. Water yield changes as a result of changes in vegetation cover from Bosh and Hewlett (1982), Sahin and Hall (1996) and Stednick (1996). Results from Bosch and Hewlett and Stednick represent the maximum increase in the first 5 years after treatment for deforestation, regrowth and forest conversion experiments or maximum change in water yield for afforestation experiments. The results from Salin and Hall are the average increases in water yield in the first 5 years after treatment.

Examples of both increases and decreases in ET and streamflow following mortality



Adams et al. (2011)
Fig. 2

Modeling Goal

So what don't we know: space-time patterns

* Complex spatial patterns (Why do some trees die and others don't; why is summer streamflow in some locations far more sensitive to warmer temperature

* How will changes evolve through time (What will future forests, water resources look like? Next decade..beyond)

* What role can management, mitigation play? (What can we do)

Start with conceptual model

- Conceptual model of how much water forests need and use
- Conceptual model of some forest management actions designed to alter:
  - streamflow/recharge
  - forest drought vulnerability
- Then select/design process-based models to improve understanding and reduce uncertainty in estimating how climate/land use change alters forest ecohydrology

Balance of supply and demand: Forest water use

Non-eco influences on demand

- Radiation (latitude, slope, aspect)
- Vapor pressure deficit (effected by temperature)

Non-eco influences on supply

- Precipitation (timing and magnitude)
- Surface characteristics (litter, soil) that influence infiltration
- Subsurface characteristics that influence subsurface storage

Eco influences on demand

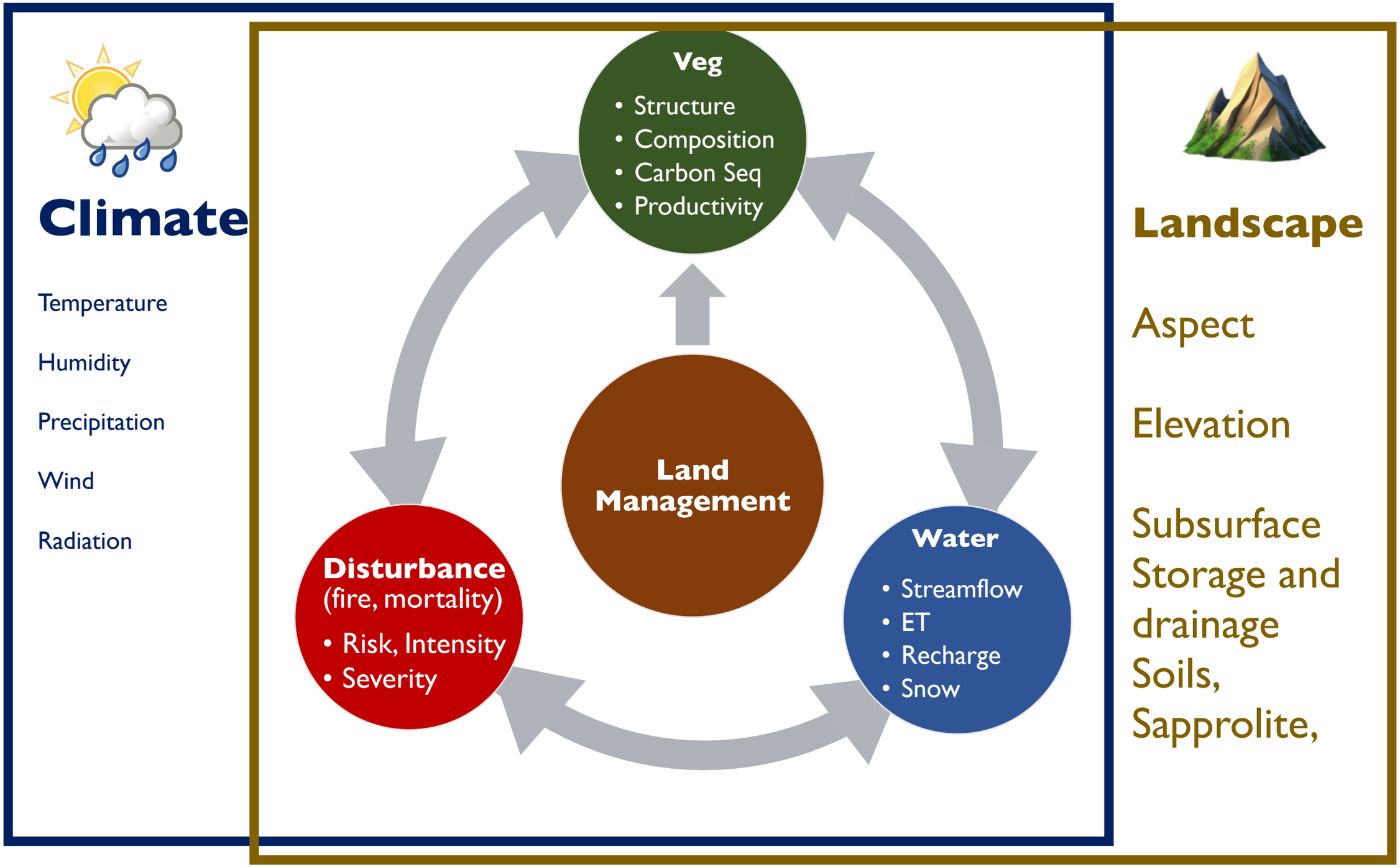
- Leaves (number, distribution)
- Ecophysiologic controls on stomatal response
- Plant height
- Ecosystem composition (shading by neighbors)

Eco influences on supply

- Interception losses
- Shading impacts on snowmelt
- Roots!

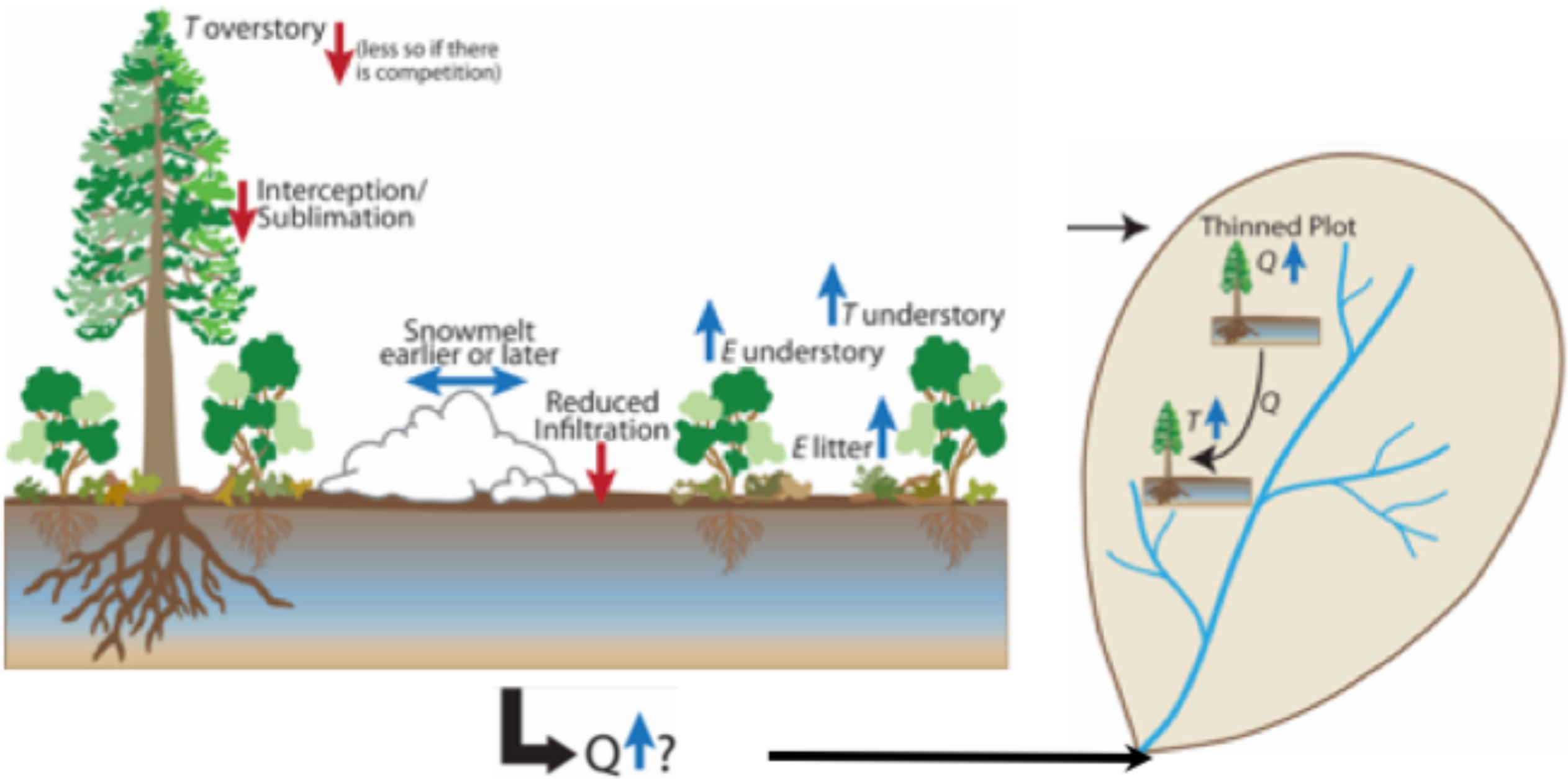
Where does climate change come in?

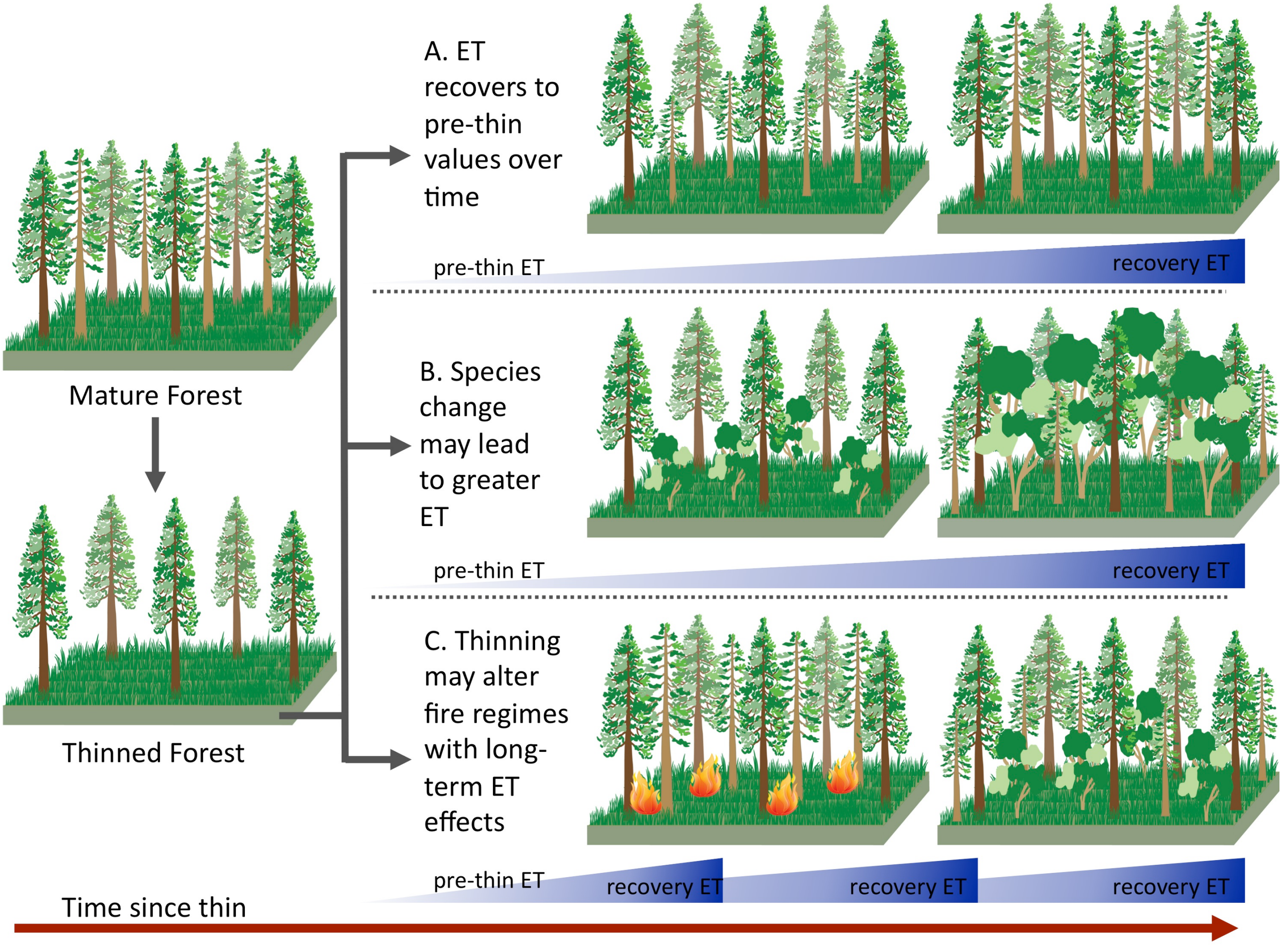
Answers are challenging because…



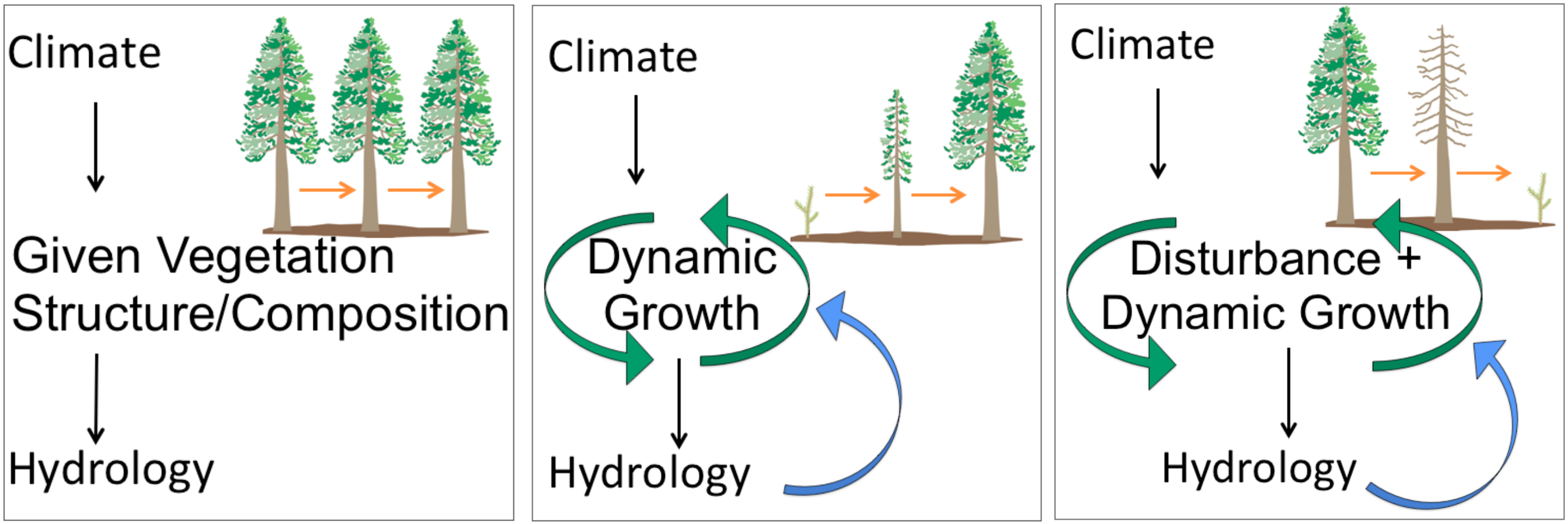
Processes are tightly coupled…highly heterogeneous in space and vary in time (seasons…years)

Why even with forest removal we might not get as much additional streamflow as we expect… COMPENSATION




Mature Forest
Thinned Forest
A. ET recovers to pre-thin values over time
pre-thin ET
recovery ET
B. Species change may lead to greater ET
pre-thin ET
recovery ET
C. Thinning may alter fire regimes with long-term ET effects
pre-thin ET
recovery ET
recovery ET
recovery ET
Time since thin

Coupled system - water-vegetation (growth + disturbance) - Flow Grow and spatial structure

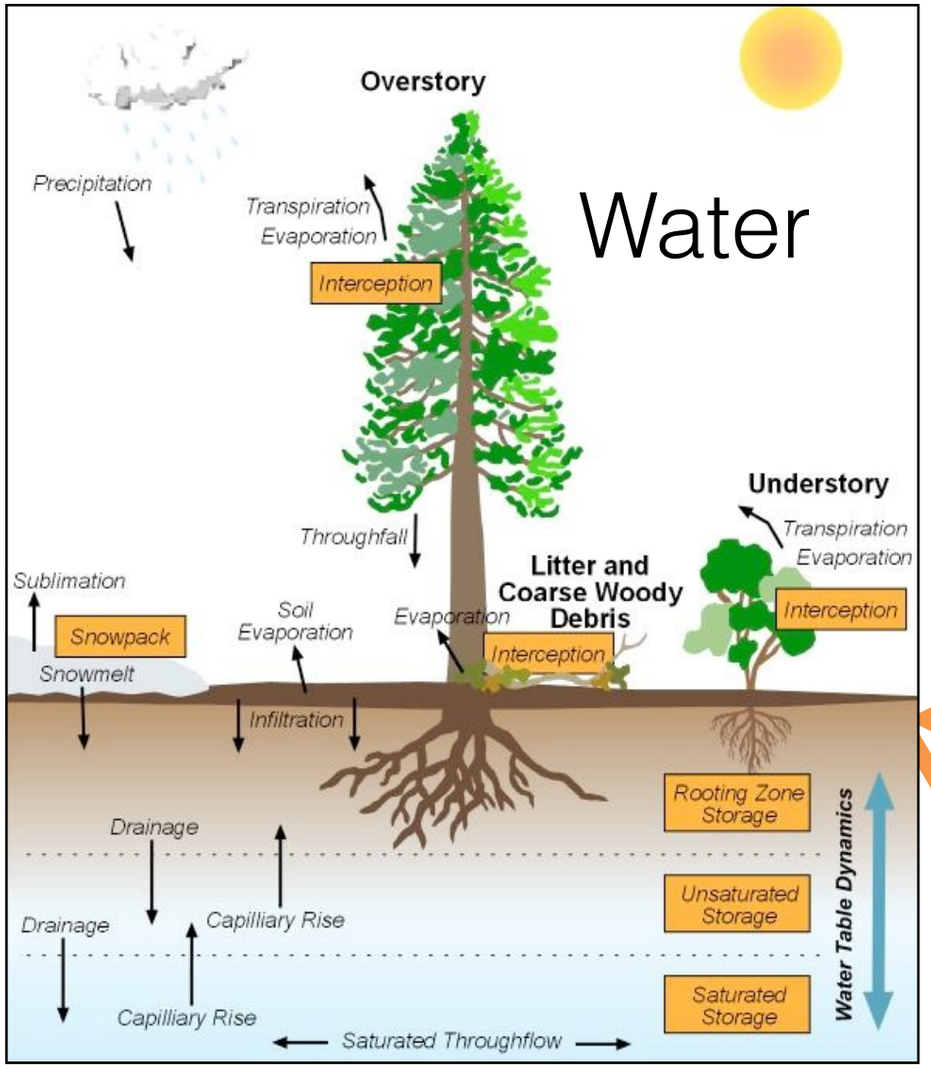


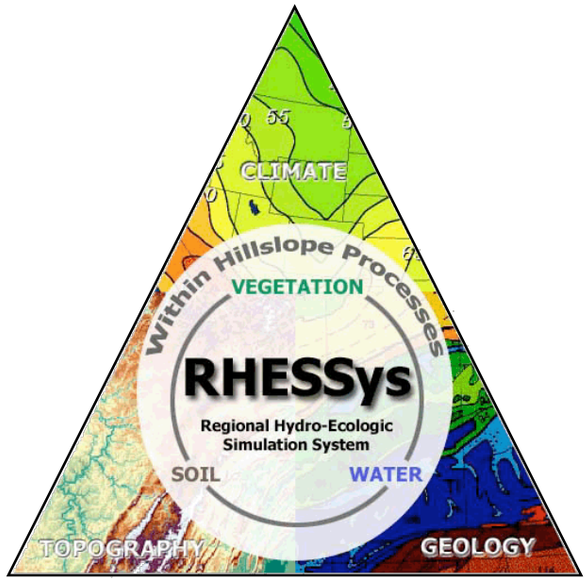
Some but not all of that change includes responding to water availability!

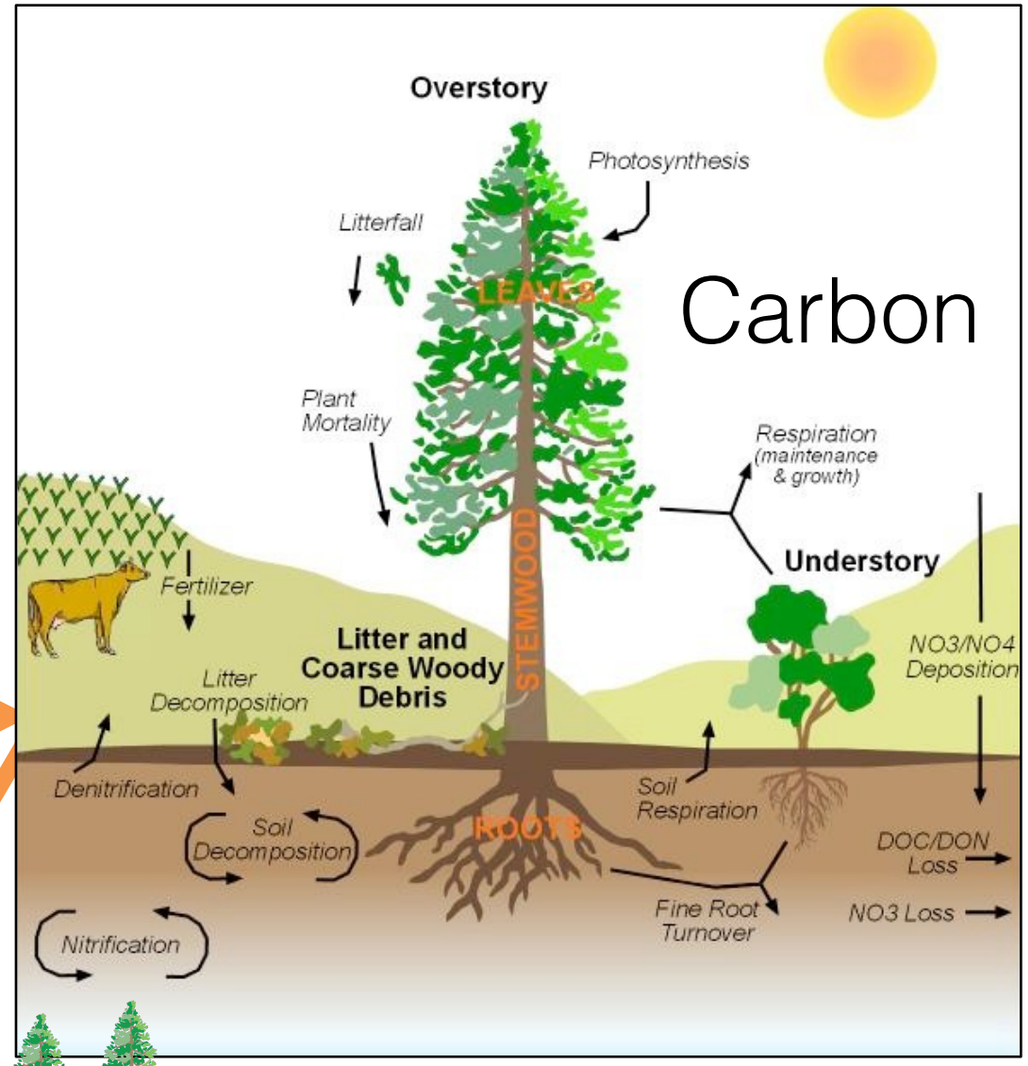
Model Selection

Fits our conceptual model

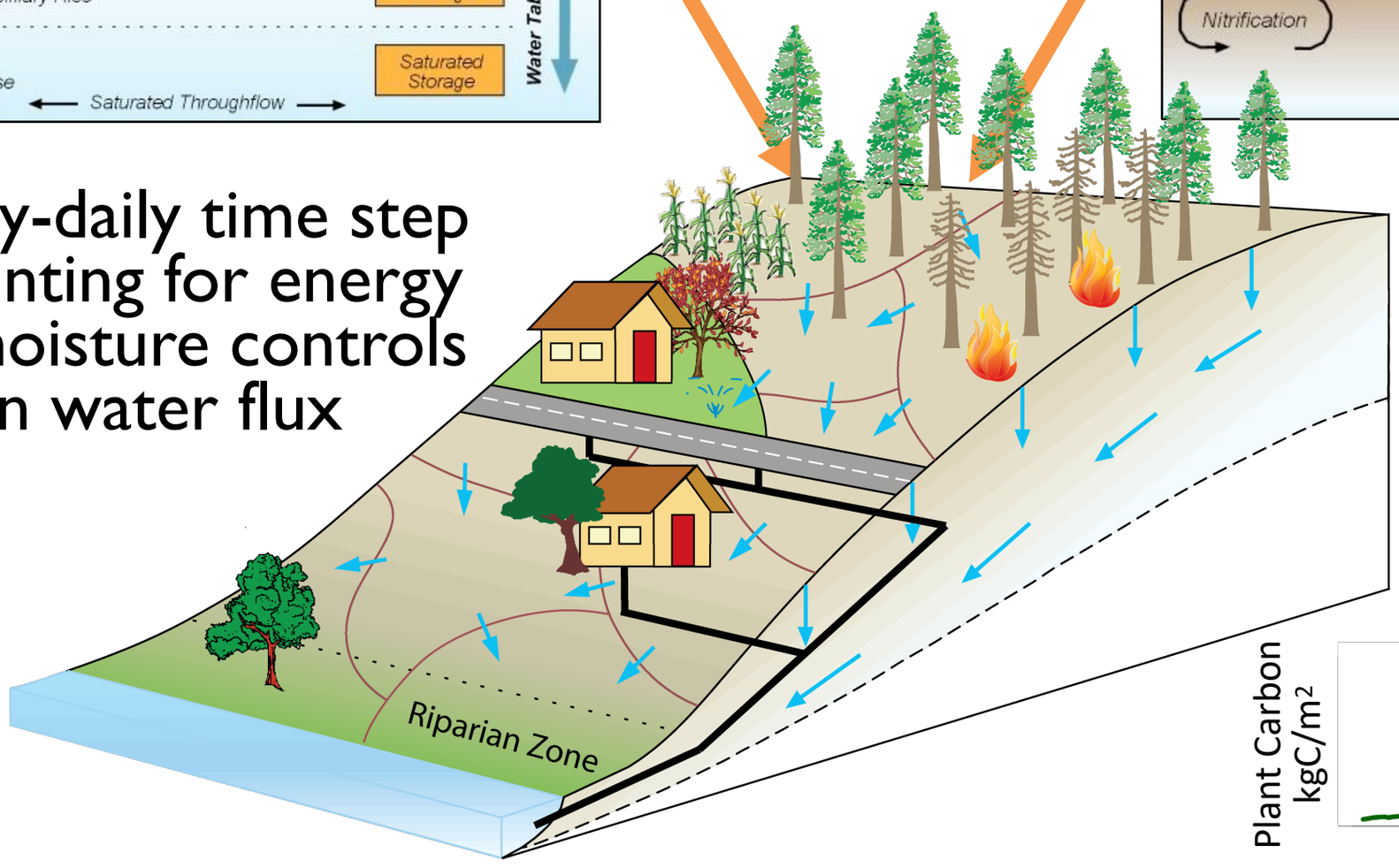
Performance

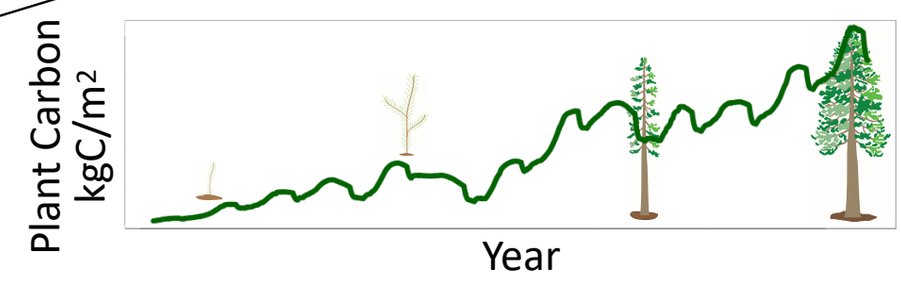




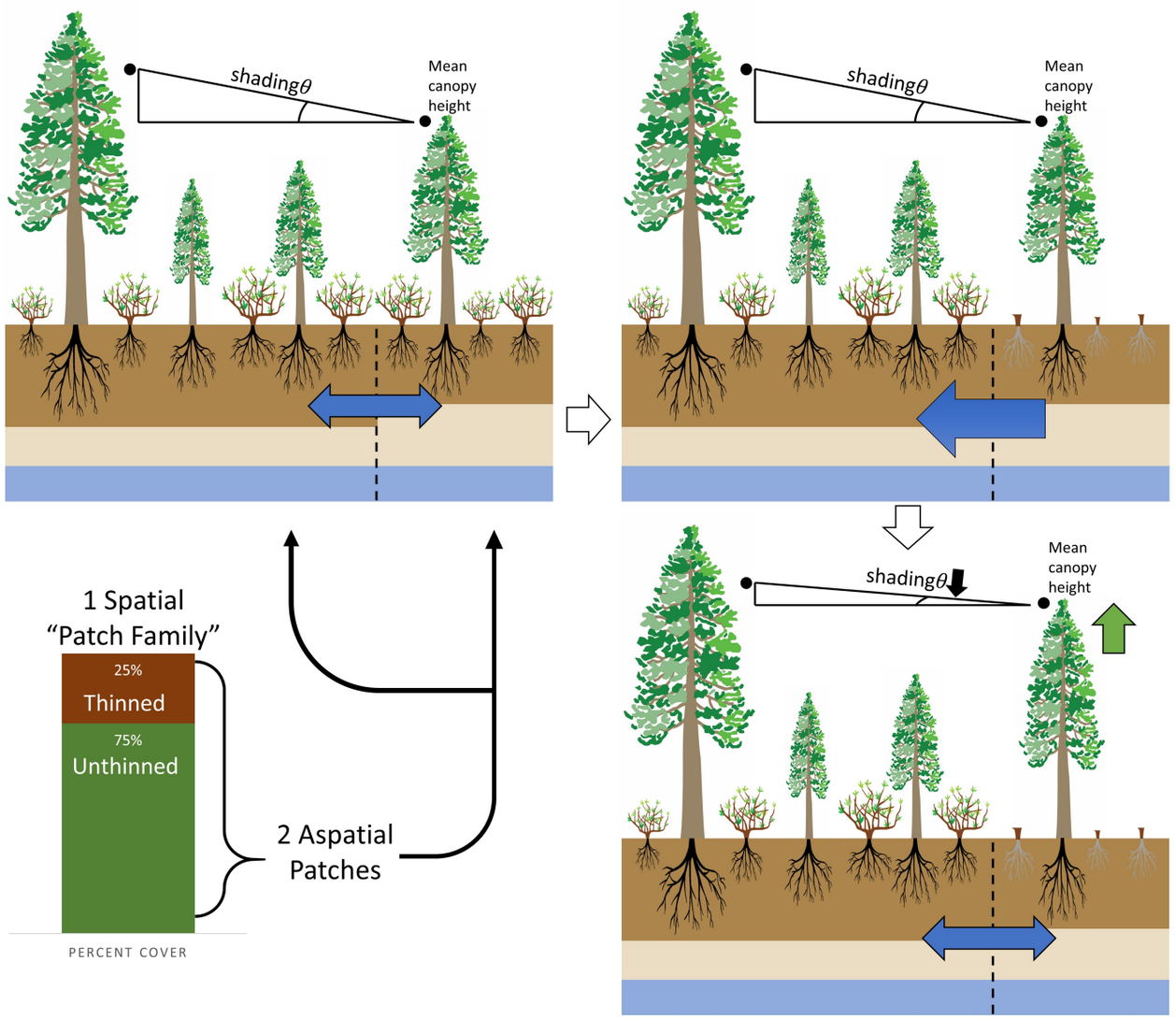


Hourly-daily time step accounting for energy and moisture controls on water flux

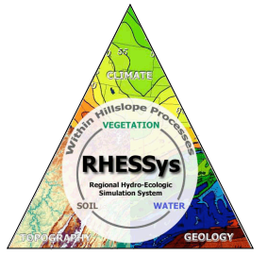


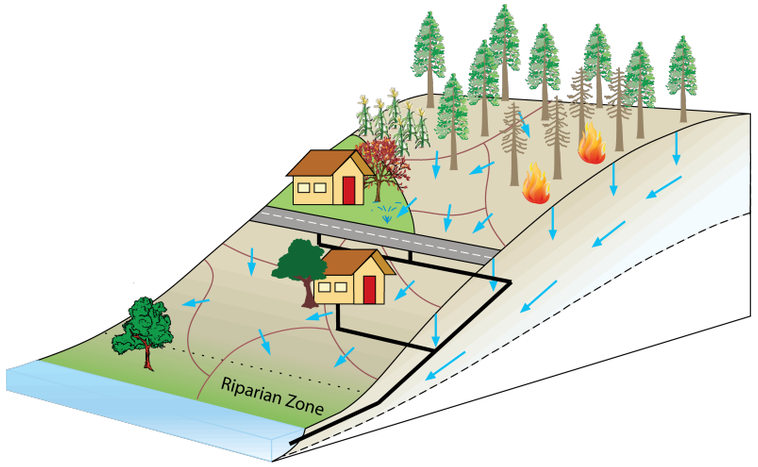


Changing Stand Structure - Implications for water and shading



Within Plot/Stand

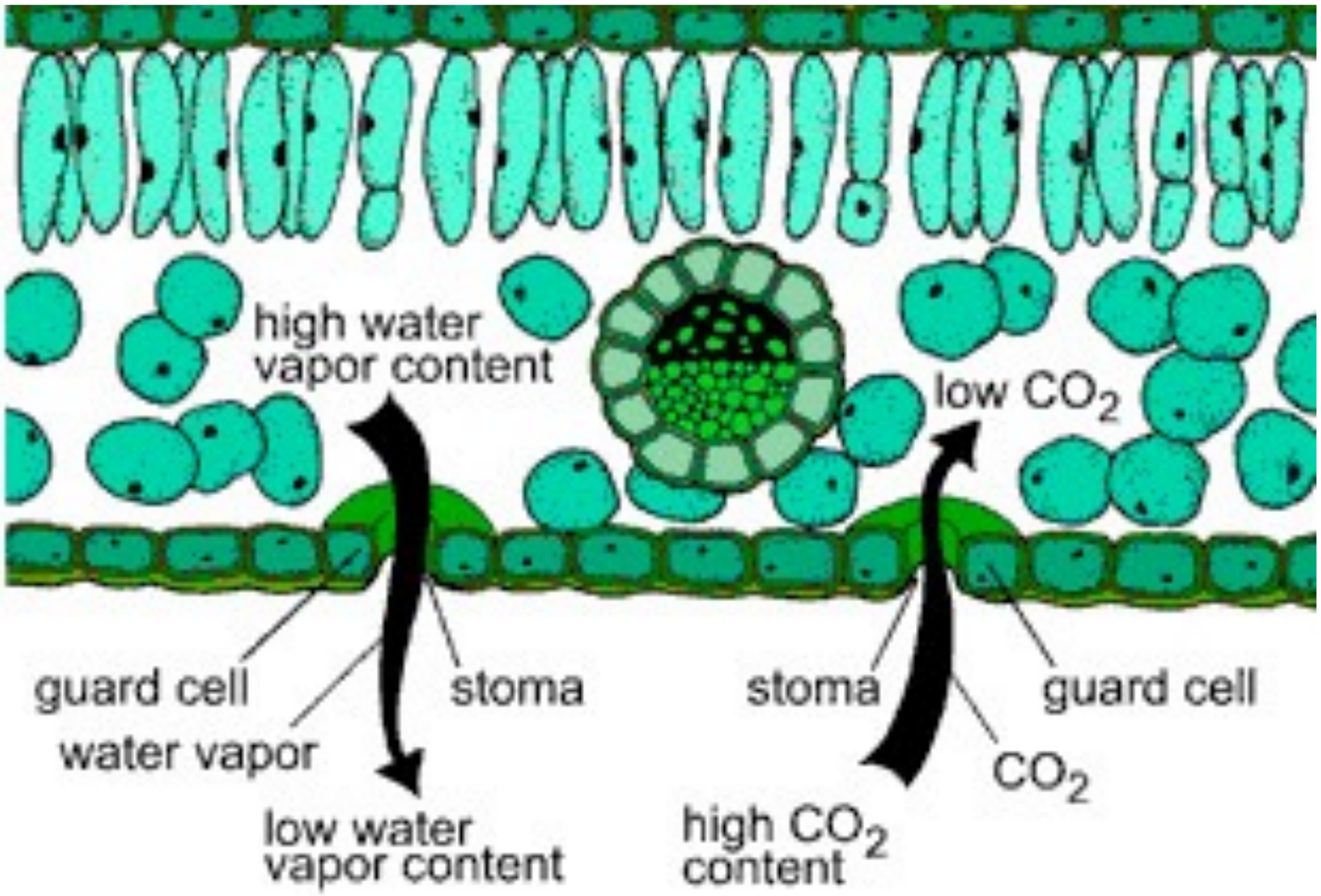




Between Plot/Stands

Process-based models - what are they

Black box of the submodes (ET for example)



Balance between water demand and water availability

Water demand from the atmosphere: vapor pressure deficit (wind) and radiation

Penman- Monteith

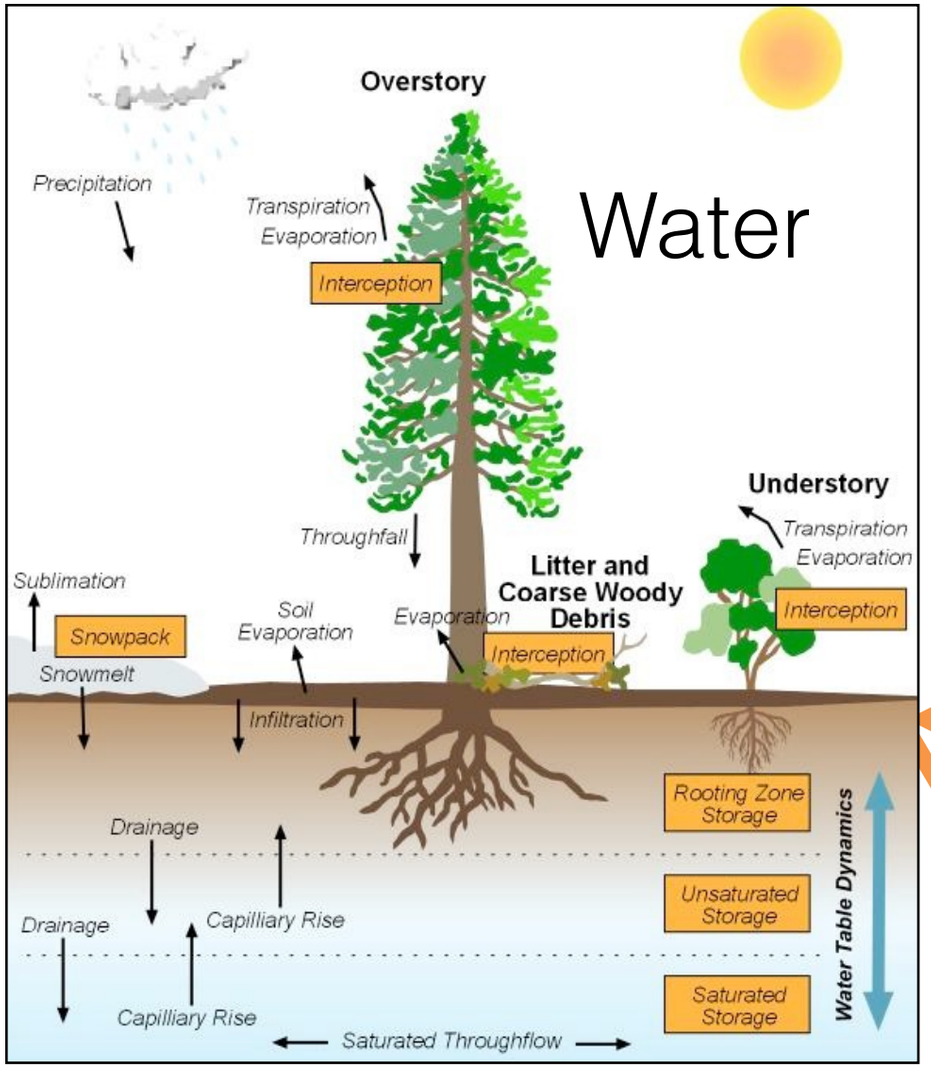
Penman

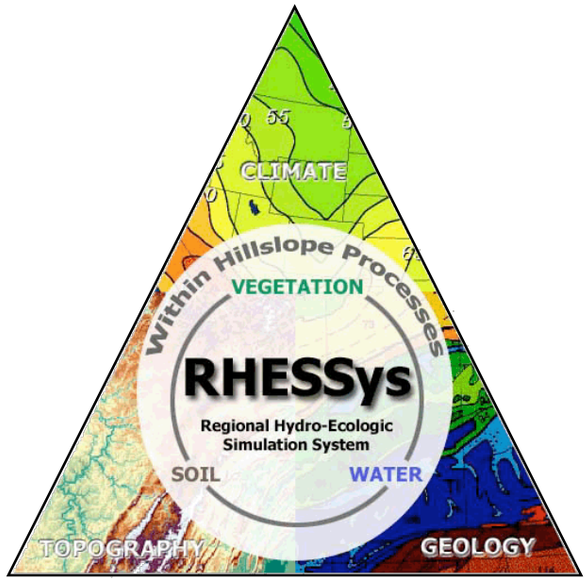
- $$E = \frac{s\,R_N + \rho_a\, c_p\, Ca\, [e_s(T_a) - e_a]}{[s + \gamma[1 + Ca/Ccan]\,\lambda_v}$$

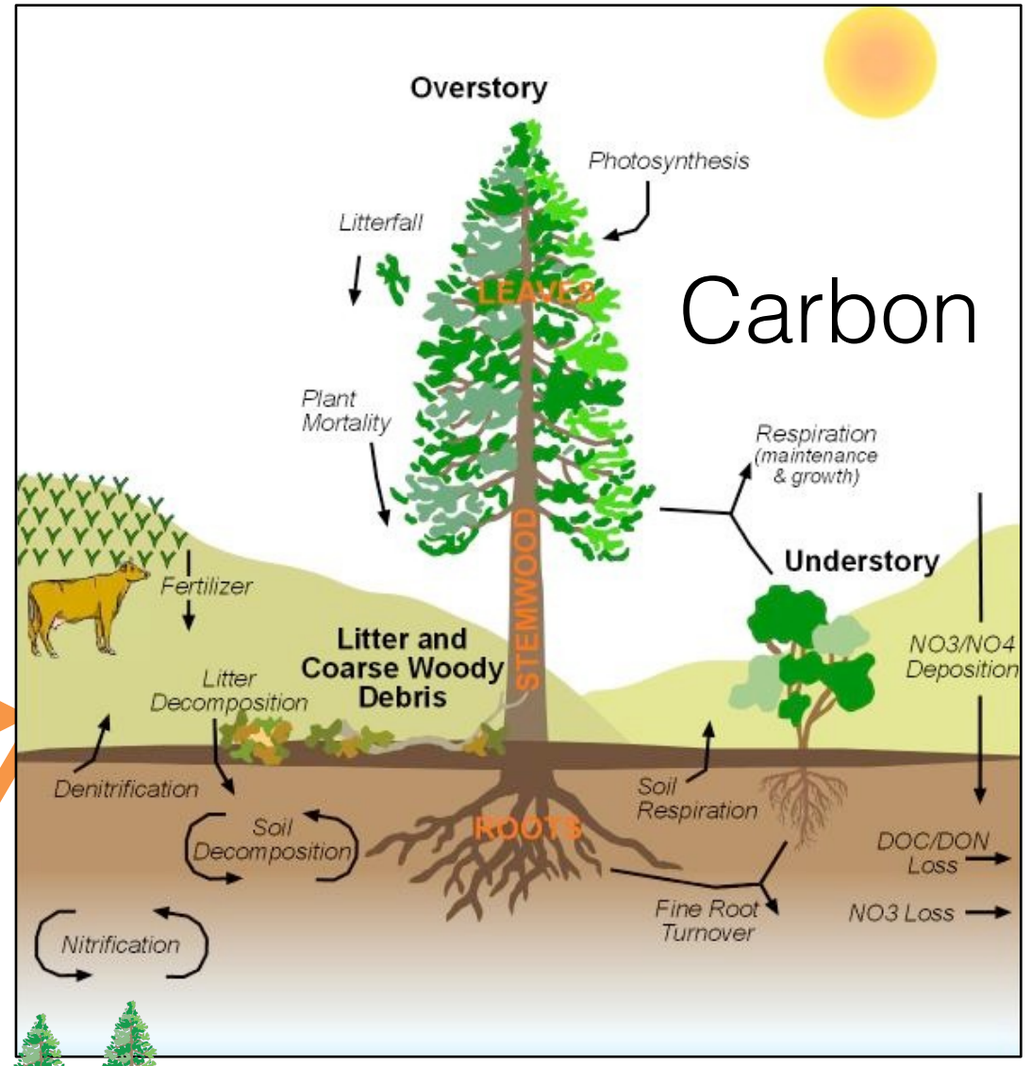
(Radiation + VPD) / availability

- s is slope of saturation vapor pressure deficit curve (Pa K−1)
- R - net radiation (W m-2)
- pa - density of the air (kg m-3)
- cp - heat capacity of the air (J kg−1 K−1)
- γ - psychrometric constant (Pa K−1)
- u - wind speed m/2
- Ca - aerodynamic conductance (m s-1) often f(windspeed)
- Ccan - canopy conductance (plant regulation of water loss)
- es, ea - vapor pressure (saturated and actual) could write as (1-relative humidity)*es
- λ_v latent heat of vaporization (MJ kg-1)

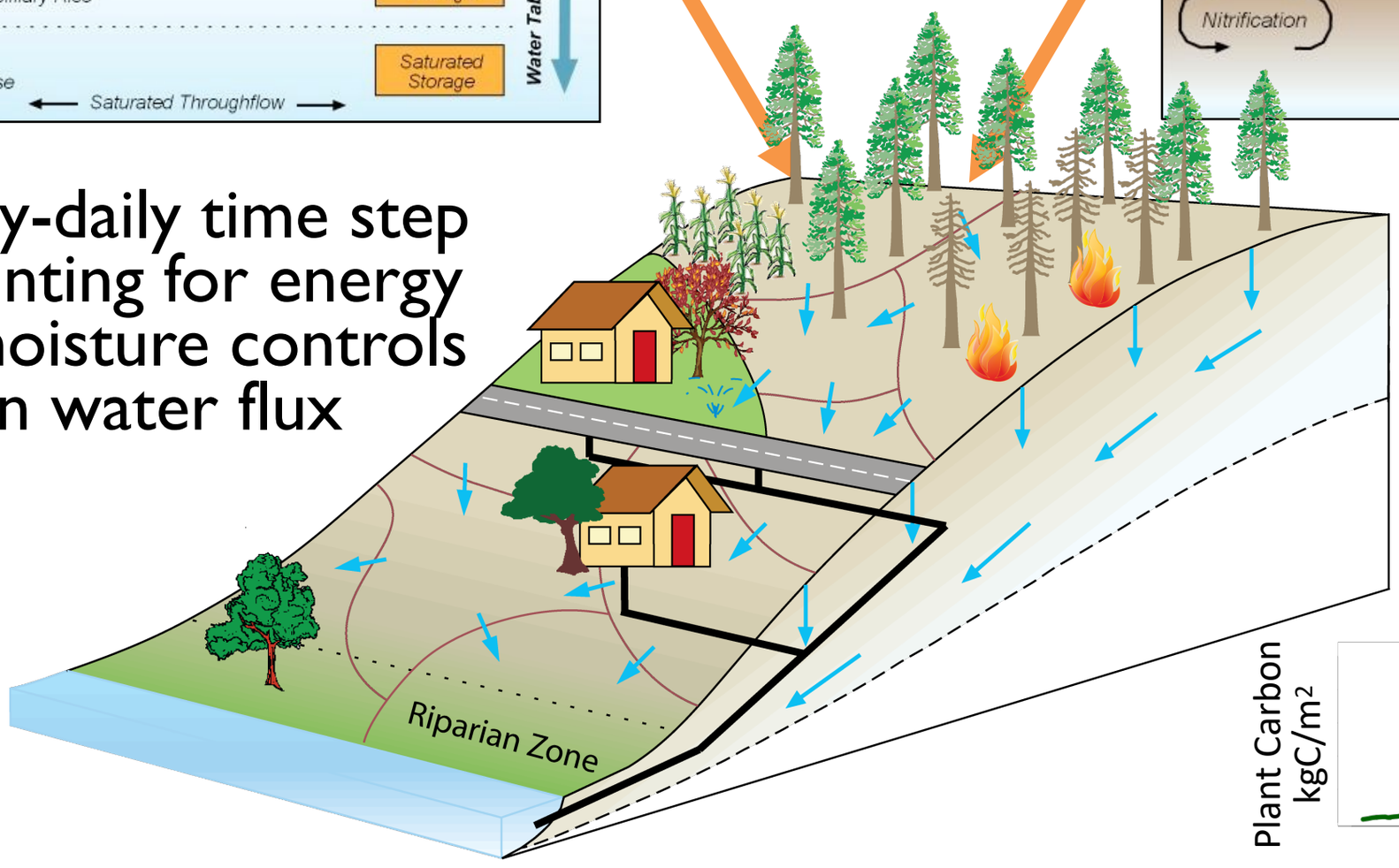
Instantaneous!!

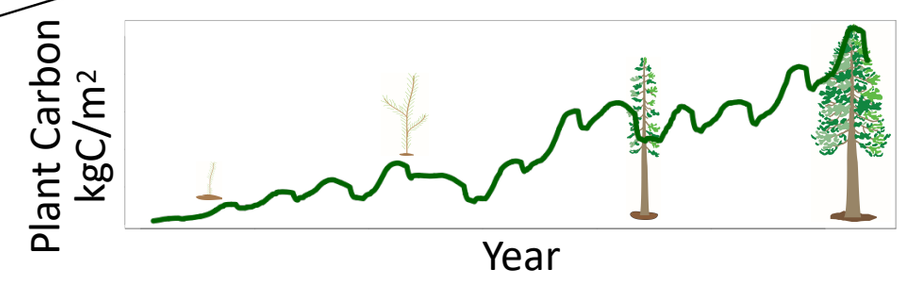






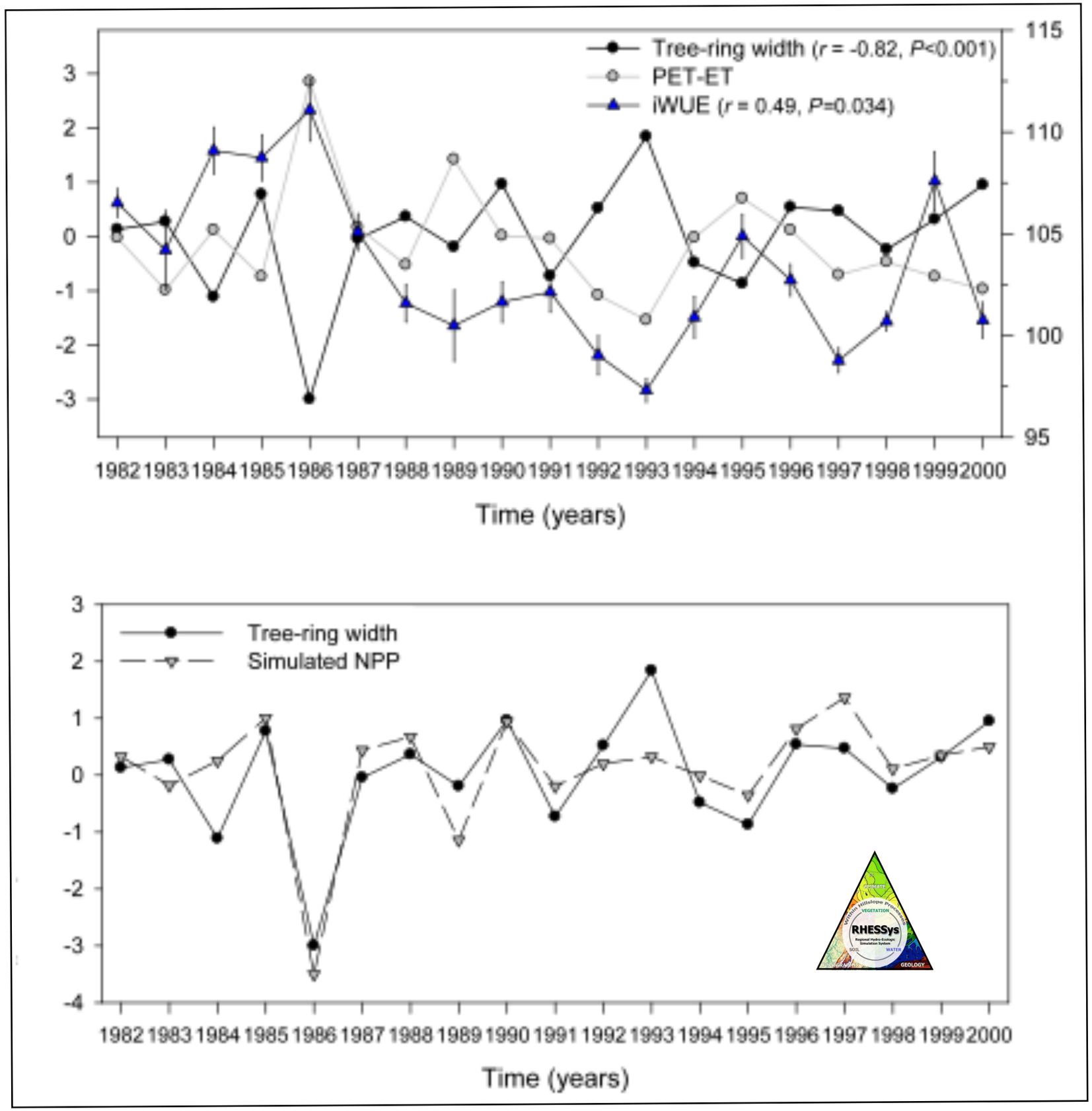
Hourly-daily time step accounting for energy and moisture controls on water flux





Model Performance

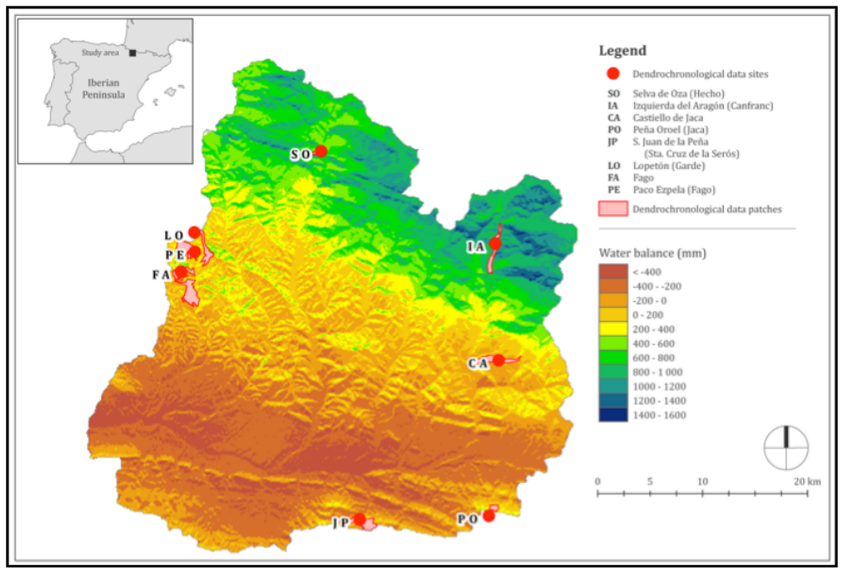
Tree Ring analysis: Example Model Assessment



Evapotranspiration deficit controls growth and net primary production:

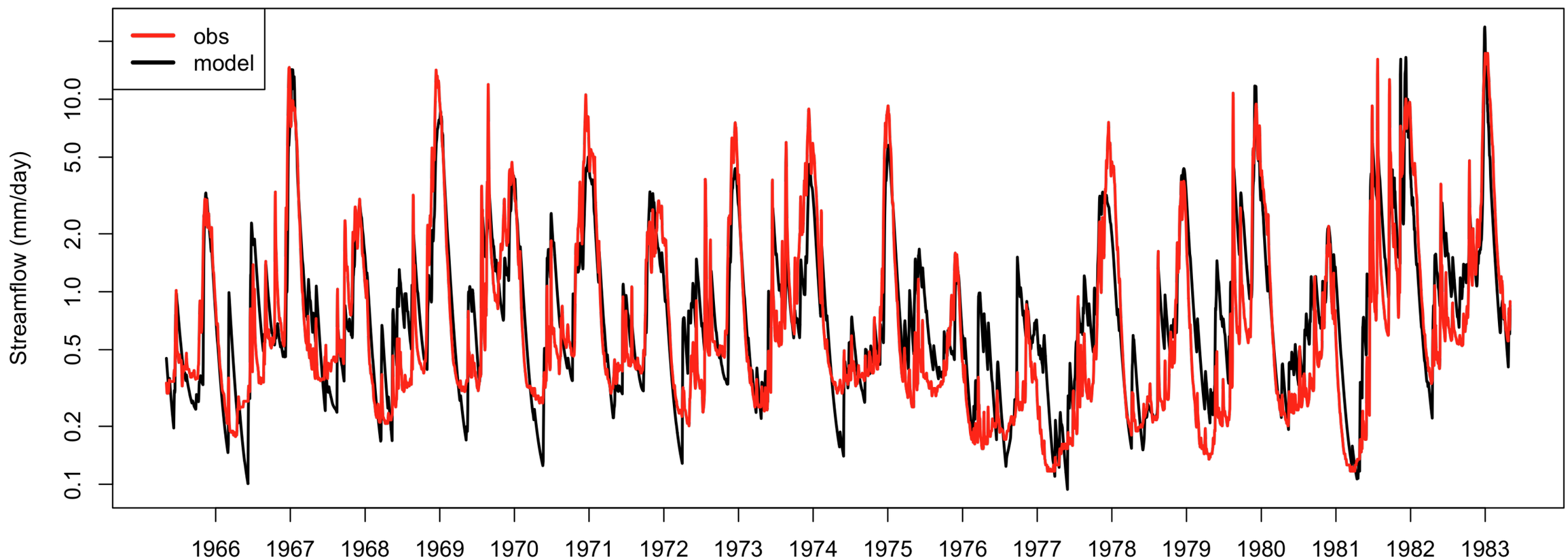
implications for Pyrenean silver fir growth under warmer drier conditions

(Vicente-Serrano et al., 2014)

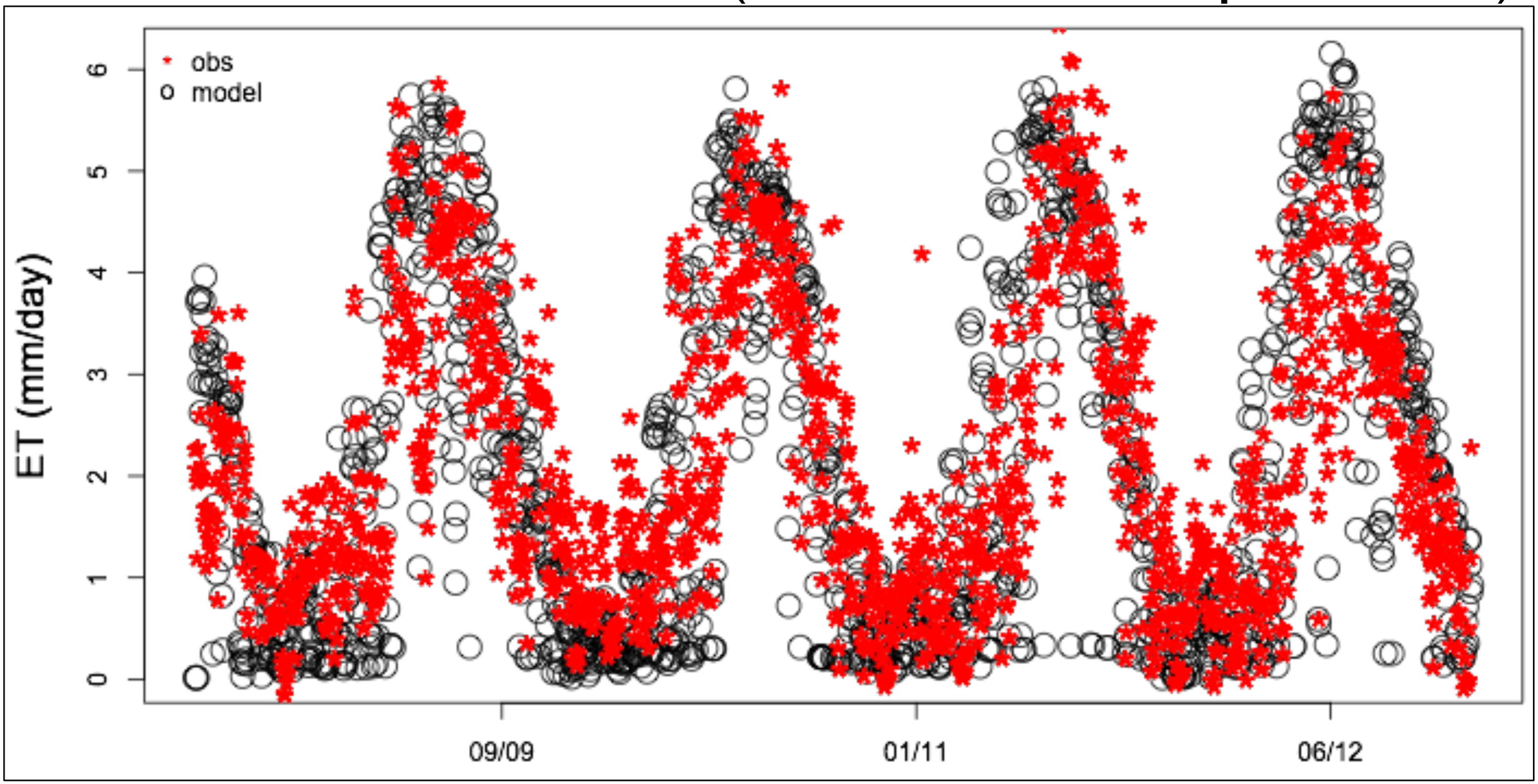


RHESSys hydrologic model performance – post calibration Streamflow (1960-2000)

NSE (daily) 0.6
NSE (log transformed daily) 0.6
Bias < 10%
Monthly R2 > 0.9



RHESSys and Observed ET - from CZO Mid Elevation Flux Tower (Calibrated soil depth of 4m!)



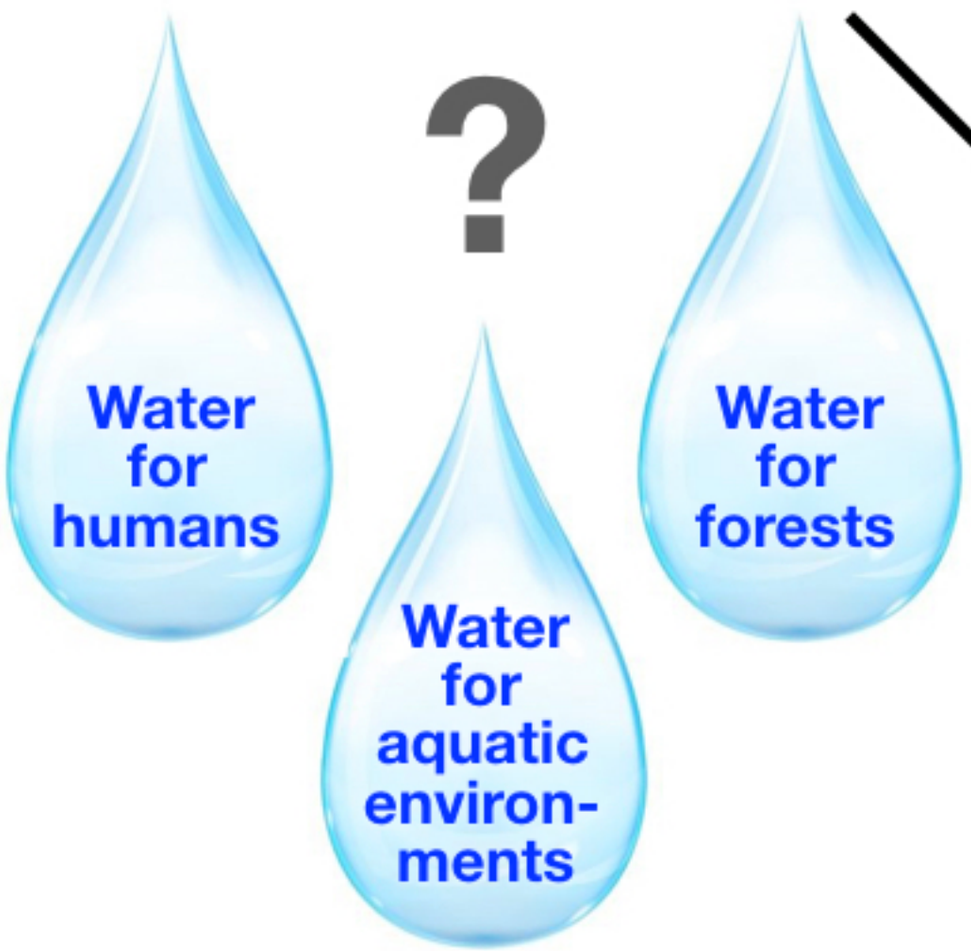
Water balance (Bales et al., 2011) and RHESSys hydrologic model simulations argue that this can only occur for rooting depth > 4m.

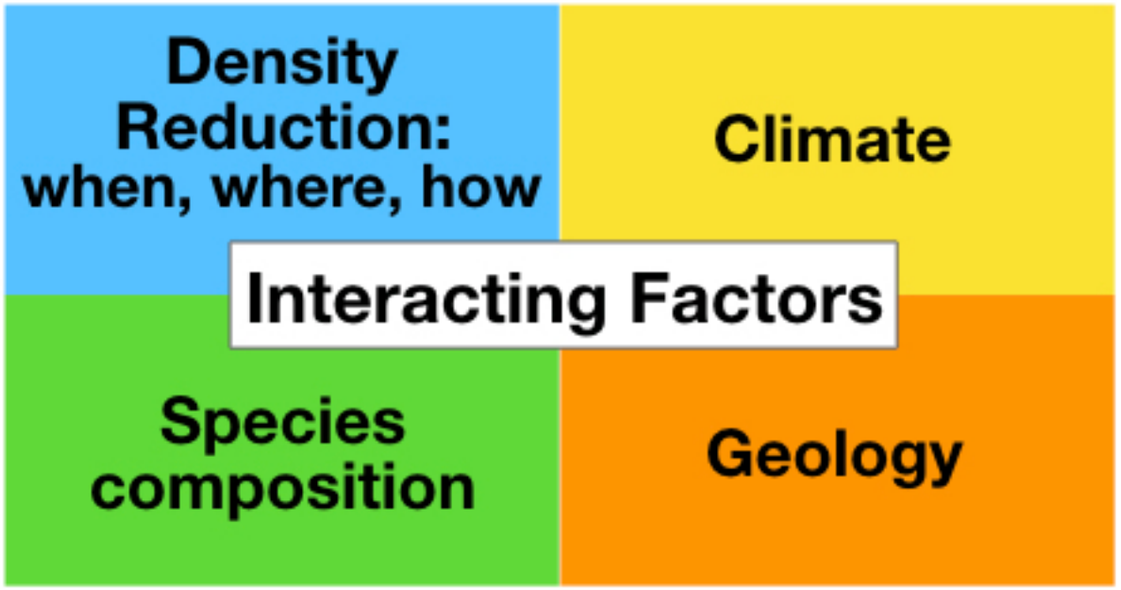
Bales, R.C. (2011) Soil moisture response to snowmelt and rainfall in a Sierra Nevada mixed-conifer forest, *Vadose Zone J.* 10 (3): 786–799. doi:10.2136/vzj2011.0001

Example: Model Application: How does forest density reduction impact water fluxes

Density Reduction in Semi-Arid Forests

Thinning and controlled burns


?
Water for humans
Water for aquatic environ-ments
Water for forests


Density Reduction: when, where, how
Climate
Interacting Factors
Species composition
Geology

Yatir Forest - planted forest, central Israel

(well study site part of LTER, Fluxnet networks)

Aleppo Pine (P. halepensis)

Med. climate - majority of rain falls during winter months

Mean annual precipitation (285mm),

Mean annual air temperature 18.2 C

http://www.weizmann.ac.il/EPS/Yakir/sites/EPS.Yakir/files/uploads/yatirneworig.jpg

Thinning Experiment in Yatir Forest

Autumn 2009 - forest plots (70m X 70 m) thinned to
300 trees/ha (approximate baseline)
200 trees/ha
100 tress/ha

147 trees monitored - stem growth, needle length, PAR, VPD, gas exchange (photosynthesis (A) and transpiration (T)

Measurements -repeated 5 field days per year

Observations

- Sap flow, leaf water potential, and biomass were measured in plots before and after thinning

Leaf Scale Measurements - but limited in time

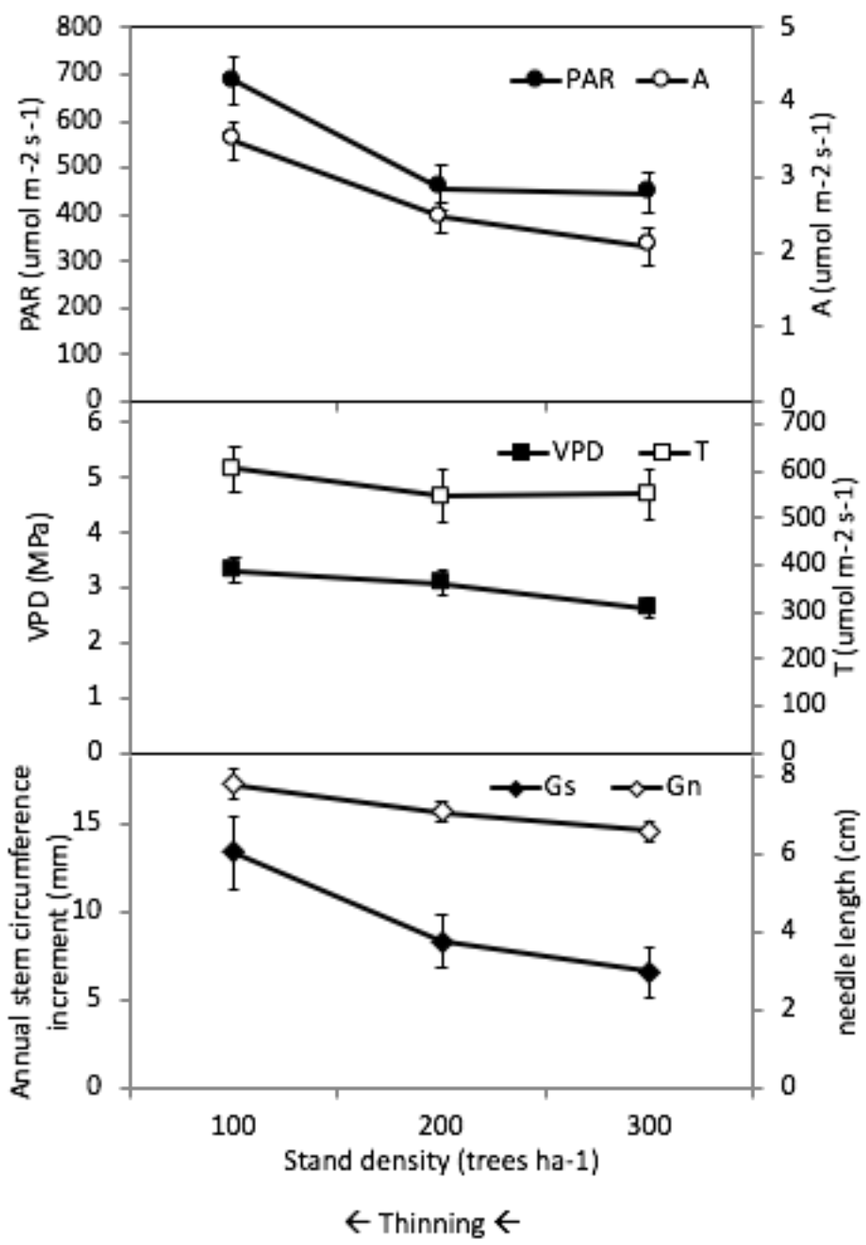
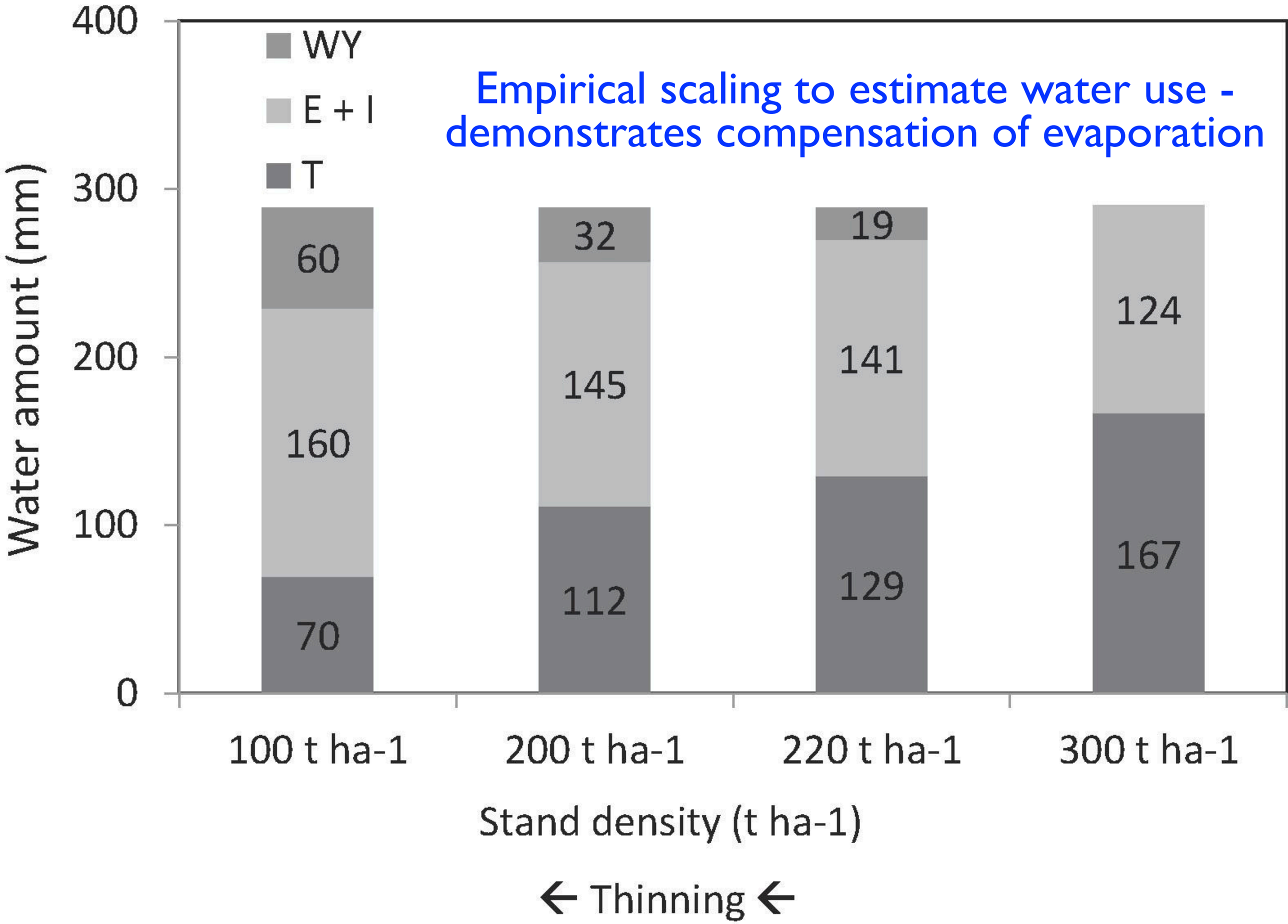


Fig. 2. Stand-density influence on leaf-scale photosynthetically active radiation (PAR) and net assimilation (A), (top); on vapor pressure deficit (VPD) and leaf transpiration (T), (middle); and on stem growth and needle length (bottom) in Yatir forest. Each data-point at top and middle panels is the mean (±SE) of 120 observations in 10 field days (2010-2012). Stem growth and needle length data-points are means (±SE) of 252 and 84 observations, respectively, in 36 field days (2010-2016).

With density reduction, leaf scale

- PAR increases
- VPD, Transpiration similar
- Assimilation increases

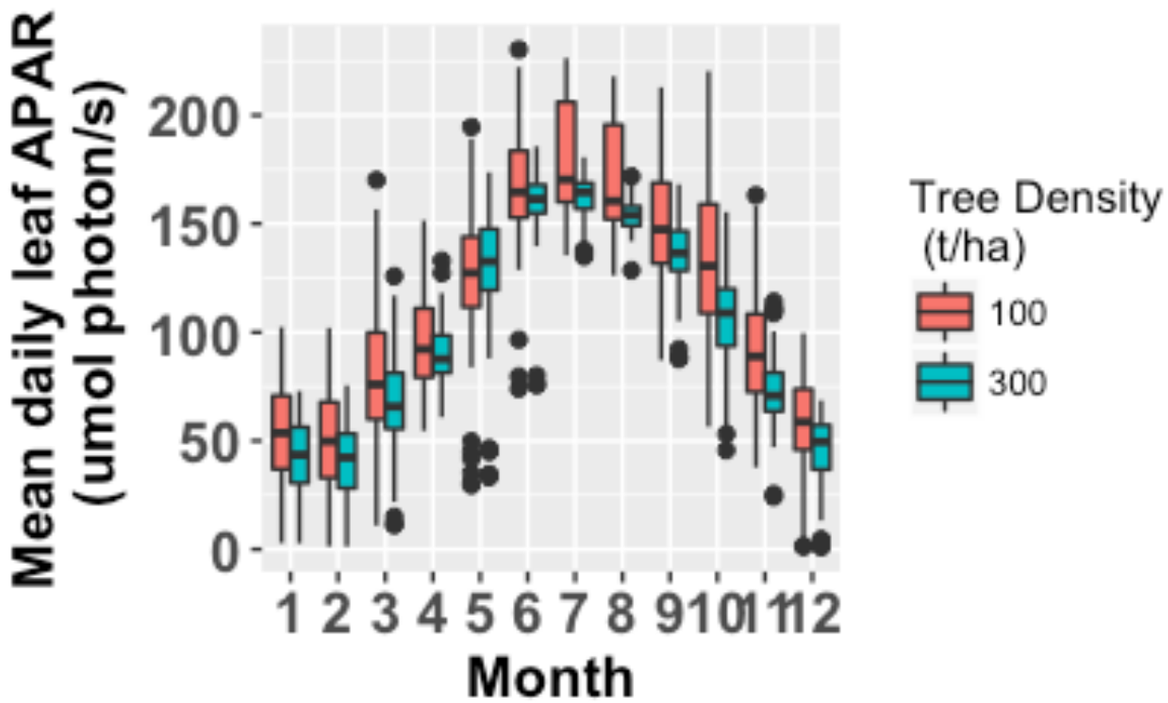
Improved leaf scale water use efficiency - because of increased light

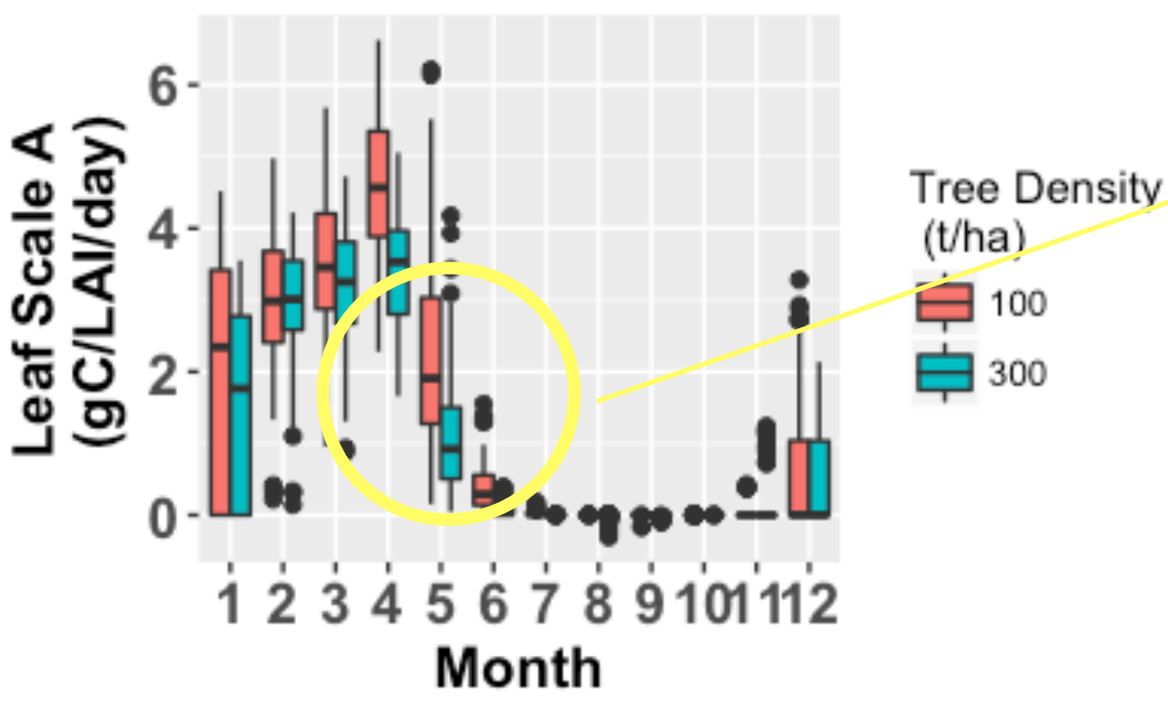

Empirical scaling to estimate water use - demonstrates compensation of evaporation
WY
E + I
T
Water amount (mm)
400
300
200
100
0
60
160
70
32
145
112
19
141
129
124
167
100 t ha-1
200 t ha-1
220 t ha-1
300 t ha-1
Stand density (t ha-1)
← Thinning ←

Empirical results show a trade off such that thinning doesn’t increase water yield - Evaporation increase balance transpiration decreases

Can we use the model to see if this generalizes through time (filling in the gaps) and across a broader range of climate forcing (beyond the 2 years of measurements)

RHESSys estimates - consistent with hypothesis - radiation effect





RHESSys estimates also show that with thinning (100 vs 300)

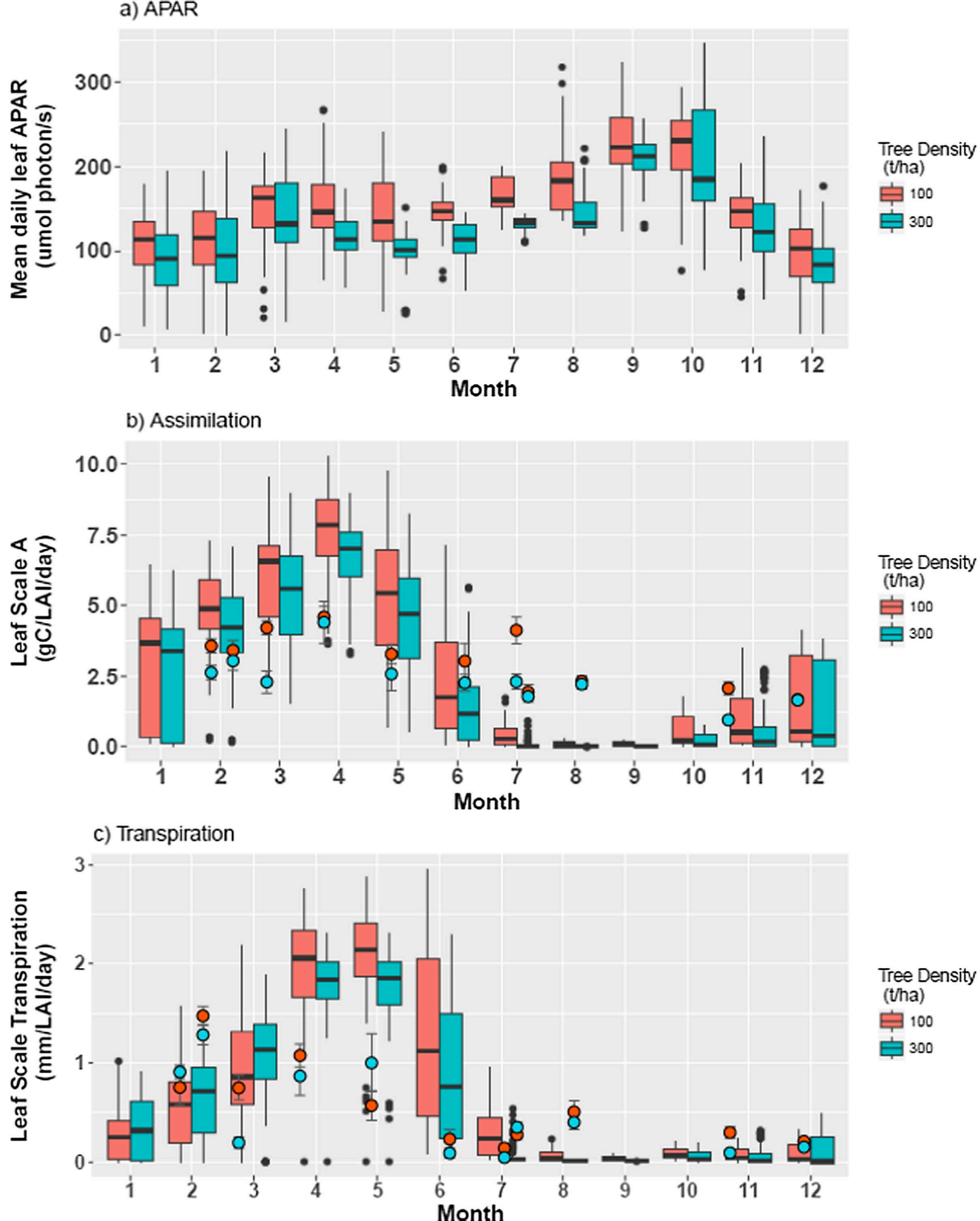
Consistent with measurements

* greater PAR
* greater leaf scale assimilation

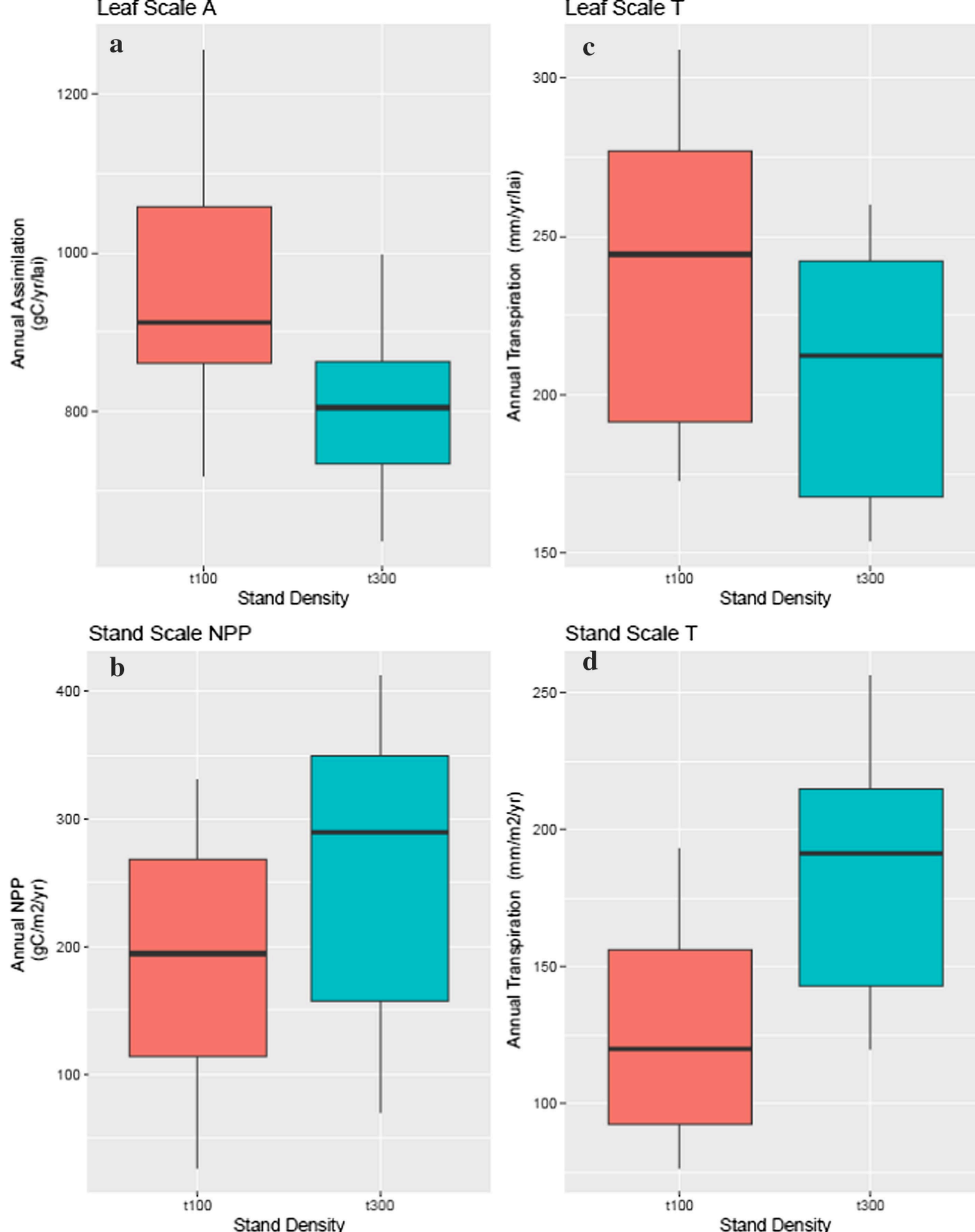
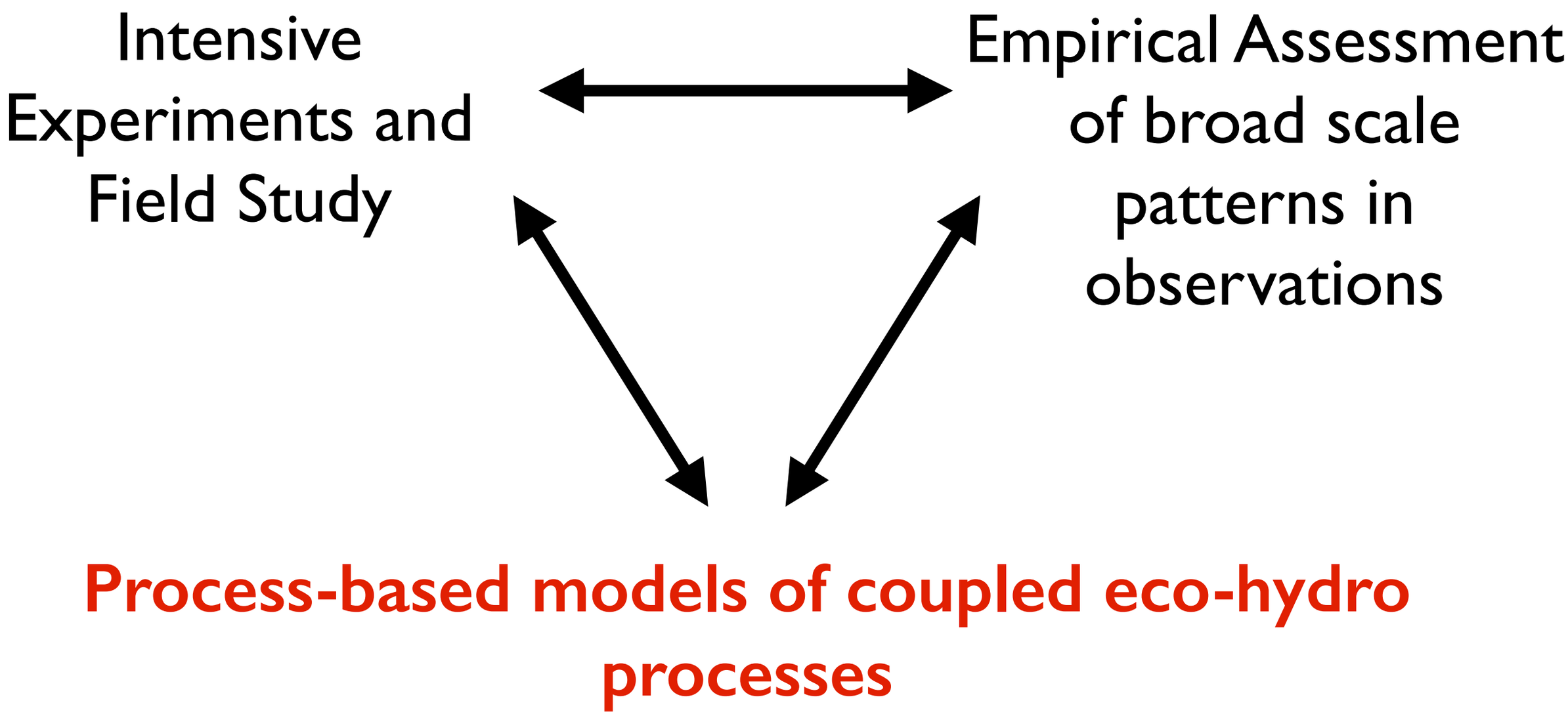
And

* reduced water limitation in May (5) and June(6) - ASSUMES adjacent trees share water

~ 40% mean gain in mean annual leaf scale assimilation (A)
Observed - 10 days ~ 60%


a) APAR
Mean daily leaf APAR (umol photon/s)
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Tree Density (t/ha)
100
300
b) Assimilation
Leaf Scale A (gC/LAI/day)
10.0
7.5
5.0
2.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Tree Density (t/ha)
100
300
c) Transpiration
Leaf Scale Transpiration (mm/LAI/day)
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Tree Density (t/ha)
100
300

Model scaling in to stand and across greater range of climate



The “tools” for the job