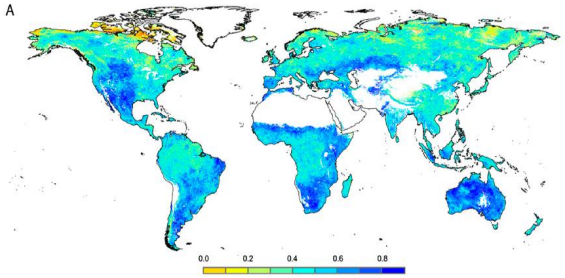
Short- and long-term impacts of drought on tree primary and secondary growth and on mortality risk

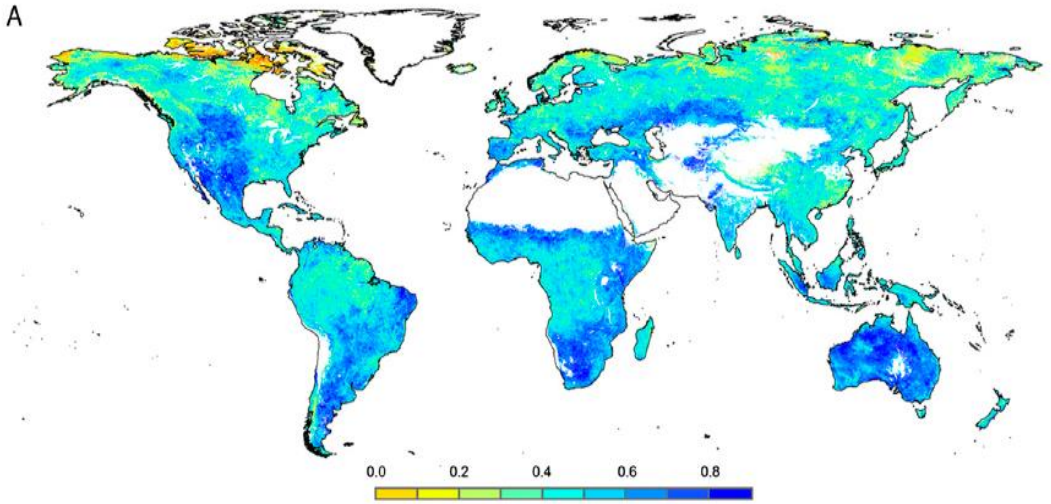
Cailleret M, et al.
INRAE, UMR RECOVER, Aix-en-Provence

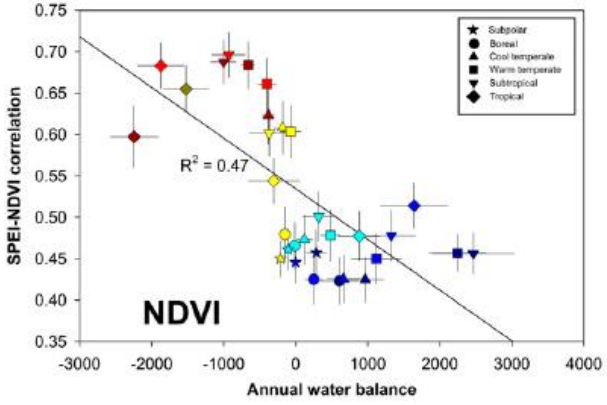


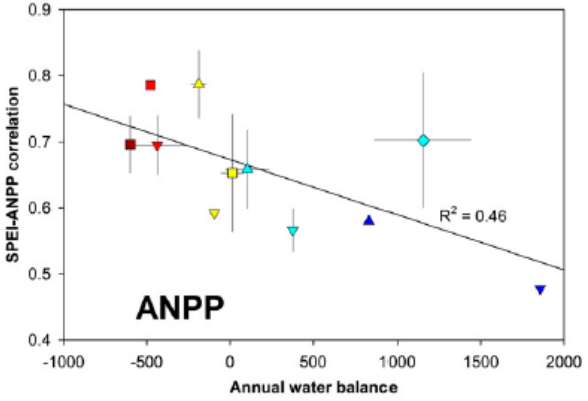
Drought is a key process affecting vegetation functions

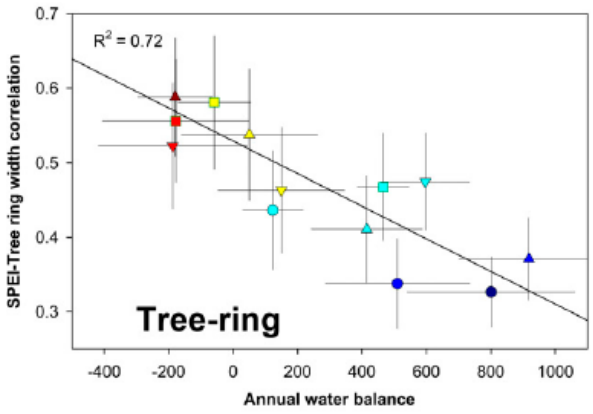
Drought is an important driver of vegetation activity and productivity, especially in dry regions

Correlation SPEI-NDVI (reflects vegetation greeness and photosynthetic activity)







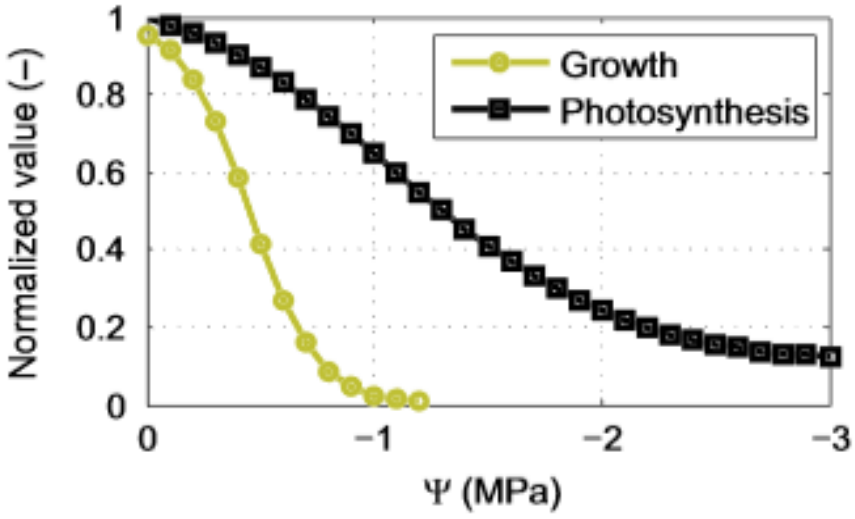


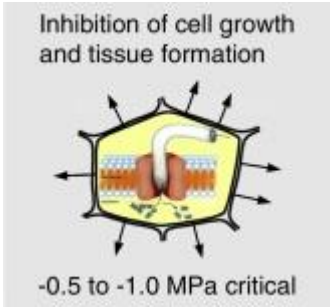
Vicente-Serrano et al. (2013 PNAS)

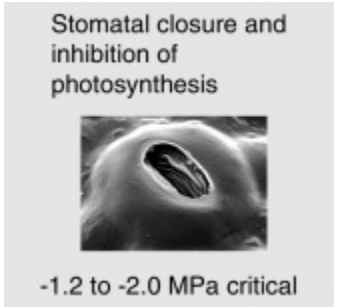
Short-term effects of drought on tree functions

First, drought impacts cell growth and tissue formation, and then photosynthesis due to the reduction in:

- stomatal conductance
- mesophyll conductance
- biochemical activities







Abundant literature on the effect on stomatal conductance : numerous empirical and optimal stomatal models

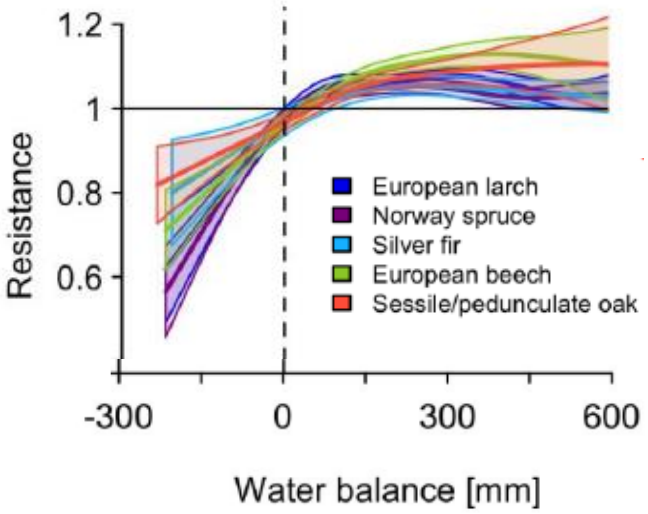
e.g., Dewar et al. (2018 New Phytol.)

Fatichi et al. (2012 New Phytol.)
Körner (2015 Curr. Op. Pl. Sci.)

Drought impacts on tree (secondary) growth

- Based on tree-ring width data

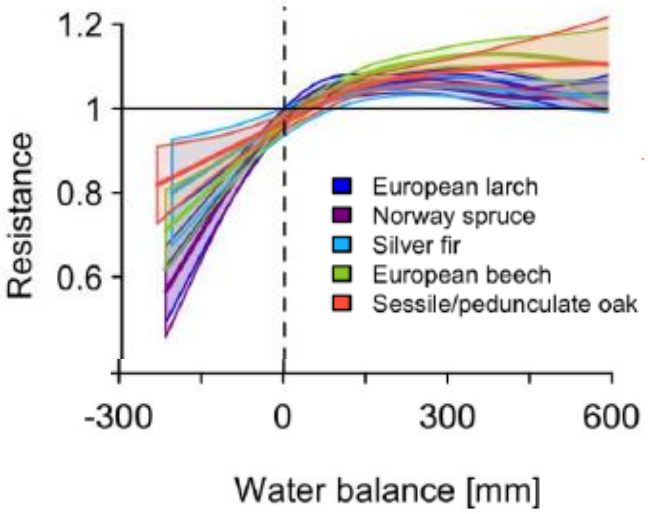
Example : focusing on resistance to drought
(Vitasse et al. 2019 GCB)



Drought impacts on tree (secondary) growth

- Based on tree-ring width data

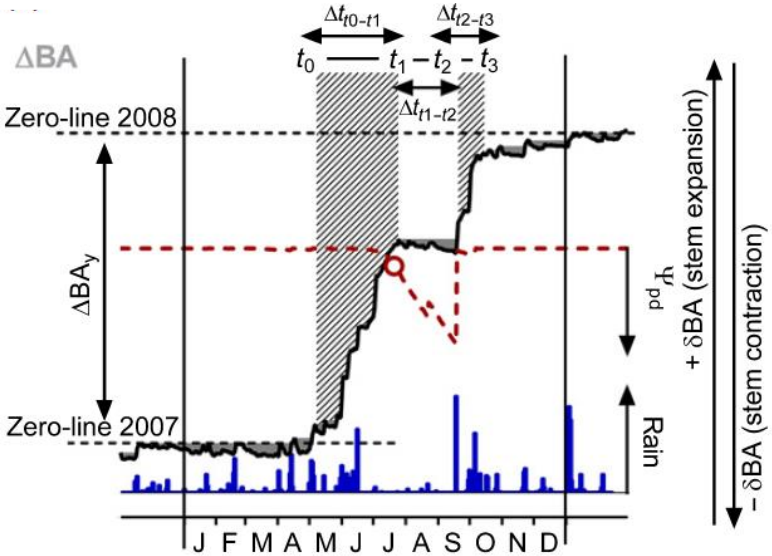
Example : focusing on resistance to drought
(Vitasse et al. 2019 GCB)



- Based on dendrometer & water potential data

Example on *Quercus ilex* (Lempereur et al. 2015 New Phytol):

Threshold of cambial activity
at ψpd = -1 MPa

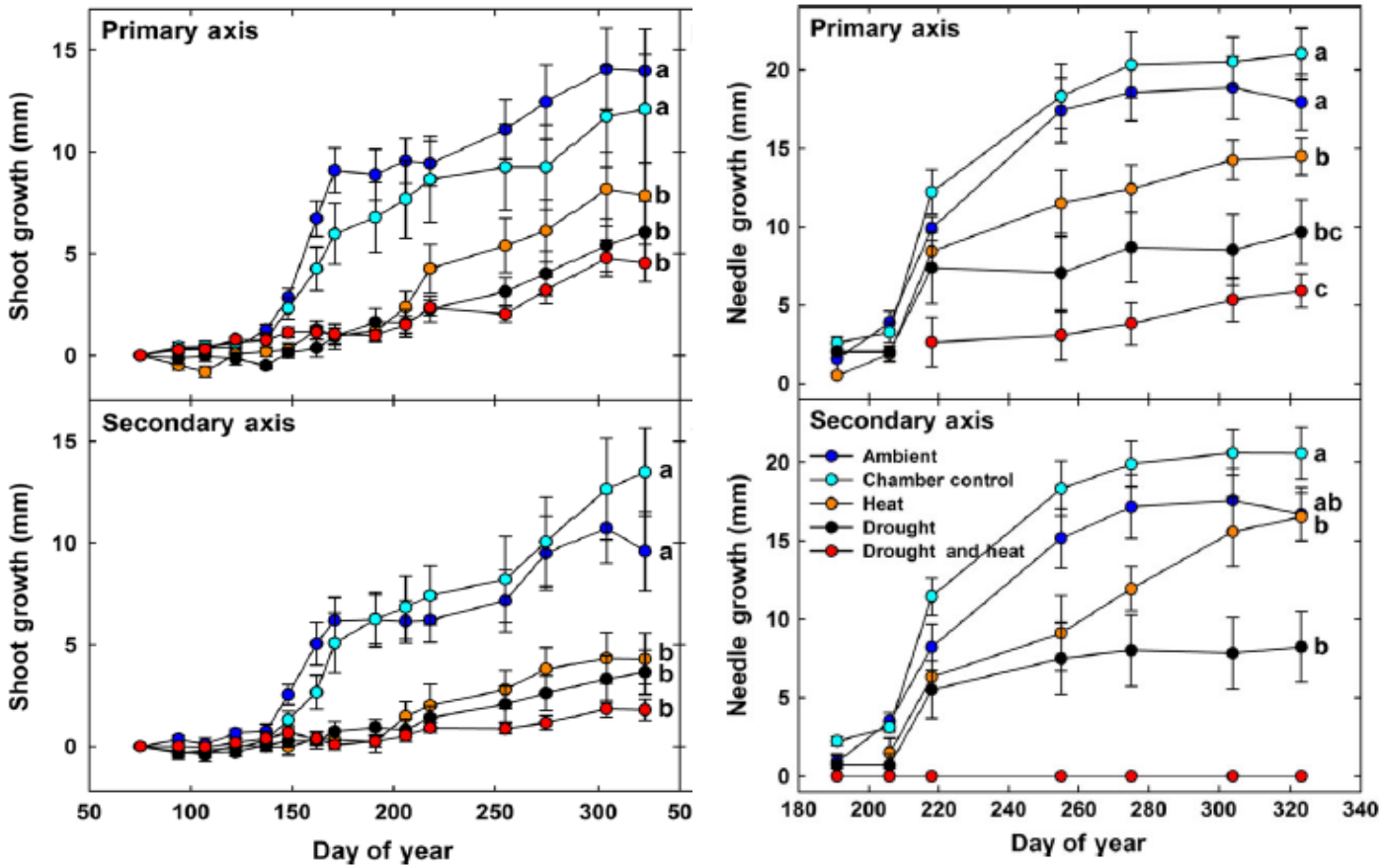


Drought impacts on primary growth

Cessation of shoot and leaf elongation when the soil becomes too dry:
Shorter shoots (less leaves) and smaller leaves during a dry year

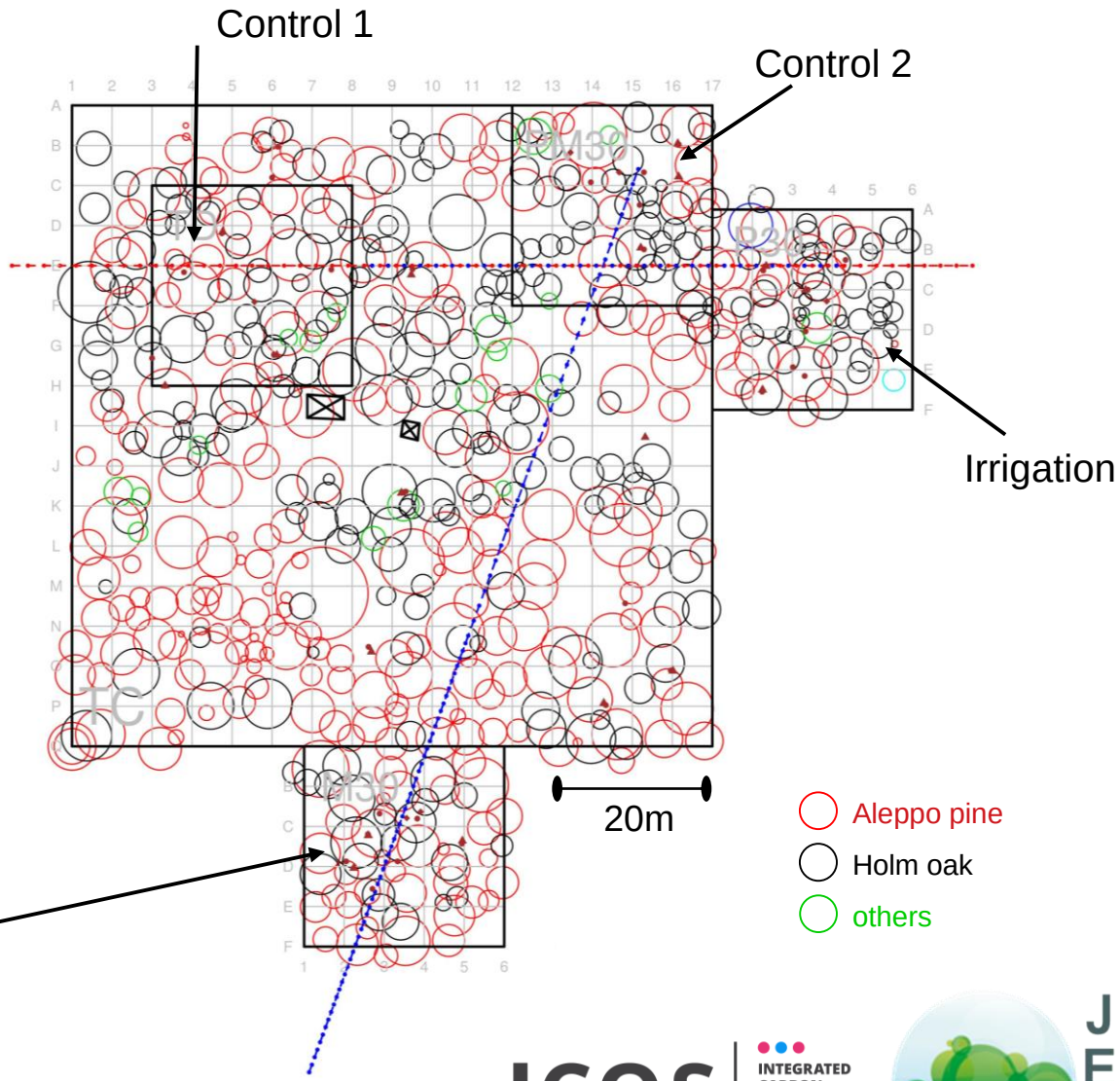
Example with Pinon pine in open-top chambers (Adams et al. 2015 GCB)

Ambient/control
drought (-45% rain)
heat (+4.8°C)
drought + heat



Insights from the experimental site of FontBlanche (2008-…)

Exclusion (-30%) since 2008



ICOS INTEGRATED CARBON OBSERVATION SYSTEM

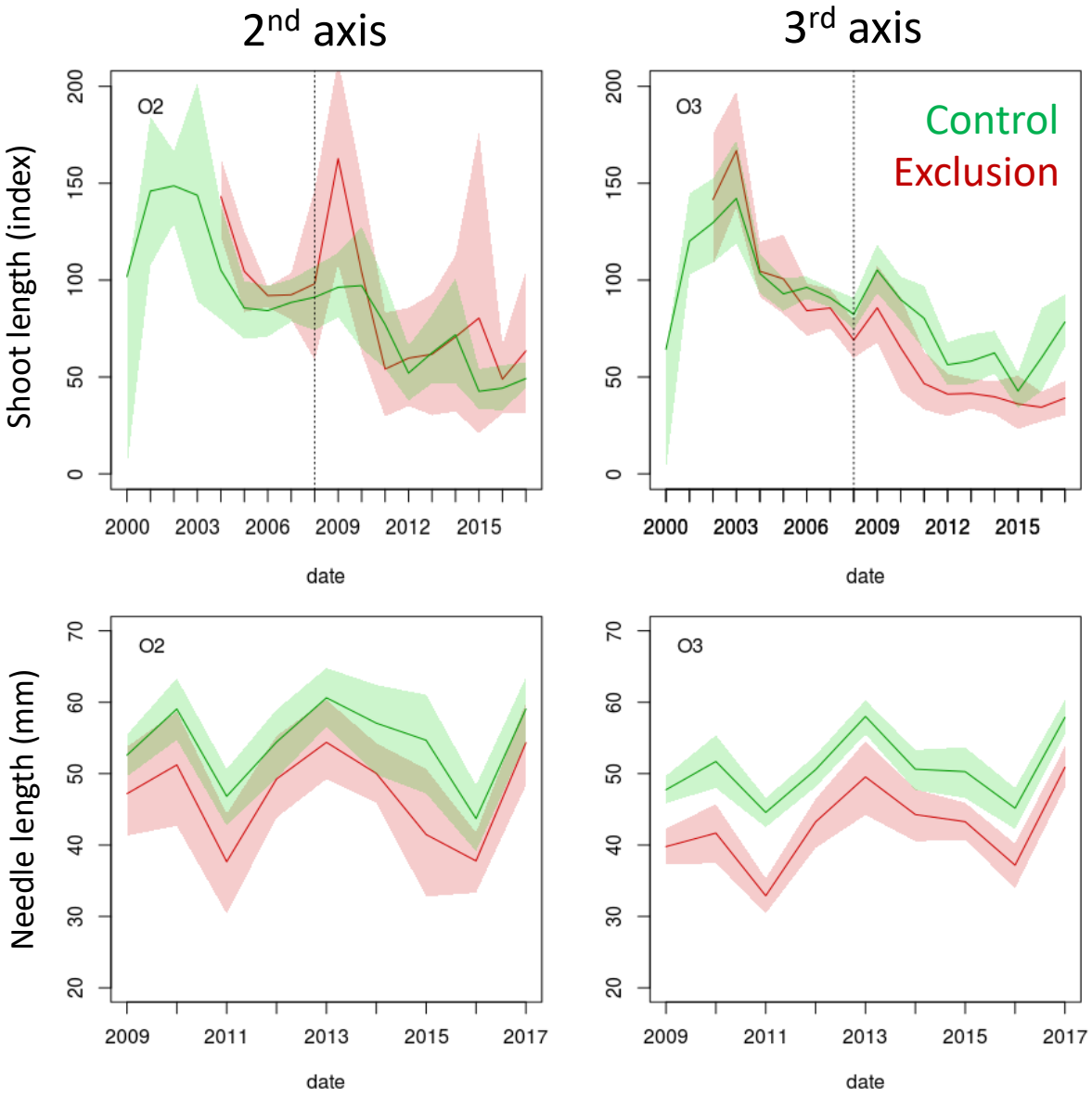
AnaEE France

JEF

Long-term effects of drought on primary growth

For Aleppo pine, we found a large reduction in shoot length, needle length, and number of ramifications

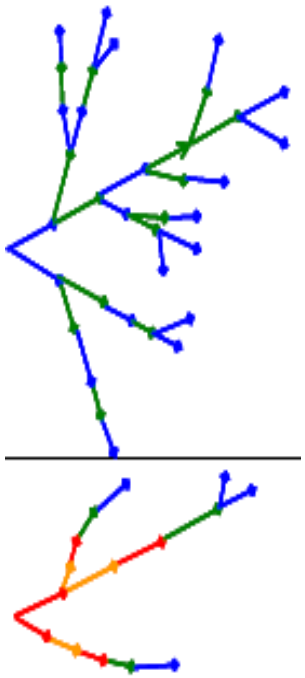
Mainly for branches from 3rd axis



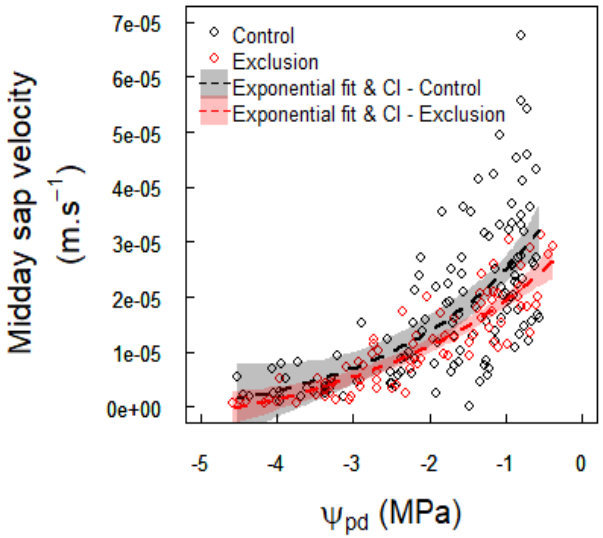
Moreno et al. (in prep)

Long-term effects of drought on primary growth

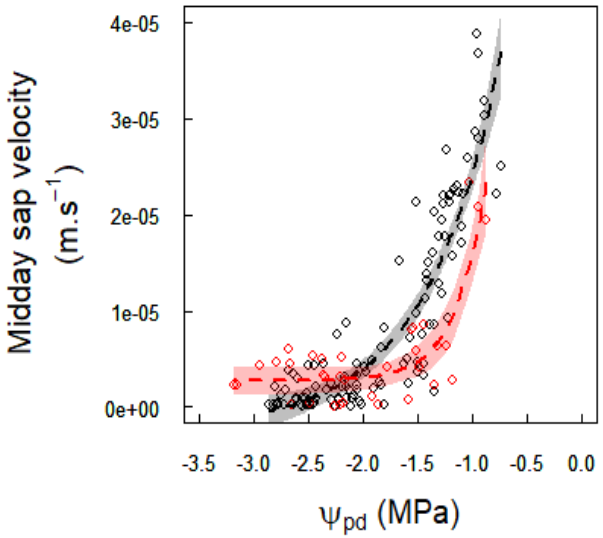
These effects on tree architecture are key : they control the leaf area over both short- and long-terms



Holm oak



Aleppo pine

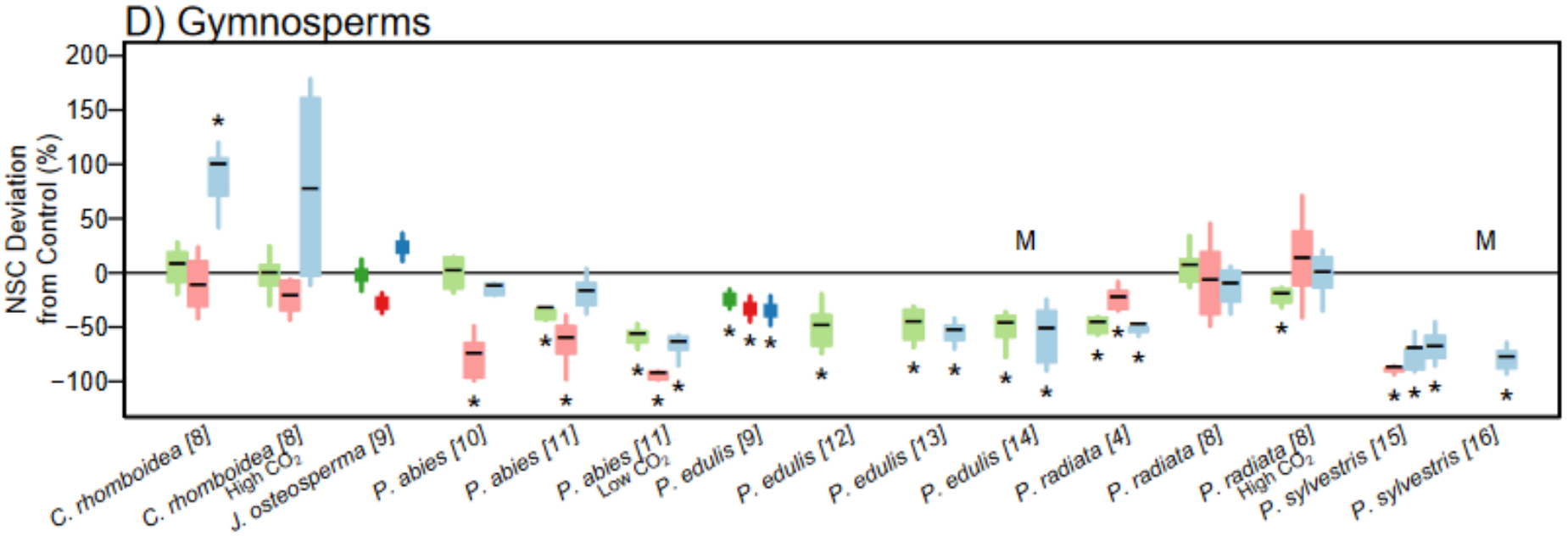


This strategy limits water consumption and is a typical acclimation process to reduce mortality risk due to hydraulic failure

Moreno et al. (in prep)

Effects of drought on mortality risk

But this reduction in leaf area also induces a decrease in carbon assimilation and may lead to mortality due to ‘carbon starvation’

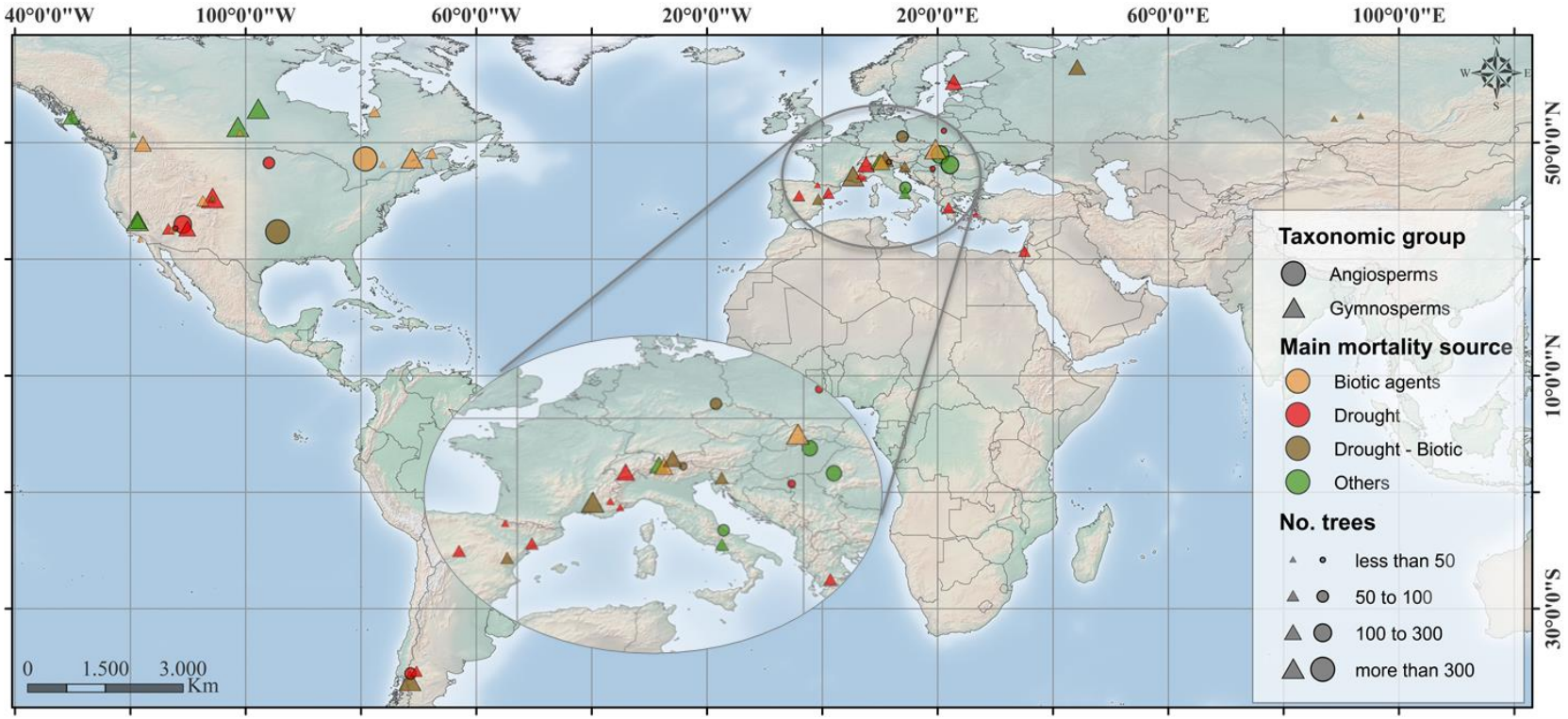


Meta-analysis of chamber experiments on saplings: Adams et al. (2017 Nat. Ecol. Evol.)

Effects of drought on mortality risk

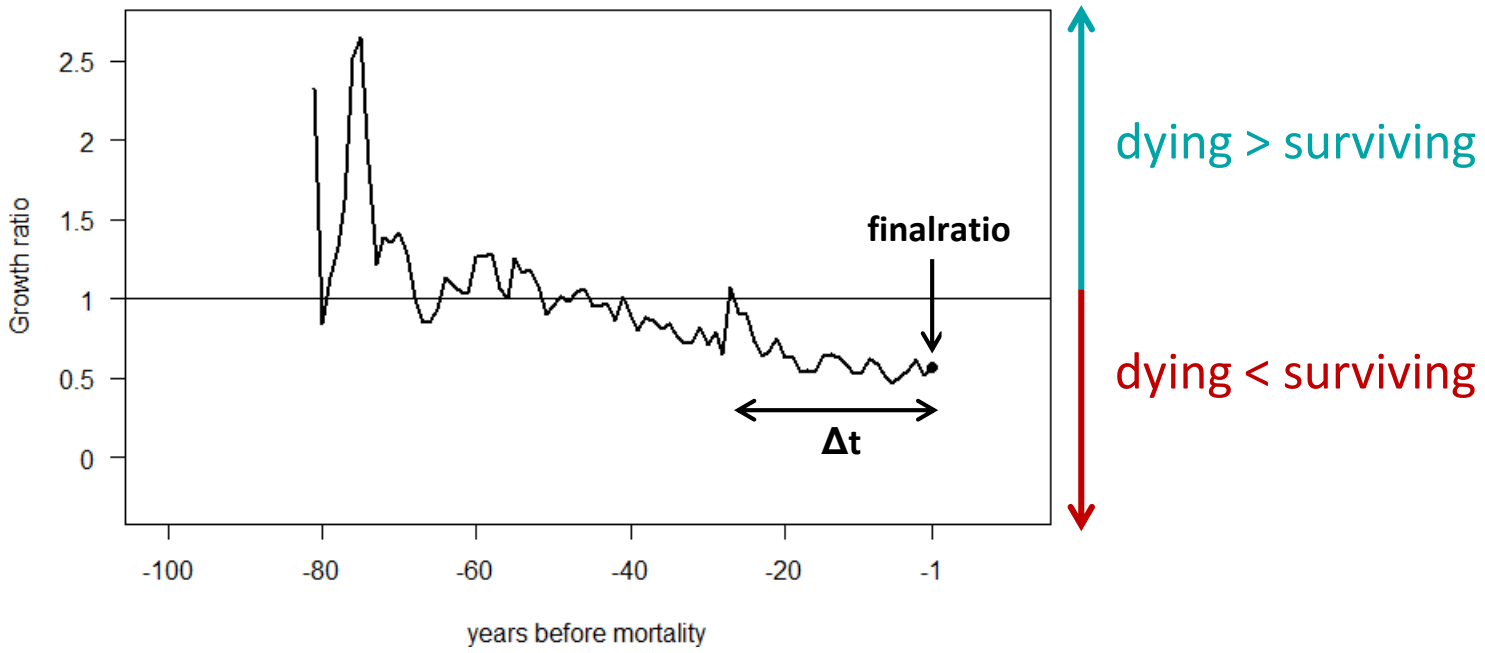
Studying these processes on adult trees is problematic :
few dead trees in the highly instrumented exclusion experiments

36 species | 198 sites | >8000 trees



Effects of drought on mortality risk

At each site and for each of the mortality events, we calculated the growth ratio between trees that died and trees that survived (with similar size)

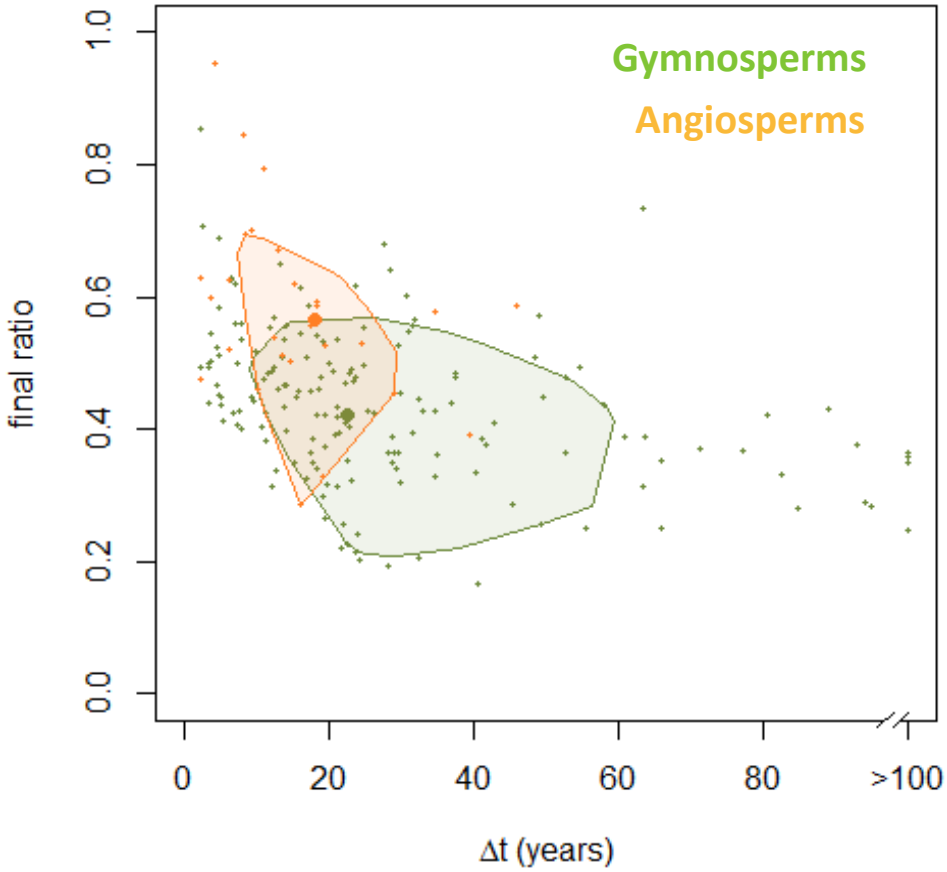


- finalratio: growth ratio the year before mortality
- Δt: duration of the last and continuous period with ratio < 1 (or >1)

Cailleret et al. (2017 GCB)

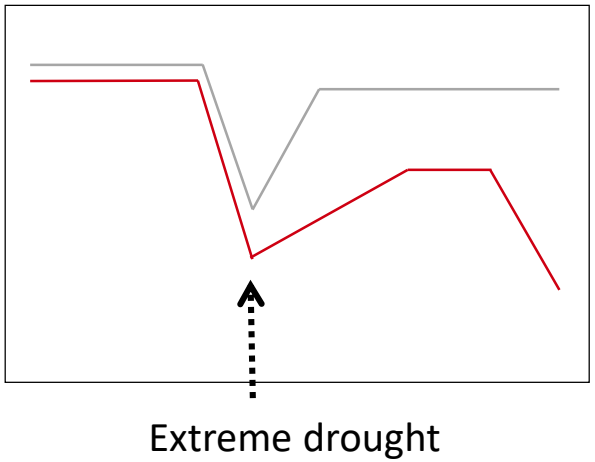
Effects of drought on mortality risk

Longer and stronger decrease in growth before death for gymnosperms



Cailleret et al. (2017 GCB)

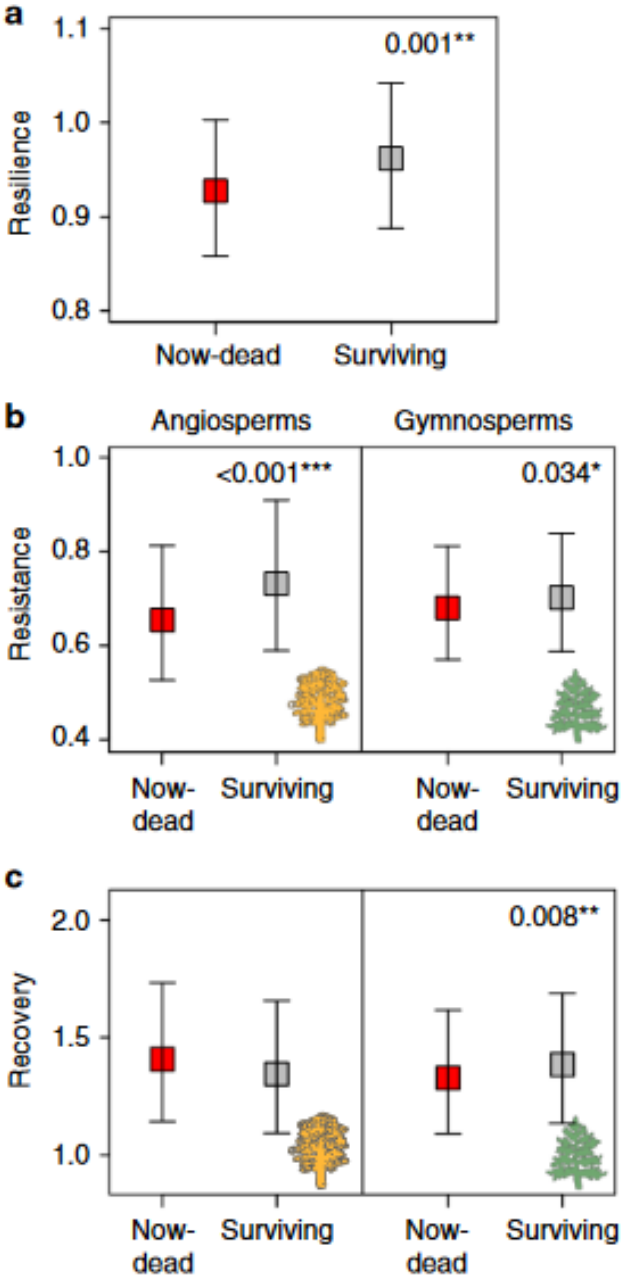
Effects of drought on mortality risk



Surviving trees had higher resilience to previous extreme droughts than dead ones

Mortality risk depends on resistance for angiosperms, and mainly on recovery for gymnosperms

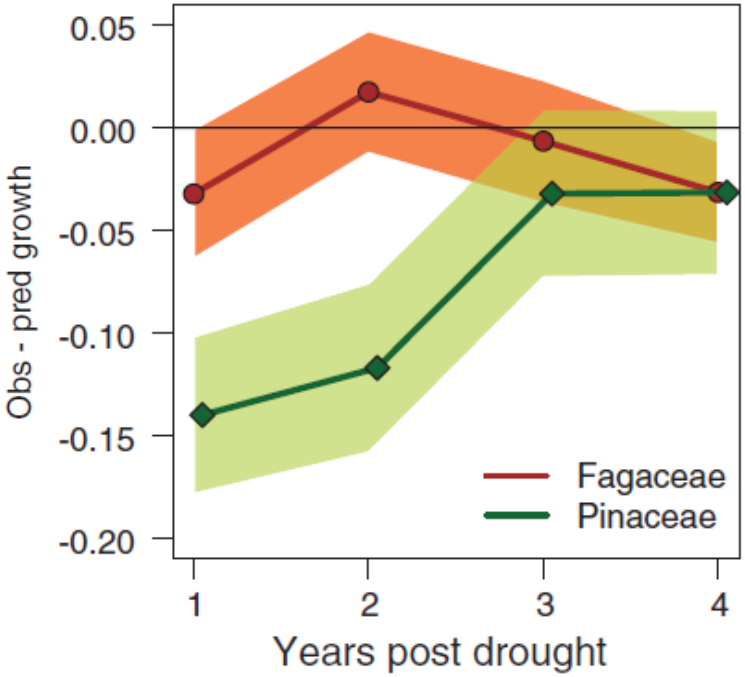
DeSoto et al. (2020 Nature Comm.)



Effects of drought on mortality risk

Angiosperms recover quickly from drought but they usually die faster: their mortality mainly depends on their drought **resistance**
Hydraulic failure preponderant

Greater importance of **recovery** in **gymnosperms** : recover slowly from drought and are able to survive a longer period with low growth
Carbon economy also matters



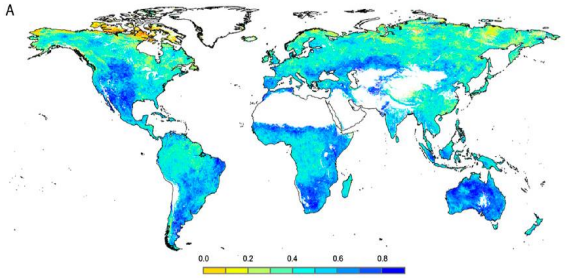
Anderegg et al. (2015 Science)

Main messages

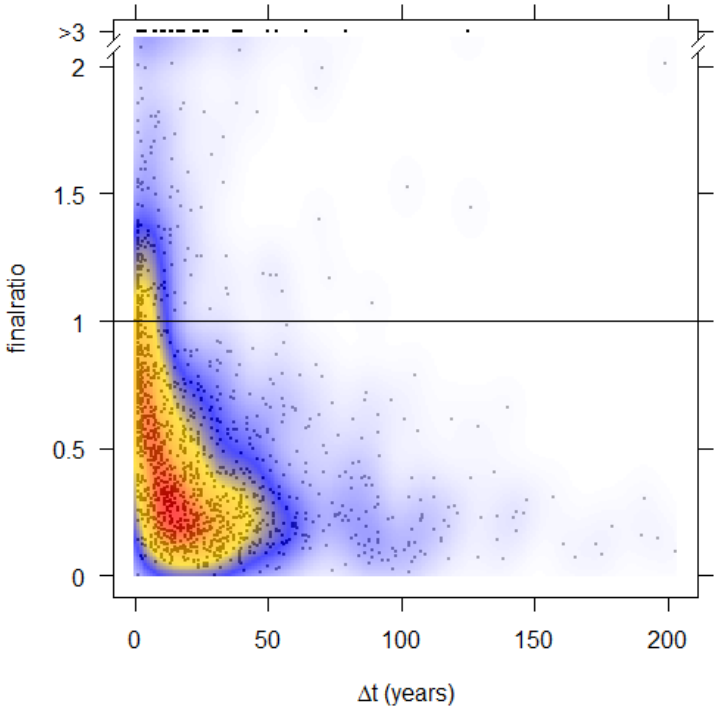
- Do not focus on secondary growth only, primary growth matters as well (leaf area, number and length of branches, reproductive organs) -> currently lacking
- Consider tree architecture in these analyses
- Tree growth patterns (rate, trend, variability, resilience) are good indicators of drought-induced tree mortality
- Mortality risk mainly depends on the short-term impacts of drought for angiosperms and on longer-term impacts for gymnosperms

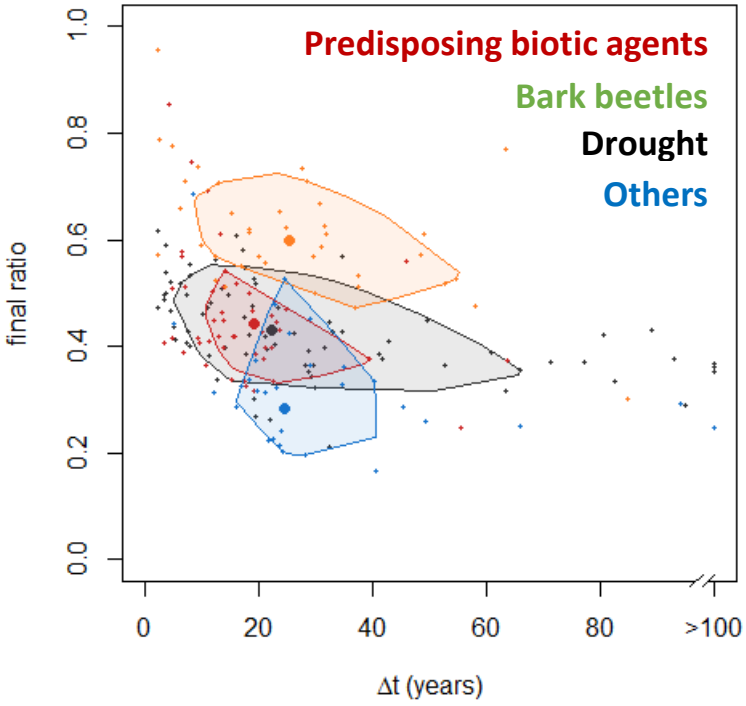
Short- and long-term impacts of drought on tree primary and secondary growth and on mortality risk

Cailleret M, Audouard M, Bigler C, Bugmann H, Dakos V, DeSoto L, Gessler A, Jansen S, Kramer K, Lopez JM, Martin-St-Paul N, Martinez-Vilalta J, Moreno M, Robert EMR, Ruffault J, Schaub M, Simioni G, Sterck F, Vennetier M, Vitasse Y



Strong and long-term growth decrease before mortality





- Dying trees had lower growth rate than living ones in 85% of the mortality events (Median of finalratio = 40%)
- Period with reduced growth from 1 to 200 years (median = 19 yrs)

Cailleret et al. (2017; Glob. Change Biol.)