The role of breeding in contemporary forestry: Forest tree breeding in Europe

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The role of breeding in contemporary forestry

Forest tree breeding in Europe

Luc E.Pâques
INRA-AGPF-Orléans (France)
Over 60 years of forest tree breeding: where do we stand?

Most breeding programmes have been started in the 50’s

Mostly conifers vs broadleaves

(\textit{planted}) \hspace{1cm} (\textit{naturally regenerated})

- 1st step: ‘Pre-breeding’ = genetic diversity studies
  = seed stands &
  provenance recommendations

- 2\textsuperscript{nd} step: ‘Breeding’: launching of recurrent
  selection schemes

  = breeding populations
  = recombination
  = evaluation
  = mass-propagation
  = deployment

Optimisation
Over 60 years of forest tree breeding: where do we stand?

> 135 ‘breeding programmes’
  for 8 species
  across 18 countries

+/- 1 programme/species/country !!

> 54 others for 11 species

Source: Treebreedex: Mertens et al.2008
Over 60 years of forest tree breeding: where do we stand?

Over **65 500** selected seed stands (57% conifers/ 43% broadleaves)

> **1 200** Seed Orchards over **7 600 ha** for around 40 species

Source: ‘Community List of Approved Basic Material for the Production of Forest Reproductive Material, based on the national lists as supplied by the Member States according to Article 10(2) of Council Directive 1999/105/EC
## FRM – seed orchards and use

In many countries, most planted material is from improved material (SO)

Questions about SO dimensioning?

### Ratio of planted area vs seed orchard area

<table>
<thead>
<tr>
<th></th>
<th>Norway spruce</th>
<th>Scots pine</th>
<th>European larch</th>
<th>Douglas-fir</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>454</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CZ</strong></td>
<td>1081</td>
<td>889</td>
<td></td>
<td></td>
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<tr>
<td><strong>DK</strong></td>
<td>5100</td>
<td>2570</td>
<td></td>
<td>927</td>
</tr>
<tr>
<td><strong>FI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>F</strong></td>
<td>5190</td>
<td>17330</td>
<td>5087</td>
<td>4371</td>
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<td><strong>D</strong></td>
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<td>8808</td>
<td>1889</td>
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<tr>
<td><strong>I</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LI</strong></td>
<td>390</td>
<td>745</td>
<td>166</td>
<td></td>
</tr>
<tr>
<td><strong>NL</strong></td>
<td>6760</td>
<td></td>
<td></td>
<td>1067</td>
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<tr>
<td><strong>NO</strong></td>
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<tr>
<td><strong>PL</strong></td>
<td>14052</td>
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<tr>
<td><strong>RO</strong></td>
<td>3681</td>
<td></td>
<td>105</td>
<td>253</td>
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<tr>
<td><strong>SK</strong></td>
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<td></td>
<td></td>
<td>304</td>
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<tr>
<td><strong>S</strong></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td><strong>SP</strong></td>
<td>48380</td>
<td></td>
<td></td>
<td>7538</td>
</tr>
</tbody>
</table>

### Results

- **Over-sized?**
- **Under-sized?**
## Expected genetic gains

*Examples of predicted genetic gains from different breeding programmes across Europe: Sitka spruce*

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Trait</th>
<th>Age</th>
<th>Seed orchard</th>
<th>Vegetative propagation (half-sib family mixes)</th>
<th>Vegetative propagation (full sib families)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Britain</td>
<td>2010</td>
<td>Diameter</td>
<td>15</td>
<td>15 - 20%</td>
<td>20%</td>
<td>20 - 30%</td>
<td>Queen Charlotte Import</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stem straightness</td>
<td>15</td>
<td>10% - 15%</td>
<td>20%</td>
<td>15 - 30%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Branching Score</td>
<td>15</td>
<td></td>
<td>10 - 15%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wood density</td>
<td>15</td>
<td>-10% to 0%</td>
<td>0%</td>
<td>0% - 10%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotation sawlog volume</td>
<td></td>
<td>Rotation age</td>
<td>approx 40%</td>
<td>approx 50%</td>
<td>Queen Charlotte Import # #</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotation volume</td>
<td></td>
<td>Rotation age</td>
<td>approx 20%</td>
<td>approx 60%</td>
<td></td>
</tr>
<tr>
<td>Ireland</td>
<td>2010</td>
<td>Height</td>
<td>15</td>
<td>15% to 20%</td>
<td></td>
<td></td>
<td>Unimproved stock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stem form</td>
<td></td>
<td></td>
<td>7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>2010</td>
<td>Diameter</td>
<td>15</td>
<td>7%</td>
<td></td>
<td></td>
<td>Unimproved Danish landrace</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stem straightness</td>
<td>15</td>
<td>12%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Volume</td>
<td>18</td>
<td>30%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wood density*</td>
<td>18</td>
<td>0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leader breaks</td>
<td>18</td>
<td>-7%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Stem straightness</td>
<td>18</td>
<td>4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Forks</td>
<td>18</td>
<td>-3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stem straightness</td>
<td>10</td>
<td>11%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diameter</td>
<td>10</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wood density*</td>
<td>10</td>
<td>0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flushing score</td>
<td>5</td>
<td>-12%</td>
<td></td>
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</tr>
</tbody>
</table>

Material from: Clone mean# or Queen Charlotte Island import in bracket.

Source: Forest Tree Breeding in Europe, Springer
‘Little gains’ ... ‘great benefits’

Genetic gain: 25 % in volume from 2$^{nd}$ generation SO

<table>
<thead>
<tr>
<th></th>
<th>Hypothesis 1</th>
<th>Hypothesis 2</th>
<th>Hypothesis 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reforested area</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002-2020 (ha)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>non improved</td>
<td>380000</td>
<td>190000</td>
<td>76000</td>
</tr>
<tr>
<td>improved</td>
<td>0</td>
<td>190000</td>
<td>304000</td>
</tr>
<tr>
<td><strong>Total volume (10^6 m^3)</strong></td>
<td>85.5</td>
<td>96.2</td>
<td>102.6</td>
</tr>
<tr>
<td><strong>H2-H1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^6$ m^3</td>
<td></td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>$10^6$ euros</td>
<td></td>
<td>534</td>
<td></td>
</tr>
<tr>
<td><strong>H3-H1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^6$ m^3</td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>$10^6$ euros</td>
<td></td>
<td></td>
<td>854</td>
</tr>
</tbody>
</table>

Maritime pine, Landes (FR)  

Lesgourguès, 2002
Over 60 years of forest tree breeding: *where do we stand?*

1) Probably (one of) the **most significant** human impact in forest management

- Quantitative & qualitative increase of timber production
- Increase of financial resources from forests

2) **But...**

- Cases of *maladaptation*: over-extension: Norway spruce...
- Breeding with a *too narrow genetic basis*: rust and poplars...
- *Under-use* of some FRM: wild cherry clones...
- *Extra-cost* of some FRM: hybrids, clones
- ‘*Invasion*’ by ‘exotics’: hybrid & Japanese larches, douglas-fir, poplars...
- Still some *orphelin species*...
- Top-quality FRM: Incentive for pure stands?, *monoculture*?
- FRM & nurseries: *vector* of diseases: *Sphaeropsis* blight, ...
- ...

Over 60 years of forest tree breeding: *where do we stand?*

3) In a ‘stable’ world

<table>
<thead>
<tr>
<th>Timber production</th>
<th>‘Stable’ climate</th>
<th>‘Known’ biotic threats</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

‘Known’ abiotic risks
What has changed? What is changing?

A mostly ‘un-stable world’

Emerging biotic threats

Species interest

‘Conflicting’ end-products

Climate change

Budget /staff

What has changed?
What is changing?

Species interest

Emerging biotic threats

‘Conflicting’ end-products

Budget /staff

Climate change

Source: Forest Research
What has changed? What is changing?

Management options have enlarged

• Classical plantations
  - clear-cutting
  - natural regeneration

• Intensive plantations
  - low density (timber)
  - high density (biomass)
  - short-rotation coppice
  - short-rotation high forest

• Mixed plantations

• Plantations with emerging species

• No plantation: natural regeneration

Breeding:
- Species priority
- Long-term / short-term
- Genetic basis
- Traits priority
- Intra/inter-species competition
- Transfer of breeding tools/results to management
What has changed? What is changing?

‘Wood’

Growing regimes

High-standard forest
SR standard forest
SR coppice

Specialisation of products

For breeding:

Growth +
Straightness, branching (Density)
Pulp-link properties

Competition
Age (juvenile wood)

Heartwood proportion
Durability
Colour
Grain angle
Extractives
Lignin <-> cellulose
MOE, MOR
EW-LW density ratio
...

What has changed?
What is changing?

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SR standard forest
SR coppice

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Durability
Colour
Grain angle
Extractives
Lignin <-> cellulose
MOE, MOR
EW-LW density ratio
...
What has changed? What is changing?

‘Climate'

For breeding:

‘Overall’ adaptation
Survival & Frost resistance
→ Breeding zones

Heat / drought / wind resistance / tolerance
→ Deployment zones

Impact on phenology
• frost
• growing season
  • growth-architecture
  • wood formation

Pest and disease resistance / tolerance

Temperature + water + wind

Pests + diseases
Most commercial seed lots are produced in seed orchards planted with selections made in cooler/wetter conditions.
## What is needed?

**Reactivity and efficiency**

### Flexibility
- Adapt: shift species / reprofile breeding populations / review deployment zones / target traits
- Shorten / speed up: breeding/selection/FRM mass-production

### Integration
- Multi-purposes/multi-traits
- Multi-disciplines
- Research → Development → Management

### Up-scaling
- Enlarge environmental conditions
- High-throughput
- Enlarge views: from regional → national → international

### Scrutiny
- Dissect traits
- More precision needed
- Inter-relationships

---

**Uncertainty → Reactivity and efficiency → Joined efforts**
Joined efforts: why?

1) To better circulate information, exchange methodologies, benefit from synergies

- Controlled crossing
- Flower induction
- Management of breeding populations
- Fingerprinting

Controlled crossing
Flower induction
Management of breeding populations
Fingerprinting

Recombination
Recruft Selection

Evaluation

Juvenile evaluation/selection
Clonal testing
Consolidated knowledge on genetic parameters
Use of MAS

FRM propagation

SO reproduction engineering
Vegetative propagation (cutting, in vitro)
Joined efforts: why?

2) To improve efficiency and valorise breeding efforts

- Critical mass: breeding efforts vs reforestation needs?
- Coherence?

Survey based on 115 breeding programmes, 28 forest tree species from 19 EU-countries

<table>
<thead>
<tr>
<th>Breeding</th>
<th>Observed fact</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed long-term breeding population</td>
<td>Among-family selection (15 out of 20)</td>
<td>Maintenance of genetic diversity</td>
</tr>
<tr>
<td>Recombination of genotypes</td>
<td>Open-pollination instead of controlled pollination</td>
<td>Control of relatedness?</td>
</tr>
<tr>
<td>One vs two-stage selection</td>
<td>Progeny testing vs clonal testing</td>
<td>Genetic gain per unit time</td>
</tr>
<tr>
<td>Breeding vs multiplication populations</td>
<td>49% not separated</td>
<td>Ineffective deployment</td>
</tr>
<tr>
<td>Breeding zones</td>
<td>No consideration for 42%; only 22% have breeding zones based on climate</td>
<td>Risk for reduced adaptedness</td>
</tr>
<tr>
<td>MAS / simulation</td>
<td>4% / 6%</td>
<td></td>
</tr>
</tbody>
</table>

*Danusevicius et al. 2010*
Joined efforts: why?

3) To better tackle challenges of common interest

- Priorities for joined breeding

  (Source: Forest Tree Breeding in Europe, Springer)

- ‘omics’-assisted selection
  high-throughput genotyping & phenotyping

- Assisted-migration of species, seed transfer
  plasticity & adaptability
How to join efforts?

An opportunity at European Union level:

"Structuring the European Research Area"
Action: Support for Research Infrastructures

State-of-the-art infrastructures

Research experimental facilities

Networking

Access

I3

Research

Essential services to the research community

Long-term integrating effect
European Tree Breeding Centre

Networking

Access
Research

Joined research & breeding

2006-2011

2012-2015

Treebreedex

A working model network of tree improvement for competitive, multifunctional and sustainable European forestry
Ac3. Geographical structure of Species genetic variability:

towards delineation of breeding zones across Europe

Ac4. Structure, organisation and long-term management of FTB material:

towards a joined management of breeding populations

Ac5. Optimisation of Breeding methods and strategies:

towards joint development of breeding activities and genetic research

Ac6. Mass-production & deployment of varieties:

share of expertise for a more efficient dissemination of varieties
Networking activities

**Surveys:** Breeding programmes/strategies across Europe
- Genetic resources
- National regulations
- Seed transfer
- Experimental facilities
- Methodologies...
- Cost/benefit of joined breeding

**Seminars/workshops**
- Adaptability/plasticity, Genetic variability and adaptive potential
- Long-term breeding strategies
- Breeding zones delineation
- Breeding programmes
- Vegetative propagation
- Seed orchard
- ABS-DUS
- Field experimental network
- Optimal deployment and use of FRM, Mutualisation of efforts...

**State-of-art reports**
- Interspecific hybridisation
- Phenotypic selection
- Regions of provenances
- Guidelines on Genetic Quality of Forest Reproductive Materials
- Roadmap for joined breeding...

**Standardisation**
- Traits assessment protocols
To provide **support tools** for R&D

- **Forest clearinghouse** (environmental data)
- **Genetic databases** (Treebreedex, Evoltree, Genfored...)

**Trees4Future web-portal**

- **Forest resources models** (Efiscen, Orchidee, Forgem, Tosia...)
- **Site-climate matching tool**
  - GIS decision-making tool (species site matching, delineation of breeding, deployment zones)
- **Statistical platform**

**Step 2**
To provide **support tools** for R&D

Plasticity expert group

Methodological and experimental support

- Phenotyping
  - Development of high-throughput phenotyping techniques
    - Phenology
    - Tree-water relation
    - Wood properties

- Definition of standards
  - Field assessment and labs
  - Data management

Phenology expert group

Genotyping

- Development of a molecular platform
- Fingerprinting
- Support to FRM/wood traceability
To give access to **key-research facilities**

28 research infrastructures in access

- Genetics, genomics & breeding
- (Eco) physiology & biotechnology
- Wood science & technology
- Modeling

Physical visits (up to 3 months) – remote services – data access

Apply now!!!

http://www.trees4future.eu/
Towards a European Tree Breeding Centre?

R&D INFRASTRUCTURES

Documentation (state-of-art)
Data (genetic resources)
Standards (labs&fields)
Experts networks

Tools

INFRASTRUCT.? (Service labs)

Management of genetic resources

IPR & Regulations
Exchange of information (workshops-seminars)
Training (scientific-technical)
Communication

Joined Research projects
Collaborative breeding programmes

Designing Trees for the Future
Joined breeding programmes...

Why not in Europe?
Thanks for your attention