# Fine-scale vegetation-climate-disturbance interactions in the boreal forest

Can we use an individual-tree model to improve coarser scale models?

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NCAR Land Model Working Group Meeting
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# Wildfire is a dominant driver of ecosystem dynamics in the boreal forest


## Impacts:

Above- and belowground C storage

Vegetation structure

Species composition

Soil depth

Soil moisture

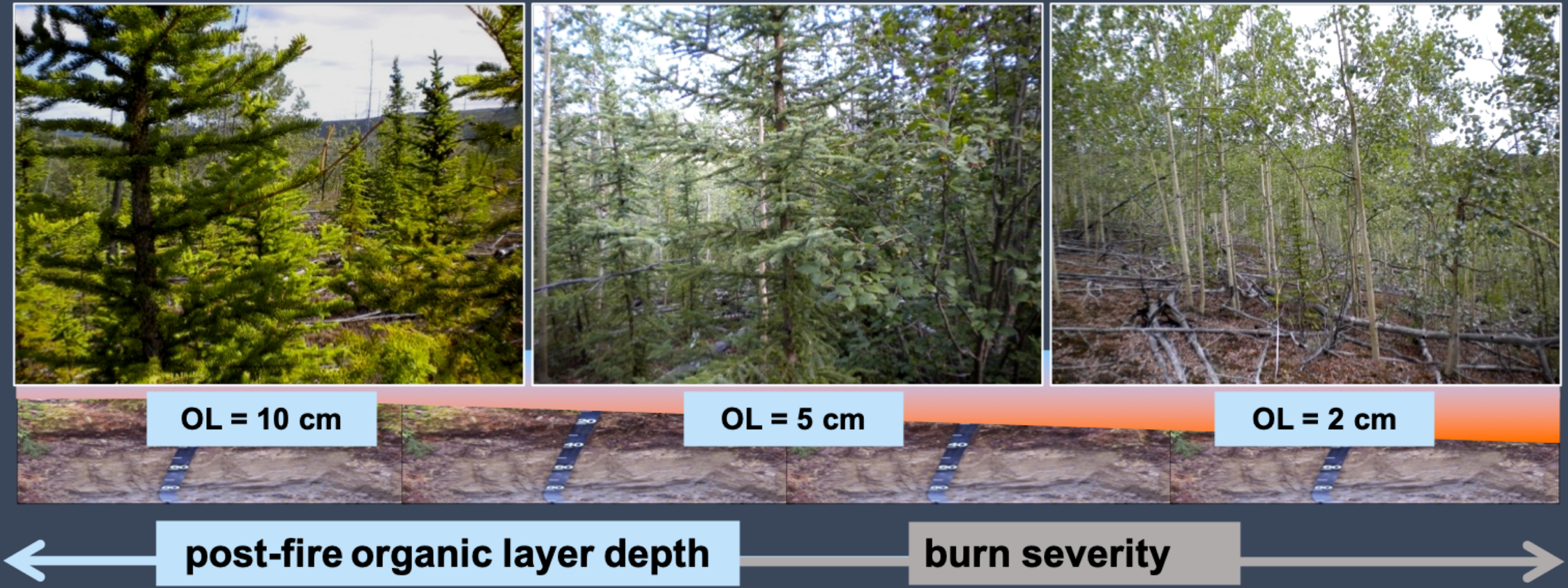
Permafrost dynamics

Albedo

Surface roughness

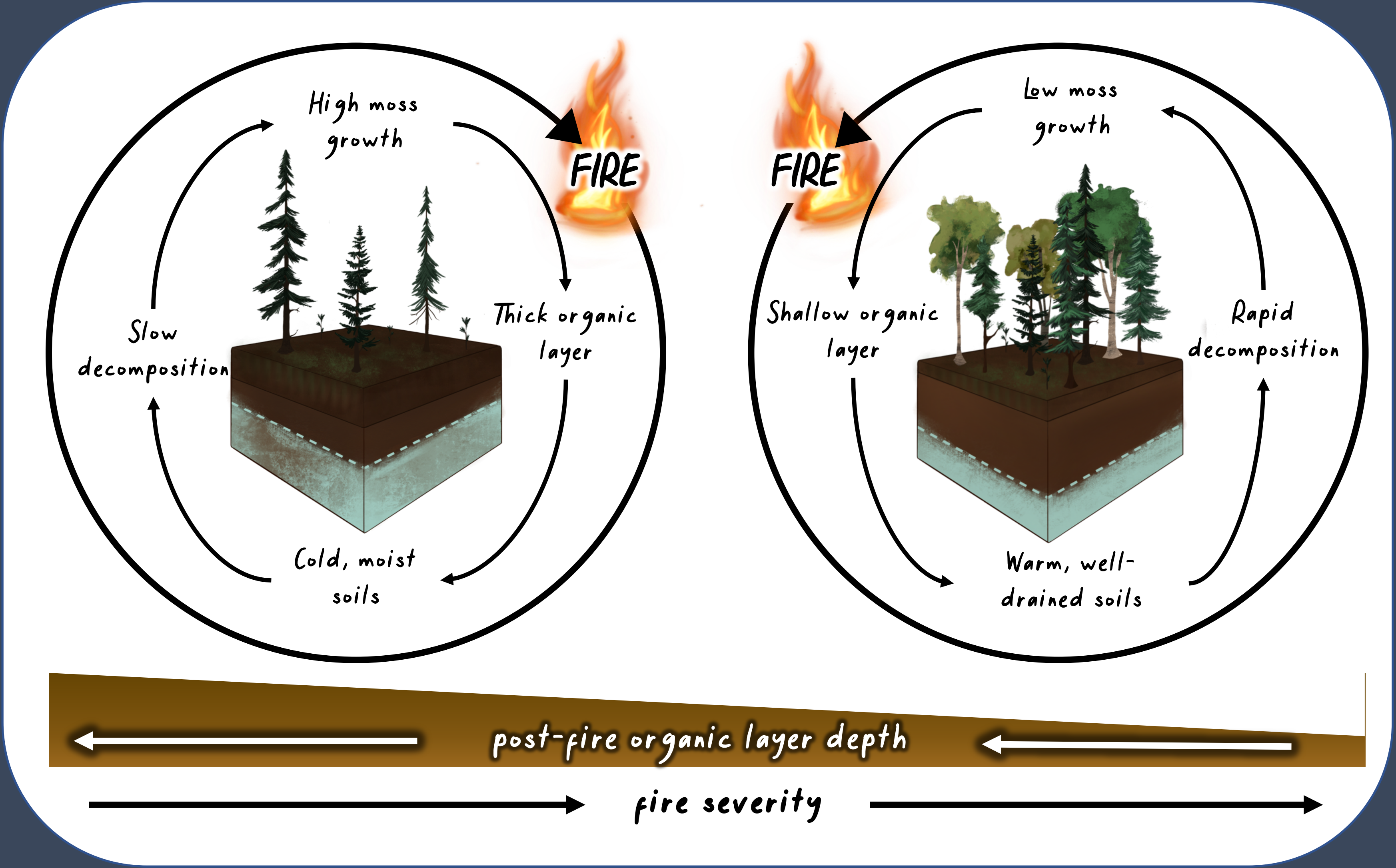
Energy & water cycling

# Wildfire severity impacts post-fire organic layer depth and forest regrowth



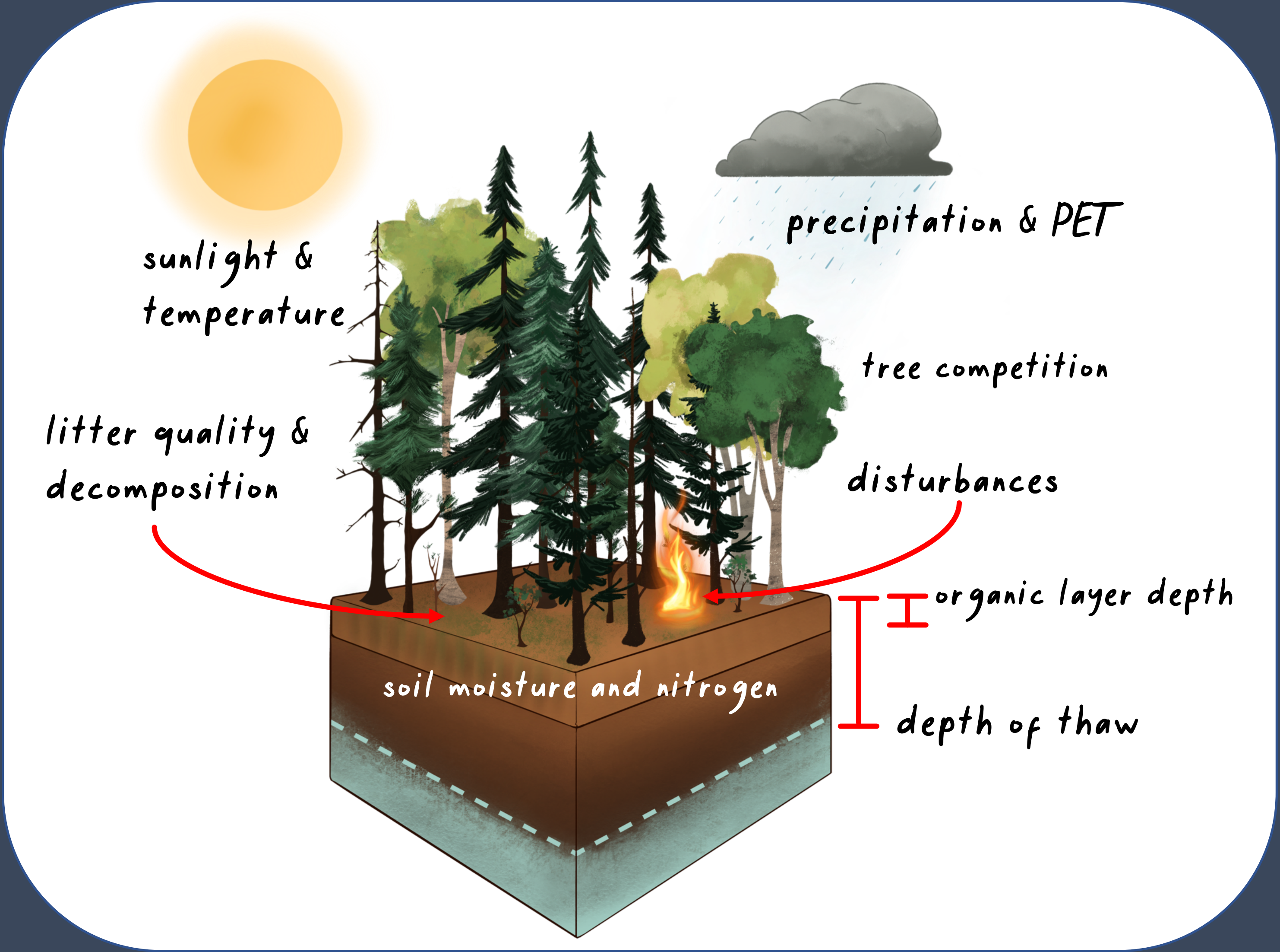

Johnstone et al. 2010

# Wildfire severity impacts post-fire organic layer depth and forest regrowth




Johnstone et al. 2010

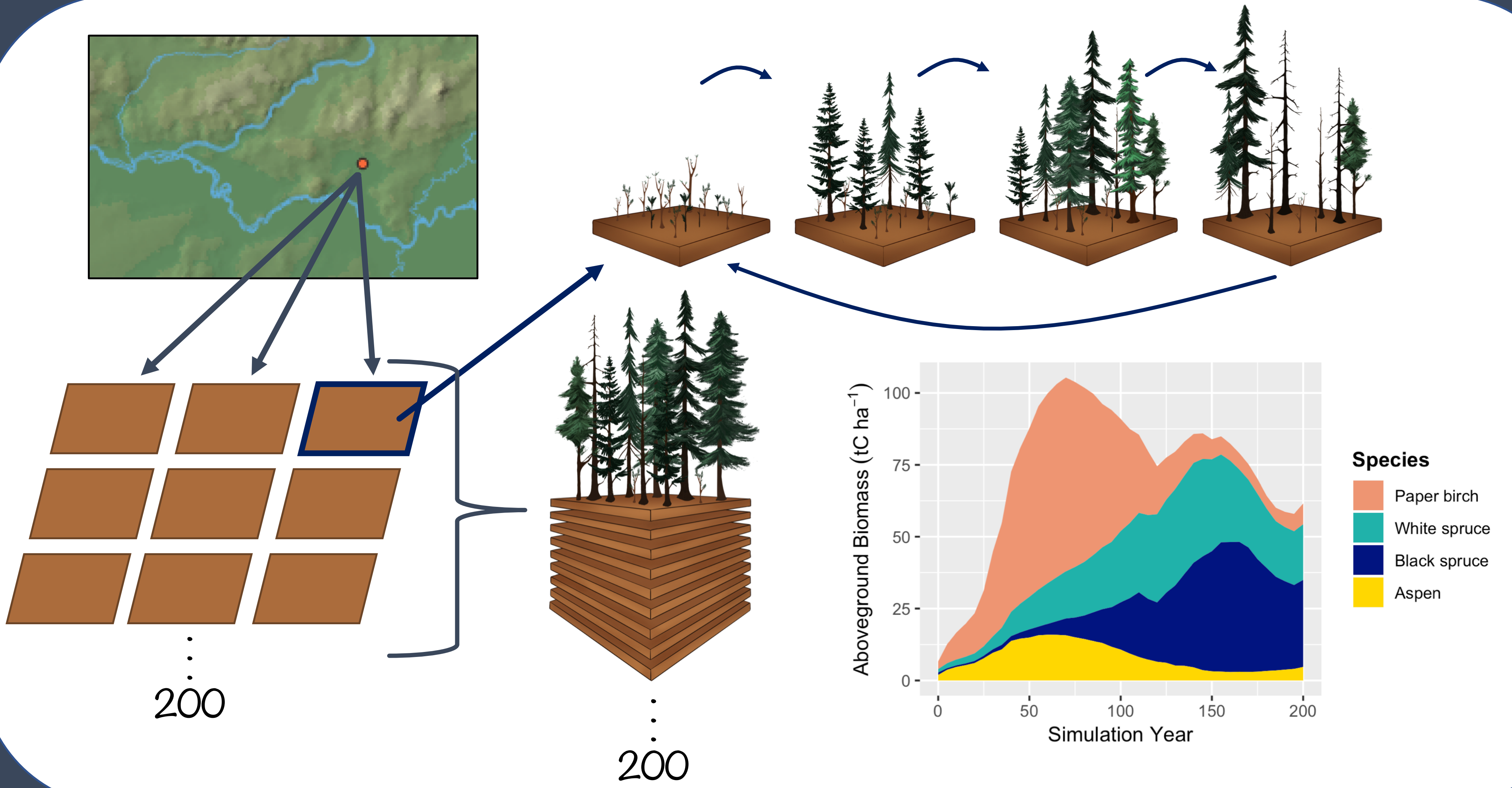
# UVAFME – an individual-based forest gap model



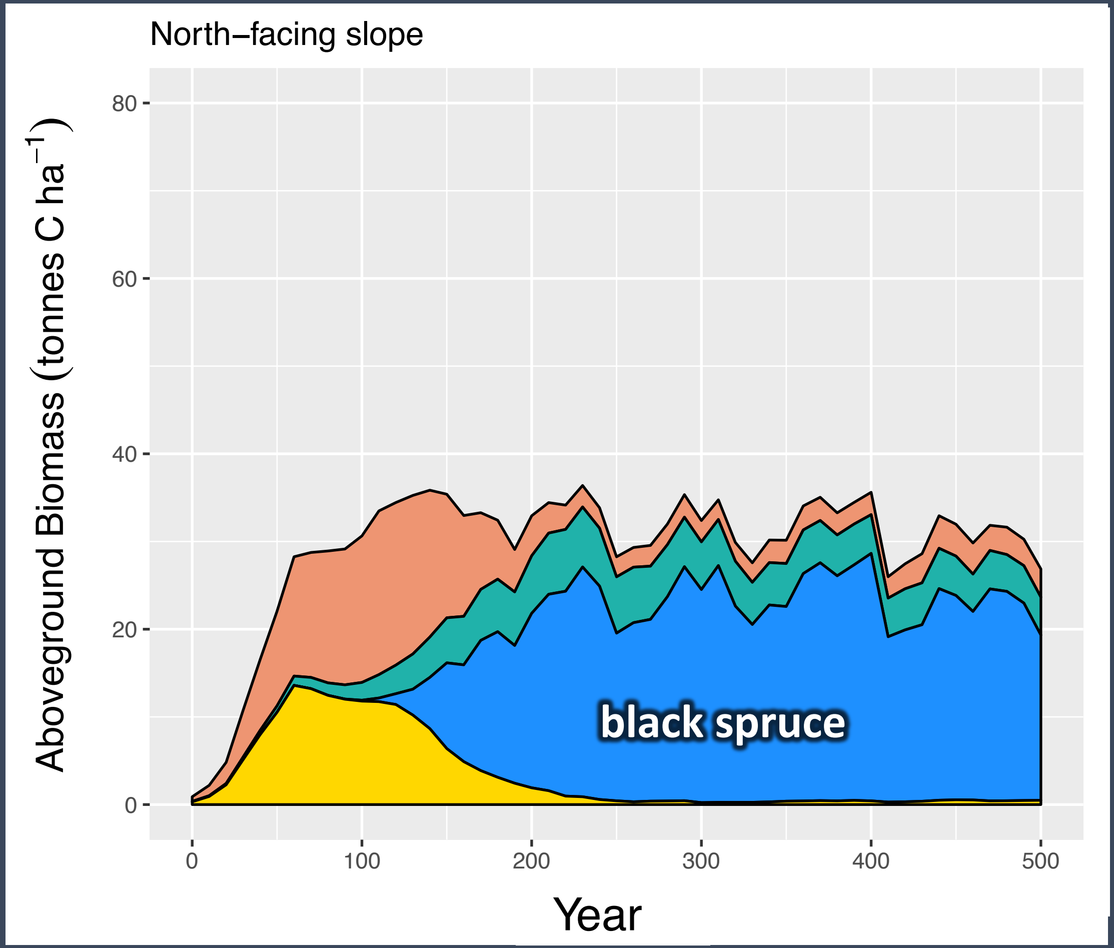

## UVAFME:

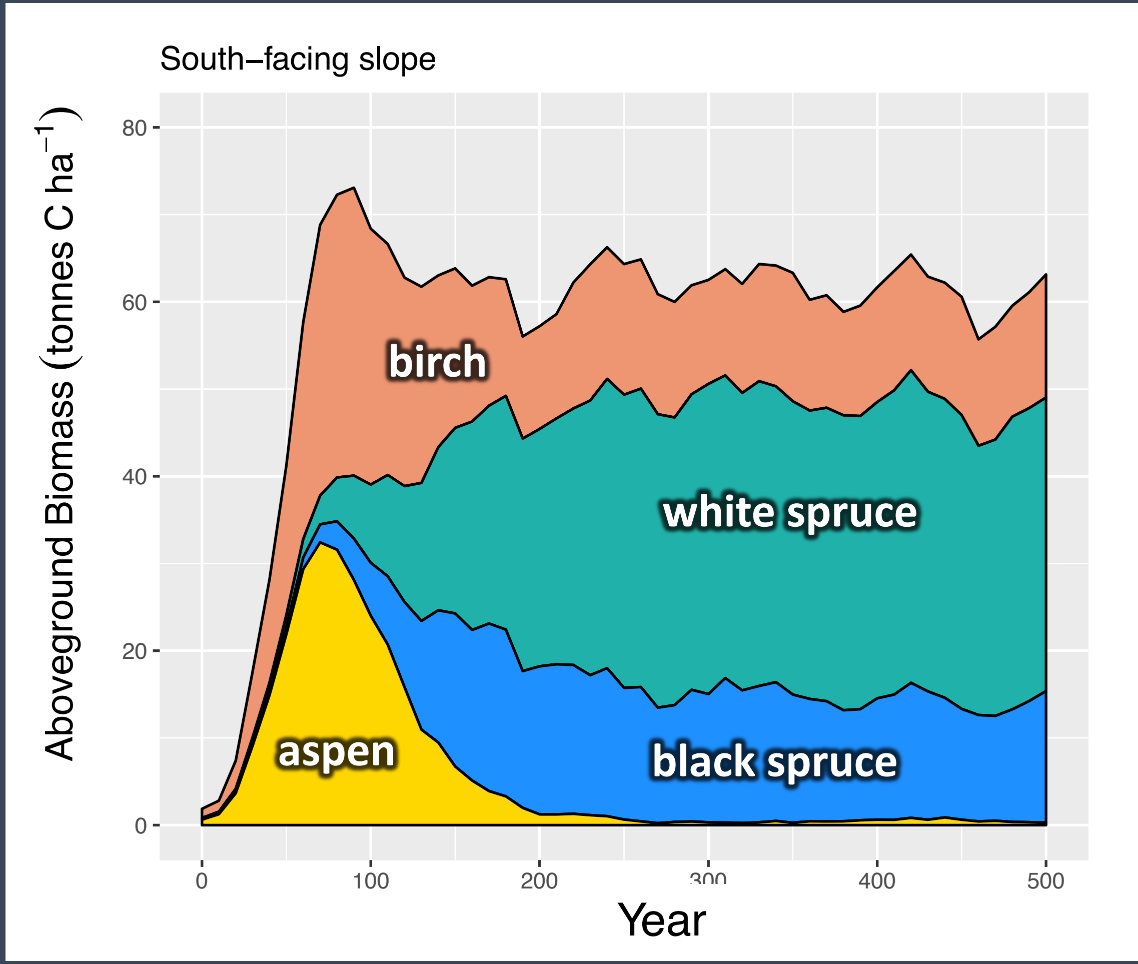
- Individual-tree growth
- Annual diameter increment growth
- Soil dynamics:
  - Moisture, decomposition, permafrost
- Moss and shrub growth

# UVAFME – an individual-based forest gap model

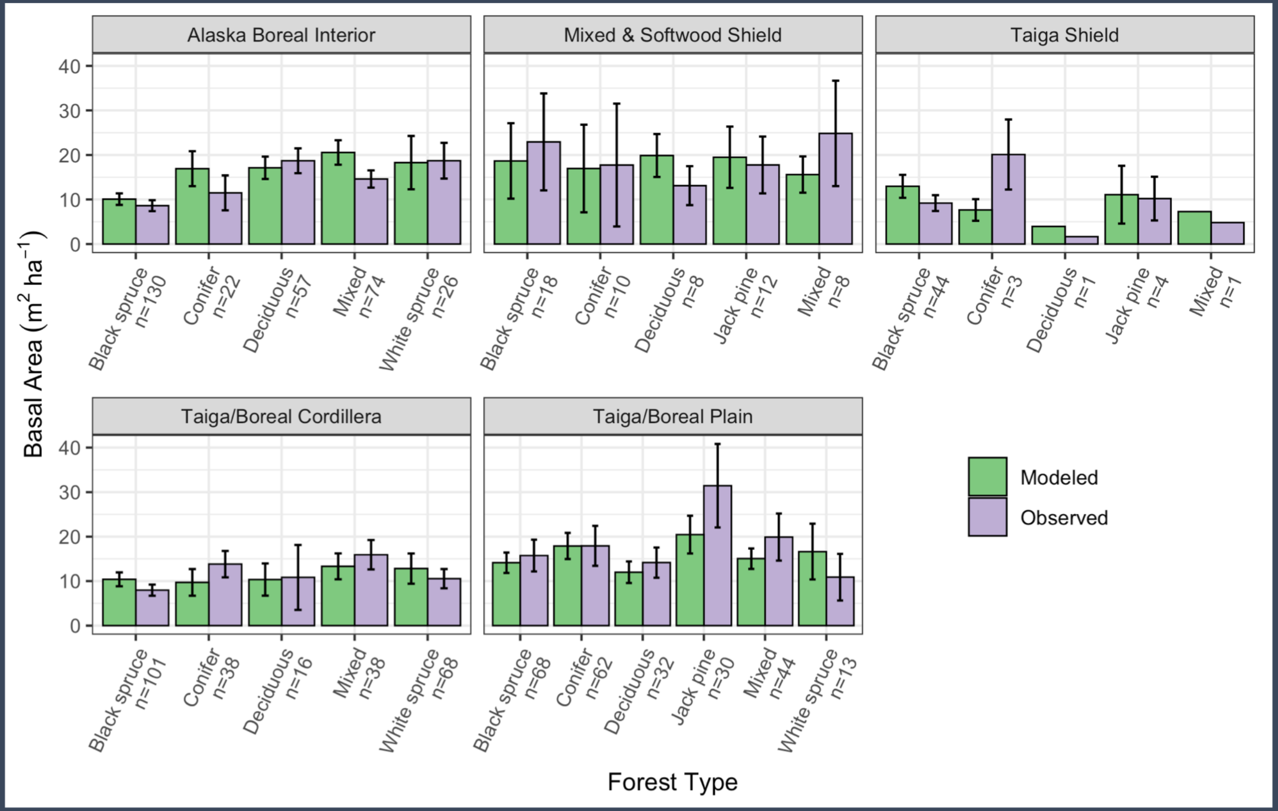


# UVAFME predicts forest dynamics well

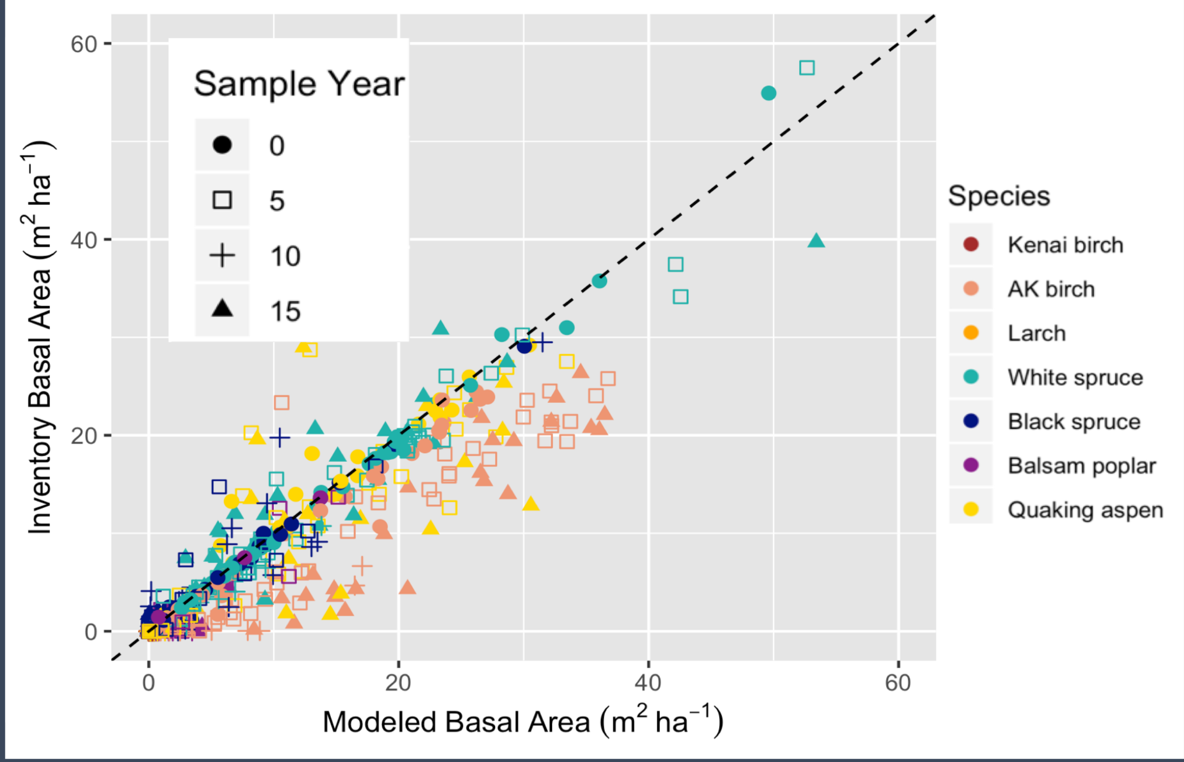


# UVAFME predicts forest characteristics well

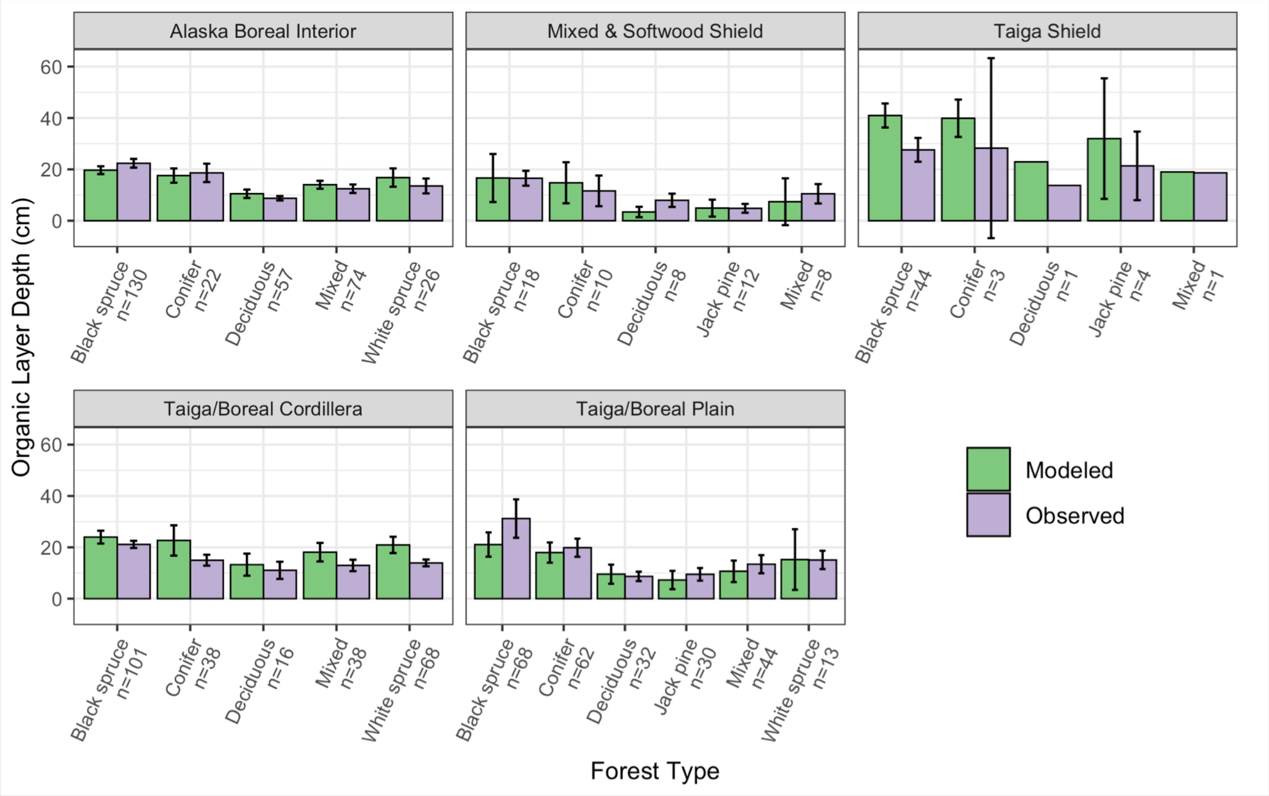


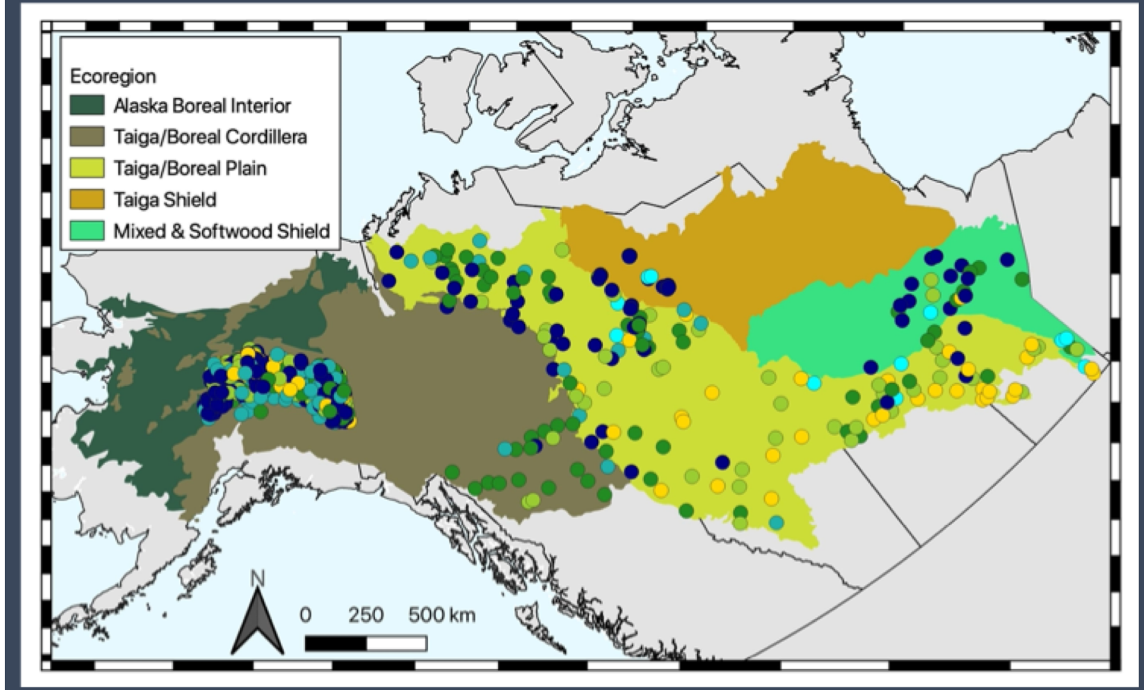

Foster et al. in prep




Foster et al. 2019

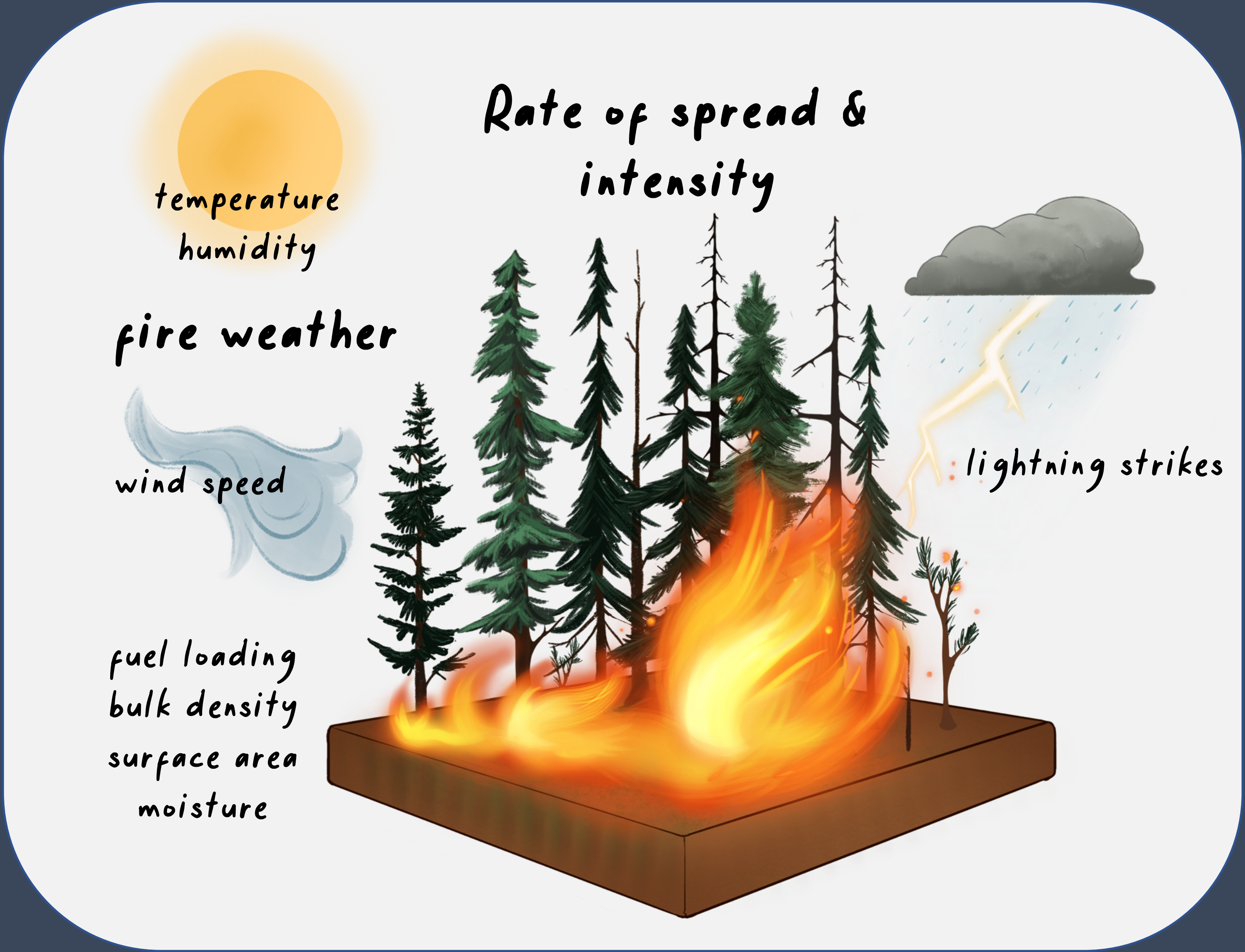
# UVAFME predicts organic layer depth well




Foster et al. in prep

# SPITFIRE in UVAFME

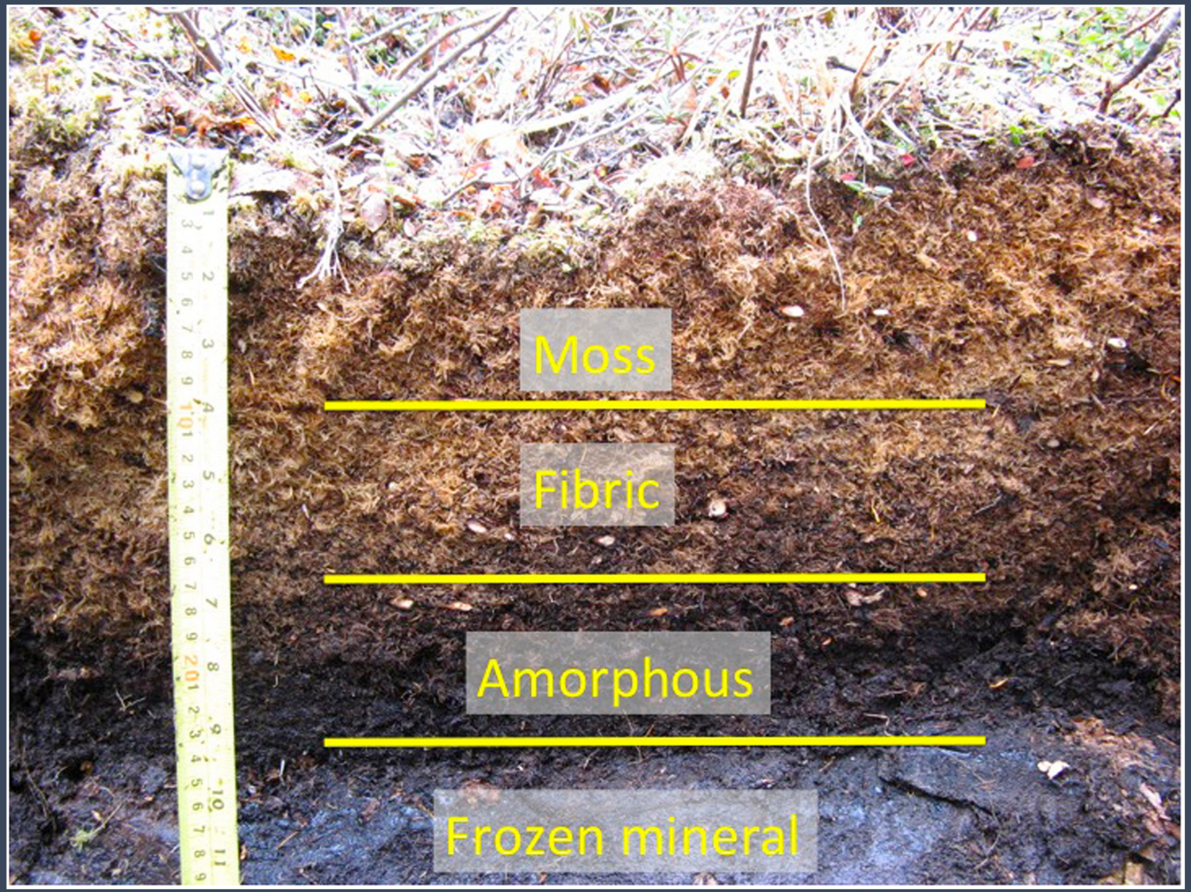



Thonicke et al. 2010
Rothermel et al. 1972
Albini 1976
Van Wagner 1983
Peterson & Ryan 1986
Van Wagner 1972

# SPITFIRE in UVAFME

- Fuel litter added annually to litter pools
  - 1-hour fuels: genus-specific leaf litter, twigs, moss
  - 10-hour fuels: small branches
  - 100-hour fuels: large branches
  - Shrubs & trees < 6 ft (1.83 m) in height

- Dead fuel decays from fresh to fibric to humic
  - Bulk density and SAV change across this time period
  - Simulate this change by scaling BD and SAV by percent remaining of the litter cohort



# SPITFIRE in UVAFME

- Ignition events are probabilistic (not a constant rate)
- Based on mean average lightning strikes and fire danger index

$$p_{ign} = r_{light} \cdot FDI$$

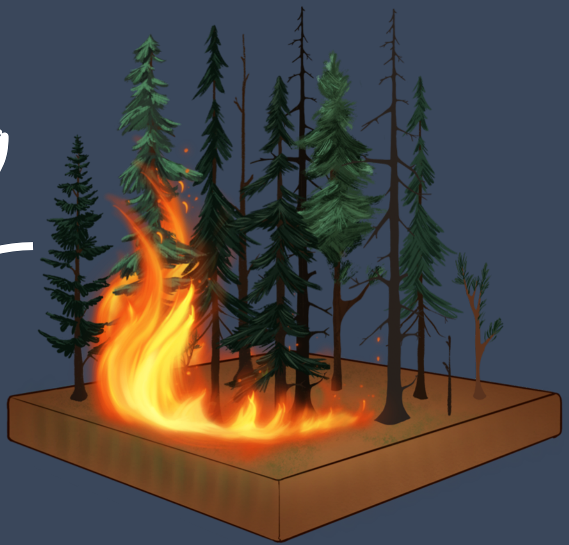
strikes day$^{-1}$

Fire Danger Index

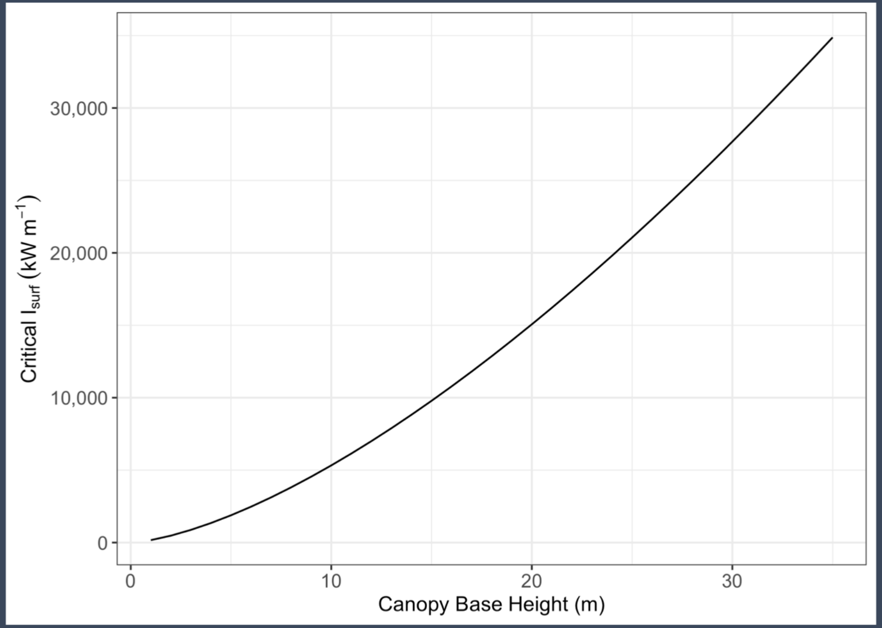
Lightning ignition rates from cloud to ground strike data

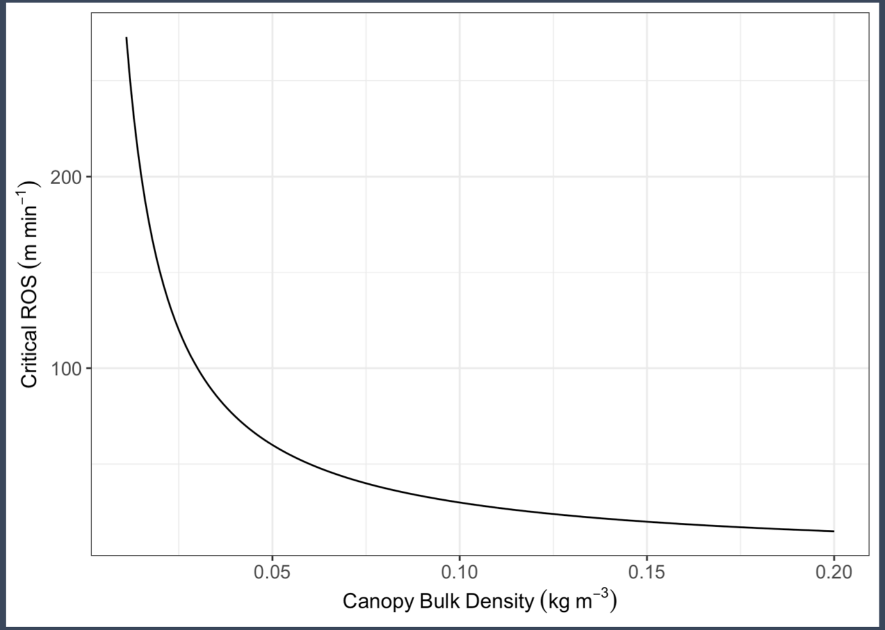
# SPITFIRE in UVAFME

passive torching

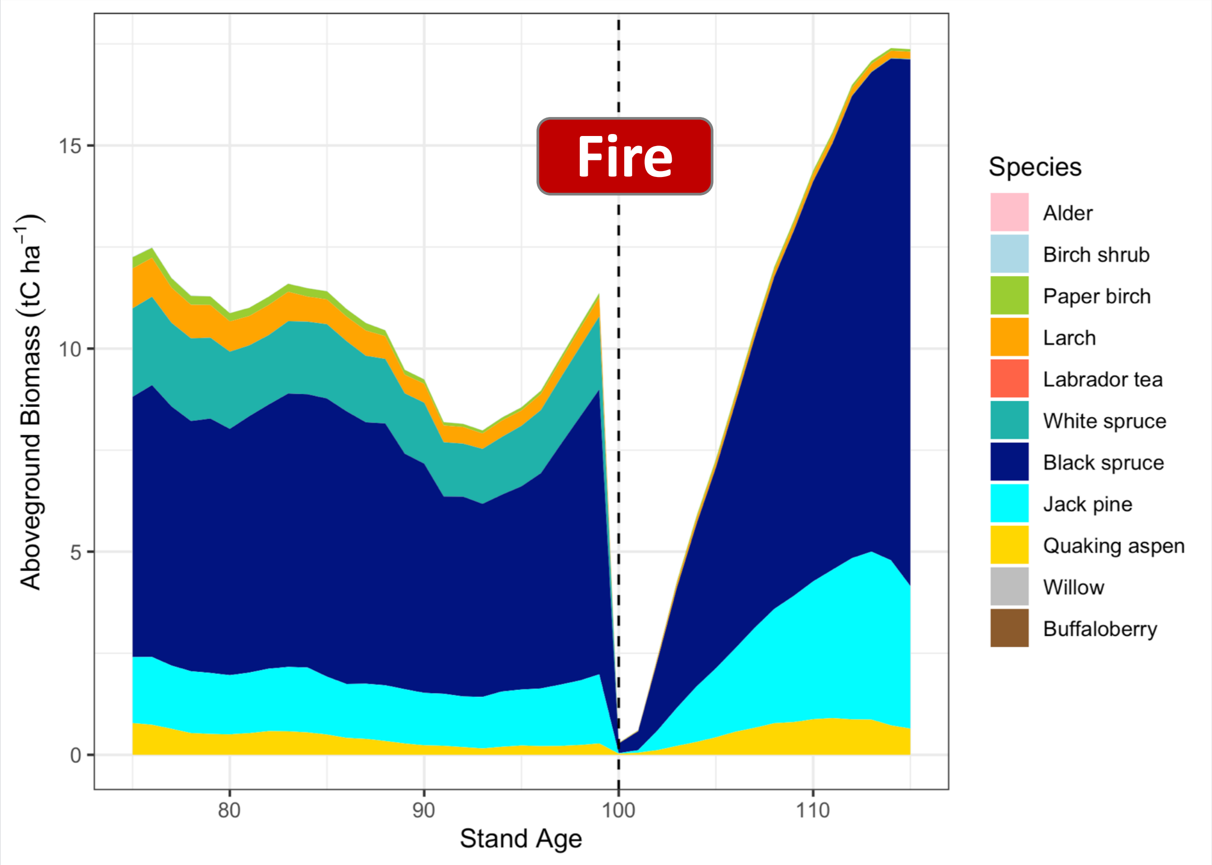


active crown fire



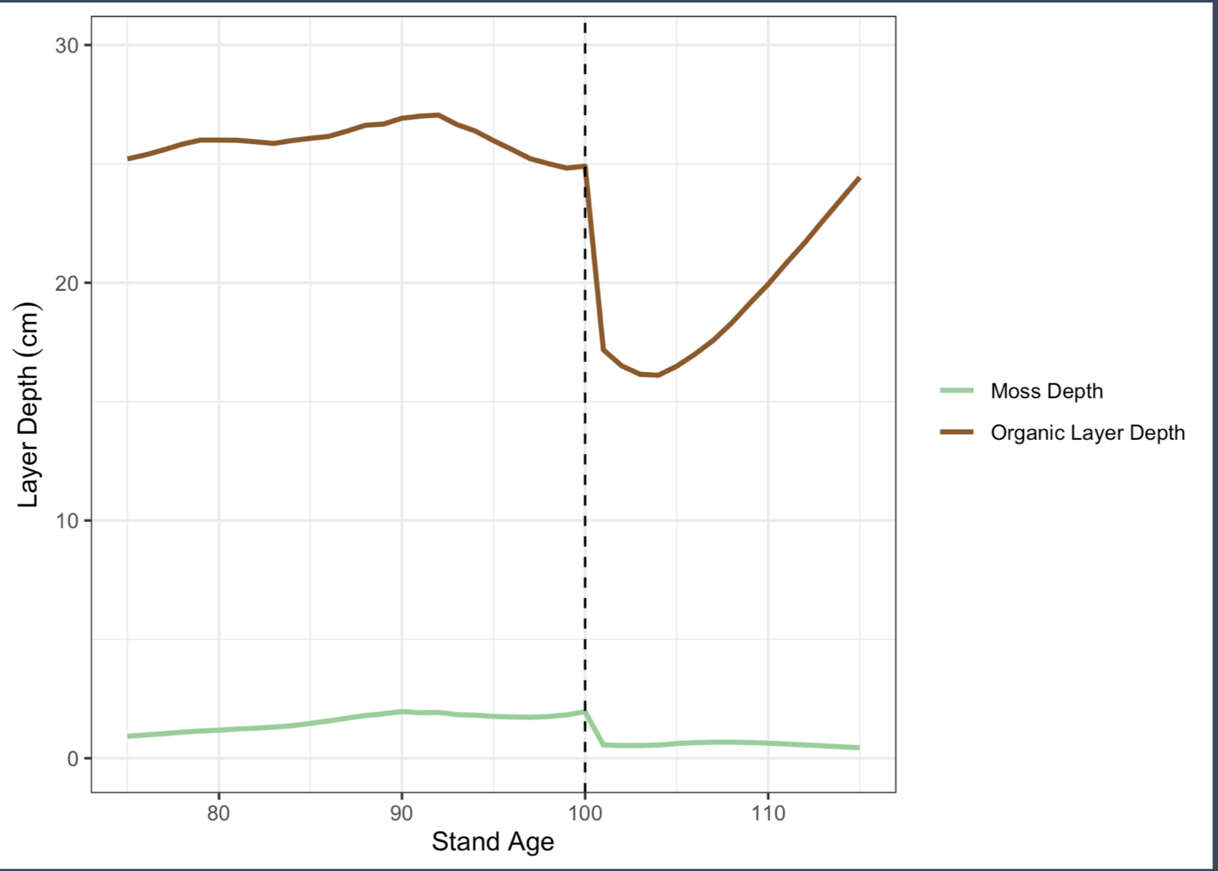



# SPITFIRE in UVAFME




UVAFME-simulated biomass before and following a high-intensity fire ($I_{surf}$ = 4300 kW m$^{-1}$)

## Smoldering combustion of organic layer

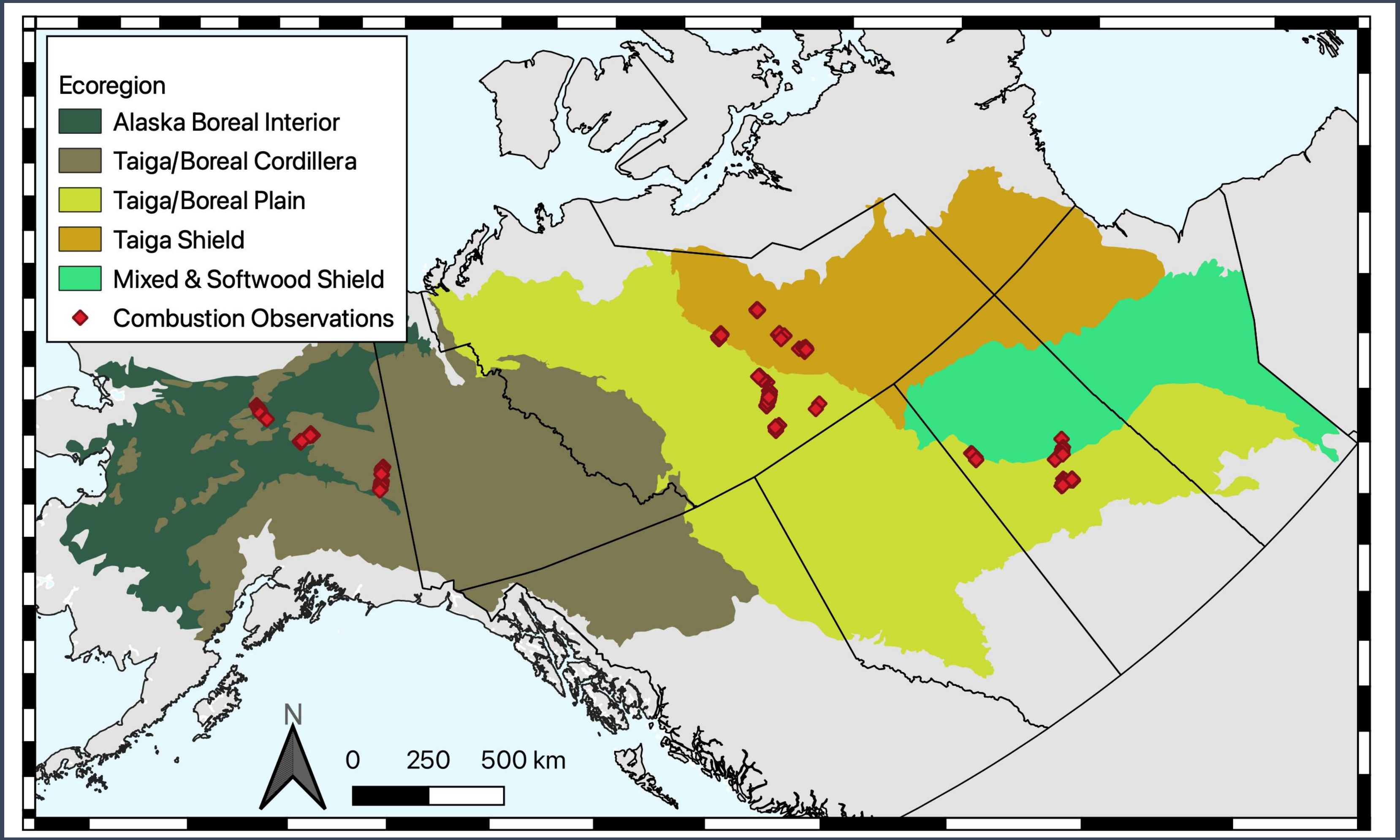


# Comparison to observed combustion data

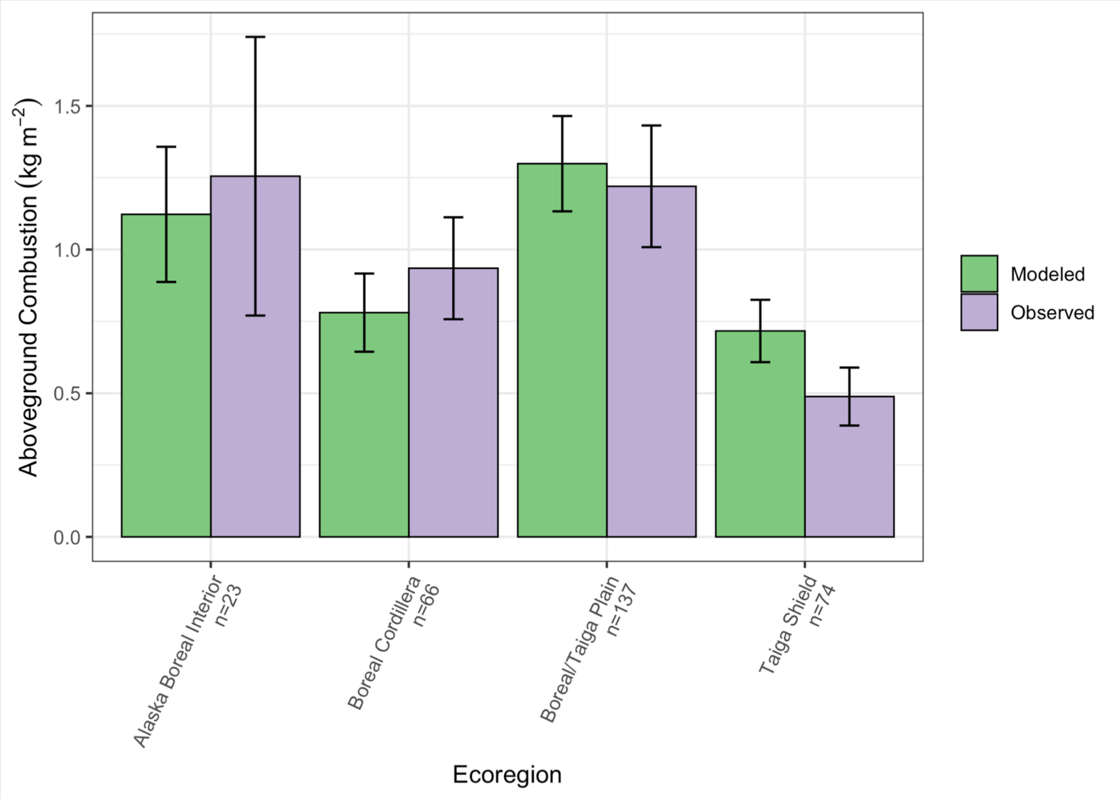
Ignitions set at stand age and day of year from combustion dataset

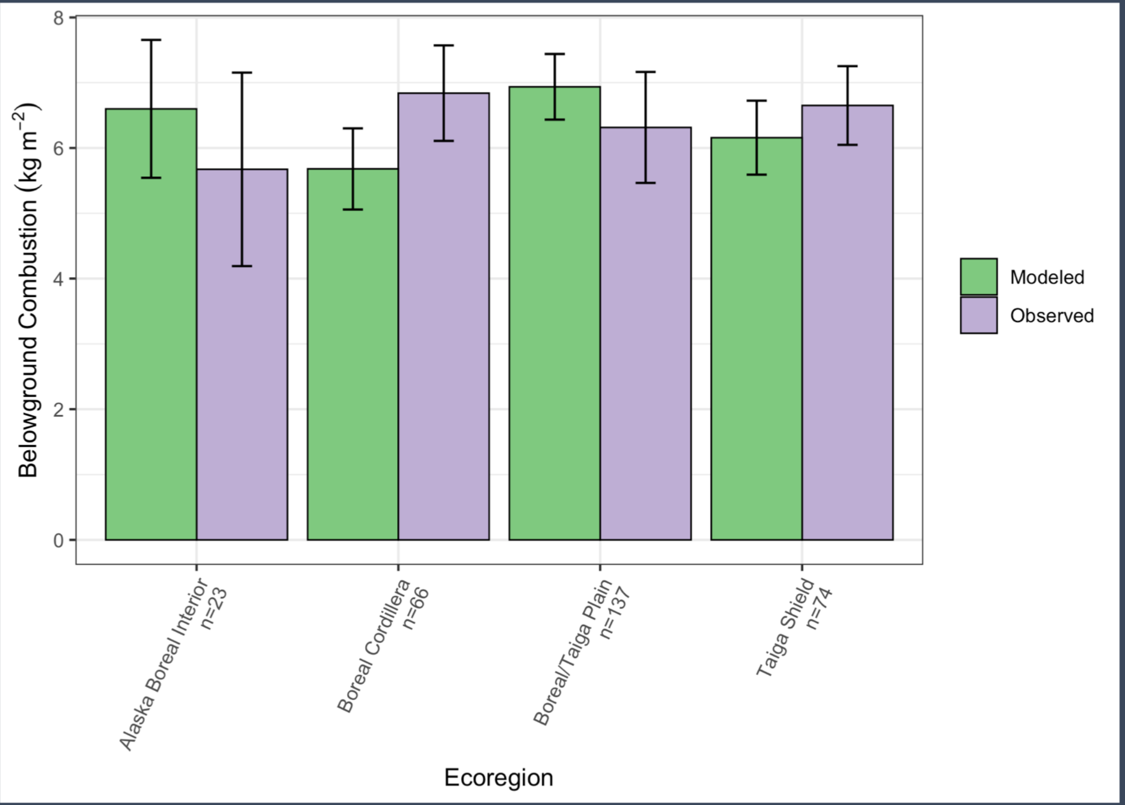
Wind speed & moisture for day of burn forced from observations

Data from Walker et al. (2019)
n = 343



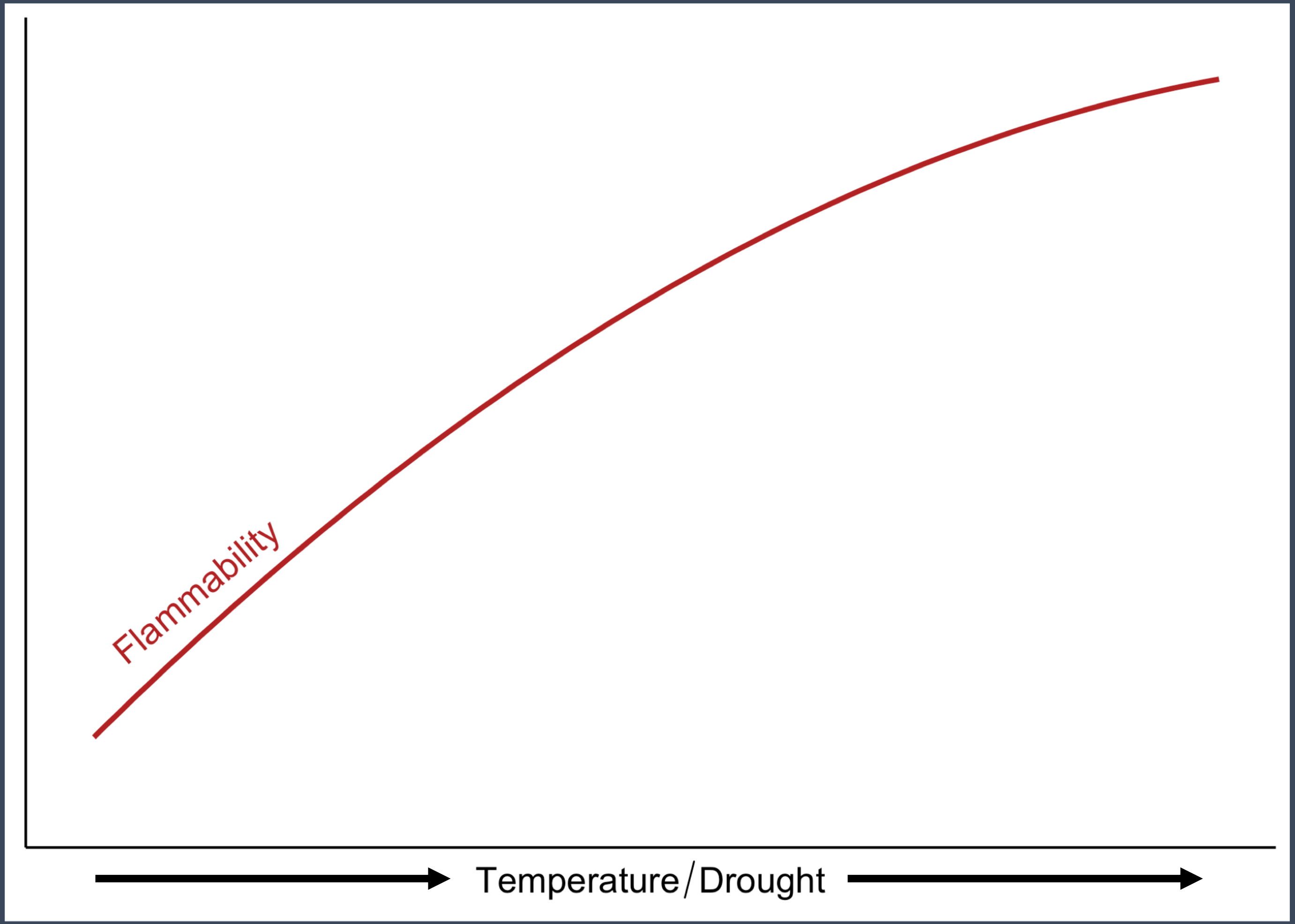
# Fuel combustion compares well with field data



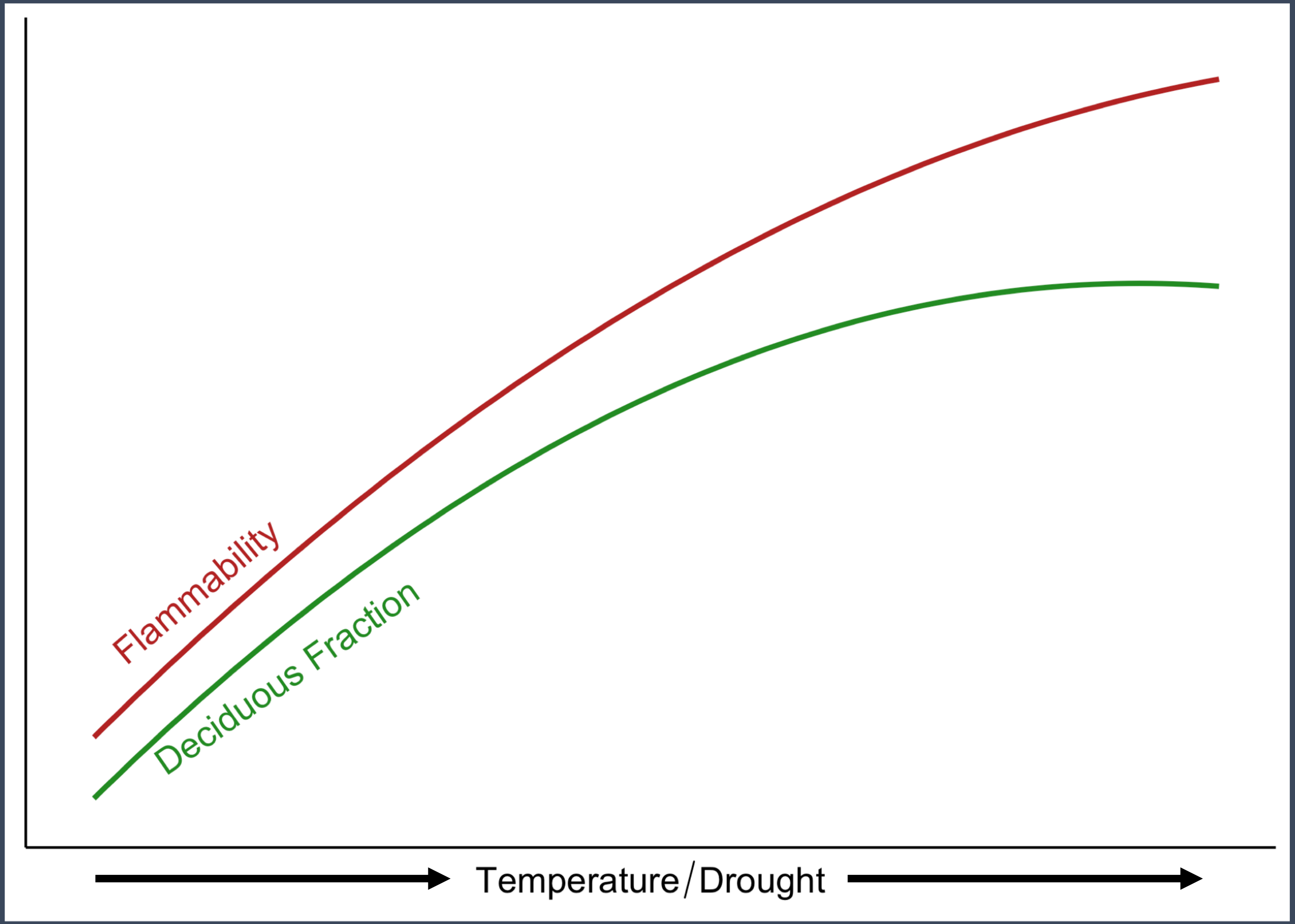




Foster et al. in prep

# We expect increasing fuel drying with climate change



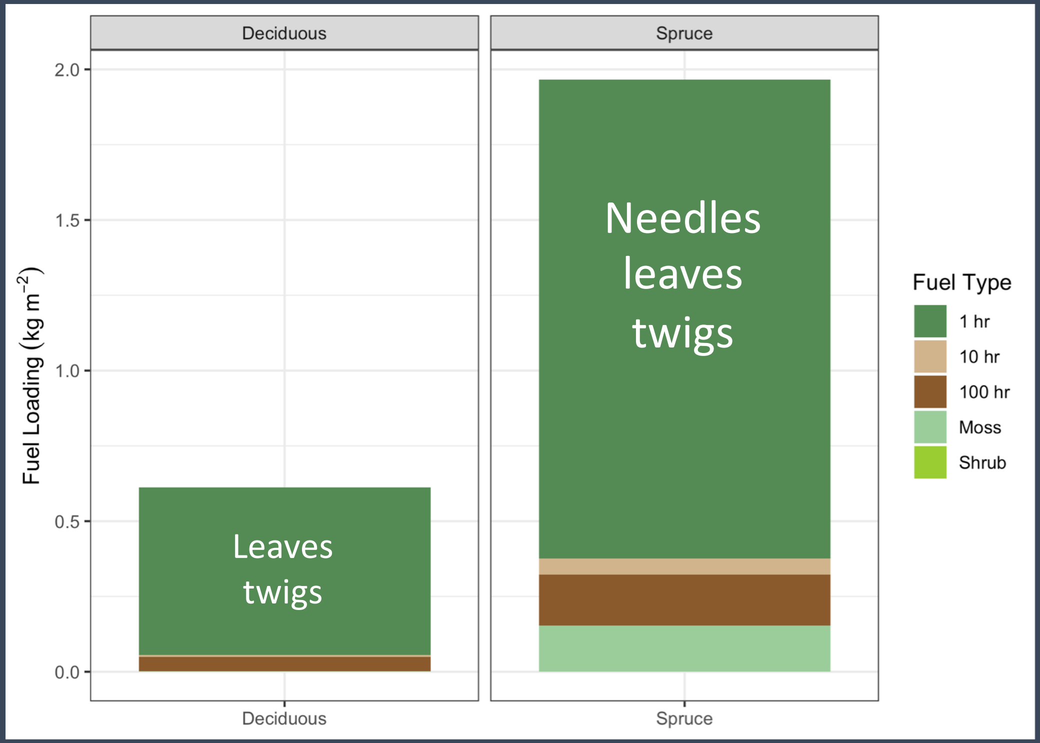
# Models also predict increasing deciduous fraction with climate change

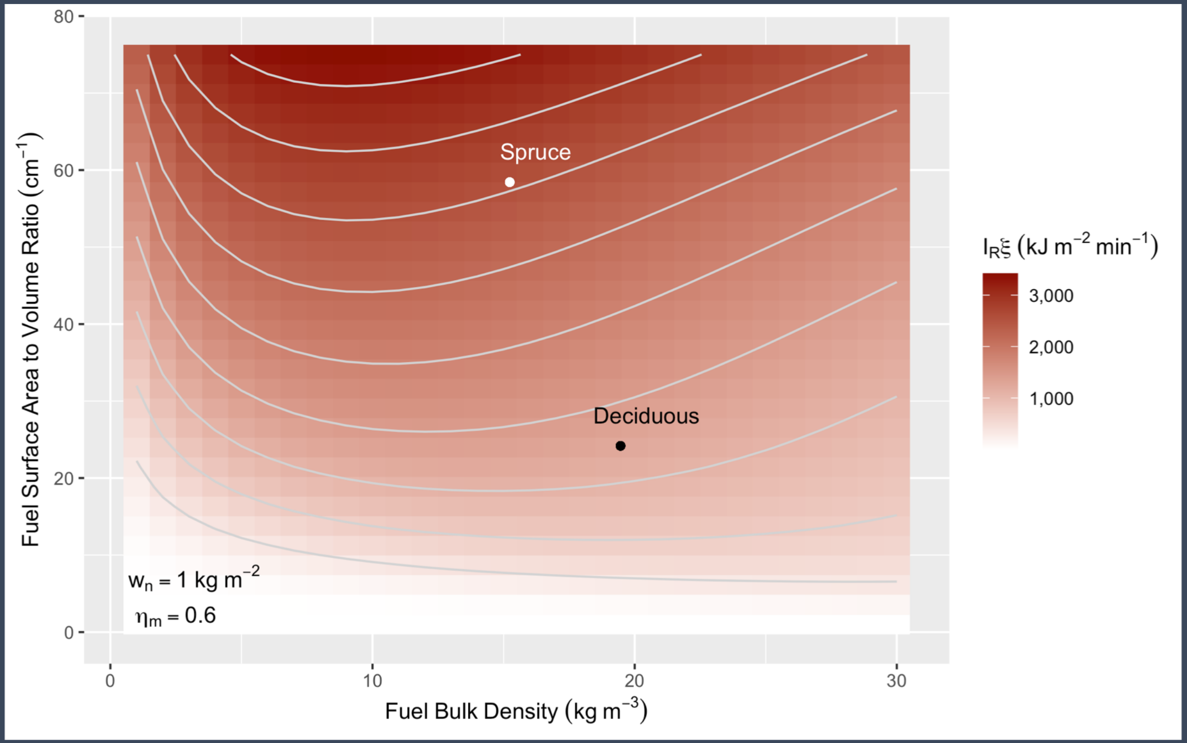


# Deciduous litter is in general less flammable than coniferous litter

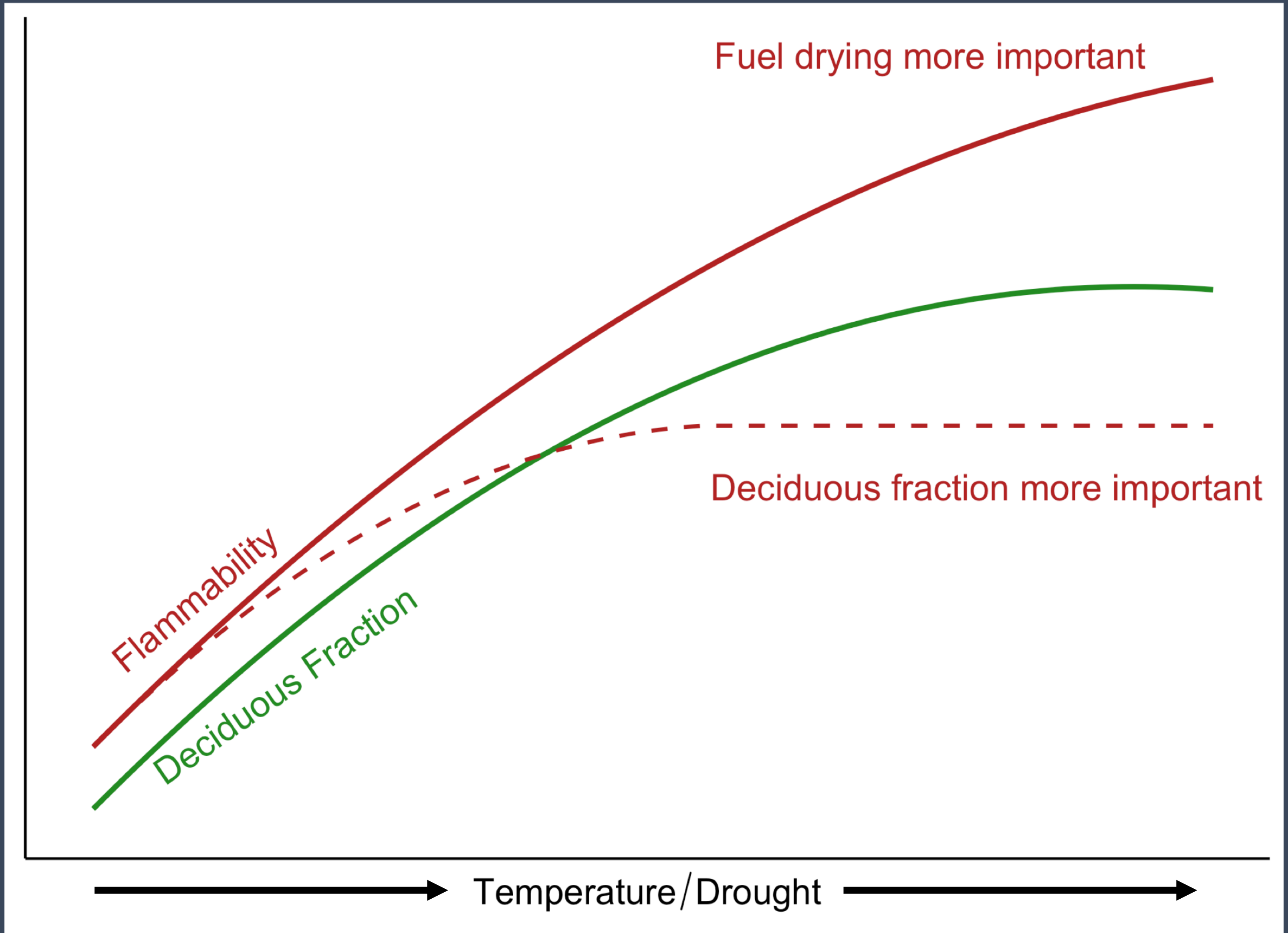
$I_R$: reaction intensity (kJ $m^{-2}$ $min^{-1}$)
$\xi$: propagating flux ratio

energy available to heat unburned fuel



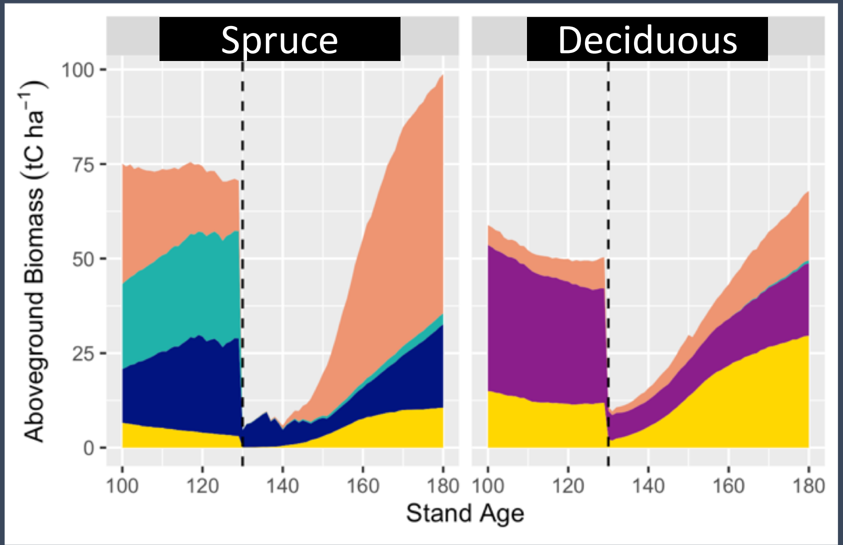
# Climate change may change these legacy effects of fire



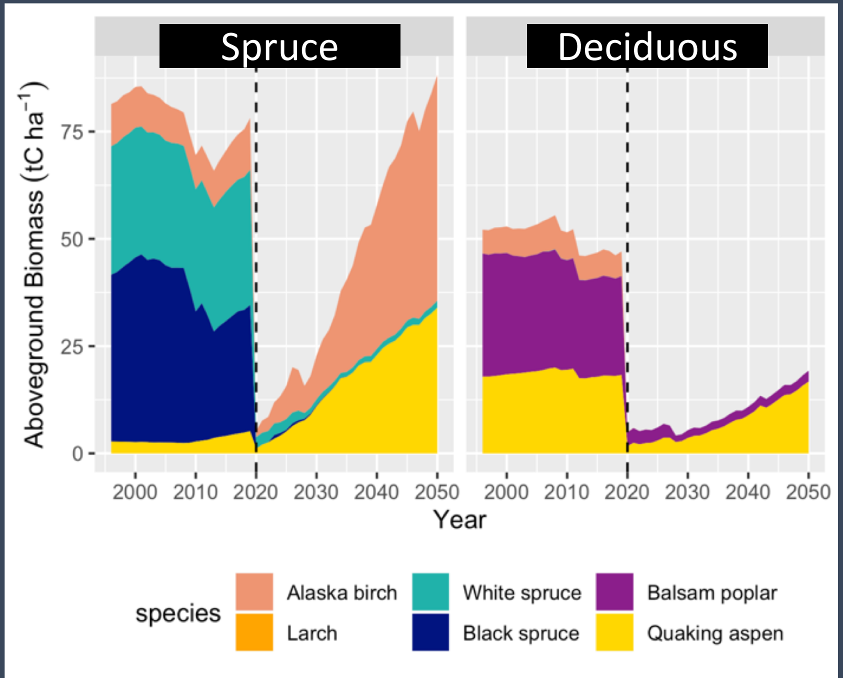
# Climate change simulations with UVAFME


Foster et al. in prep

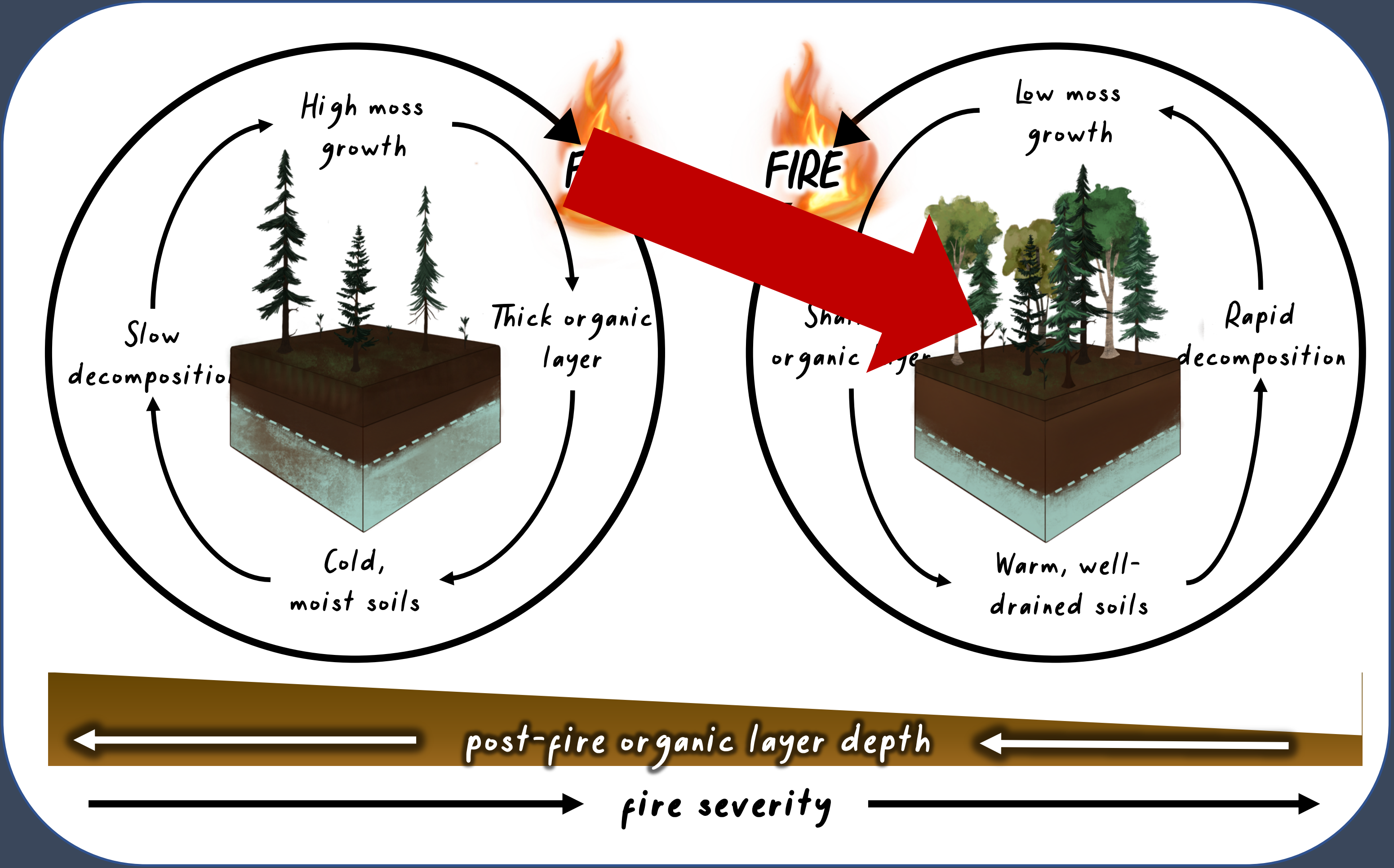
## Historical climate



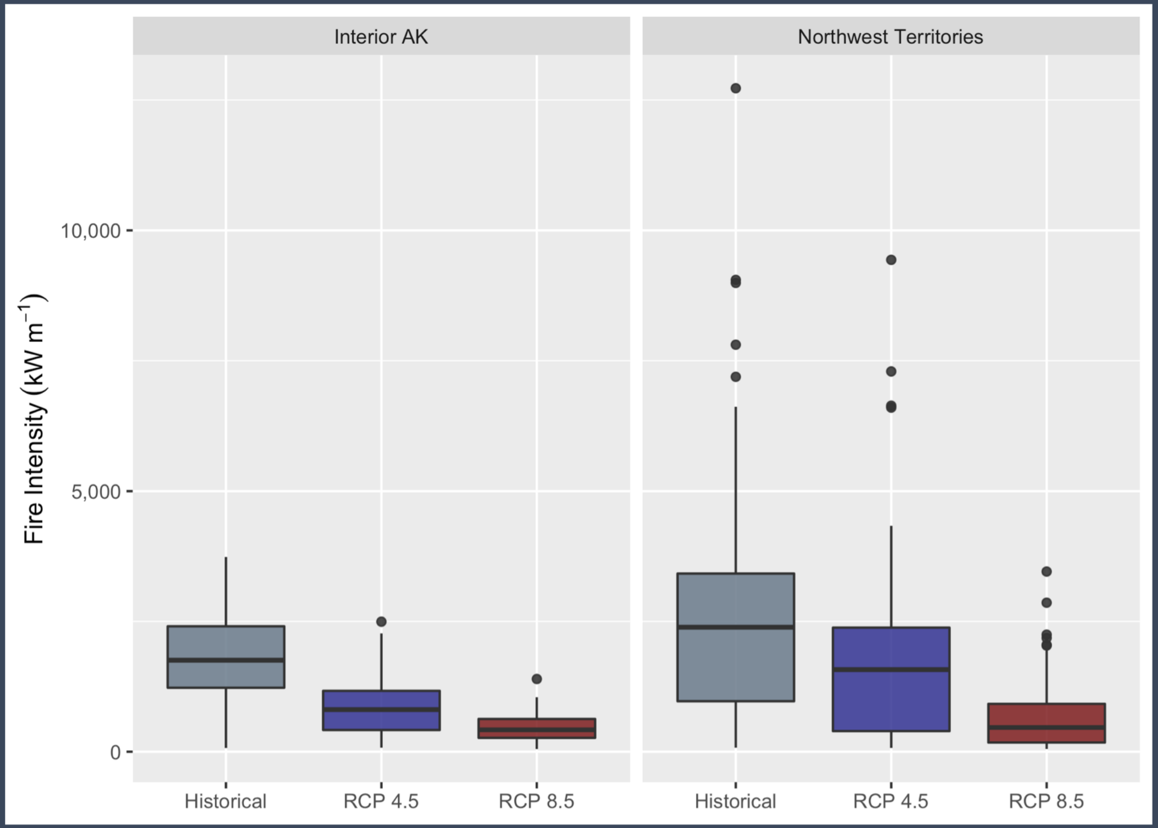

## RCP 8.5

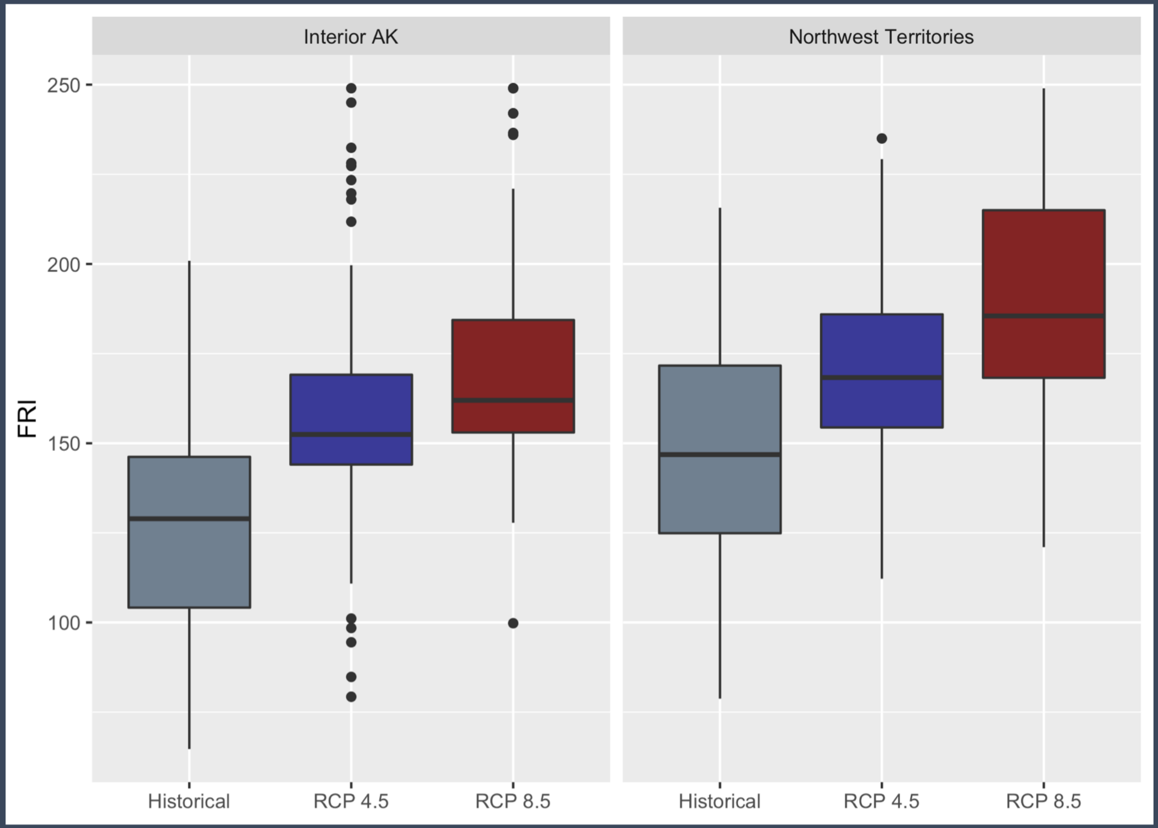



# Change in legacy lock with climate change?



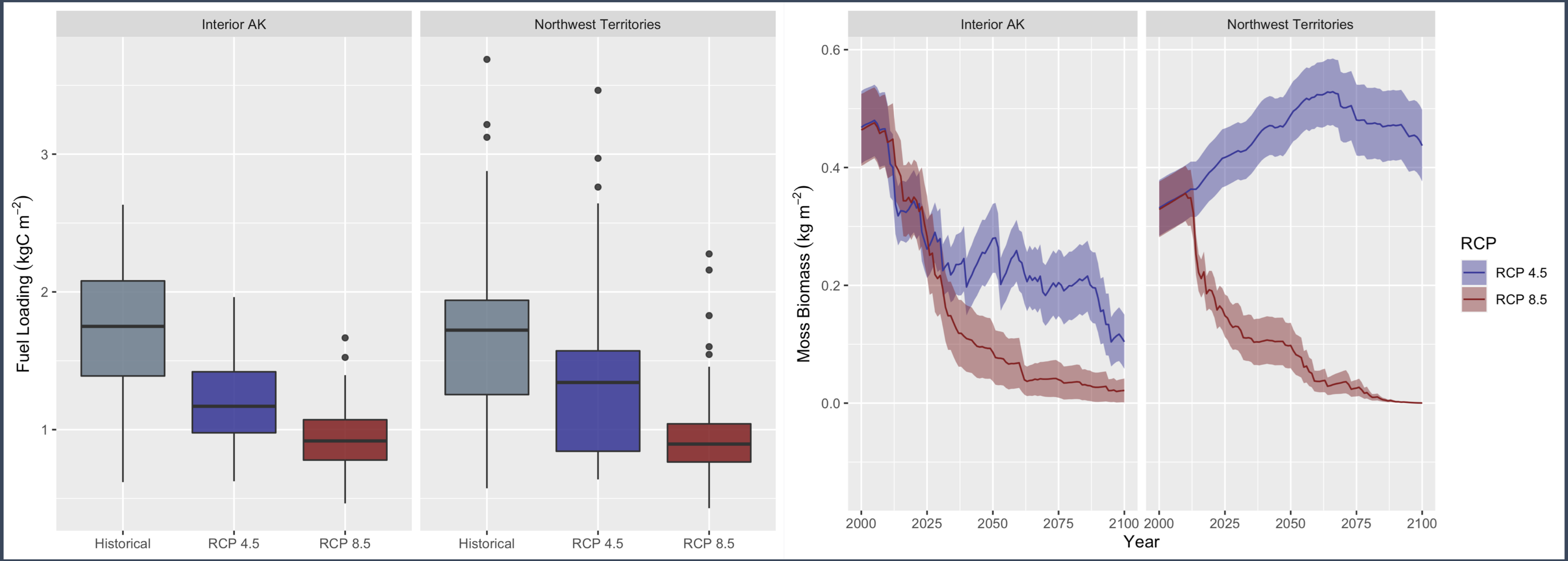
# Fire intensity declines and fire return interval increases with climate change as a result of decreasing fuel loading




Foster et al. in prep

# Change in fuel loading and fuel type (i.e. less moss) drive changes in fire regime in the future

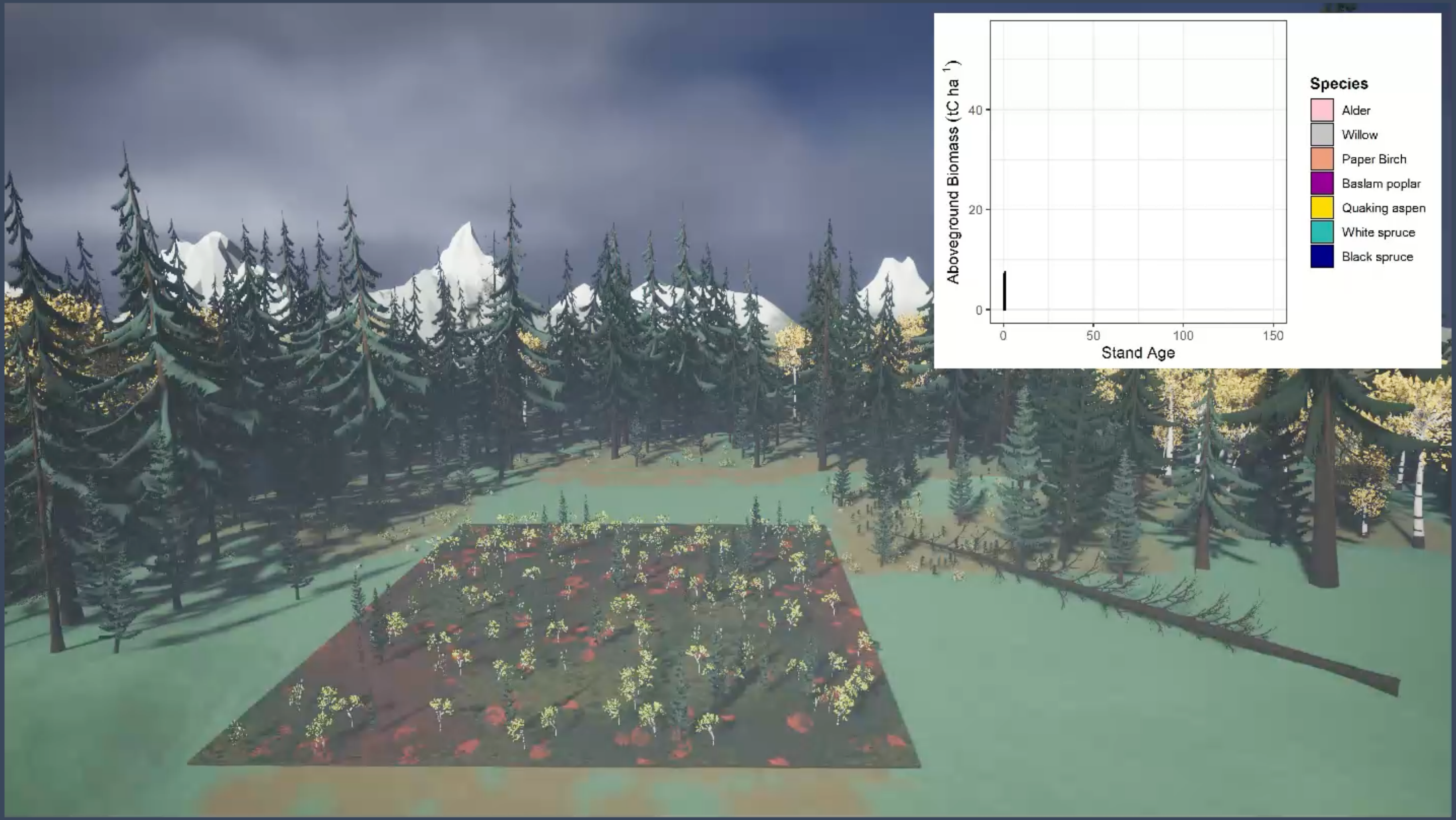



Foster et al. in prep

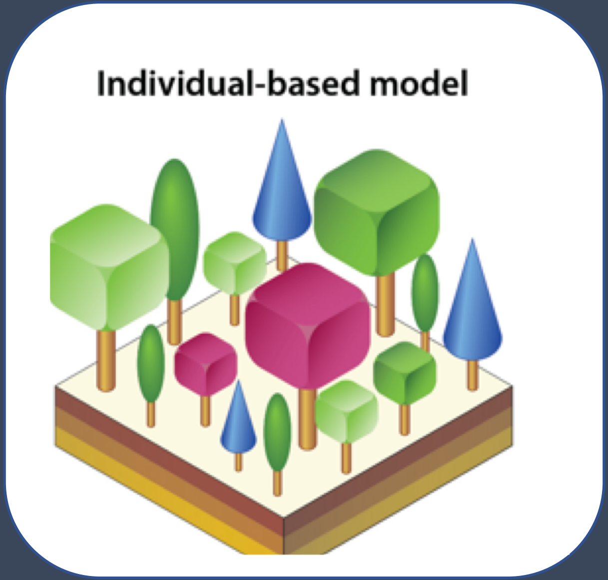
# How can we use this detailed model to inform Earth-system models?

## Shared similarities

Size structure
Process-based fire (SPITFIRE)
Detailed vegetation-ecosystem connections
Dynamic ecosystem assembly
Based on "first principles" of ecology



# UVAFME vs. FATES




## Individual trees

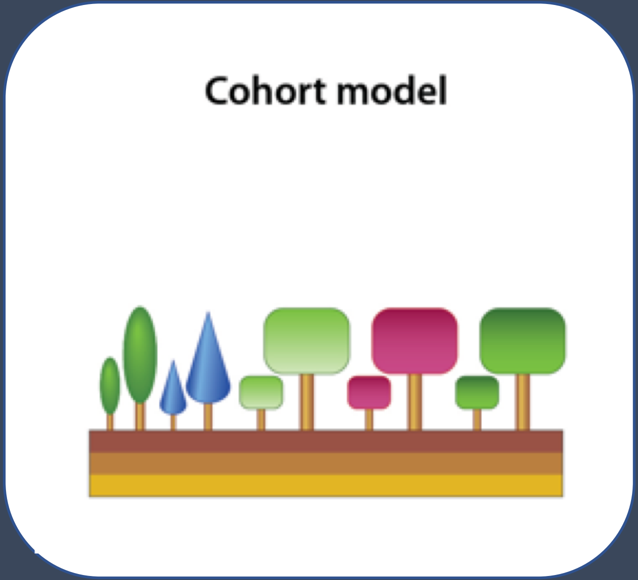
Diameter growth & allometry

Annual growth

“Simple” parameters, fairly few

200 (or user-defined) plots/patches run independently, all from bare ground

Soil dynamics are plot-specific




## Cohorts

Photosynthesis & allometry

Daily, sub-daily growth/allocation

More complex parameters

Patch creation & aggregation dynamics

Shared soil column

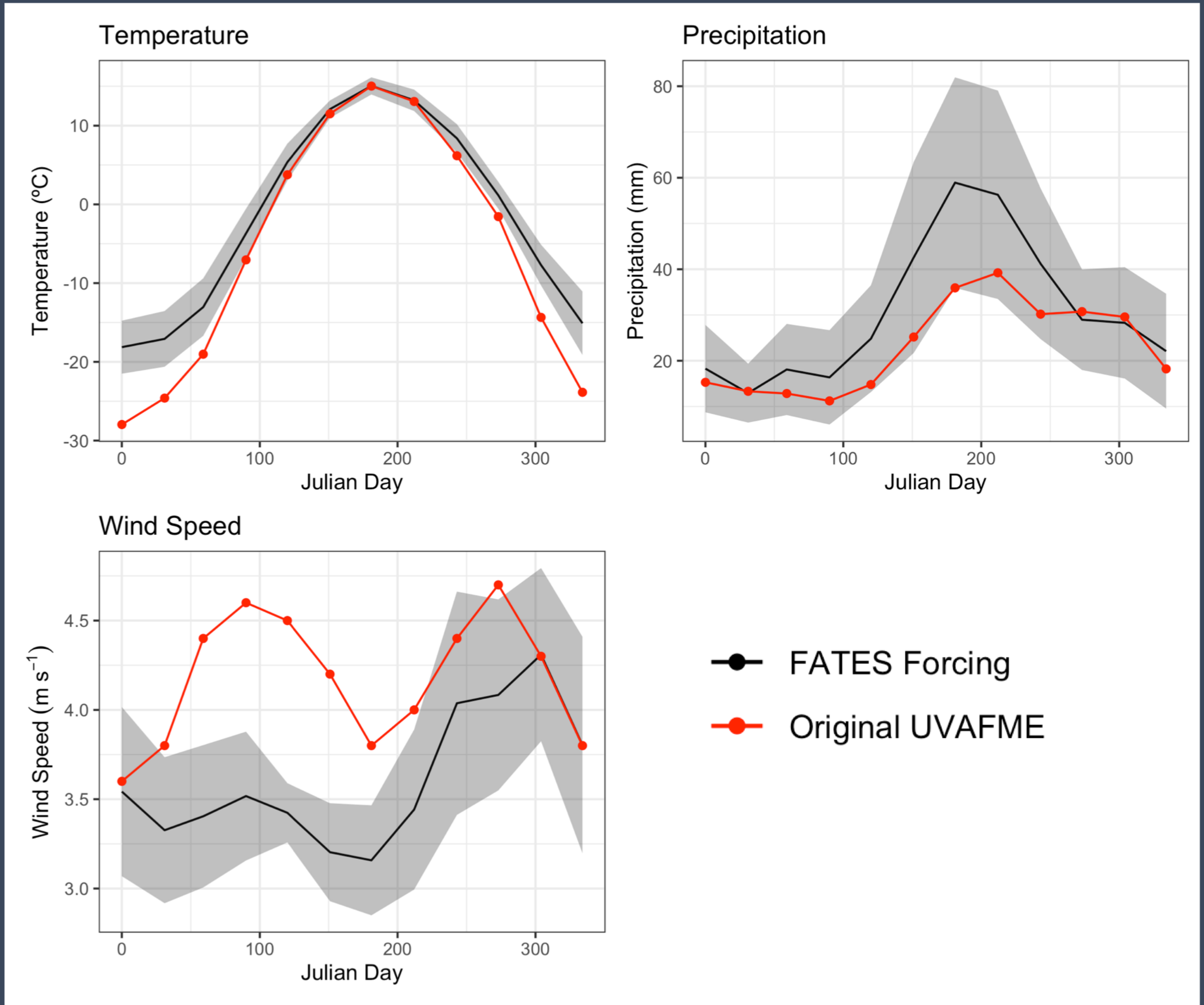
Fisher et al. 2017

# Force UVAFME with FATES environmental conditions

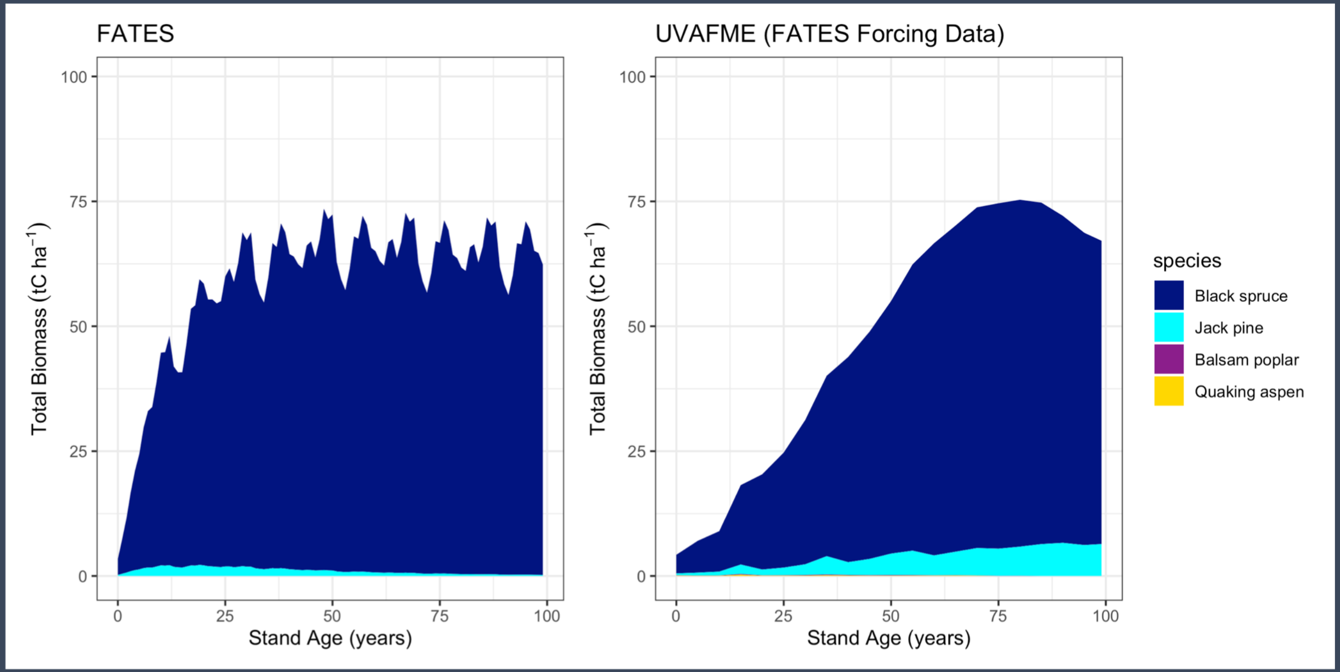
Difference between models will be a result of processes and interactions

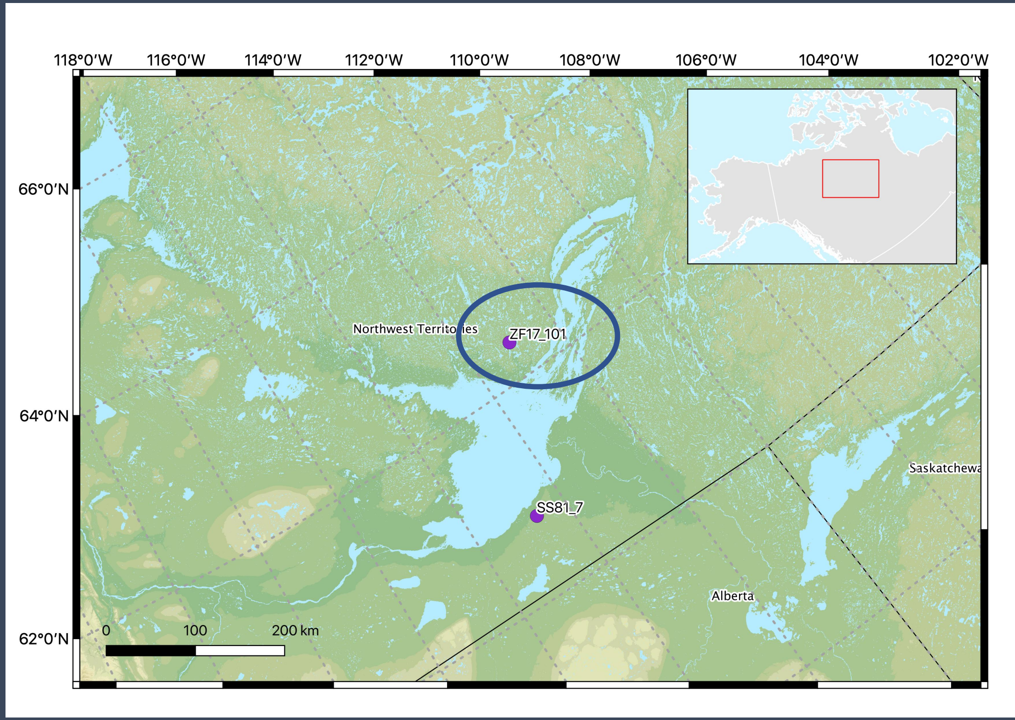
**Forcing:**

- temperature
- precipitation
- active layer thickness
- soil moisture (ice & liquid)
- solar radiation
- wind speed
- relative humidity



# What can we learn from combining FATES and UVAFME simulations?



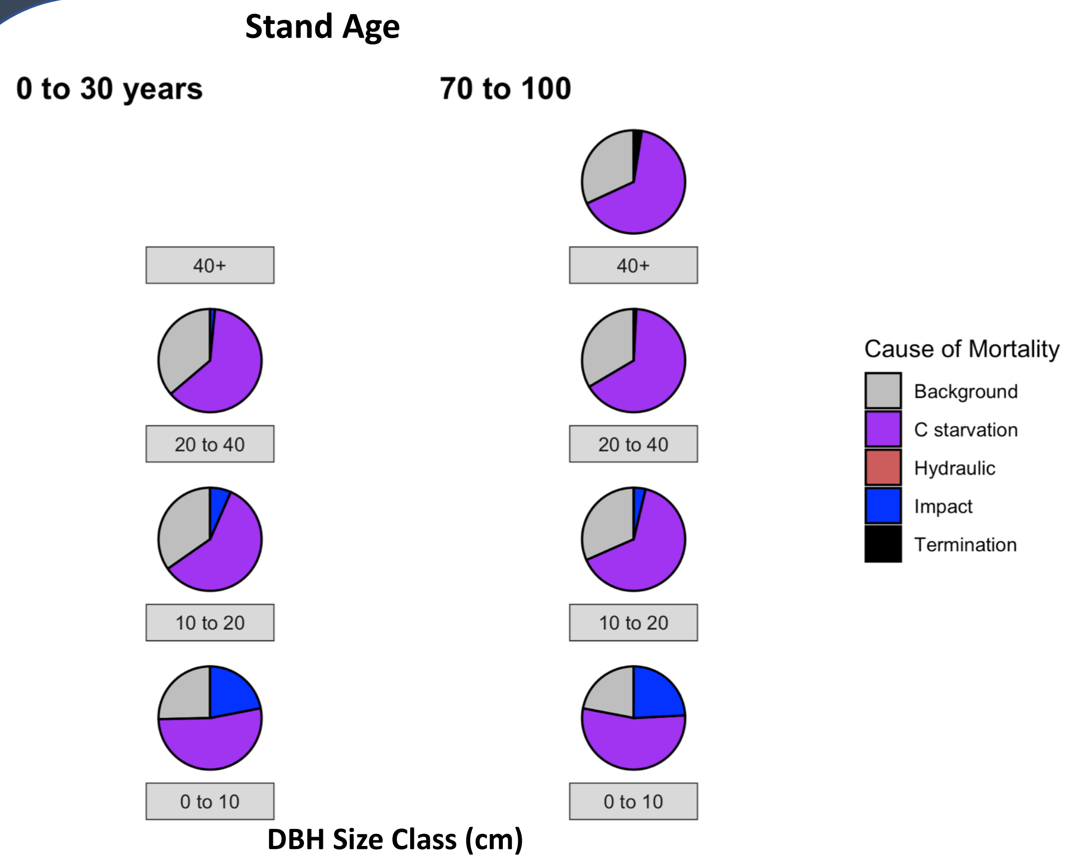




**FATES forcing:**
NASA GLDAS 25km (2000-2018)
FATES - Soil carbon spin up then log stand

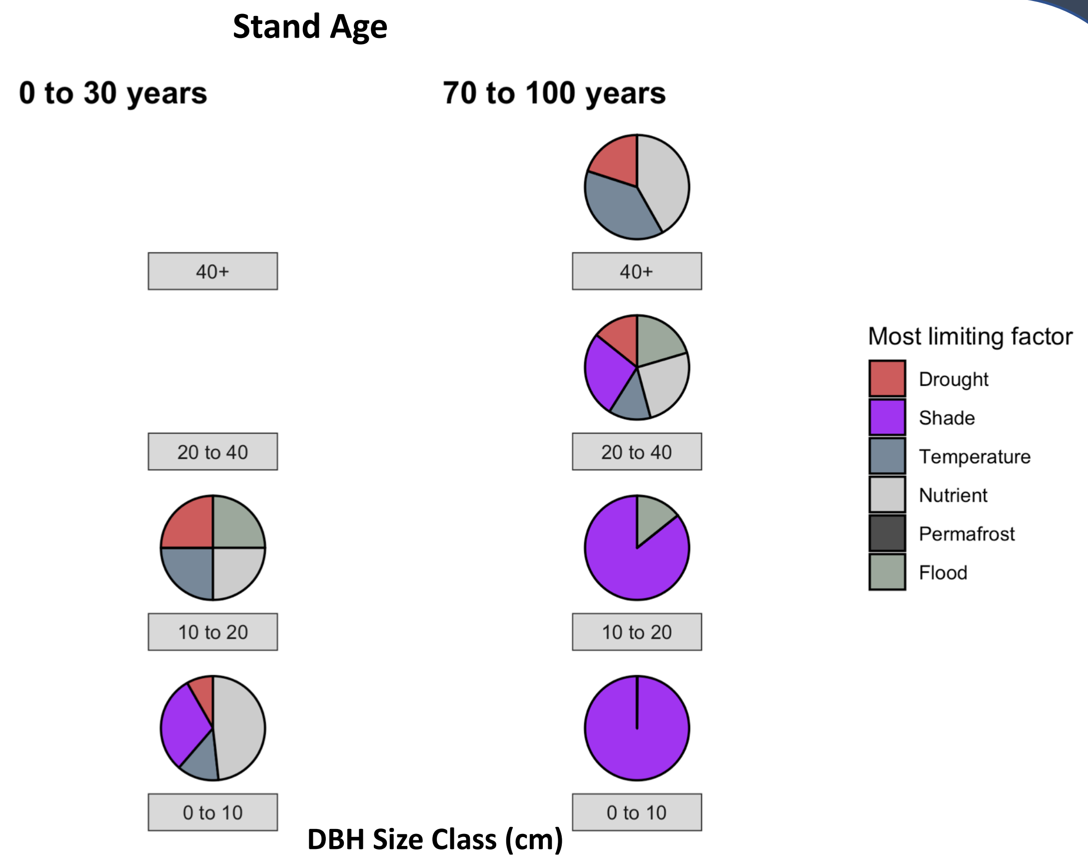
**Nutrients:**
FATES – carbon only
UVAFME – carbon & nitrogen

# Difference in what limits growth with stand age and tree/cohort height

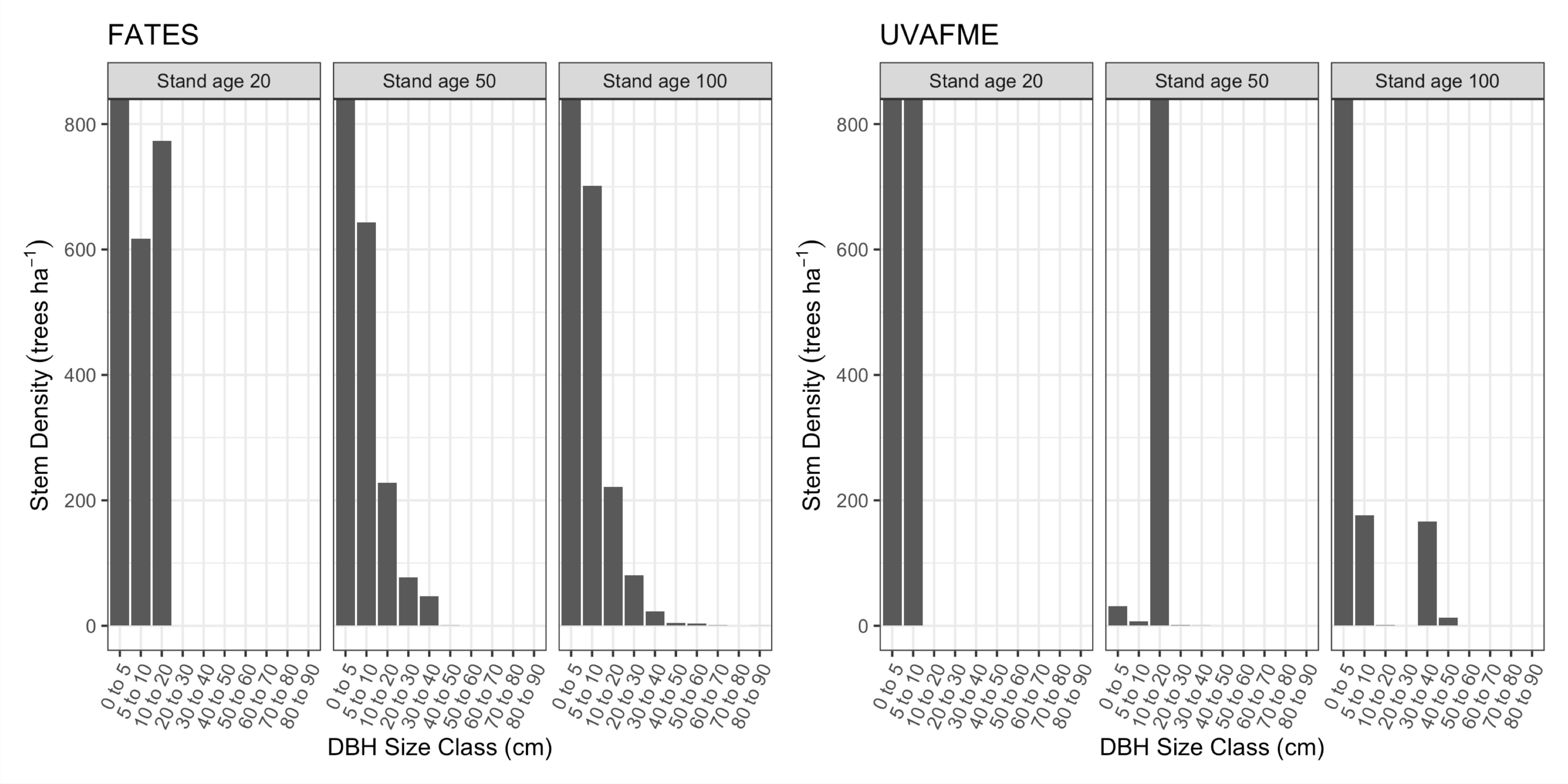
## FATES – mortality rates




## UVAFME - stochastic mortality



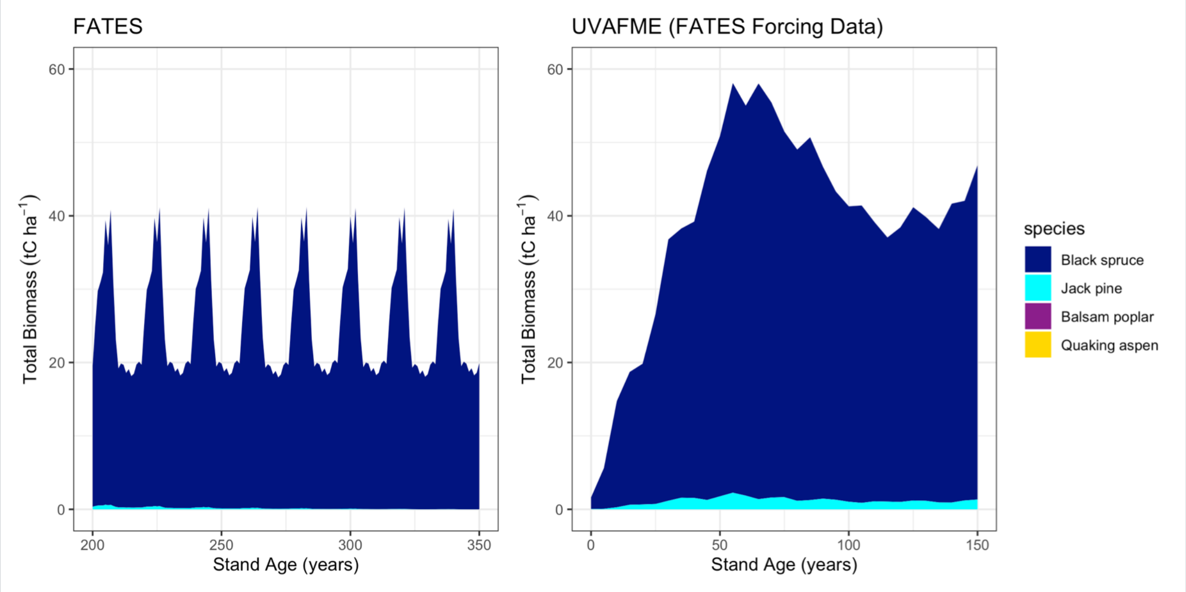
# Size structure depicts two different landscapes

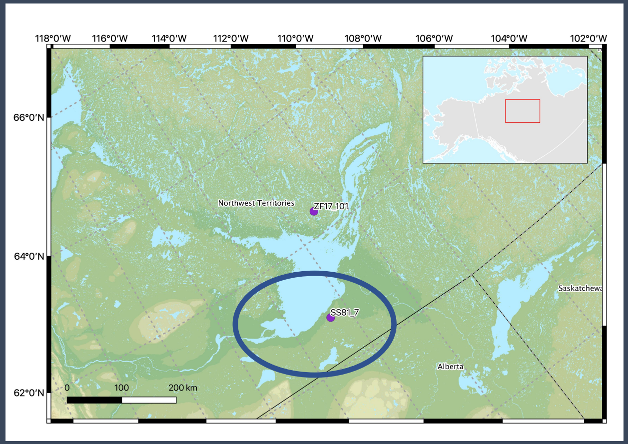



*Note different stem density scales

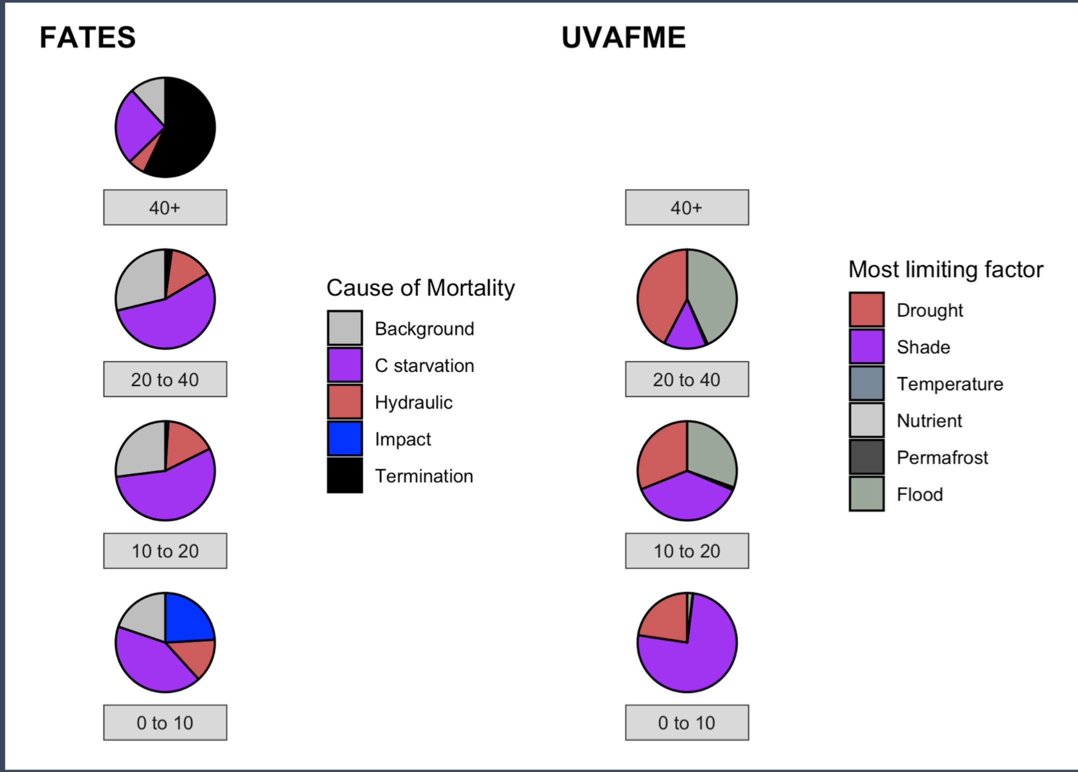
# Strange episodic mortality in FATES – permafrost?

**SS81** Black spruce dominant, with permafrost



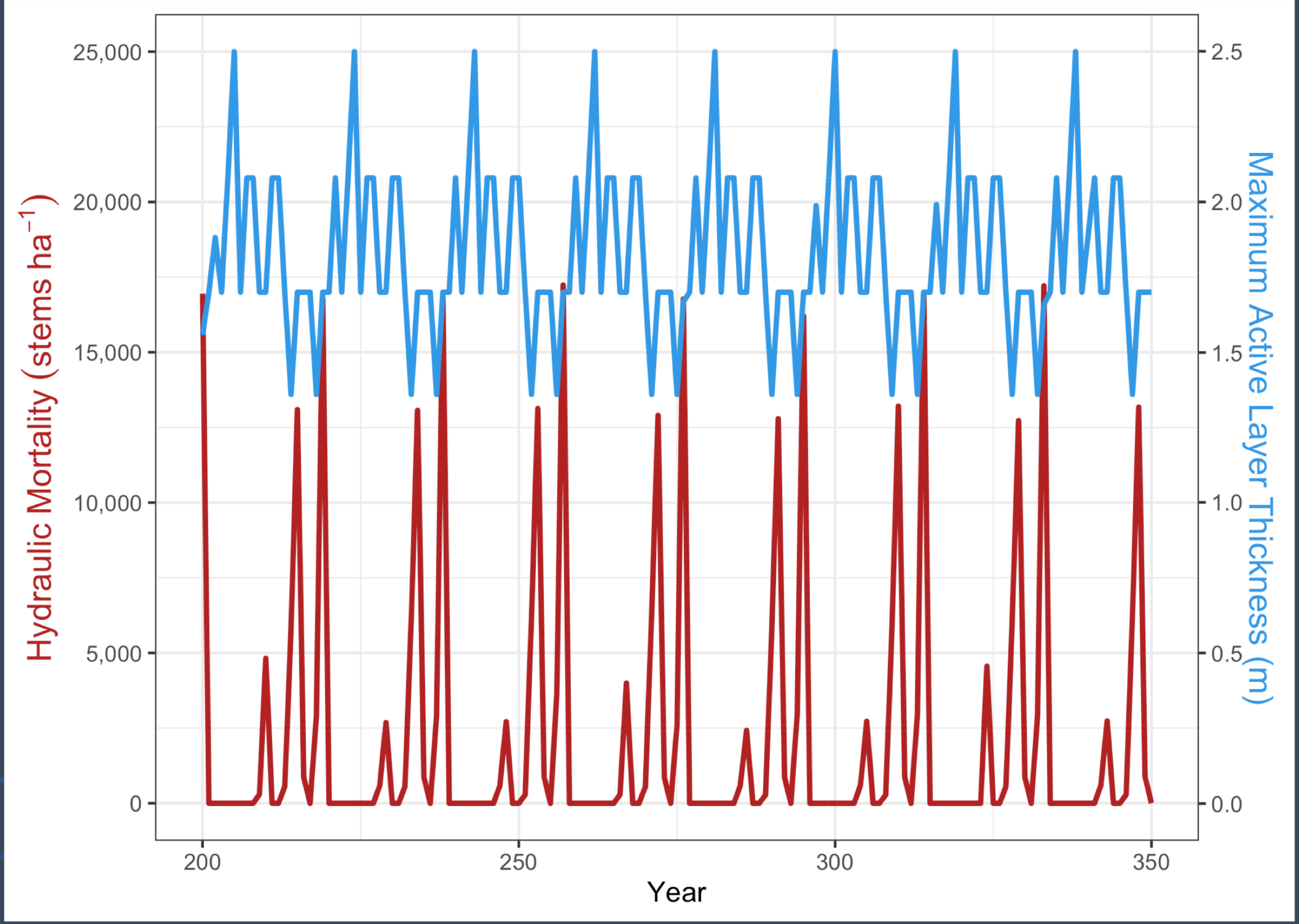




## Old Growth Conditions



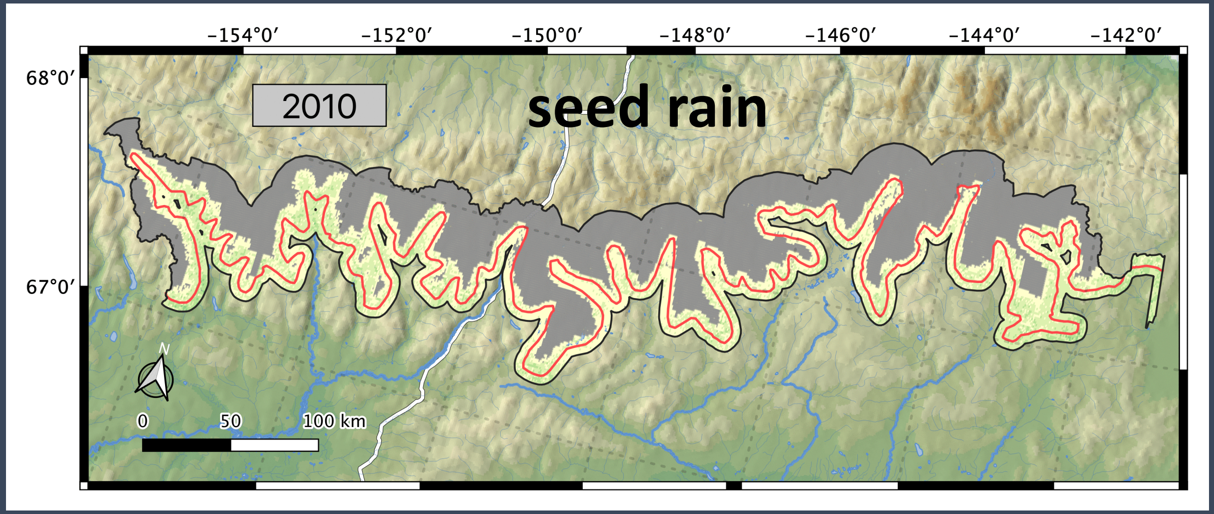

**DBH Size Class (cm)**

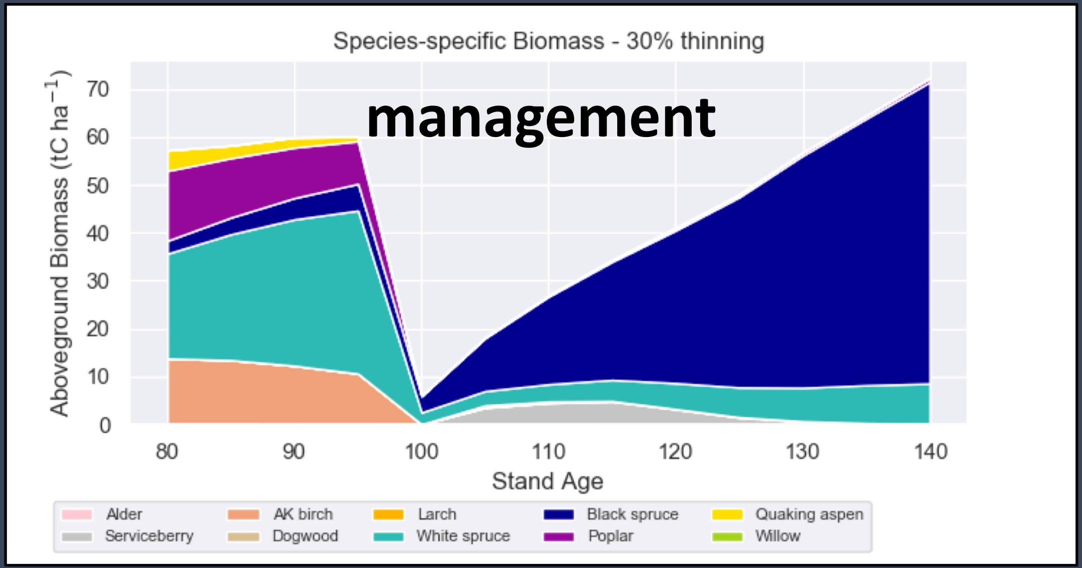
# Strange episodic mortality in FATES – permafrost?



# Conclusions

- Gap models can act as a field data surrogate across broader regions
  - Data needs for validation can be prohibitive
- Ideal comparison with FATES because they are so similar
- Highlight processes that drive vegetation dynamics
- Consideration of structure allows for detailed vegetation-climate-soil feedbacks



# Acknowledgements







SERDP
DOD ▪ EPA ▪ DOE

NAU HPC MONSOON

ABoVE
ARCTIC – BOREAL VULNERABILITY EXPERIMENT

NORTHERN ARIZONA UNIVERSITY

# Thank you!

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https://uvafme.github.io

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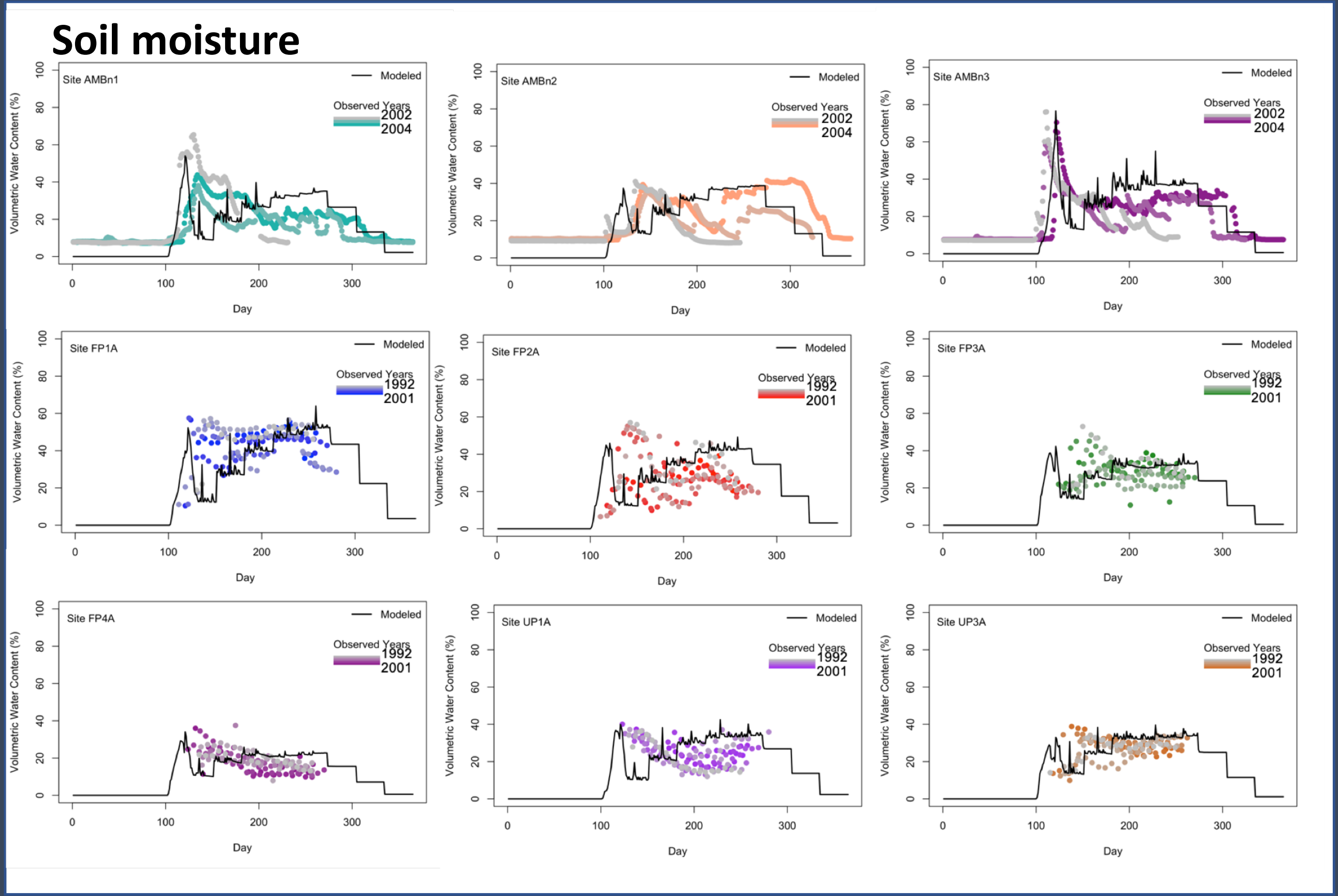
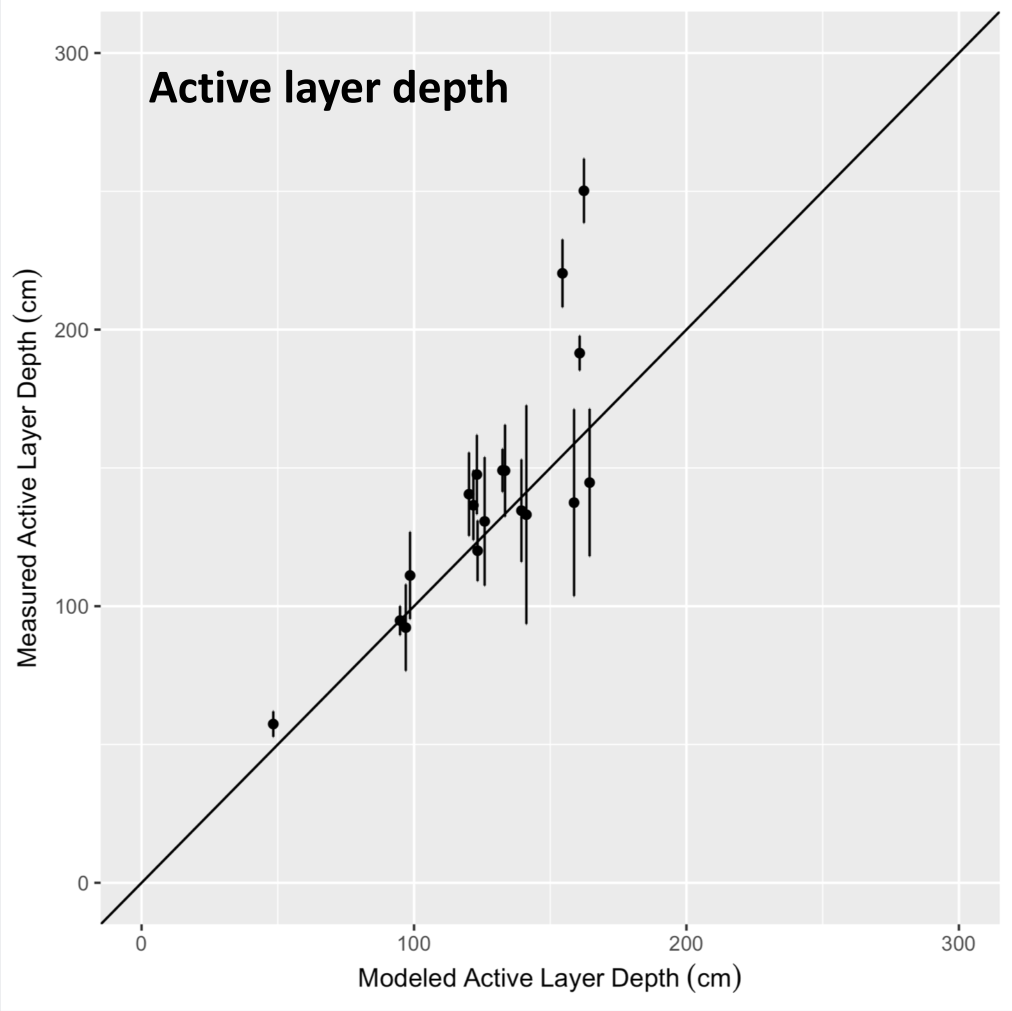
# UVAFME predicts soil moisture & permafrost well



# UVAFME annual growth – DBH increment