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Applied Tree Breeding: Planting the Right Tree at the Right Place

Patrick Lenz

Canadian Wood Fibre Centre

… and Claire Depardieu, Jean-Philippe Laverdière, Martin Girardin, Nathalie Isabel, Simon Nadeau, Isabelle Duchesne, Martin Perron, Jean Beaulieu, Jean Bousquet, …




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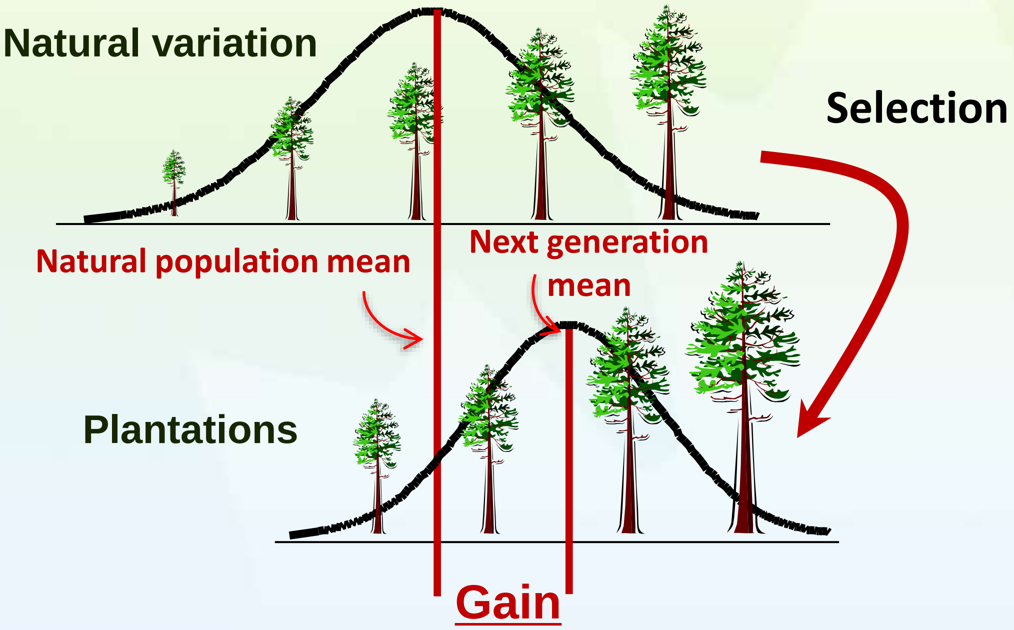
Sharing Research Knowledge to Support the 2 Billion Trees Program …

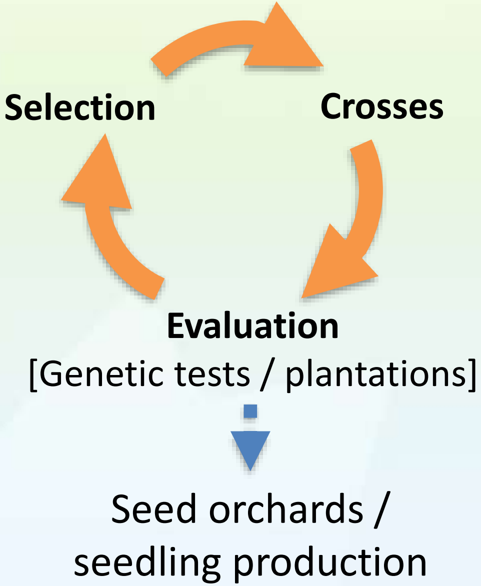
- Across Canada: 550 million seedlings planted per year
  - Mostly conifers
- Planting of 2 billion incremental trees
  = seedling production of 3 to 4 years

Most of the planted seedlings come from improved seedlots

The principle of tree breeding



Traditional breeding cycle



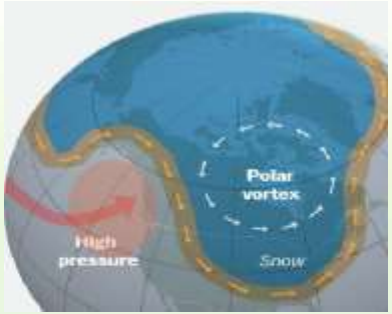
Climate change – increased stress for the boreal forest

- Constrained precipitation periods
- Increased annual temperatures
- Rapid arctic warming is weakening the jet stream and polar vortex

(Kug et al, 2015, Nat Geosci)

→ More **frequent** and **intense** drought episodes

→ Extreme temperatures in the ***off seasons***



Sources: NASA, NWS

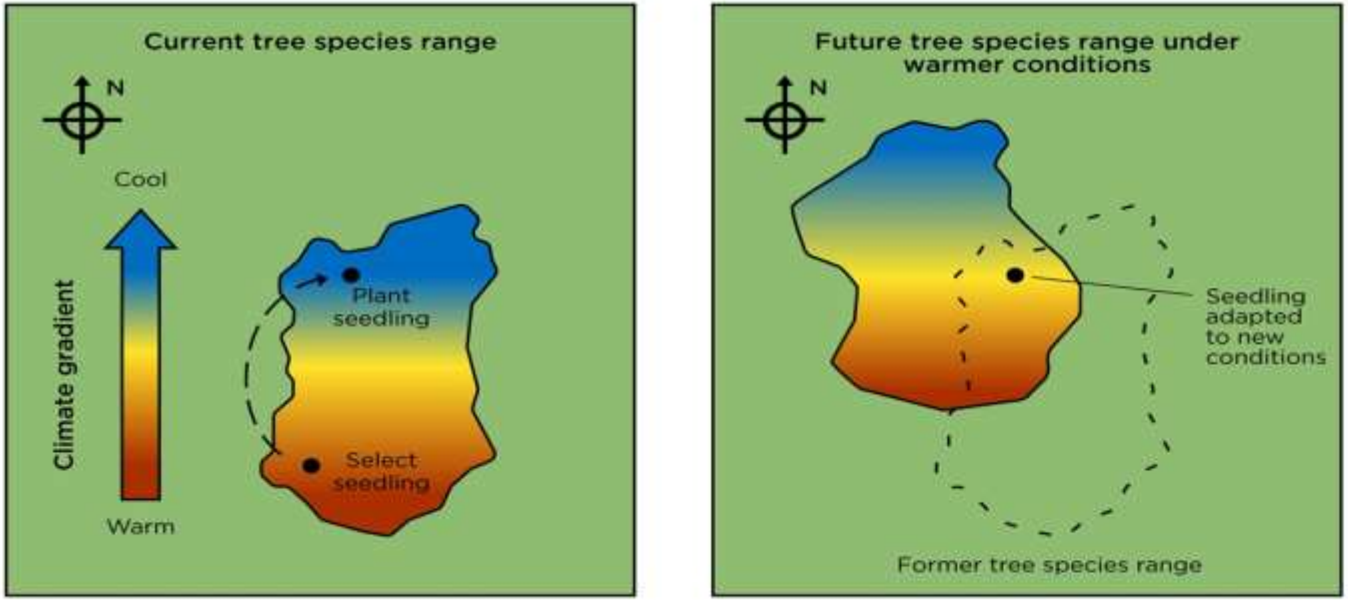
Impacts of drought on boreal forest trees:

- **Reduction of** radial and apical **growth**
- Increased **susceptibility** to pests and diseases

Other climatic extremes:

- Extreme cold temperatures and more **frequent thaw** periods
- **Spring** and early **fall frosts**

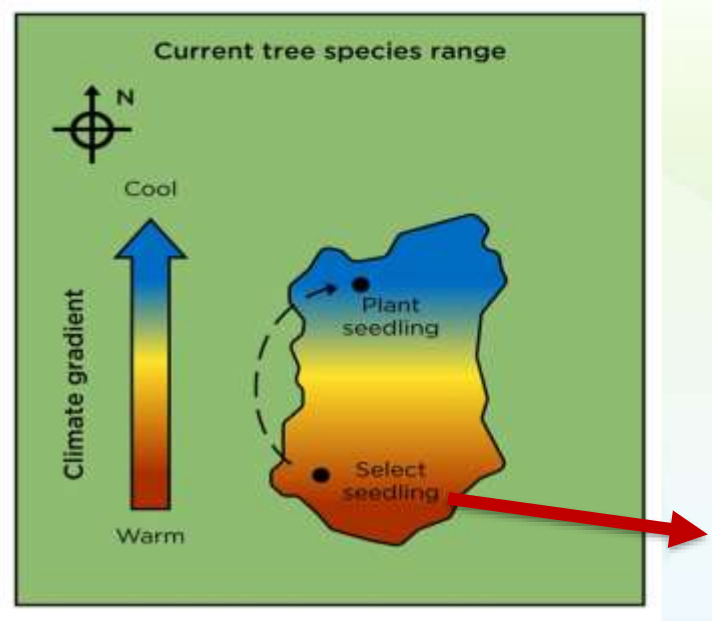
Preparing for future climate: Assisted gene flow



The State of Canada's Forest 2020

→ Migrating seedlots according to predicted future climate
→ Many breeding programs consider climate through seed deployment guidelines

The pitfalls of assisted migration



- Without knowledge of the species' genetics, moving seedlots is associated to significant risks
- Good climate models exist, but
  - Difficulties to predict extreme events
- Hardly considered: Bio-physiological variables, soil, phenology, interplay with pests and diseases
  - ➢ Need for more complex modelling approaches
- Target population for migration already lack adaptation to present environment

Genetic trials for studying adaptation

<u>Genetic trials</u>

- Even-aged plantation of genetically distinct populations, families …
- Follow experimental design
- Repeated in different environments

<u>Legacy provenance trials</u>

- First genetic experiments from the 1960-70’
- Initial aim: Identification of seedlots with superior growth and volume production
- Approaching rotation age

Investigating the effect of migration in legacy trials

- Sampling of black spruce provenance trials in Québec
- Growth and wood core analyses
- Obtain genomic profiles of a couple thousand trees

nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-021-21222-3 OPEN

Annual aboveground carbon uptake enhancements from assisted gene flow in boreal black spruce forests are not long-lasting

Martin P. Girardin[1,2✉], Nathalie Isabel[1,3], Xiao Jing Guo[1], Manuel Lamothe[1], Isabelle Duchesne[4] & Patrick Lenz[3,4]

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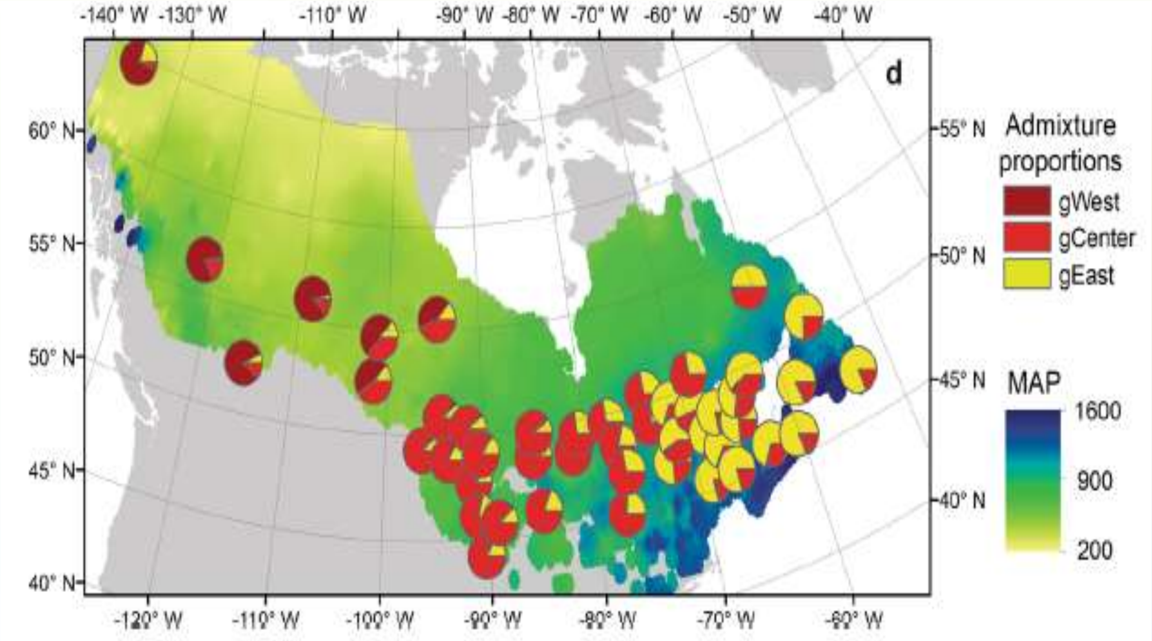
Genetic structure matters!

- Although one species, distinct genetic lineages can be identified
  - Migration from glacial refugia
- Genetic structure is an important variable for modelling net primary productivity

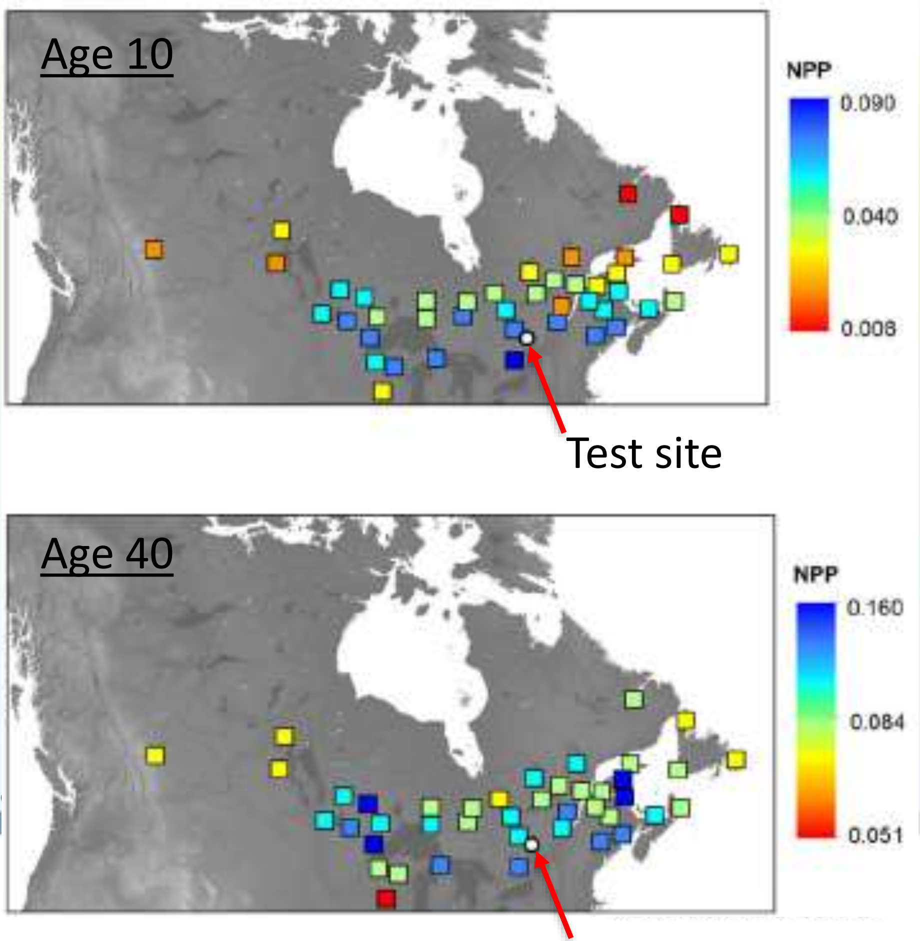


Average genetic admixture proportions describe the among population differences

Provenance productivity varies with time

Southern Laurentian Mountains test site:

- Good performance of meridional provenances at juvenile age
- After 40 years of growth, specific provenances from the central and eastern lineage have become top performers



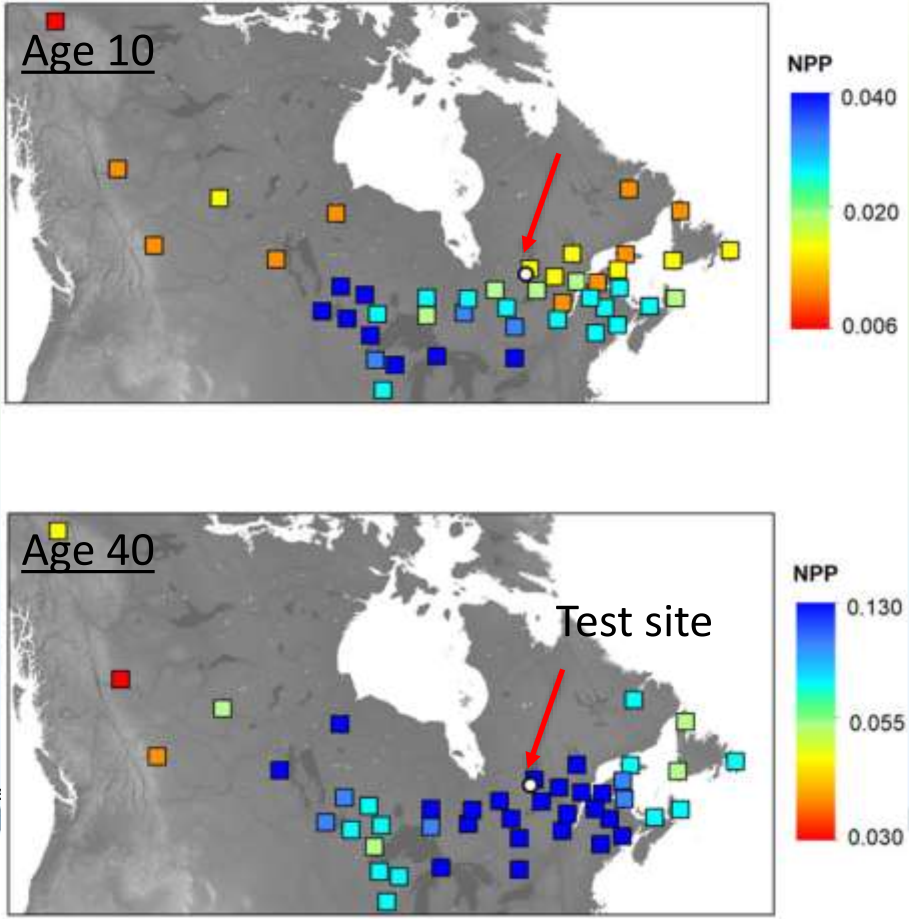
Provenance variation is site-specific

Central Quebec, continental test site:

- Good performance of Great-Lakes provenances at juvenile age
- After 40 years of growth, “local” provenances from central Quebec became top performers

➢ **Growth enhancements** from assisted gene flow are **not long-lasting**

➢ **Need for systematic genetic testing** to identify best adapted seed stock

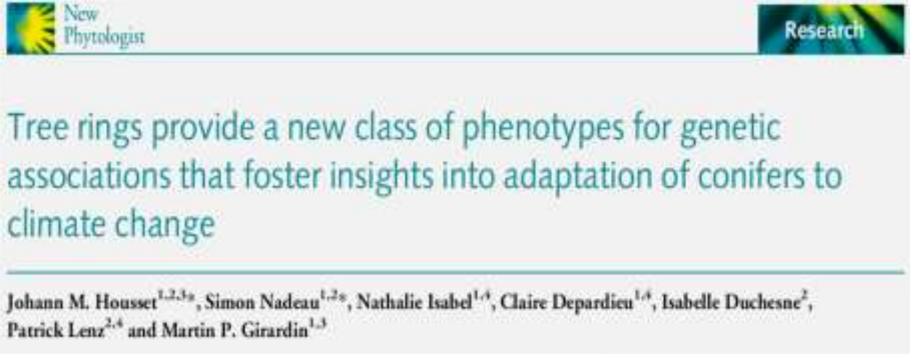


How can we better characterize adaptation in breeding material

- Growth can be seen as an indicator of adaptation to *present* climate
- How can we foresee *future* growth reactions?
  - due to climate extremes (drought periods, late and early frost)

Sources: NASA, NWS

→look into the past, use tree ring data and growth-climate relationships for genetic analyses

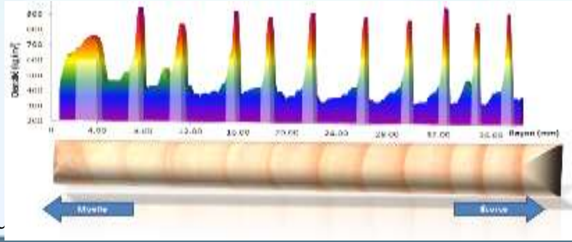


New Phytologist

Research

Tree rings provide a new class of phenotypes for genetic associations that foster insights into adaptation of conifers to climate change

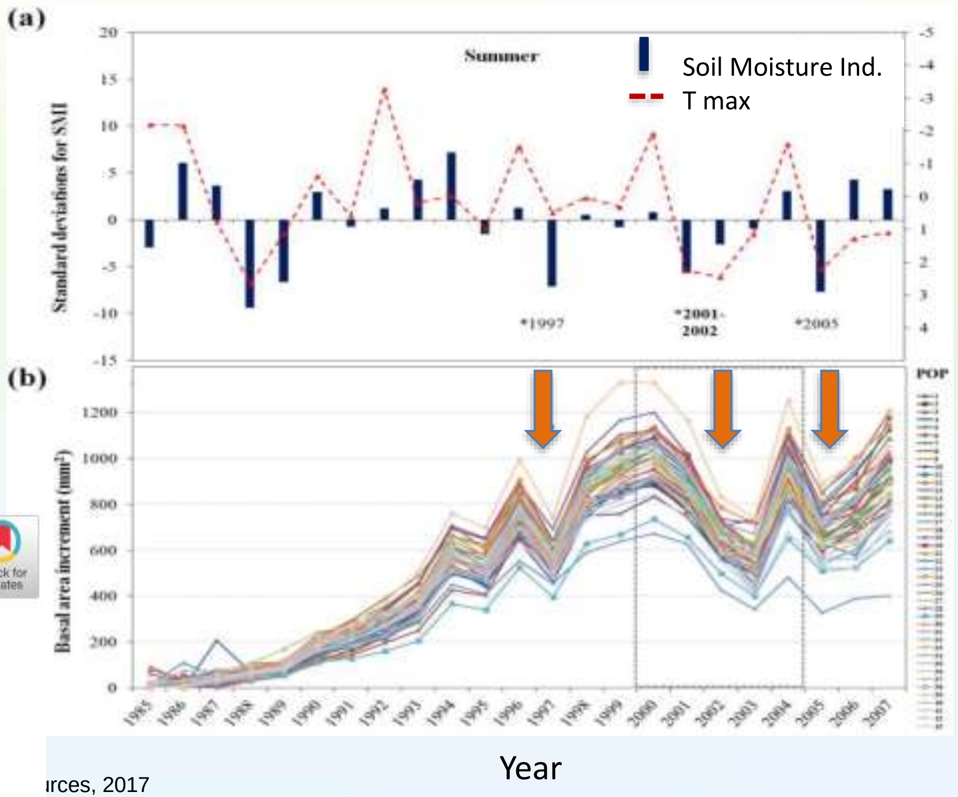
Johann M. Housset[1,2,3*], Simon Nadeau[1,2*], Nathalie Isabel[1,4], Claire Depardieu[1,4], Isabelle Duchesne[2], Patrick Lenz[2,4] and Martin P. Girardin[1,3]



Housset et al. 2018, Eastern white pine

Drought-related growth reduction in white spruce

- Growth ring data from 1500 trees from a 30 year old provenance trial
- Seed sources from southern Quebec
- General reduction of basal area increment (BAI) in years with low soil moisture



rces, 2017

New Phytologist
Research
Check for updates

Adaptive genetic variation to drought in a widely distributed conifer suggests a potential for increasing forest resilience in a drying climate

Claire Depardieu[1,2], Martin P. Girardin[1], Simon Nadeau[3], Patrick Lenz[2,3], Jean Bousquet[2] and Nathalie Isabel[1,2]

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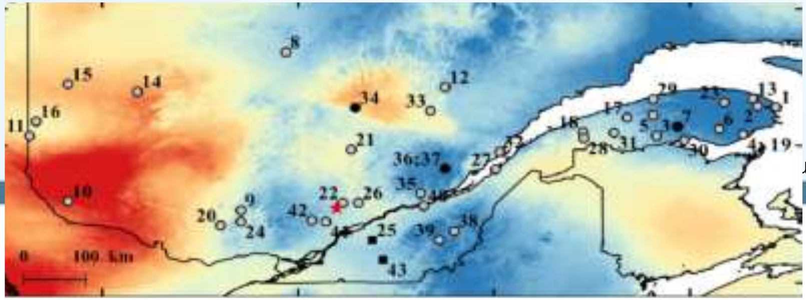
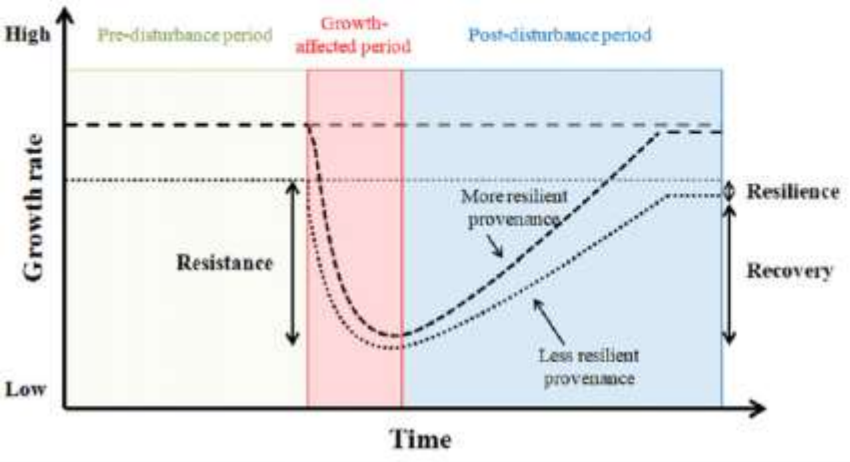
Estimating drought resistance and resilience

- Quantification of adaptation using growth reaction coefficients
- Higher resilience to drought events in populations from drier geographical origins than from more humid origins
  - Represents **signs of local adaptation**
  - Adaptive genetic variation in response to changing local condition can shape vulnerability at the intra-specific level



Characterisation of growth reduction during drought



From Depardieu et al. 2020, New Phytol. Resistance, resilience and recovery coefficients as adapted from Lloret et al. 2011

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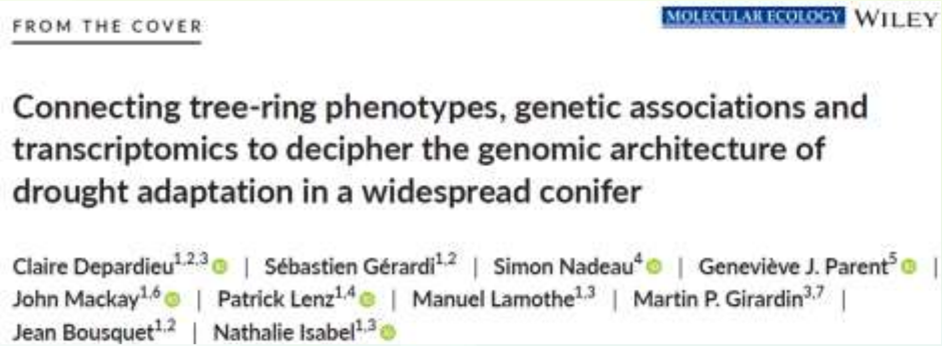
Deciphering the genetic architecture of drought adaptation

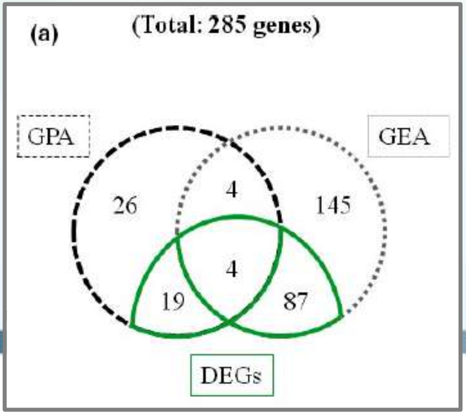
- Using resistance and resilience coefficients allowed finding genes associated with drought adaptation
- Giving fundamental insights in genetic architecture of adaptation


FROM THE COVER

MOLECULAR ECOLOGY WILEY

Connecting tree-ring phenotypes, genetic associations and transcriptomics to decipher the genomic architecture of drought adaptation in a widespread conifer

Claire Depardieu[1,2,3] | Sébastien Gérardi[1,2] | Simon Nadeau[4] | Geneviève J. Parent[5] | John Mackay[1,6] | Patrick Lenz[1,4] | Manuel Lamothe[1,3] | Martin P. Girardin[3,7] | Jean Bousquet[1,2] | Nathalie Isabel[1,3]



Using tree ring phenotypes in breeding

Evaluation in active breeding population:

- 19 year-old white spruce polycross trial
- Replicated on 3 sites
- Estimation of resistance and resilience coefficients

Drought stress:

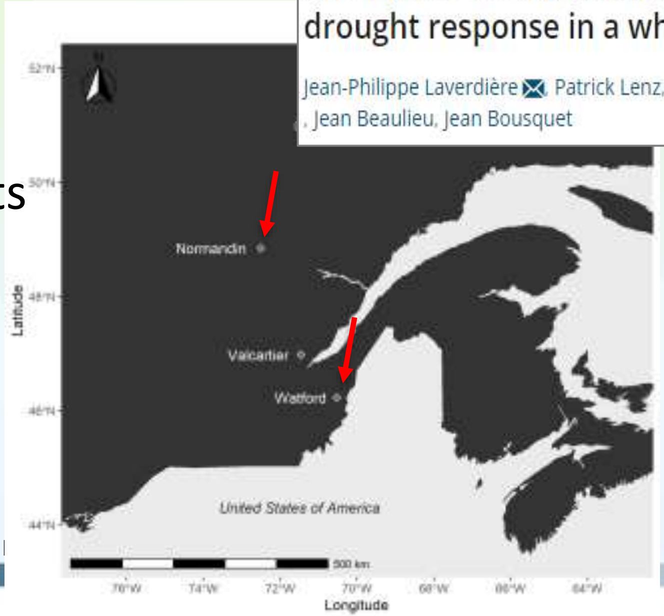
- Normandin: 2010
- Watford: 2012

Evolutionary Applications
Open Access
Evolutionary approaches to environmental, biomedical and socio-economic issues

ORIGINAL ARTICLE | Open Access

Breeding for adaptation to climate change: genomic selection for drought response in a white spruce multi-site polycross test

Jean-Philippe Laverdière, Patrick Lenz, Simon Nadeau, Claire Depardieu, Nathalie Isabel, Martin Perron, Jean Beaulieu, Jean Bousquet

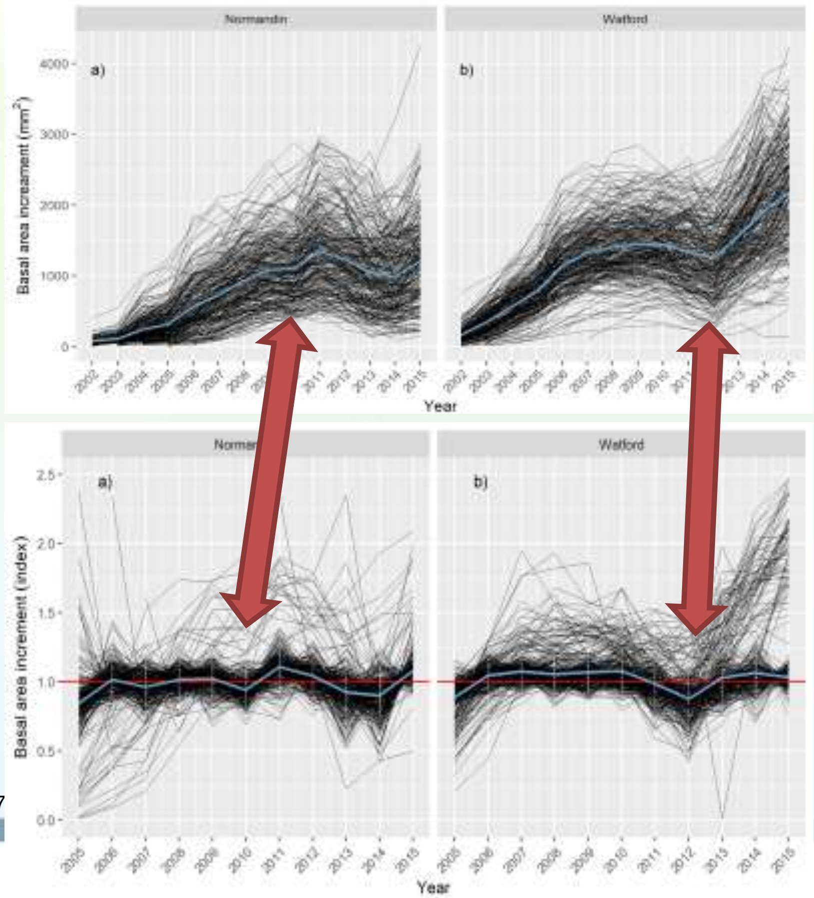


The effect of drought on radial growth

- Drought slows relative growth
- Timing and the effect of drought was different in both environments

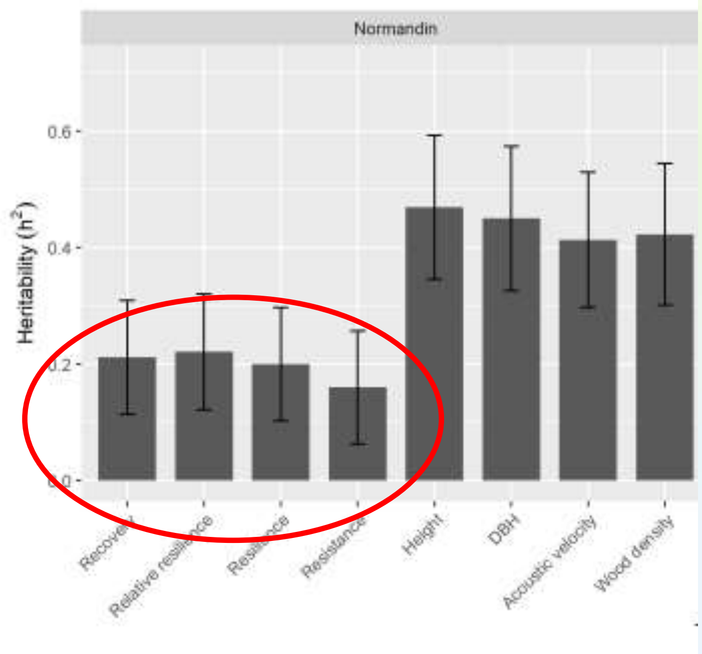
	Normandin (north)	Watford (south)
Age at the moment of drought	13	15
Intensity of drought	++	+
Timing of drought	Early-mid growing season	Mid-late growing season

➢ Importance to consider equal effects in selection decisions



Promising results for including adaptive phenotypes into genomic selection models

- Acceptable levels of genetic control and good accuracy of genomic selection models
- Consider resistance and resilience in selection decisions is feasible



Multi-trait genomic selection can address key needs in breeding for adapted seedling stock

1) Need to combine diverse selection objectives

- Including adaptive phenotypes – besides growth and other quality or resistance traits – into breeding programs demands for efficient multi-trait selection methods

2) Seen the **rapid pace of environmental change**

- Need to **speed up the selection process** and include genetic markers for predicting traits at a very juvenile stage (without measuring them)

SPECIAL ISSUE ORIGINAL ARTICLE

Evolutionary Applications WILEY

Multi-trait genomic selection for weevil resistance, growth, and wood quality in Norway spruce

Patrick R. N. Lenz[1,2] | Simon Nadeau[1] | Marie-Josée Mottet[3] | Martin Perron[2,3] | Nathalie Isabel[2,4] | Jean Beaulieu[2] | Jean Bousquet[2]

Concluding remarks (1)

- Studies from legacy genetic trials have shown that assisted gene flow **may not enhance productivity** and carbon sequestration
- There is a need for **augmenting our knowledge on genetic variation** and structure linked to adaptation, which is especially true for non-commercially species
  - **Enhancing systematic genetic testing** in various environments

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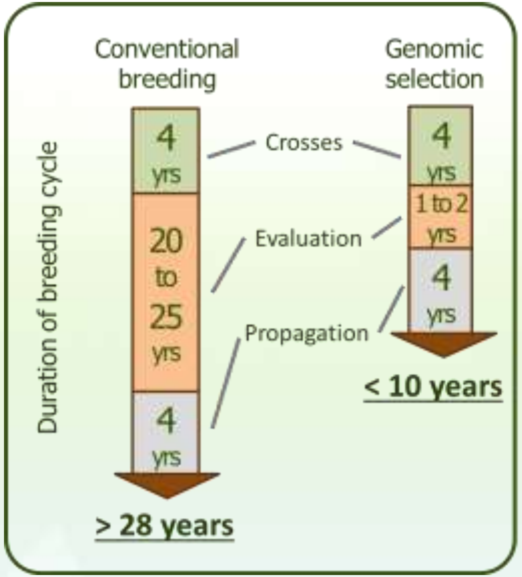
Concluding remarks (2)



- Tree ring phenotypes present a promising way to include **resistance to drought into tree breeding decisions**
- Conventional breeding is slow; **genomic selection** implemented at the operational level will allow to **more precisely and more quickly select adapted and productive seedling stock.**

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SpruceUp

FastTRAC

Fast Tests for Rating and Amelioration of Conifers

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