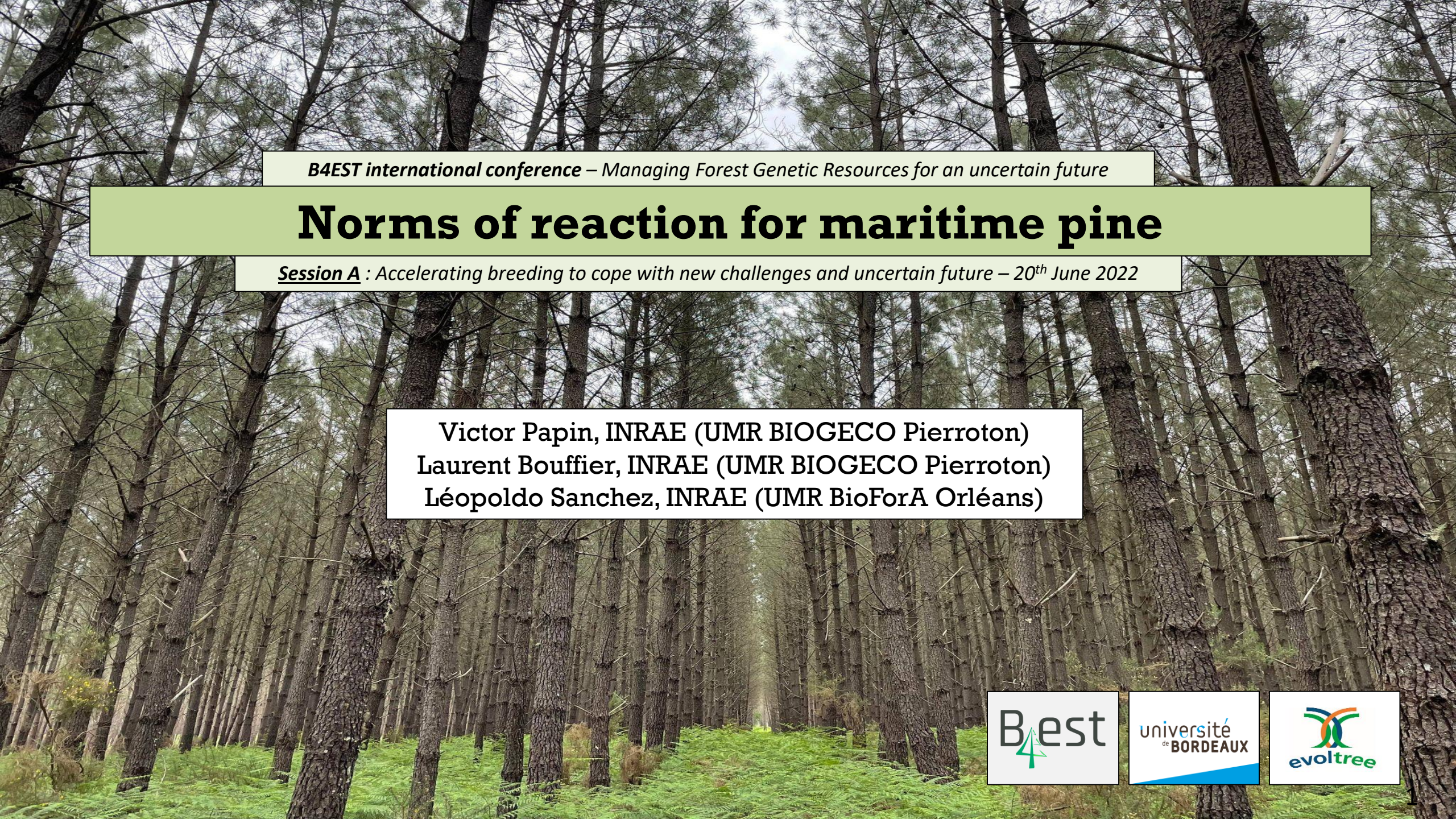


B4EST international conference *– Managing Forest Genetic Resources for an uncertain future*

Norms of reaction for maritime pine

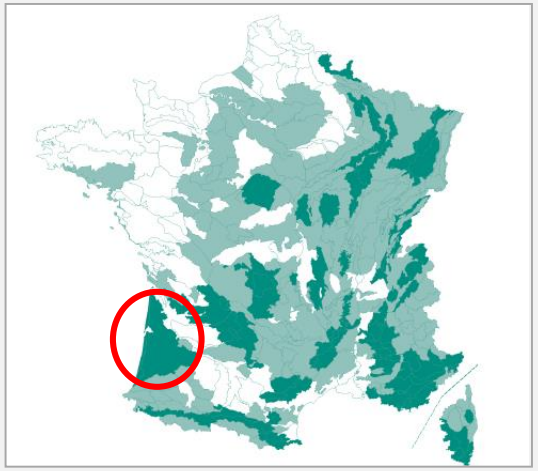
Session A *: Accelerating breeding to cope with new challenges and uncertain future – 20th June 2022*

Victor Papin, INRAE (UMR BIOGECO Pierroton)
Laurent Bouffier, INRAE (UMR BIOGECO Pierroton)
Léopoldo Sanchez, INRAE (UMR BioForA Orléans)

Maritime pine (*Pinus Pinaster*) breeding in France

« Landes de Gascogne » forest

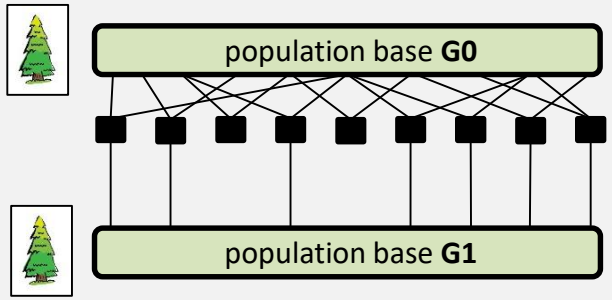
- **0,8 million hectares** (24% of French wood harvest)
- Main uses in carpentry, joinery, stationery



- Plantations with **improved seedlings**
- Mainly based on the **Landes provenance**

Recurrent selection scheme

- Started in the ~**1960** → **3rd genetation** today

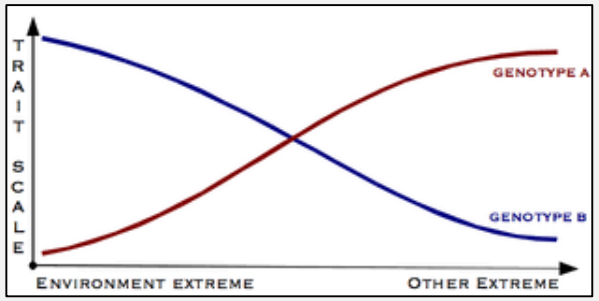


- Targeted traits :
  - **Growth** (height, circumference, straightness)
  - **Adaptation** to the environment
  - Wood **quality**
- **Genetic values** estimated with **pedigree**

Dynamic phenotypes : NoR

- Classical selection focuses on **final growth traits**
- Integrative phenotypes with **no consideration of the environment**

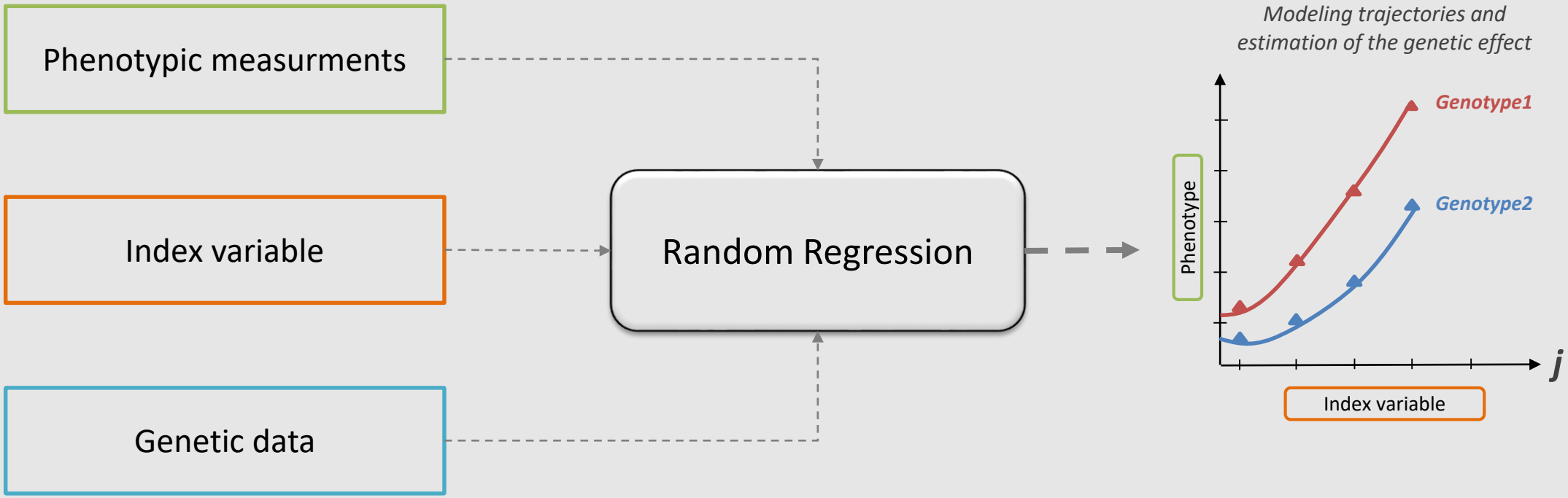
NoR : pattern of phenotypic expression of a single genotype across a range of environments



- Consideration of **dynamic** and **explicative** traits
- Evaluation and prediction of **genetic values** taking account of the **environnement** (even in unobserved environments)

Norm of reaction for Maritime pine – Papin, Bouffier, Sanchez-Rodriguez

Construction of norms of reaction



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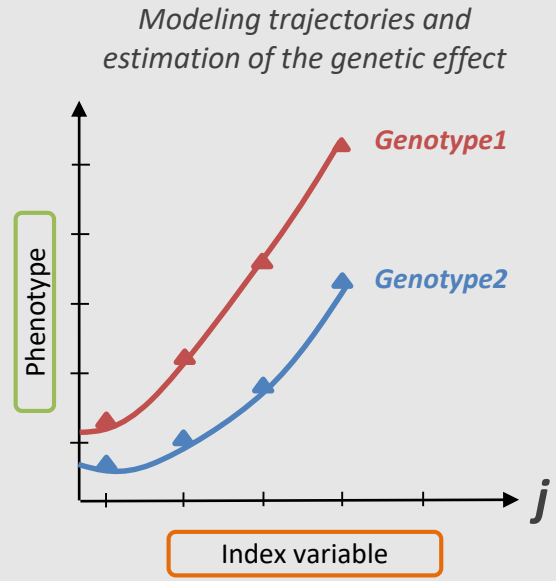
Construction of norms of reaction

Phenotypic measurments

Index variable

Genetic data

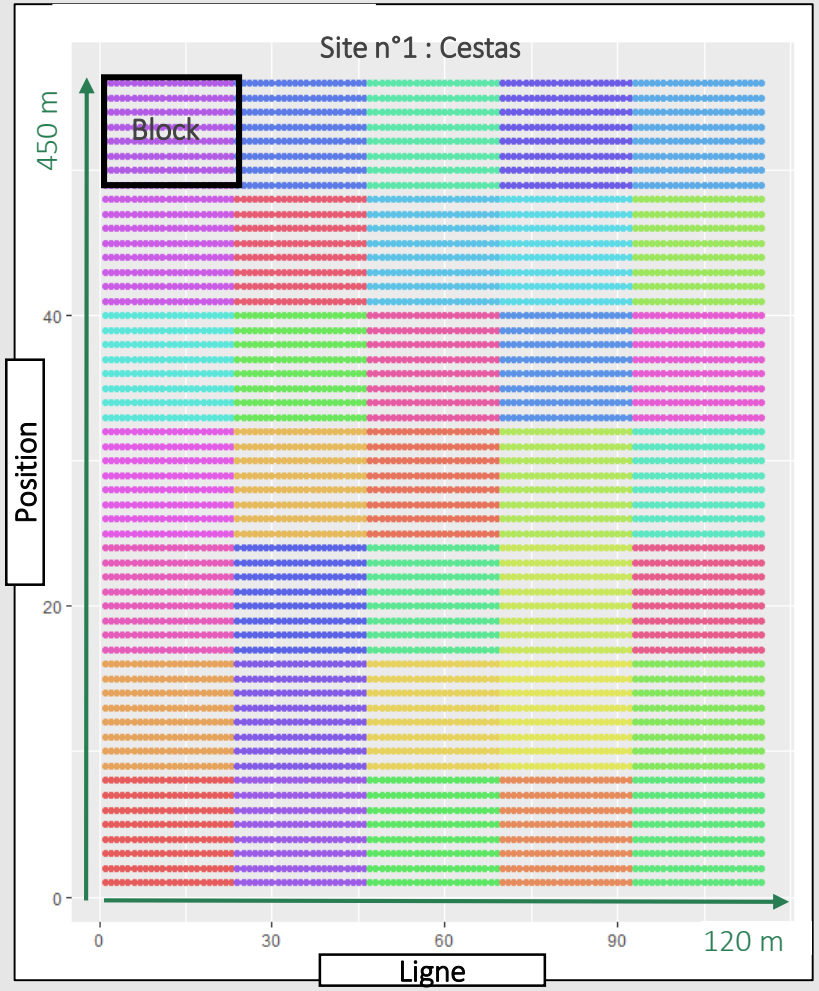
Random Regression



Norm of reaction for Maritime pine – Papin, Bouffier, Sanchez-Rodriguez

Experimental design and measurments

Experimental design for maritime pine (6300 trees)

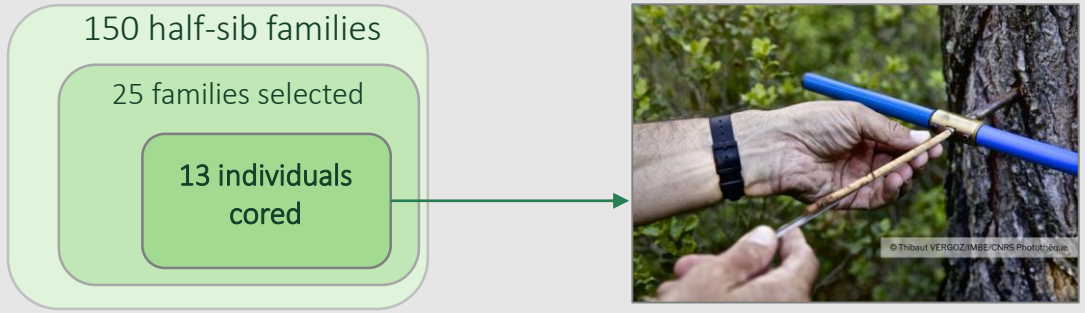


Experimental design

- 2 locations : Cestas (humid) & Escource (dry)
- Installation in **1996** : **26** years old trees
- **150** half-sib families with **35** individuals/family → **6300** trees per site
- **Complete** block design (1 individual of each family per block)

Phenotypic measurments :

- Classical growth measures at different ages (height, circumference, straightness)
- Core sampling of **325** trees per site :



Environmental measurments :

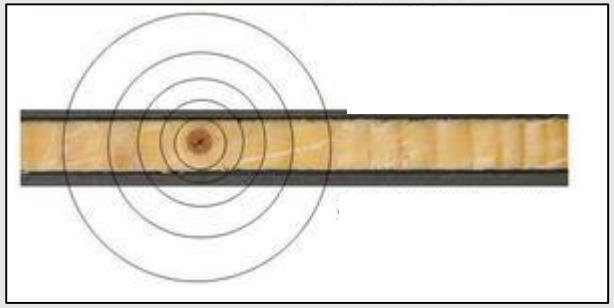
- Conventional annual climate measurements (temperature, rainfall...)

Norm of reaction for Maritime pine – Papin, Bouffier, Sanchez-Rodriguez

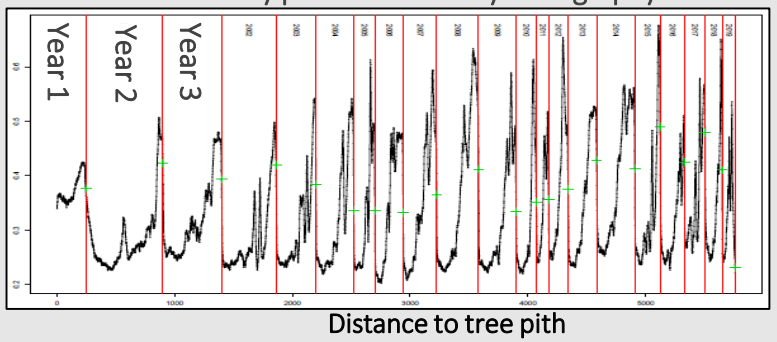
Experimental design and measurments

Core sampling

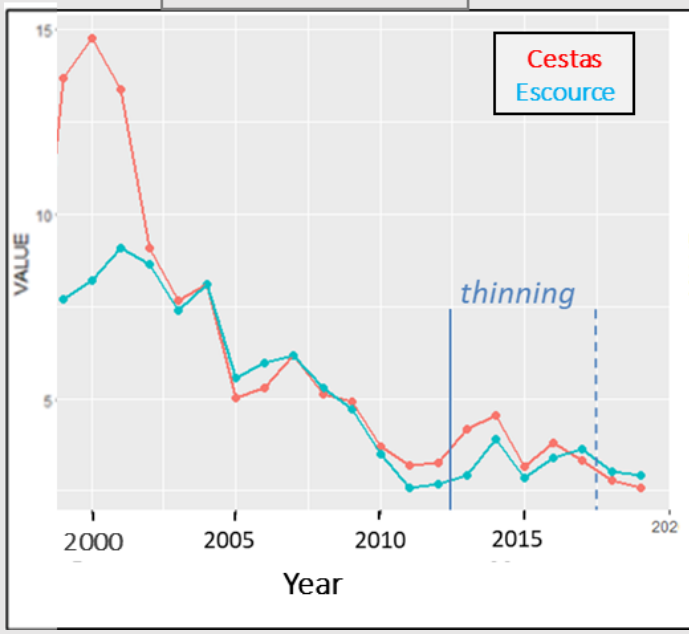
Cutting in boards



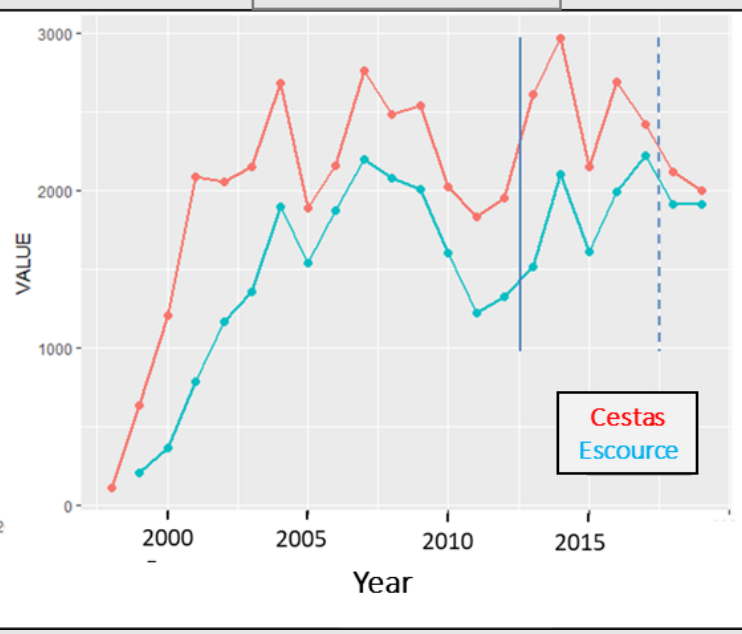
Density profile after X-ray radiography



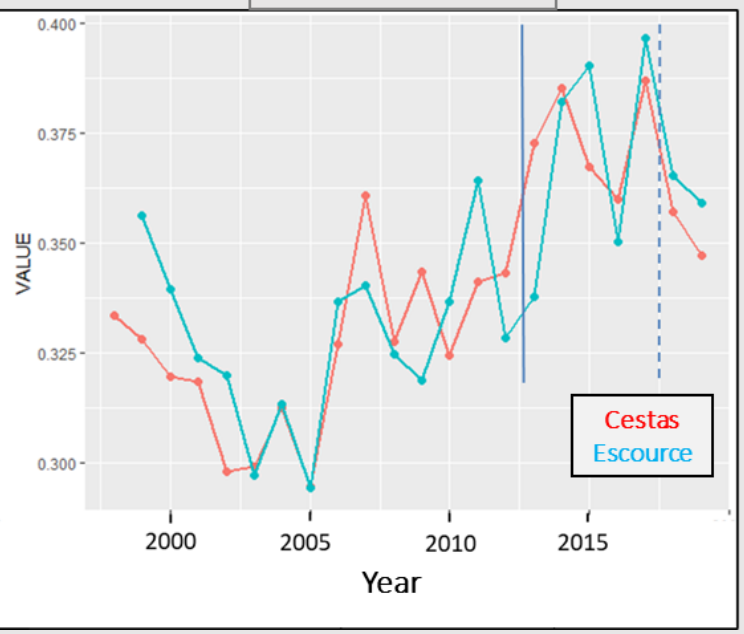
Ring width



Ring surface



Ring mean density



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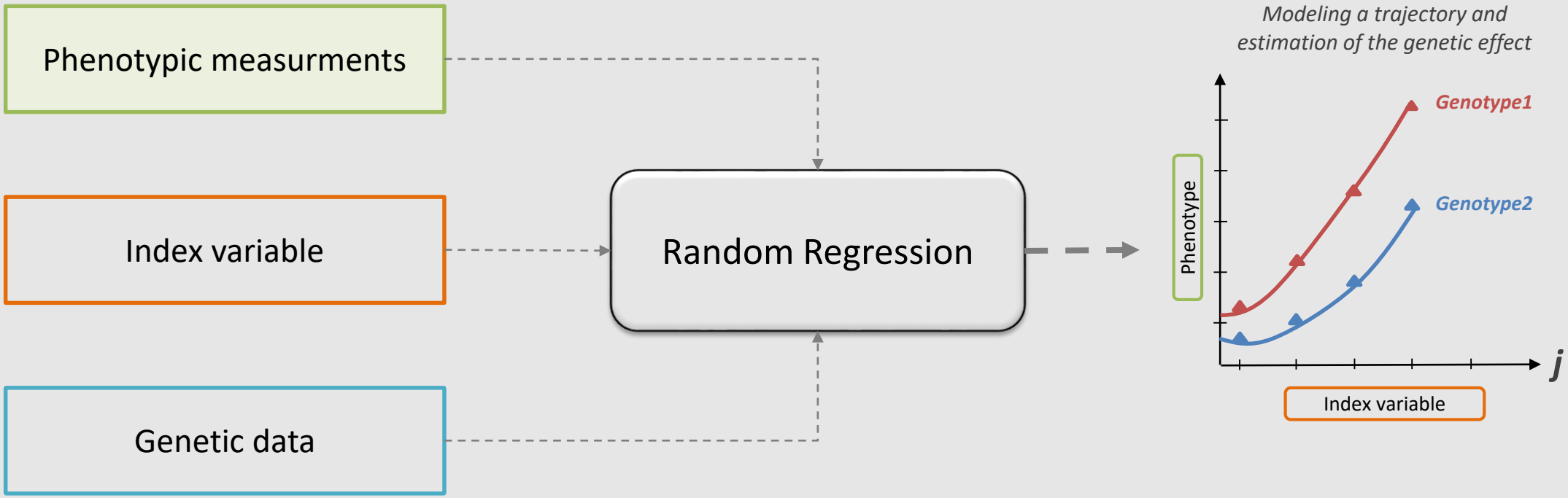
Construction of norms of reaction



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Construction of norms of reaction

Phenotypic measurments

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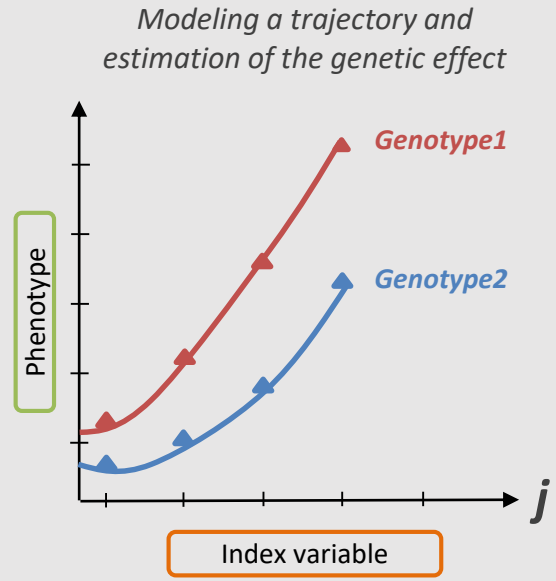

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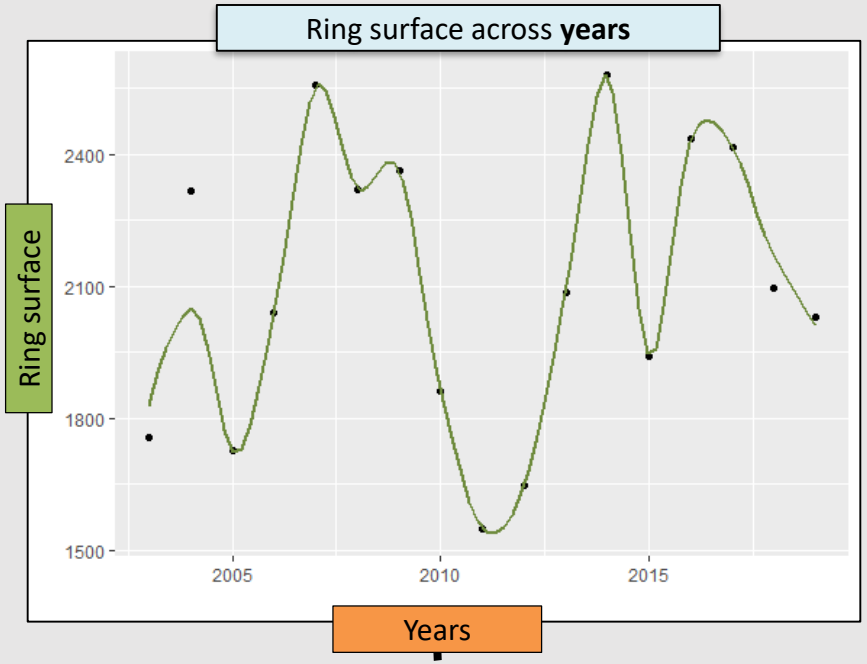
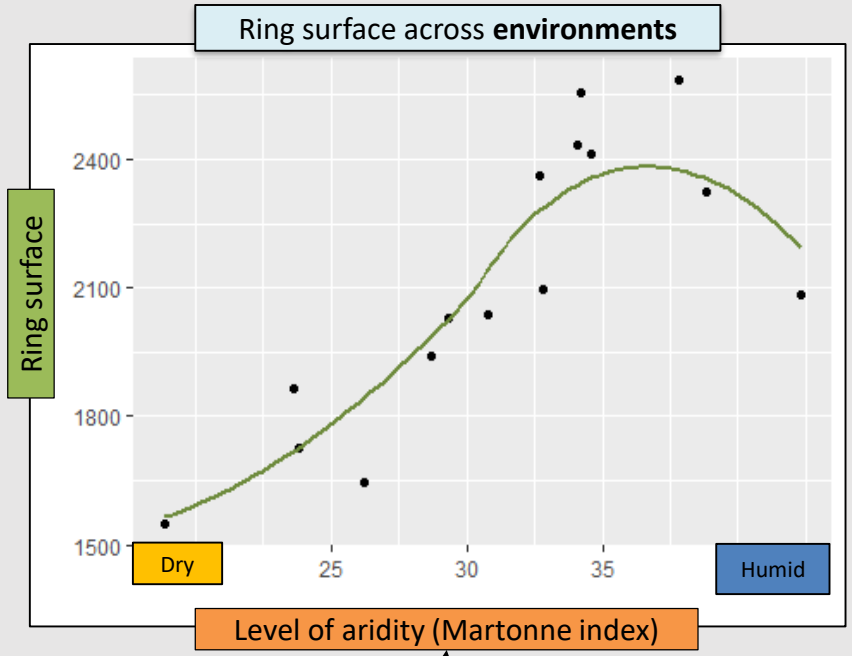
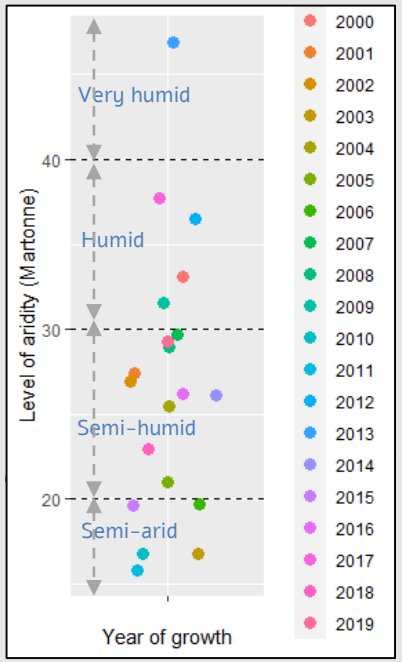




***For each year**, characterization of global aridity with Martonne index*

$$I = \frac{12p}{t + 10}$$

p : cumulative rainfall (mm)
t : mean temperature (°C)



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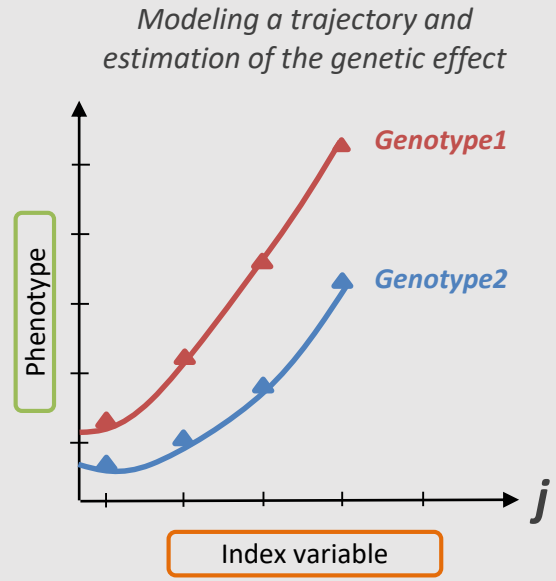

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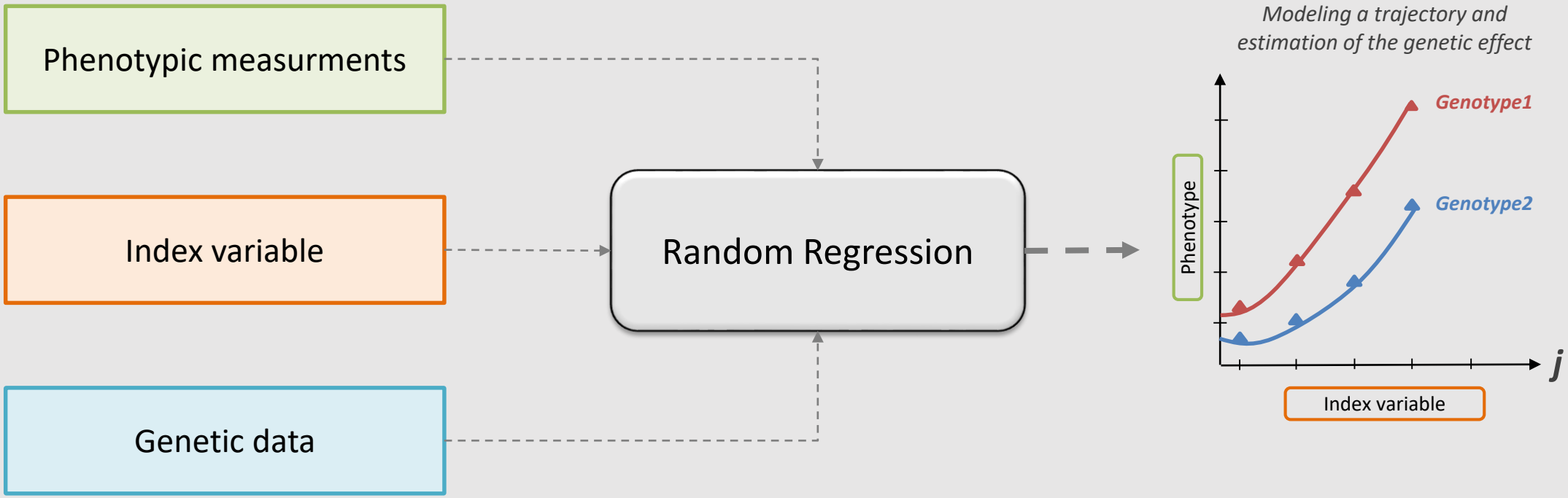
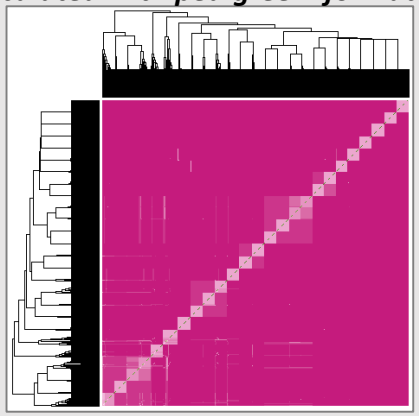


Norm of reaction for Maritime pine – Papin, Bouffier, Sanchez-Rodriguez

Construction of norms of reaction

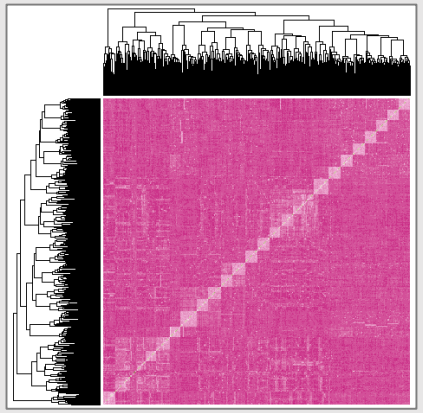
A matrix

calculated with pedigree information

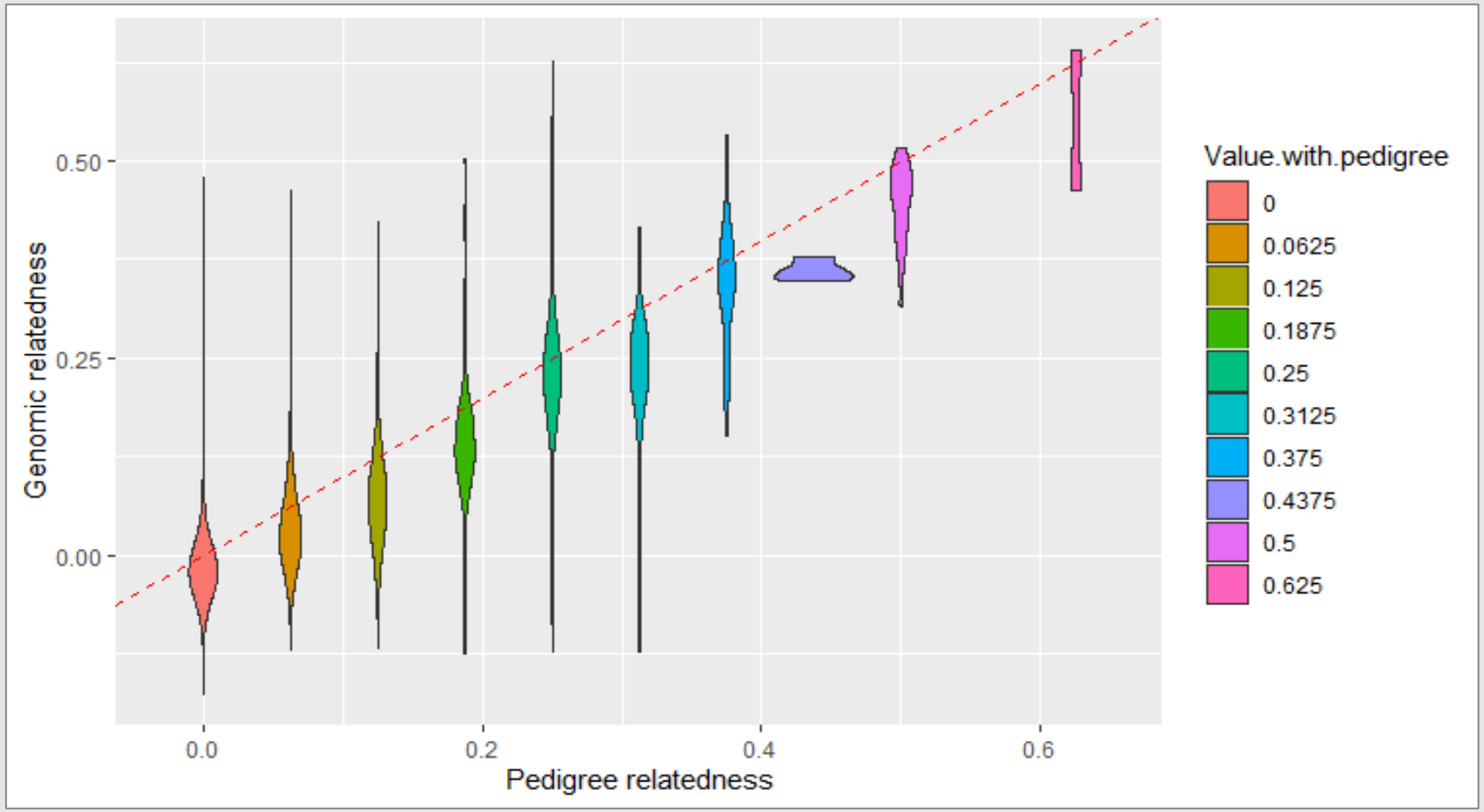


G matrix ***(VR1)***

Calculated with 3000 SNPs information



Comparison of relatedness calculated with genomic data and relatedness calculated with pedigree data



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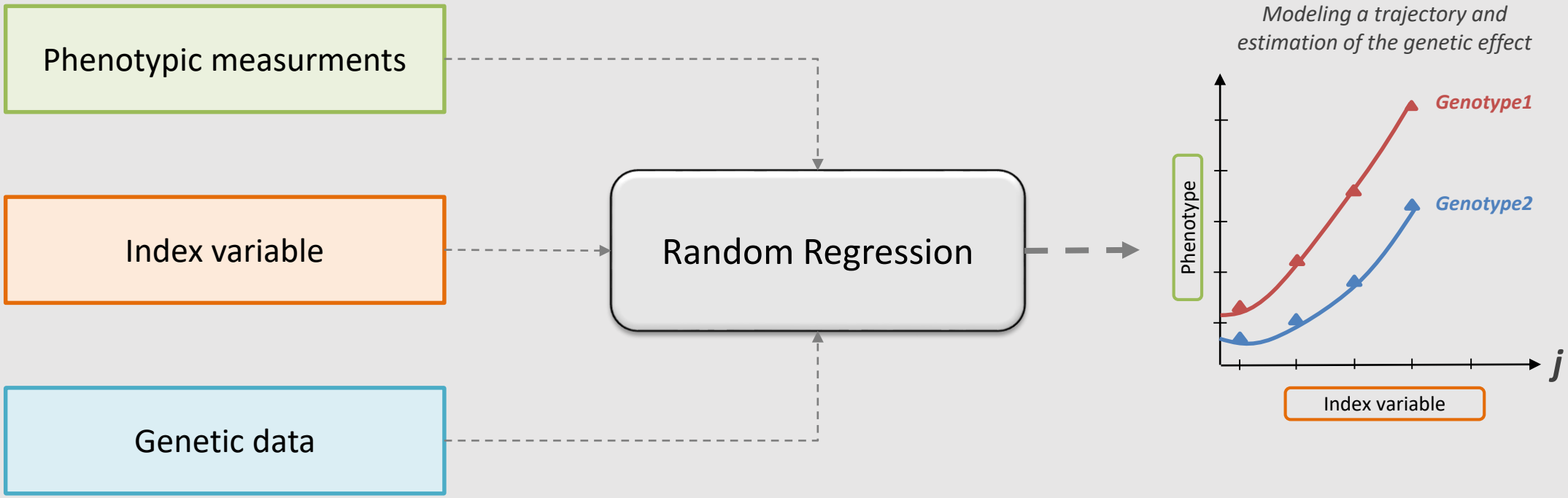

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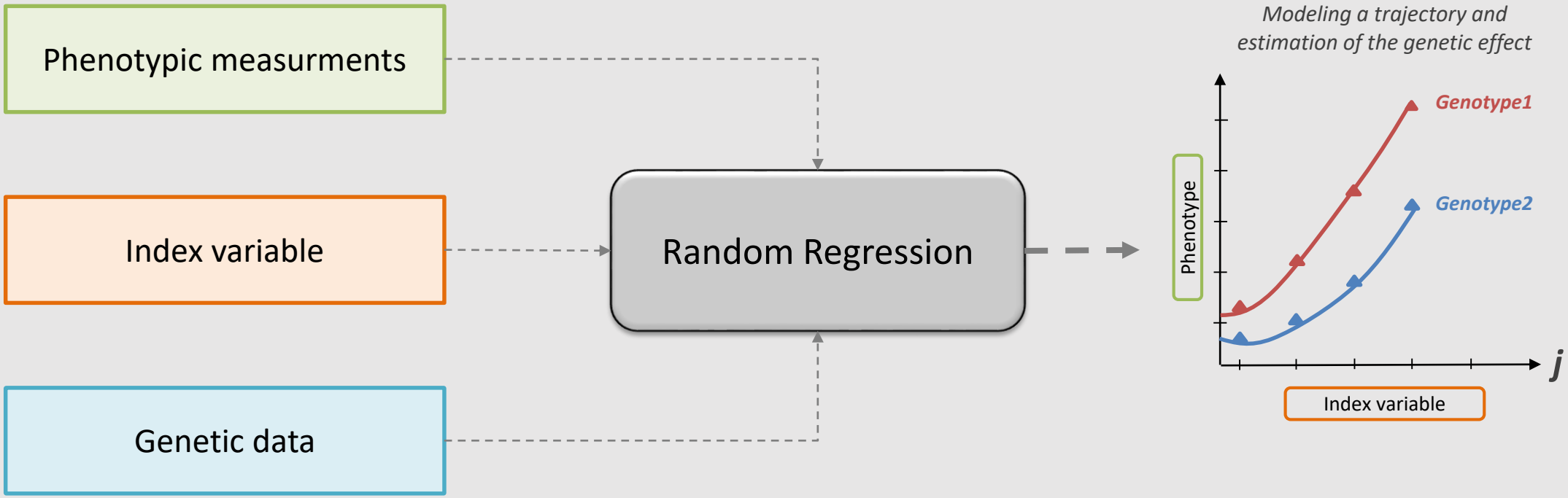
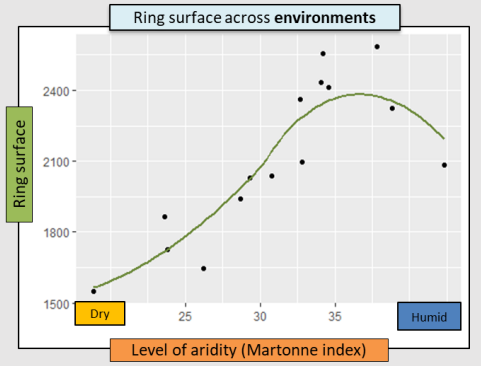


Norm of reaction for Maritime pine – Papin, Bouffier, Sanchez-Rodriguez

Random regression model (RRM)

- We model **individual trajectories** according to the **level of aridity of the environment** (Martonne index)



Fixed part

Random part

For individual i :

$$y_{ij} = \sum_{r=1}^{k_m} m_{ir}\,\varphi_r(t_j) + \sum_{r=1}^{k_\alpha} \alpha_{ir}\,\varphi_r(t_j) + \sum_{r=1}^{k_\gamma} \gamma_{ir}\,\varphi_r(t_j) + \varepsilon_{ij}$$

Inter-ring phenotypic trait :

ring surface for the indiviudal i, at the the environment j

Mean trajectory as fixed effect:

- The mean trajectory of the ring surface acrros the environments for the whole trees
- One mean trajectory per site

Additive genetic random effect

- Based on one individual i
- Effect variance constraine by a kinship matrix (constructed with pedigree information)

Permanent environmental random effects

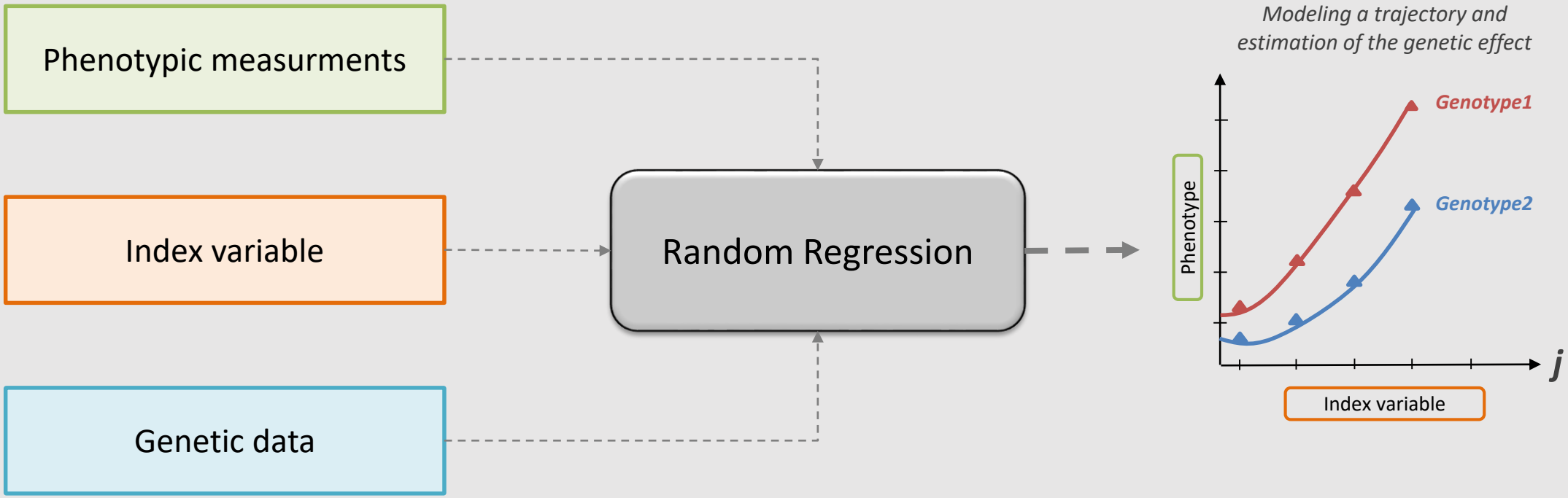
Overall effects due to the individual i but not from additive genetic origin

Residuals

a heterogeneous residual variance for each environnement

- Mean trajectories, additive genetic effect and permanent environmental effects are modeled by **2-order Legendre polynomials**

Construction of norms of reaction



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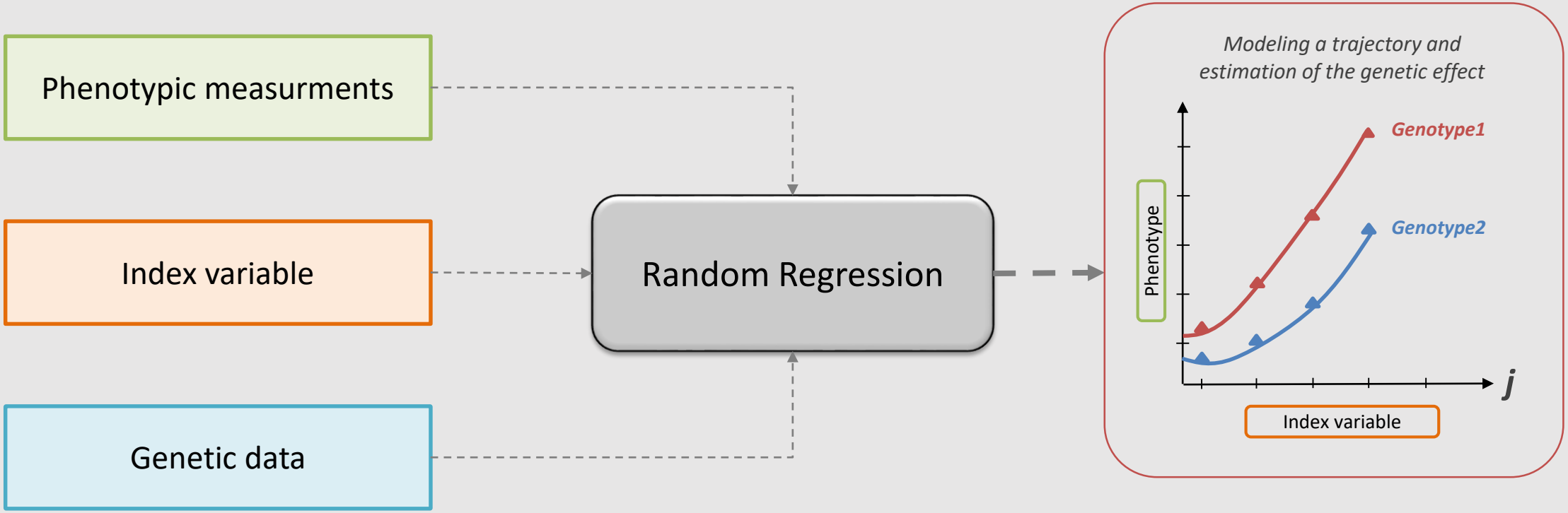
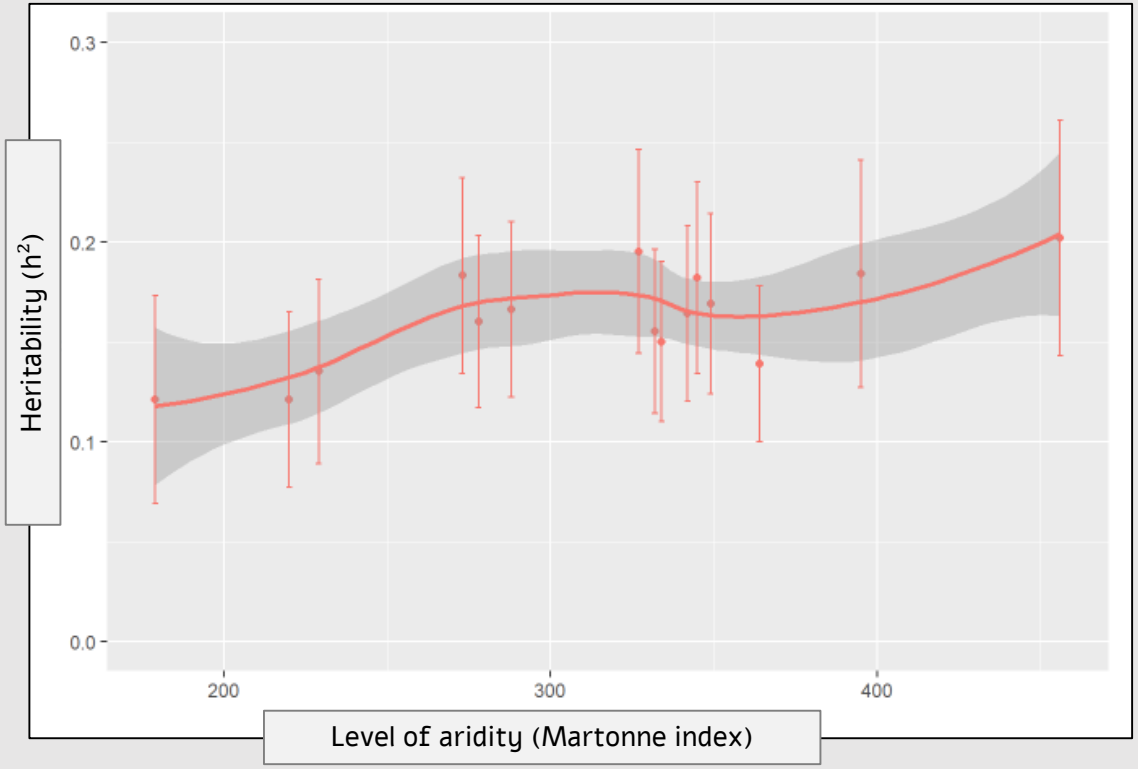


Norm of reaction for Maritime pine – Papin, Bouffier, Sanchez-Rodriguez

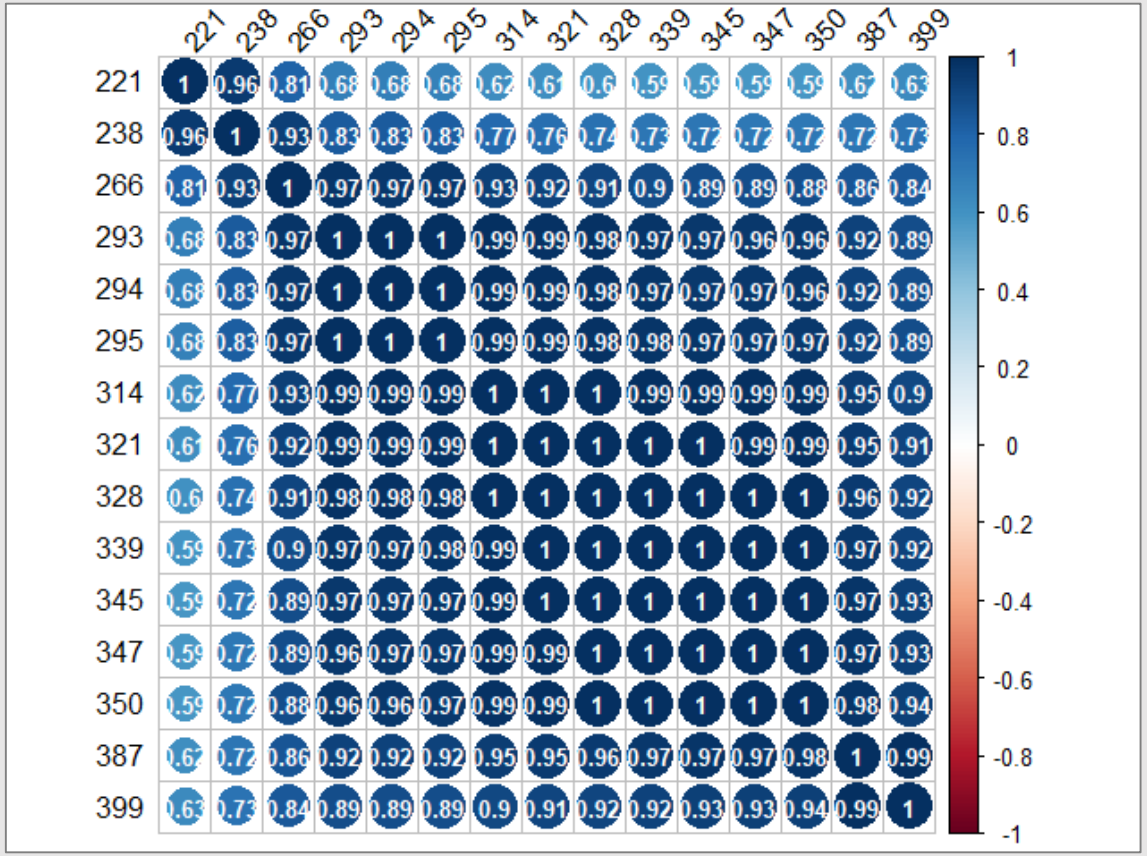
Norms of reaction : heritabilty and genetic correlations

$$y_{ij} = \textit{Mean trajectory}\,(t_j) + \textit{Additive genetic effect}_i(t_j) + \textit{Permanent envionmental effect}_i(t_j) + \varepsilon_{ij}$$

Heritability of ring surface estimated with a random regression model of order 2 (RRM2)



Genetic correlations between environments (levels of aridity) estimated with RRM2



Norms of reaction : additive genetic trajectories

$$y_{ij} = \textit{Mean trajectory}\,(t_j) + \textit{Additive genetic effect}_i(t_j) + \textit{Permanent envionmental effect}_i(t_j) + \varepsilon_{ij}$$

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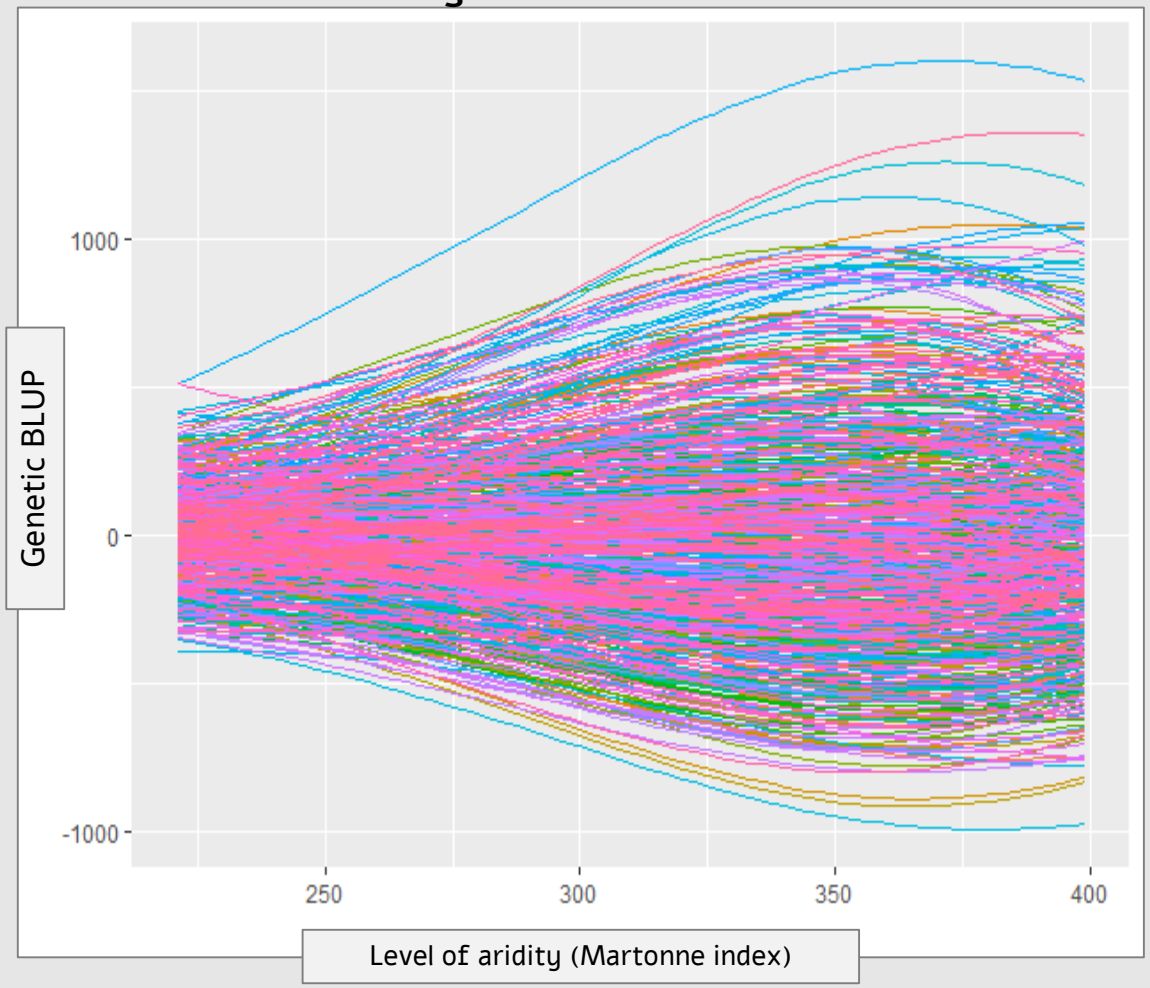
Evolution of individual genetic values across environments



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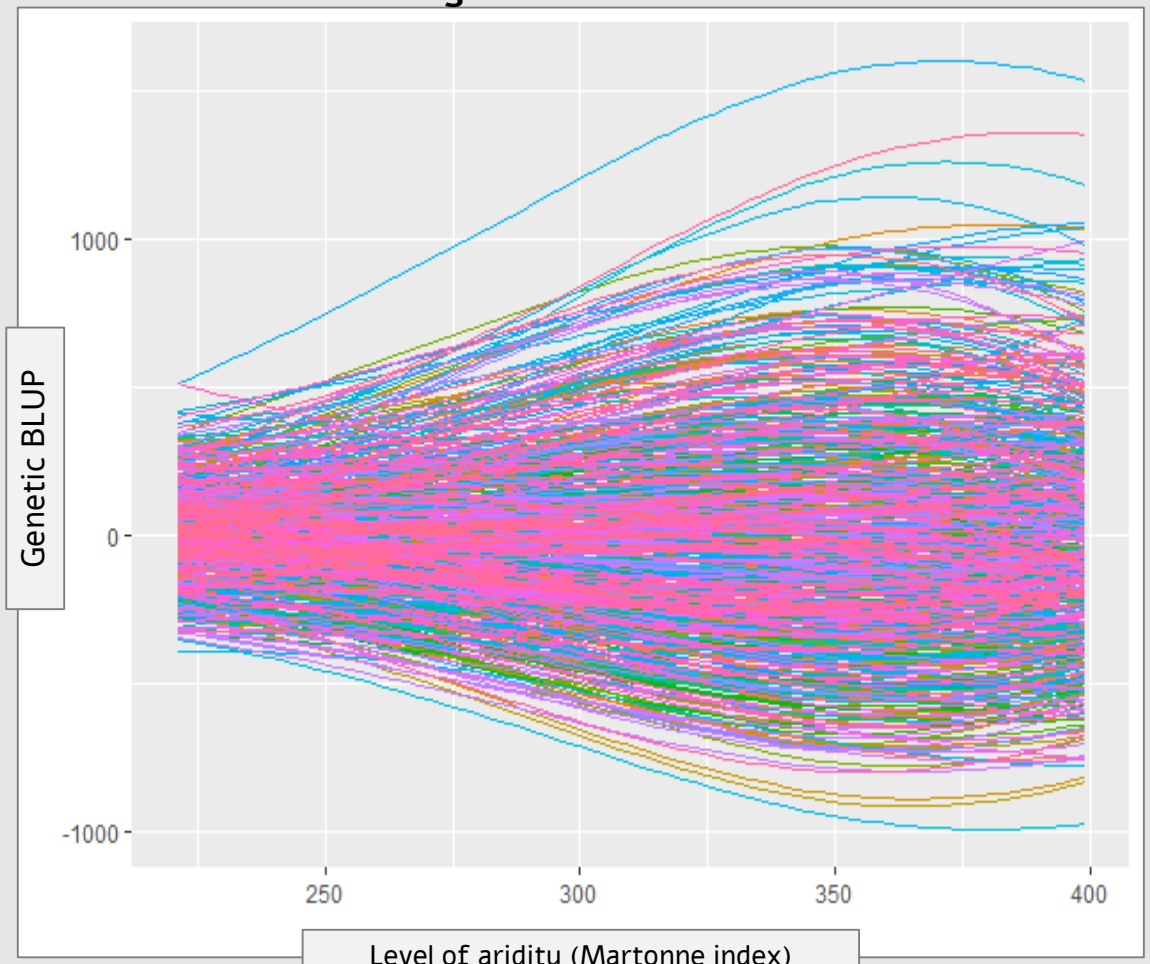
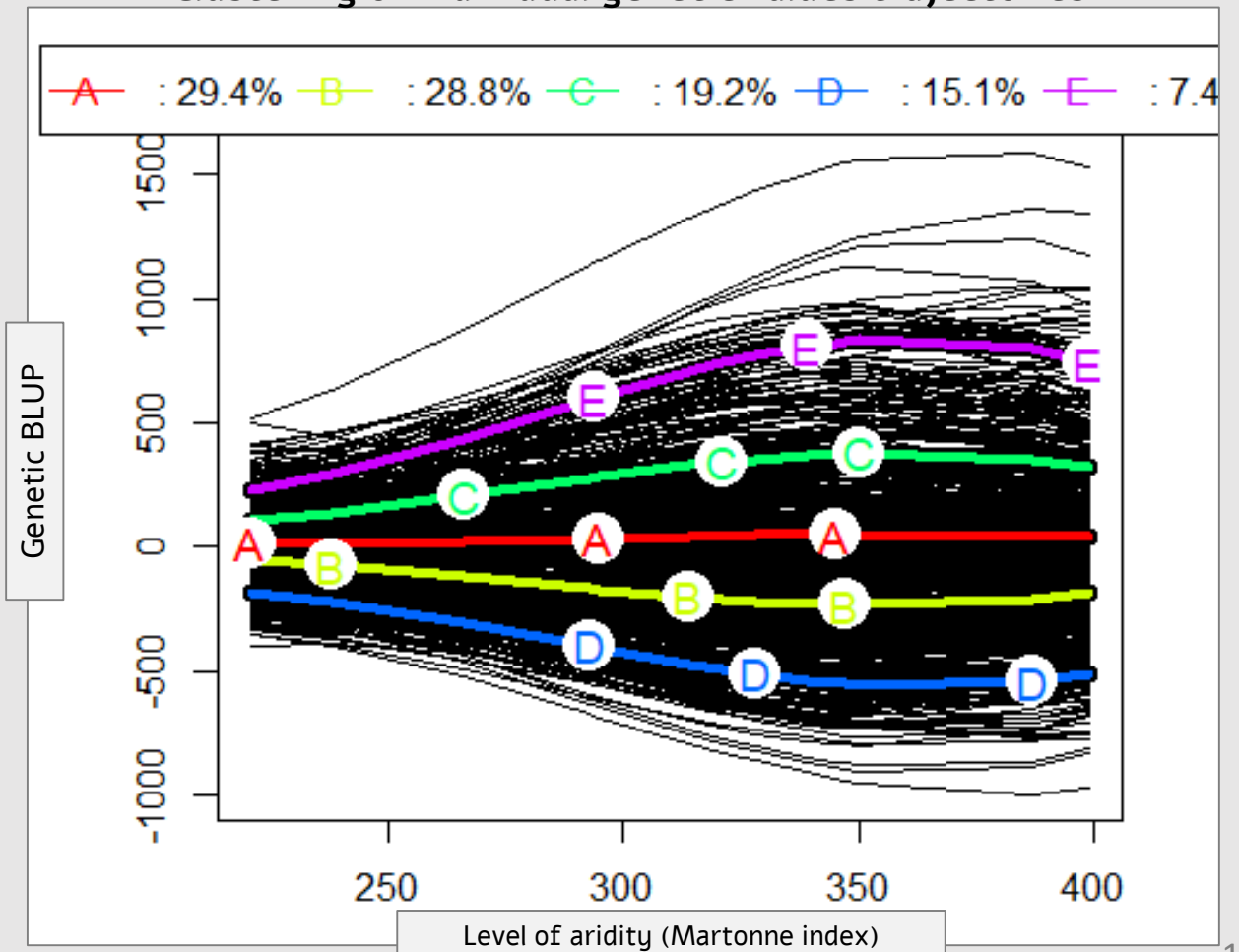
Clustering of trajectories (Genolini et al. 2015)

Evolution of individual genetic values across environments



Clustering of individual genetic values trajectories



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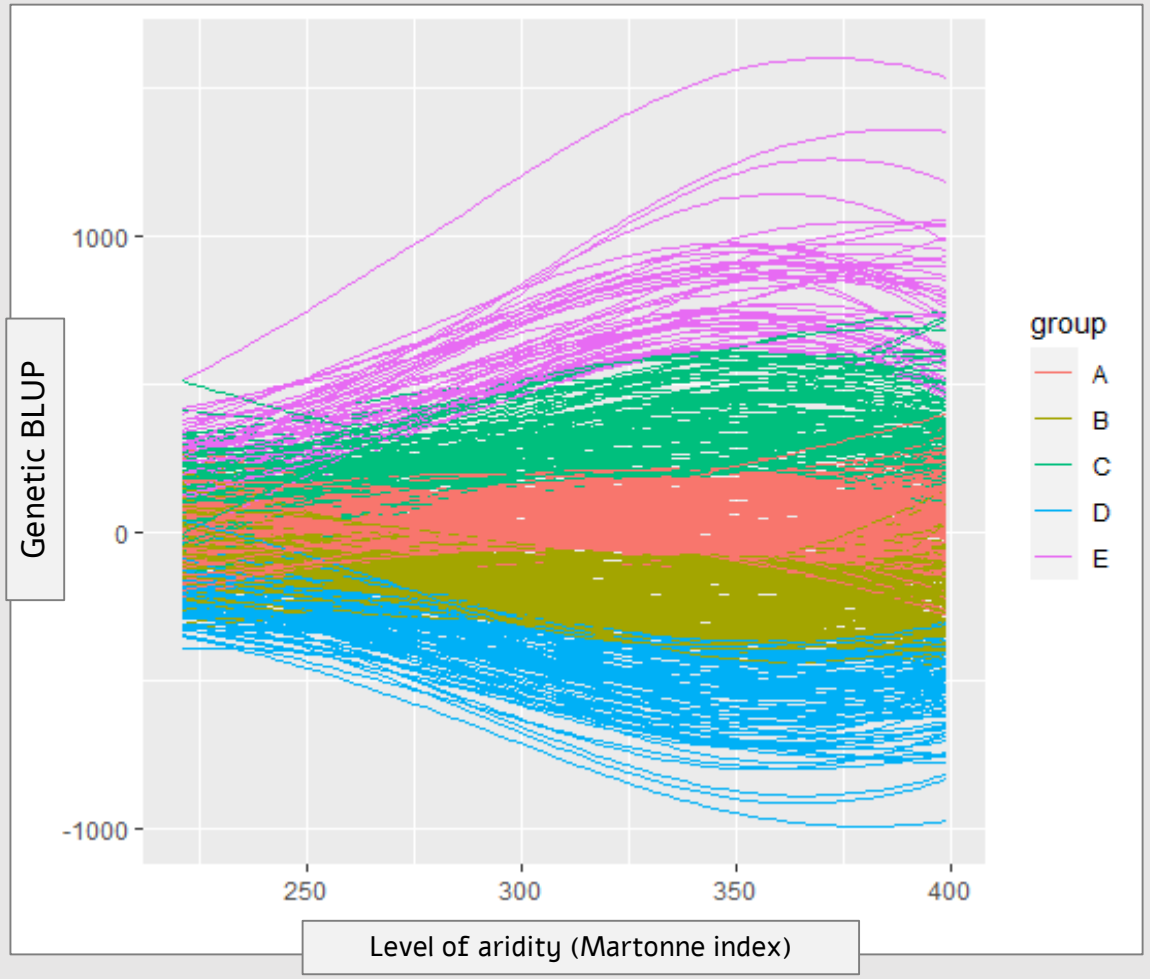
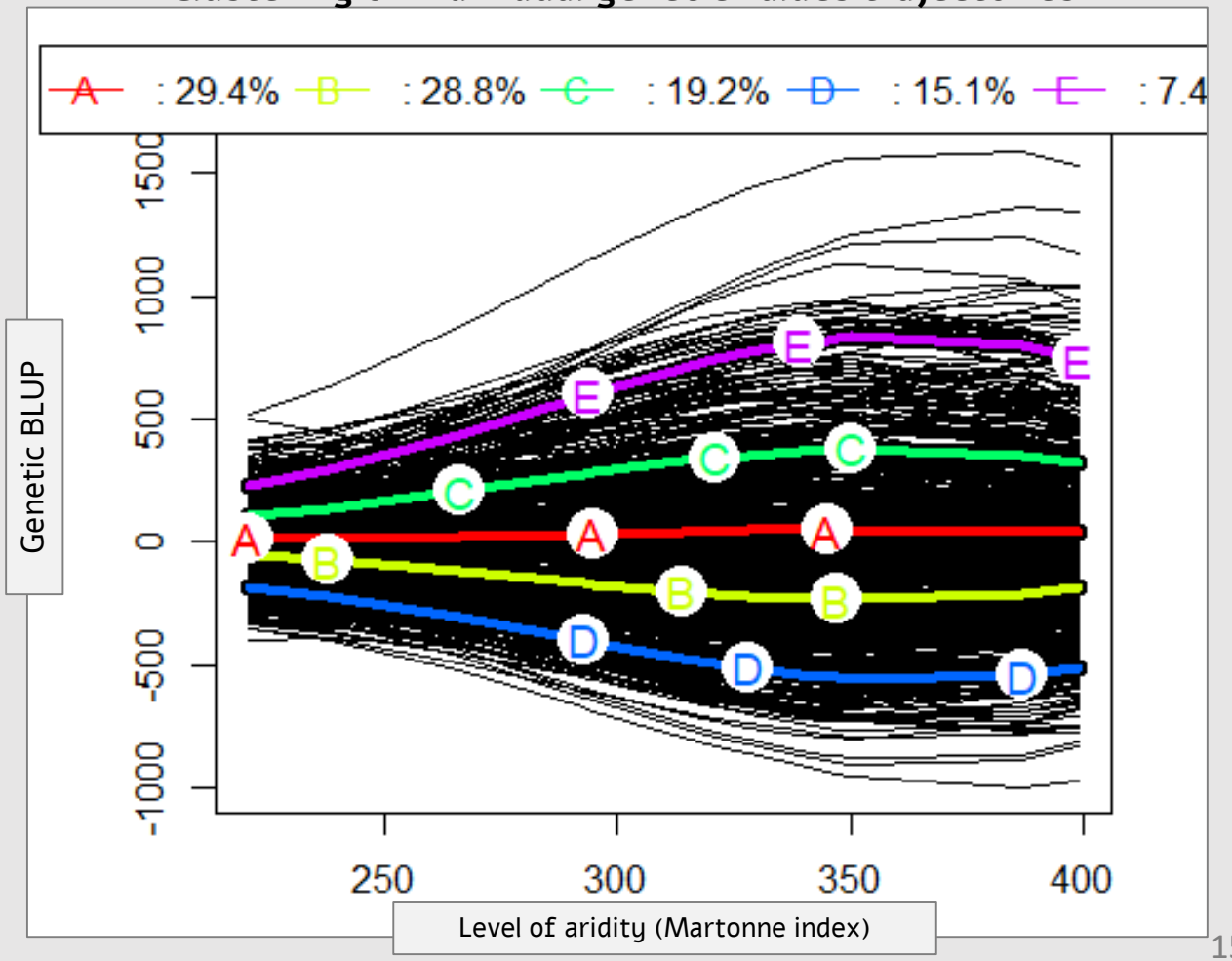
Evolution of individual genetic values across environments



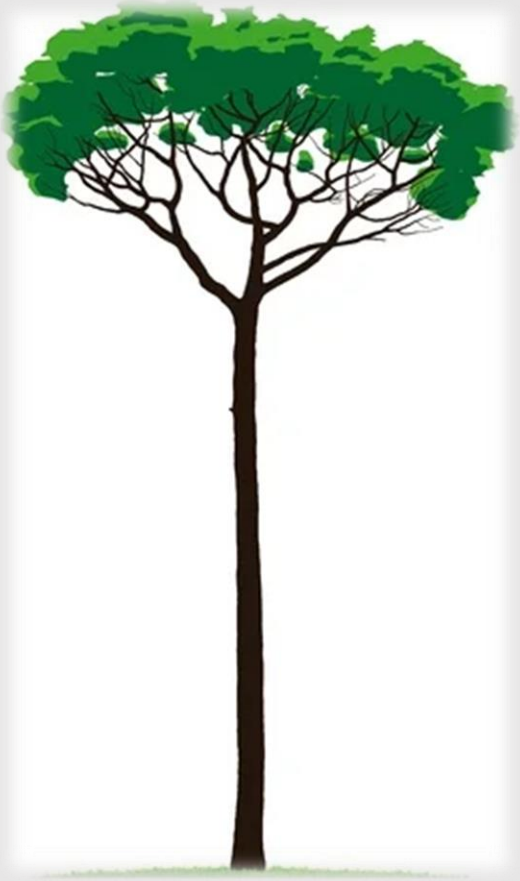
Clustering of individual genetic values trajectories



Conclusion and prospects

- **With :**
  - Phenotypic measurments : densitometric profiles
  - Simple climatic characterization : Martonne's aridity index
  - Genetic data : pedigree or molecular markers information

→ **Norms of reaction** : individual genetic values across a range of environments



- **Main prospects :**
  - Improve **environmental characterization :**
    - Consideration of previous years, better differentiation of experimental sites…
    - Use of a **growth simulation model** (GO+ : based on environmental characteristics of each site (stand density, groundwater height)) to incorporate more explanatory parameters into the annual index (soil water reserve, evapotranspiration demand)
  - Extend to other **inter-ring phenotypic traits** (ex: average ring density)
  - Construct NoR for **intra-ring growth**

Thank you for your attention