New modeling methods on plasticity and norms of reaction for Larch and Douglas-fir

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New modeling methods on plasticity and norms of reaction for Larch and Douglas-fir

- 7 October 2021 9h00 – 10h30, Philippe Rozenberg
- Mainly based on works with Alejandro Martinez-Meier, Thibaud Chauvin, Margarita Escobar-Sandoval and Luc Pâques, with contributions by many others

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773383

Basics of the estimation of phenotypic plasticity (pp)

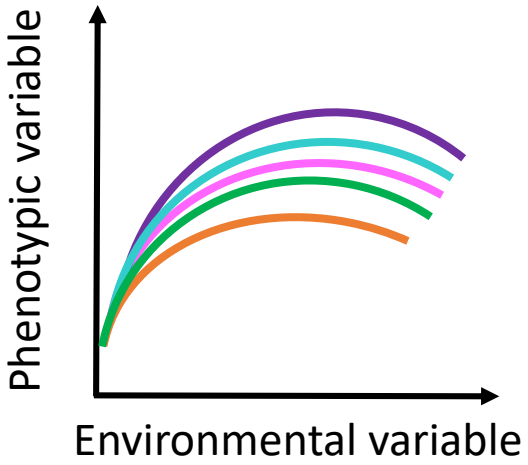
- Many definitions, most of them converge to something like:
  - « Ability of a **genotype** to produce different **phenotypes** in different **environments** »
- Property of a **single genotype**:
  - **Individual** or **clone**
- For **other types of genetic entities** (families, provenances, species), another expression: plastic response, average plasticity, family/provenance plasticity, response curve…
- Always based on **repeated measurements** of phenotypic traits
- Environment varies over **space** and **time**
  - Phenotypic measurements repeated over **space > clones**
  - Phenotypic measurements repeated over **time > individuals**

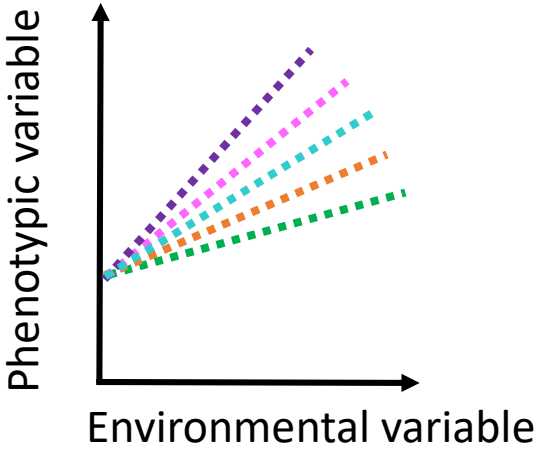
Basics of the estimation of phenotypic plasticity (pp)

- To **reveal** the **existence** of pp:
  - Correlation coefficients, analysis of variance
- To **reveal** the existence of **genetic variation** of pp:
  - Genotype × Environment studies
- To **quantitatively estimate** pp:
  - Indices
  - **Norms of Reaction** (nor)

Norm of Reaction

- A quantitative relationship between a **phenotypic variable** and an **environmental variable**





Norm of Reaction

- **Repeat** measurements of a phenotypic **and** of an environmental variable
  - Over **space** or over **time** (tedious and time consuming)
- Increase the probability of **finding a relationship**
  - **Maximize** the variation
  - **Optimize** the number of measurements
- Solutions:
  - Over time
  - Automation
  - Retrospective measurements

Space- and *time*- related *pp*

	Type of genotype	Source of phenotypic variation	Components of environmental variation	Main problems
Over **space**	clones	**Environment** only	**biotic** and **abiotic** components: competition, soil, climate, exposition	Identify and measure the **relevant environmental** variables. Mean site value as a proxy?
Over **time**	individuals	**Environment** + **development** (ontogeny)	Mainly **climate** then **competition** (beyond a certain duration)	**Confusion** between development and environmental effects

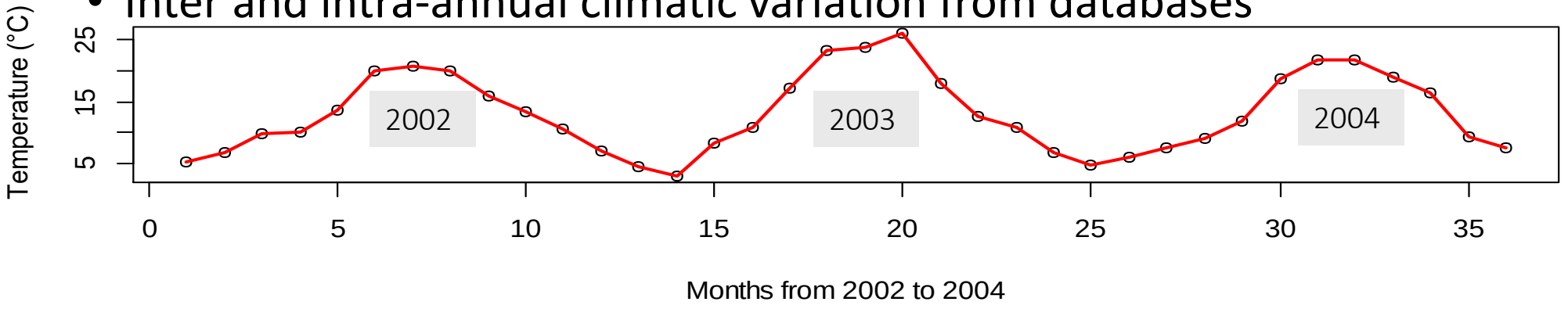
Automation

- Automatic point dendrometers
- Variation of stem radius along the growing season
  - Radial growth
  - Dynamics of stem water
- Climatic variation along the growing season

Retrospective measurements

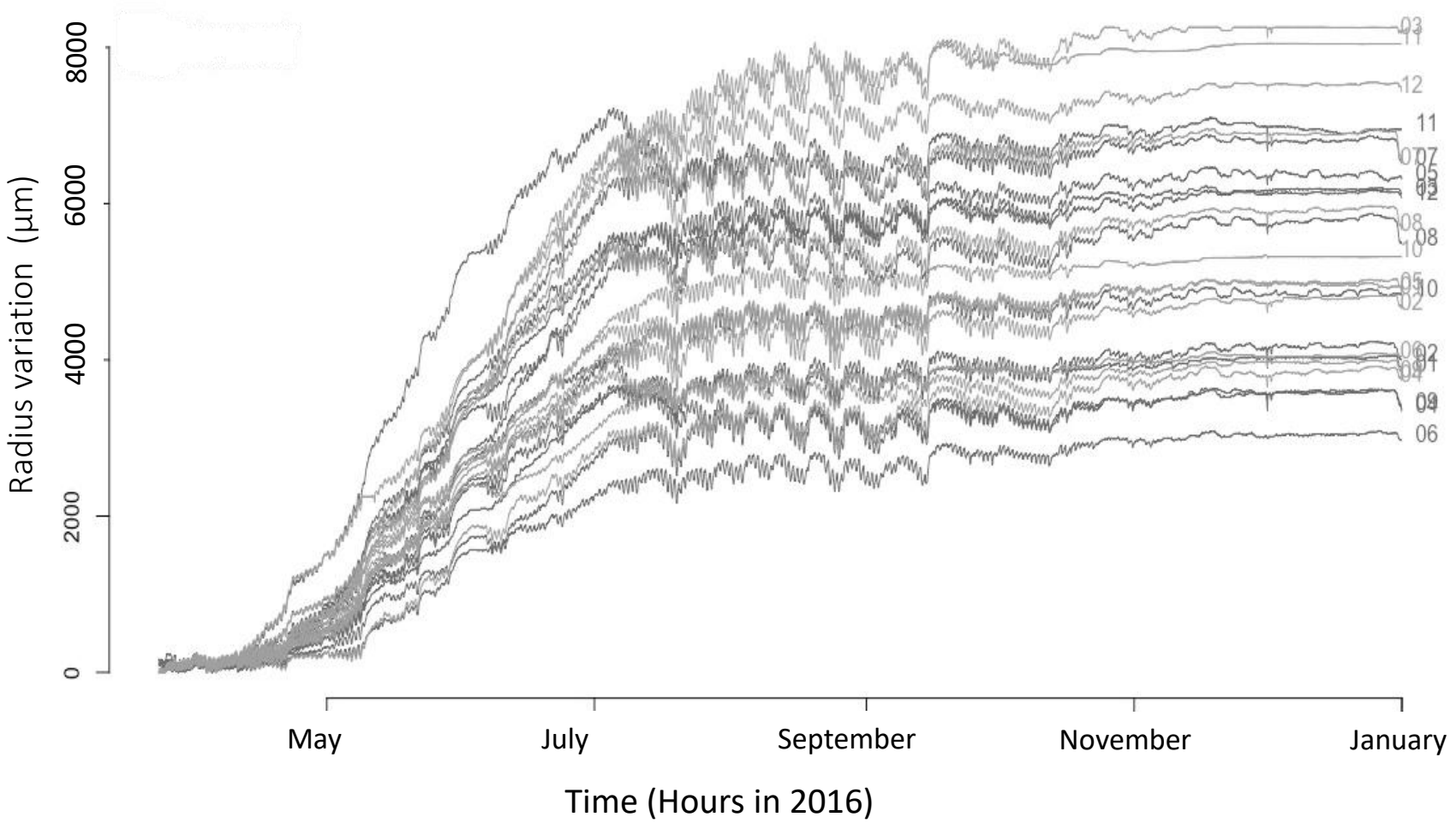
- Tree-ring analysis
  - Inter and intra-ring variation of wood properties

  - Inter and intra-annual climatic variation from databases



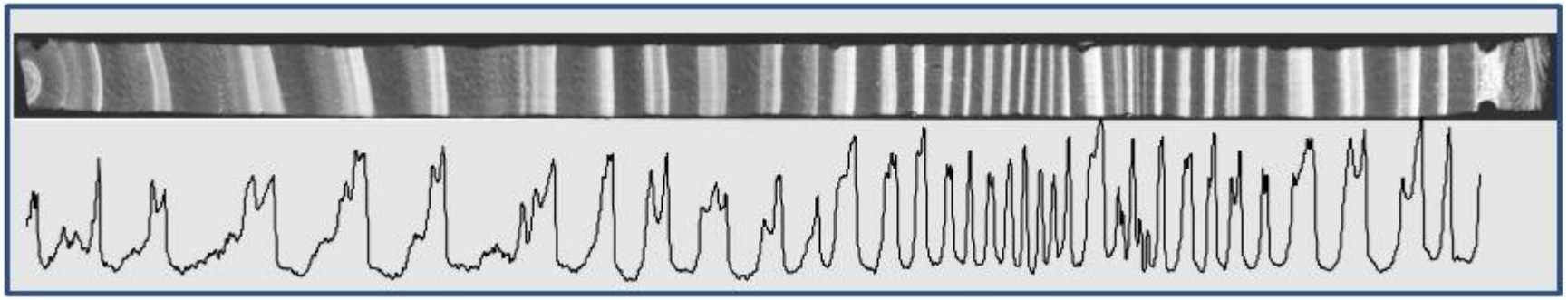
Fitting *nor* with curves of **radius variation**

- **First** case study:
  1: variation of *pp* of **stem water dynamics** in three *Larix* species



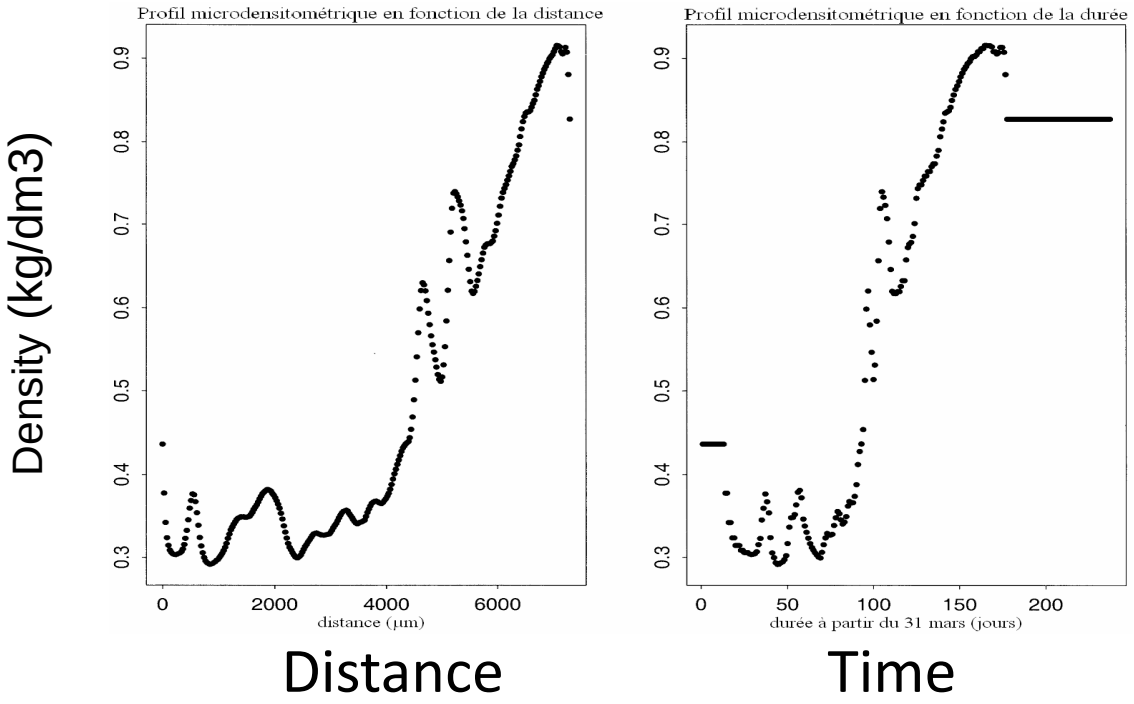
Fitting *nor* with *inter-ring* microdensity data

- **Second** and **third** case studies
  - 2: Variation of inter-ring *pp* along an elevation gradient in *Larix decidua*
  - 3: Provenance variation of inter-ring *pp* in *Pseudotsuga menziesii*



Fitting nor with *intra-ring* microdensity data

- 4: Preliminary results and perspectives

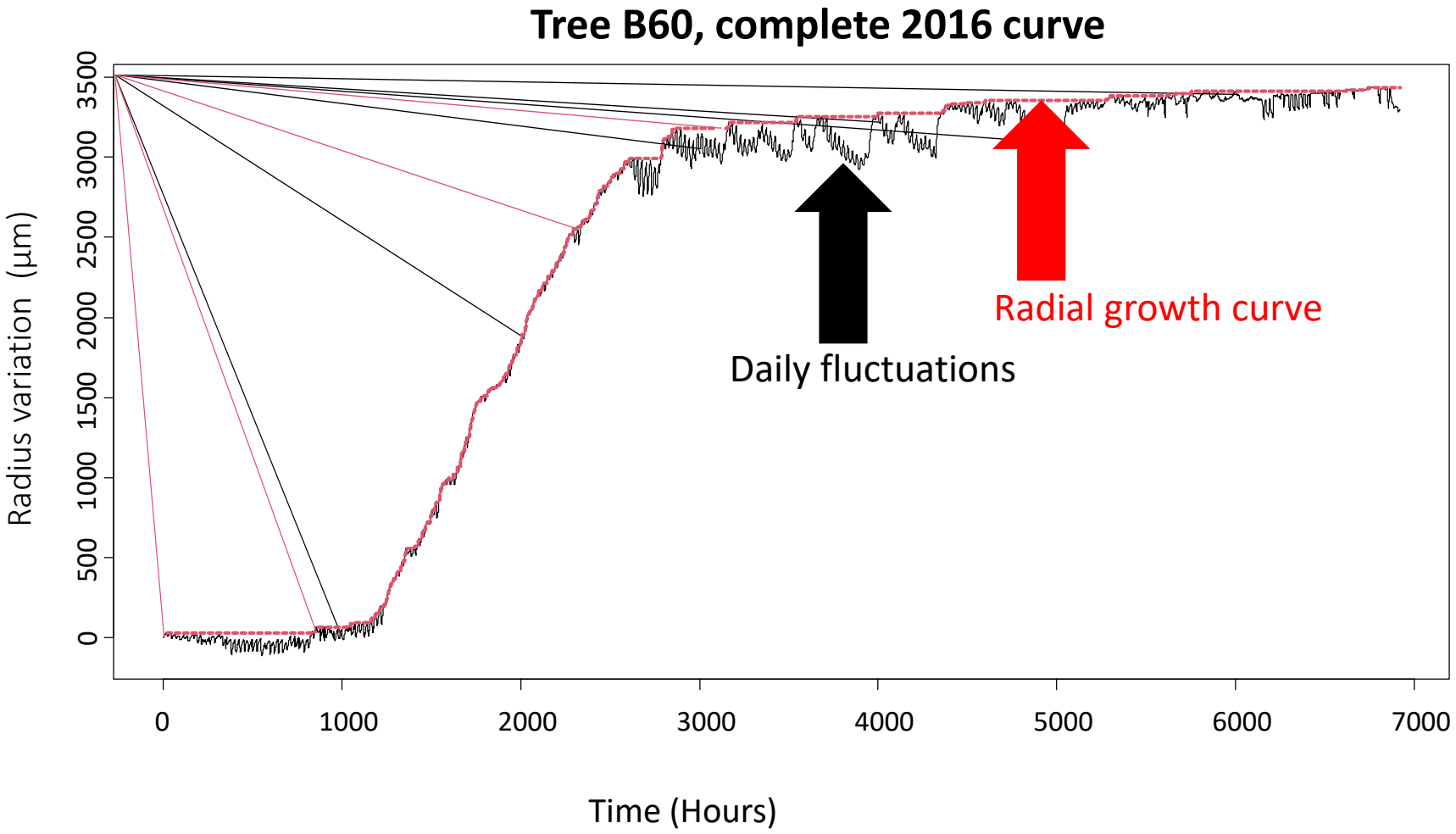


Distance Time

1. Fitting *nor* with curves of radius variation

First case study

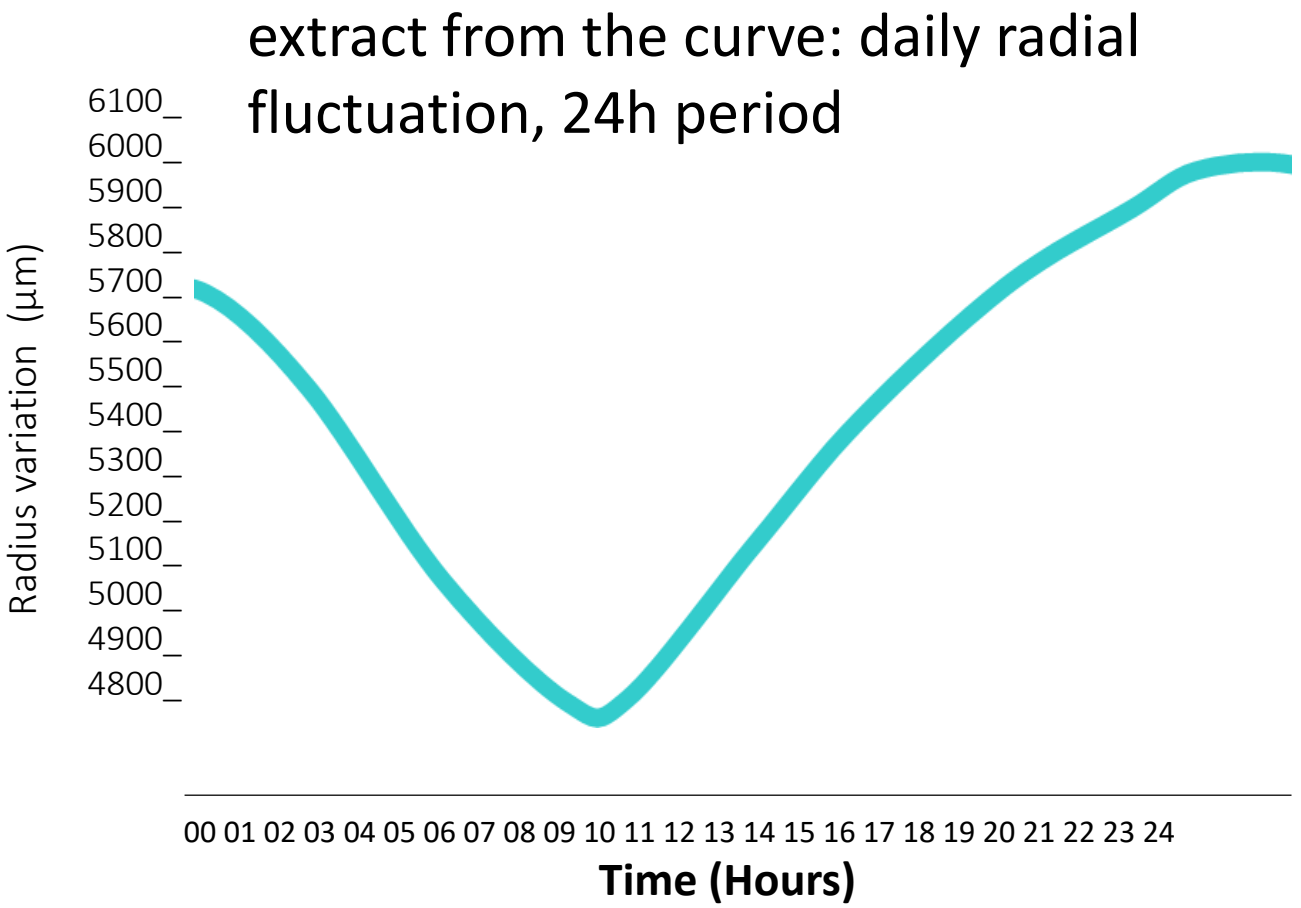
Fitting *nor* with curves of radius variation



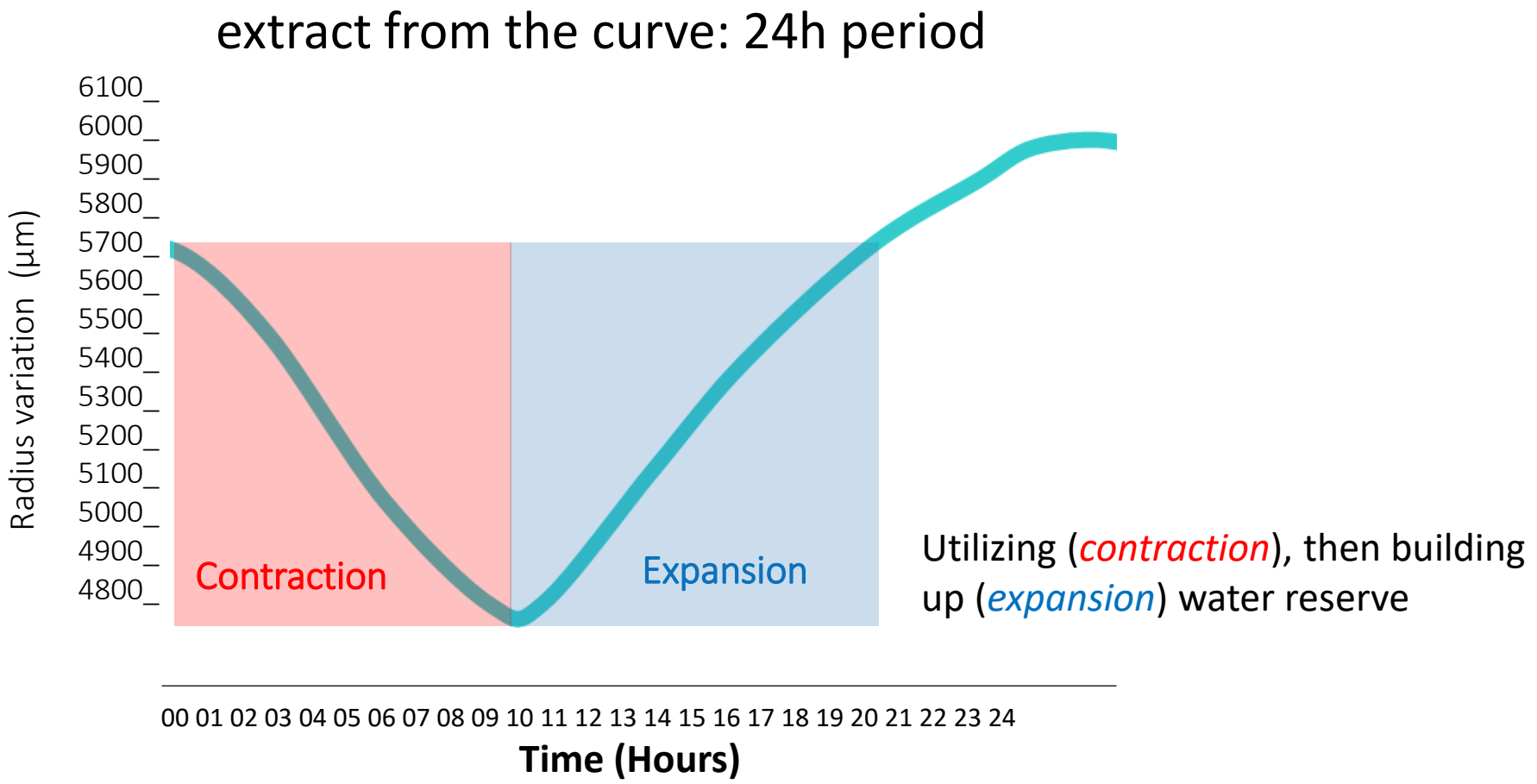
Two components:

- Low frequency component: the radial growth (accumulation of new xylem cells)
- High frequency component: the daily radial fluctuations (dynamics of stem water)

Fitting *nor* with inter-ring microdensity data

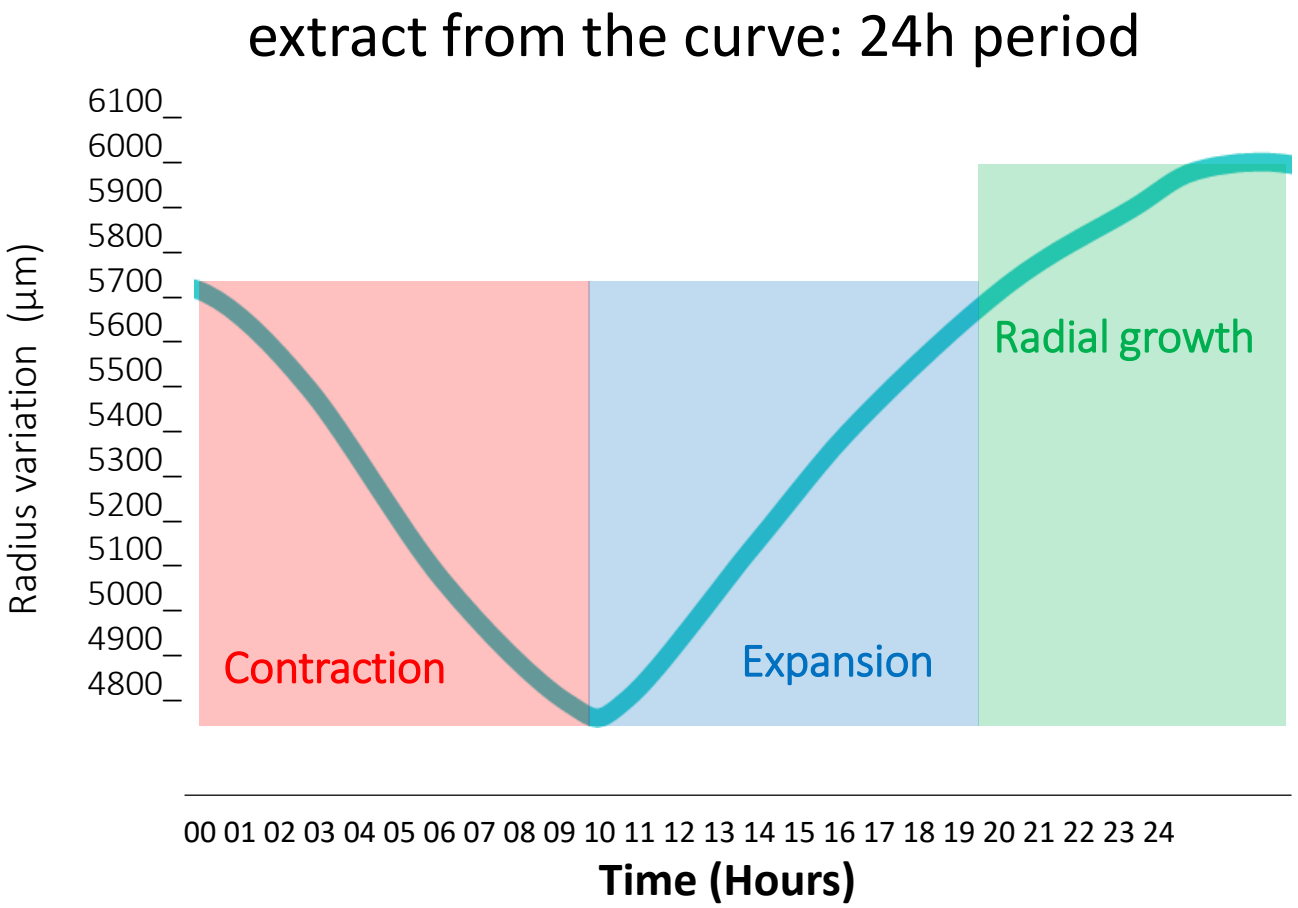


Fitting *nor* with inter-ring microdensity data

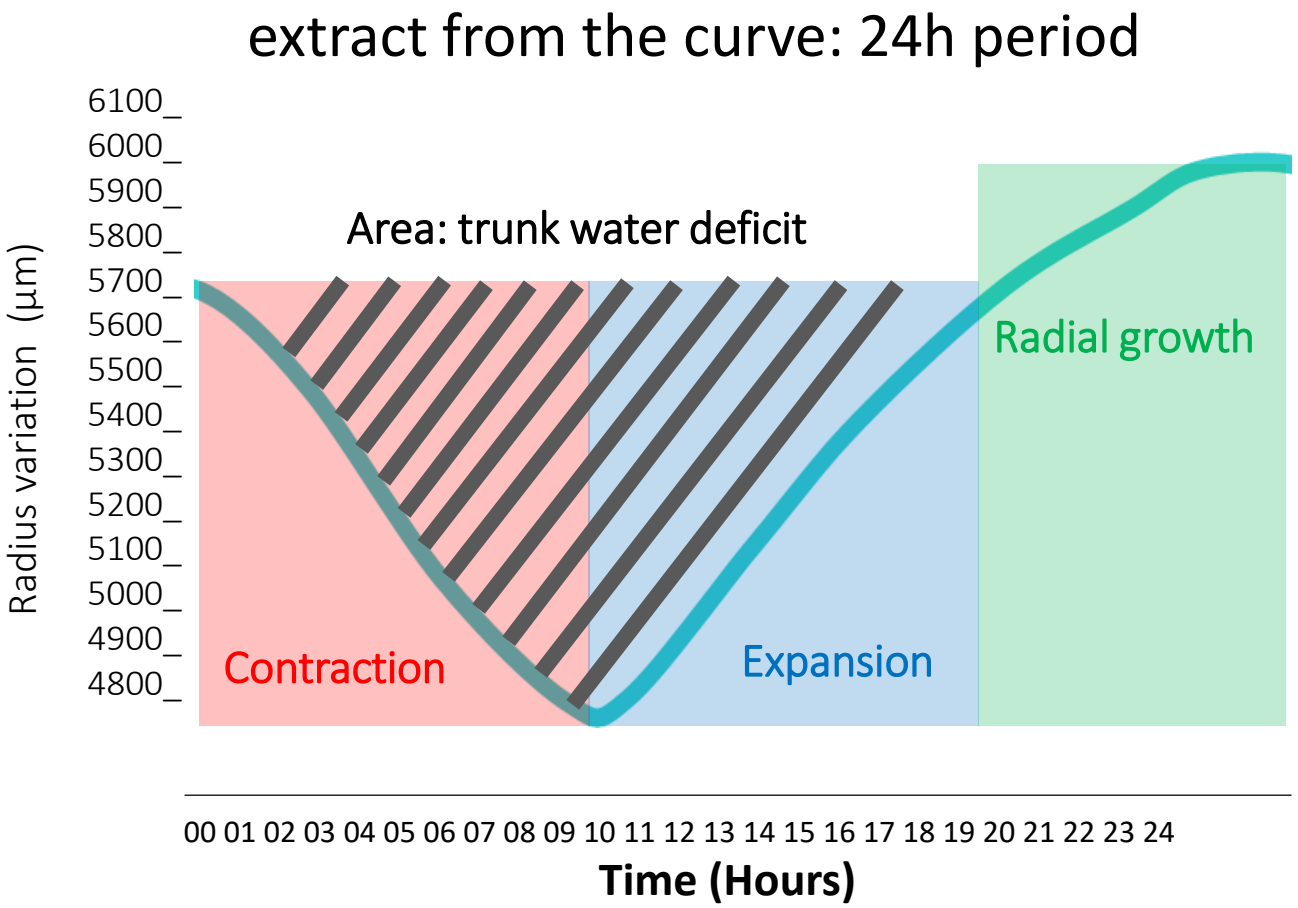


Utilizing (*contraction*), then building up (*expansion*) water reserve

Fitting *nor* with inter-ring microdensity data



Fitting *nor* with inter-ring microdensity data



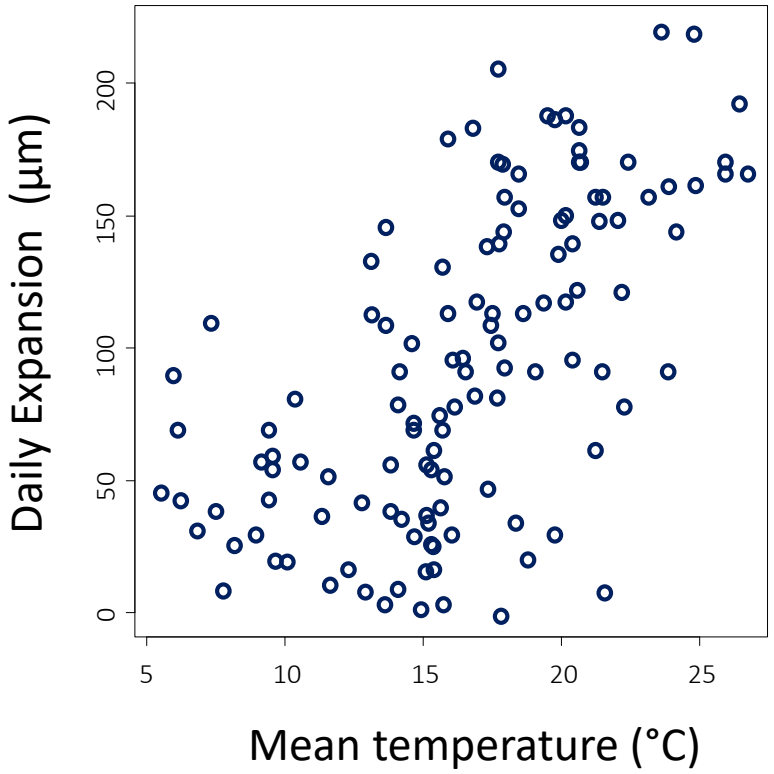
Fitting *nor* with inter-ring microdensity data

- 197 trees of three species (European larch, Japanese larch and hybrid larch)
- Four phenotypic variables estimated for each 24h period
  - Radial **growth**
  - Three *water dynamics* variables: **contraction**, **expansion**, **trunk water deficit**
- At the same time we measure four climatic variables
- We investigate the 16 possible **relationships** (all the **pairs** of phenotypic and climatic variables)

Fitting *nor* with inter-ring microdensity data

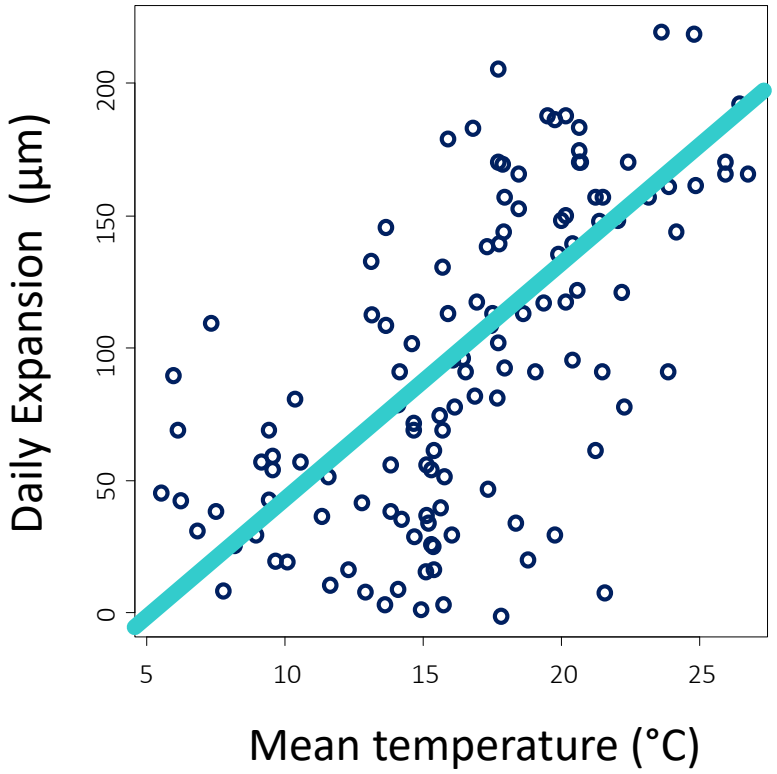
Example : one tree, one pair of phenotypic/climatic variables

Expansion (µm/day) and mean temperature



Fitting *nor* with inter-ring microdensity data

Expansion (µm/day)



r = 0.76, **p** < 0.05

Slope = 8.90 µm/°C

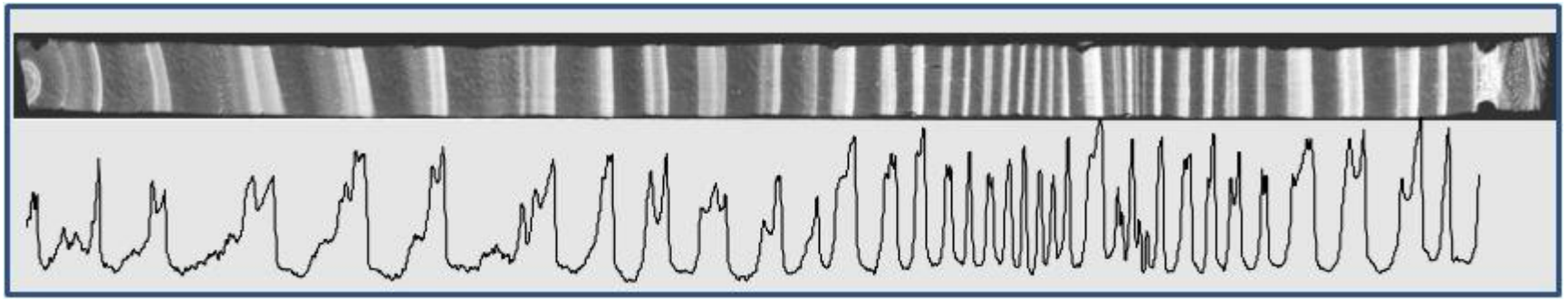
= an estimate of pp

Some results

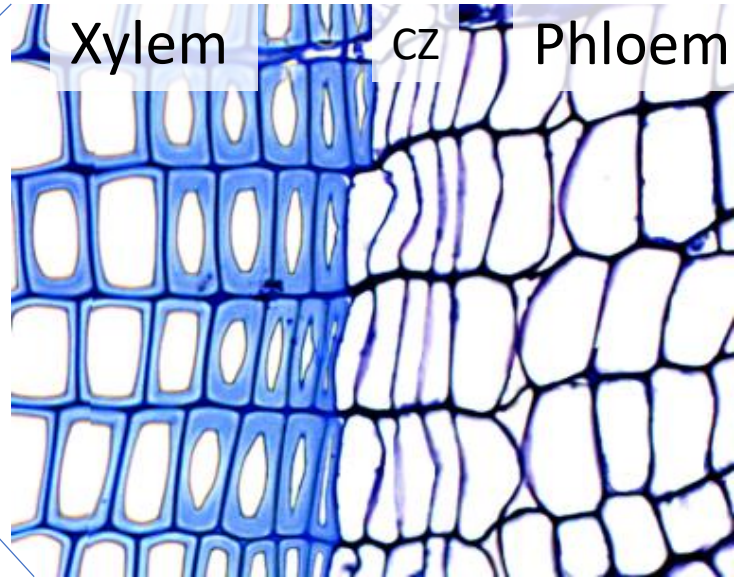
- *nor* fitted for **89%** of the trees
- Better fitted for:
  - *Trunk water deficit* and *contraction*
- With
  - *Temperature* and *soil water reserve*
- *PP is variable*
  - *Environmentally*
  - *Between species*
- Hybrid and Japanese larch > **more plastic** than European larch
- J**apanese** larch more plastic for stem **water dynamics**
- **Hybrid** larch is plastic for stem **water dynamics** and **radial growth**
- Related to the **functional characteristics** of the species

2. Fitting *nor* with *inter-ring* microdensity in *Larix decidua*

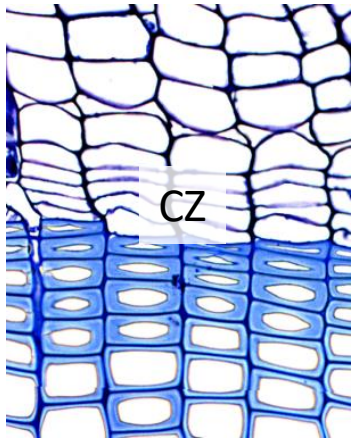
Second case study



Periodicity of wood formation in temperate climate



Conifers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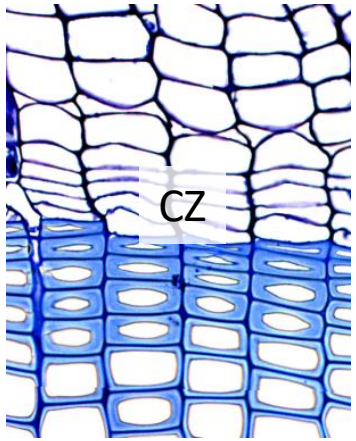
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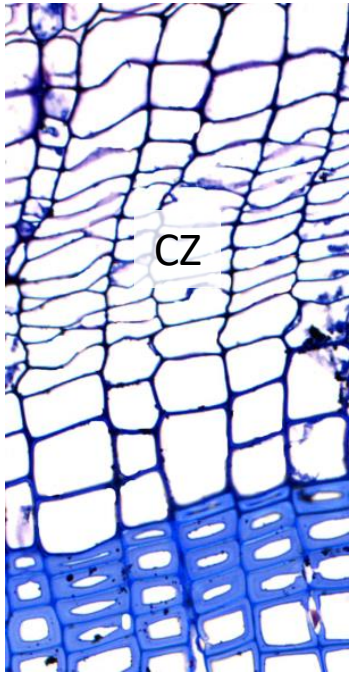
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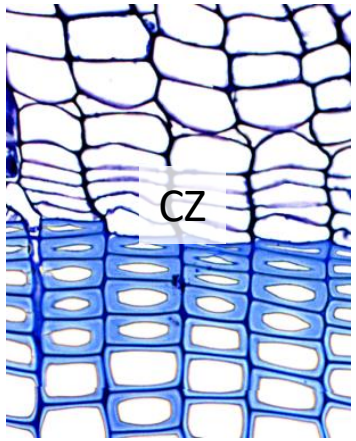
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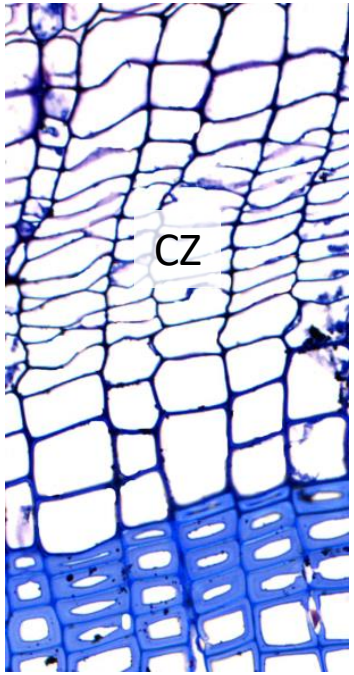
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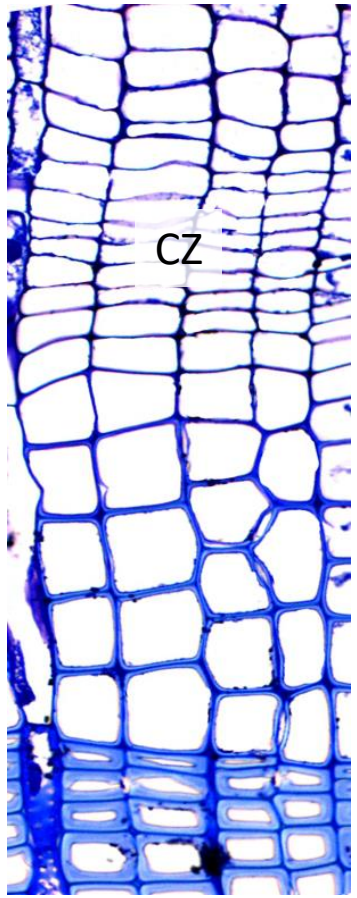
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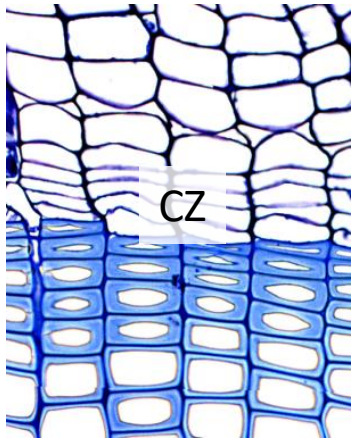
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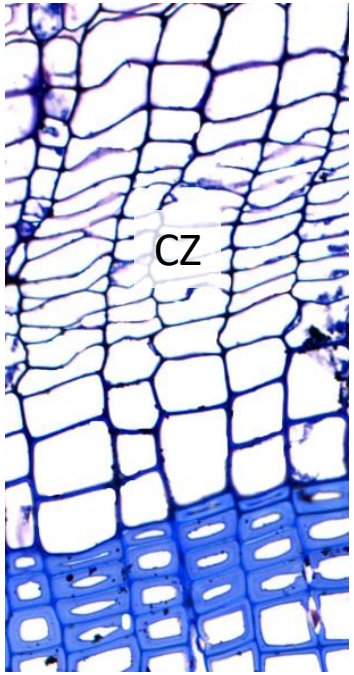
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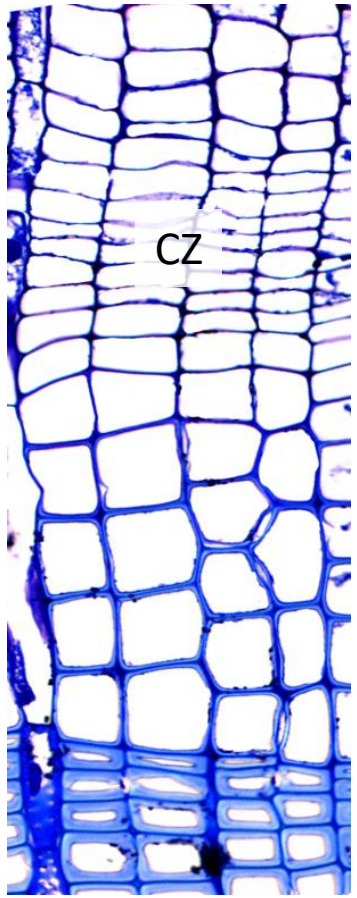
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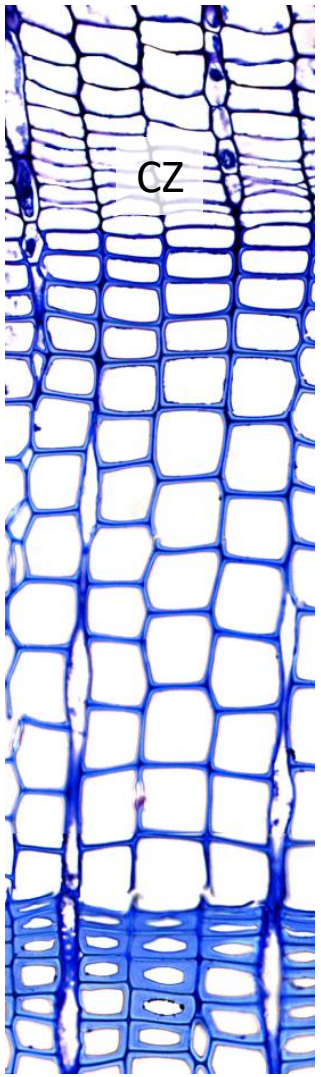
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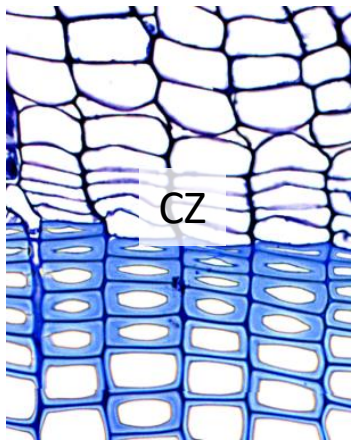
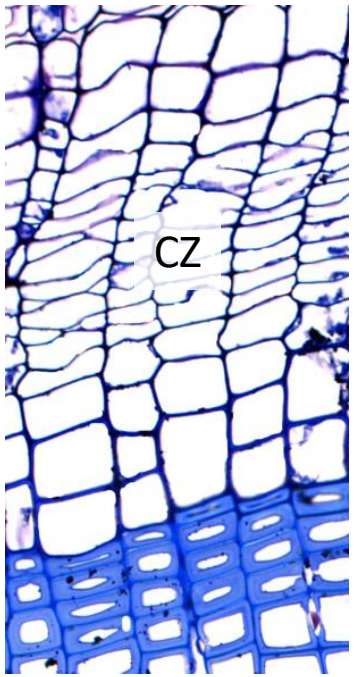
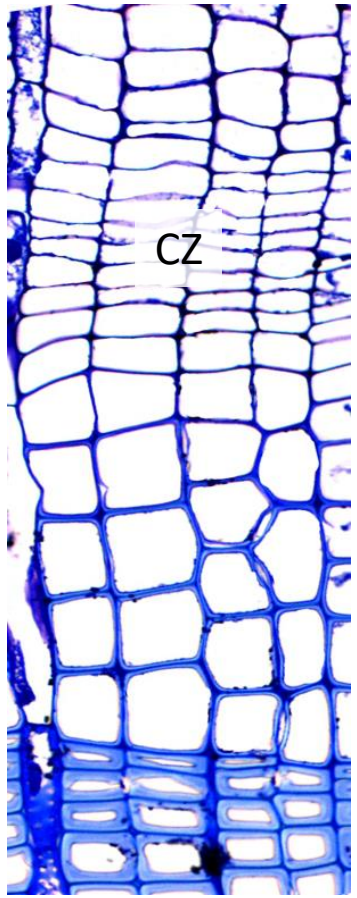
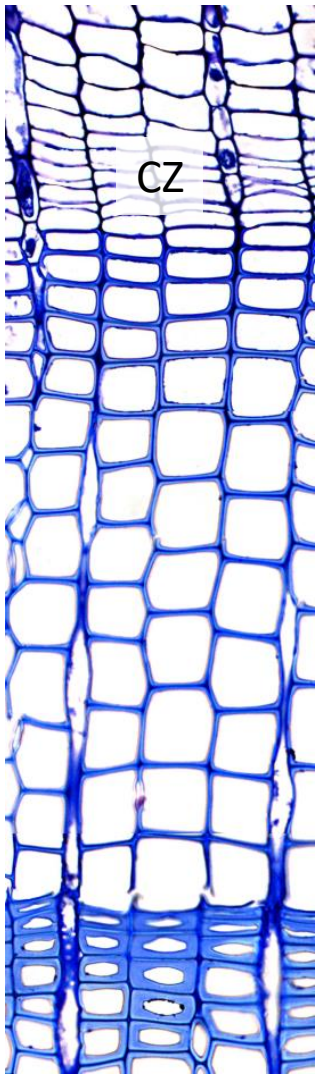
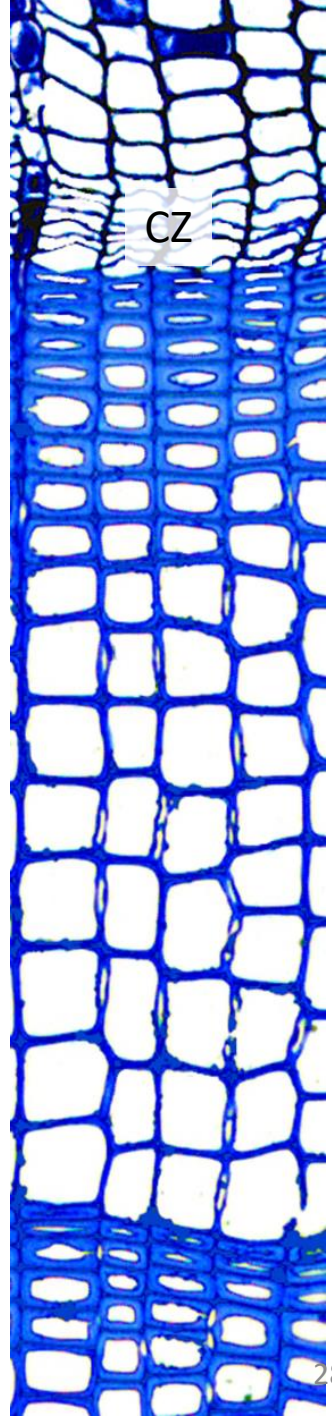




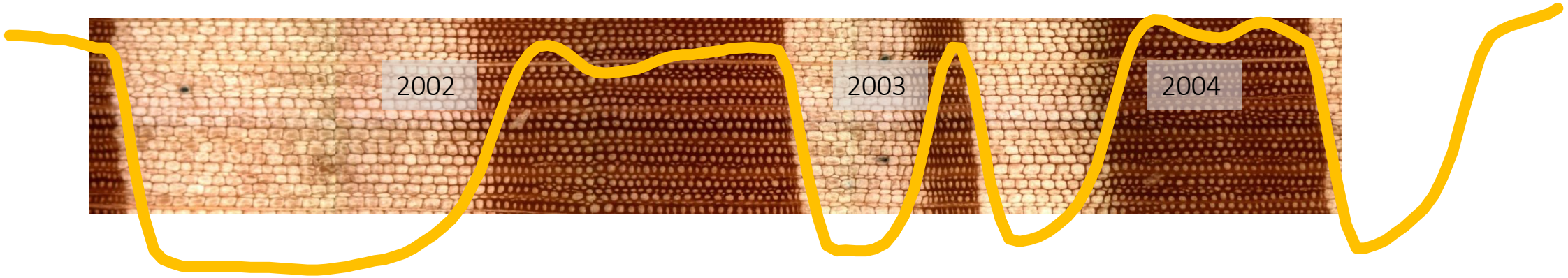




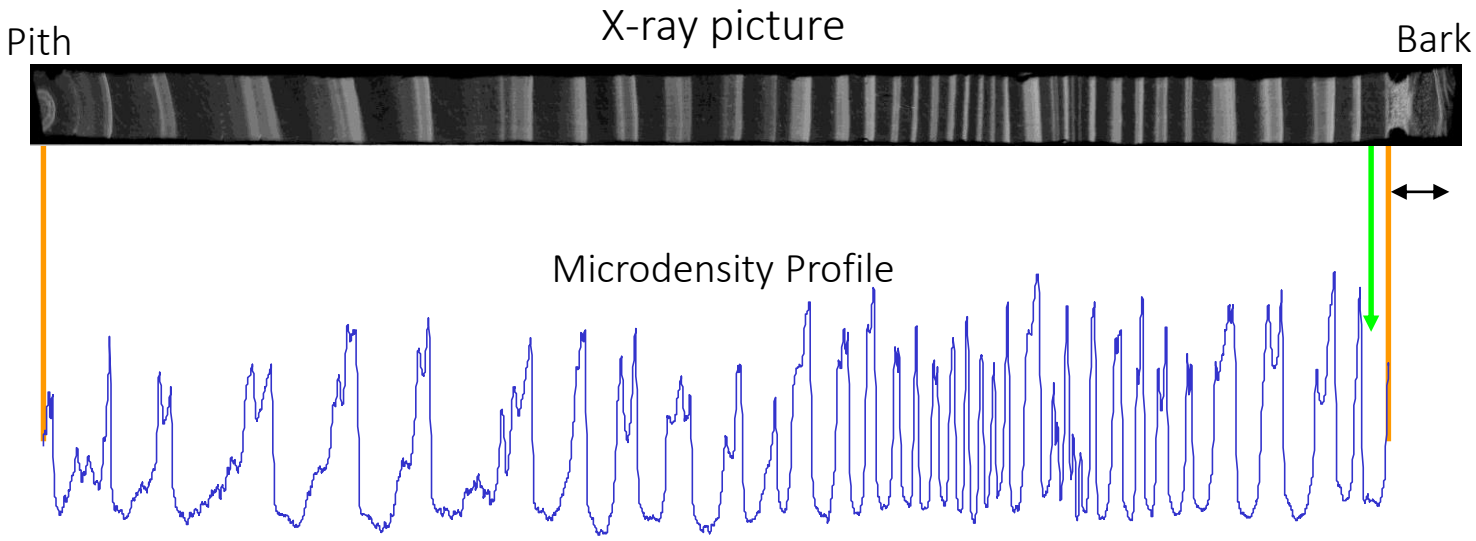


Images and inspiration by Cyrille Rathgeber et al.

These changes are well depicted by X-ray microdensitometry

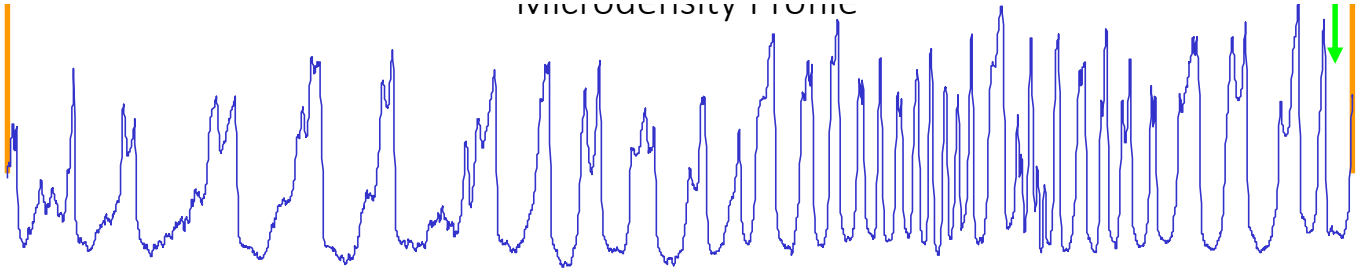


Inter annual variation



Time-series of inter-annual phenotypic variation

Inter-annual variation

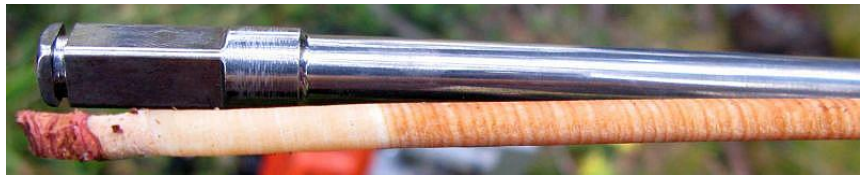


Larch across an elevation gradient

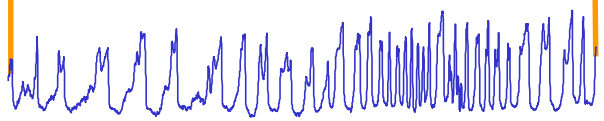
Increment cores and microdensity

a) Collection of wood samples

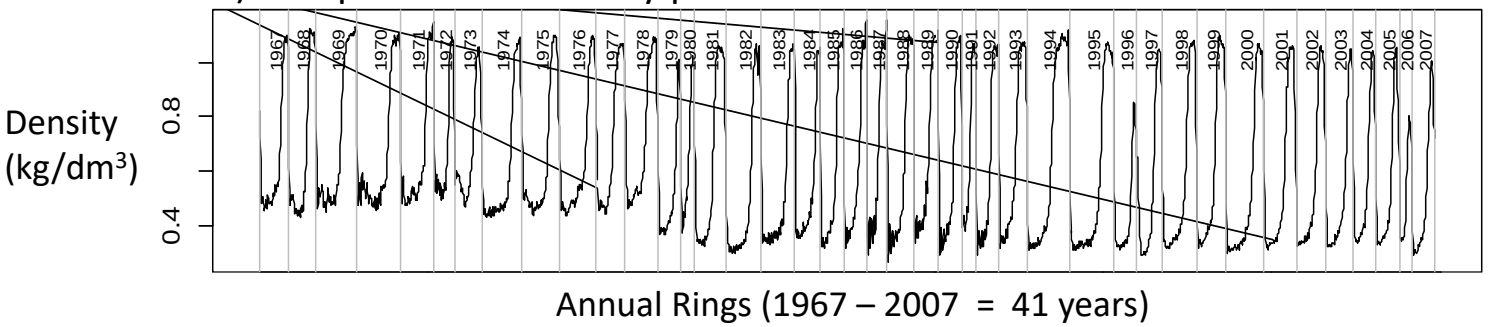
b) Wood samples



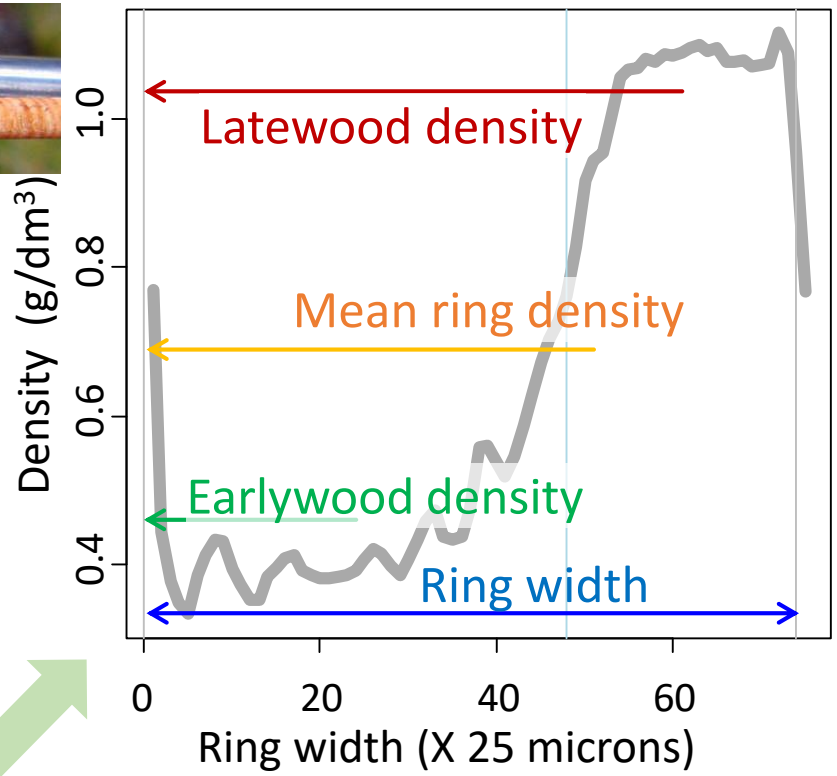
c) X-ray and microdensity profile



d) Complete microdensity profile



e) Annual ring variables



Phenotypic and environmental variables

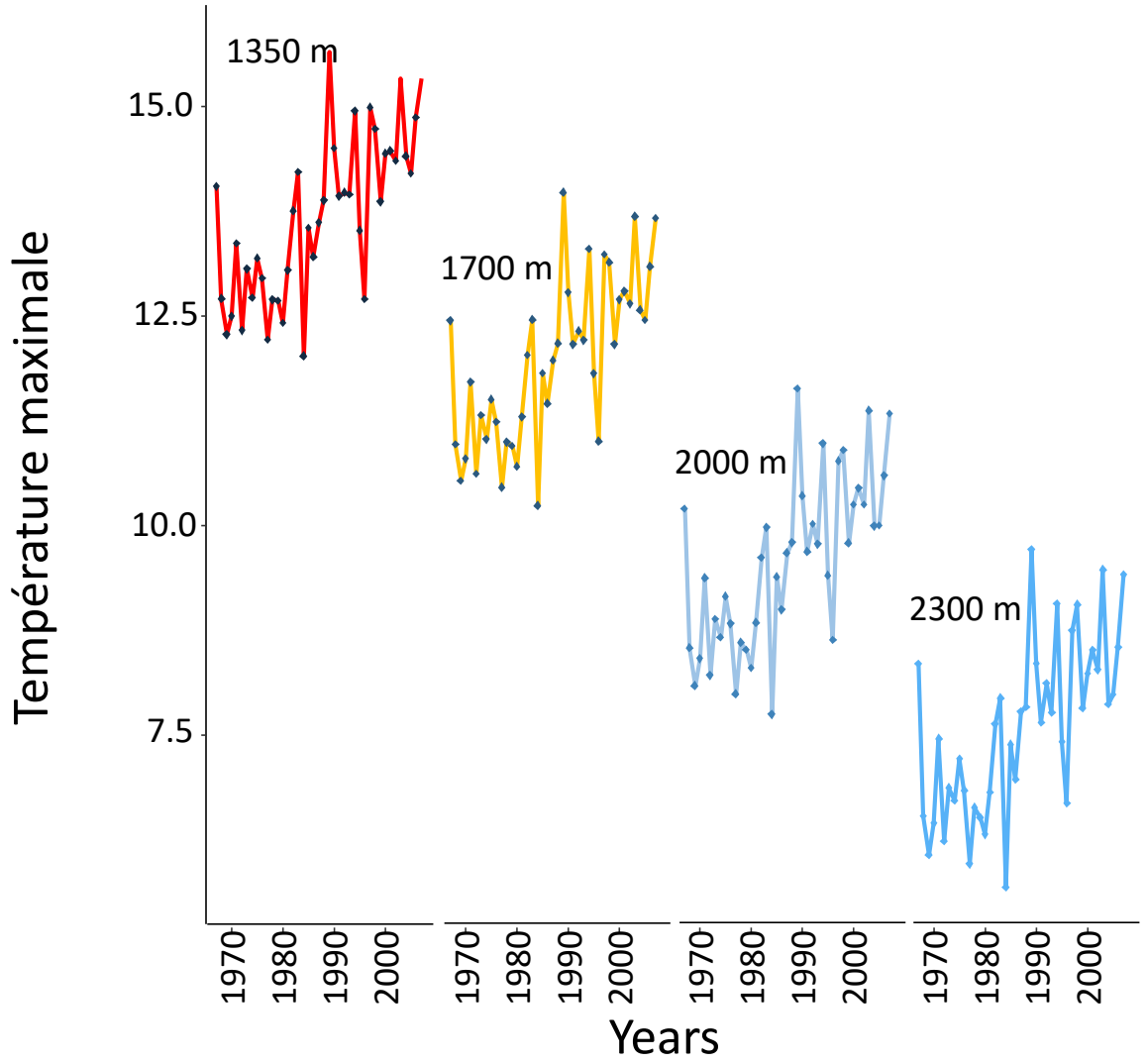
Annual Ring variables

- Ring variables
- Ring width
- Ring density
- Earlywood width, density
- Latewood width, density
- 1968 to 2007 = 41 annual rings

Annual environmental data

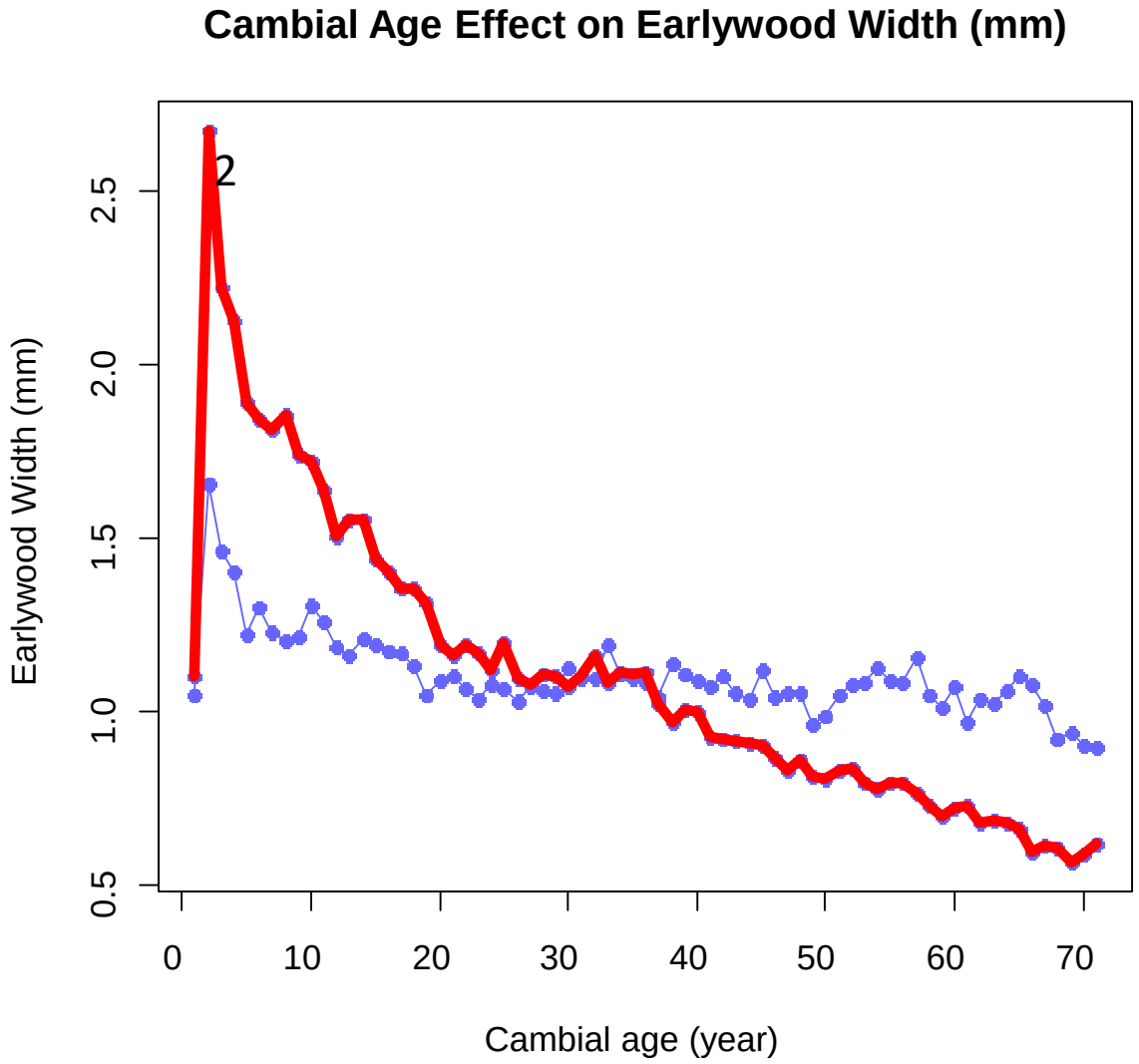
- Climatic variables
- Weather data from the local Météo-France database
- Adjusted from the elevation effect
- Temperature, precipitation
- 1967 to 2007 = 41 years

Temperature



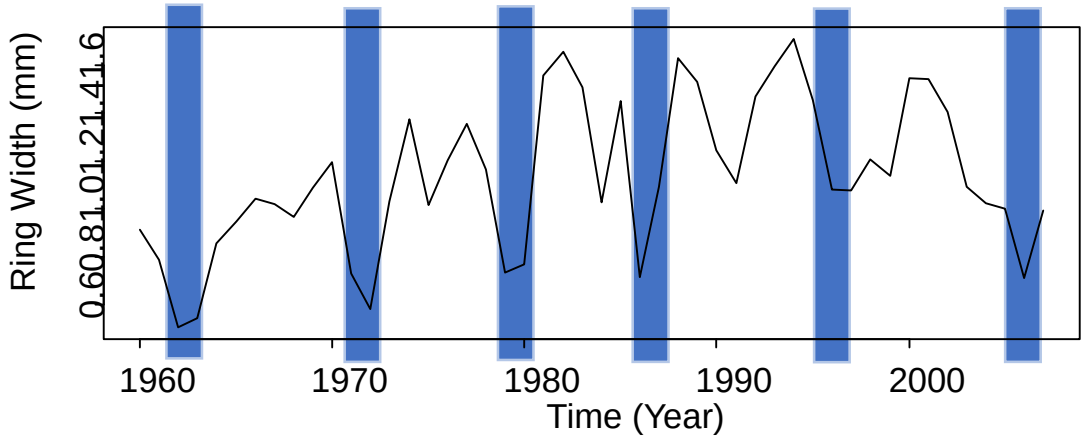
Caution!

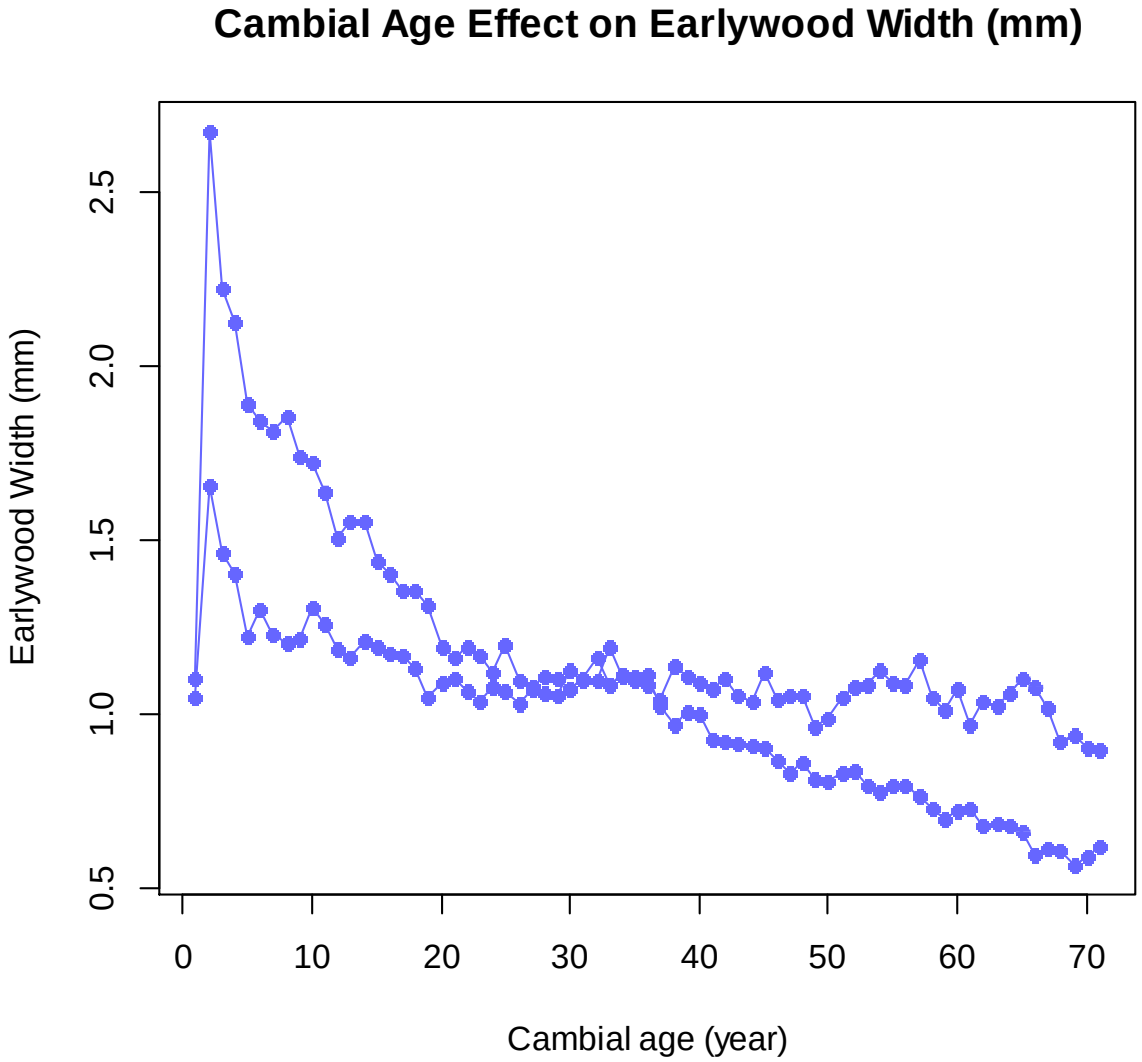
- Not only *environment* explains inter ring variation…



Caution!

- Not only *environment* explains inter ring variation…
- Not only *climate* explains inter ring environmental variation…
  - Competition with other trees
  - Competition with other organisms

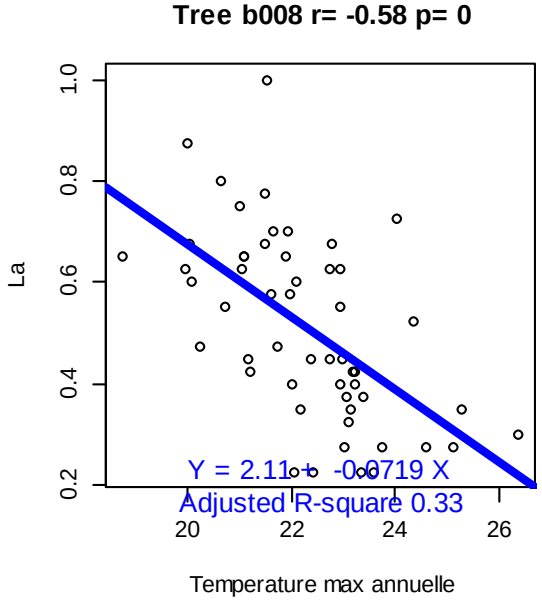


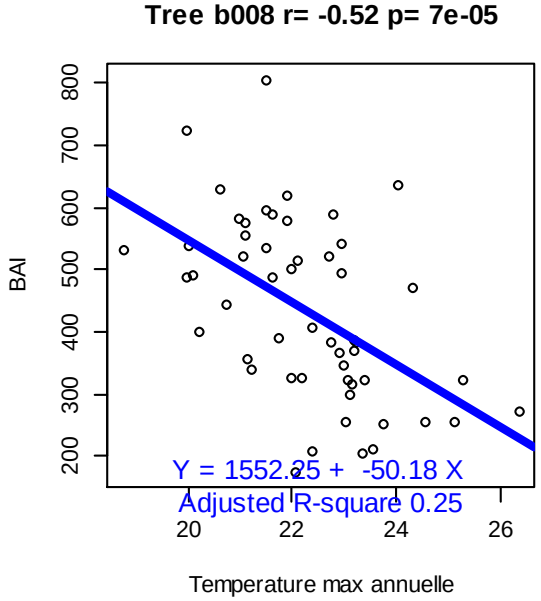


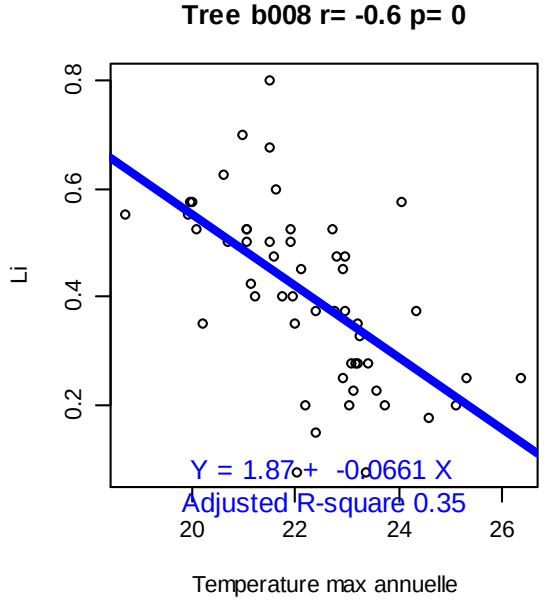
Alain Roques et al

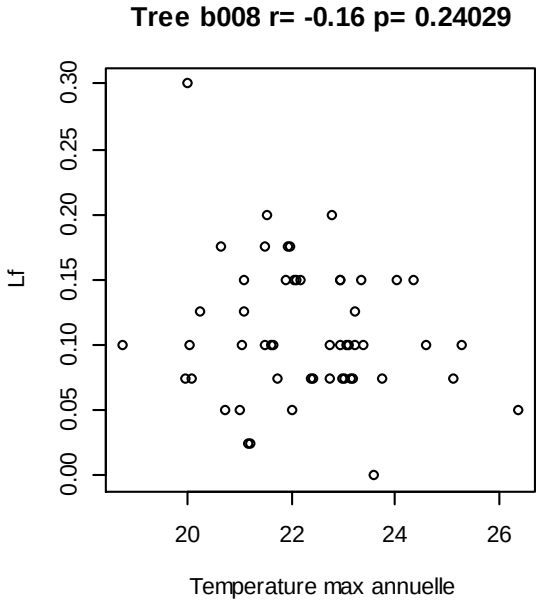
Inter-Annual Reaction Norms

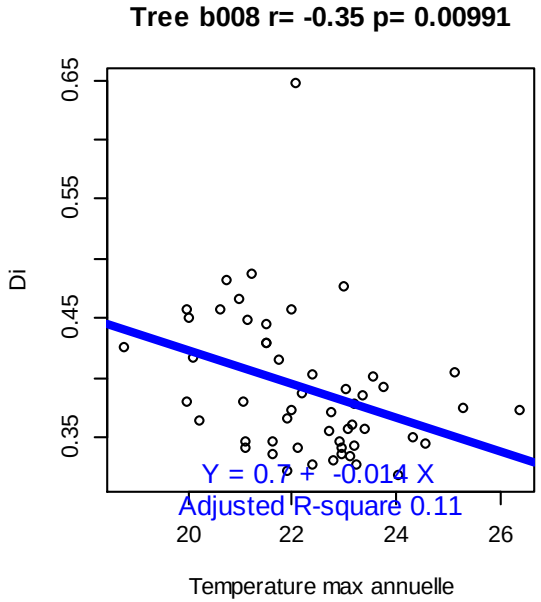
- Tree 8
- 6 ring variables
- Slope = estimate of pp
- Positive and negative

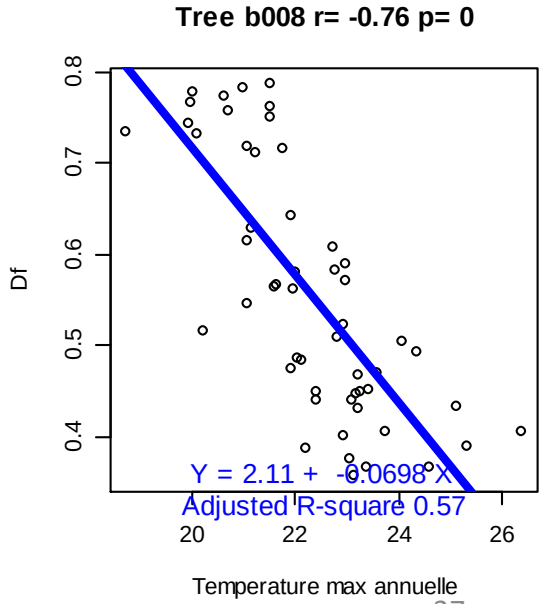








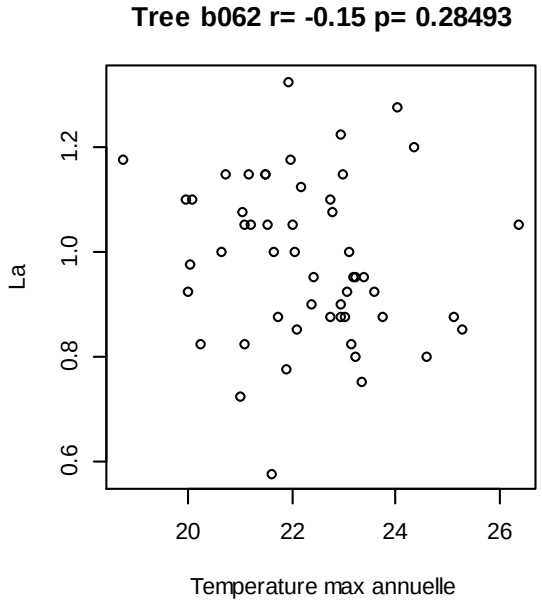


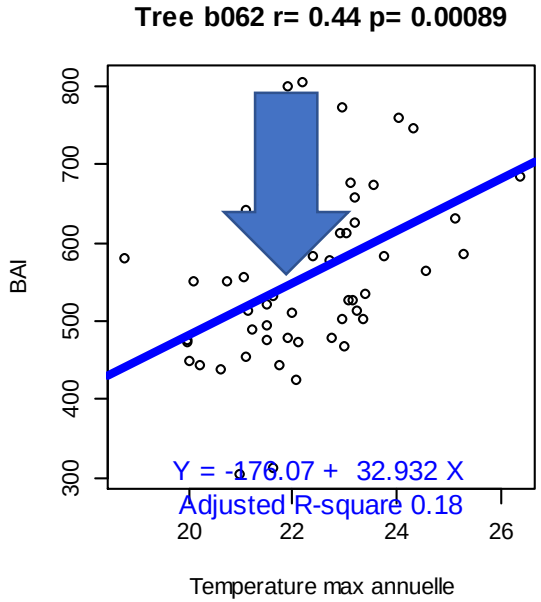


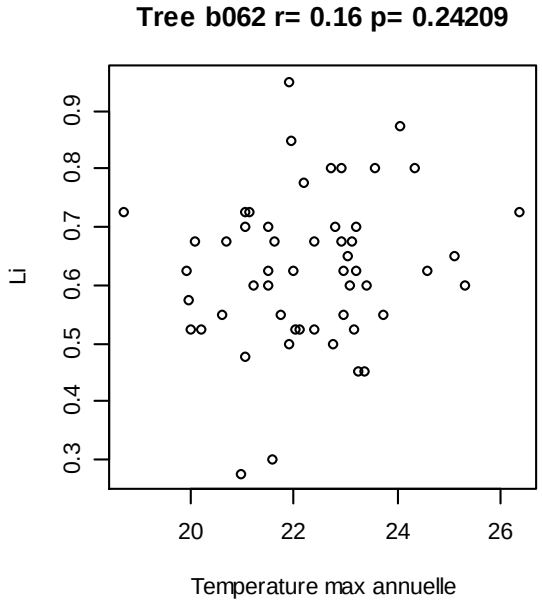
Margarita Escobar-Sandoval et al

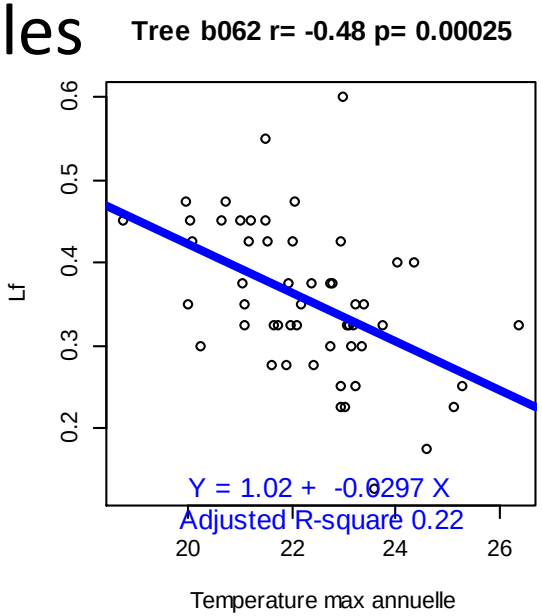
Tree 62

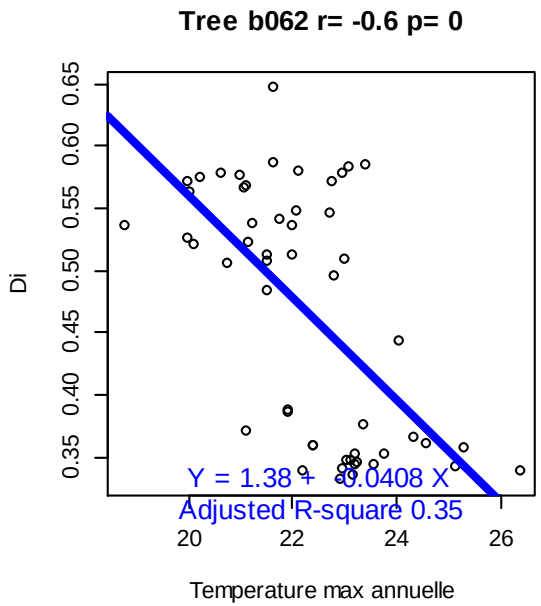
6 ring variables

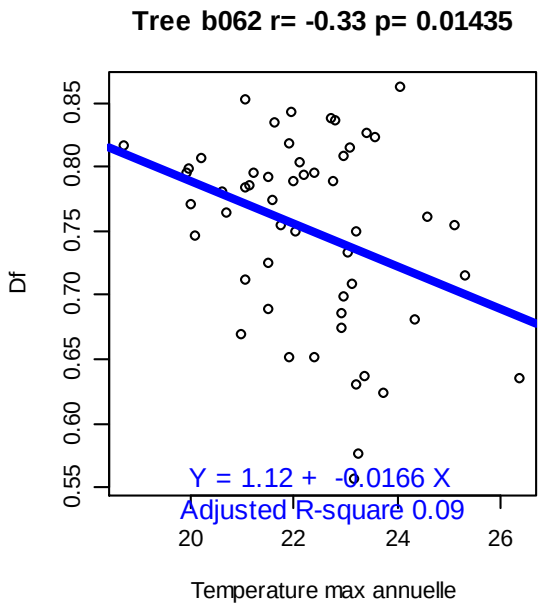






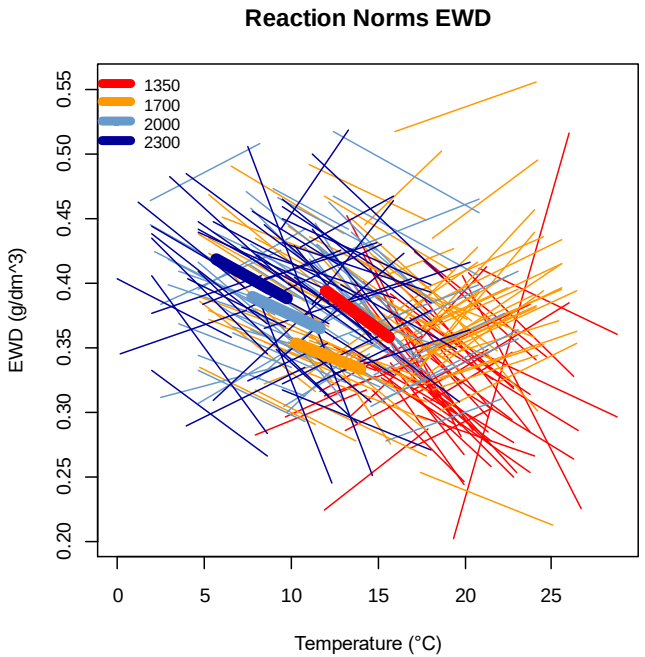


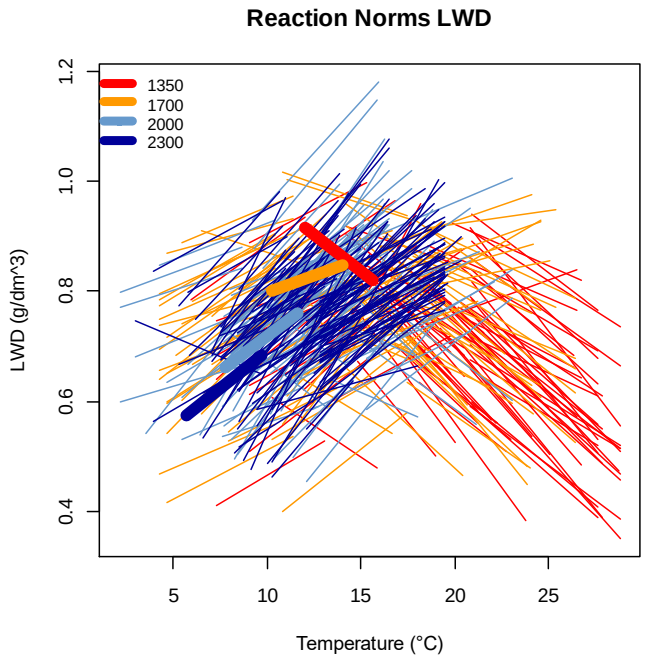


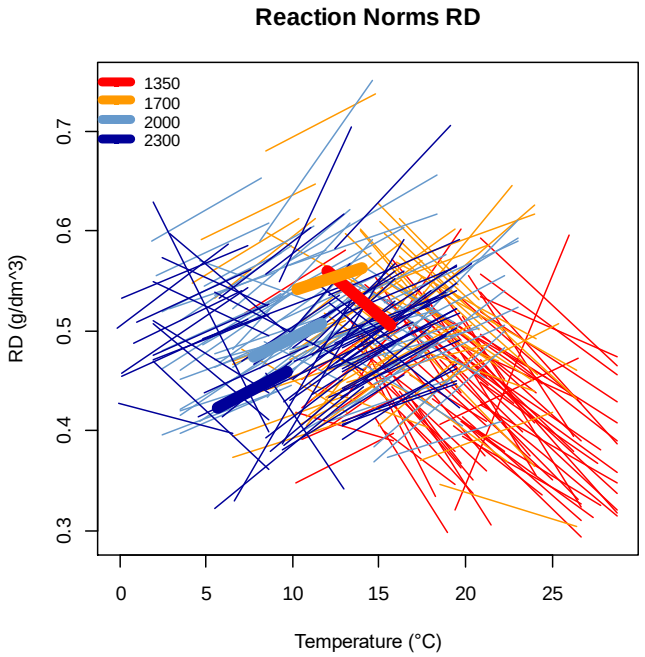


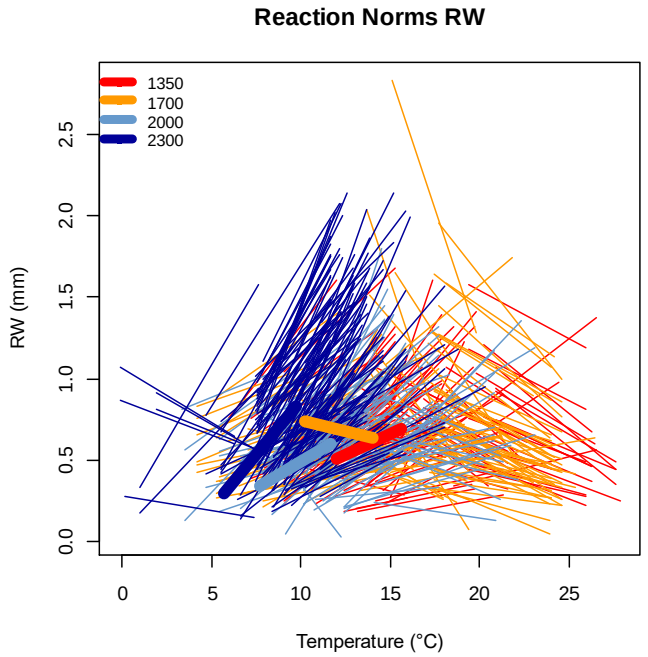
Margarita Escobar-Sandoval et al

All the nor
Pp estimated for 71% of the trees
Four ring variables
Four elevation levels

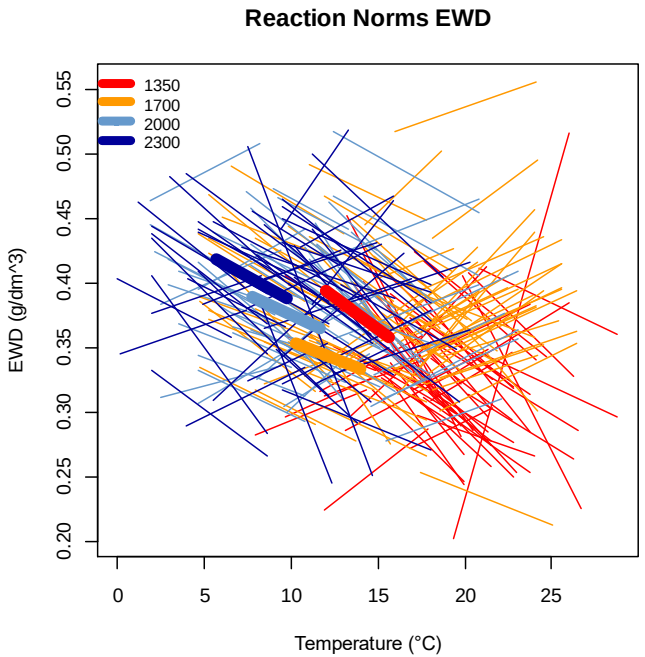


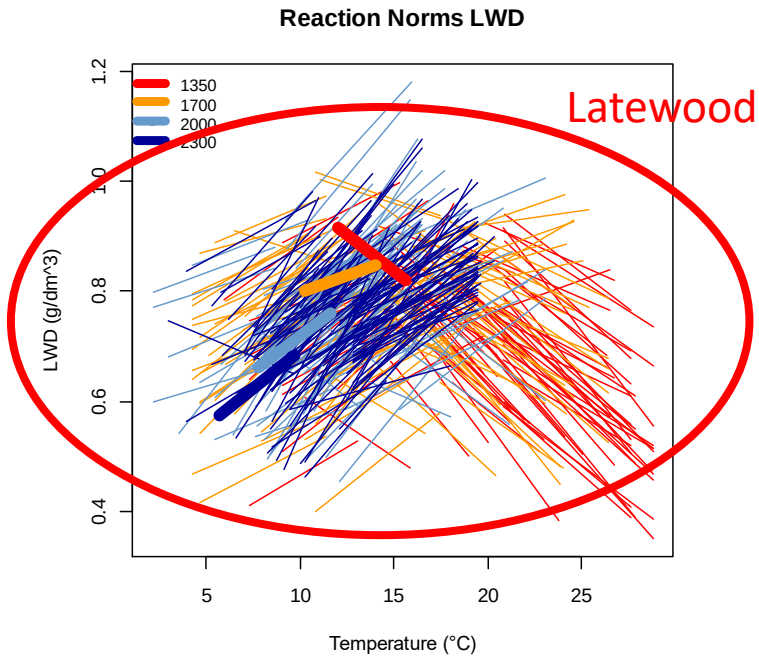


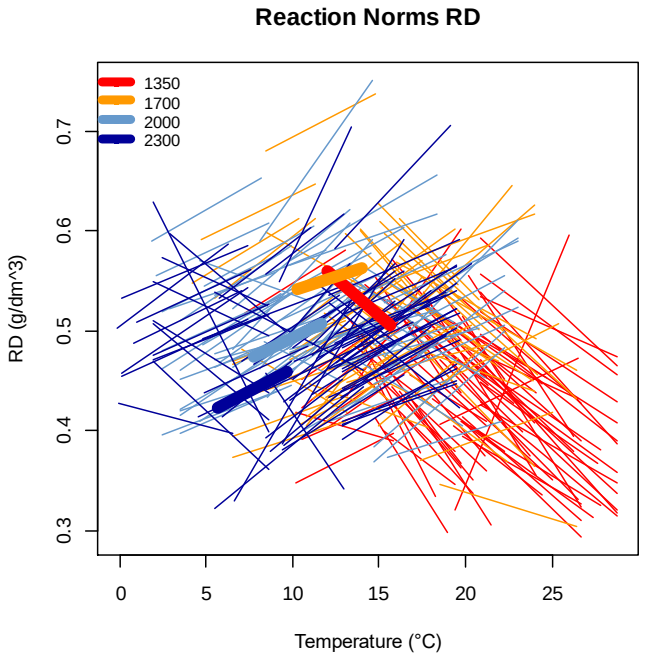


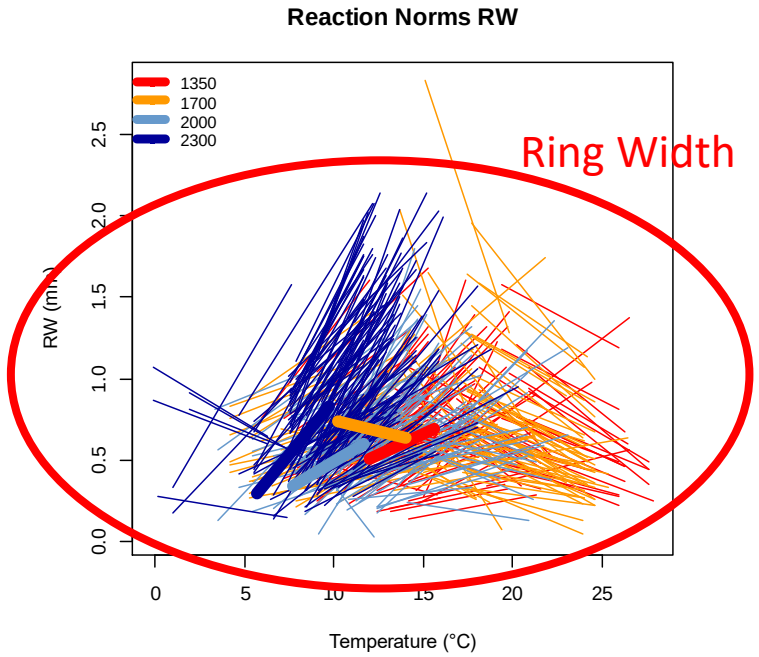


All the nor
Four ring variables
Four elevation levels

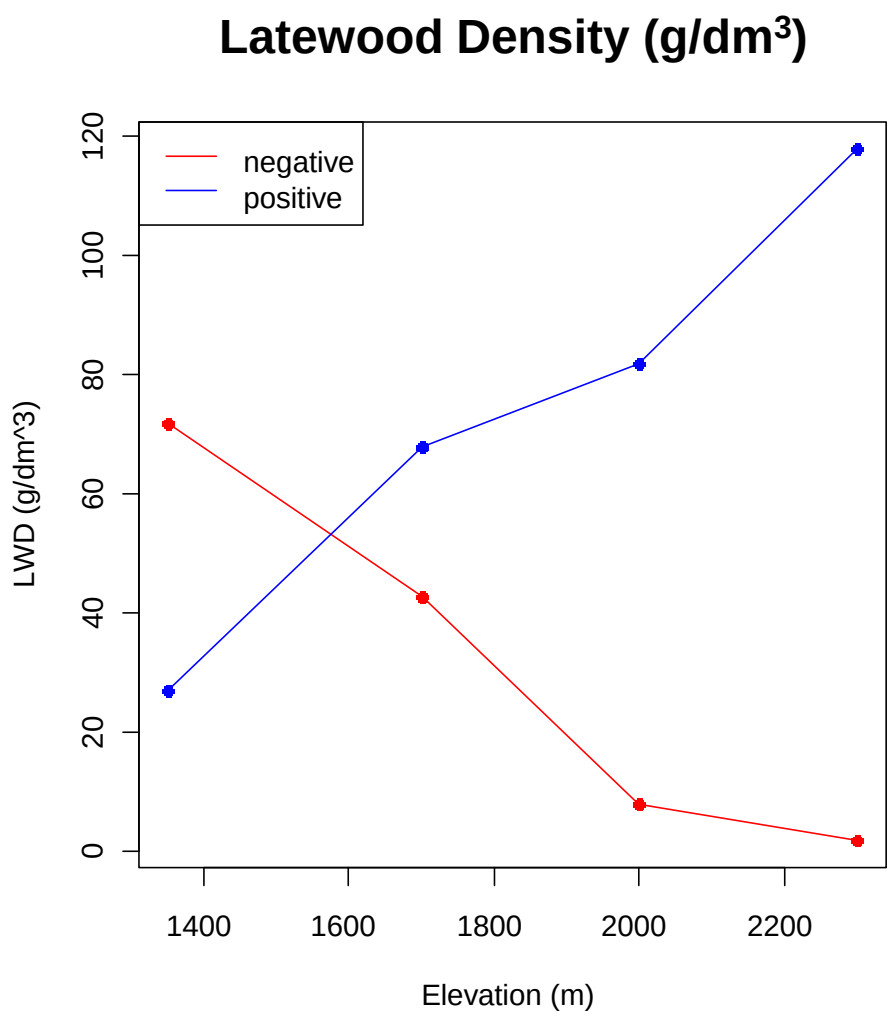


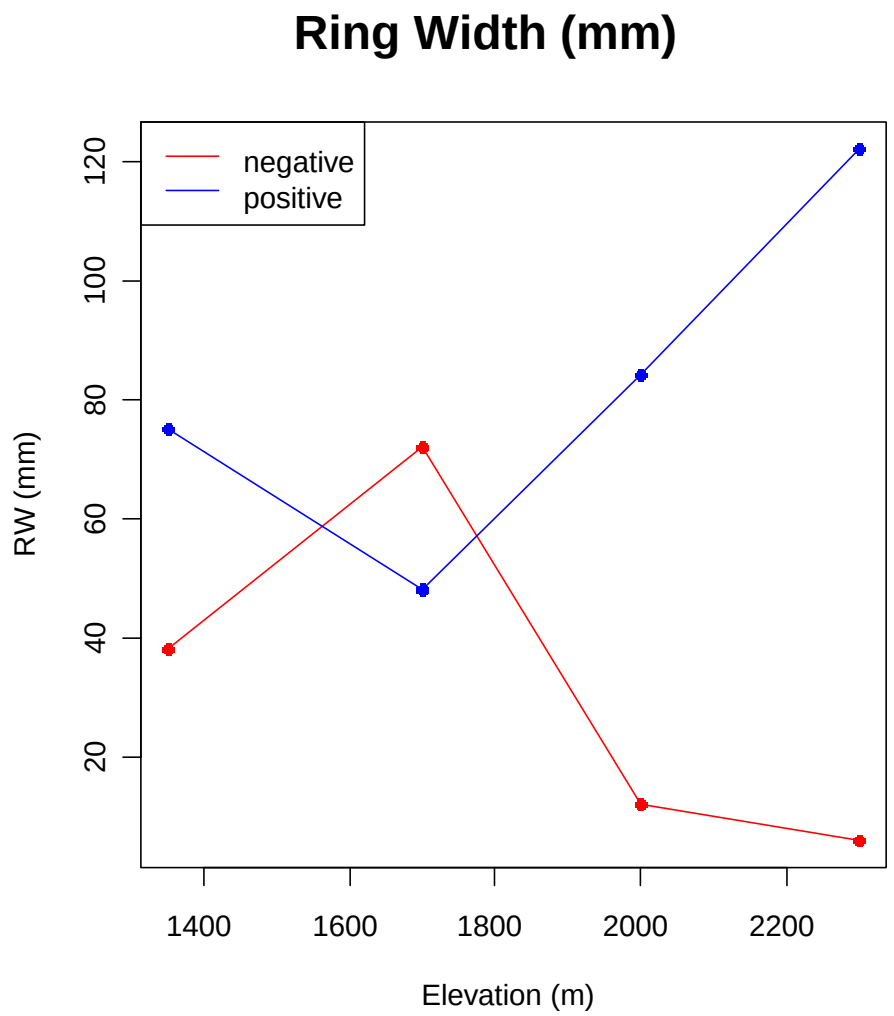




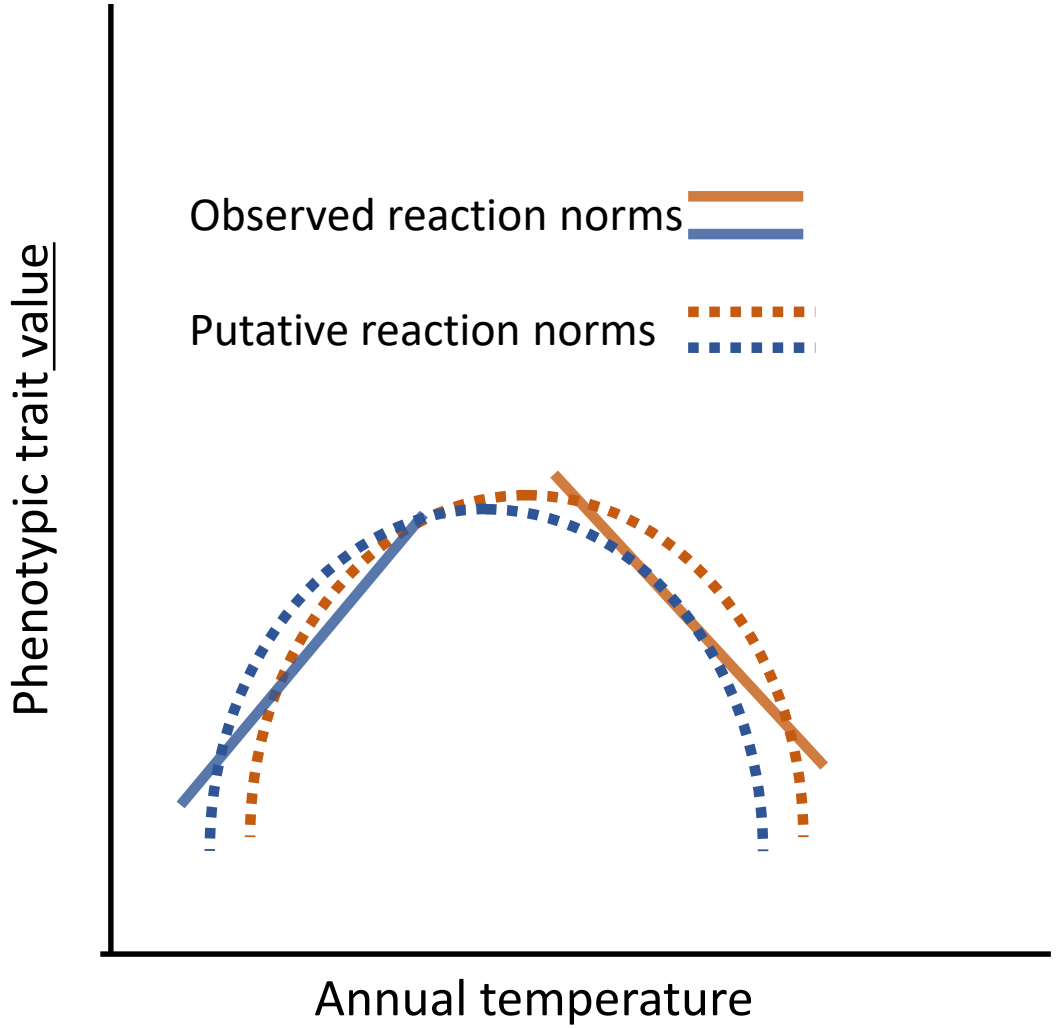


Number of trees with positive/negative *pp*



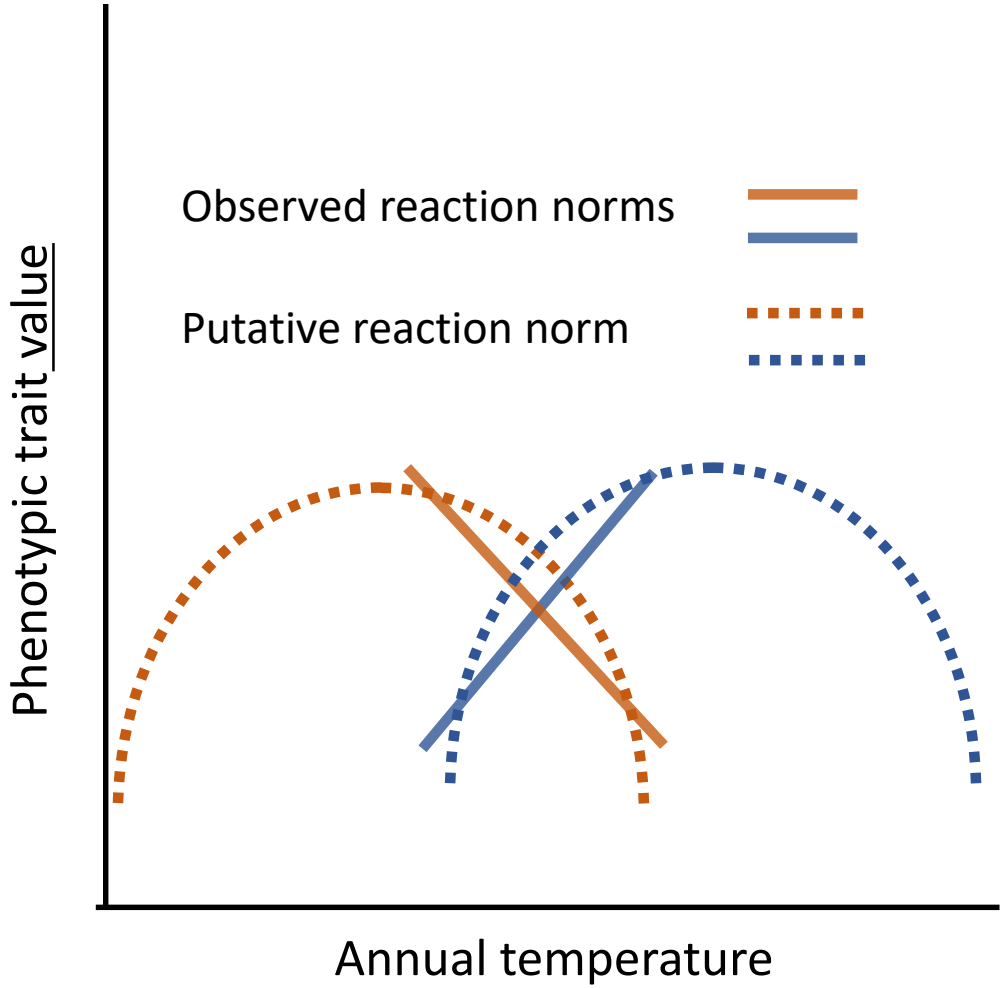


Discussion



nor observed at the **bottom** (orange with a negative slope) and at **the** top (blue with a positive slope) of the elevation gradient: **segments of unique nonlinear reaction norms?**

Discussion



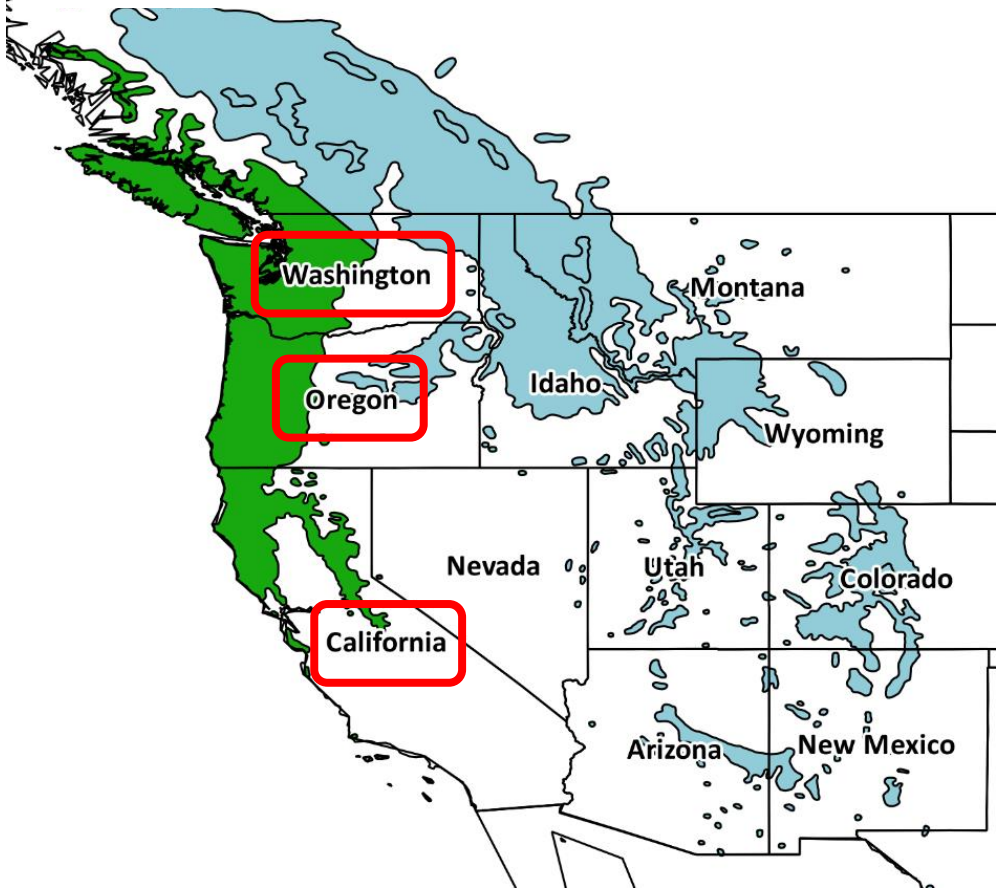
two trees with opposite slopes of nor at the same elevation level : similar nonlinear shape but shifted along the temperature axis?

3. Fitting *nor* with inter-ring microdensity in *Pseudotsuga menziesii*

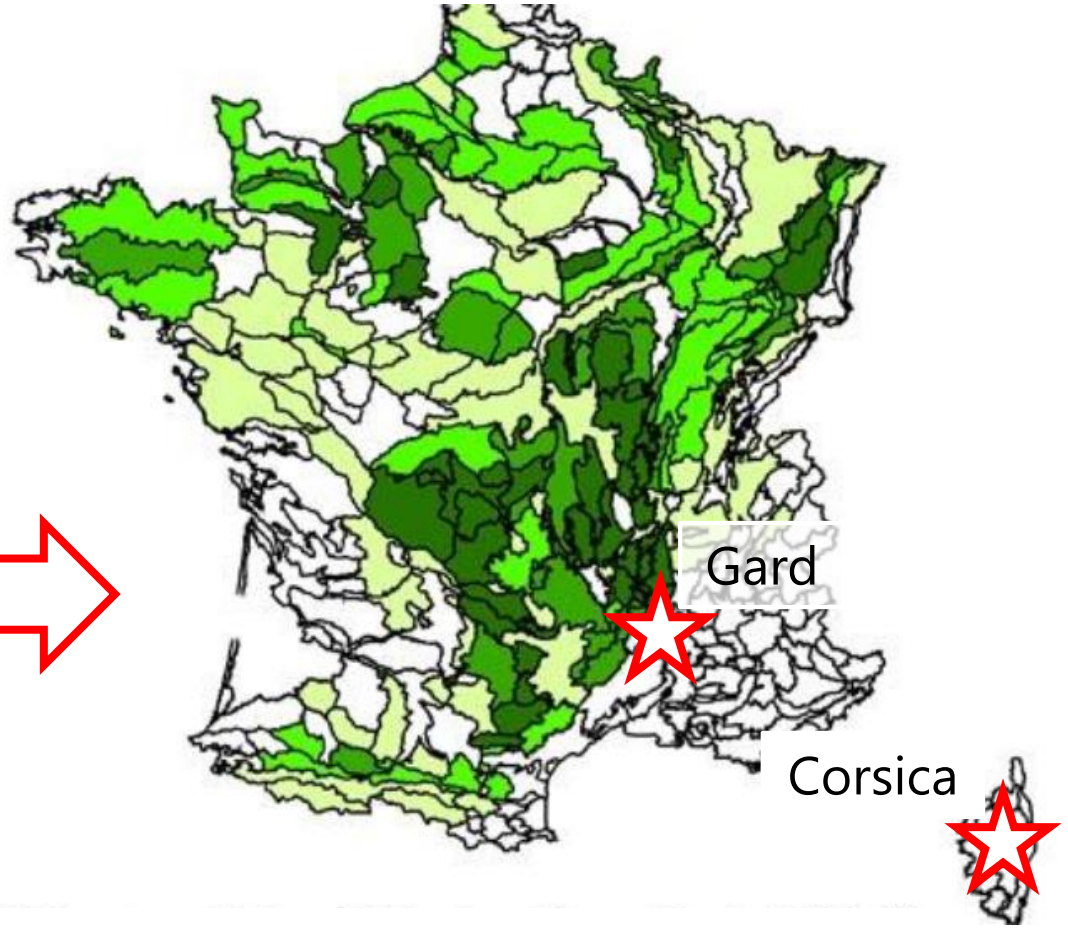
Third case study

Experimental design

28 provenances from Washington (4), Oregon (4) and California, coastal (10) and interior (10)

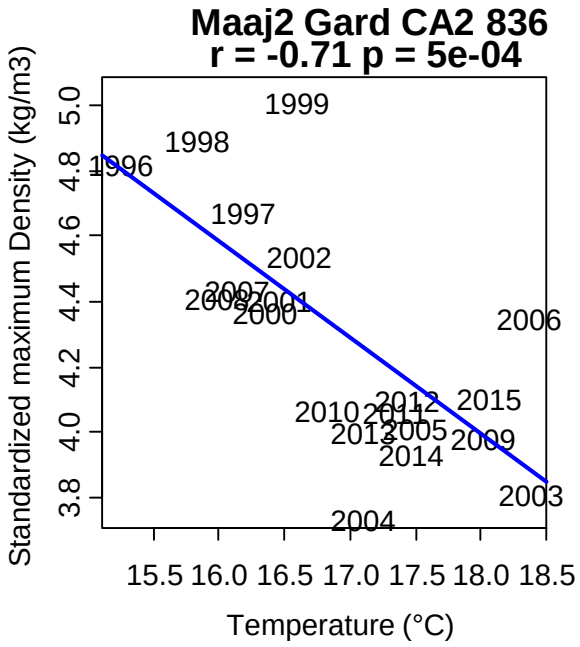


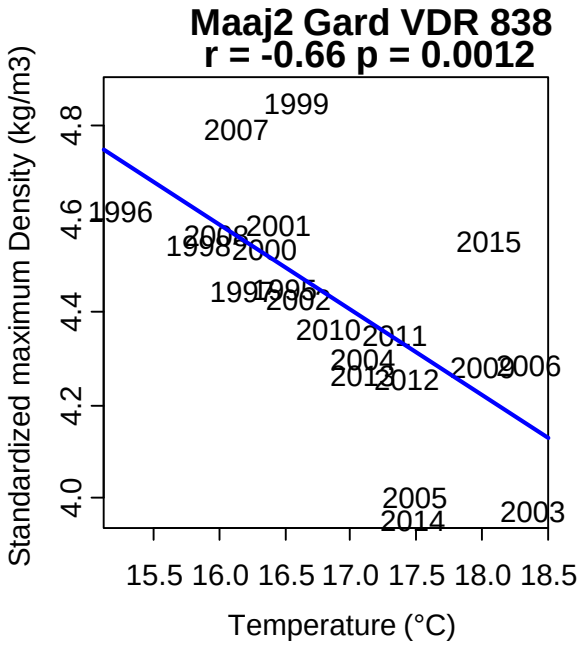
Two experimental trials in Southern France with 1467 trees in total

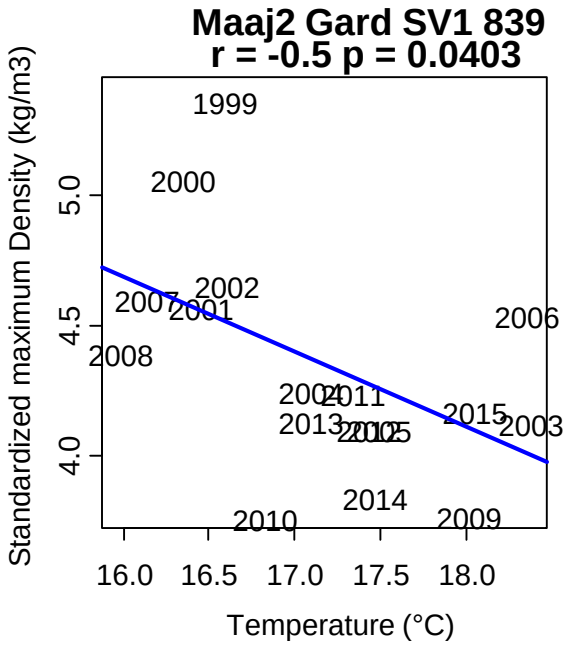


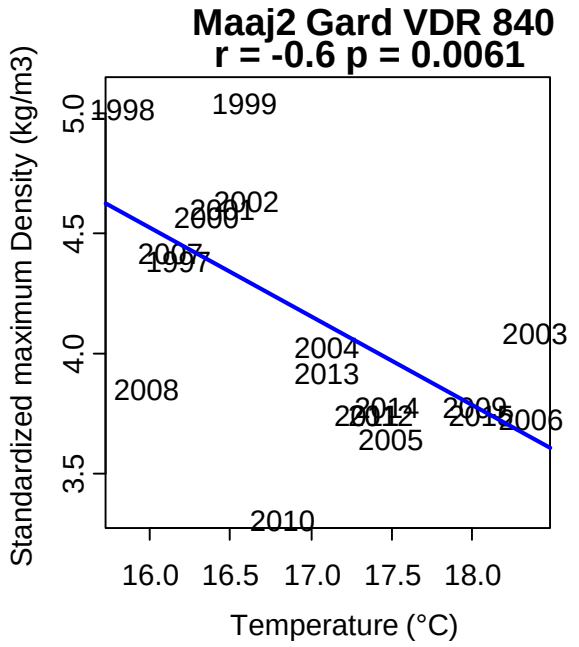
Available data

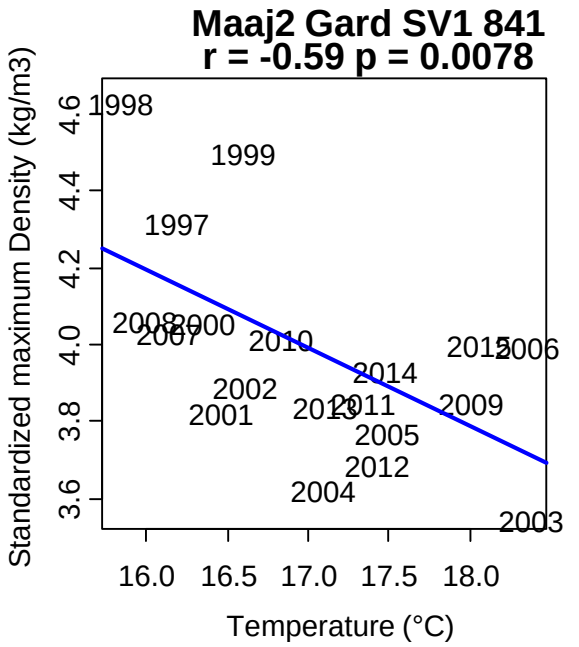
- 1467 microdensity profiles with on average **20 rings** per tree (generally between 19 and 21 rings for most trees, between 1997 and 2016)
  - Several **growth** and **density** ring variables
- Météo-France climatic data between 1990 and 2016 with temperature and precipitation

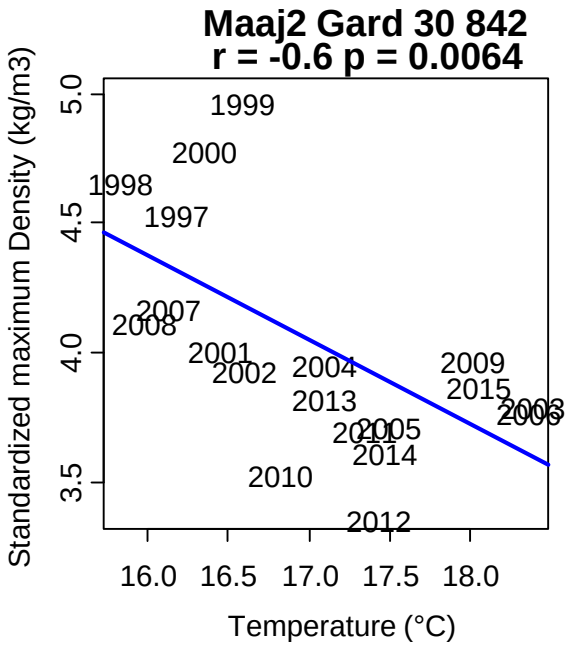

Maaj2 Gard CA2 836
r = -0.71 p = 5e-04
Standardized maximum Density (kg/m3)
Temperature (°C)

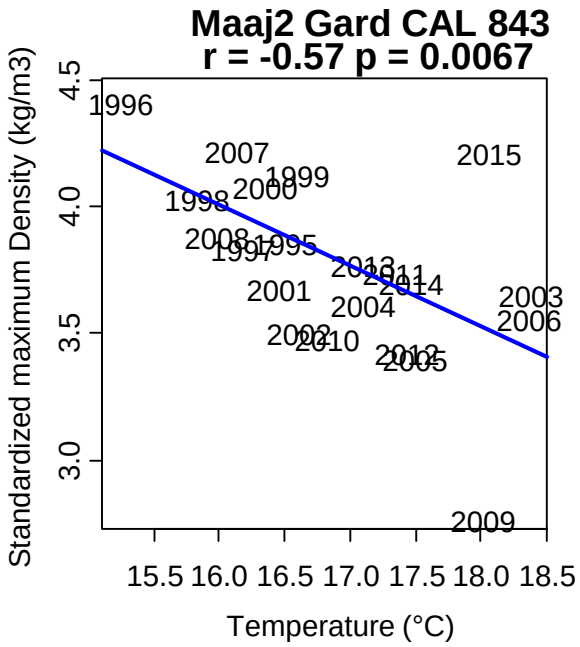

Maaj2 Gard VDR 838
r = -0.66 p = 0.0012
Standardized maximum Density (kg/m3)
Temperature (°C)

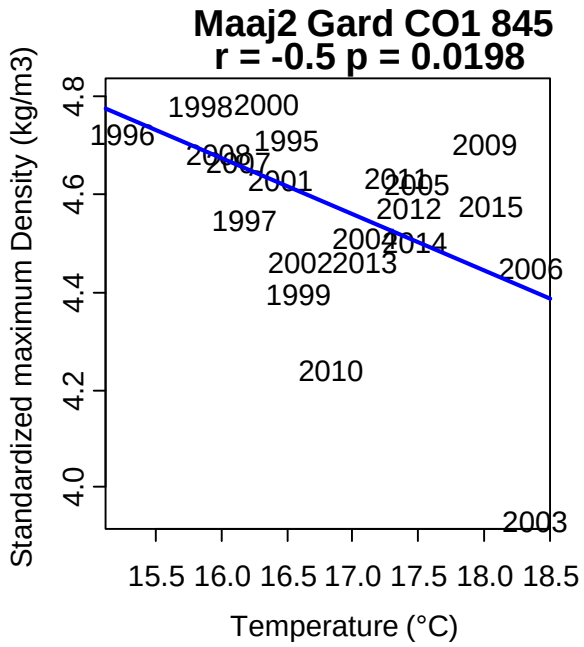

Maaj2 Gard SV1 839
r = -0.5 p = 0.0403
Standardized maximum Density (kg/m3)
Temperature (°C)


Maaj2 Gard VDR 840
r = -0.6 p = 0.0061
Standardized maximum Density (kg/m3)
Temperature (°C)


Maaj2 Gard SV1 841
r = -0.59 p = 0.0078
Standardized maximum Density (kg/m3)
Temperature (°C)


Maaj2 Gard 30 842
r = -0.6 p = 0.0064
Standardized maximum Density (kg/m3)
Temperature (°C)

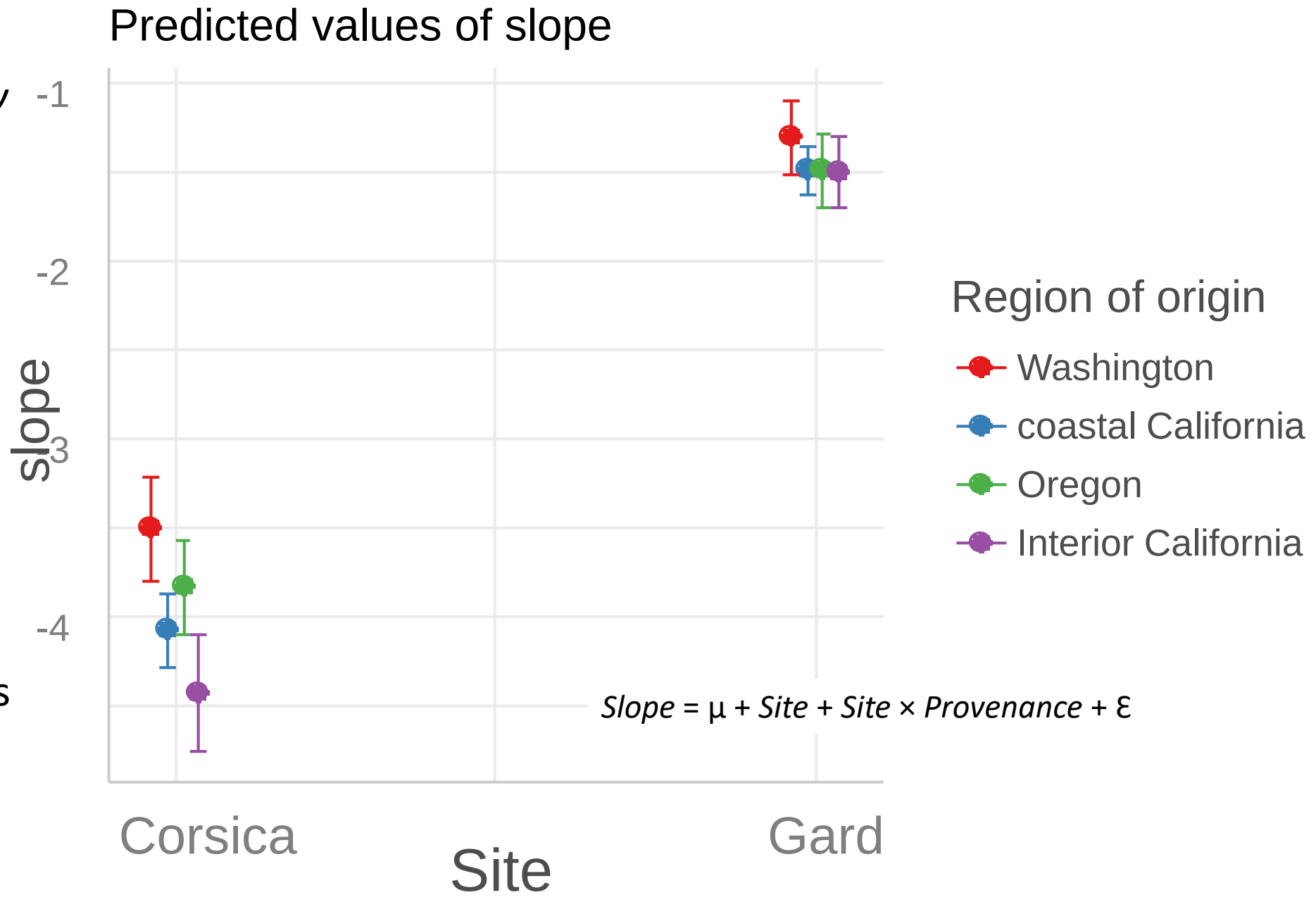

Maaj2 Gard CAL 843
r = -0.57 p = 0.0067
Standardized maximum Density (kg/m3)
Temperature (°C)


Maaj2 Gard CO1 845
r = -0.5 p = 0.0198
Standardized maximum Density (kg/m3)
Temperature (°C)

Maximum ring density
Vs
Mean temperature of
June to September

45% of the trees with estimates of pp

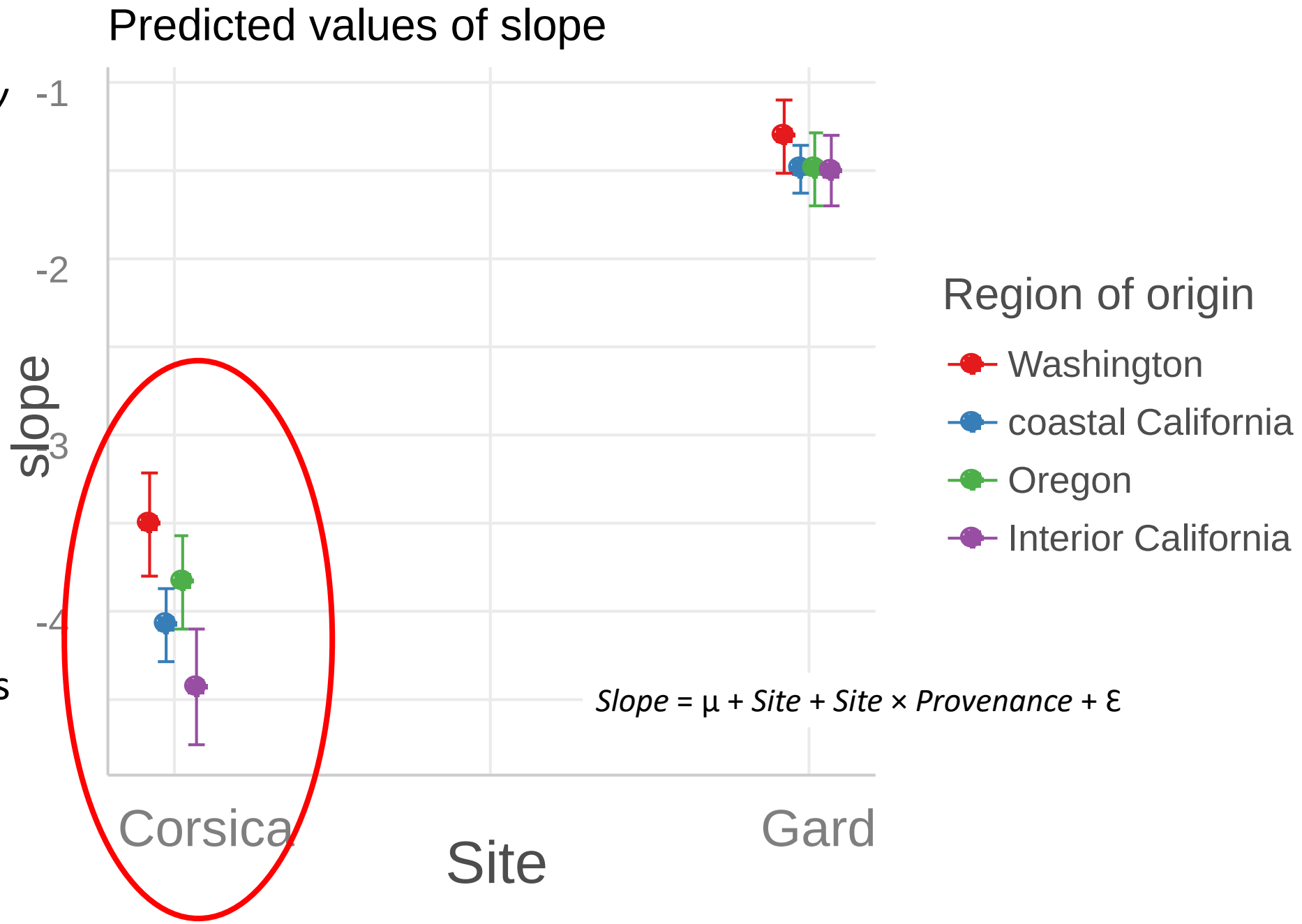
pp is negative
Max ring density decreases when temperature increases



Maximum ring density
Vs
Mean temperature of
June to September

45% of the trees with estimates of pp

pp is negative
Max ring density decreases when temperature increases



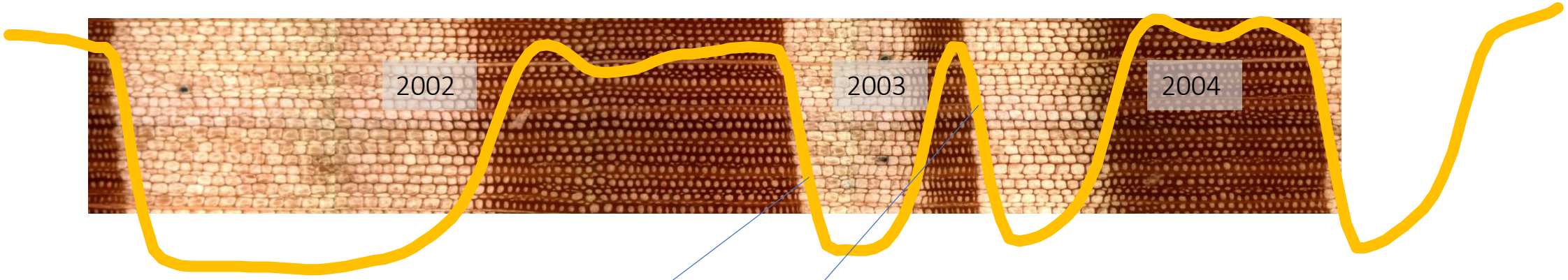
Preliminary results

- Less statistical power (20 rings), less pp estimates. Bias?
- More than 50% of the trees without pp estimates:
  - Lack of statistical power
  - Or null plasticity?
  - (how to test for null plasticity?)
- Significant variation between the sites
  - Pp is much higher (more negative) in the dryer site (Corsica)
- Significant variation between the provenances in Corsica
- Interior Californian provenances are more plastic than Coastal Californian, Oregon and Washington

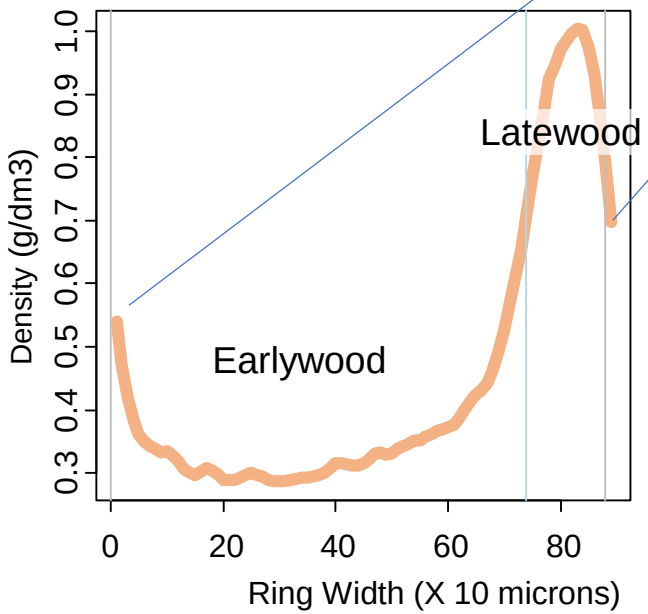
4. Perspectives: *Intra-ring nor,* an old but little explored track

Intra-ring nor

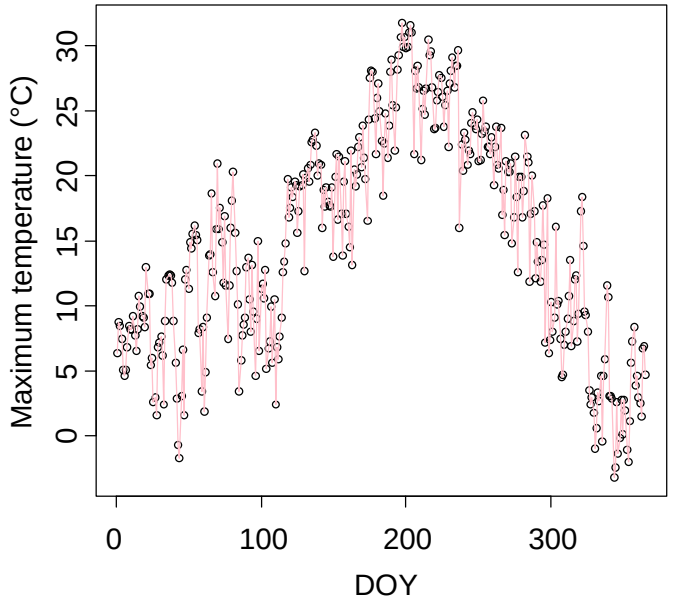
Intra-annual



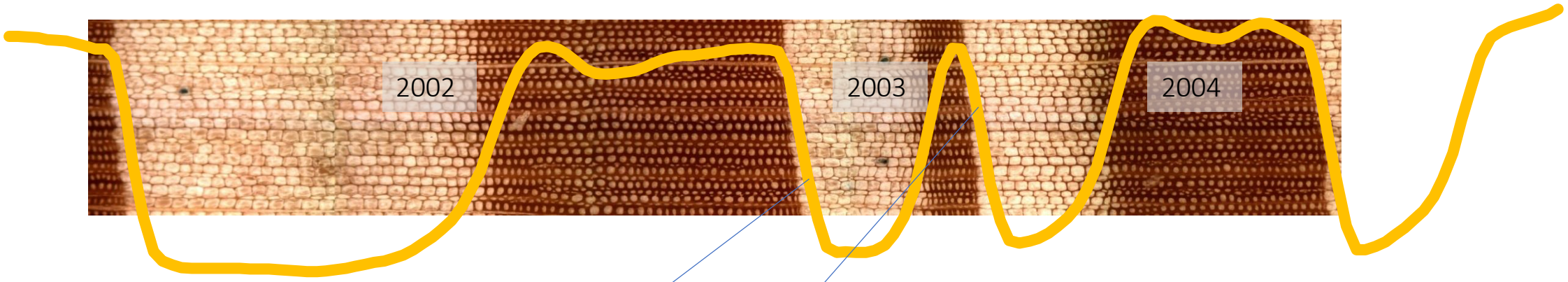
Ring microdensity profile



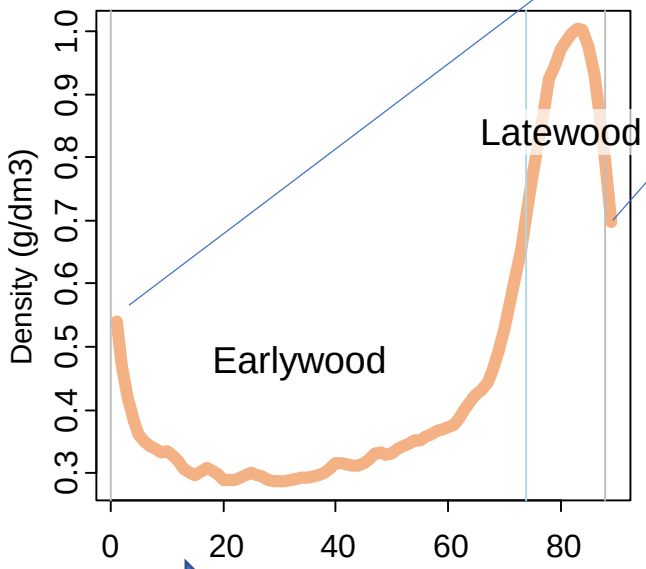
Climatic variable



Intra-annual

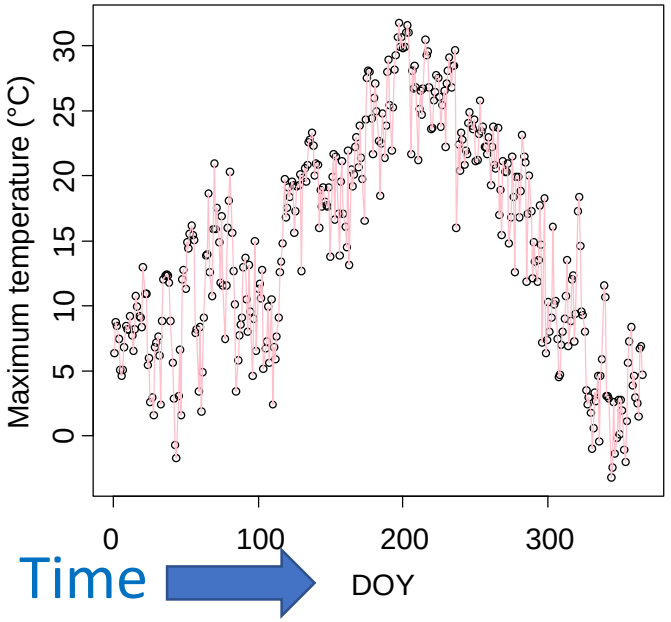


Ring microdensity profile



Distance

Climatic variable

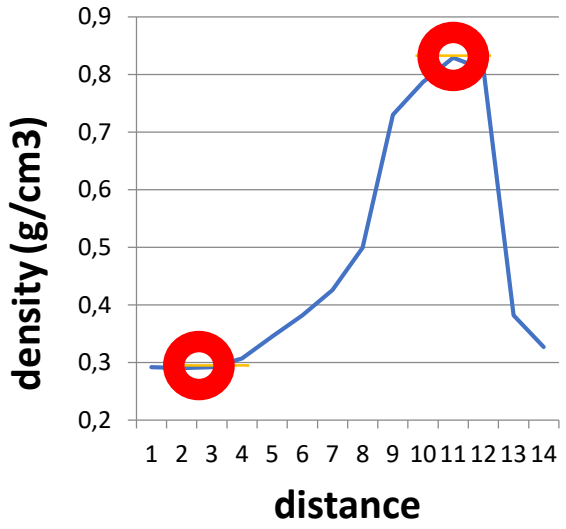


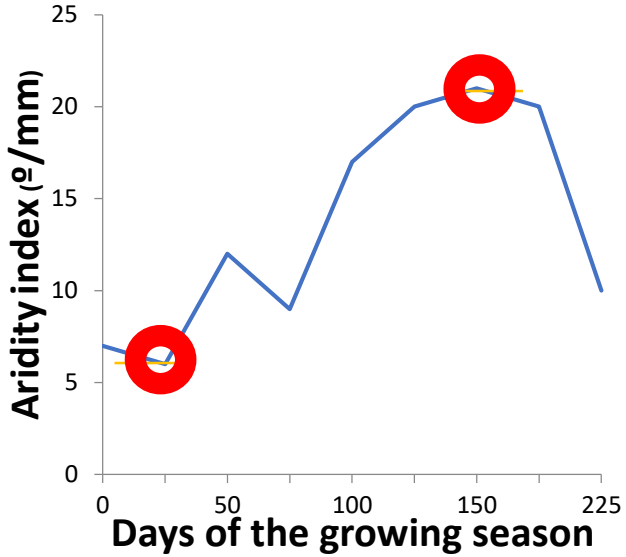
Time

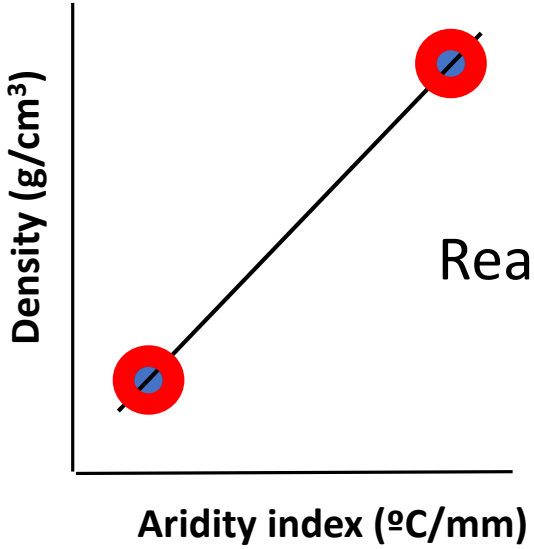
…some trials

- Indirect retrospective synchronization
  - Minimalistic reaction norm: two-points
  - *Breakpoints*
  - *Optimized* synchronization

…Two points nor





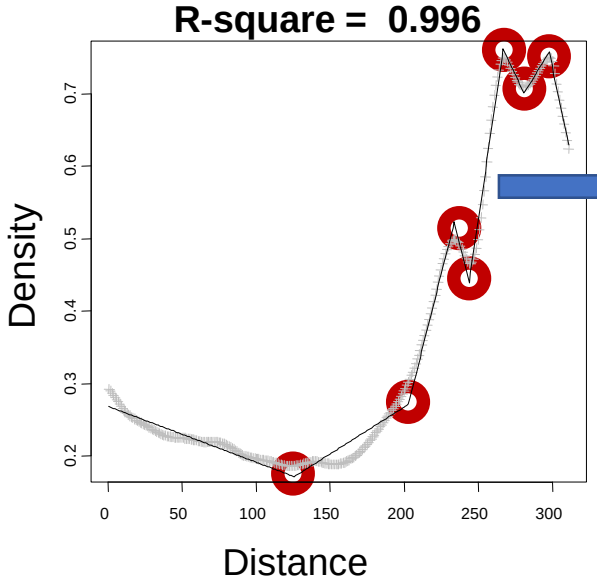


Reaction Norm

Maria Joao Gaspar

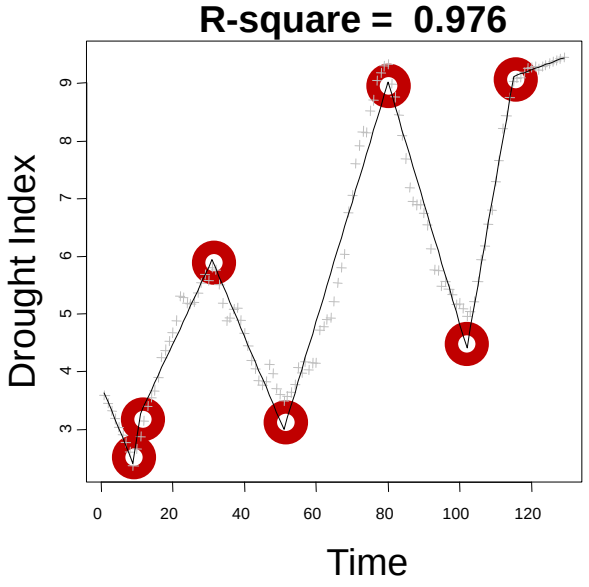
…Breakpoints

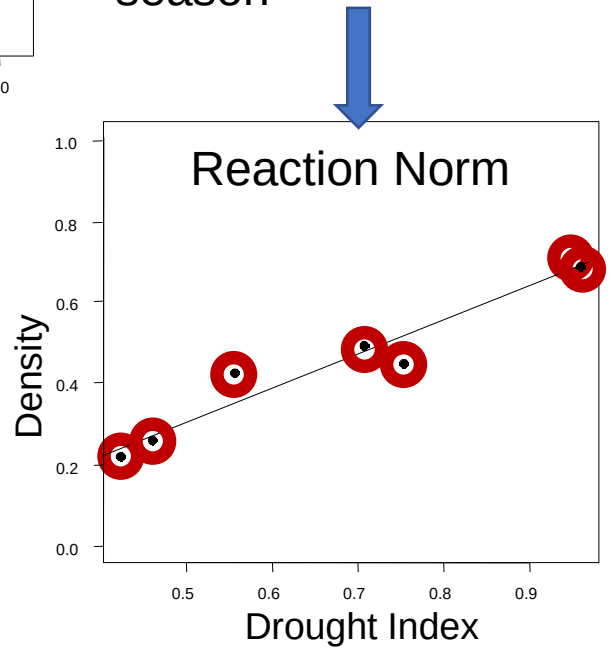
Ring microdensity profile



Ring density profile
+
Drought index of the same growing season

Climatic variable





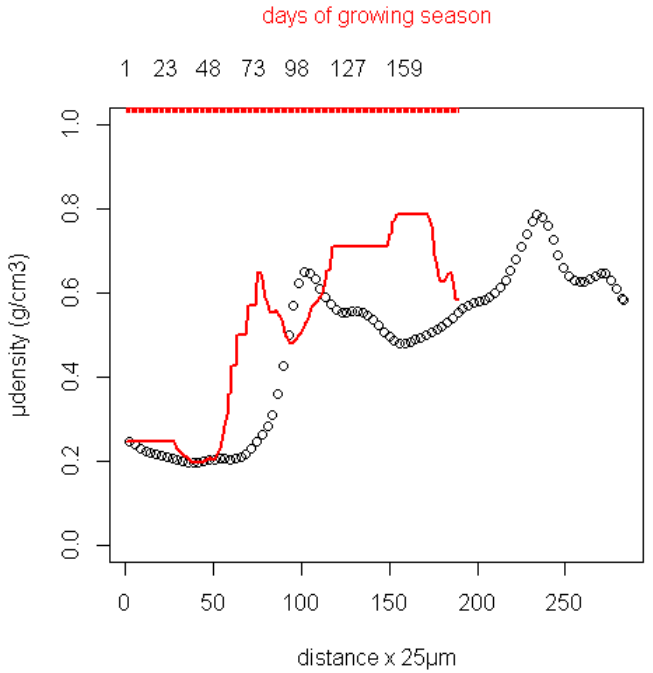
Nahum Sanchez-Vargas et al
Alejandro Martinez-Meier et al

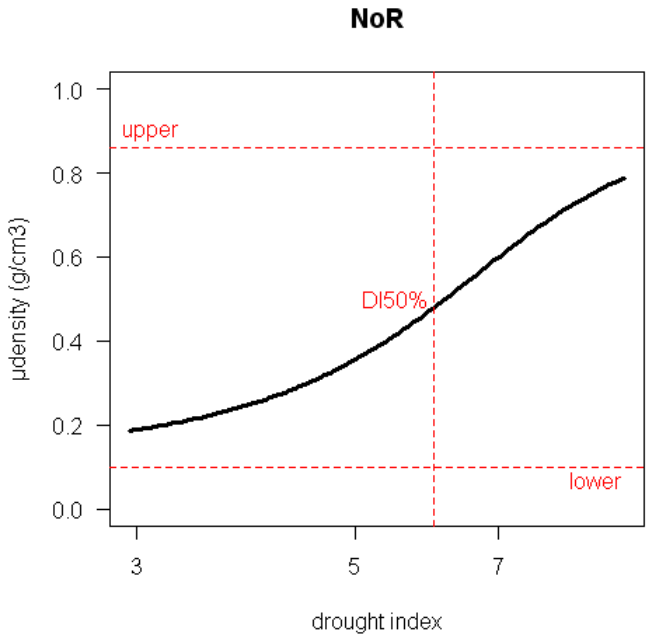
Optimized synchronization

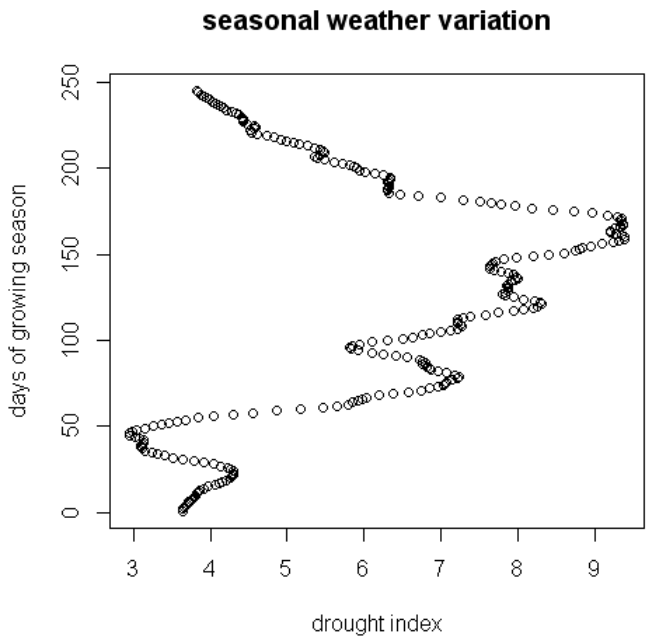
Synchrodendro

Leopoldo Sanchez

Sara Marin
Manuela Ruiz-Diaz





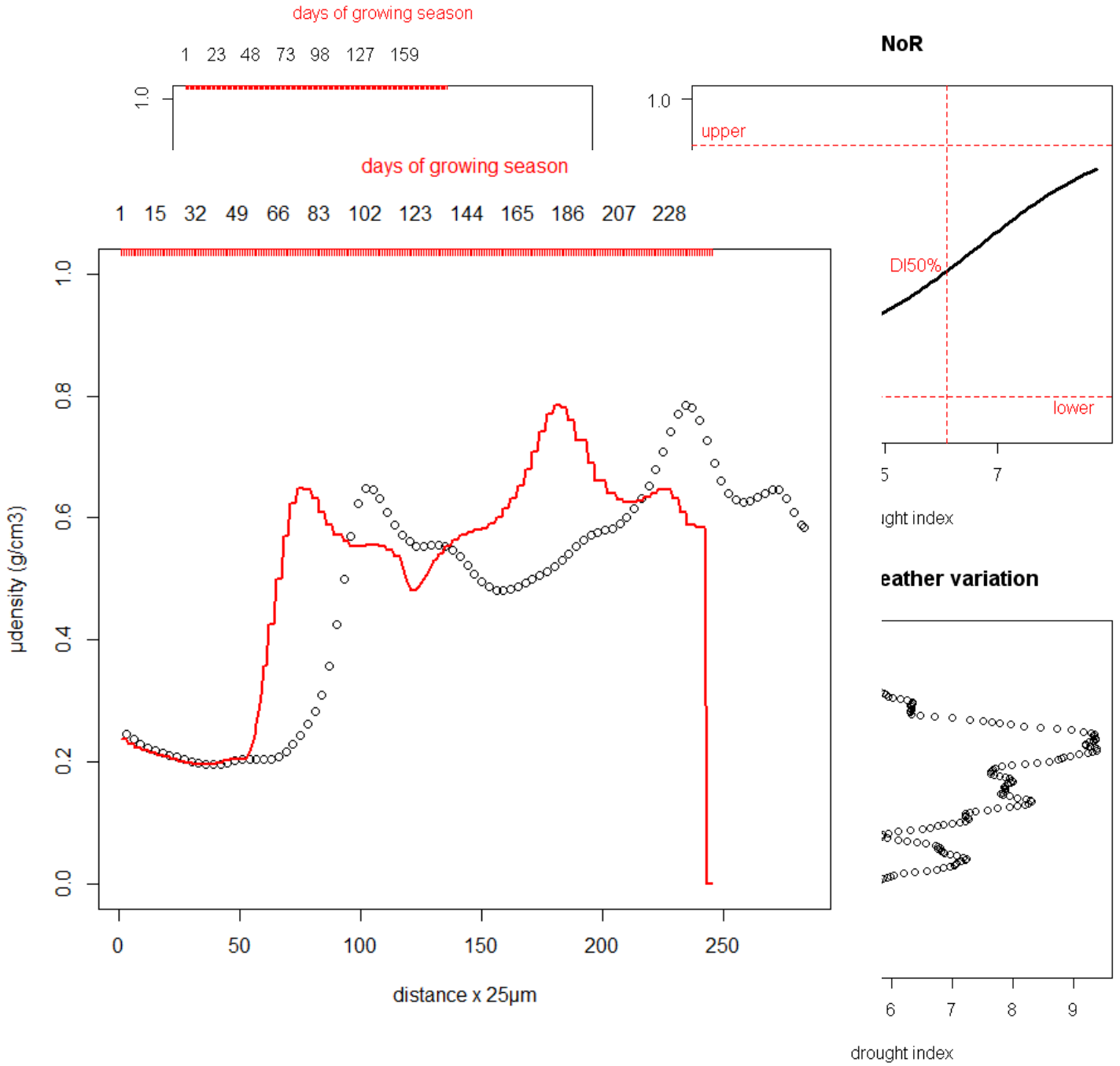


Optimized synchronization

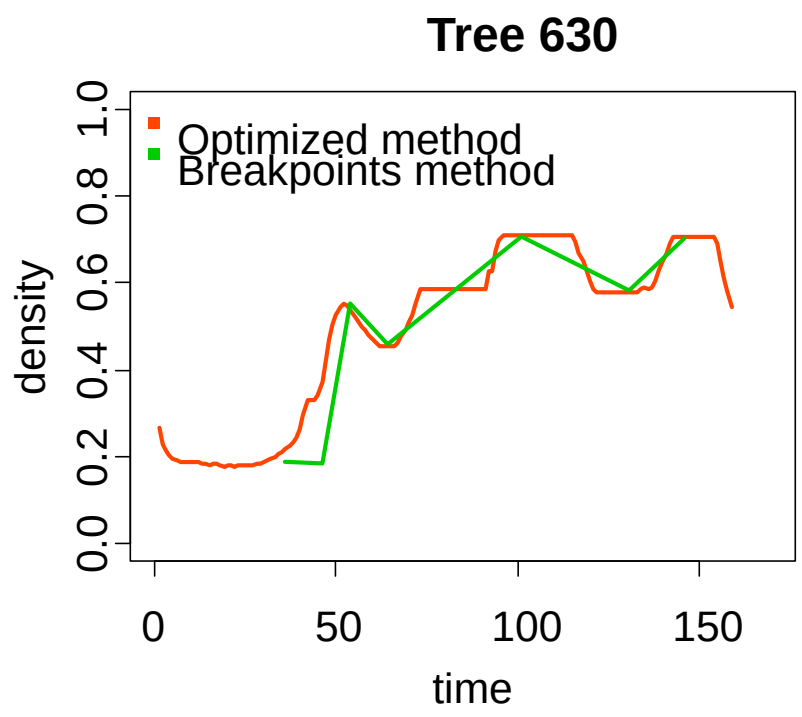
Synchrodendro

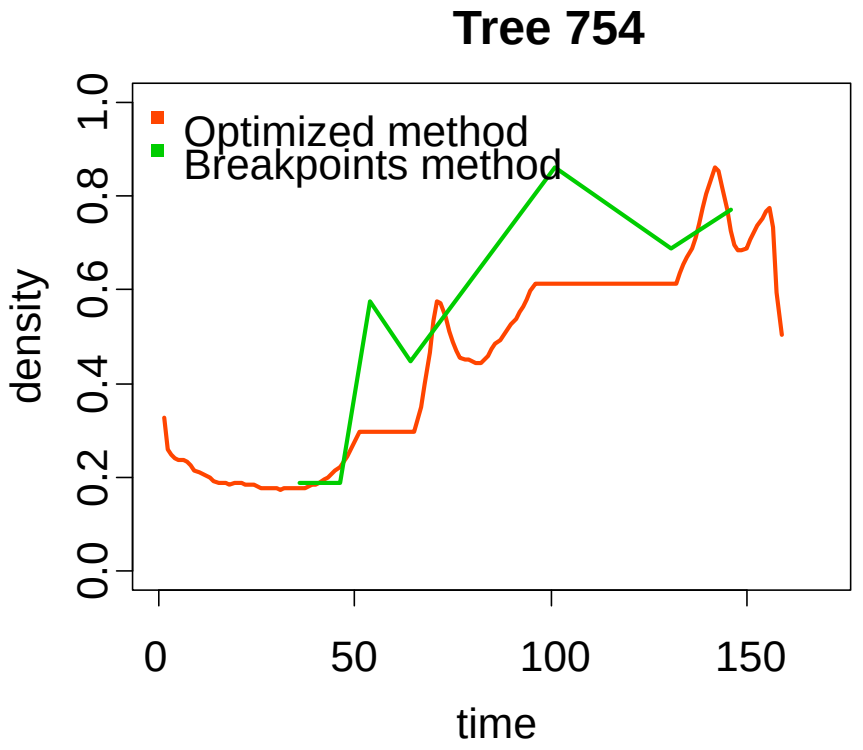
Leopoldo Sanchez

Sara Marin
Manuela Ruiz-Diaz



Breakpoints and optimized

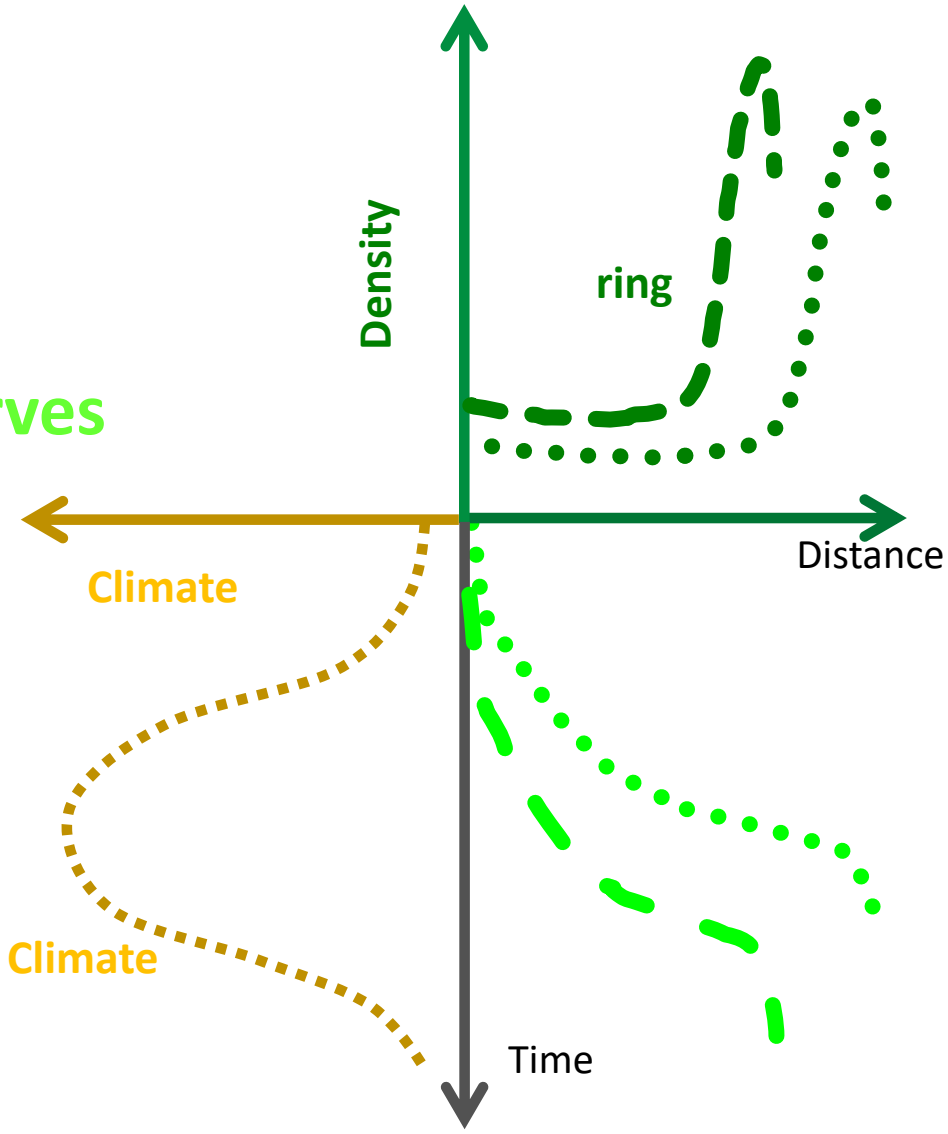




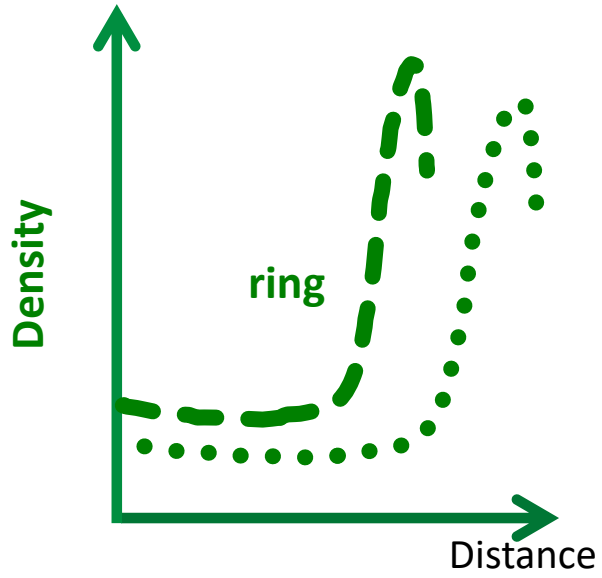
Sara Marin

…some trials

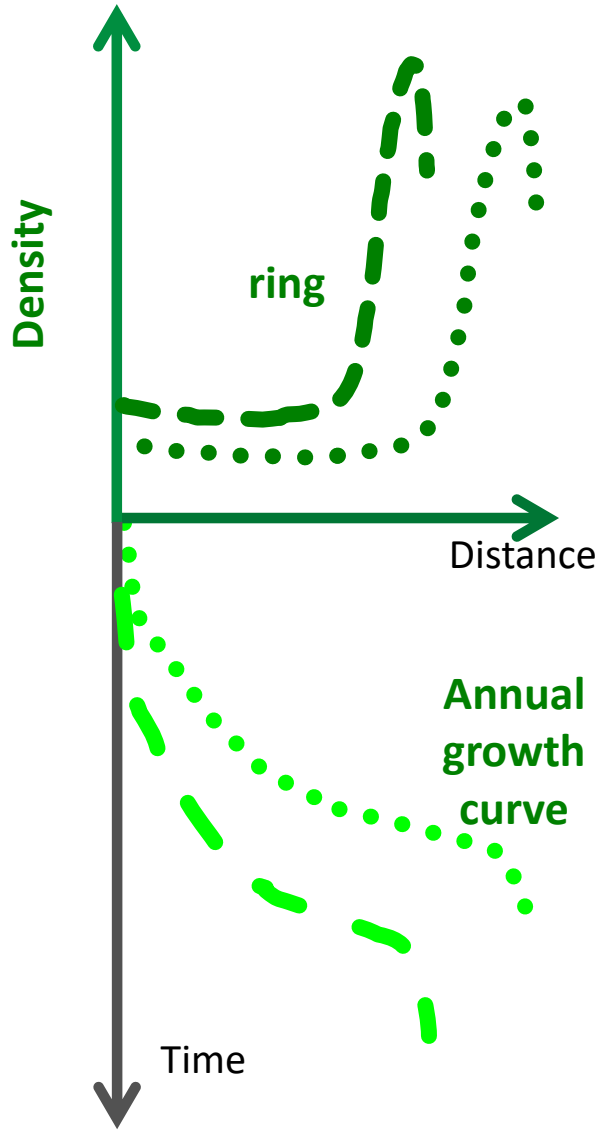
- Direct synchronization
  - Based **on radial growth curves**



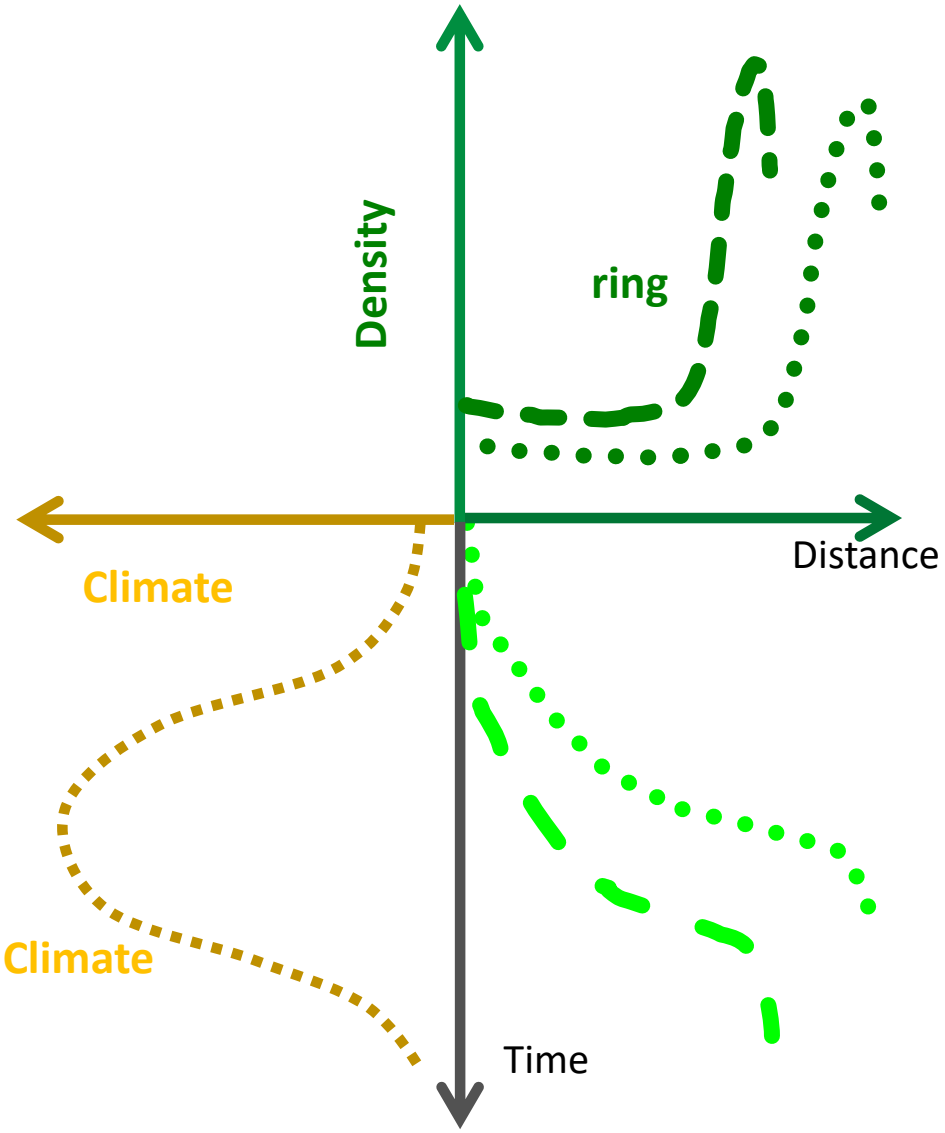
Intra-annual



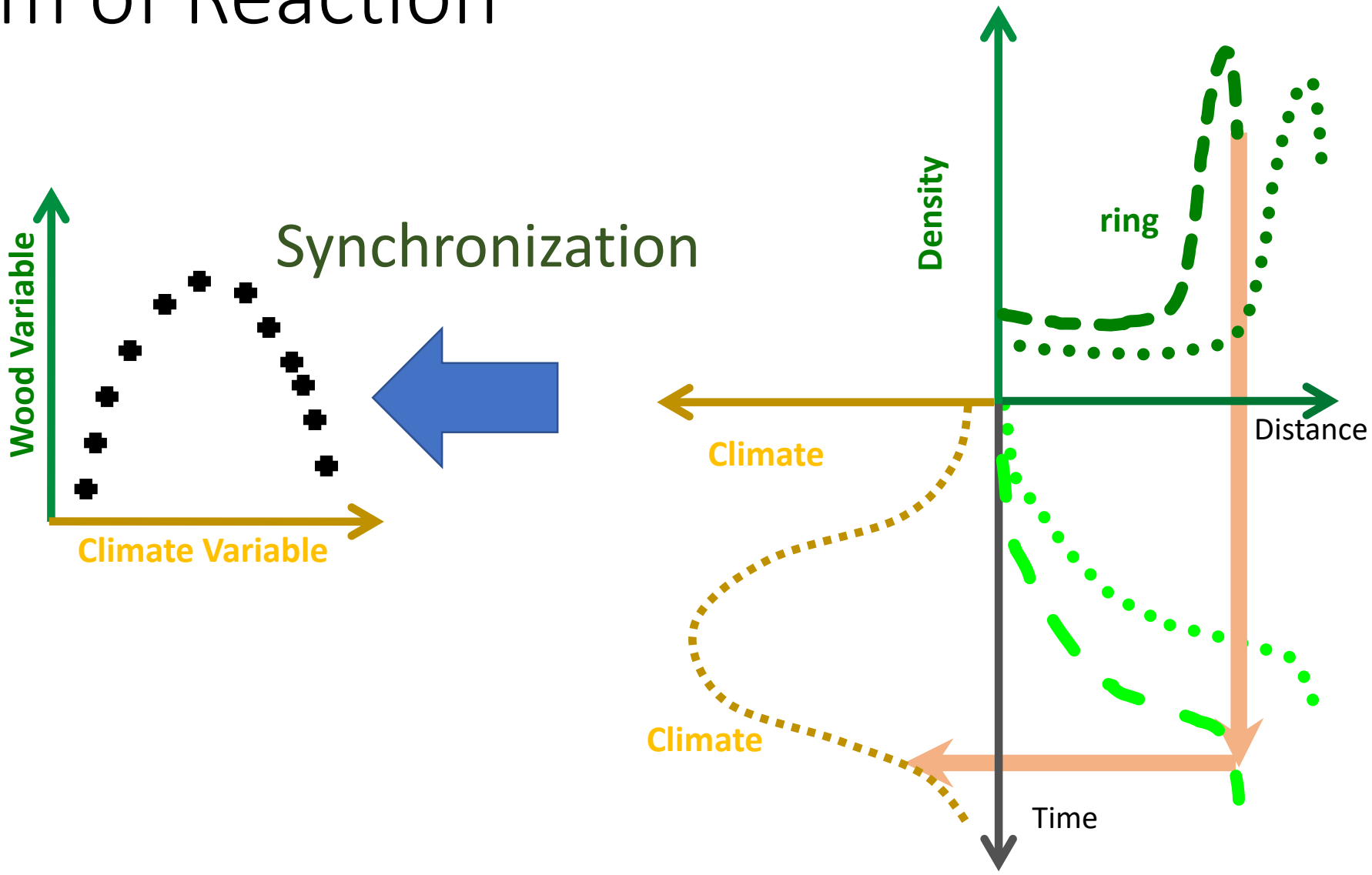
Point dendrometer



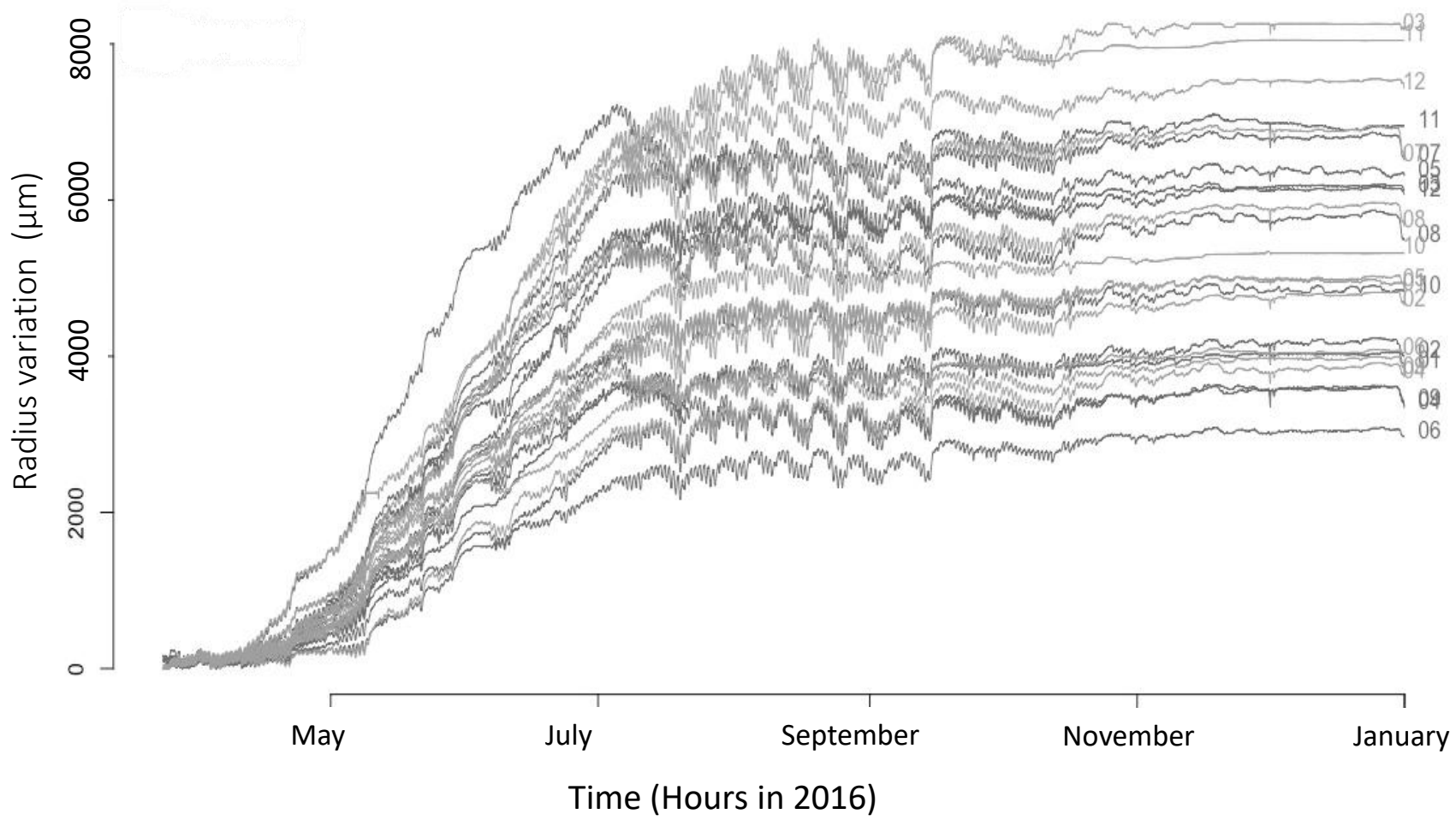
Climatic variable



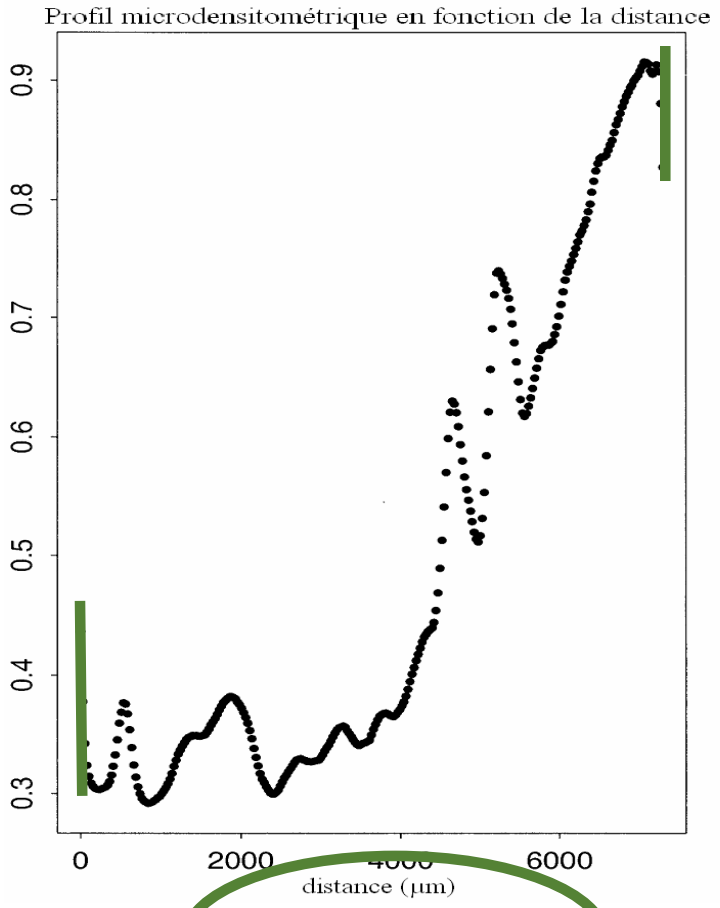
Norm of Reaction



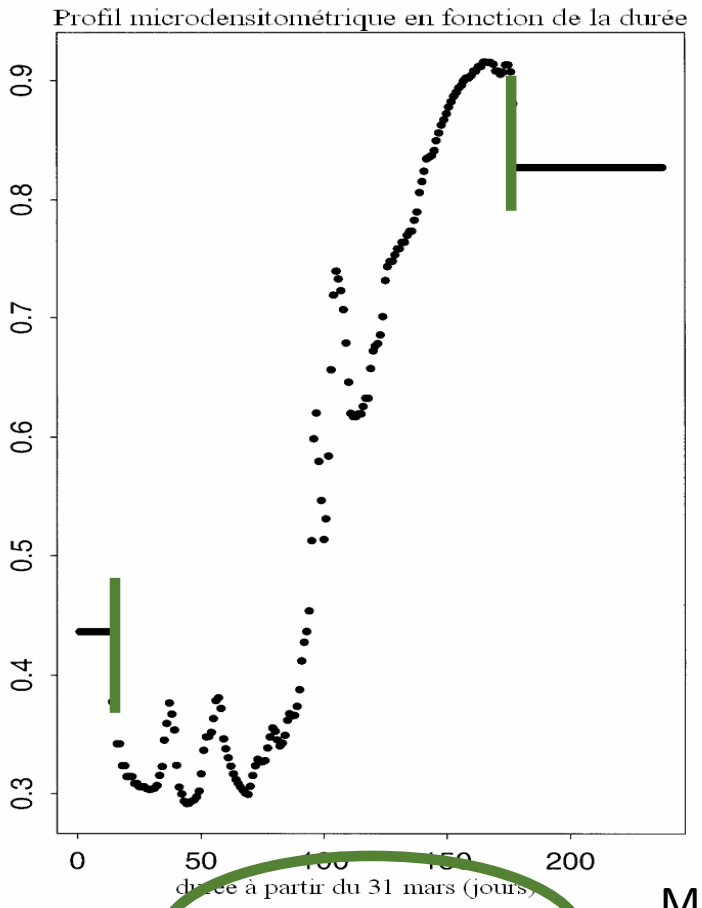
Fitting *nor* with curves of **radius variation**



Example of a synchronized (*dynamic*) ring profile



Distance



Time

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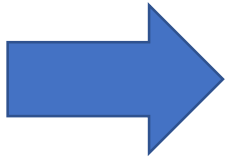
One concern

- To what extent 100% of intra ring variation can really be explained by intra annual climate variation ?
  - Delayed effects?
  - What about earlywood/latewood variation?

Work in progress in larch (starting PhD)

- Radial growth curves
- Ring microdensity profiles
- Climatic time series



intra-ring reaction norms

Direct synchronization

- Reference to develop **indirect** methods

Conclusion

- Microdensity time-series (as well as any other kind of tree-ring time-serie) are robust data for constructing RN
- Inter- and intra-ring are two possible time scales with different strengths and weaknesses
  - Inter-ring:
    - Easy synchronization, tree age should be over 25-30 years
    - Many confounding factors
  - Intra-ring
    - As many RN as the number of rings
    - When no radial growth curve is available, synchronization is tricky
    - All the phenotypic variation explained by climate?

Conclusion

- Data preparation, correction and validation are time consuming and often tedious tasks not to be underestimated
- Statistical concerns when fitting large numbers of linear regression. Decrease the probability thresholds? Work only with nor estimated on a large majority of trees?
- Linear mixed models, random regression
  - To improve global computing and analysis efficiency
  - Limited by individual tunings useful to improve fitting ability: fairly different phenotypic and environmental time-series for different individuals
  - In this case, how to compare *nor* fitted with different climatic time-windows?
- *Nor* as a complex phenotypic dynamic trait
- This new dynamic trait encompasses in **one value** the variation of the original phenotypic variable within a given range of environmental variation

Thanks for your attention