Ring-specific vulnerability to embolism reveals accumulation of damage in the xylem

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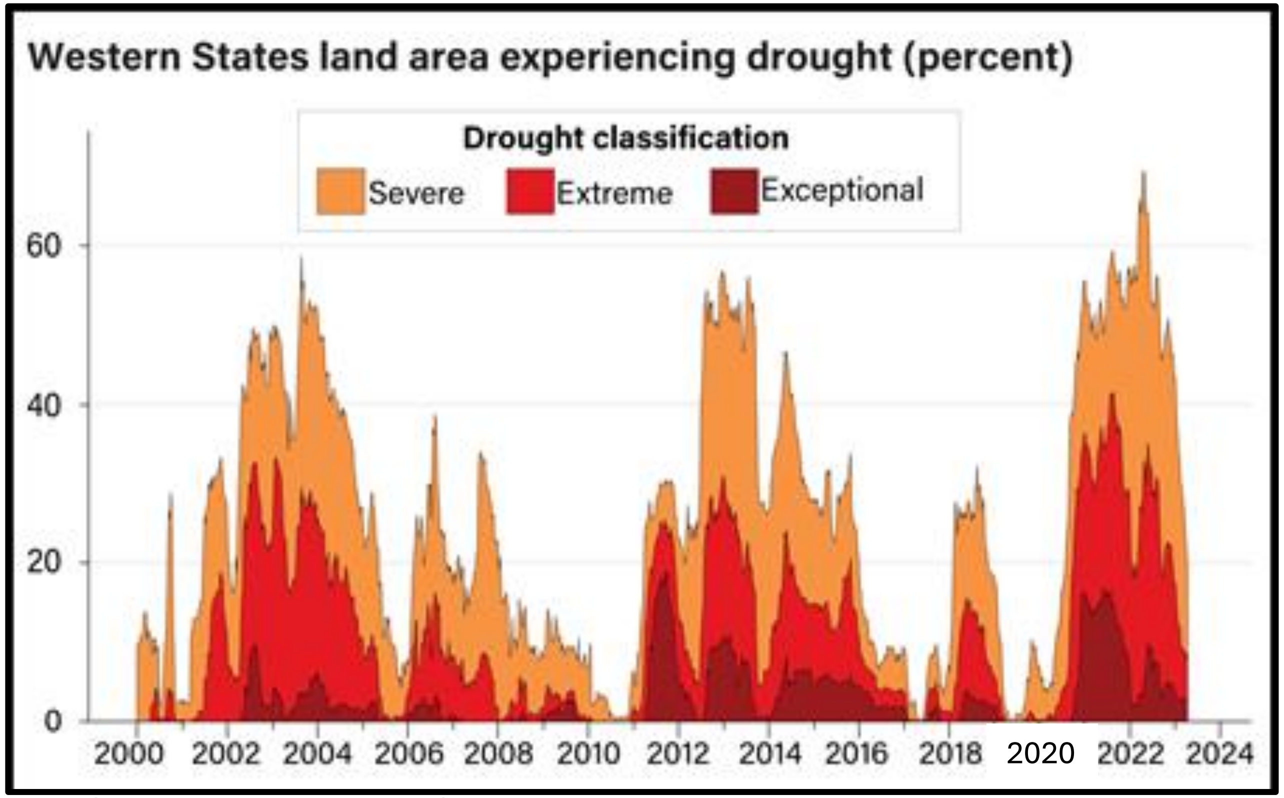
Droughts in the Western US



USDA Economic Research Service

More land area experiencing exceptional droughts

Sierra Nevada Conservancy

Dying trees = Climate feedbacks

Less forest carbon uptake

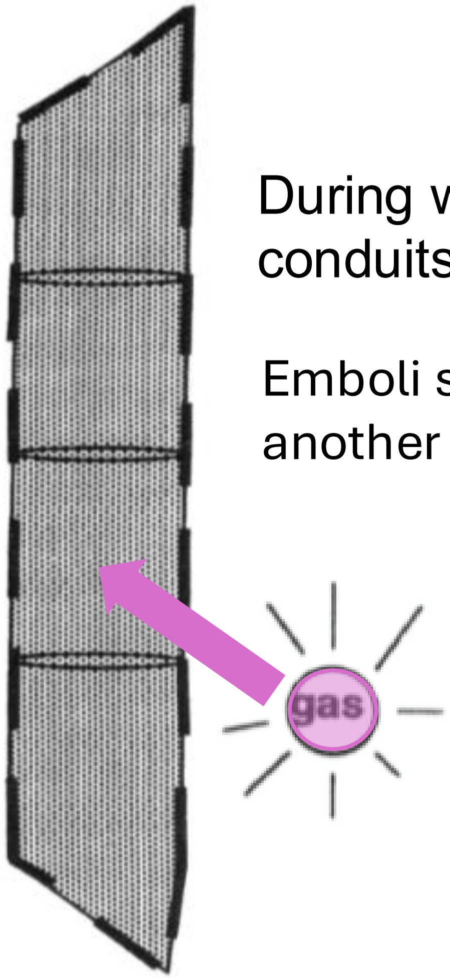
Decomposing trees release CO_2

Sudden Aspen Decline (SAD)

- Widespread mortality event of aspen (*Populus tremuloides*)
- SAD tied to droughts

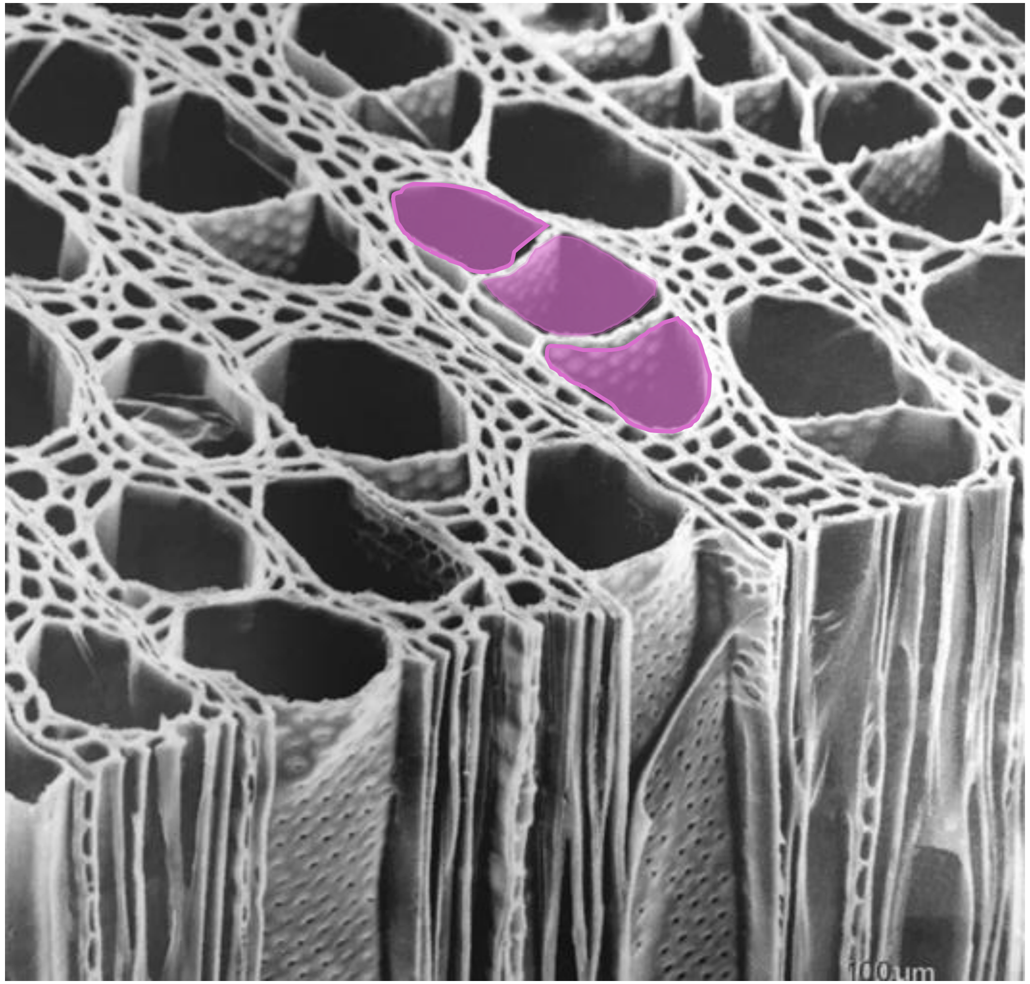
Dixie National Forest

Drought stress and emboli



During water stress, emboli form in conduits

Emboli spread from one conduit to another through the pits

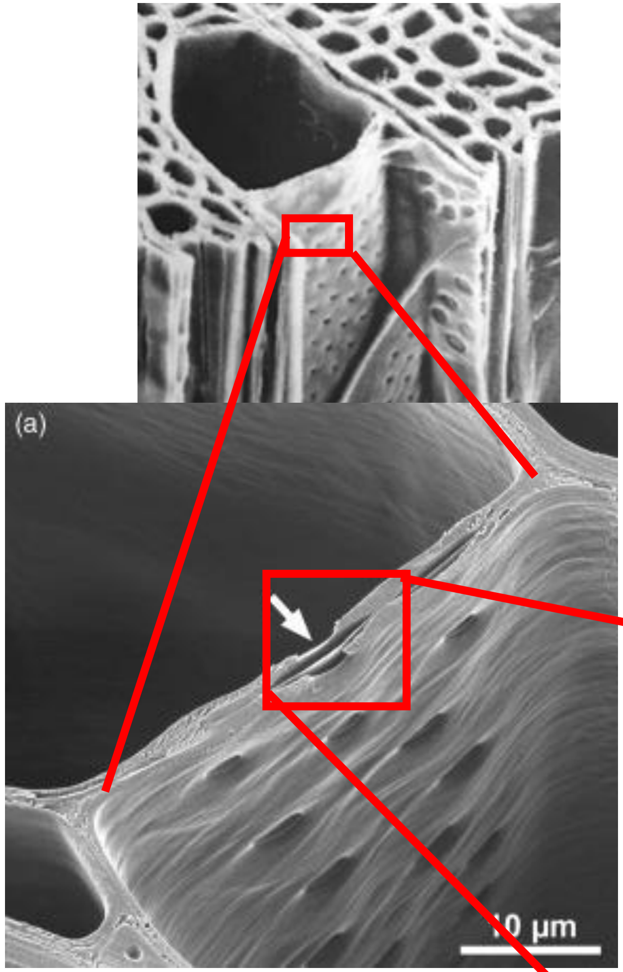


Langan, Ewers, and Davis 1997

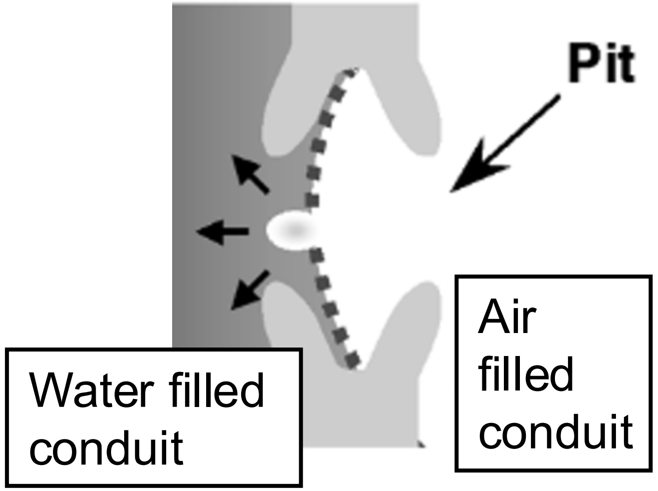
Embolism Fatigue

Damages the pits and makes them "leaky" to the spread of emboli

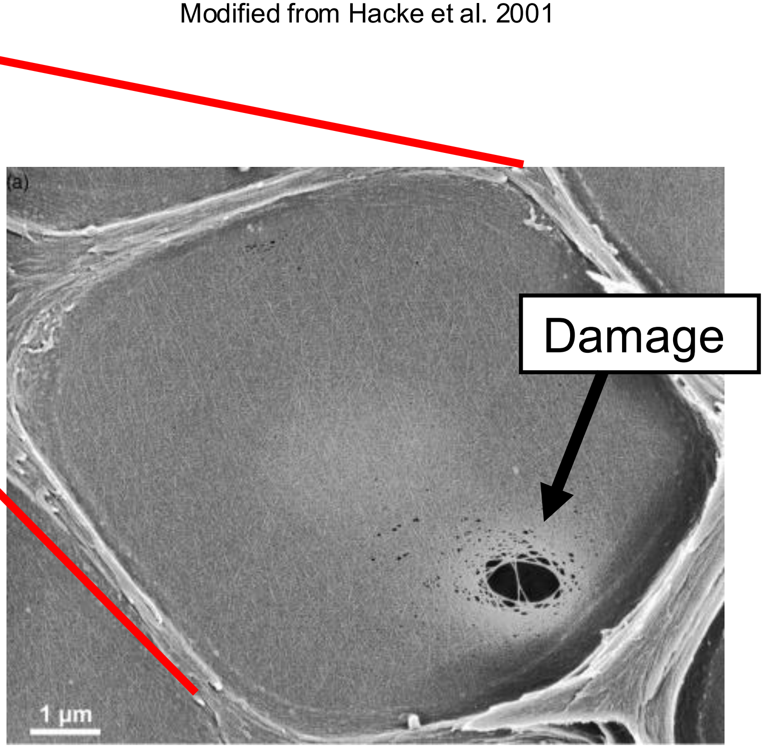
More vulnerable to future droughts



Yuzou Sano 2016



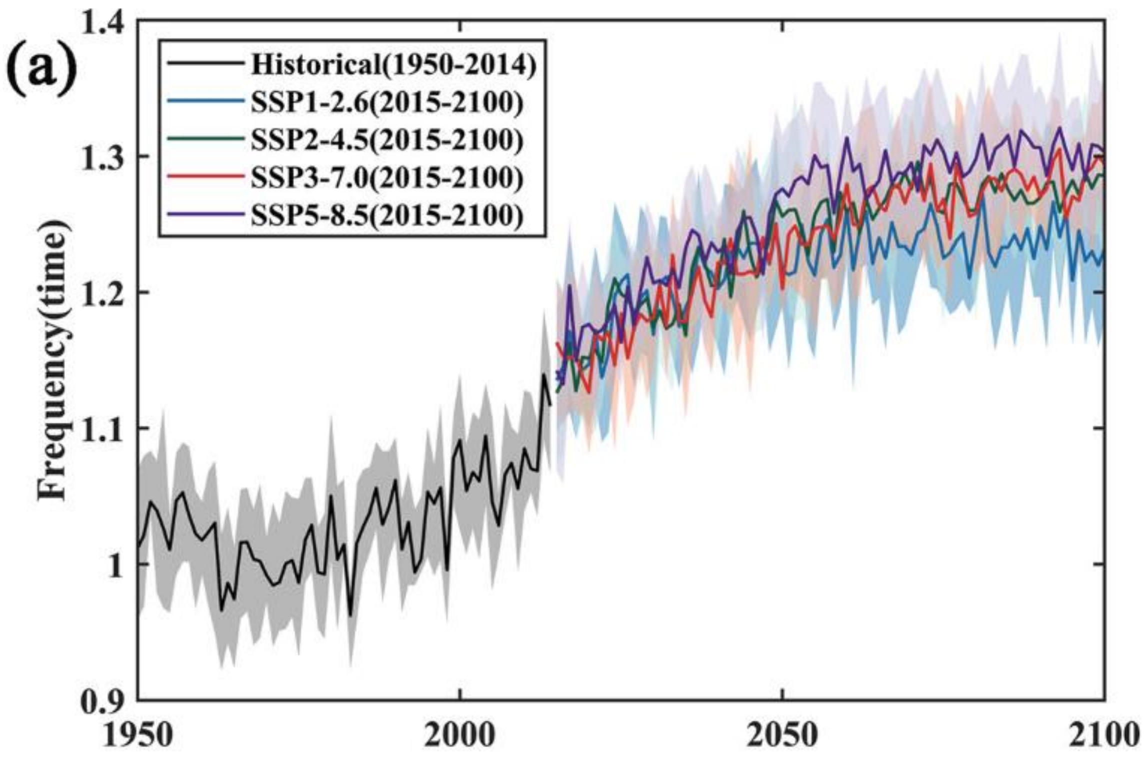
Modified from Hacke et al. 2001



Yuzou Sano 2016

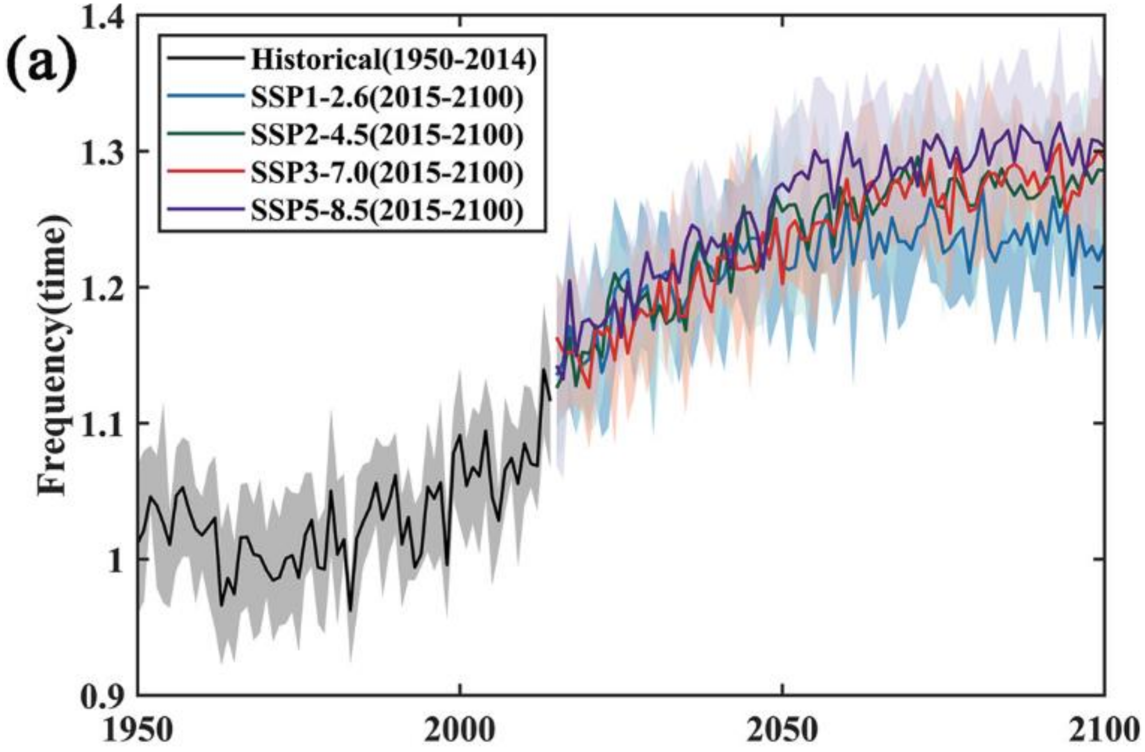
Knowledge gap

- Most studies only focus on plant response of a single drought



Knowledge gap

- Most studies only focus on plant response of a single drought



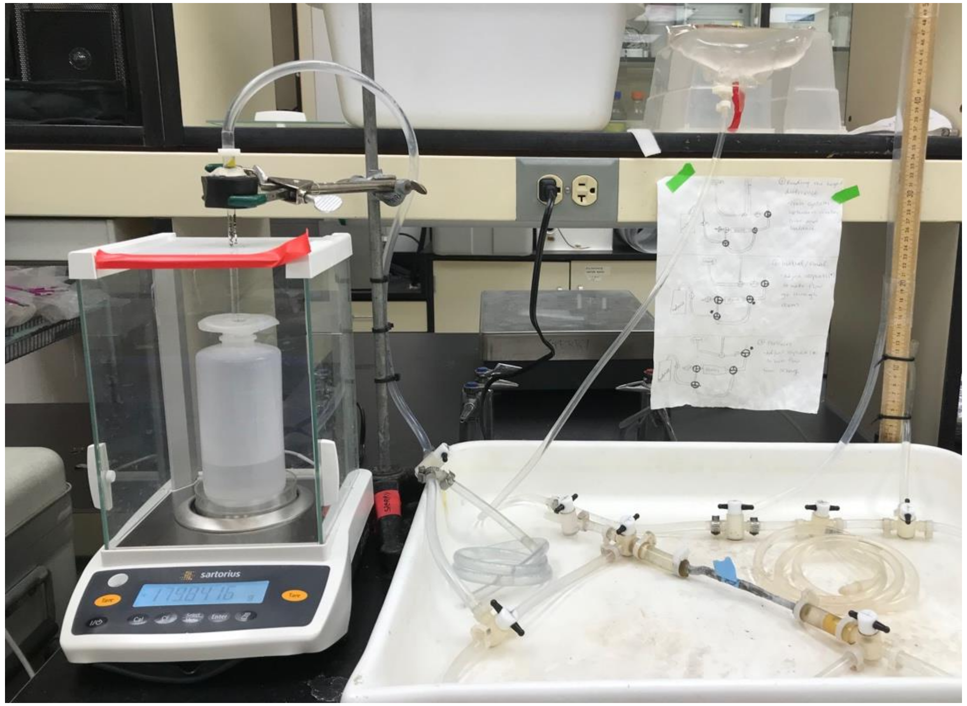
How will plants respond to recurrent droughts?

Main Questions

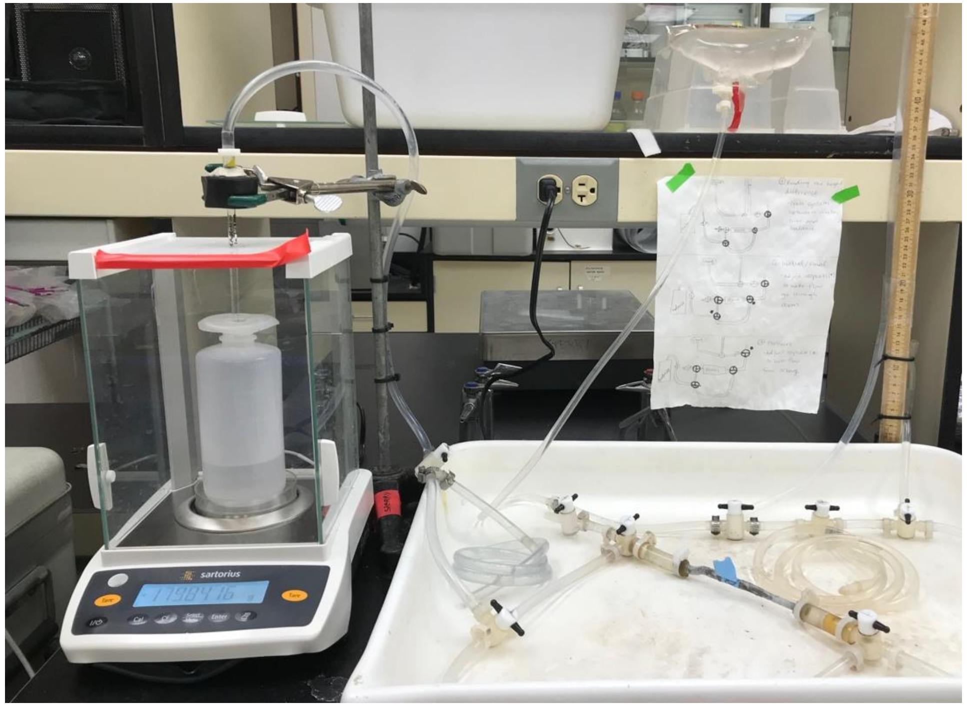
- How do recurrent droughts affect tree xylem and drought responses?
- How does the hydraulic system change across multiple years to impact hydraulic function and tree drought responses?

- Need a new method to measure hydraulic function as it ages
- Already have methods to measure hydraulic function but are limited and cannot measure age differences in the same branch

Measuring hydraulic function

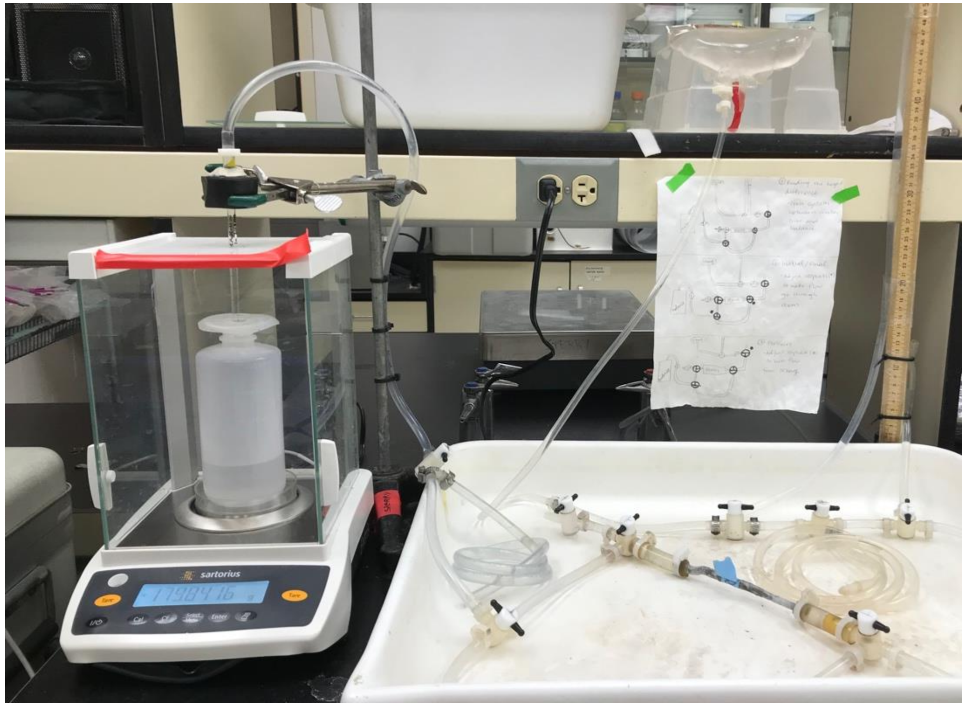


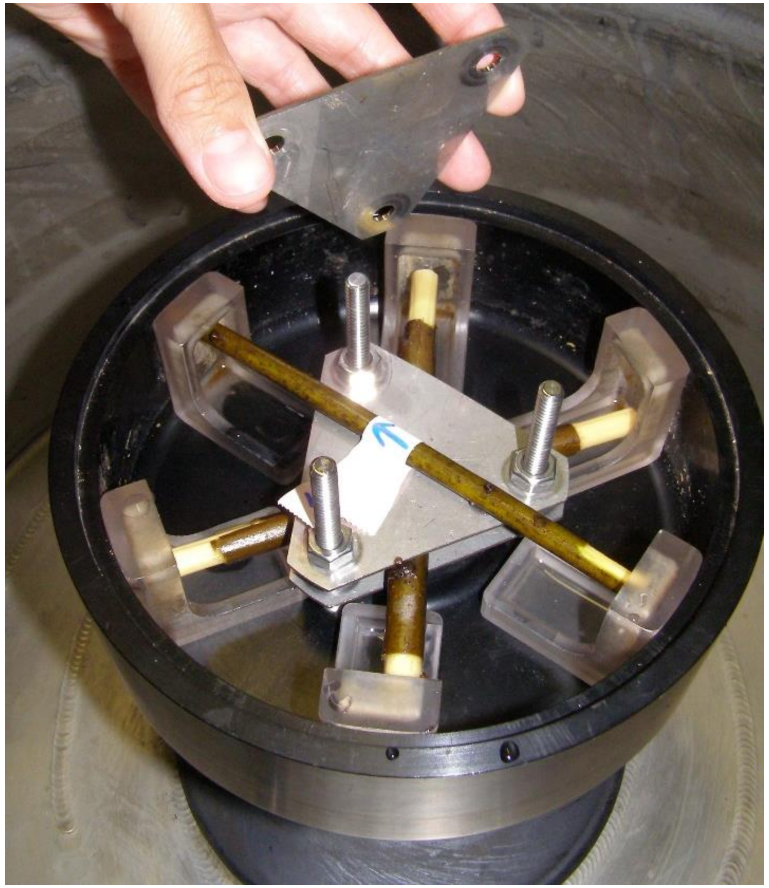
Measuring hydraulic function



K_{max}

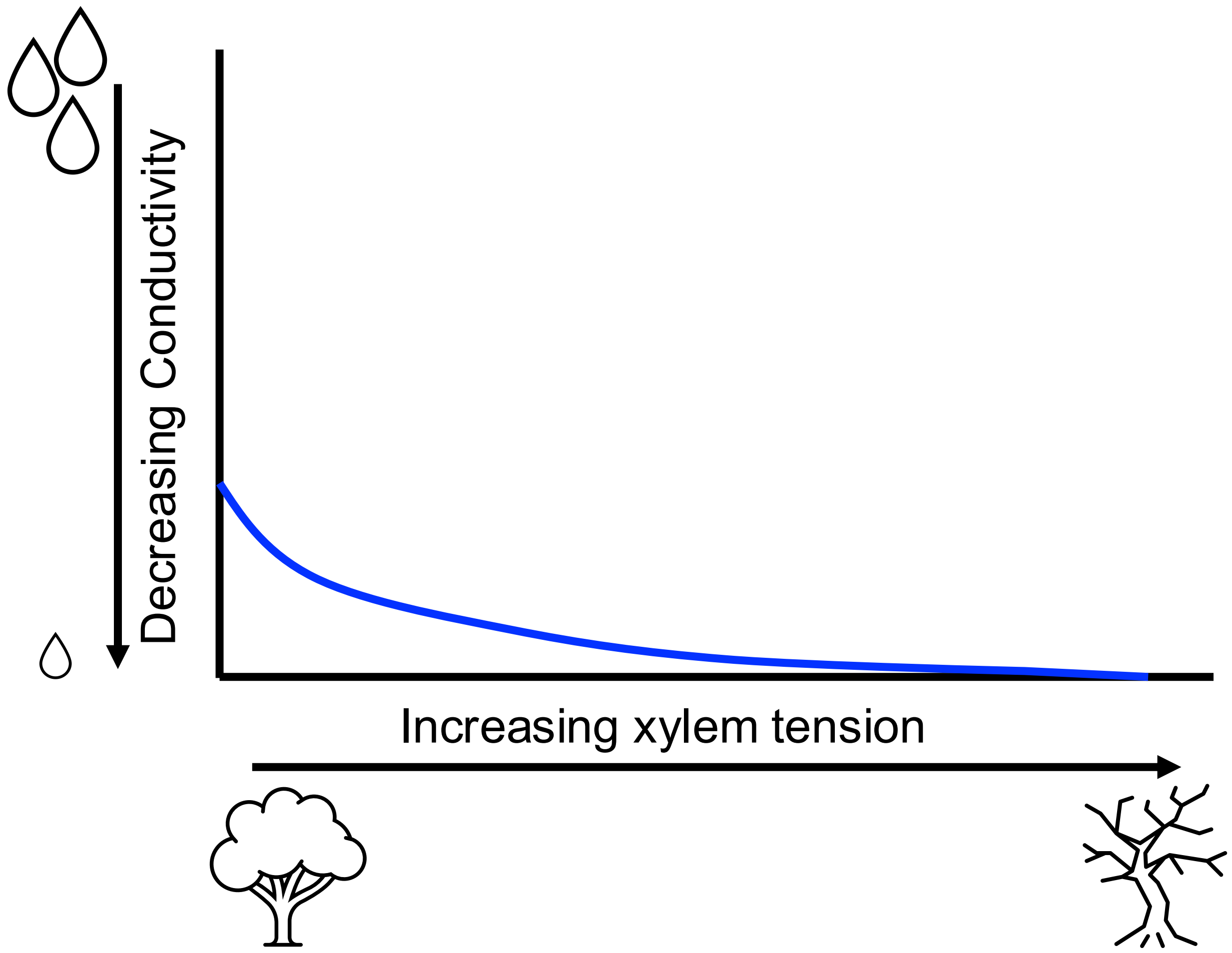
Measuring hydraulic function

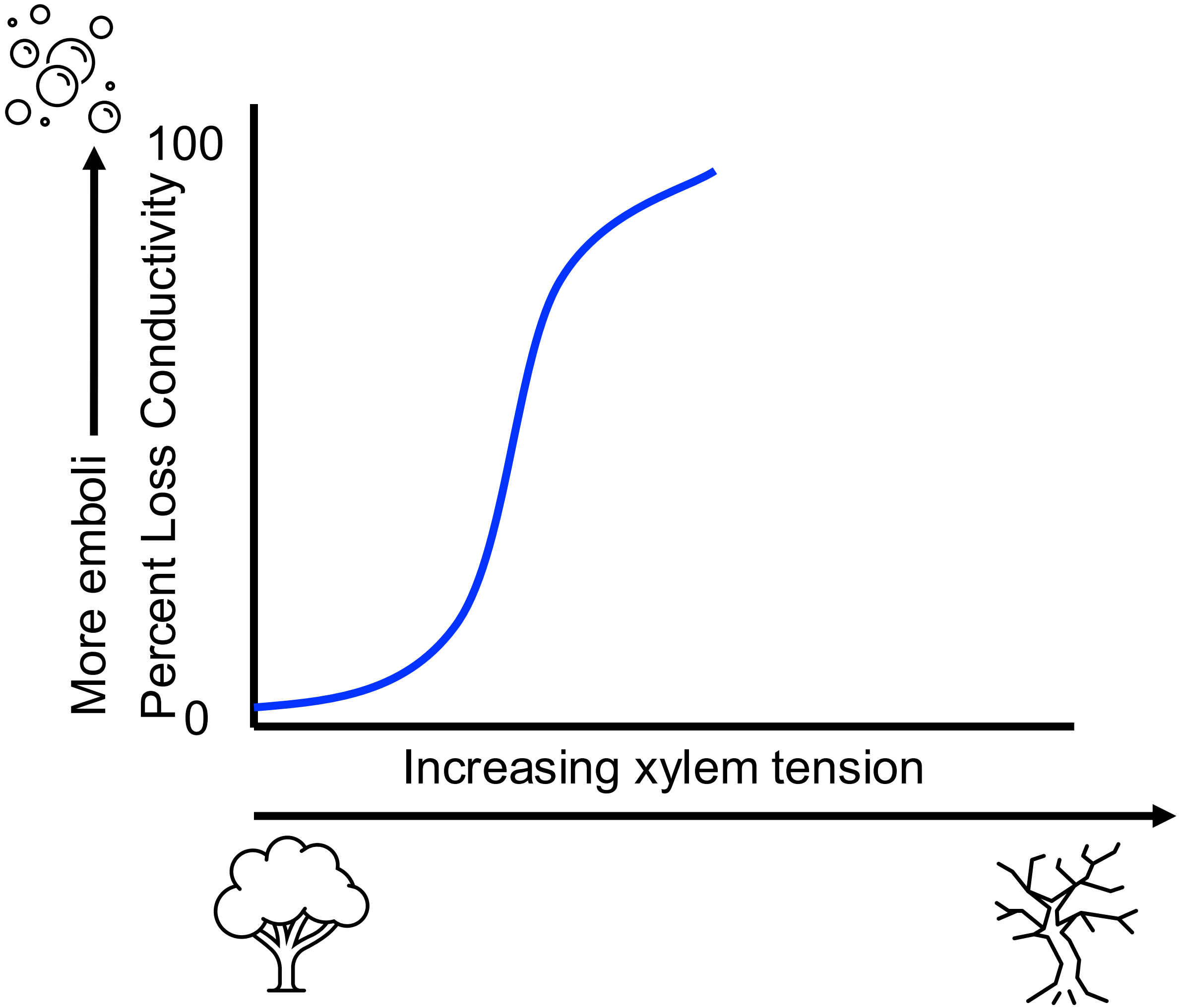



Jacobsen

Conductivity Curves & Vulnerability Curves

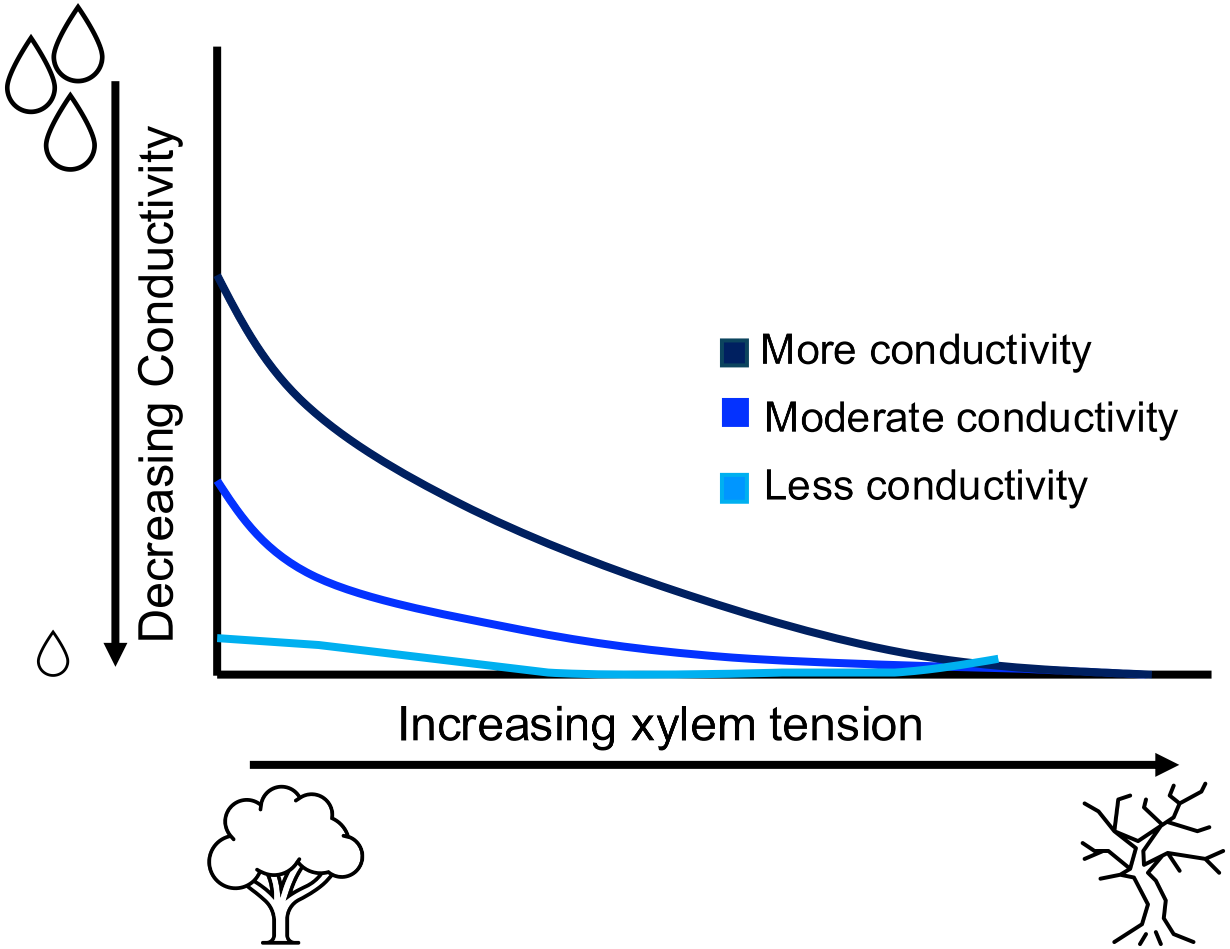
Hydraulic measures result in two complimentary sets of data

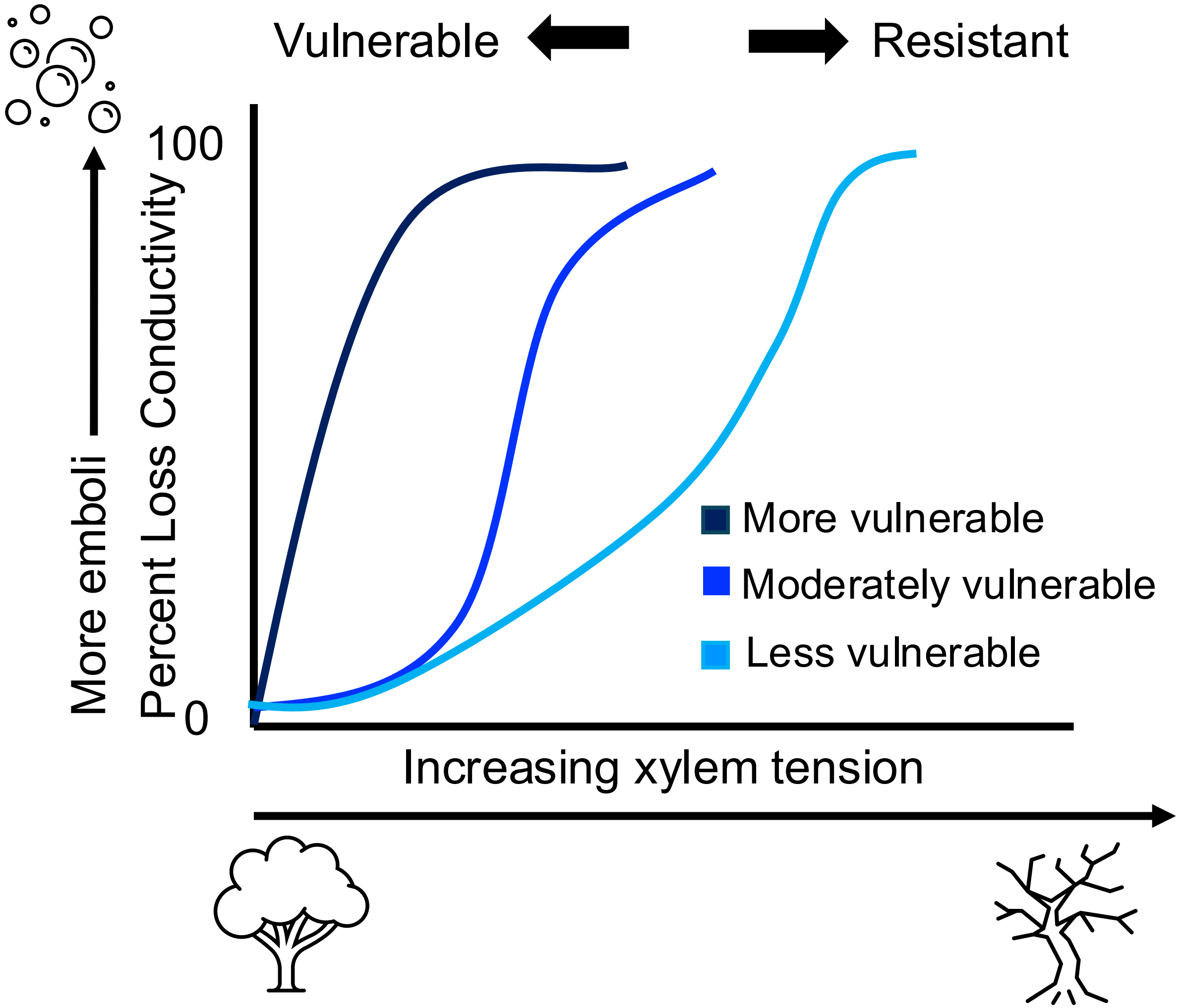




Conductivity Curves & Vulnerability Curves

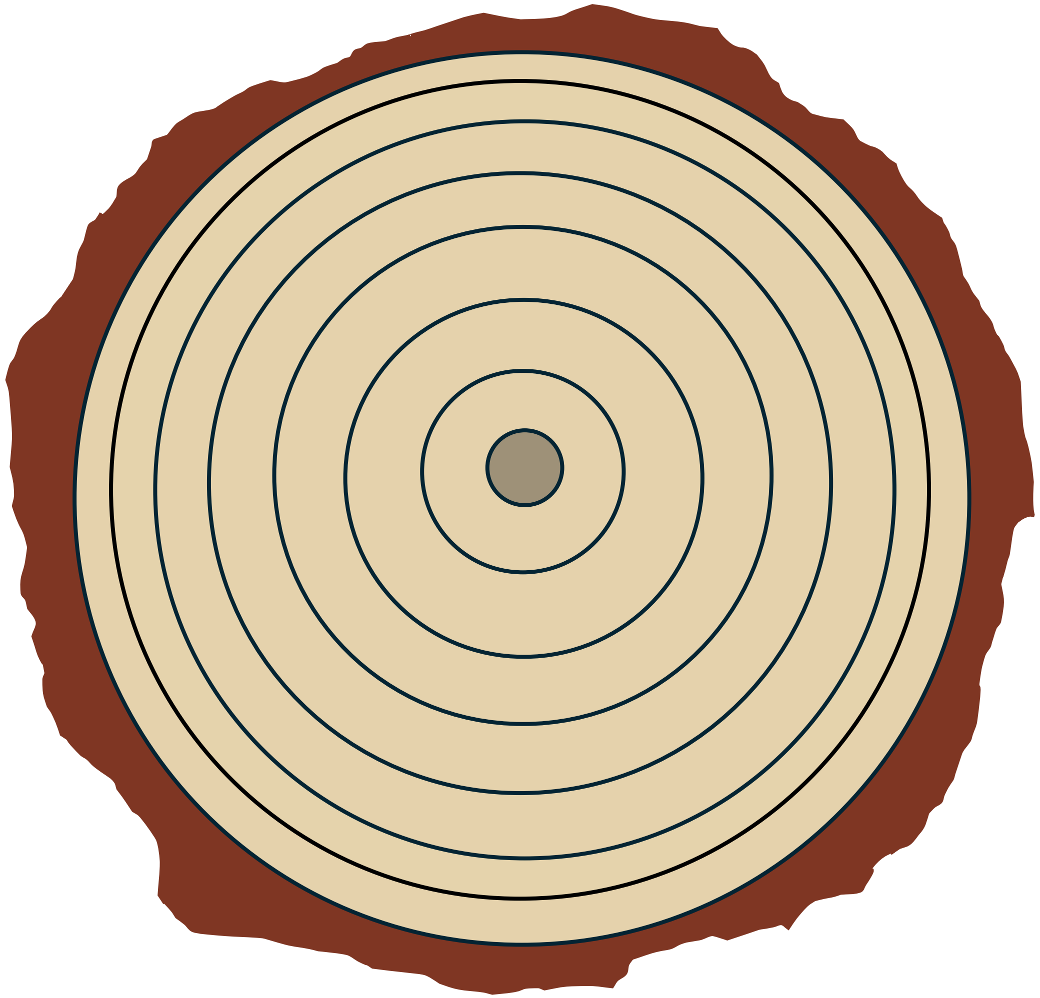
Hydraulic measures result in two complimentary sets of data





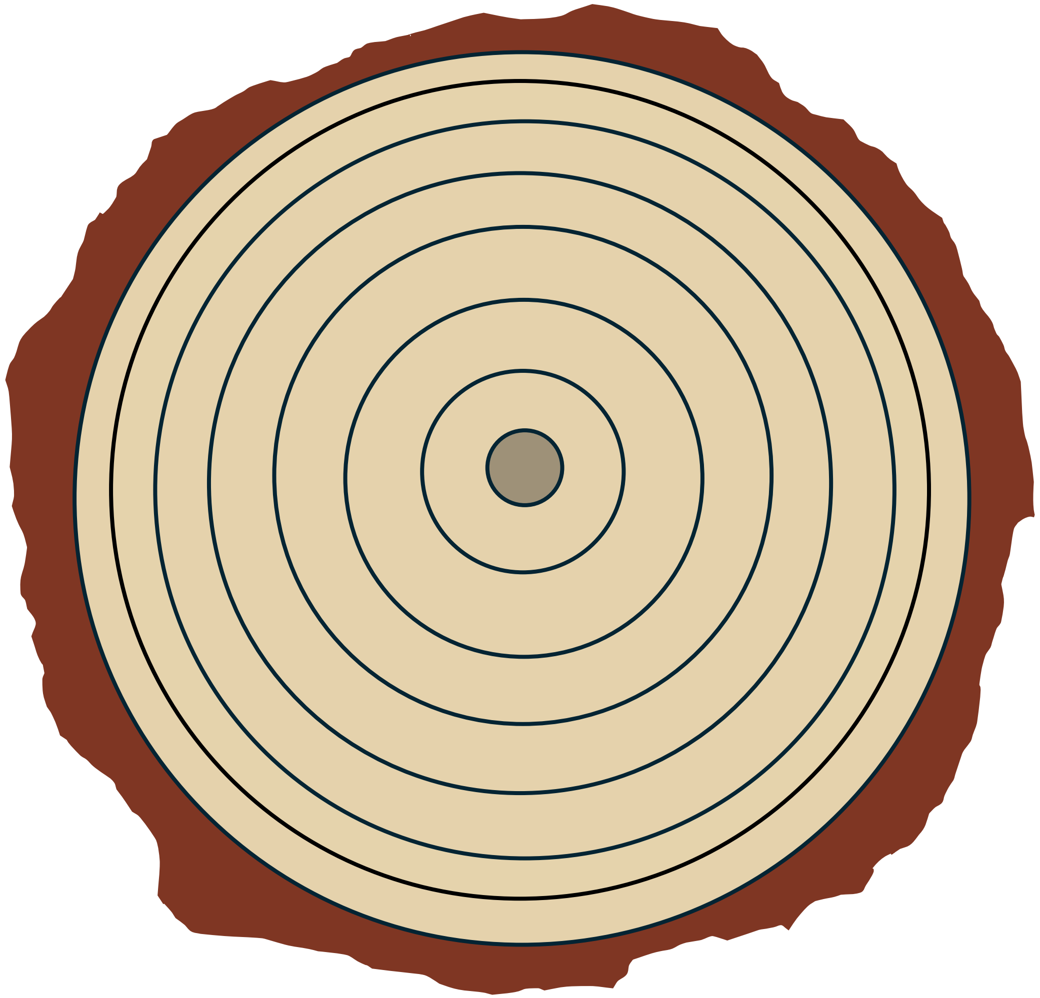
Limitations

- Works great for measuring hydraulic conductivity and vulnerability of a stem



Limitations

- Works great for measuring hydraulic conductivity and vulnerability of a stem
- But this is done on the entire cross-sectional area of the stem

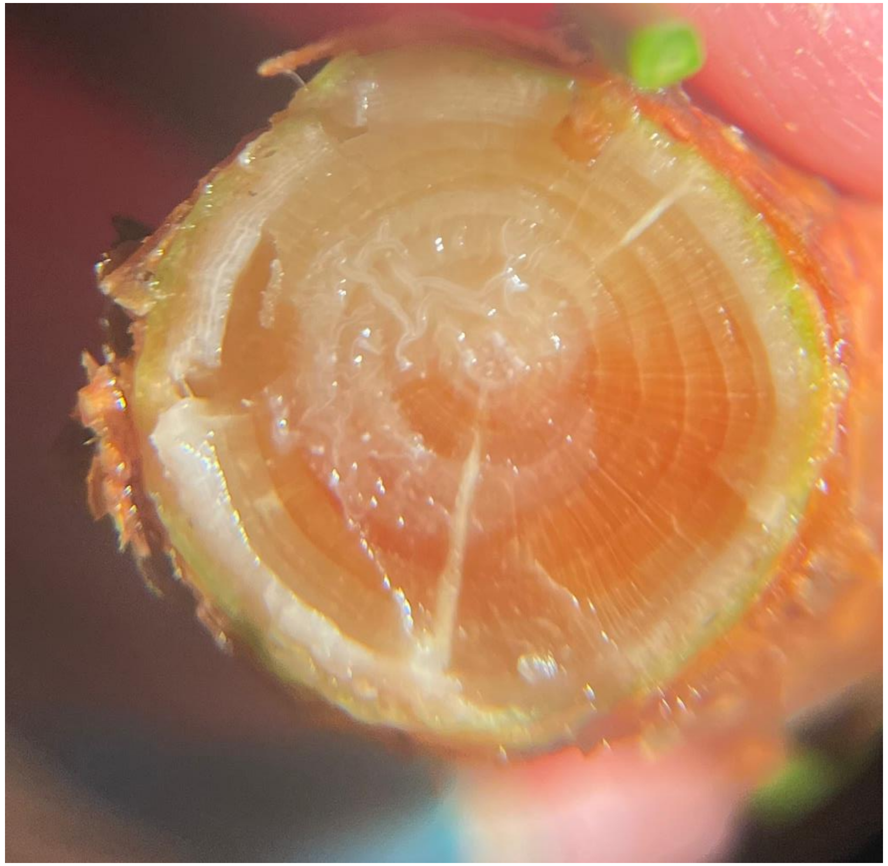


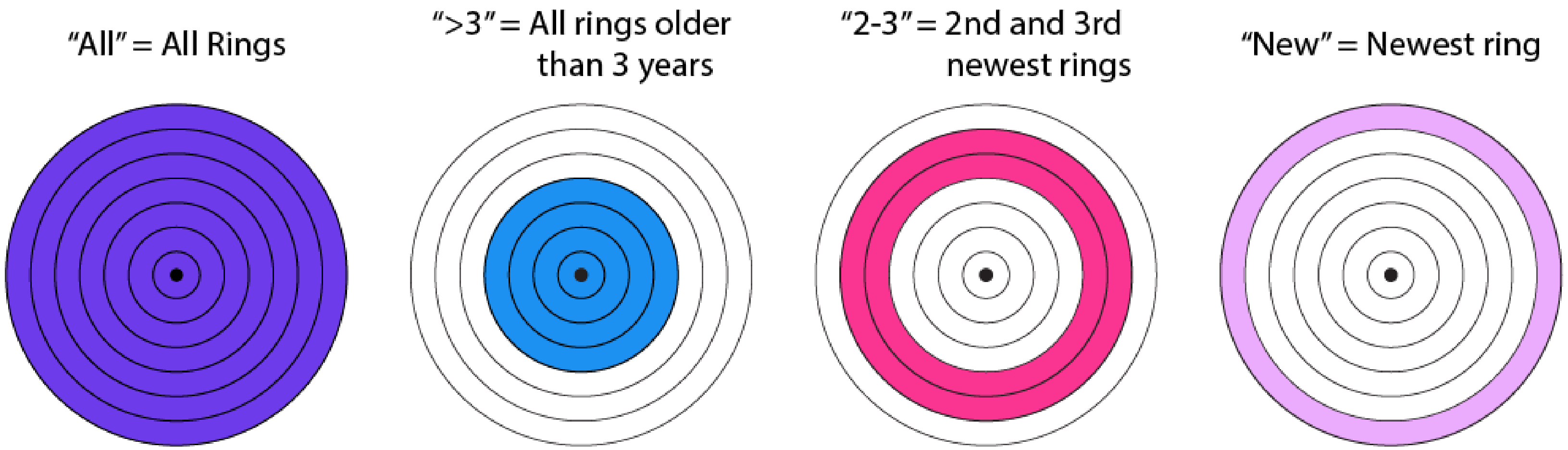
New Method

Measures individual “bins” of rings

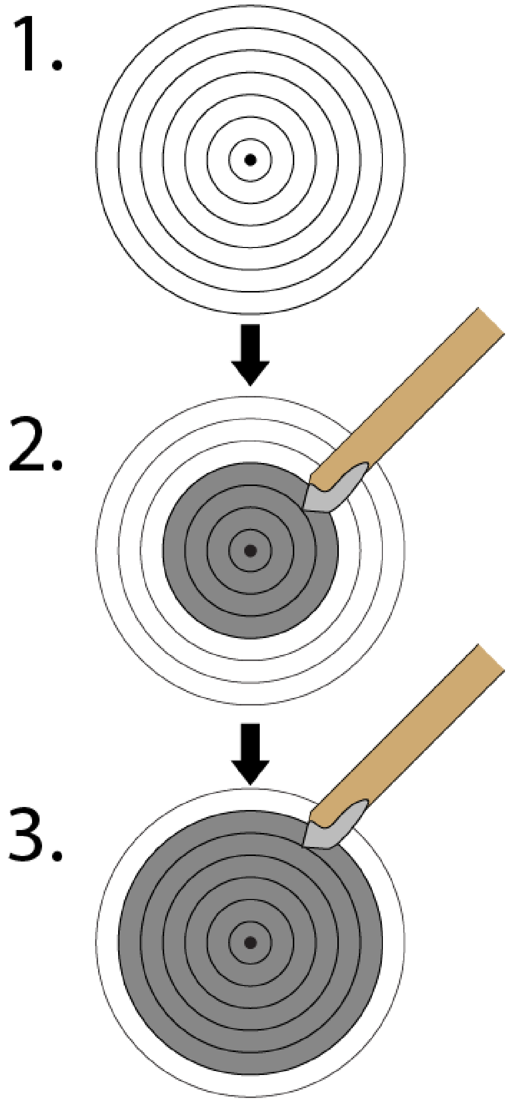
Measures function as xylem ages

How vulnerable and how conductive each ring is within a single stem





New Method



Step 1: Measure conductivity of all rings (K_{all})

K_{all} = K of "All"

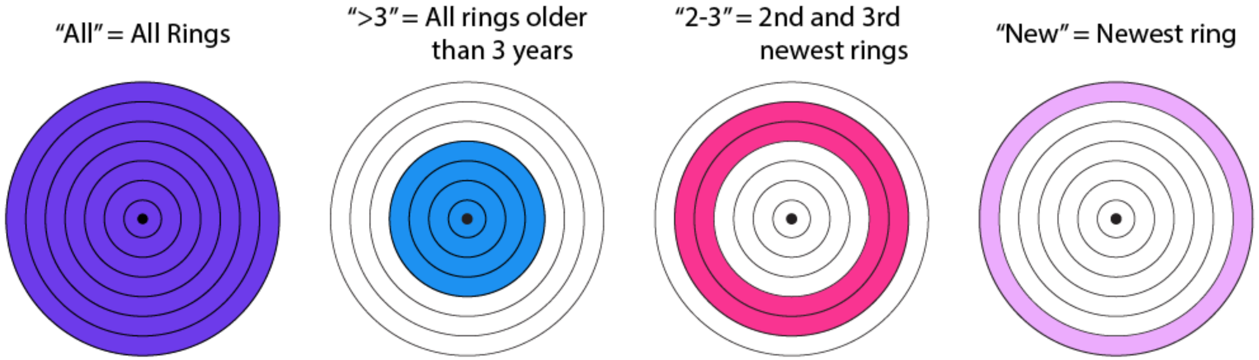
Step 2: cover rings older than 3 years with superglue
measure conductivity ($K_{1\text{-}3}$)

$K_{all} - K_{1\text{-}3}$ = K of ">3"

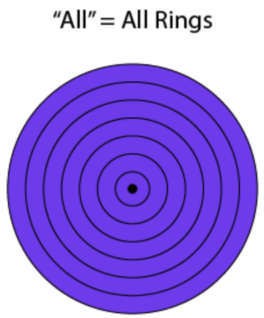
Step 3: apply glue to 2 additional rings, covering all but the newest ring
measure conductivity (K_{outer})

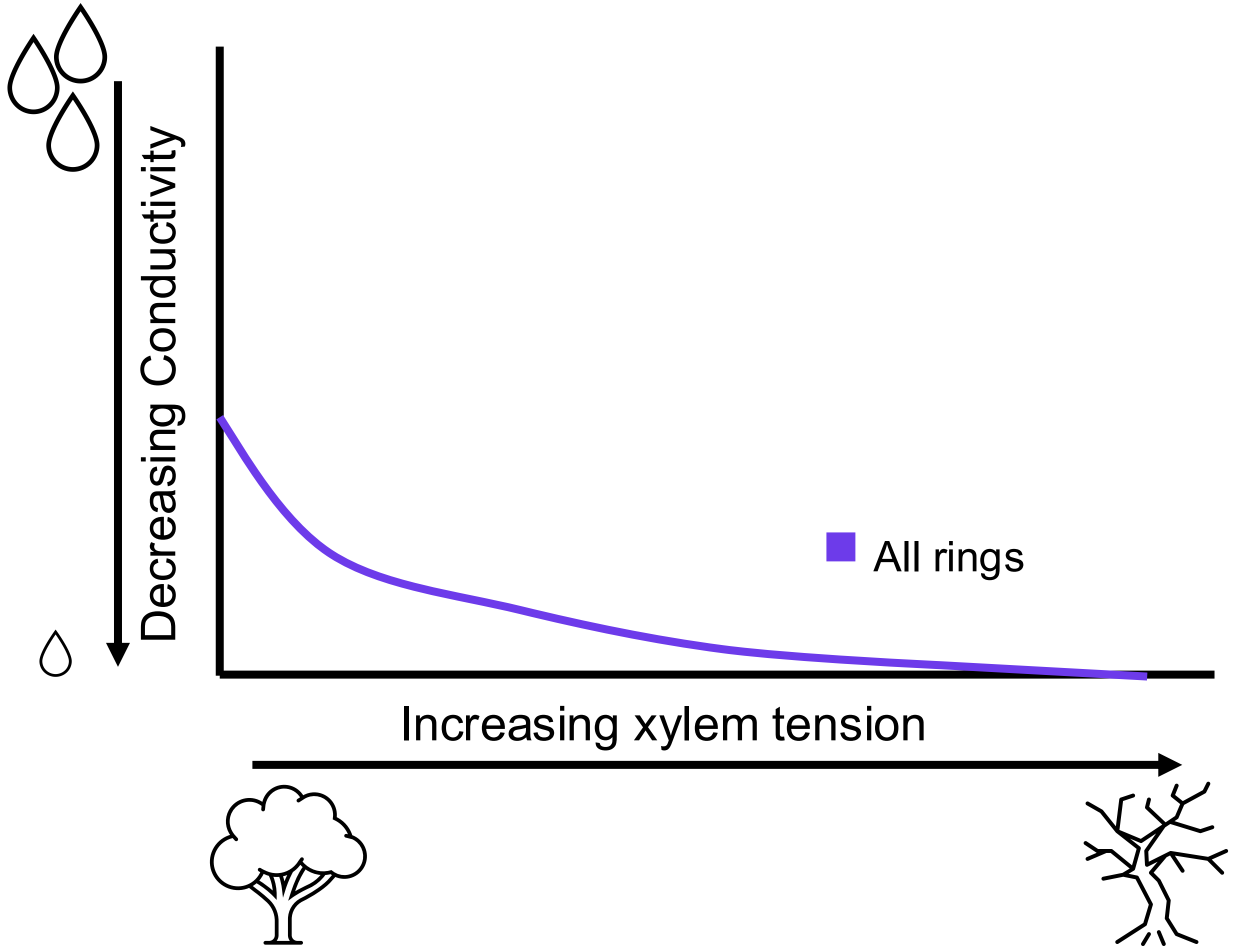
$K_{1\text{-}3} - K_{outer}$ = K of "2-3"

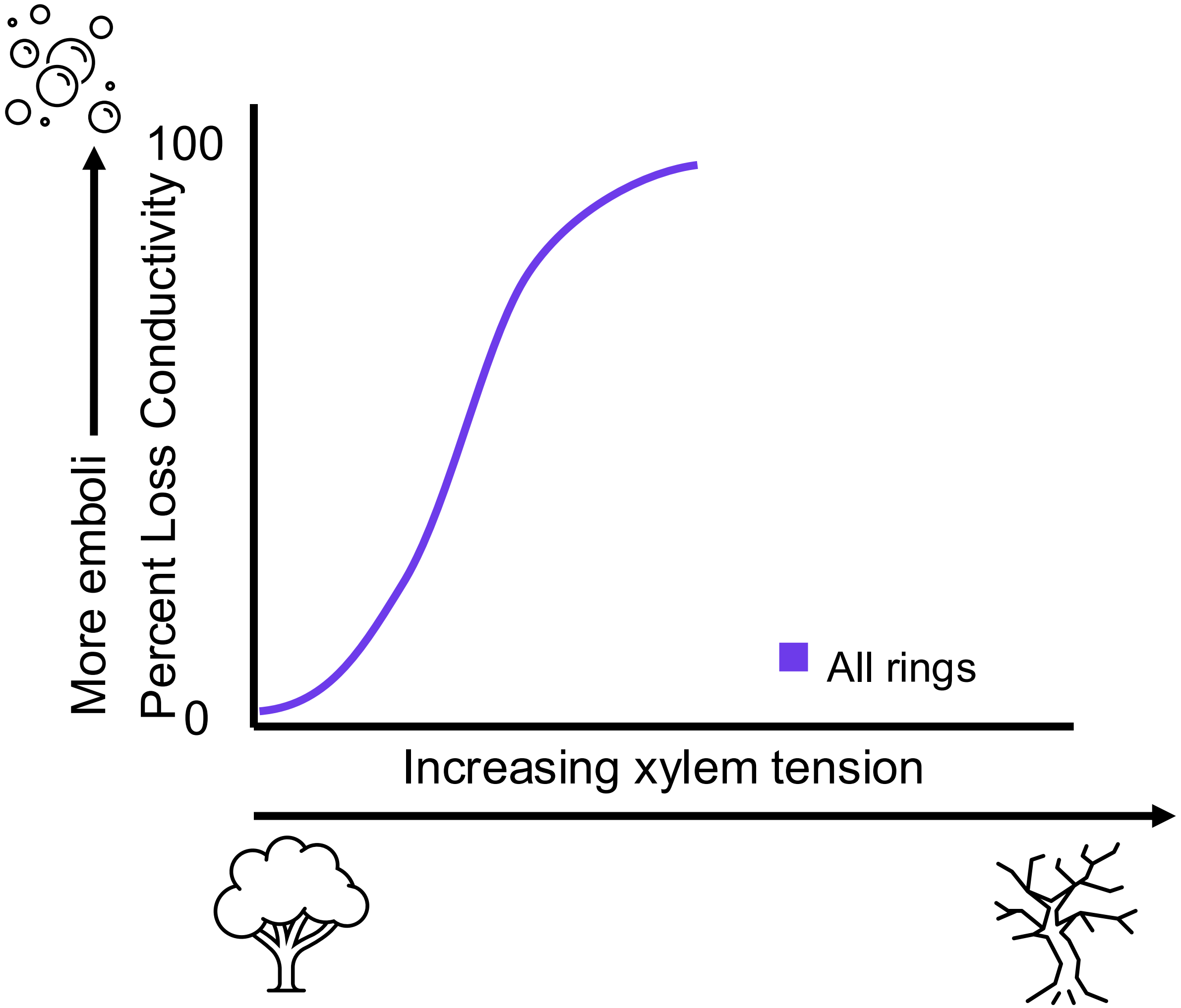
K_{outer} = K of "New"



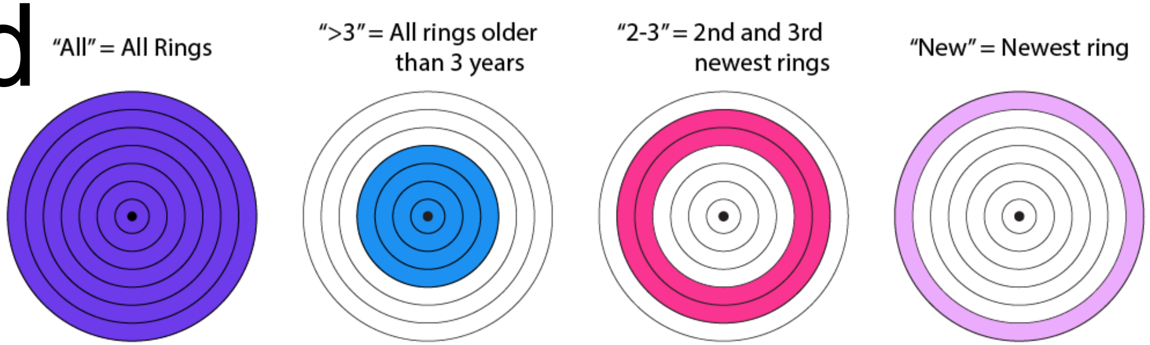
Old Method


"All" = All Rings

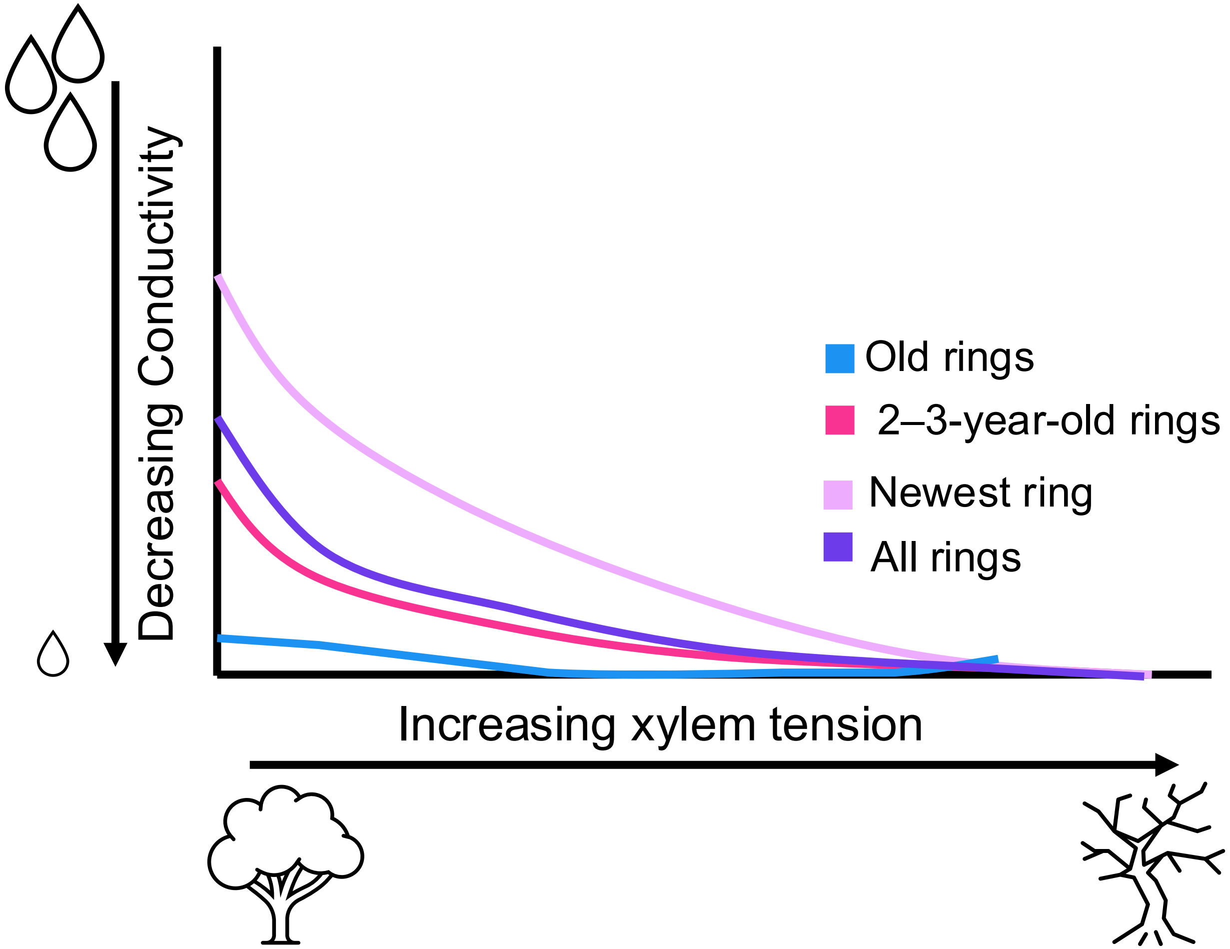

Decreasing Conductivity
All rings
Increasing xylem tension

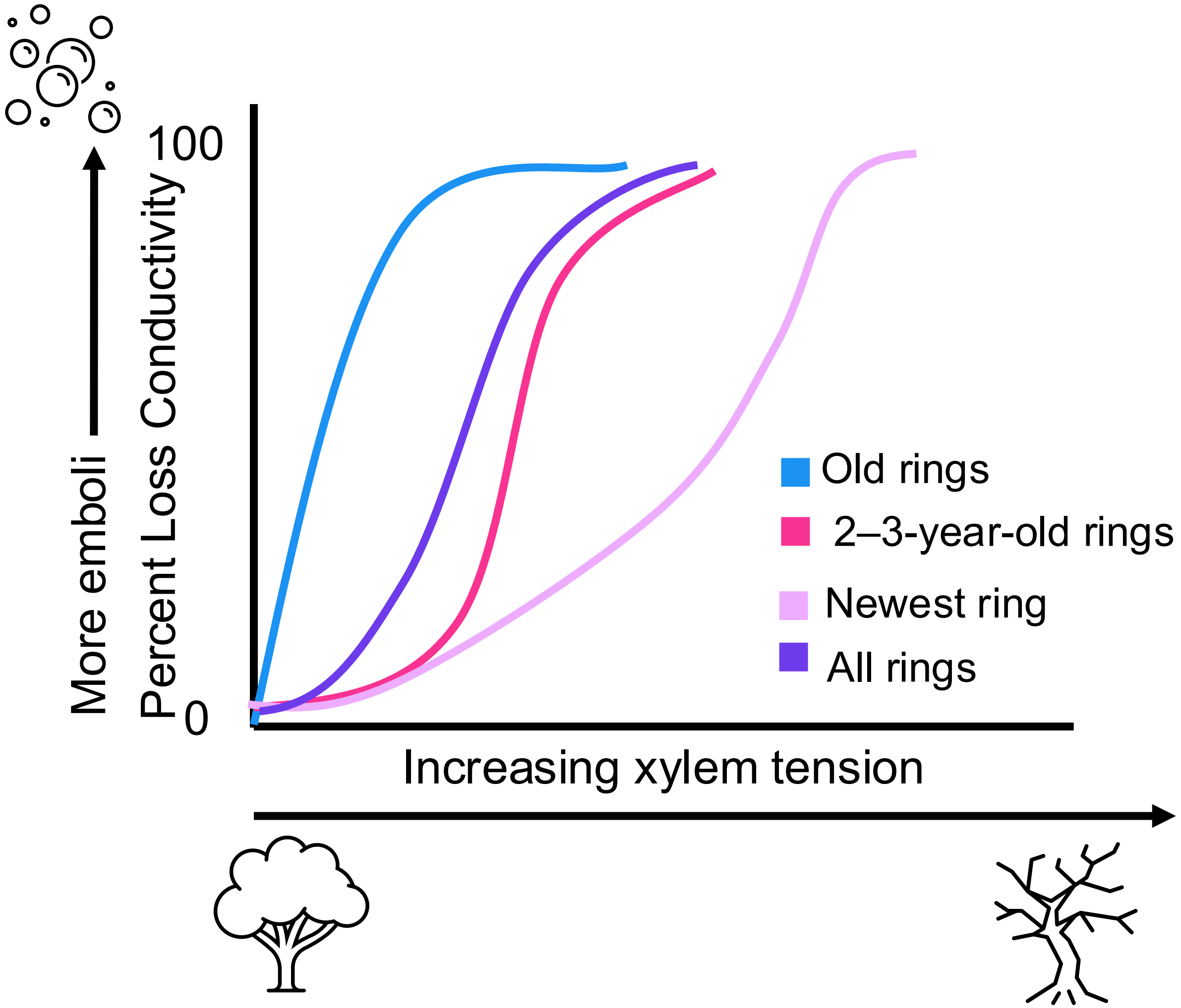

100
0
More emboli
Percent Loss Conductivity
All rings
Increasing xylem tension

New Method



All within one stem!





With this method we can now address…

- How do different aged rings differ in their ability to resist embolism?
- How do different aged rings differ in their ability to conduct water?
- How do trees from different drought regimes change in their hydraulic structure and function?

A case study with 5 aspen populations

Previous work comparing between populations along climatic gradient :

Dry sites = more vulnerable to emboli

Kerr et al. 2023. *New Phytologist*

A case study with 5 aspen populations

Previous work comparing between populations along climatic gradient :

Dry sites = more vulnerable to emboli

Counter intuitive: Expect acclimation to their local environment

Kerr et al. 2023. *New Phytologist*

A case study with 5 aspen populations

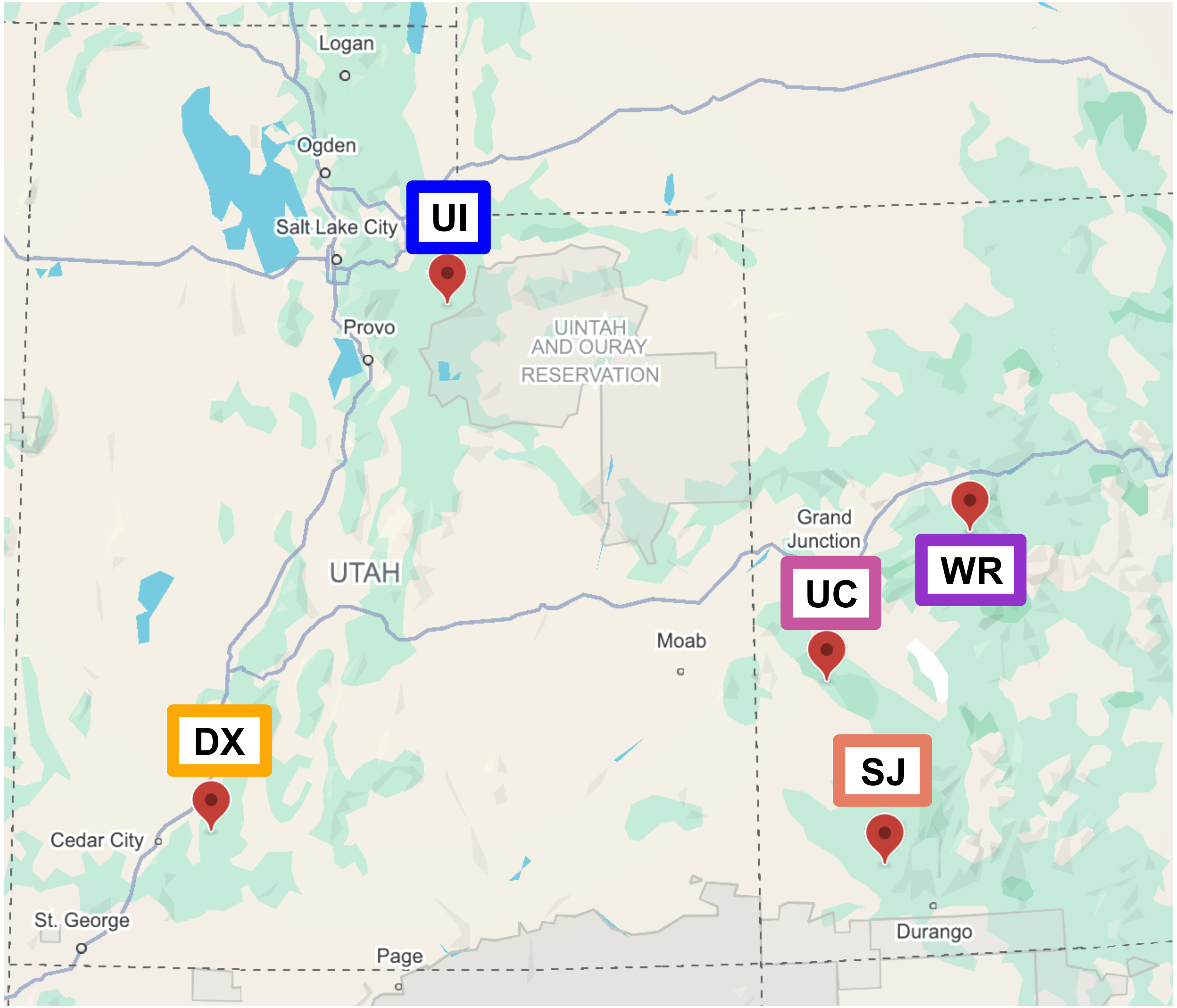
Previous work comparing between populations along climatic gradient :

Dry sites = more vulnerable to emboli

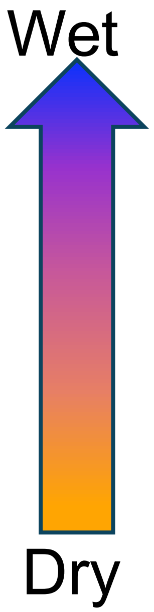
Counter intuitive: Expect acclimation to their local environment
Are these sites displaying damage signals due to repeat droughts?

Kerr et al. 2023. *New Phytologist*

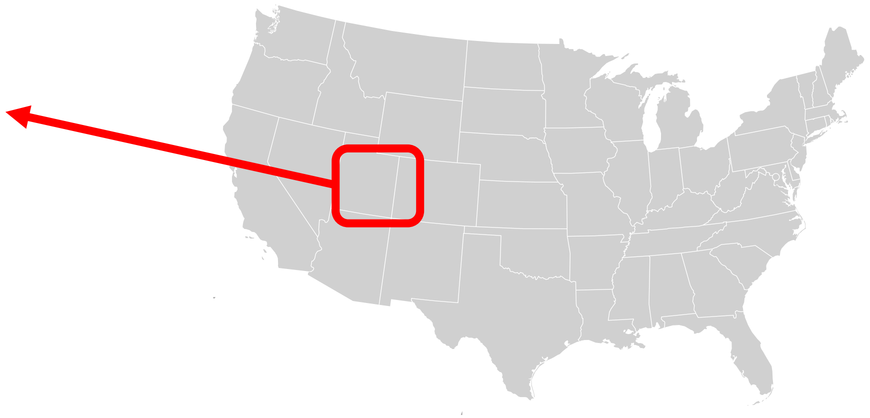
Study Sites



Google Maps



- Uinta (UI)
- White River (WR)
- Uncompahgre (UC)
- San Juan (SJ)
- Dixie (DX)

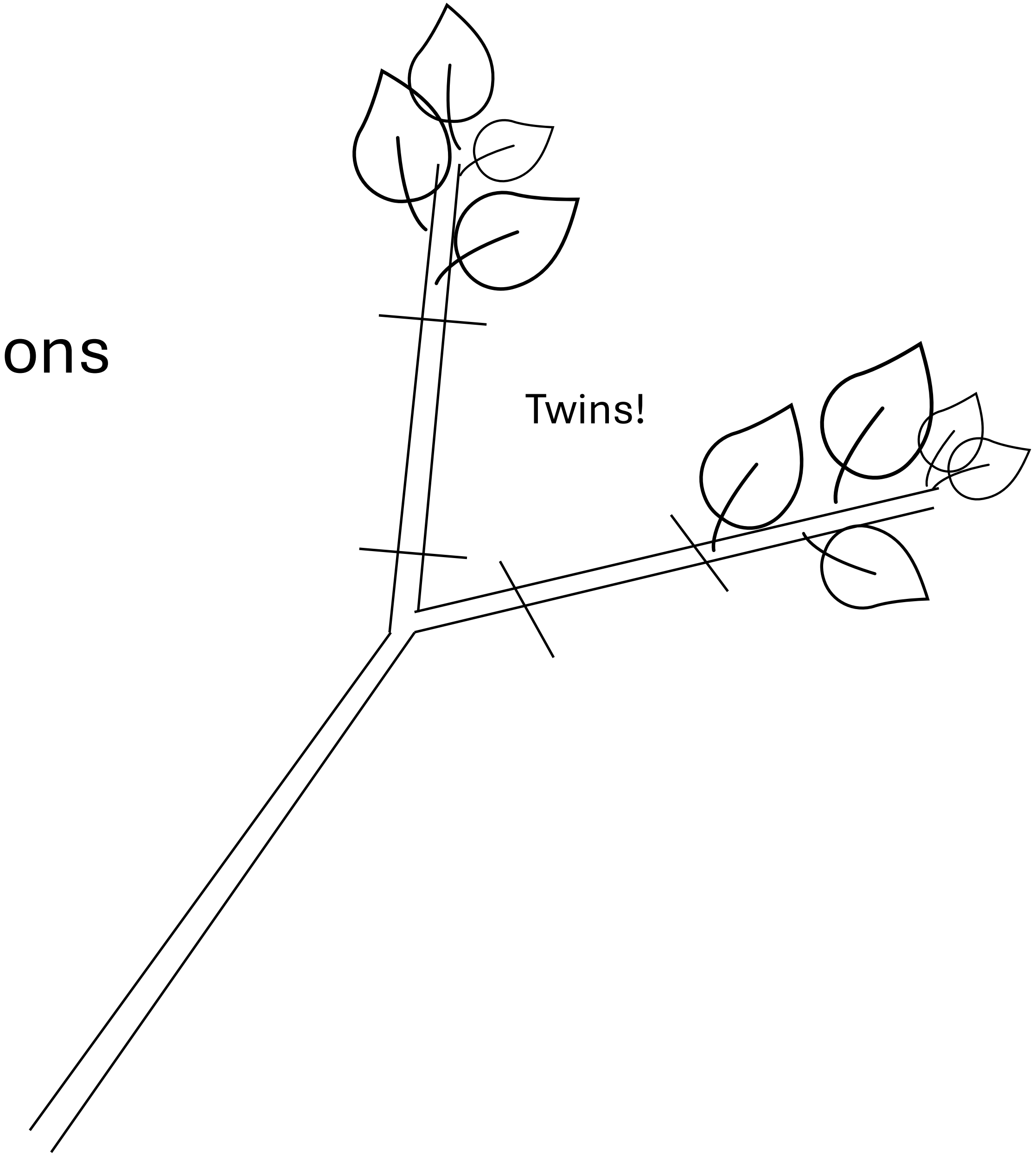


Sample collection

Trembling Aspen (*Populus tremuloides*)

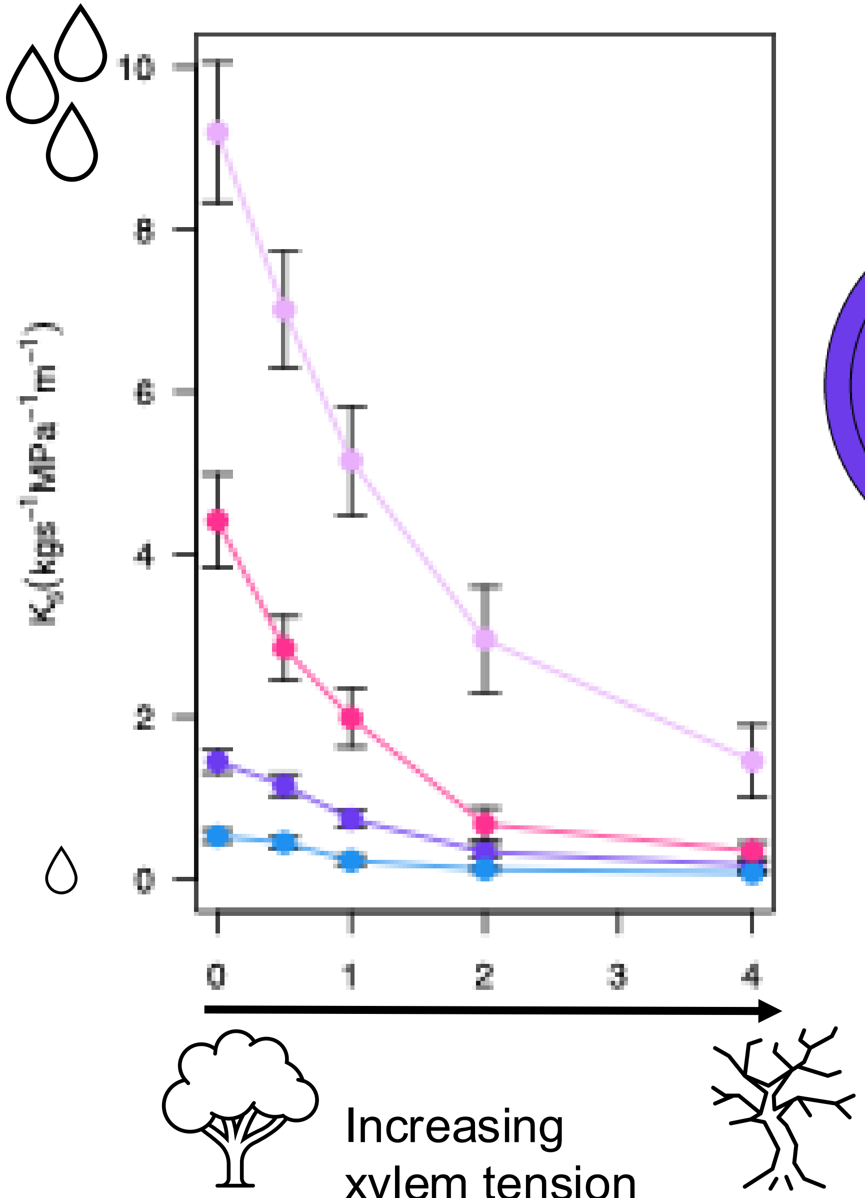
Used forked branches

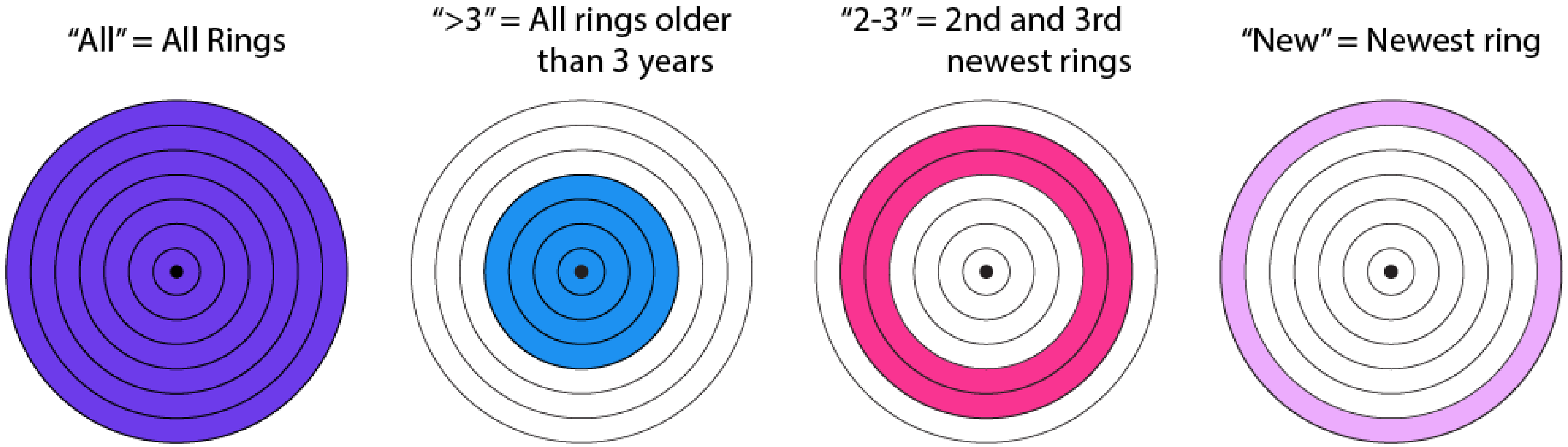
- one branch used for dye perfusions
- one branch used for hydraulics



Do we see differences between different aged rings?

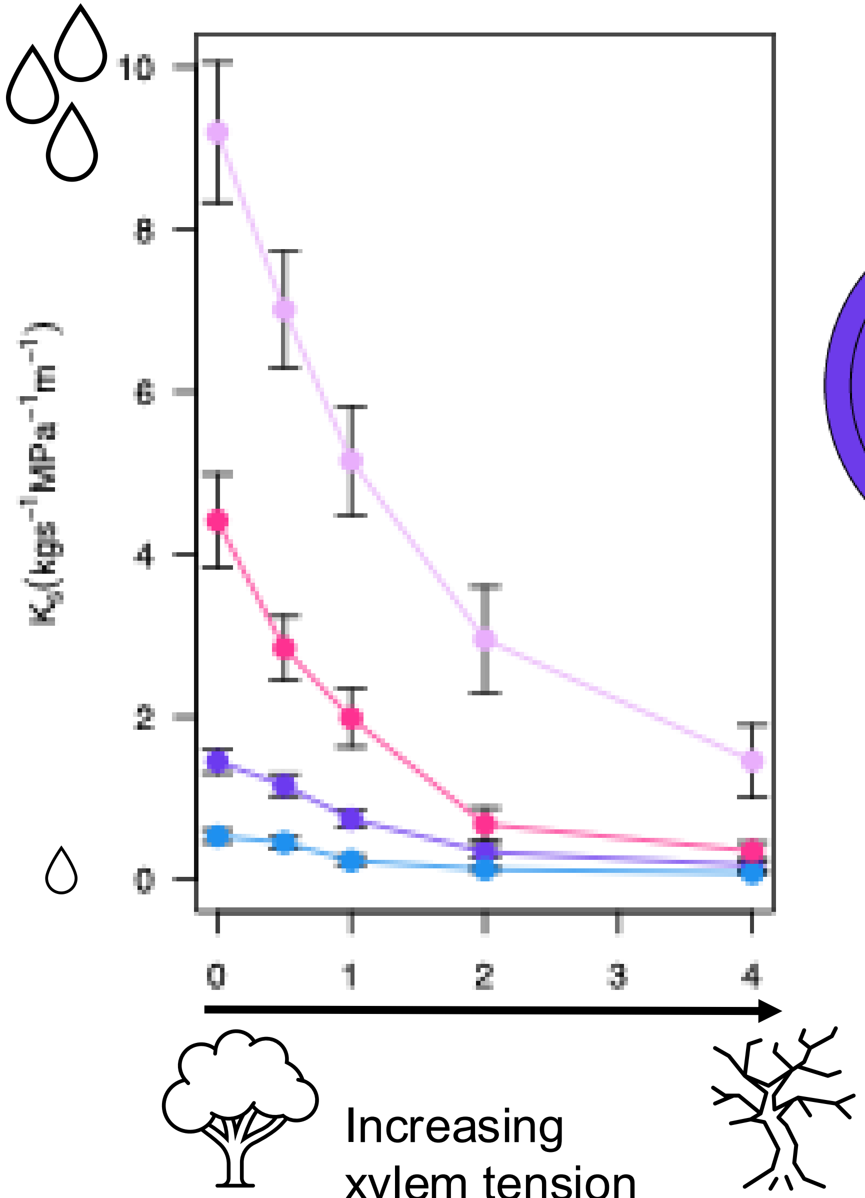
Conductivity results across rings

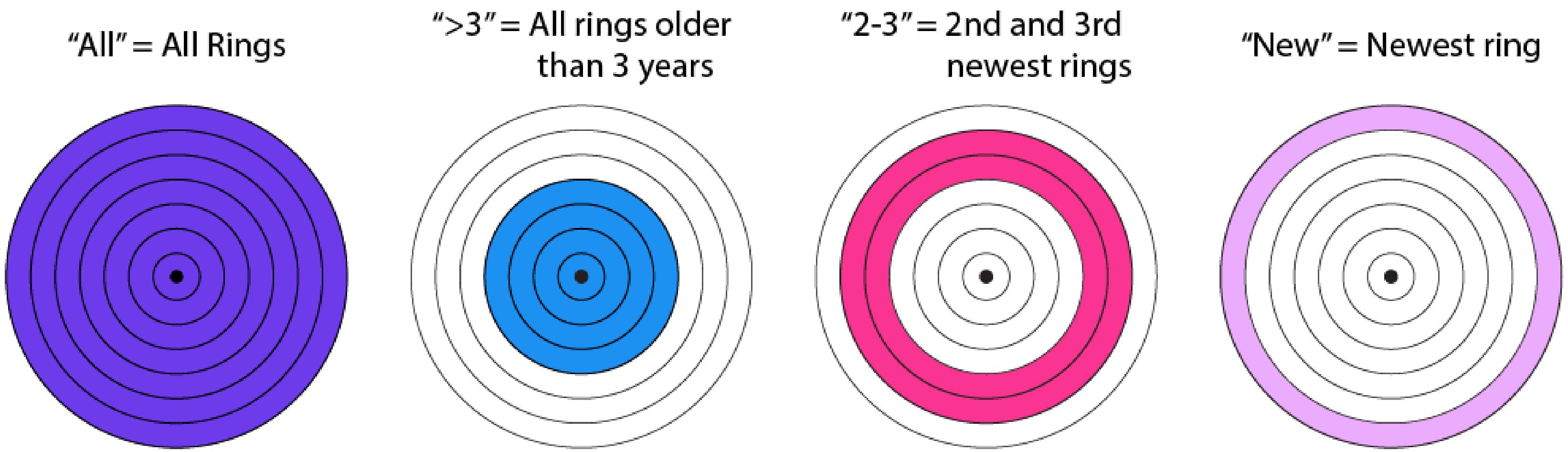




Fickle et al. 2025. *New Phytologist*.

Conductivity results across rings

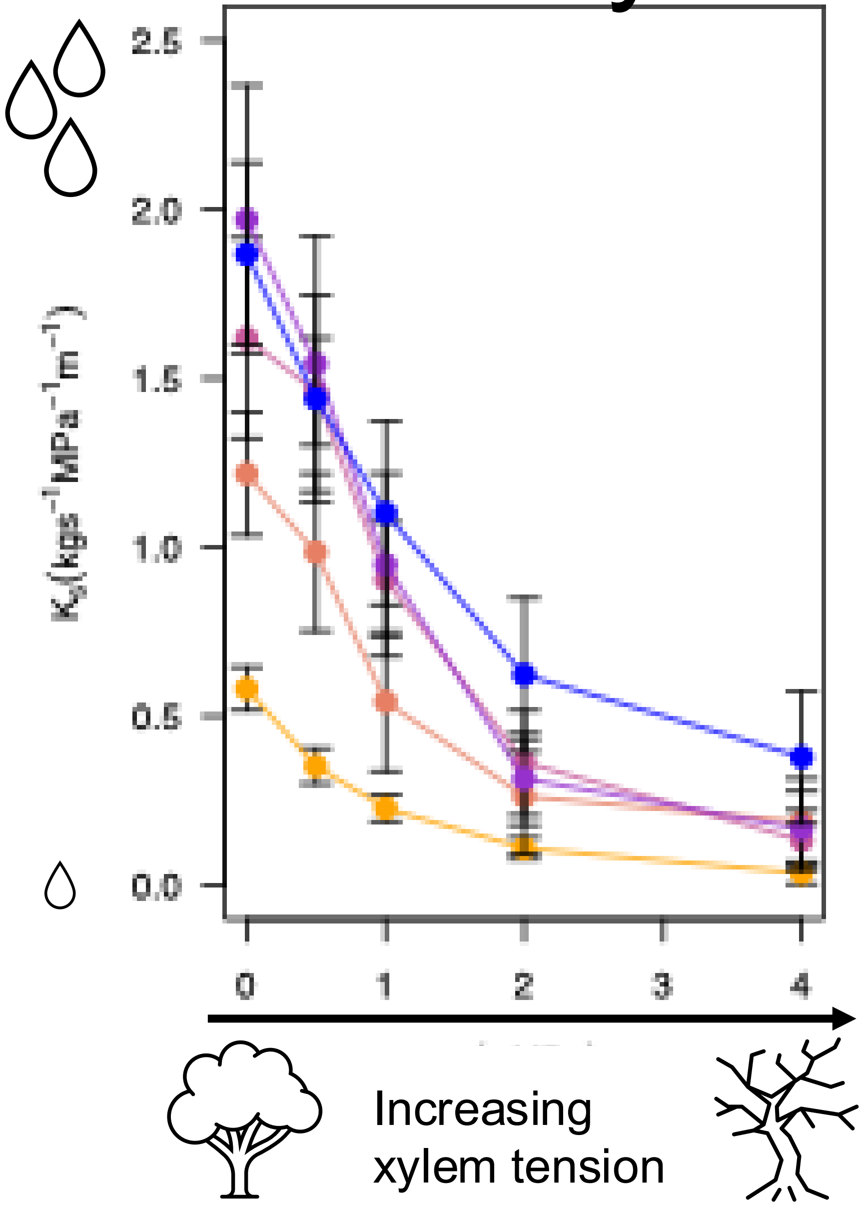




Newest ring= Highest conductivity
2–3-year-old ring= Intermediate conductivity
Oldest rings = Lowest conductivity

Fickle et al. 2025. *New Phytologist*.

Conductivity results across populations



Wet

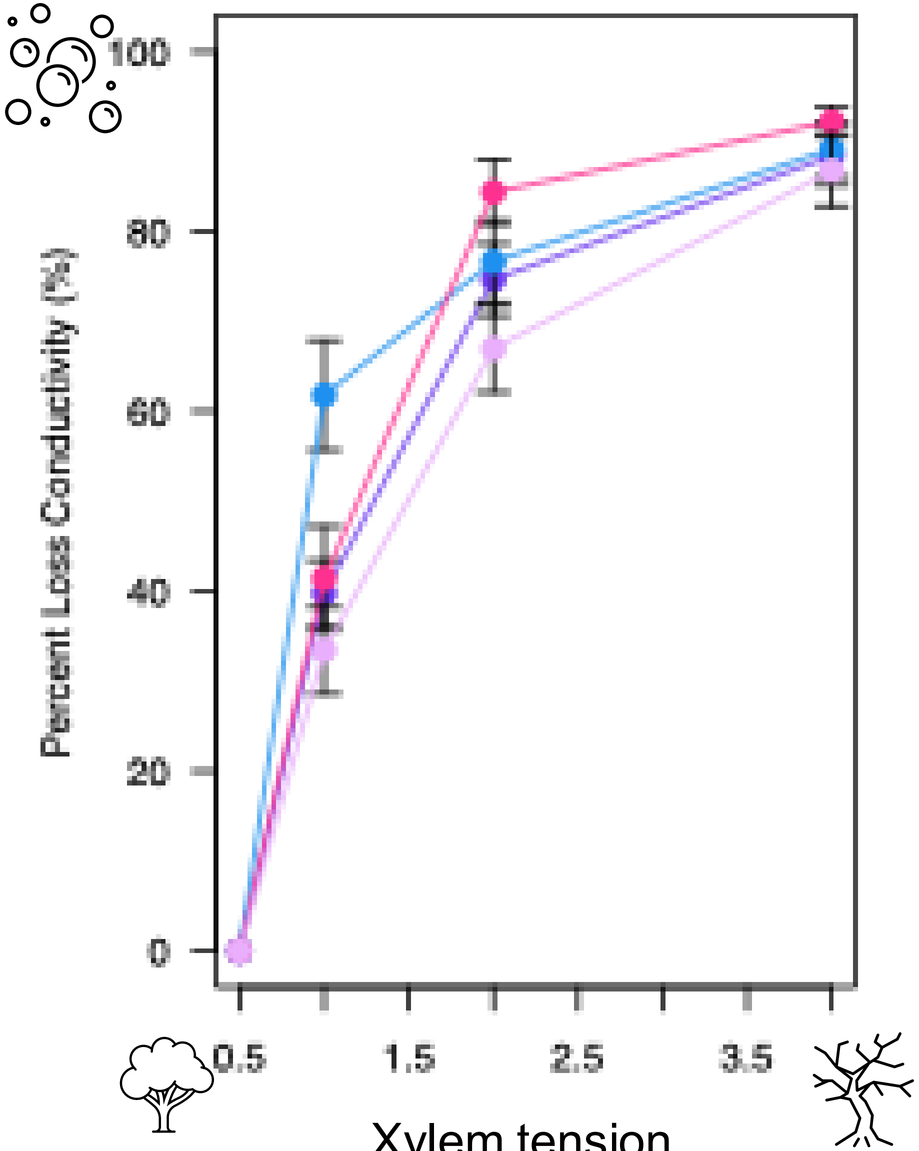
Dry

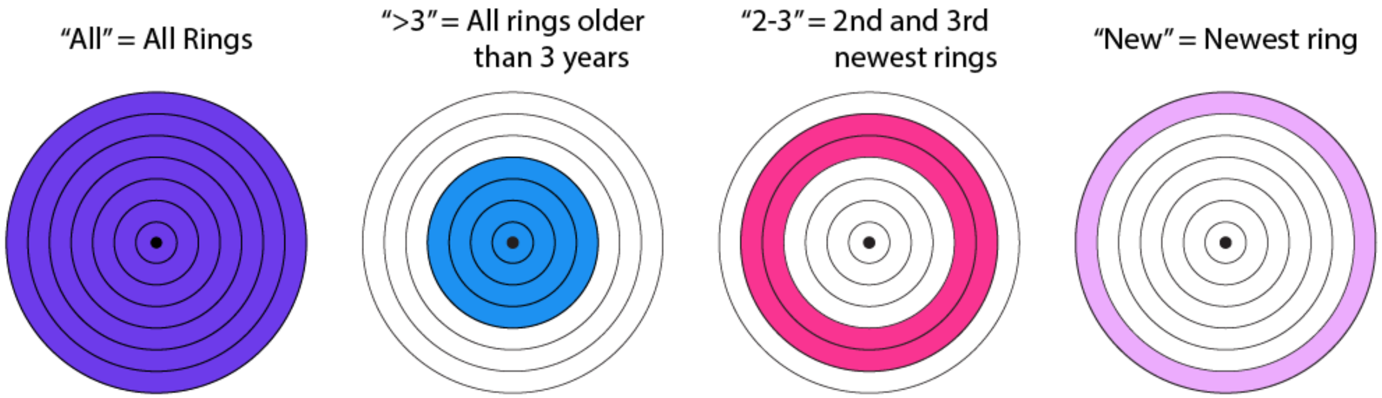
Population:
- Uinta
- White River
- Uncompahgre
- San Juan
- Dixie

Wettest populations = high conductivity
Driest populations = low conductivity

Fickle et al. 2025. *New Phytologist*.

Vulnerability curves across rings

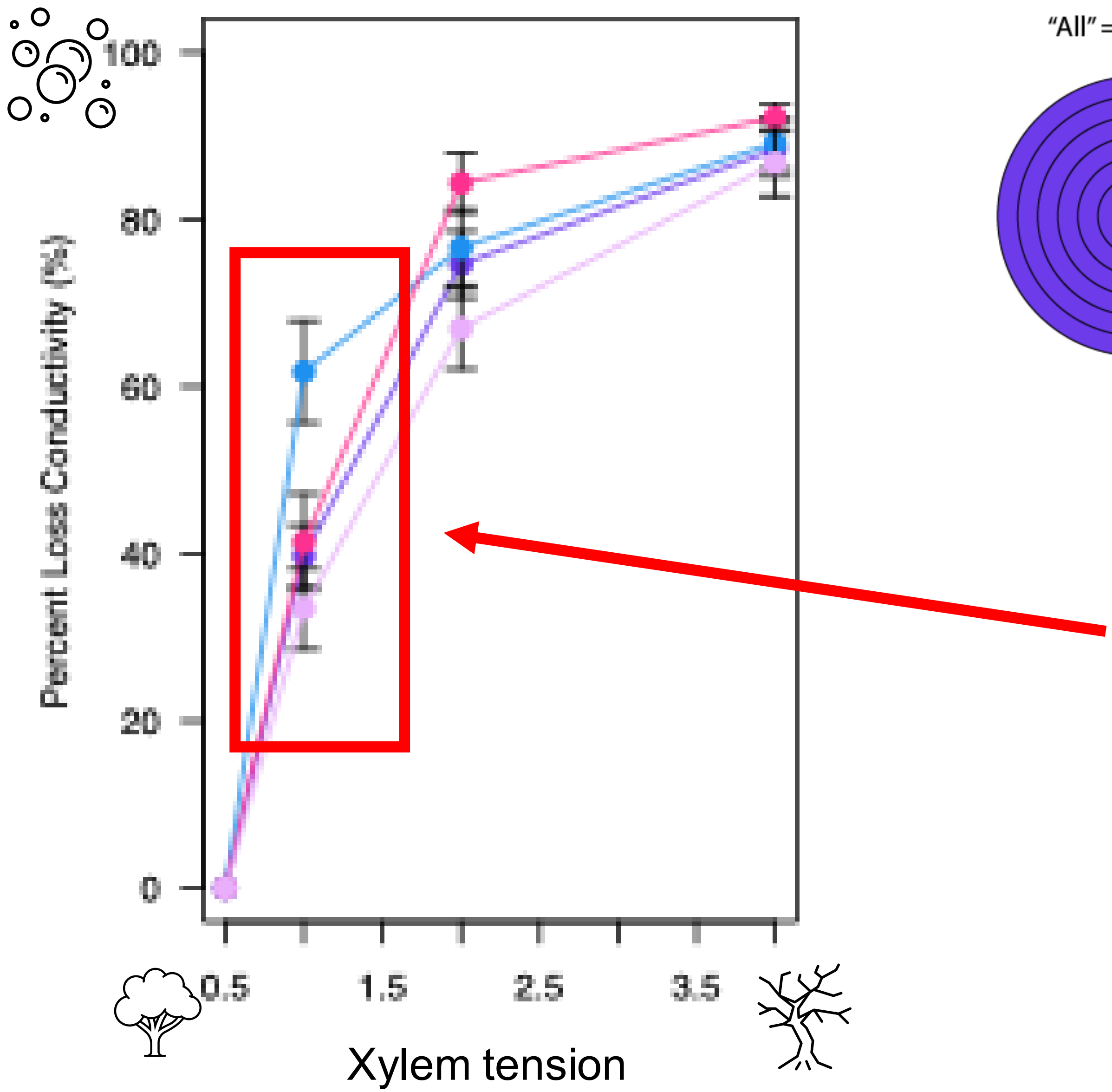


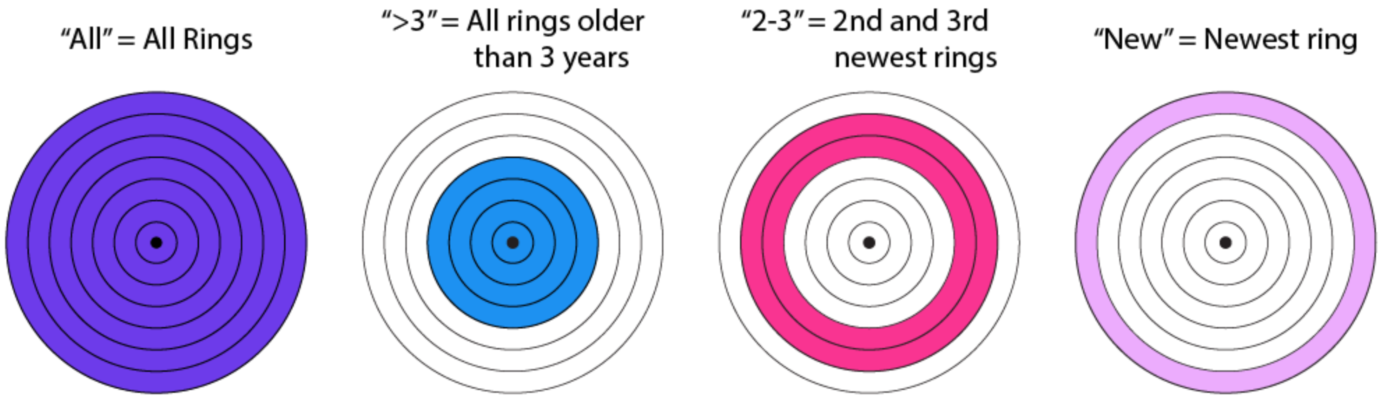


Generally:
Old rings more vulnerable
New rings more resistant

Fickle et al. 2025. *New Phytologist*.

Vulnerability curves across rings



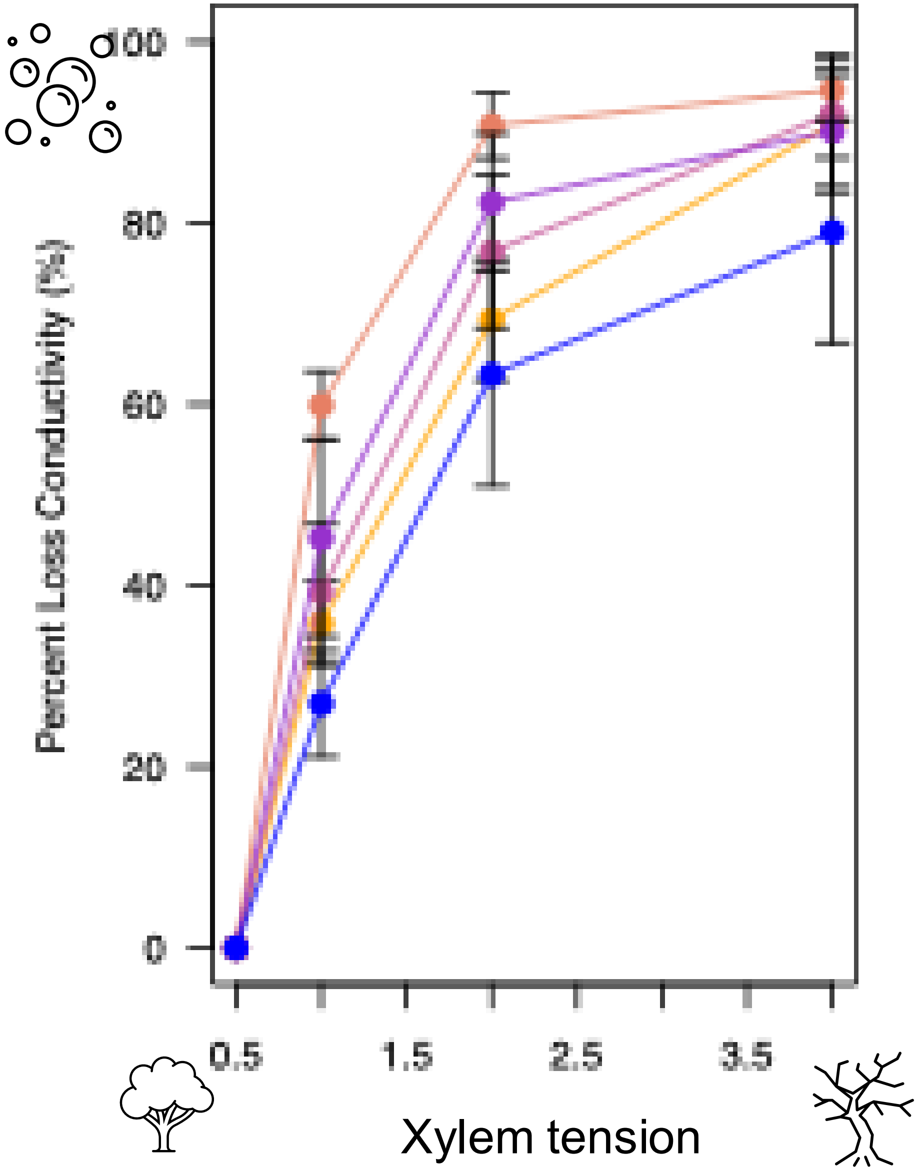


Biggest differences seen at xylem tension of 1MPa

Average Aspen summer midday xylem tension

Fickle et al. 2025. *New Phytologist*.

Vulnerability curves across populations



Wet

Dry

Population:
- Uinta
- White River
- Uncompahgre
- San Juan
- Dixie

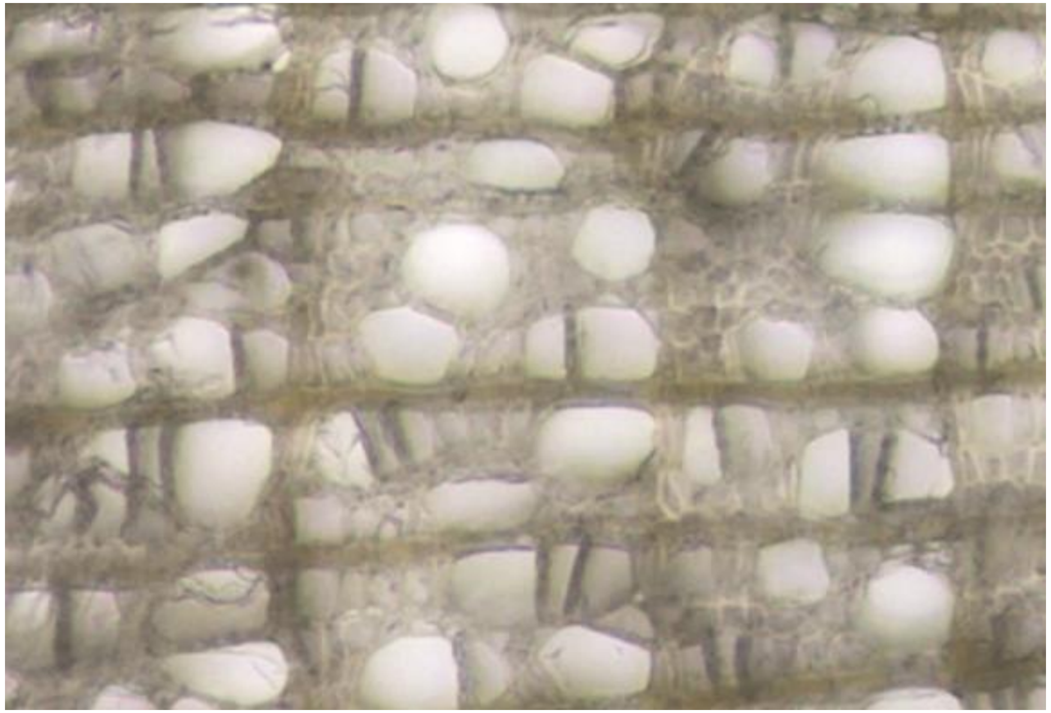
Dry site (SJ) more vulnerable
Wet site (UI) more resistant

Fickle et al. 2025. *New Phytologist*.

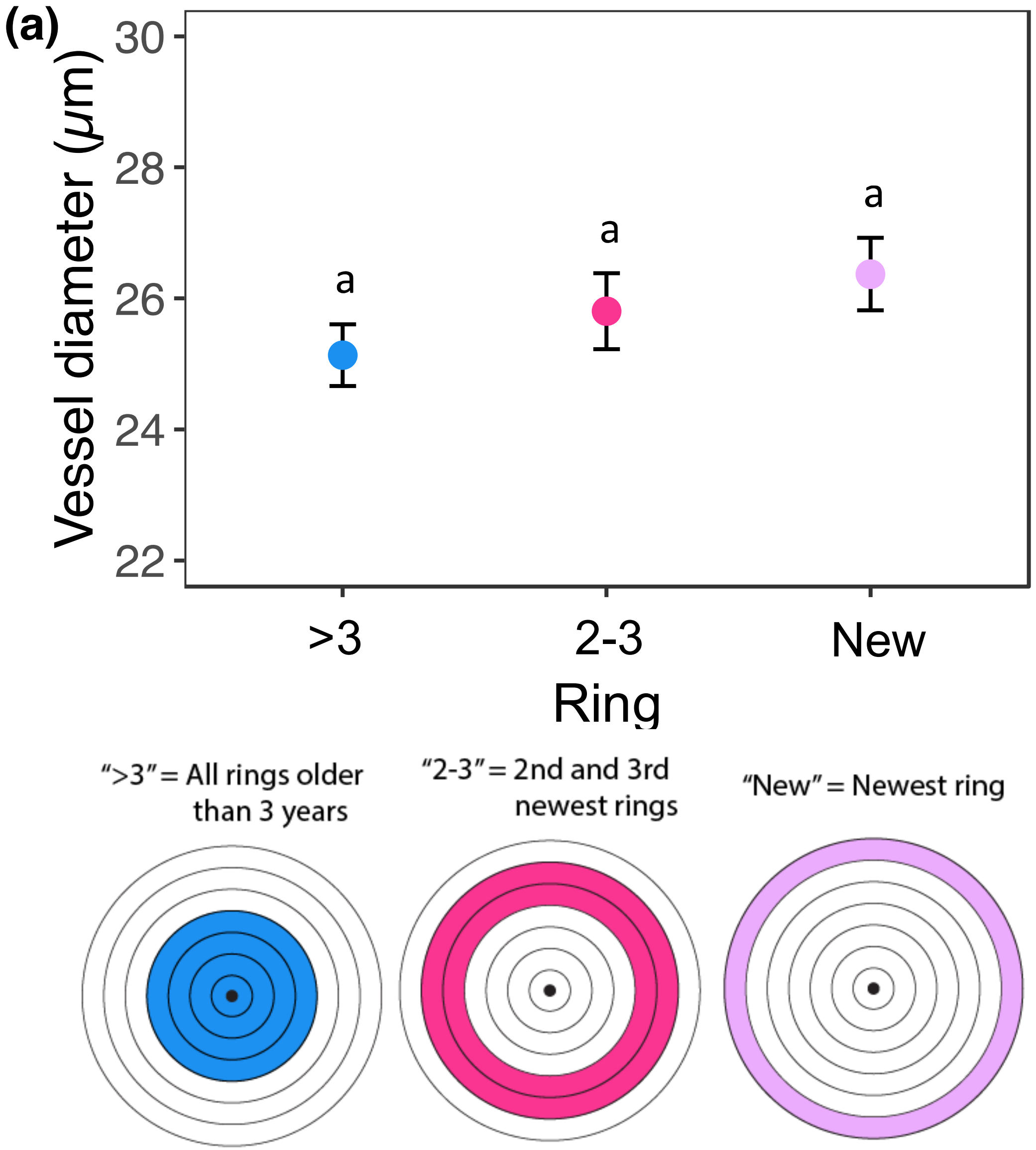
Why do we see differences in the amount of conductivity in each ring?

Vessel diameter?

- Larger vessel diameters= less resistance to flow, more water conductance
  - conductivity related to VD^4



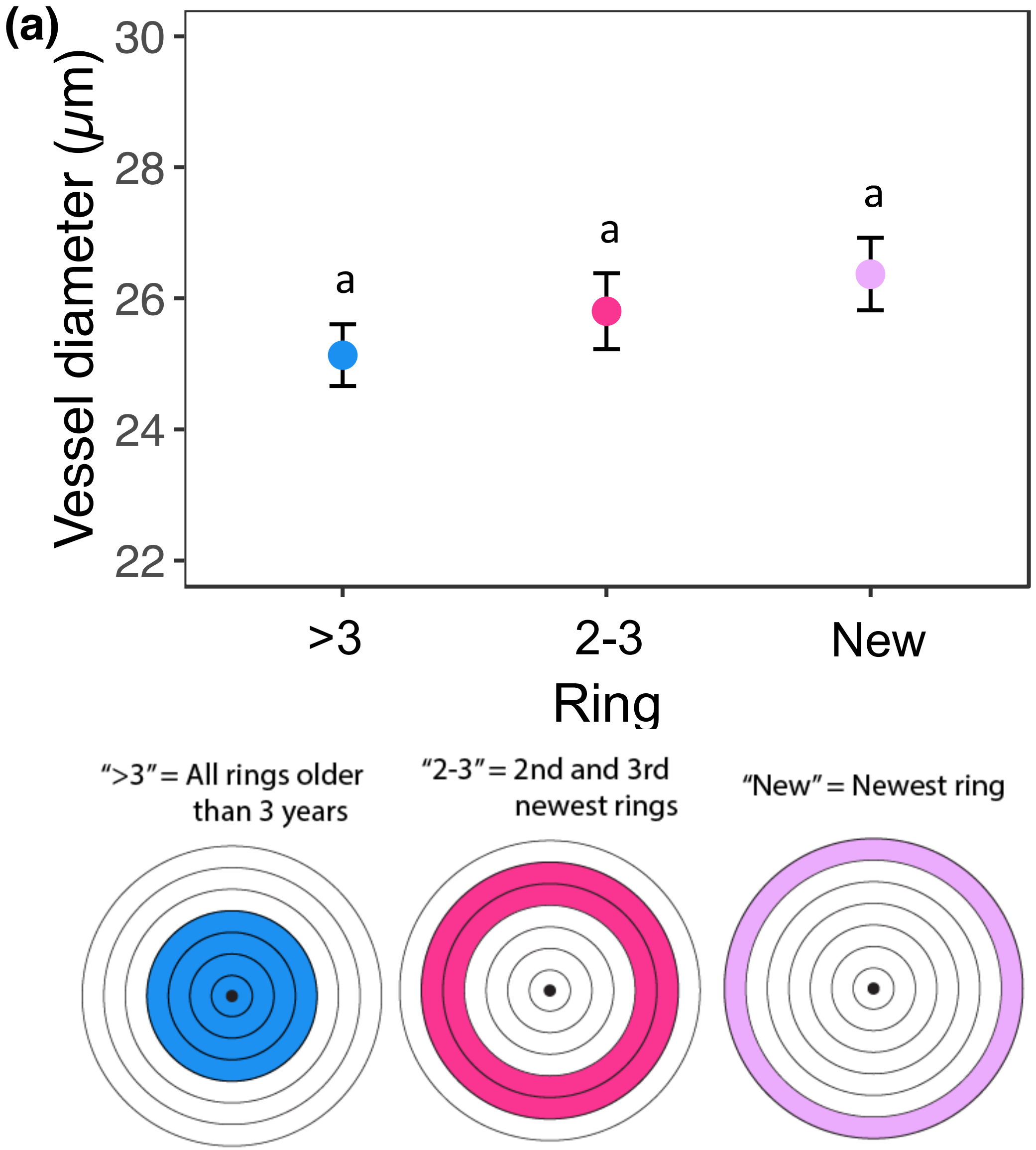
Vessel diameter



No difference in vessel diameter size between the different rings

Fickle et al. 2025. *New Phytologist*.

Vessel diameter



No difference in vessel diameter size between the different rings

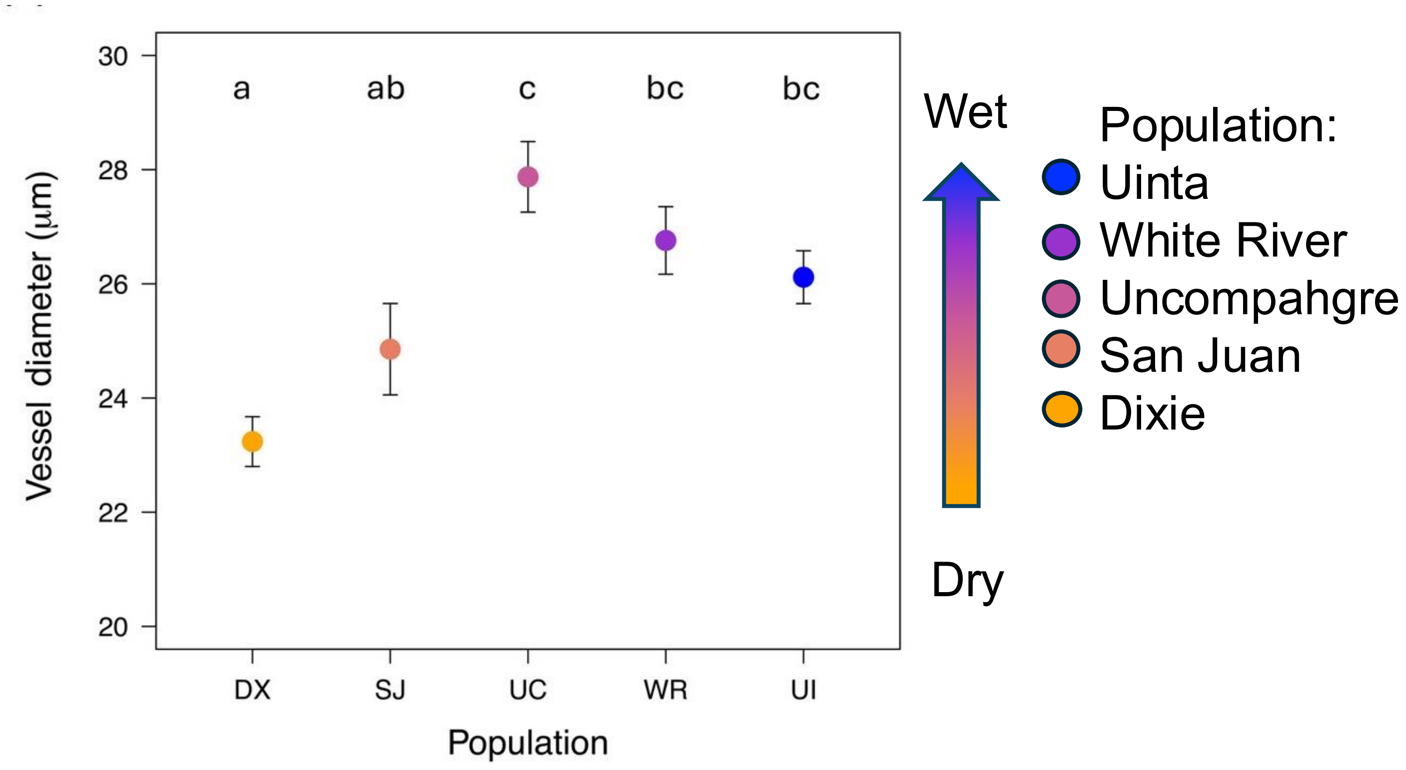
Differences in hydraulic conductance between rings ≠ differences in VD

- Difference is likely due to xylem damages

Fickle et al. 2025. *New Phytologist*.

Vessel diameters between populations

There were differences between populations.

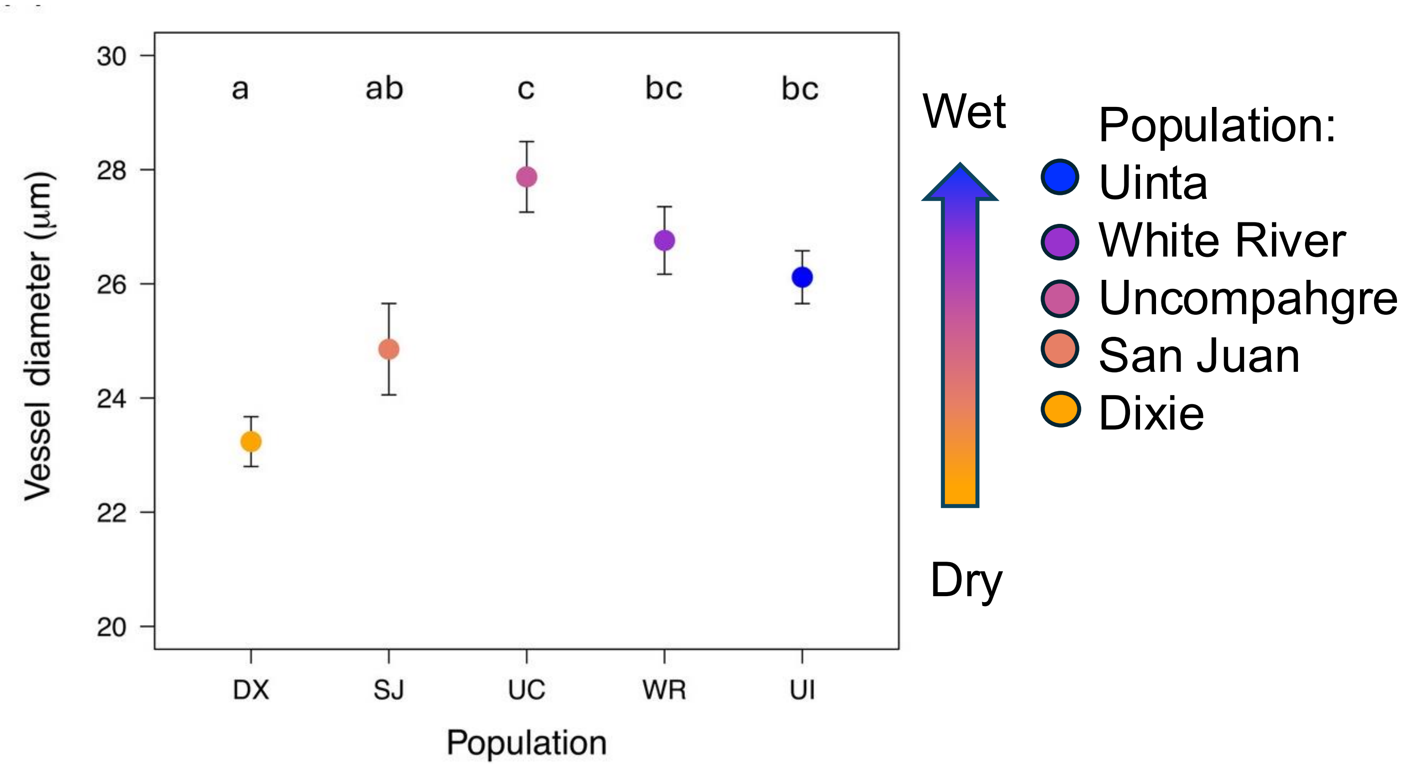


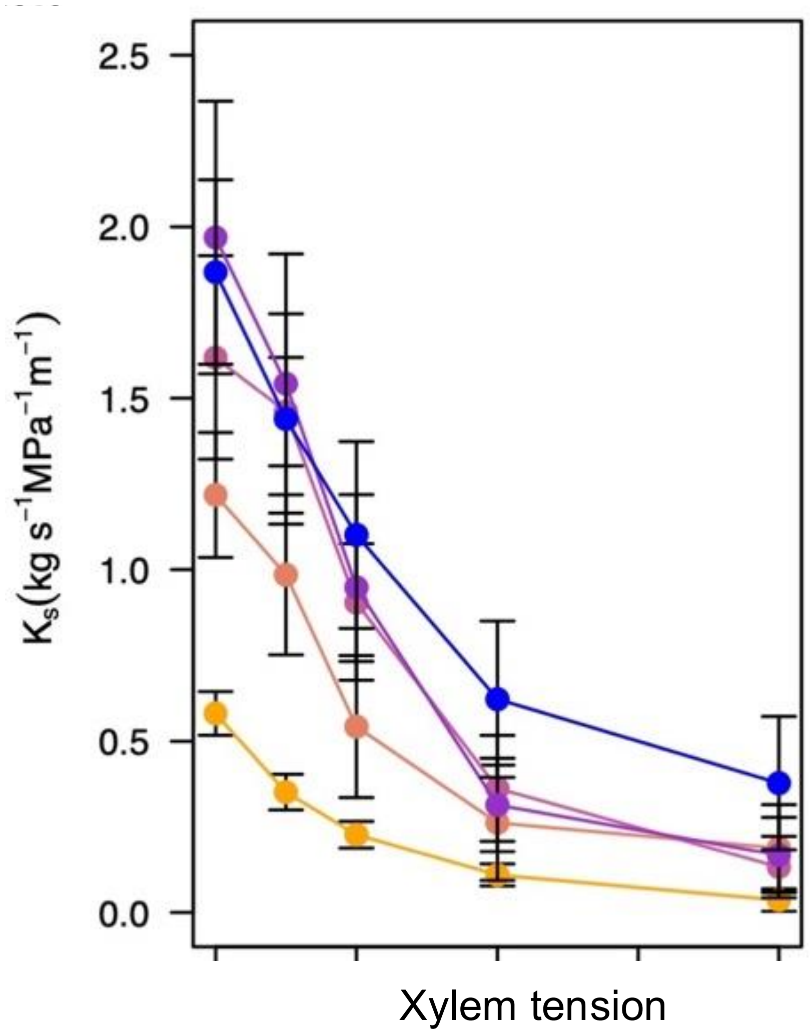
Fickle et al. 2025. *New Phytologist*.

Vessel diameters between populations

There were differences between populations.

Supports differences in conductivity findings.





Fickle et al. 2025. *New Phytologist*.

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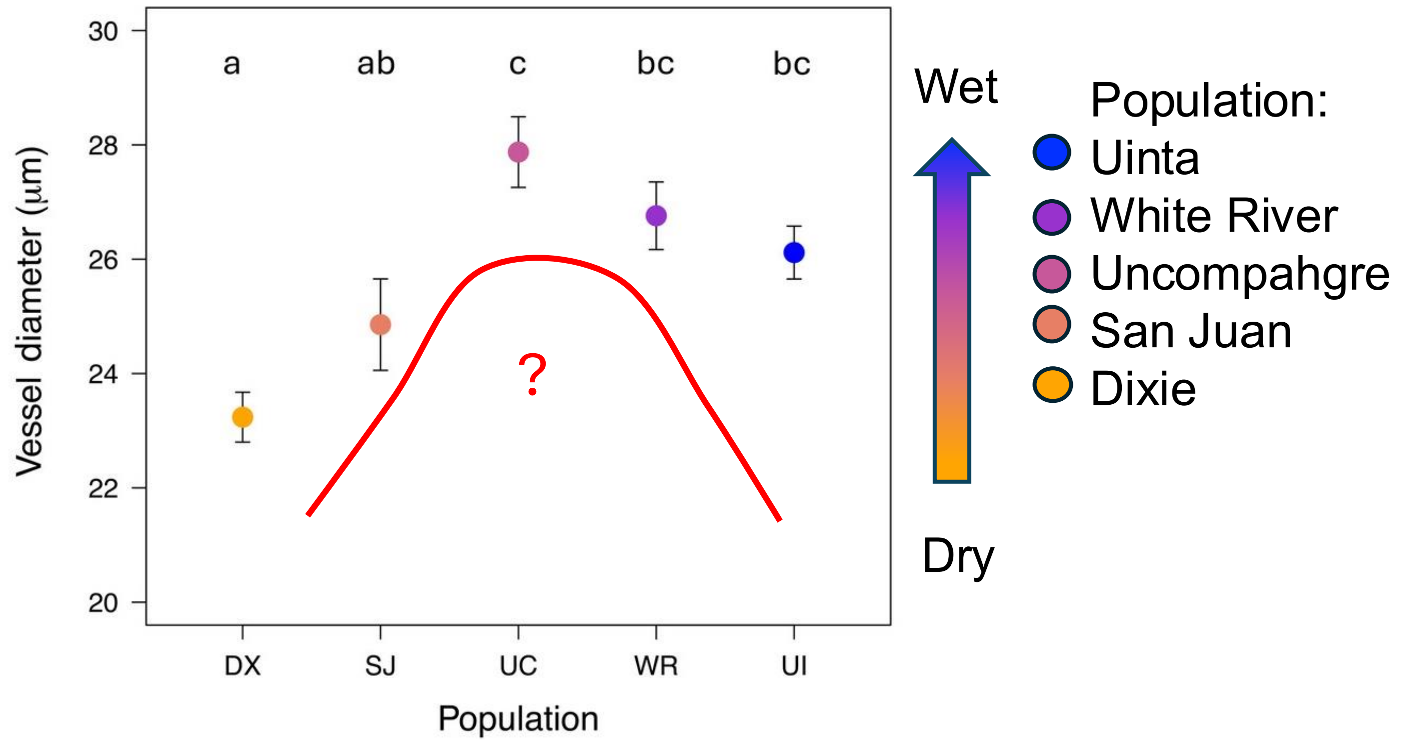
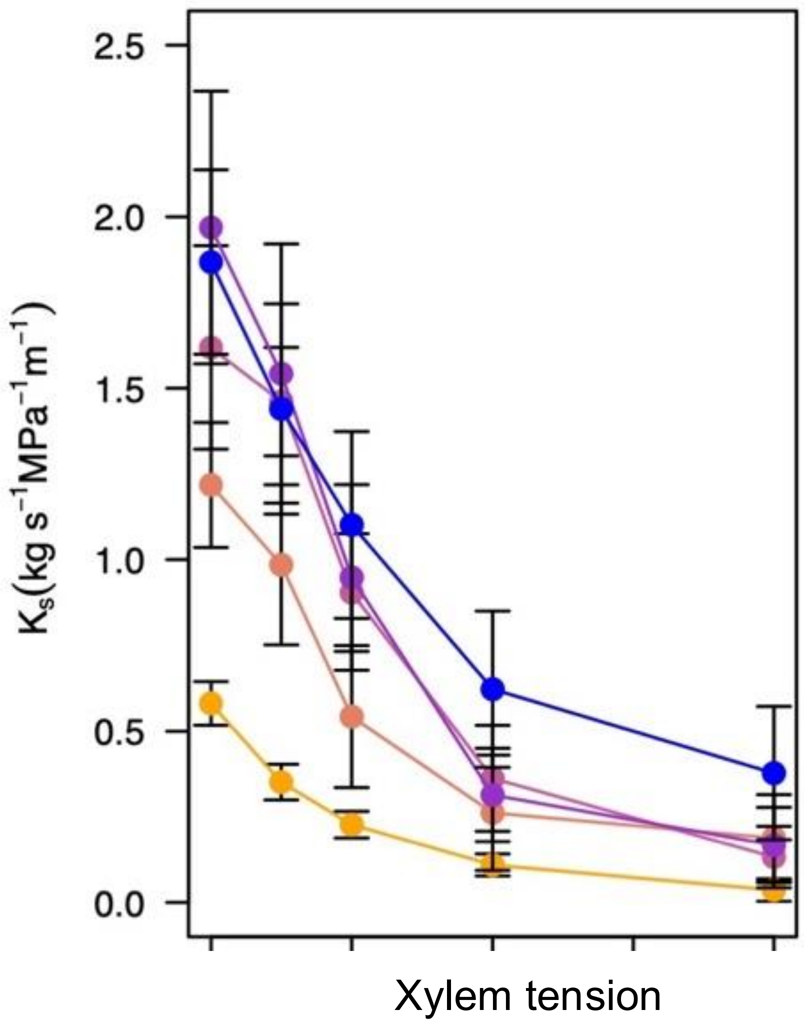
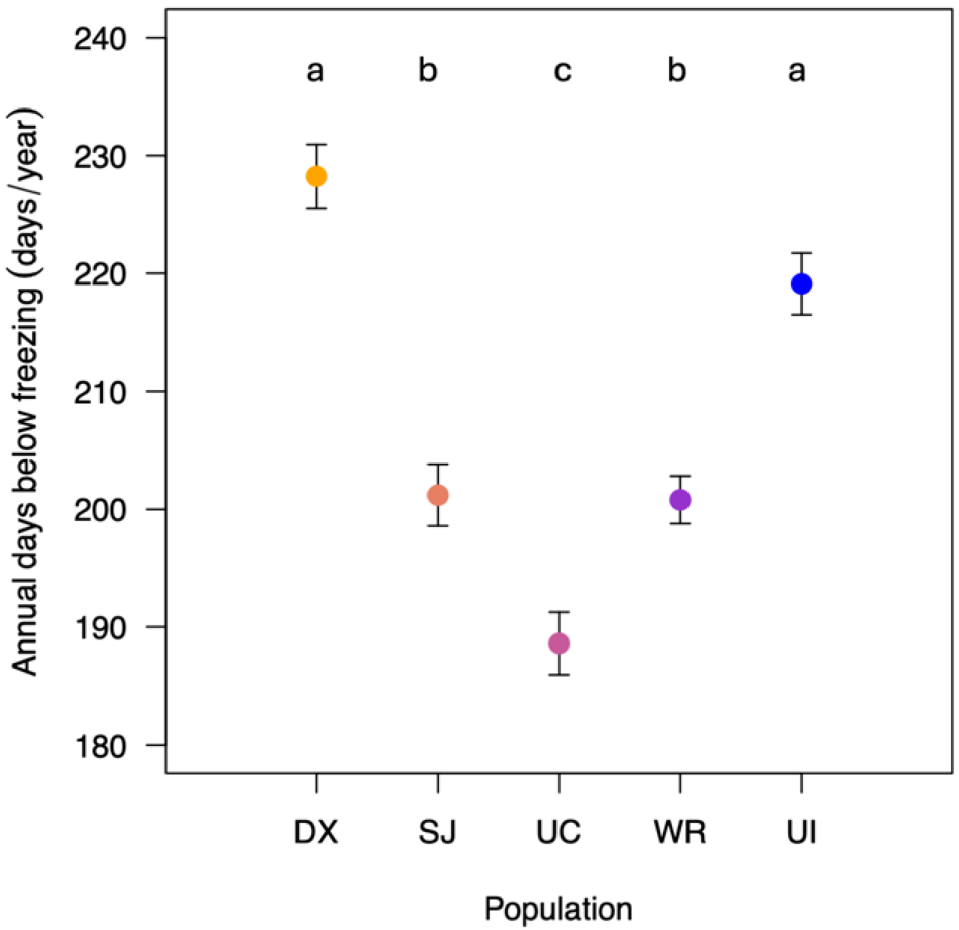


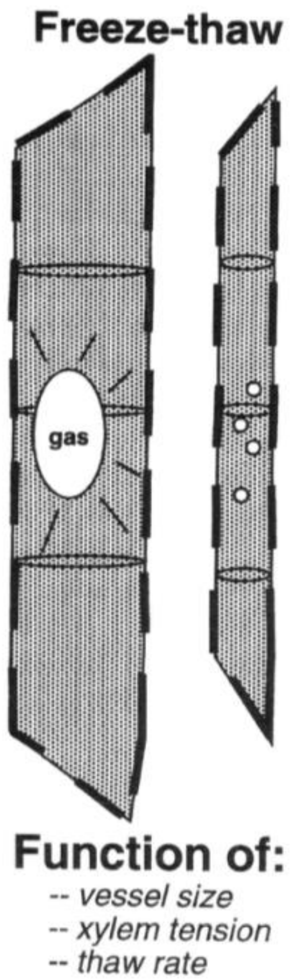
Supports differences in conductivity findings.



Fickle et al. 2025. *New Phytologist*.

Vessel diameters & Freeze-thaw embolism





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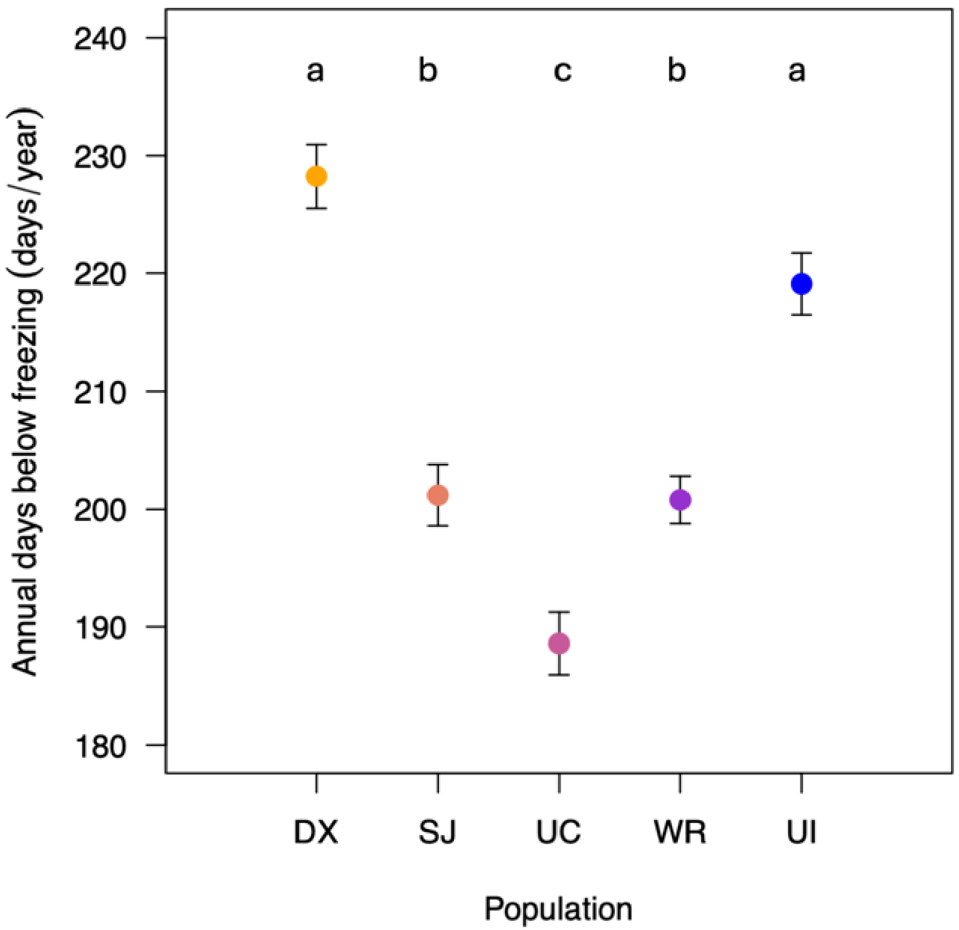
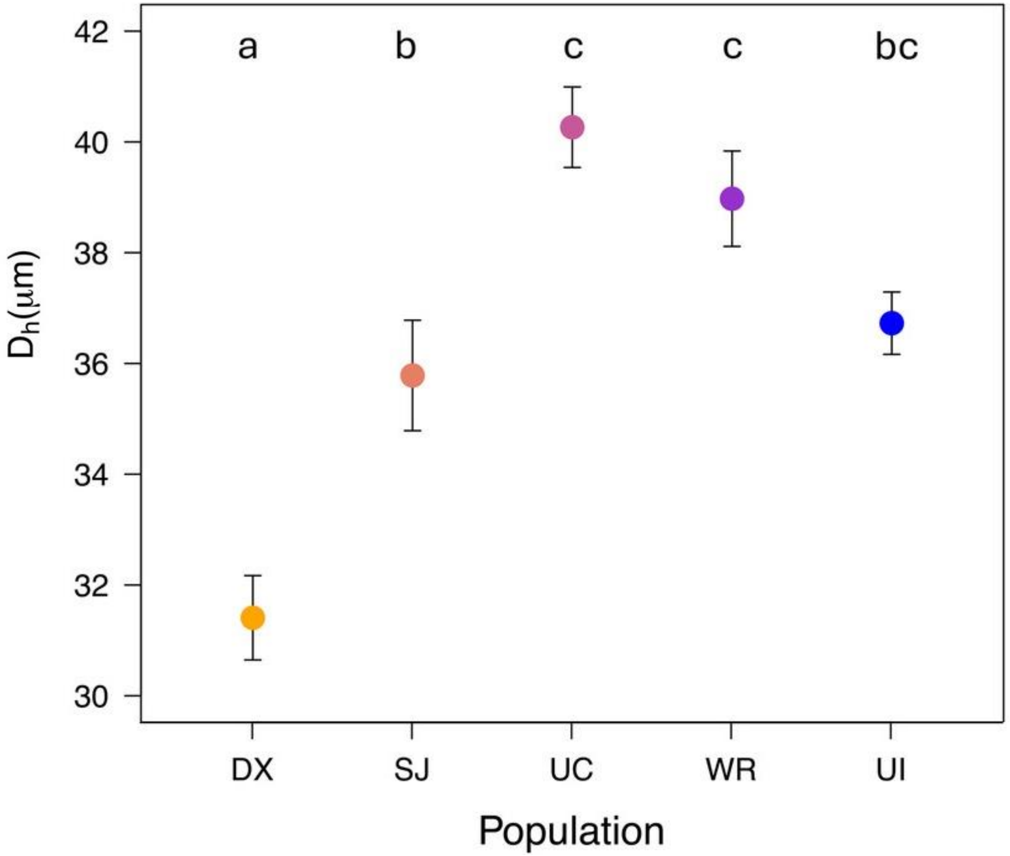
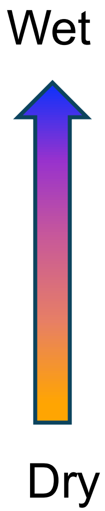
Vessel diameters & Freeze-thaw embolism







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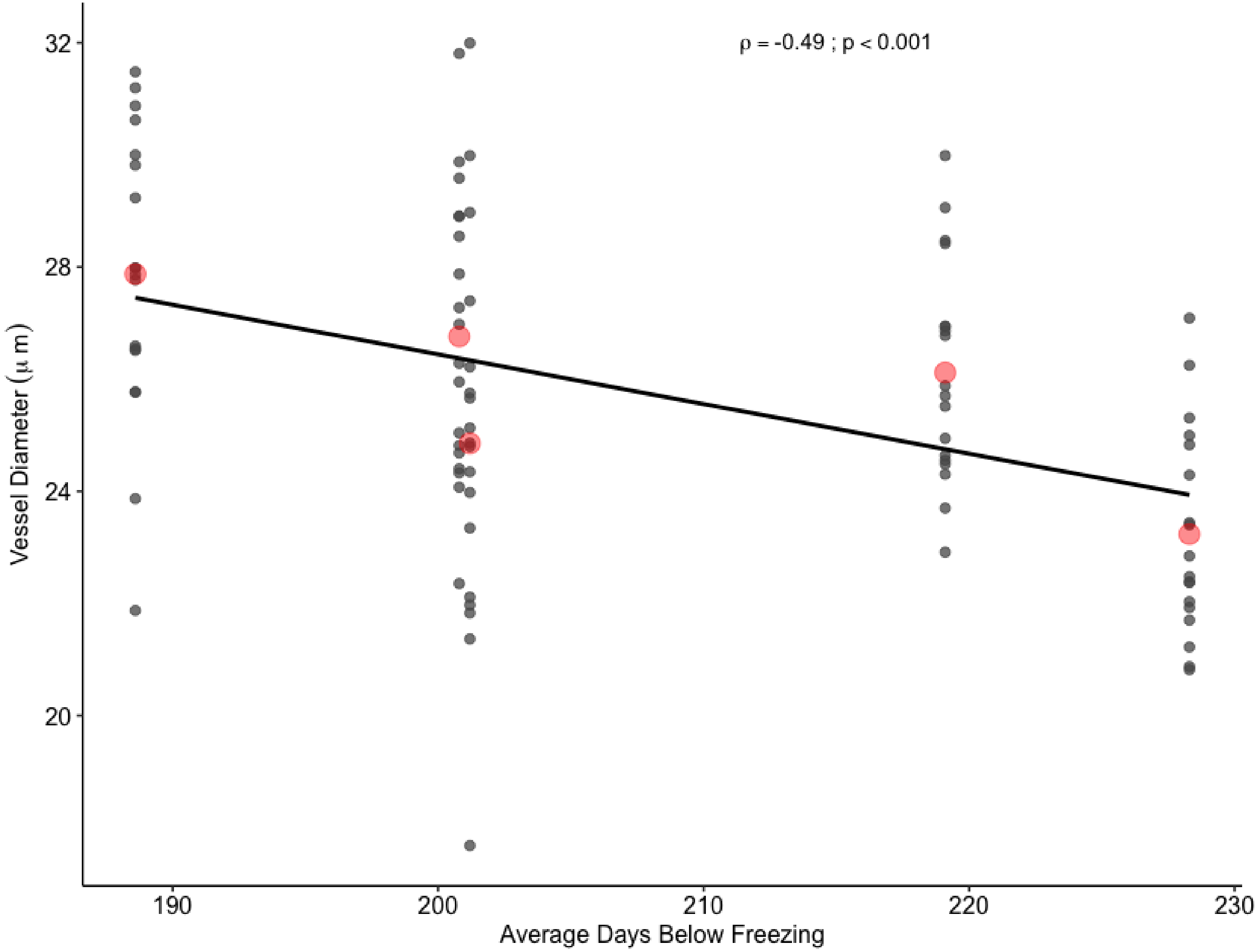
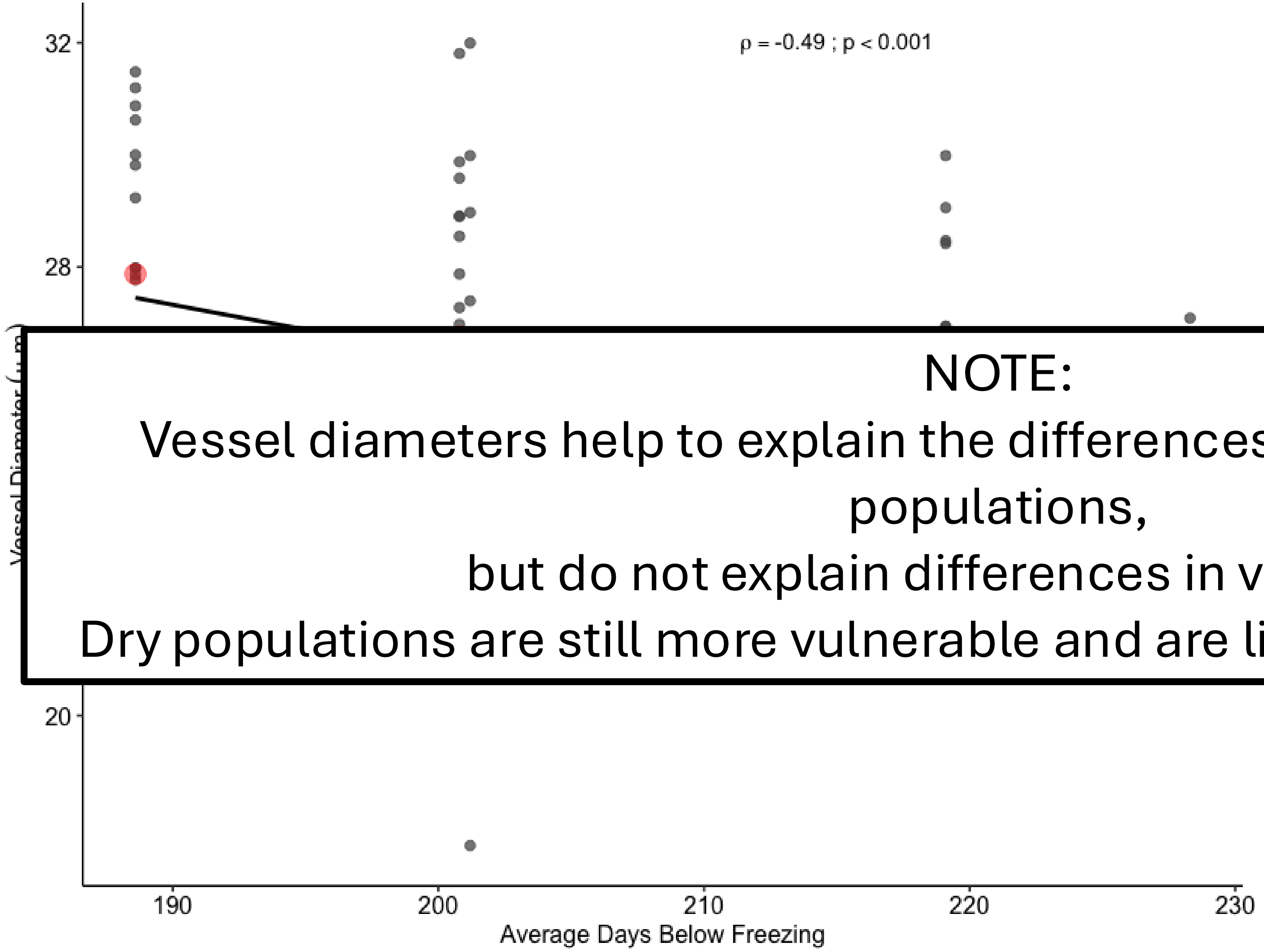
Vessel diameters & Freeze-thaw embolism



Significant correlation between the vessel diameter size and the number of days below freezing

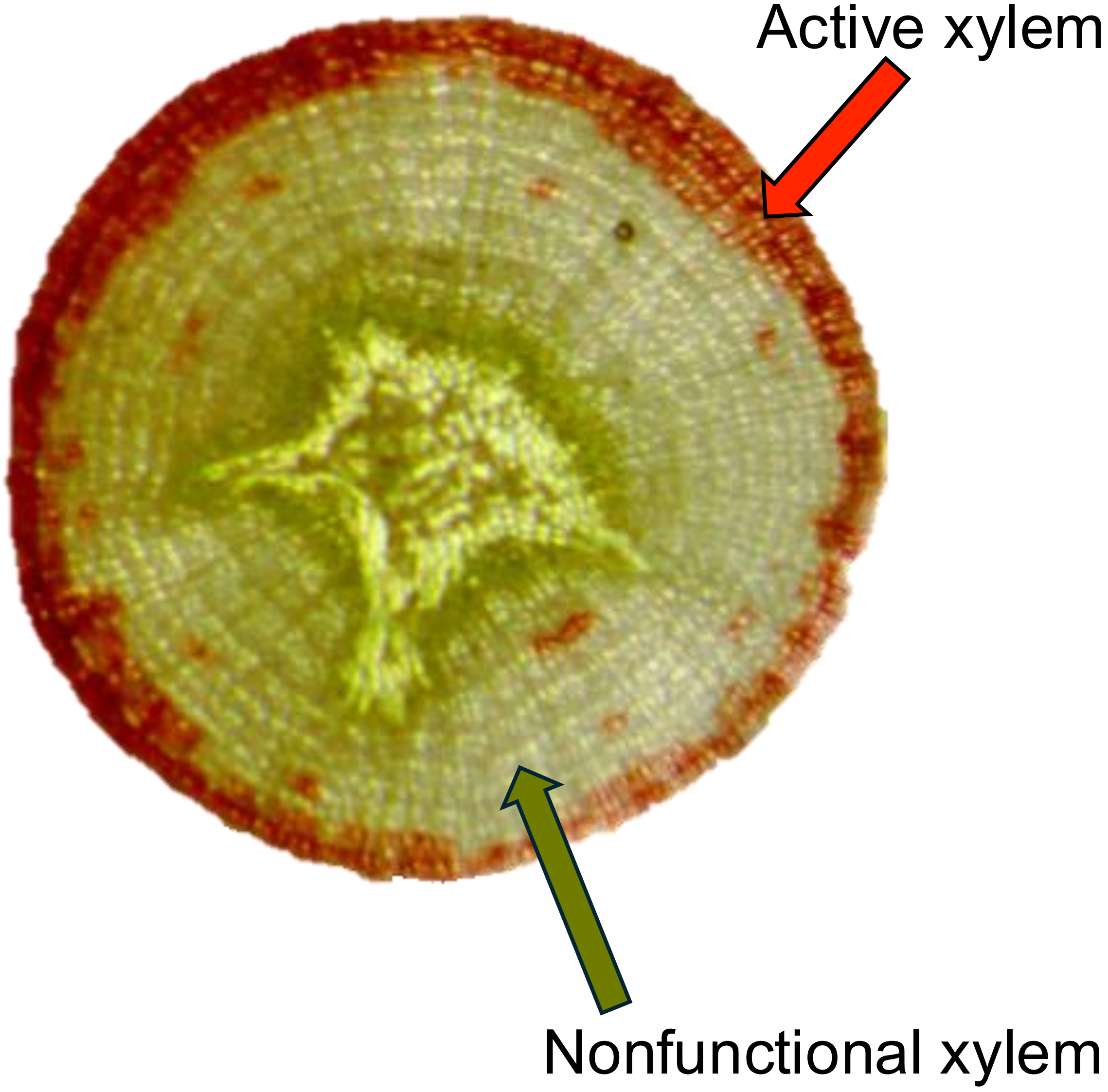
Vessel diameters & Freeze-thaw embolism



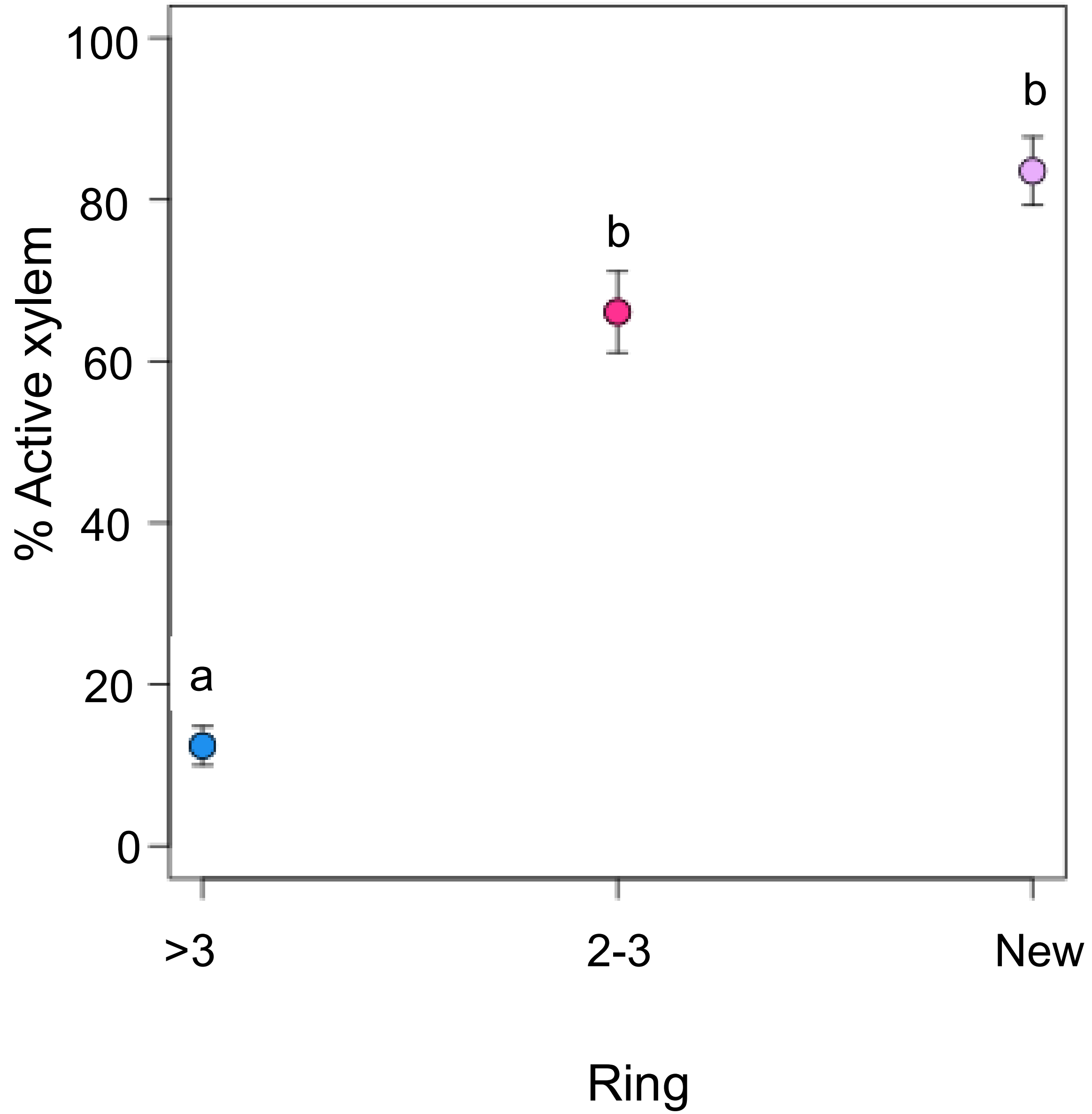
NOTE:
Vessel diameters help to explain the differences in conductivity between populations,
but do not explain differences in vulnerability
Dry populations are still more vulnerable and are likely due to drought damage

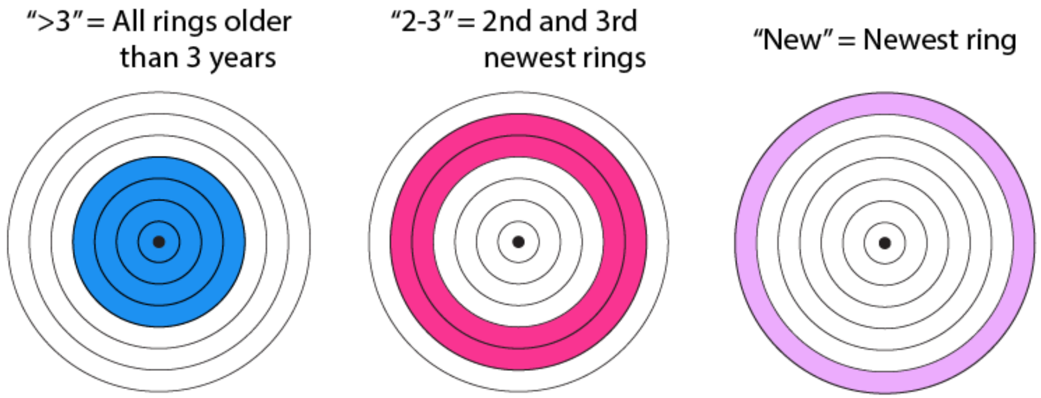
How do these hydraulic measurements compare to active xylem area?

Dye Perfusions



Dye Perfusions across rings





Old rings had significantly less active xylem

Supports conductivity data

No differences between the poulations

Fickle et al. 2025. *New Phytologist*.

Ring Level Differences

- Do different aged rings transport water differently?
  - Old rings= conduct less water
  - New rings= conduct more water

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- Do different aged rings resist embolism differently?
  - Old rings= more vulnerable to embolism at average conditions
  - New rings= more resistant to embolism at average conditions
- Why are there differences between the rings?
  - Not due to vessel diameter differences, but likely due to damages
  - Old rings had significantly less active xylem

Population Level Differences

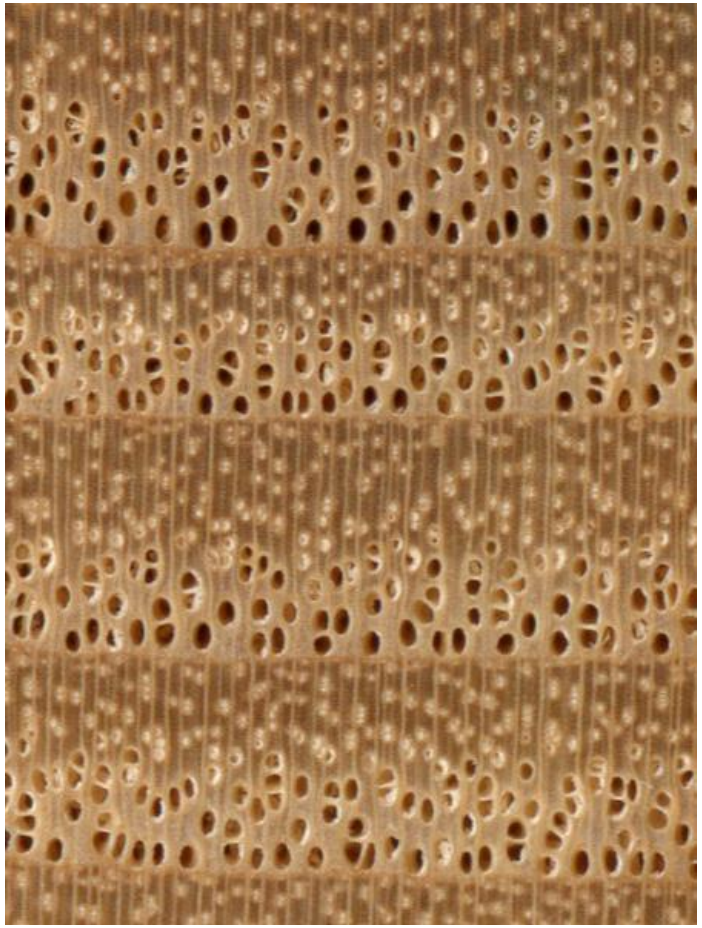
- Wettest site- More resistance to embolism
- Driest sites- More vulnerable to embolism
  - dry sites experiencing some kind of damage
- Differences in vessel diameter and the amount of conductivity

Wood anatomy type

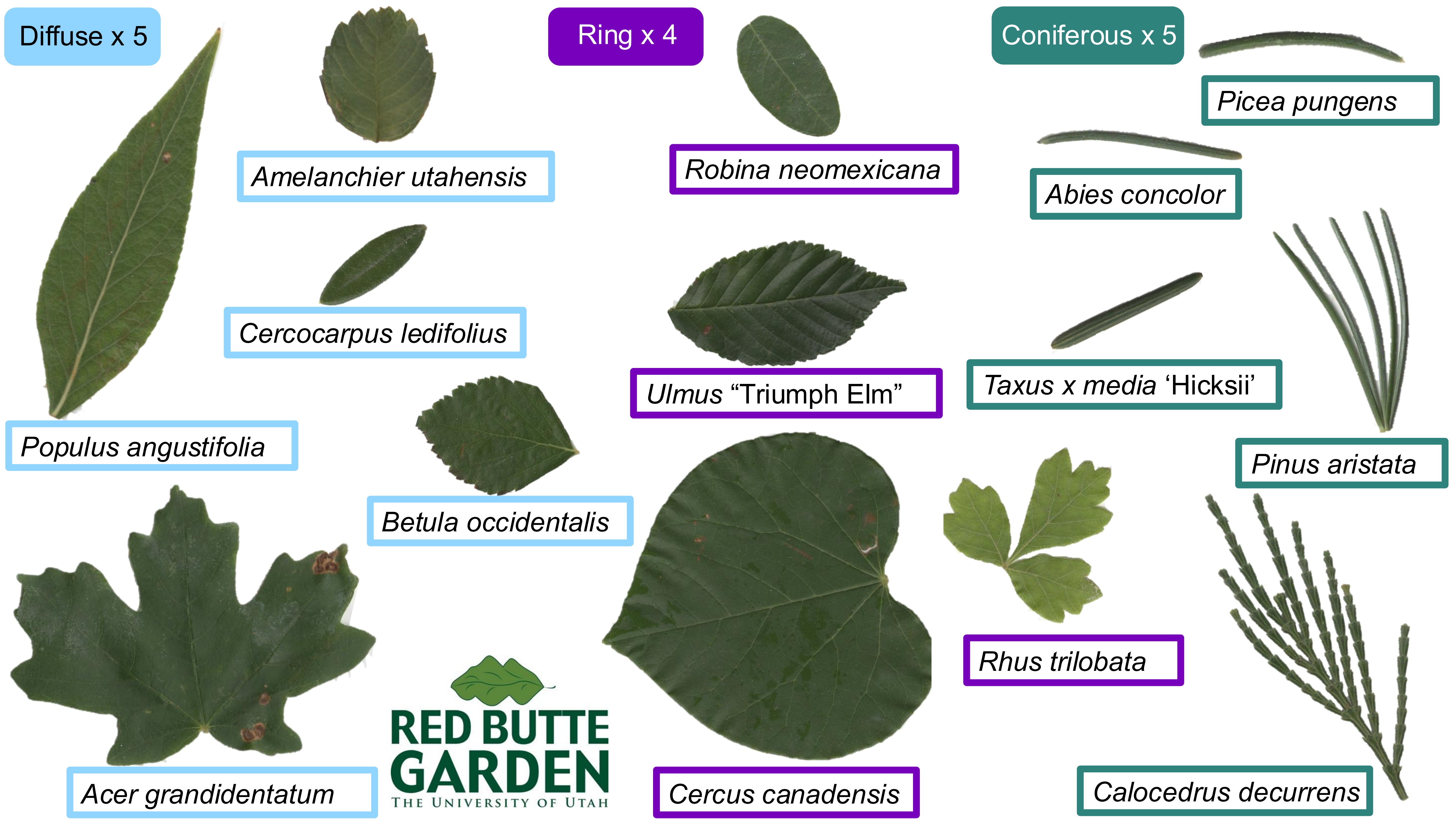
Coniferous

Diffuse-porous

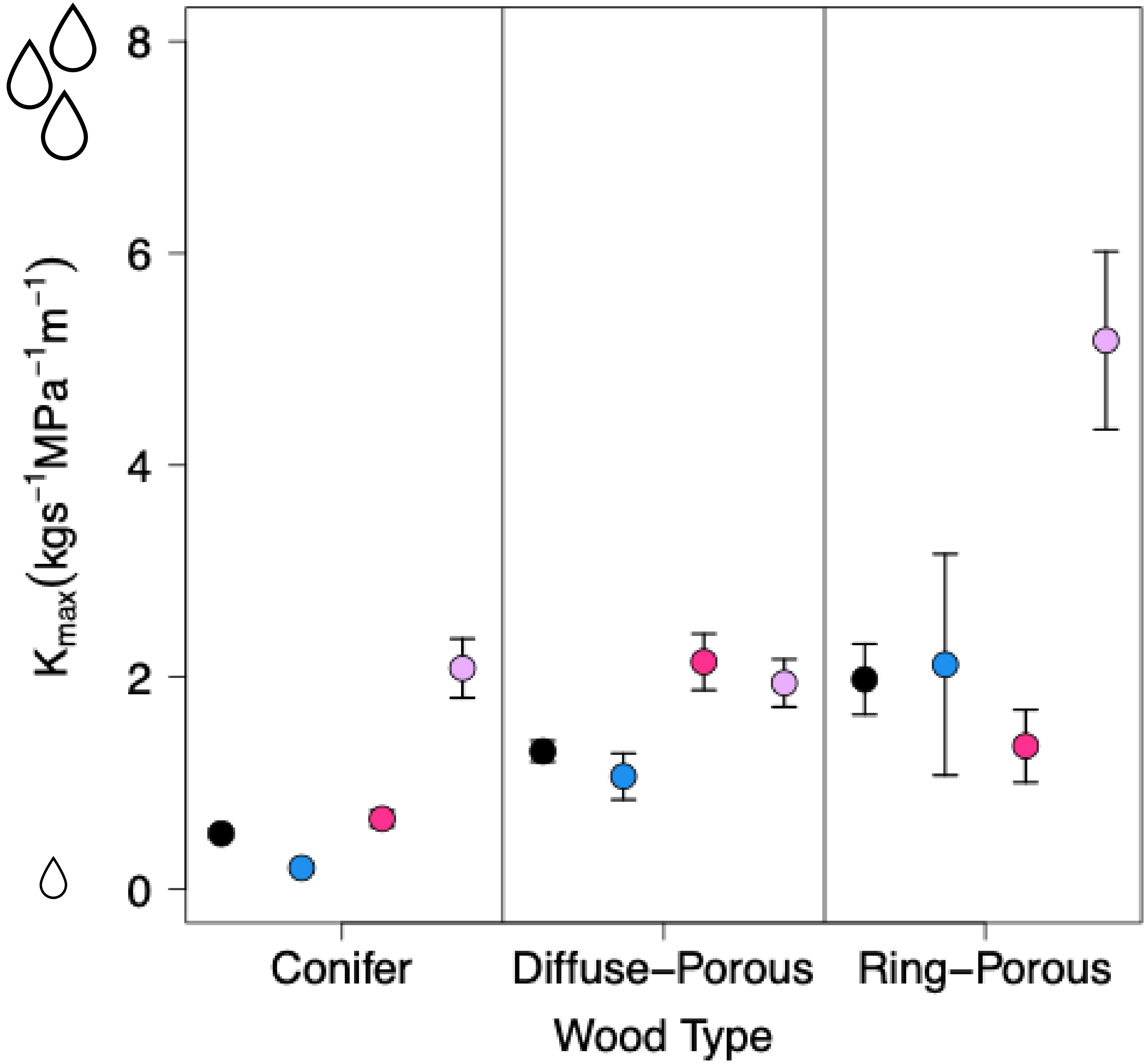
Ring-porous

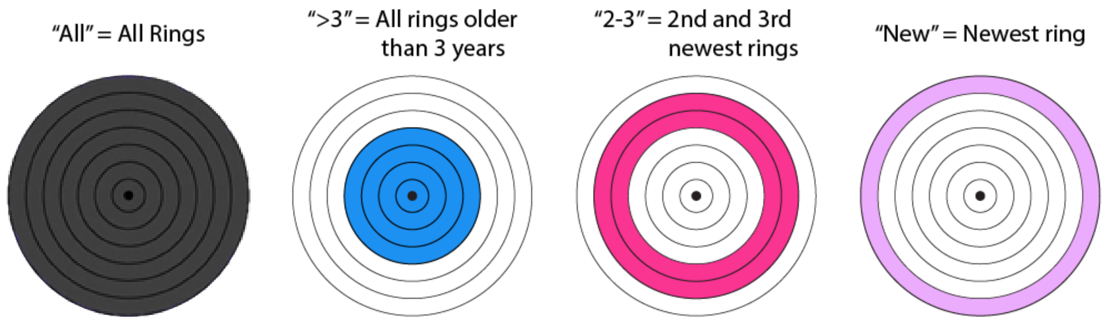


The Wood Database


Diffuse x 5
Amelanchier utahensis
Cercocarpus ledifolius
Populus angustifolia
Betula occidentalis
Acer grandidentatum
Ring x 4
Robina neomexicana
Ulmus “Triumph Elm”
Cercus canadensis
Rhus trilobata
Coniferous x 5
Picea pungens
Abies concolor
Taxus x media ‘Hicksii’
Pinus aristata
Calocedrus decurrens
RED BUTTE GARDEN
THE UNIVERSITY OF UTAH

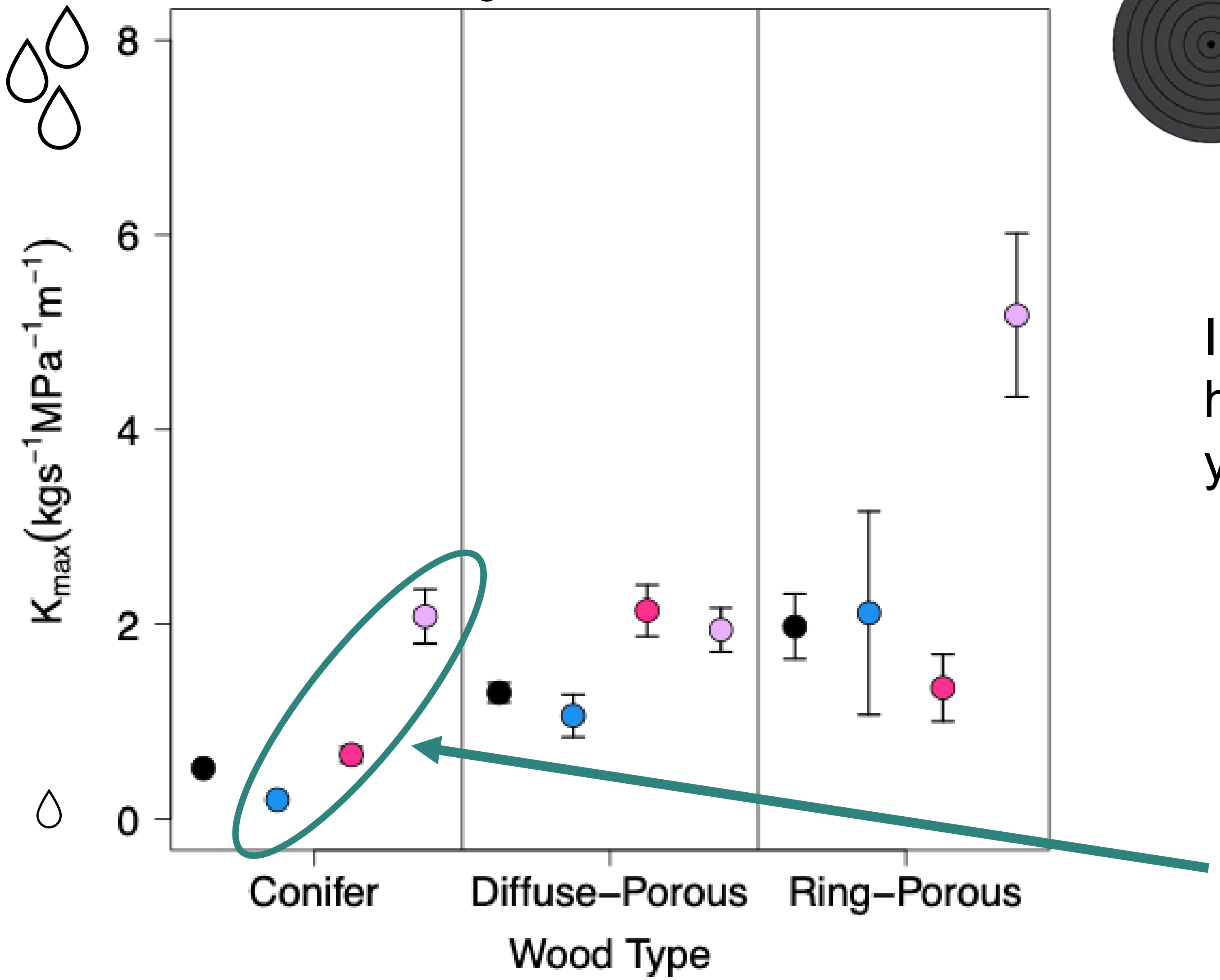
Conductivity

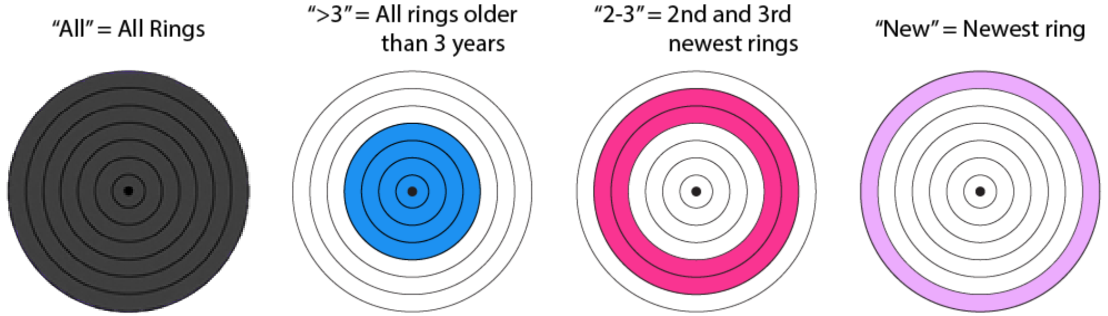




In all wood types, newest ring had higher conductivity than rings >3 yrs

Conductivity

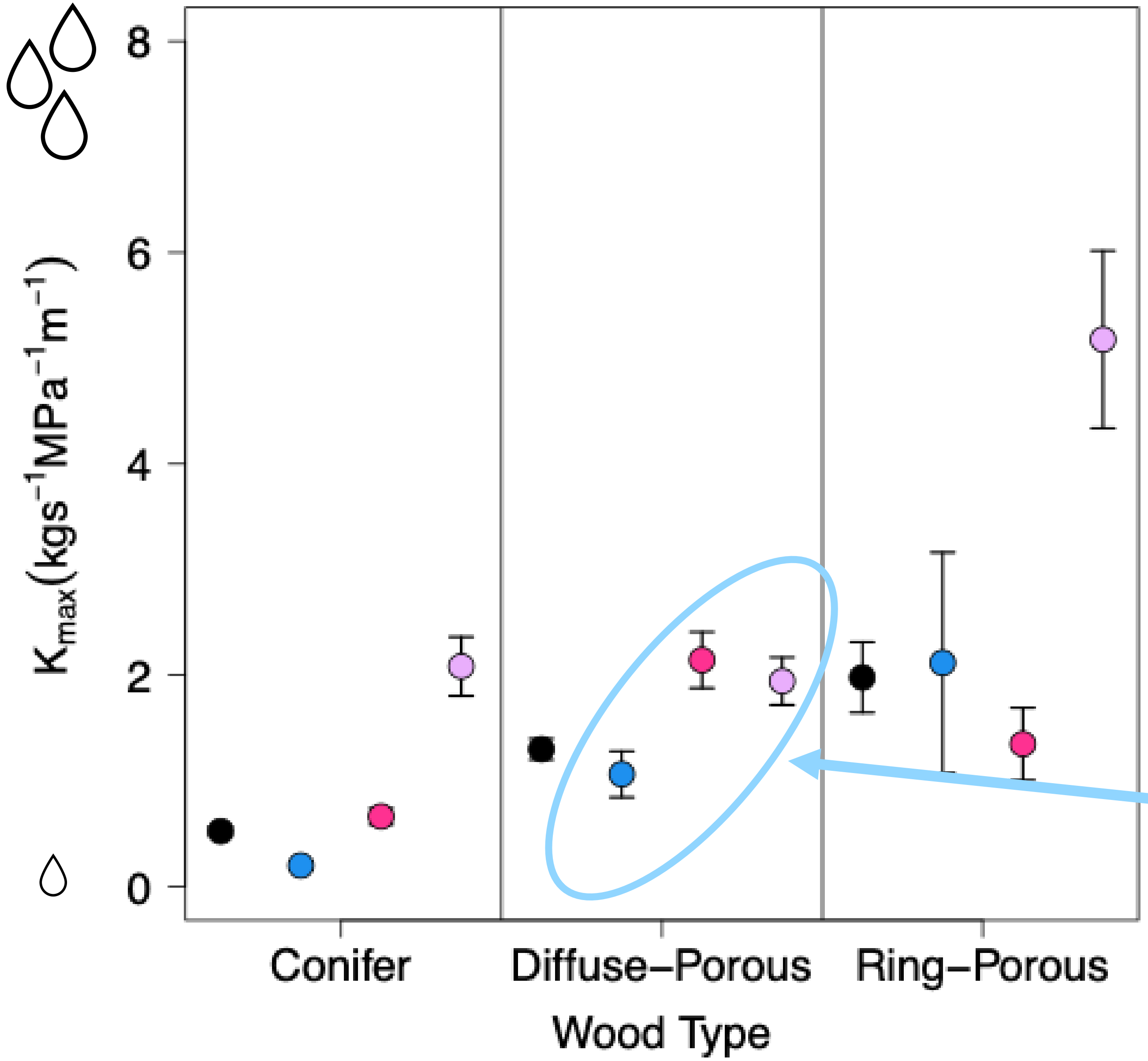


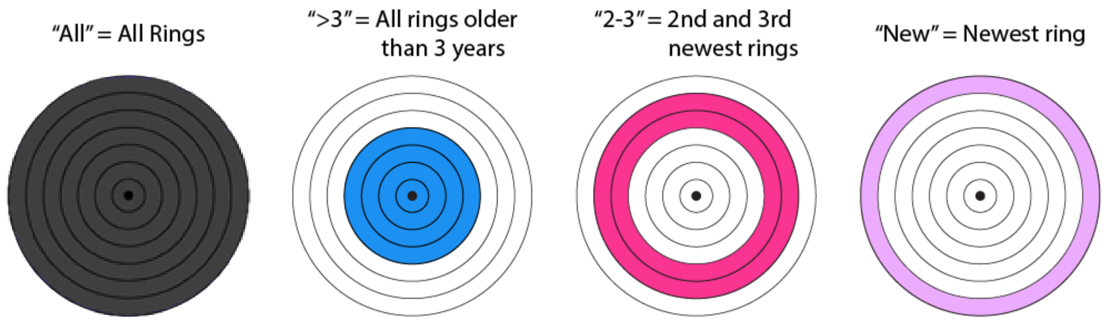


In all wood types, newest ring had higher conductivity than rings >3 yrs

Conifers:
Old rings < 2-3 yr < Newest ring

Conductivity

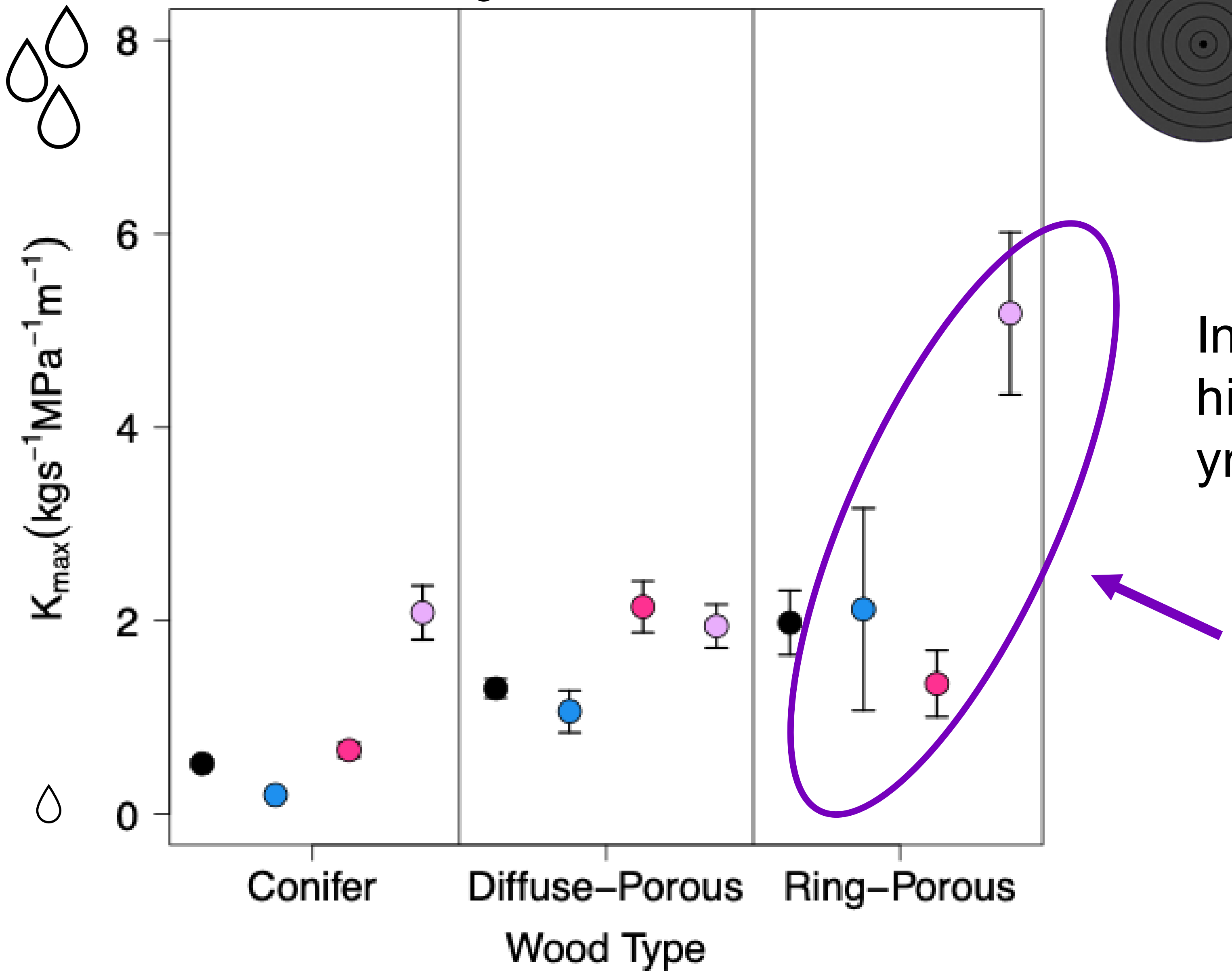


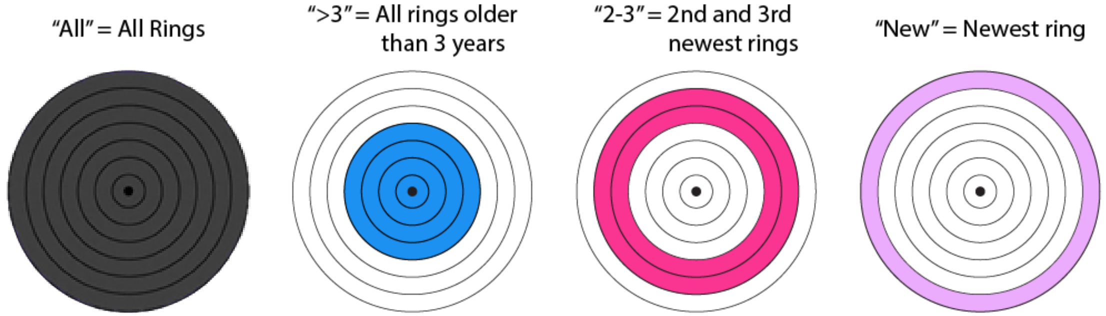


In all wood types, newest ring had higher conductivity than rings >3 yrs

Diffuse:
Old rings < 2-3 yr = Newest ring

Conductivity

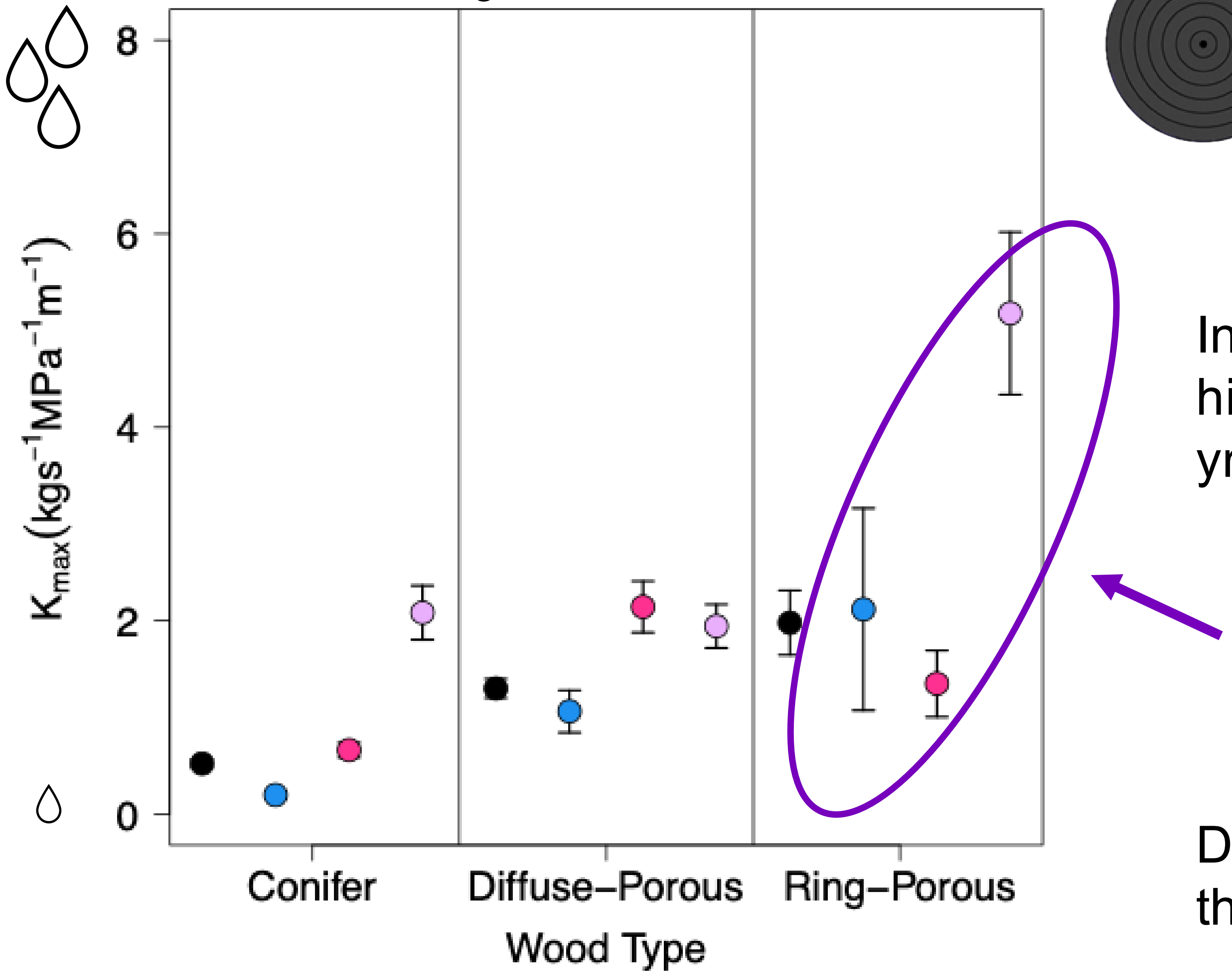


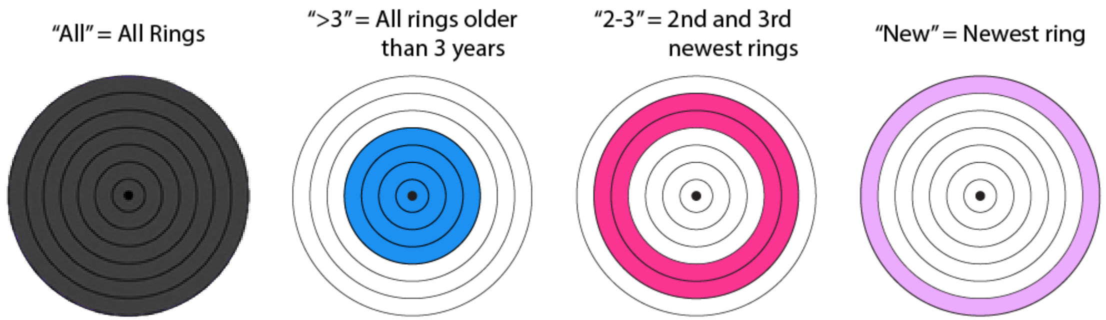


In all wood types, newest ring had higher conductivity than rings >3 yrs

Ring:
Old rings = 2-3 yr < Newest ring

Conductivity





In all wood types, newest ring had higher conductivity than rings >3 yrs

Ring:
Old rings = 2-3 yr < Newest ring

Different wood anatomies retire their rings at different rates

Same General Patterns in different wood anatomical types

- Does wood age differently by wood anatomy types in conductivity and vulnerability?
  - Yes, patterns of hydraulic deterioration with age, but with differing rates between wood types

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But Wait…

Looking for Data!

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Objective: determine Intra-annual and inter-annual anatomical plasticity across a species range

Anatomical images / ROXAS files

Pinus sylvestris and *Picea abies*

Anytime 1900-present