Forest Ecology and Management 517 (2022) 120256

Contents lists available at ScienceDirect

Forest Ecology and Management

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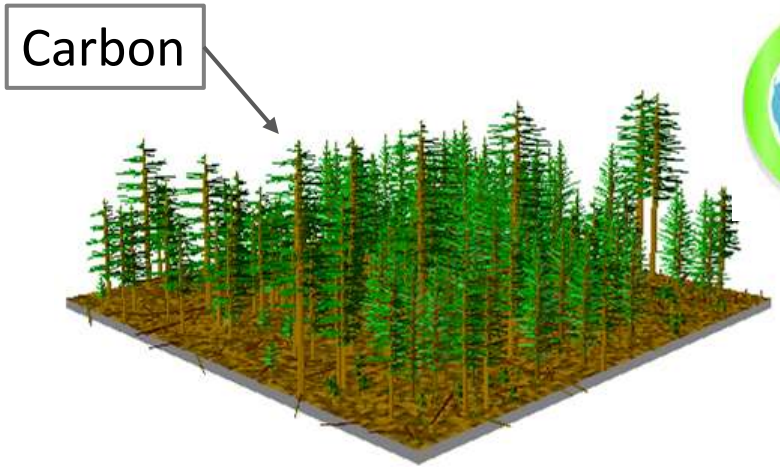
# Climatic sensitivities derived from tree rings improve predictions of the Forest Vegetation Simulator growth and yield model

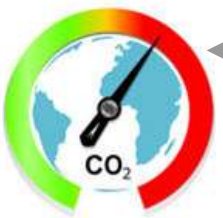
Courtney L. Giebink [a,*], R. Justin DeRose [b], Mark Castle [c], John D. Shaw [d], Margaret E.K. Evans [a]

6.20.23
Growth and Yield
Innovations Conference

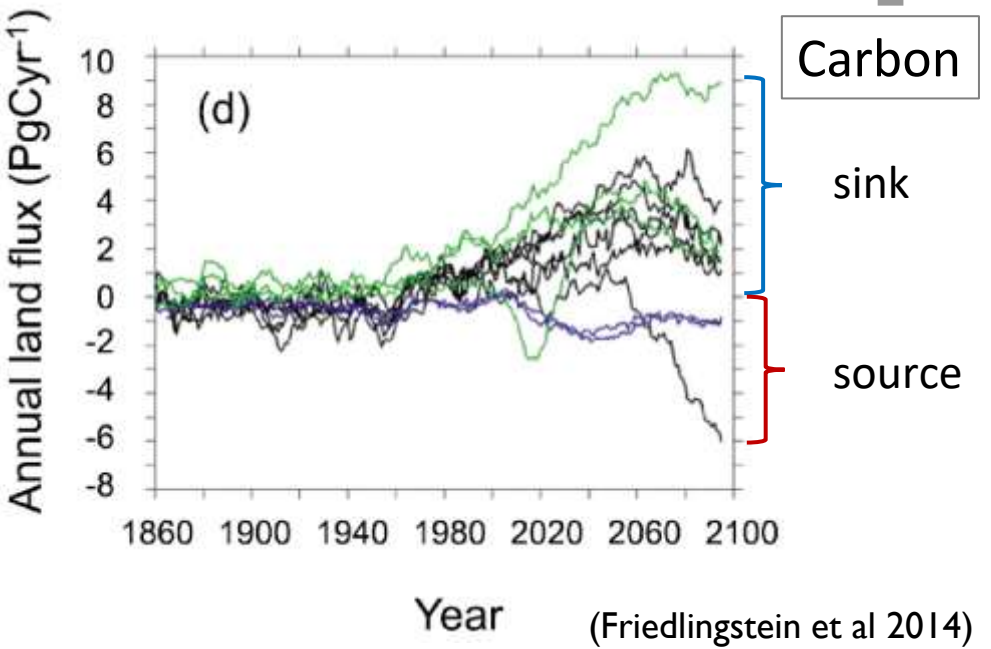
THE UNIVERSITY OF ARIZONA

UA SCIENCE
Laboratory of Tree-Ring Research




*What is the role of forests in the carbon cycle under changing climate?*

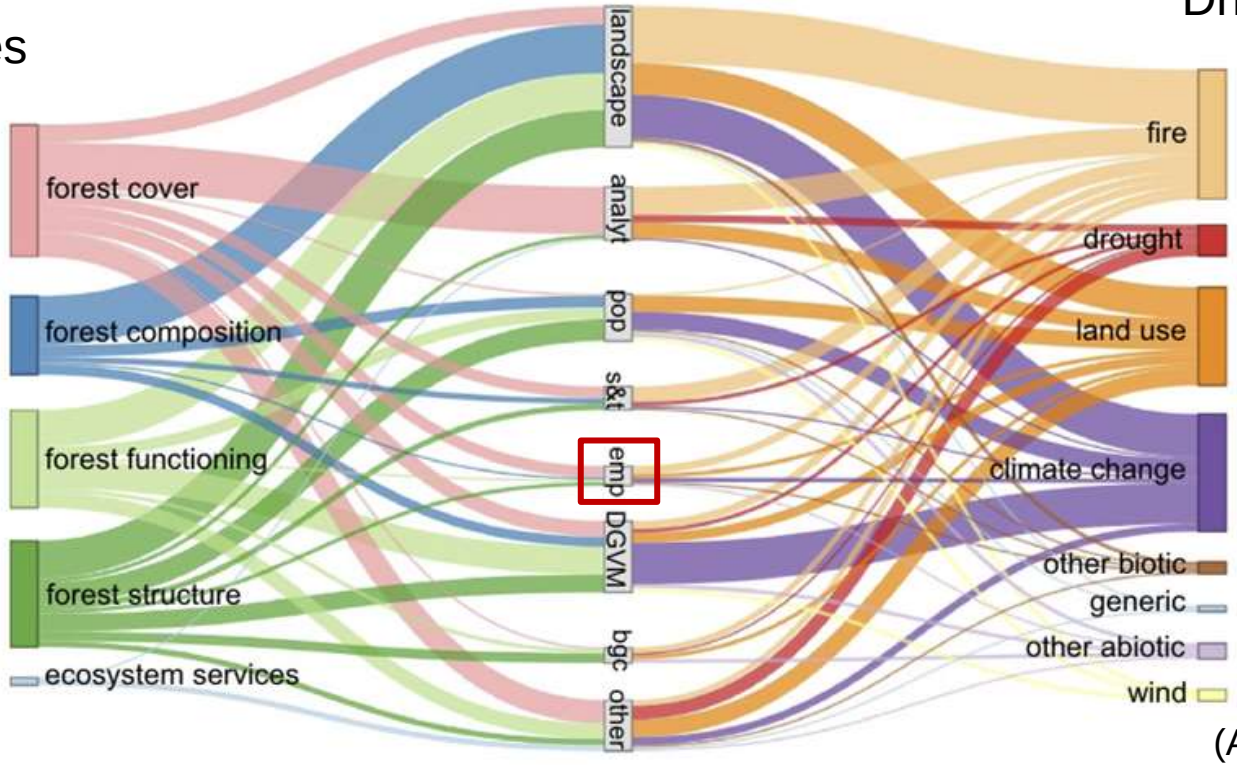



(Friedlingstein et al 2014)

# Forest Simulation Models

Forest Attributes

Drivers




(Albrich et al. 2020)

# Stand- level growth and yield model

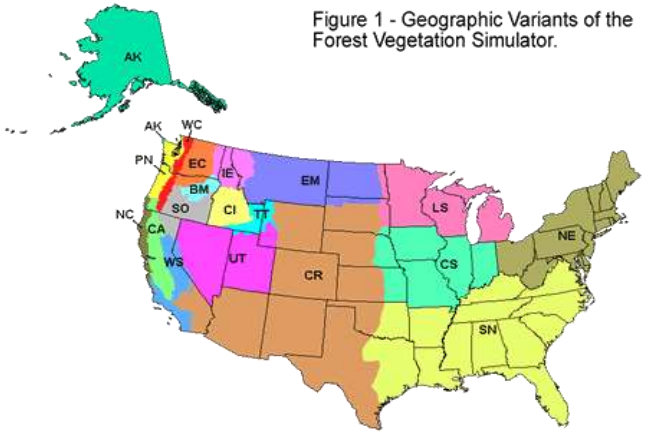
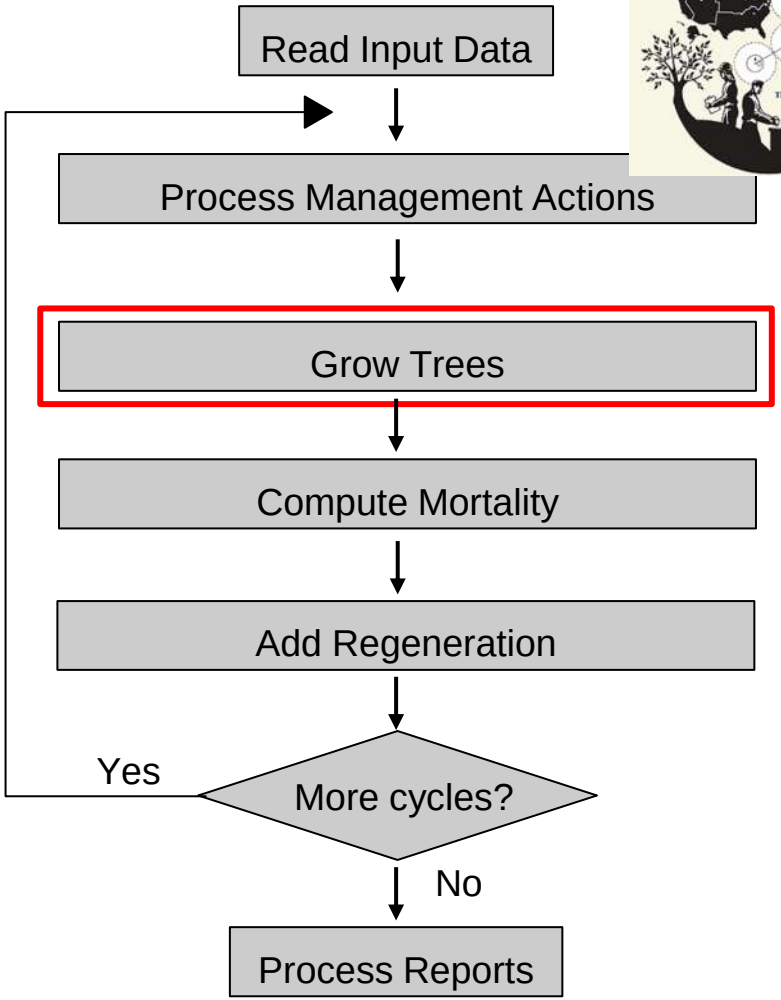



Figure 1 - Geographic Variants of the Forest Vegetation Simulator.



# FVS large-tree diameter growth model

**Growth = f (Tree-level, Site-level biophysical, Competition)**

## Tree-level

- ***DBH*** = tree size
- ***CR*** = crown ratio is a measure of tree vigor

## Site-level biophysical

- ***SI*** = Site index
- ***SL*** = Slope
- ***sin(ASP-.8)*SL*** = Solar radiation by eastness
- ***cos(ASP-.8)*SL*** = Solar radiation by northness

## Competition

- ***BAL*** = basal area of trees larger than subject tree
- ***PCCF*** = subplot crown competition factor
- ***CCF*** = stand crown competition factor
- ***SDI***= stand density index

# FVS large-tree diameter growth model

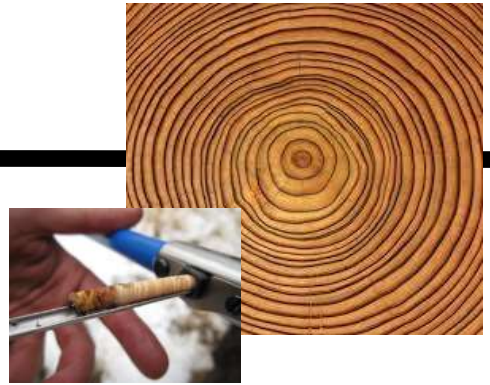
Growth = f (Tree-level, Site-level biophysical, Competition)

Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics

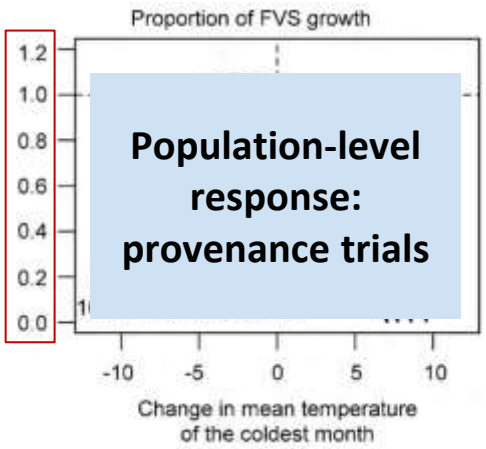
Nicholas L. Crookston[a,*], Gerald E. Rehfeldt[a], Gary E. Dixon[b], Aaron R. Weiskittel[c]

Forest Ecology and Management 260 (2010) 1198–1211

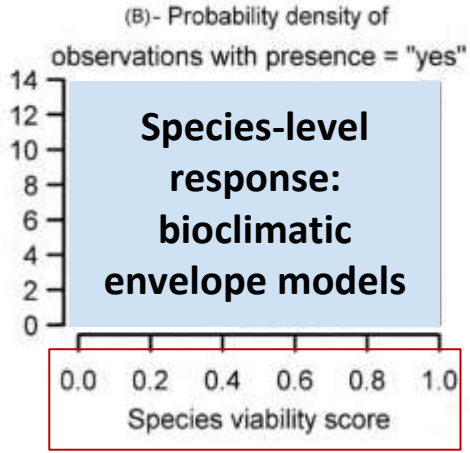
Tree growth



Climate




**Population-level response: provenance trials**




**Species-level response: bioclimatic envelope models**

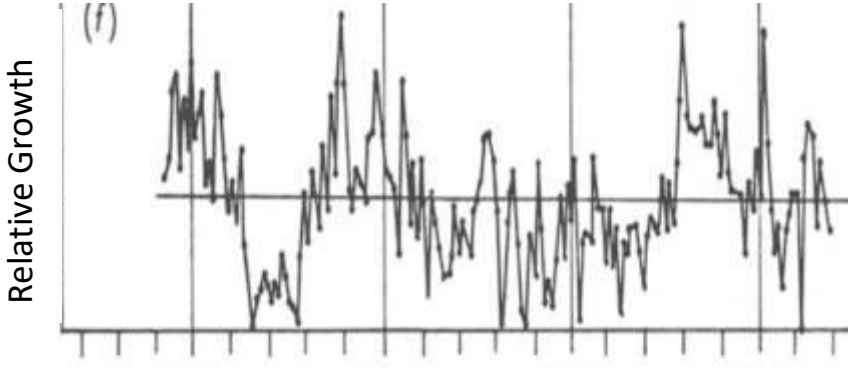
(Crookston et al. 2010)

# Dendrochronology

Cook's Linear
Aggregate Model (1985)

**G = C + A + D1 + D2 + E**

G - Growth
C - Climate signal
A - Age related trend
D1 - Disturbance within forest community
D2 - Disturbance outside forest community
E - variability



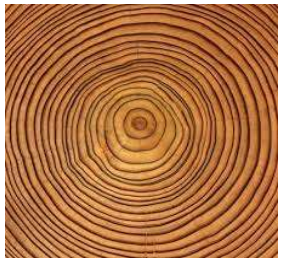

(Cook and Kairiukstis 1990)

# Growth = f (Tree-level, Site-level biophysical, Competition)

Cook's Linear
Aggregate Model (1985)

**G = C + A + D1 + D2 + E**

G - Growth
C - Climate signal
A - Age related trend
D1 - Disturbance within forest community
D2 - Disturbance outside forest community
E - variability

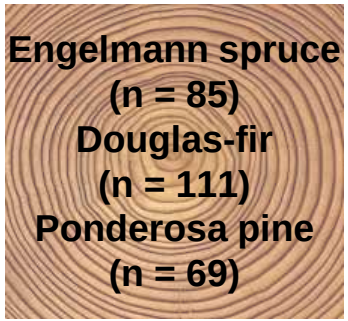


# Building the Forest Inventory and Analysis Tree-Ring Data Set

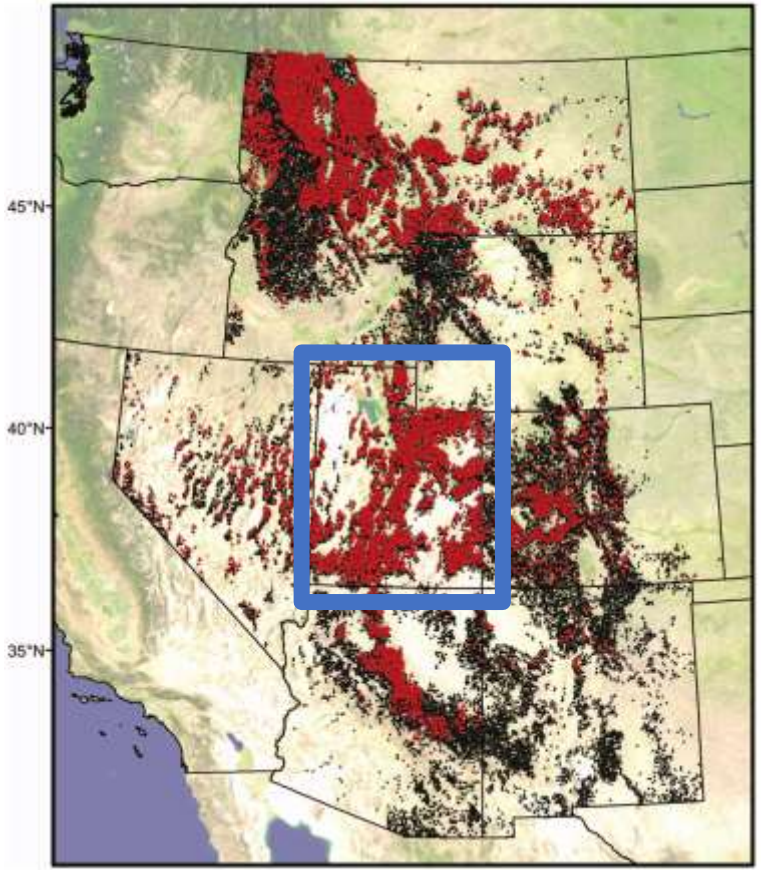
Robert J. DeRose, John D. Shaw, and James N. Long

*Journal of Forestry*
2017 155(4): 283-291

- Tree-ring data
- Inventory plots




+




DeRose, Shaw and Long 2017

# Workflow

What are the important drivers of tree growth?

Does the use of tree-ring data improve model performance?

How do predictions of growth with improved models differ from the base FVS model?

Growth = f (Tree-level, Site-level biophysical, Competition)

↓

Annualize (10→1)

↓

Add interannual climate effects

↓

Reduce by removing terms

↓

Add complexity

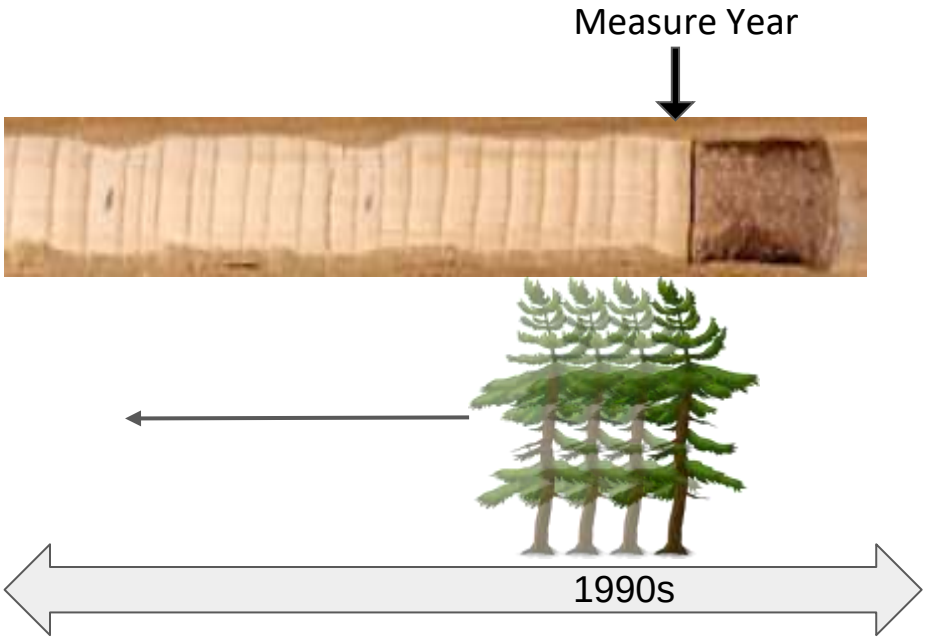

Growth = f (Tree-level, Site-level biophysical, Competition)

↓

Annualize (10→1)

# Calibration

## 1) Annualize tree size (DBH)




## 2) Calculate/obtain predictors

| **DBH** | **Competition** (CCF, PCCF, BAL, SDI) | **Tree-level** (CR) | **Site-level biophysical** (SI,SL,ASP) |
|---|---|---|---|
| $DBH_t$ | $Competition_t$ | CR | |
| ... | ... | ... | |
| $DBH_{t-n}$ | $Competition_{t-n}$ | CR | |

Growth = f (Tree-level, Site-level biophysical, Competition)

Annualize (10→1)

Models

- Full Annual

Growth = f (Tree-level, Site-level biophysical, Competition)

Annualize (10→1)

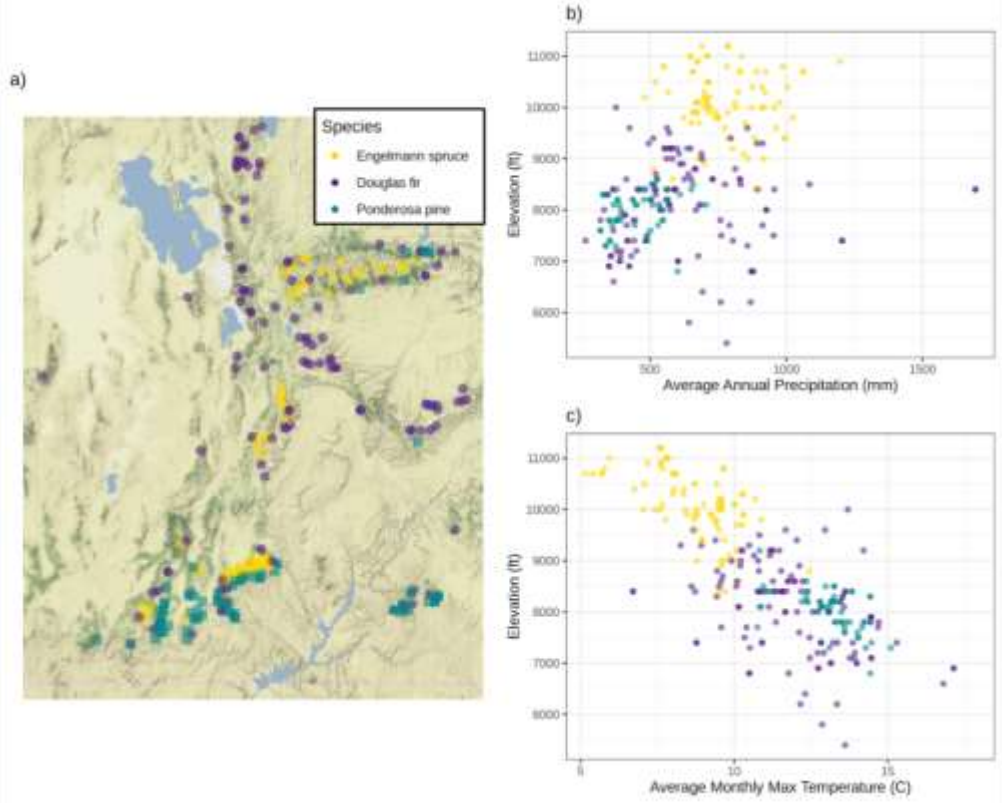
Add interannual climate effects

Models

- Full Annual

# Interannual Climate Effects

- Seasonal (1, 3, 6 month) climate-growth correlations
  - Temperature
    - DF: February - July
    - PP: June - August
    - ES: Previous August
  - Precipitation
    - Previous June - September (16 month)



Growth = f (Tree-level, Site-level biophysical, Competition)

↓

Annualize (10→1)

↓

Add interannual climate effects

Models

- ● Full Annual
- ▲ Full Climate

Growth = f (Tree-level, Site-level biophysical, Competition)

↓

Annualize (10→1)

↓

Add interannual climate effects

↓

Reduce by removing terms

Models

- ● Full Annual
- ▲ Full Climate

Growth = f (Tree-level, Site-level biophysical, Competition)

↓

Annualize (10→1)

↓

Add interannual climate effects

↓

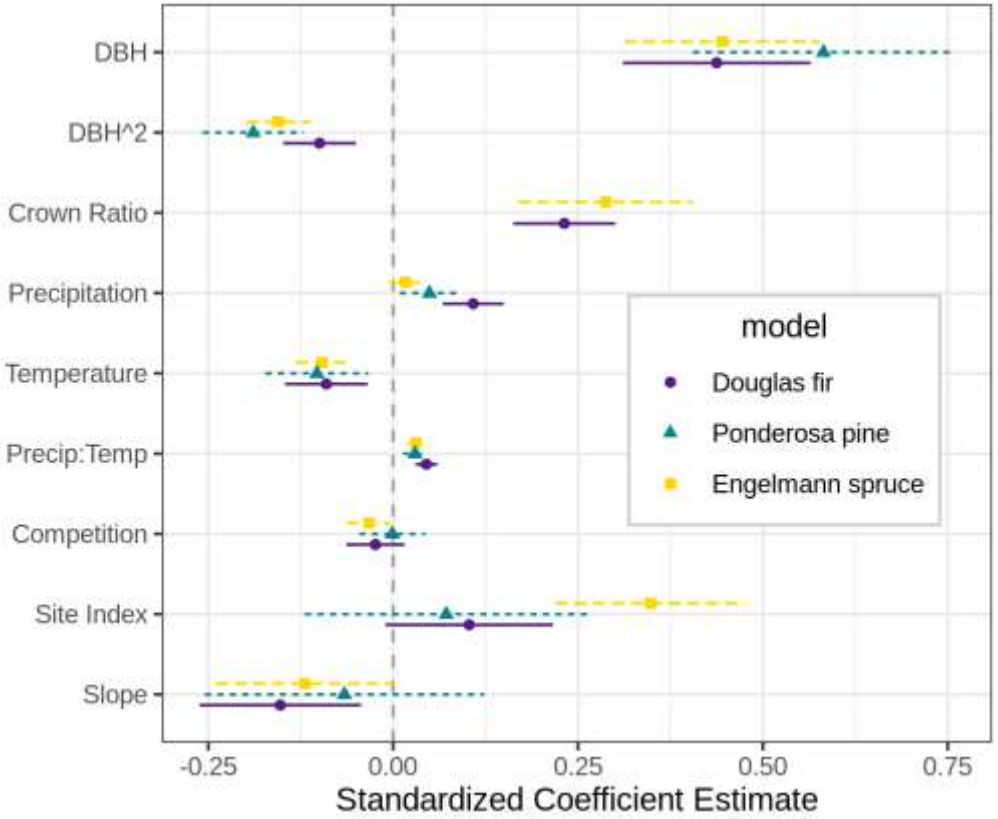
Reduce by removing terms

Models

- ● Full Annual
- ○ Reduced Annual
- ▲ Full Climate
- △ Reduced Climate

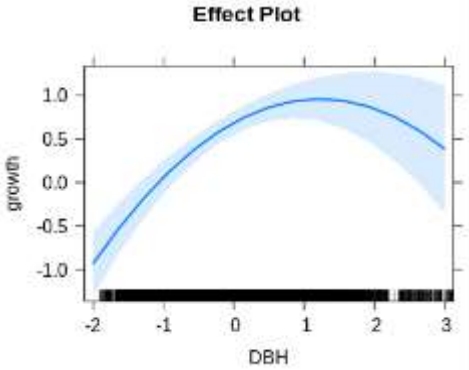
# Reduced Climate Models

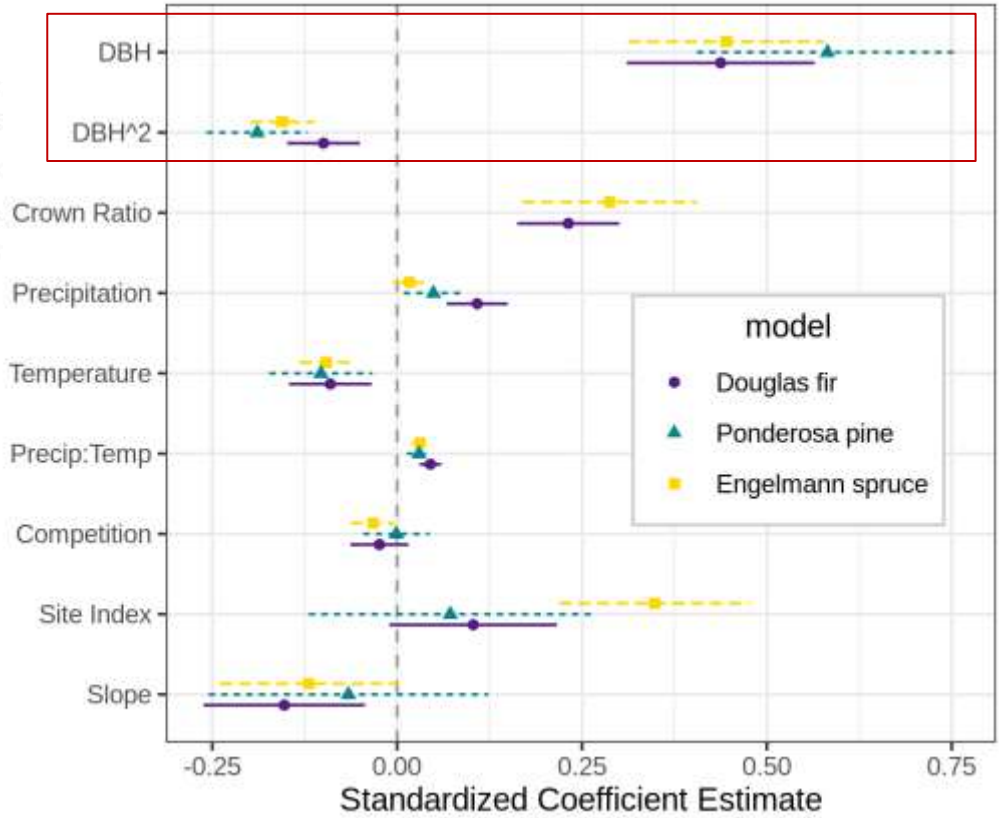
Growth = f (tree-level, site-level biophysical, competition,climate)



# Reduced Climate Models

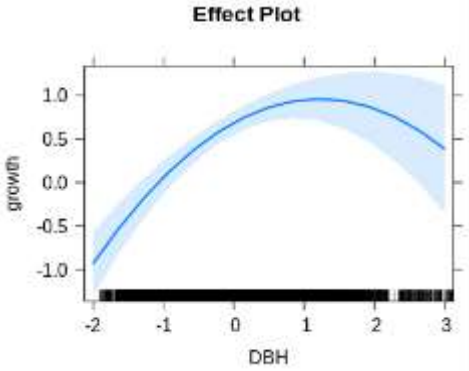
Growth = f (**tree-level**, site-level biophysical, competition, climate)

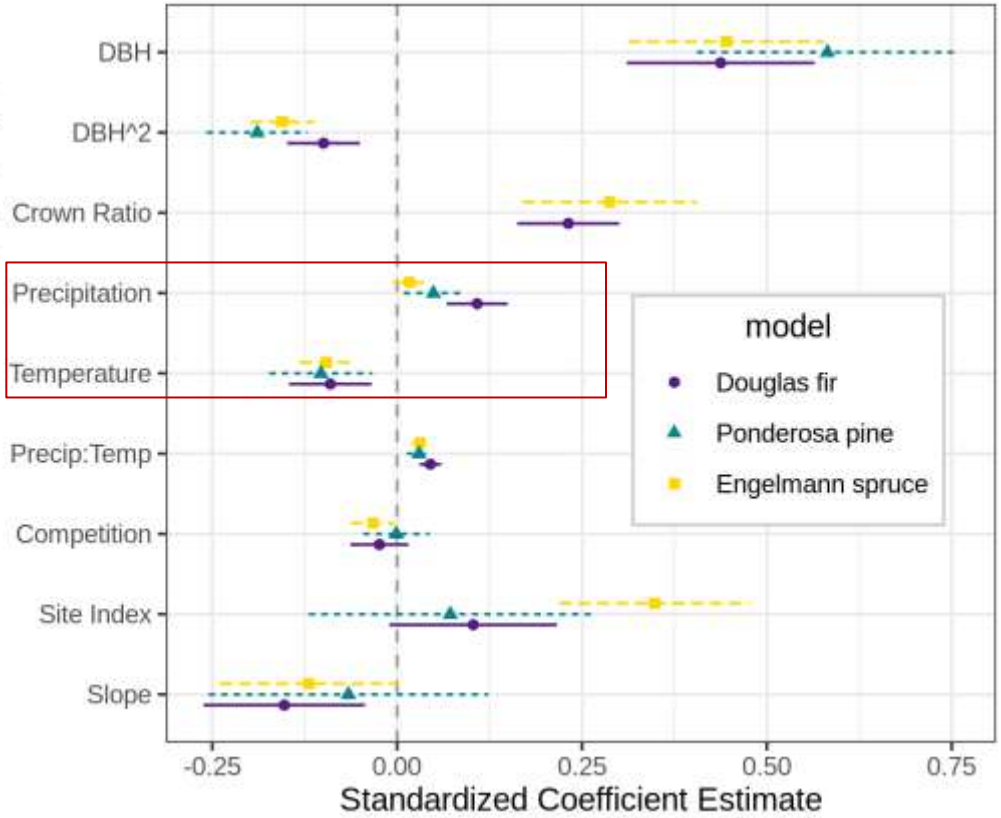


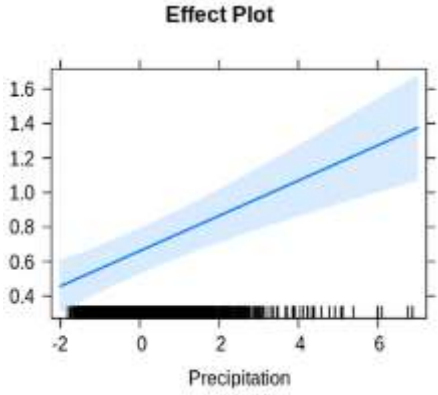



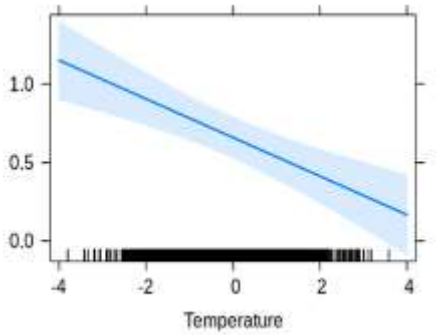
# Reduced Climate Models

Growth = f (tree-level, site-level biophysical, competition, **climate**)



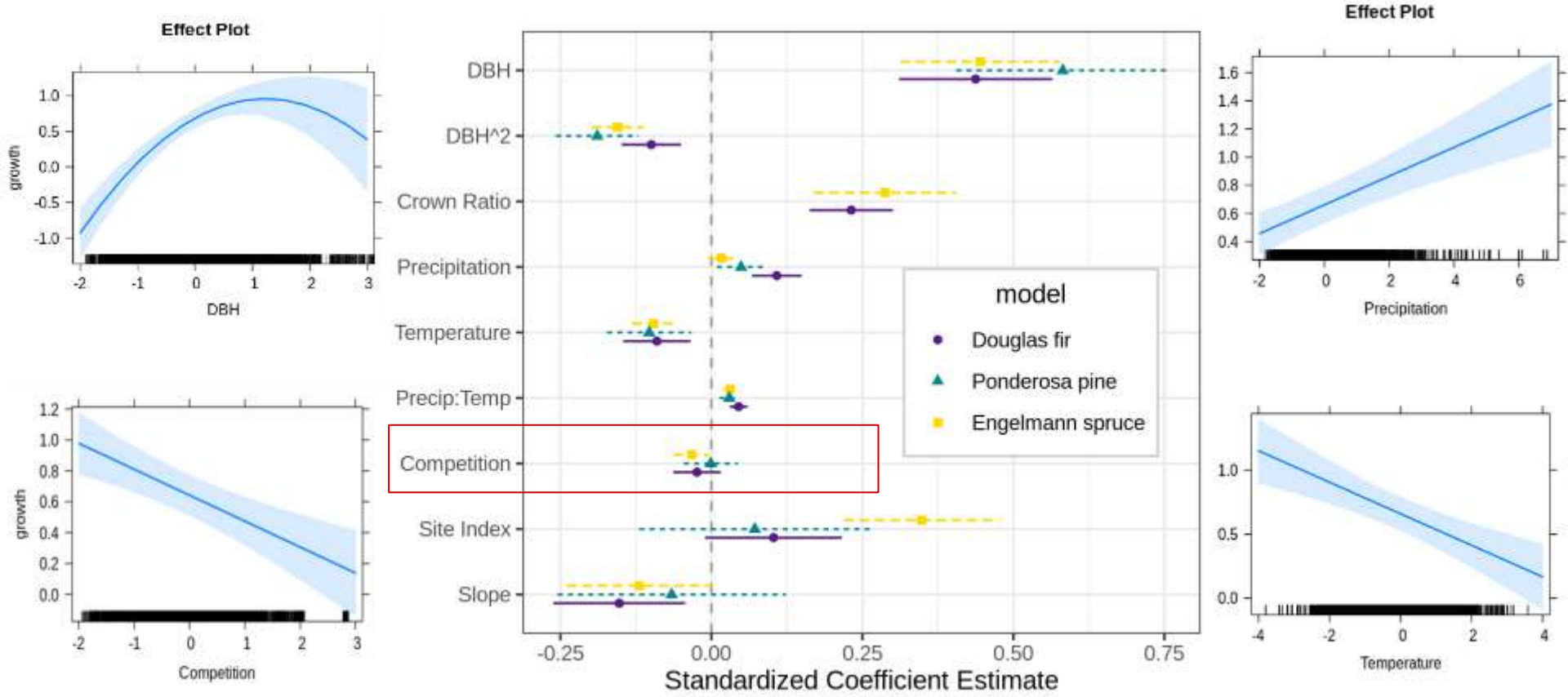



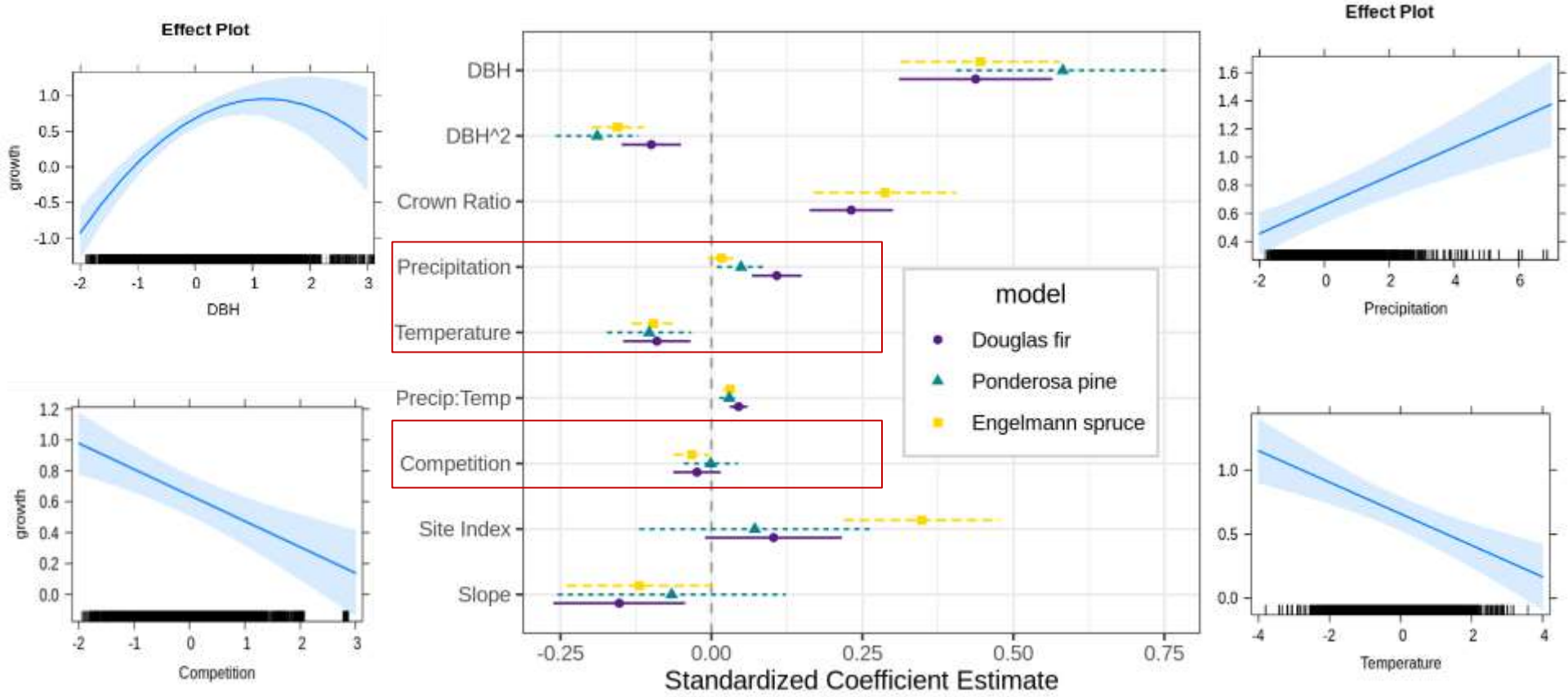
# Reduced Climate Models

Growth = f (tree-level, site-level biophysical, competition, climate)



# Reduced Climate Models

Growth = f (tree-level, site-level biophysical, competition,climate)



Growth = f (Tree-level, Site-level biophysical, Competition)

↓

Annualize (10→1)

↓

Add interannual climate effects

↓

Reduce by removing terms

↓

Add complexity:

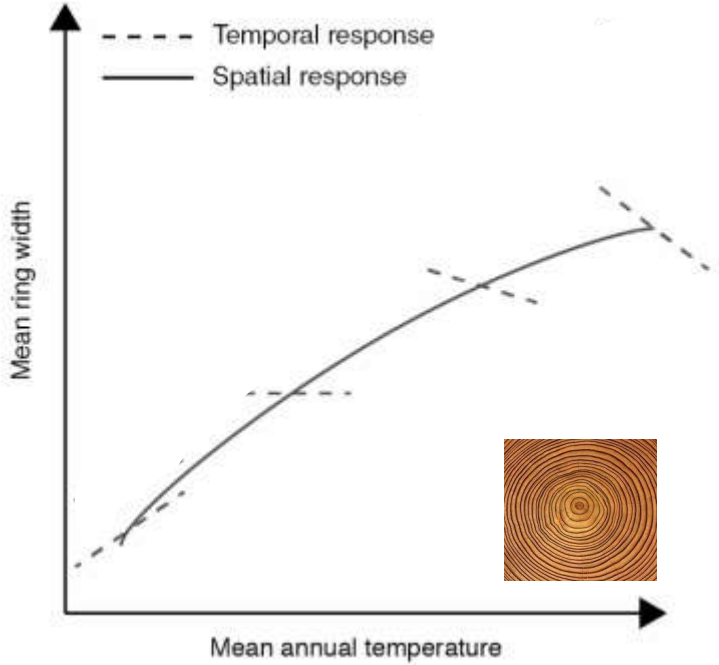
spatial heterogeneity in climate sensitivity with climate normals (average) and interactions

Models

- ● Full Annual
- ○ Reduced Annual
- ▲ Full Climate
- △ Reduced Climate

# Population-level response
## 1) Spatial heterogeneity in climate sensitivity

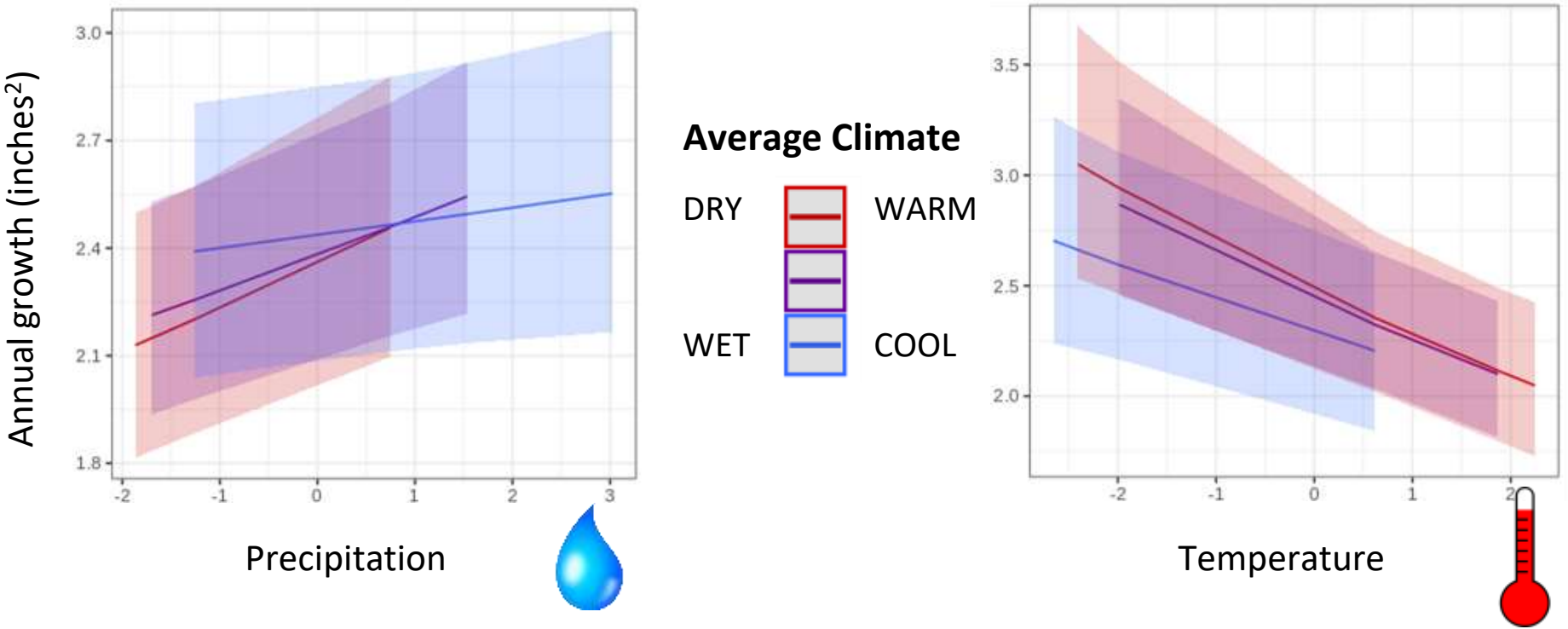
- Temporal: interannual climate
- Spatial: average climate (climate normals)




(Klesse et al. 2020)

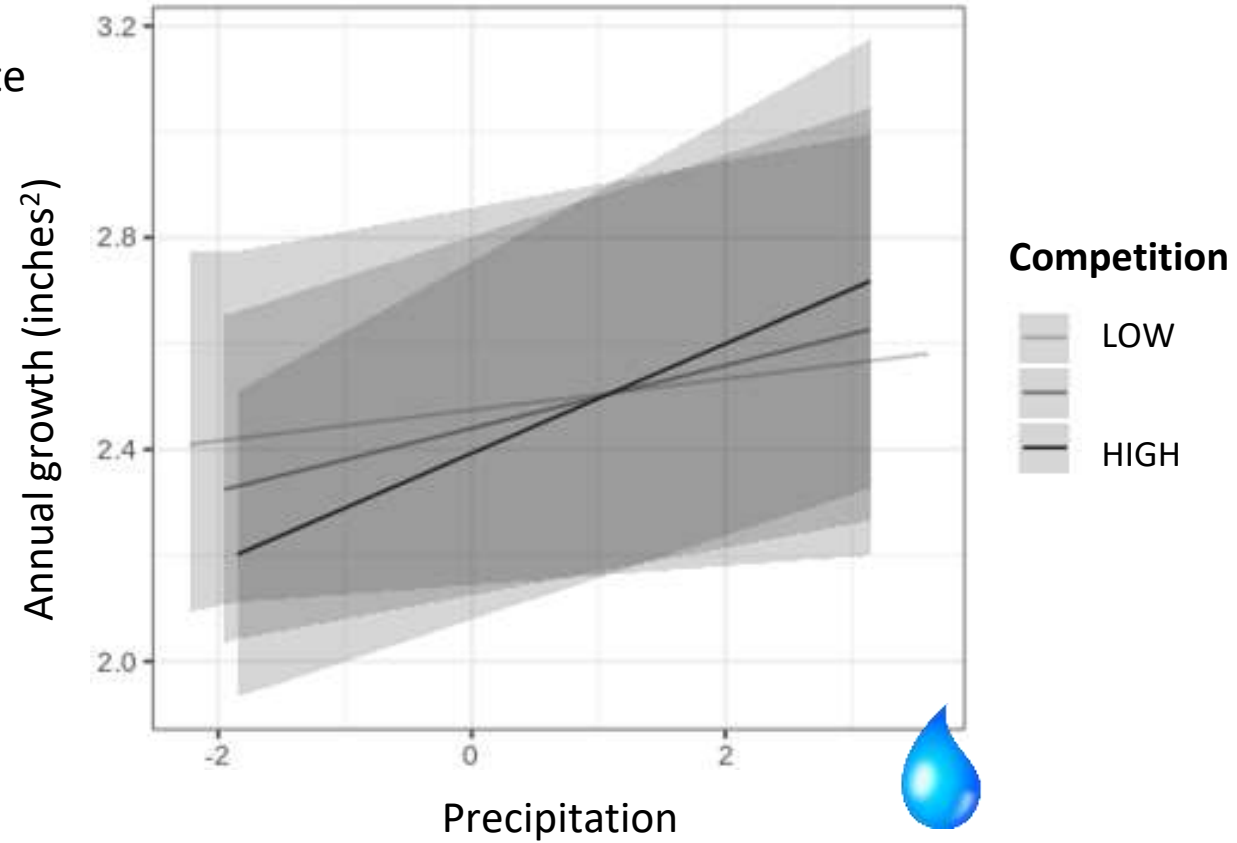
# Spatial heterogeneity in climate sensitivity

★ More sensitive at warm and dry locations



# Interactions - climate:competition

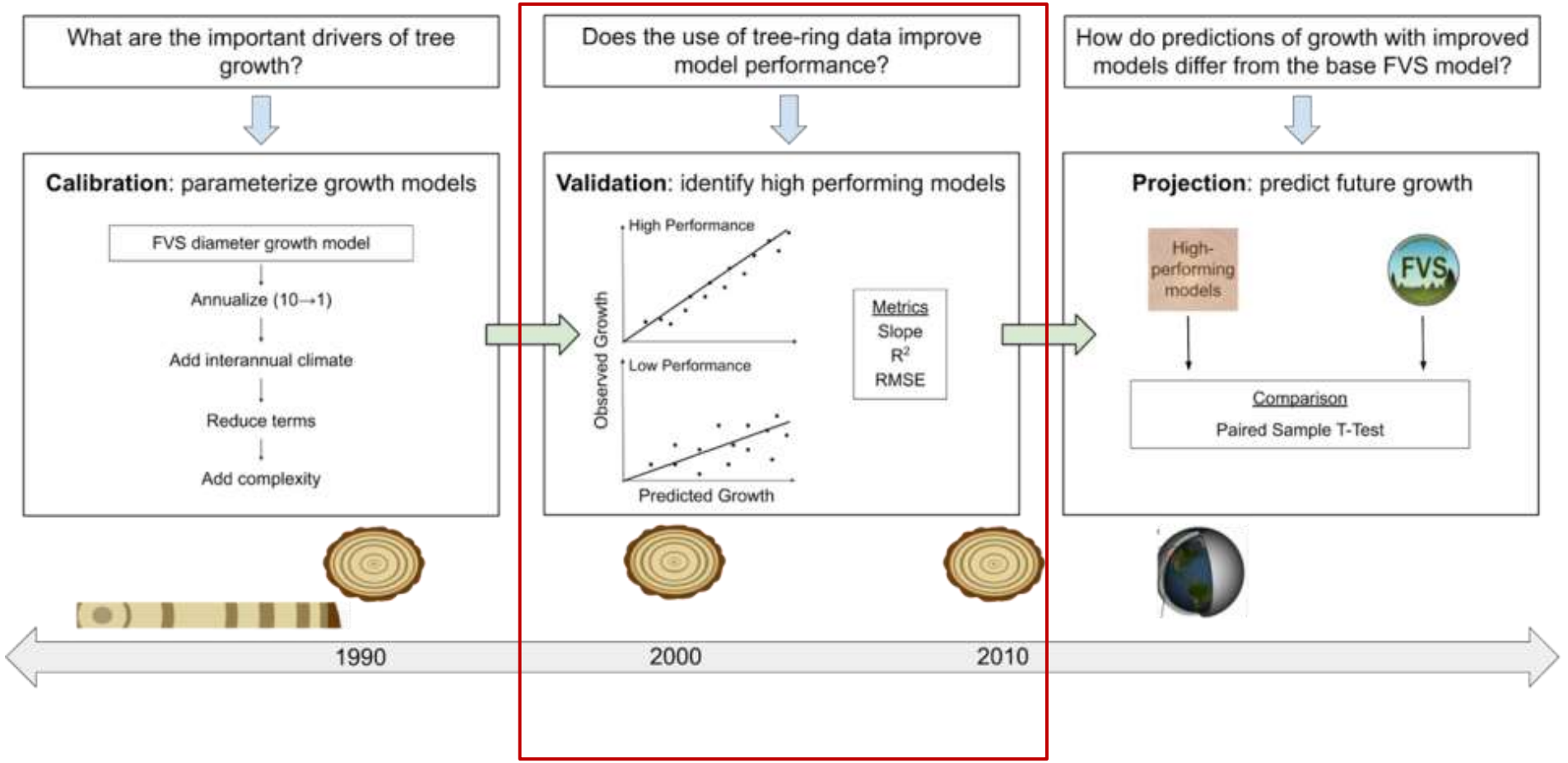
★ Competition increases climate sensitivities



# Calibration: refined understanding of drivers

- Important drivers of tree growth
  - Tree-level variables (size and crown ratio) had the largest effect
  - Climate and competition are small but well constrained
- Climate sensitivity is greater at warm and dry locations
- Competition increases climate sensitivities

# Workflow

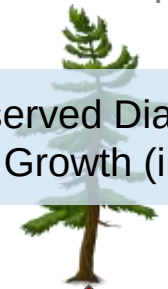

What are the important drivers of tree growth?
Does the use of tree-ring data improve model performance?
How do predictions of growth with improved models differ from the base FVS model?
Calibration: parameterize growth models
FVS diameter growth model
Annualize (10→1)
Add interannual climate
Reduce terms
Add complexity
Validation: identify high performing models
High Performance
Low Performance
Observed Growth
Predicted Growth
Metrics
Slope
R2
RMSE
Projection: predict future growth
High-performing models
FVS
Comparison
Paired Sample T-Test
1990
2000
2010

# Calibration

out-of-sample **Validation**

Measure Year

Engelmann spruce (n = 1144)
Douglas-fir (n = 891)
Ponderosa pine (n = 384)

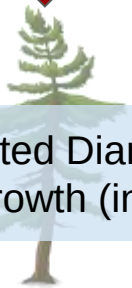


Observed Diameter Growth (in)

1990s

2000s

2010s

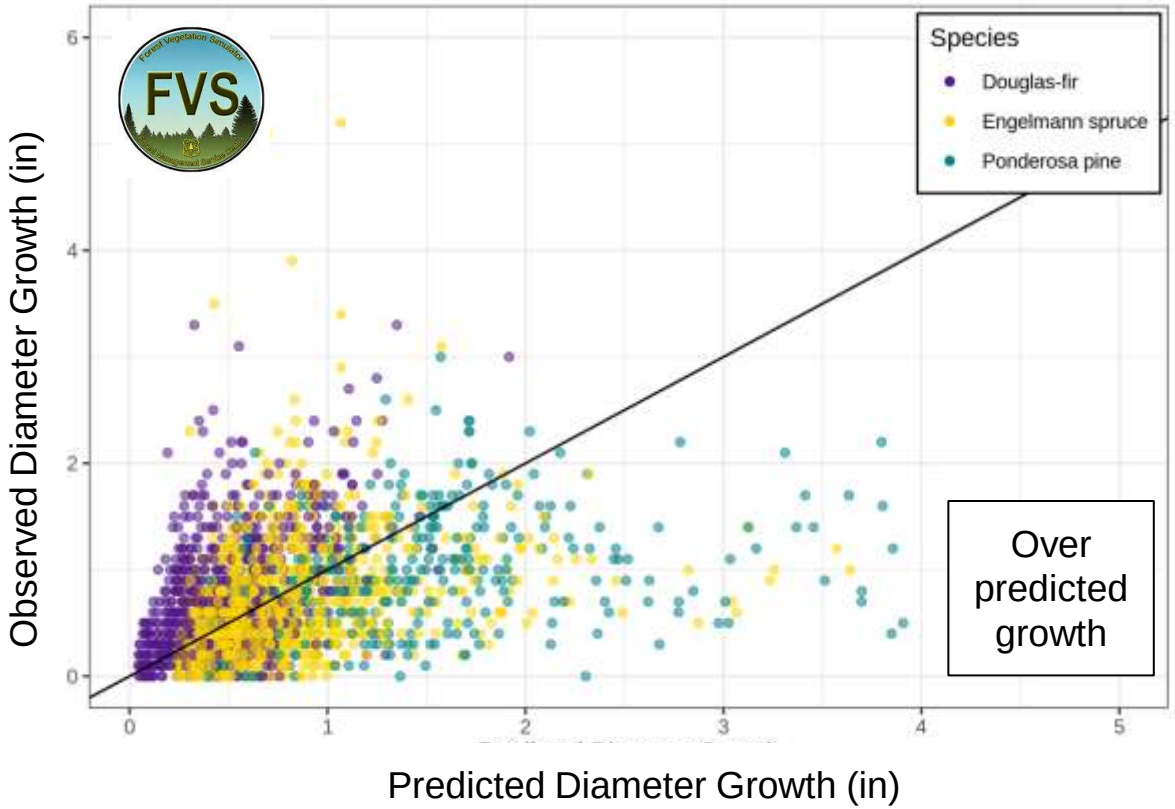


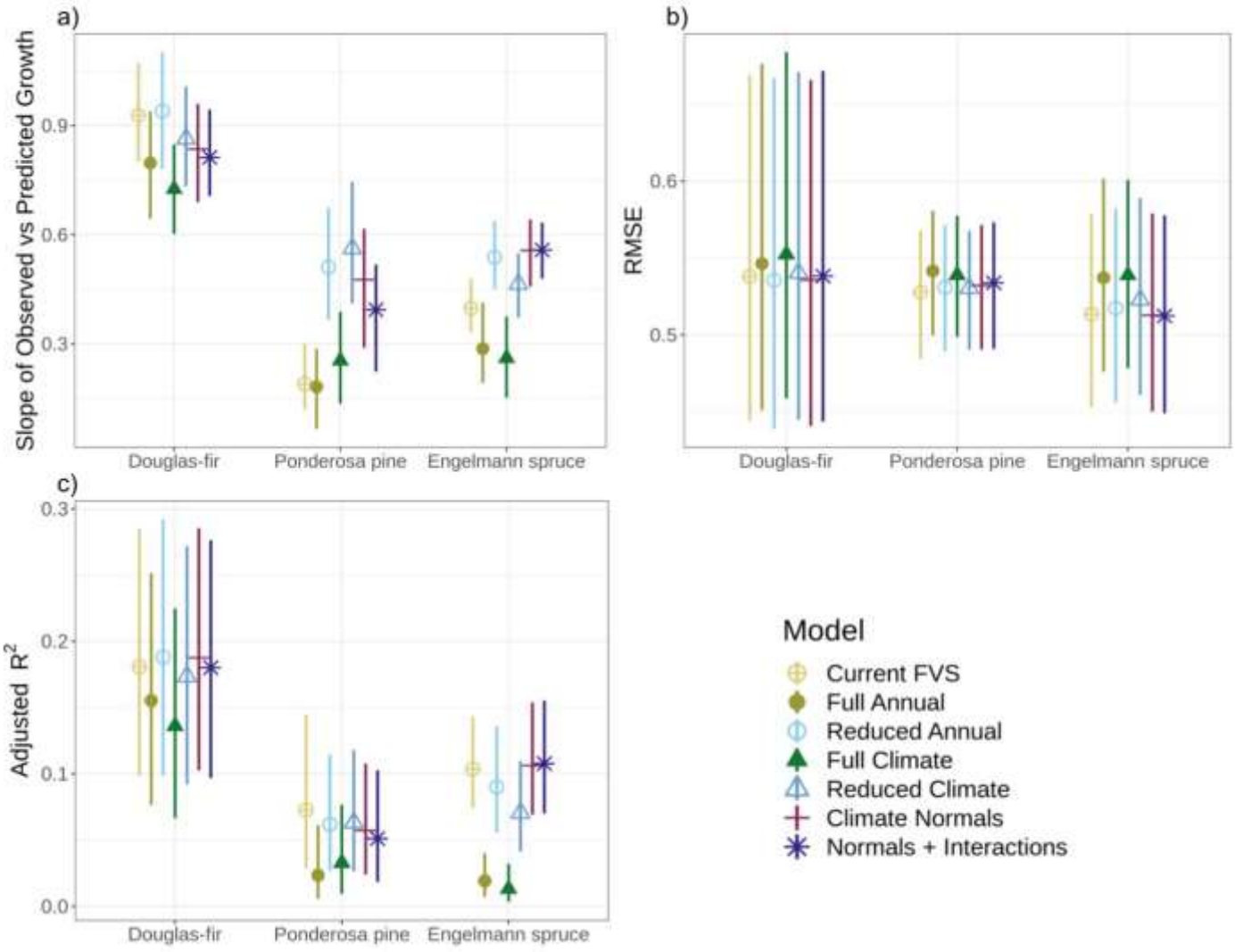
Predicted Diameter Growth (in)

Alternative Growth Models

# Validation metrics

- Observed vs Predicted Diameter Growth (in)
  - Slope ≈ 1
  - High Adjusted $R^2$
  - Low RMSE

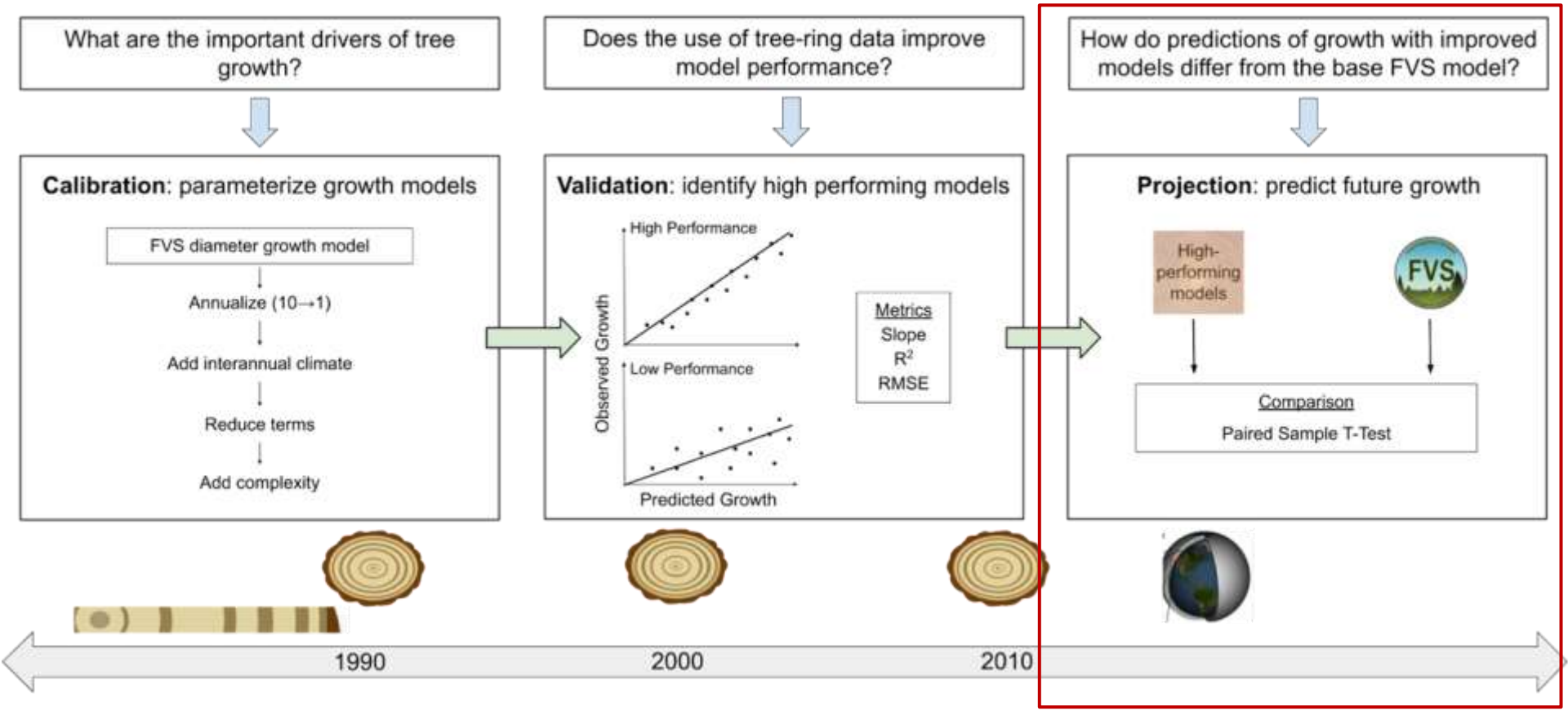



a)
Slope of Observed vs Predicted Growth
0.9
0.6
0.3
Douglas-fir
Ponderosa pine
Engelmann spruce
b)
RMSE
0.6
0.5
Douglas-fir
Ponderosa pine
Engelmann spruce
c)
Adjusted $R^2$
0.3
0.2
0.1
0.0
Douglas-fir
Ponderosa pine
Engelmann spruce
Model
Current FVS
Full Annual
Reduced Annual
Full Climate
Reduced Climate
Climate Normals
Normals + Interactions

# Validation: improved prediction

- Including all predictors in a growth model parameterized with tree rings reduces model performance
- Growth is over predicted by FVS in ponderosa pine and Engelmann spruce
    - Addition of climate effects improves growth prediction

# Workflow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High Performance
Low Performance
Observed Growth
Predicted Growth
Metrics
Slope
$R^2$
RMSE
Projection: predict future growth
High-performing models
FVS
Comparison
Paired Sample T-Test
1990
2000
2010

# Validation

Identified high performing models

1. Reduced annual
2. Reduced with climate
3. Reduced with climate plus climate normals
4. Reduced with climate plus climate normals and interactions

# Projection

Engelmann spruce
(n = 1340)
Douglas-fir
(n = 995)
Ponderosa pine
(n = 460)

$$RGR = \frac{DBH_{2060} - DBH_{initial}}{DBH_{initial}}$$

2010s

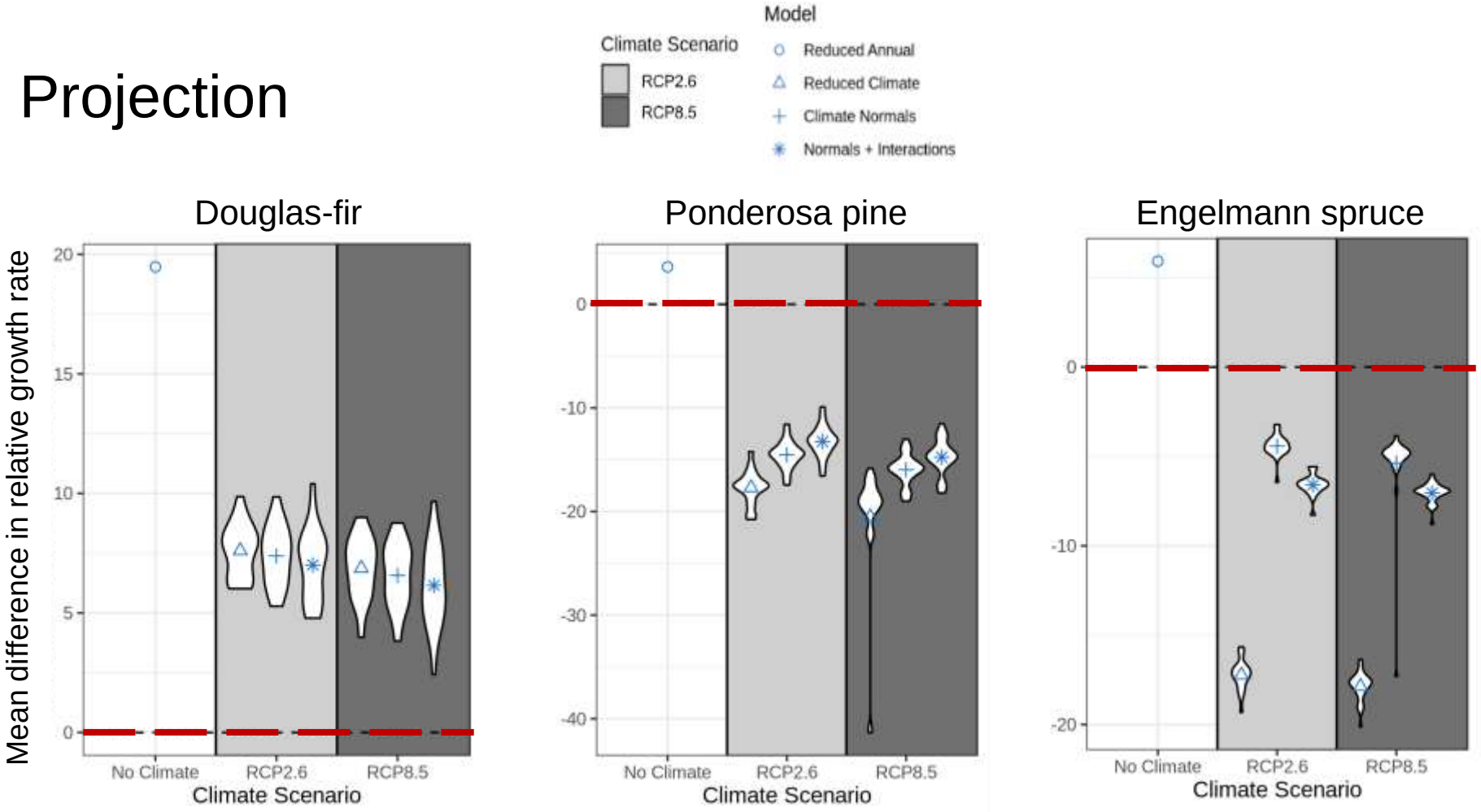
Paired Sample T-Test

2060

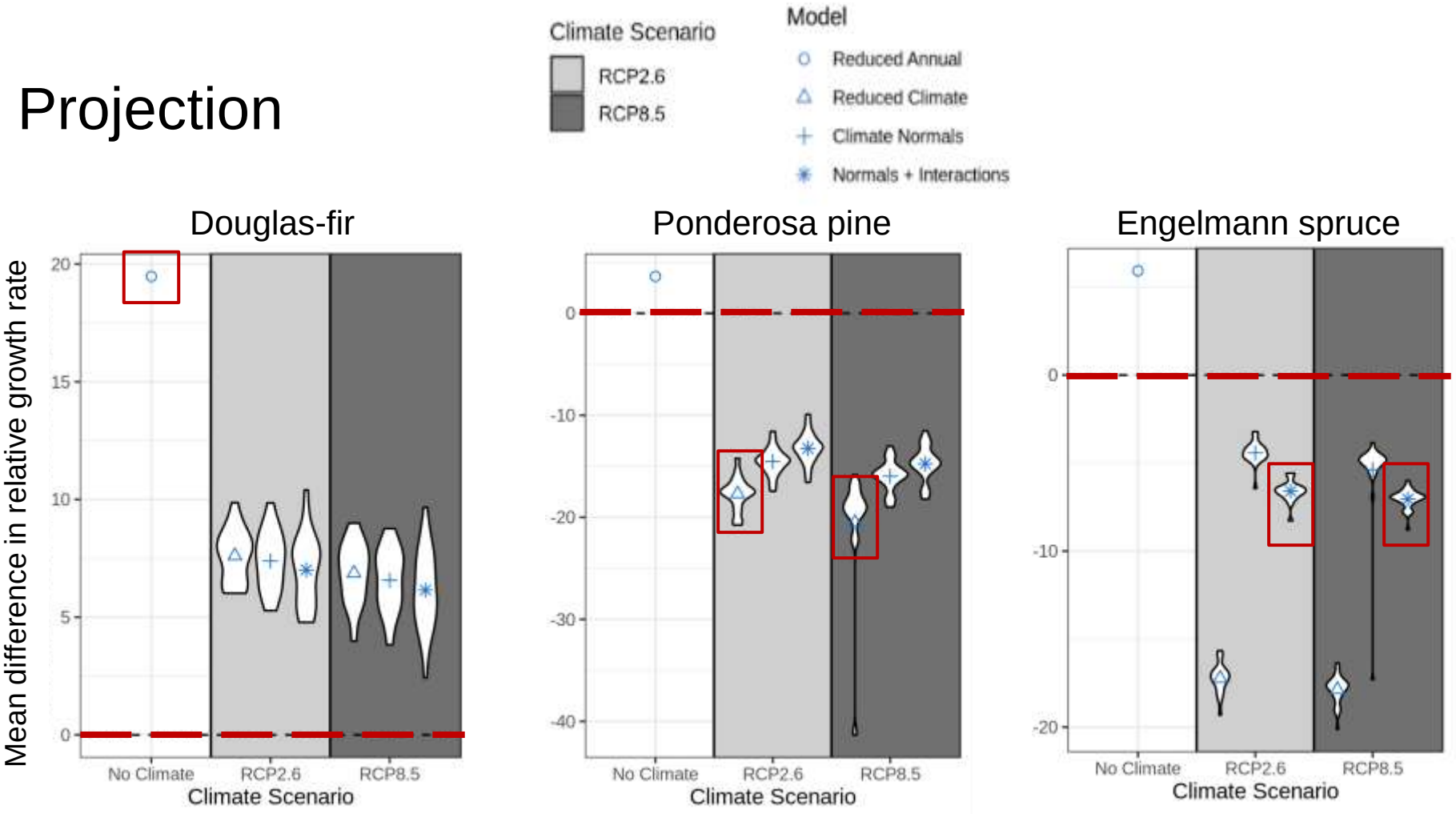
FVS

$$RGR = \frac{DBH_{2060} - DBH_{initial}}{DBH_{initial}}$$

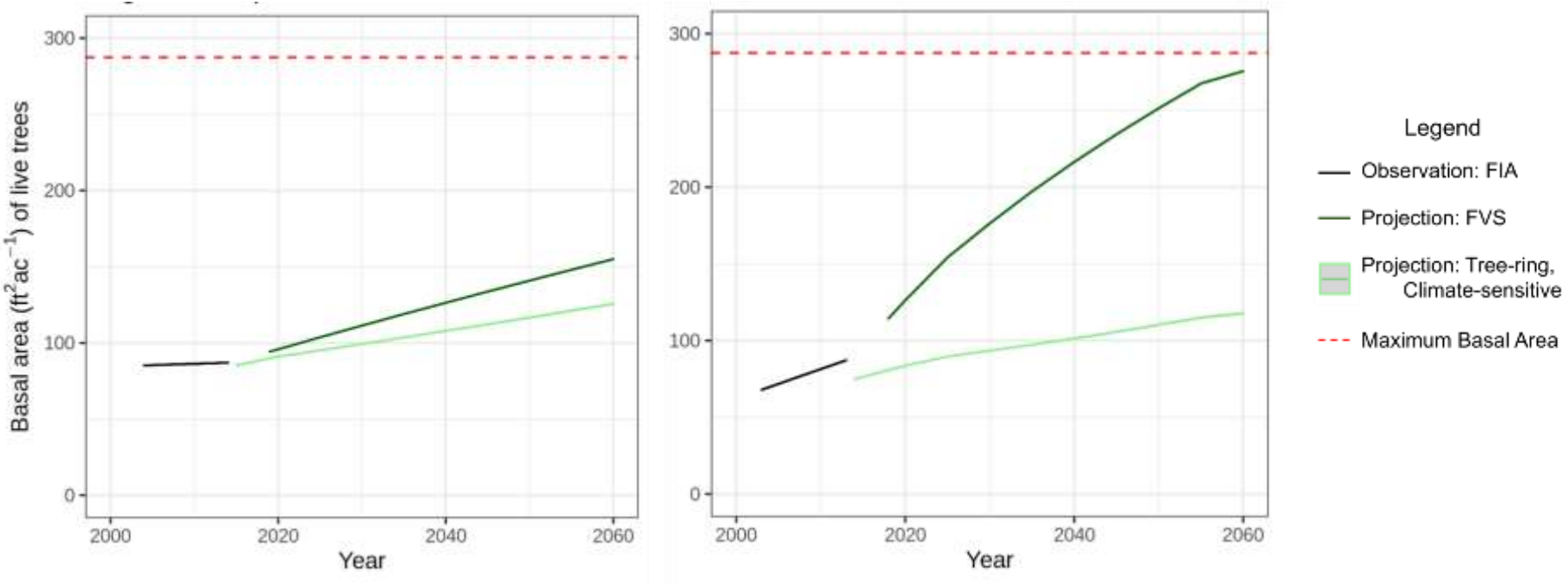
# Projection


Model
Climate Scenario
RCP2.6
RCP8.5
Reduced Annual
Reduced Climate
Climate Normals
Normals + Interactions
Douglas-fir
Ponderosa pine
Engelmann spruce
Mean difference in relative growth rate
20
15
10
5
0
-10
-20
-30
-40
No Climate
RCP2.6
RCP8.5
Climate Scenario

# Projection


Climate Scenario
RCP2.6
RCP8.5
Model
Reduced Annual
Reduced Climate
Climate Normals
Normals + Interactions
Douglas-fir
Ponderosa pine
Engelmann spruce
Mean difference in relative growth rate
20
15
10
5
0
-10
-20
-30
-40
No Climate
RCP2.6
RCP8.5
Climate Scenario

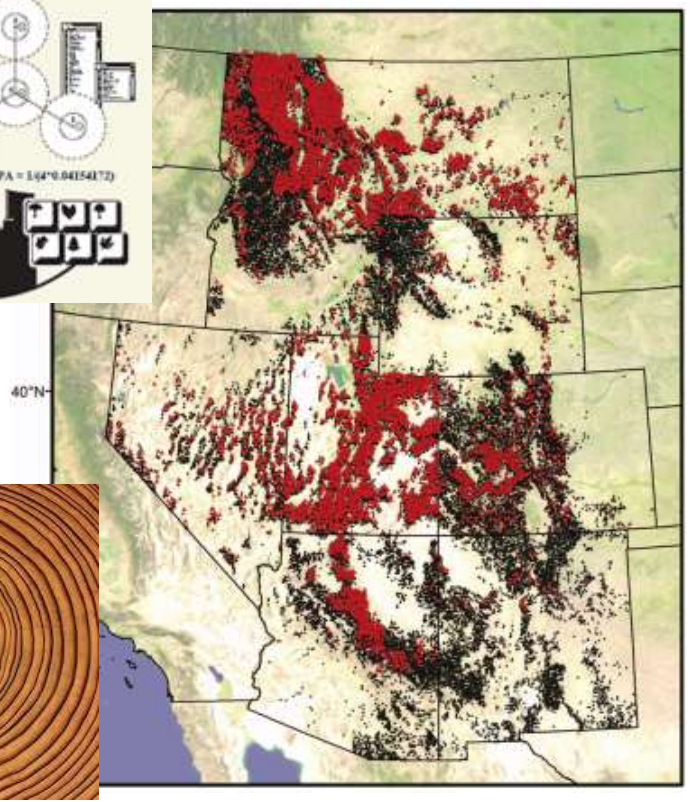
# More accurate predictions of the carbon uptake potential of forests under climate change

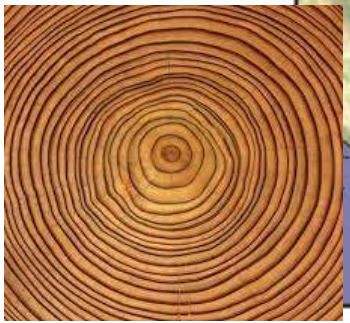


# Conclusions

- Calibration: what are the important drivers of tree growth estimated from tree-ring and forest inventory data?
  - Climate and competition
- Validation: does the use of tree-ring data improve model performance?
  - Yes! But improvements are species-specific.
- Projection: how do predictions of growth with improved models differ from the base FVS model?
  - Climate is expected to cause a decline in growth in ponderosa pine and Engelmann spruce, but accounting for local adaptation in Engelmann spruce moderates reductions in growth.

# Reproducible Workflow



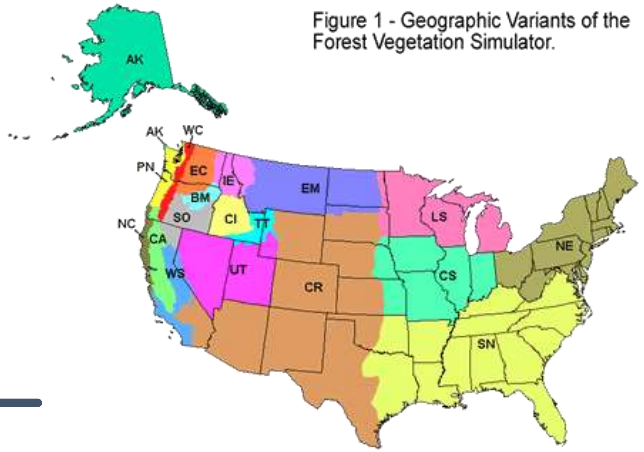
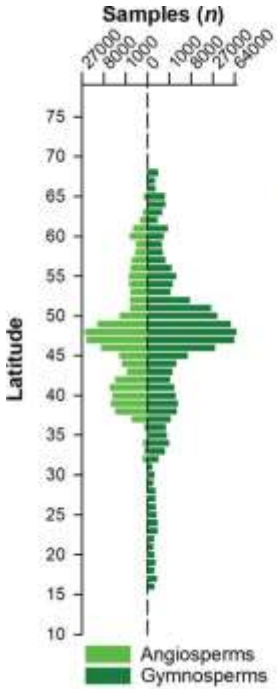
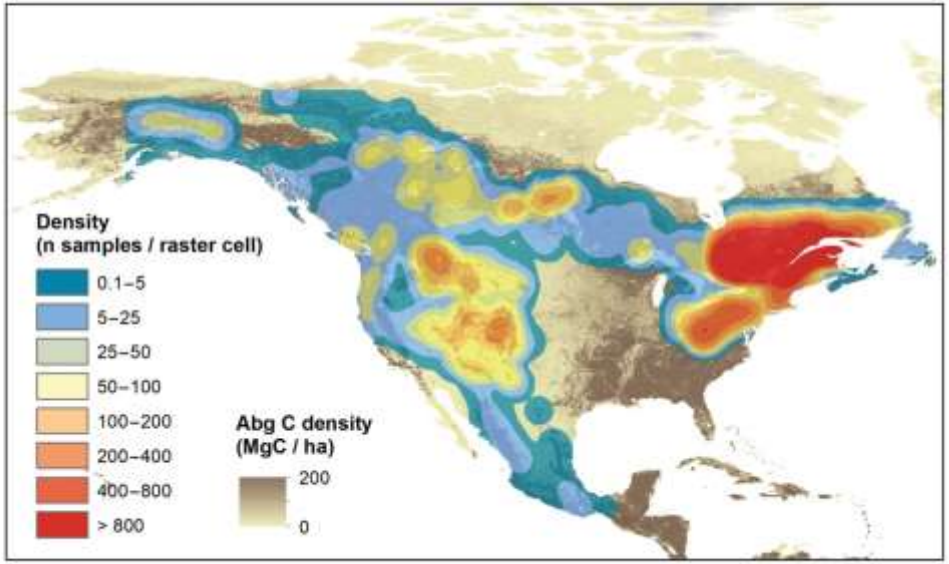



Figure 1 - Geographic Variants of the Forest Vegetation Simulator.

# Adding Tree Rings to North America's National Forest Inventories: An Essential Tool to Guide Drawdown of Atmospheric $CO_2$

MARGARET E. K. EVANS, R. JUSTIN DEROSE, STEFAN KLESSE, MARTIN P. GIRARDIN, KELLY A. HEILMAN, M. ROSS ALEXANDER, ANDRÉ ARSENAULT, FLURIN BABST, MATHIEU BOUCHARD, SEAN M. P. CAHOON, ELIZABETH M. CAMPBELL, MICHAEL DIETZE, LOUIS DUCHESNE, DAVID C. FRANK, COURTNEY L. GIEBINK, ARMANDO GÓMEZ-GUERRERO, GENARO GUTIÉRREZ GARCÍA, EDWARD H. HOGG, JUHA METSARANTA, CLÉMENTINE OLS, SHELLY A. RAYBACK, ANYA REID, MARTIN RICKER, PAUL G. SCHABERG, JOHN D. SHAW, PATRICK F. SULLIVAN, AND SERGIO ARMANDO VILLELA GAYTÁN

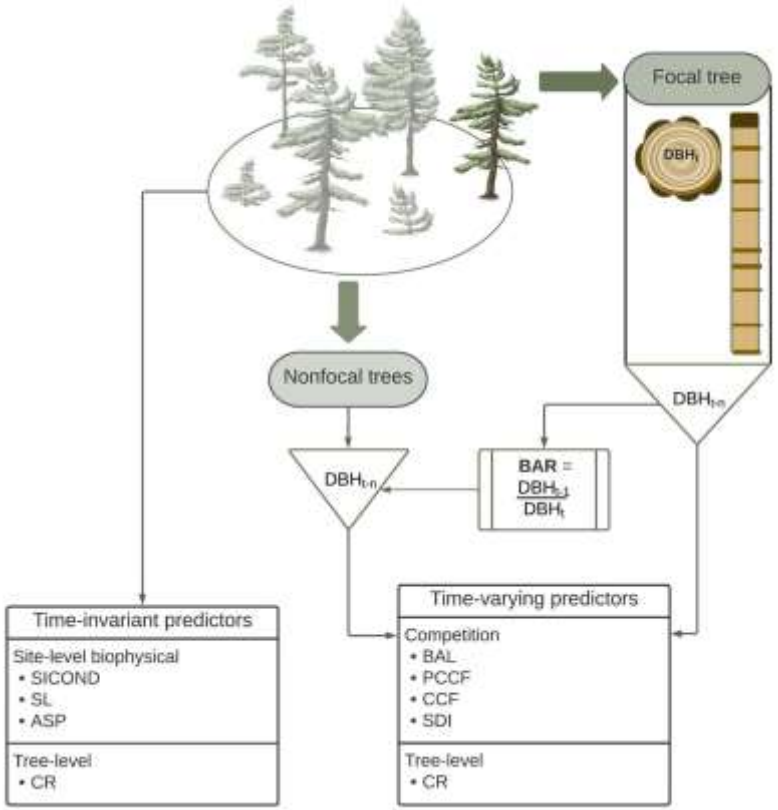


# Thank You!

**Courtney.Giebink@usda.gov**

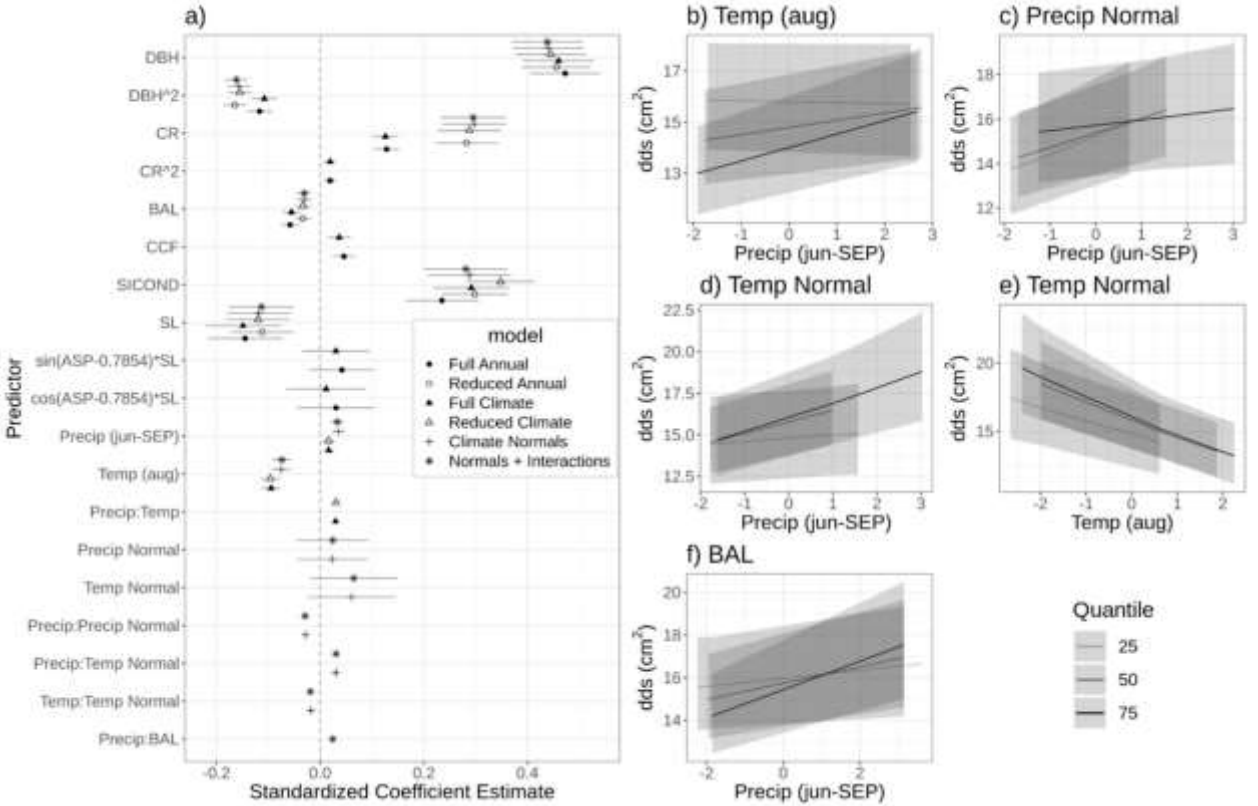
# Calibration



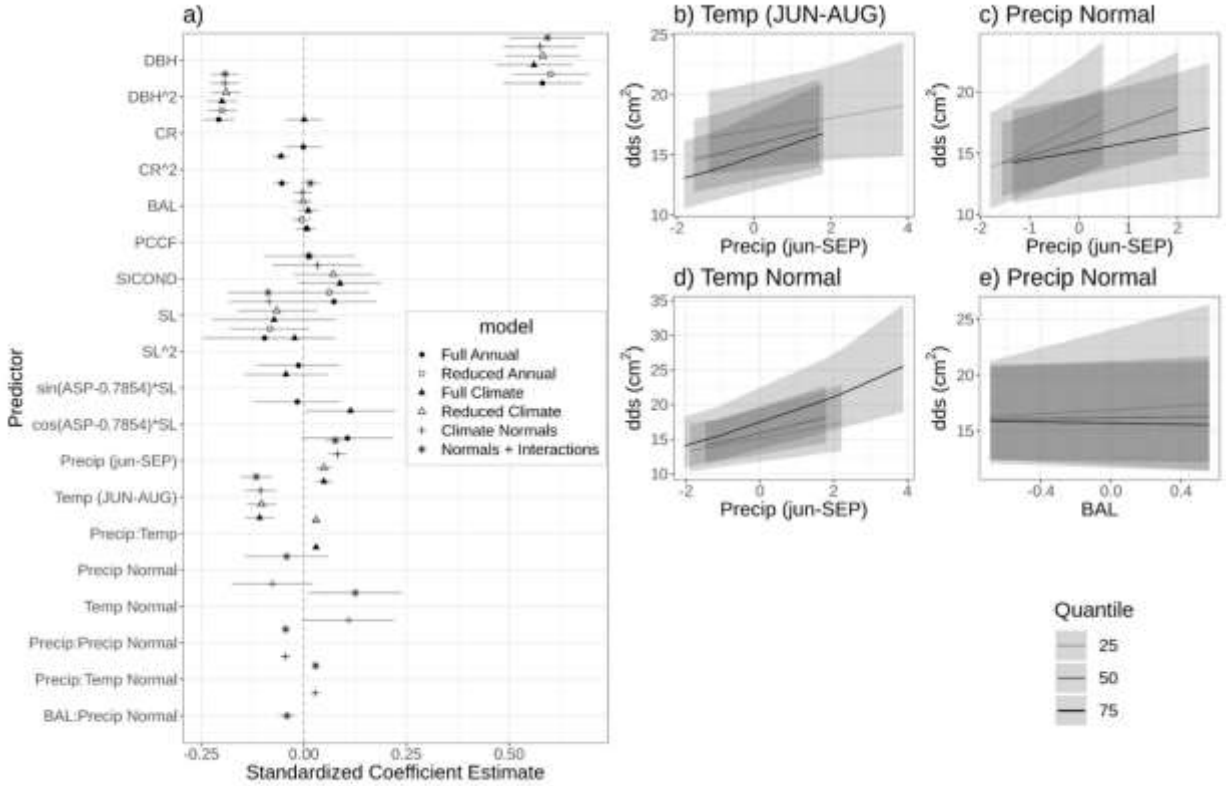

## 2) Calculate/obtain predictors

| **DBH** | **Competition** (CCF, PCCF, BAL, SDI) | **Tree-level** (CR) | **Site-level biophysical** (SI,SL,ASP) |
|---|---|---|---|
| $DBH_t$ | $Competition_t$ | CR | |
| ... | ... | ... | |
| $DBH_{t-n}$ | $Competition_{t-n}$ | CR | |

# Douglas-fir


a)
DBH
DBH^2
CR
CR^2
BAL
CCF
SICOND
SL
sin(ASP-0.7854)*SL
cos(ASP-0.7854)*SL
Precip (jun-SEP)
Temp (aug)
Precip:Temp
Precip Normal
Temp Normal
Precip:Precip Normal
Precip:Temp Normal
Temp:Temp Normal
Precip:BAL
Predictor
-0.2
0.0
0.2
0.4
Standardized Coefficient Estimate
model
Full Annual
Reduced Annual
Full Climate
Reduced Climate
Climate Normals
Normals + Interactions
b) Temp (aug)
c) Precip Normal
d) Temp Normal
e) Temp Normal
f) BAL
dds (cm²)
Precip (jun-SEP)
Temp (aug)
Quantile
25
50
75

# Ponderosa pine



# Engelmann spruce