Tree Improvement: An International Perspective and Opportunities for the U.K.

John MacKay
ICF Annual Conference - 27 April 2016

Productivity  Diversity  Sustainability
Outline

Tree Improvement (TI)
  – Productivity
  – Forest health

Genomics
  – The Power
  – And The Promise

Opportunities for the UK
Productivity

Large Impacts Delivered
Loblolly pine (*Pinus taeda*)

S-E USA
- Produces 18% of the world’s industrial round wood
- Pine planted area: 2% of world’s forests

Sources: [www.fs.fed.us/database/](http://www.fs.fed.us/database/)
Impacts of silviculture and Tree Improvement

*1 foot\(^3\)/acre = 0,06944m\(^3\)/ha
1 hectare (ha) = 10,000 m\(^2\)

Source: Fox et al. 2008
Eucalyptus

- Native of Australia
- 734 known species
- From tropical and subtropical areas
Eucalyptus yields from intensive Tree Improvement and silviculture

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<tbody>
<tr>
<td>Wood volume (m³/ha/year)</td>
<td>30</td>
<td>35</td>
<td>45</td>
<td>50+</td>
</tr>
<tr>
<td>Wood fibre yield (dry tons/ha/year)</td>
<td>6.4</td>
<td>8.1</td>
<td>10.2</td>
<td>11.3</td>
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</table>
Wood for Biomass and Bio-Energy
Aggressive DOE (USA) tree domestication targets

- Capture and Allocation of Carbon
  - Increased photosynthesis
  - Optimized photoperiod response
  - Optimized crown and leaf architecture
  - Greater carbon allocations to stem diameter vs height growth

- Biomass
  - Controlled and readily processable cellulose, hemicellulose, and lignin
  - Tailored biomass composition with value-added chemicals
  - Enhanced biomass production per acre by manipulation of photomorphogenic responses

- Tolerance and Sustainability
  - Pest and disease resistance
  - Drought and cold tolerance
  - Floral sterility
  - Regulated dormancy
  - Delayed leaf senescence
  - Optimal nutrient acquisition and use
  - Rhizosphere and microbial community health

http://genomics.energy.gov/gallery/biomass/detail.np/detail-01.html
Forest Health

Developing the Science
Ash Dieback Tolerance

Association study in population that included resistant trees from Denmark

- Identified:
  - DNA variations
  - Gene expression variations

- Predictive value:
  - Combined index of all 14 markers combined gave a correlation of $R^2 = 0.24$

Harper et al. 2015 Molecular markers for tolerance of European ash..., Scientific Reports, 6: 19335
GM of American chestnut for blight resistance

- Resistance breeding: hybridizing with Chine chestnut (co-evolved with pest)
- Developing side-by-side with GM work

Transgene: wheat oxalate oxidase gene driven by the VspB vascular promoter. Breaks down oxalic acid produced by the fungal pathogen
Commercial deployment: Insect tolerant poplars in China

Insect tolerance for defoliators and borers
- “Tree North” forest belt
- Bt toxin gene

Research plantation

- Only known commercial-scale cultivation of insect tolerant GM forest trees
- Two varieties planted since 2002, in seven provinces: 490 ha (= 4.9 km²) by 2011
The Power of Genomics

Predicting Outcomes
Genomic Selection: Predicting Breeding Value (BV)

Breeding populations

GEBV = genomic-estimated breeding value

90%

Training dataset

Build a model to estimate GEBVs

10%

Validating dataset

Estimate GEBVs

Accuracy

Correlation between GEBVs and standard BVs
Genomic selection accuracies within and between environments and small breeding groups in white spruce

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Abstract

Background: Genomic selection (GS) may improve selection response over conventional pedigree-based selection if markers capture more detailed information than pedigrees in recently domesticated tree species and/or make it more cost effective. Genomic prediction accuracies using 1748 trees and 6932 SNPs representative of as many distinct gene loci were determined for growth and wood traits in white spruce, within and between environments and breeding groups (BG), each with an effective size of $N_e \approx 20$. Marker subsets were also tested.
A Case Study: Genomic Selection in White Spruce

Advanced-Breeding Population

<table>
<thead>
<tr>
<th>Trait</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.80</td>
</tr>
<tr>
<td>Diameter (DBH) (cm)</td>
<td>0.84</td>
</tr>
<tr>
<td>Wood density (Kg/m³)</td>
<td>0.88</td>
</tr>
<tr>
<td>Cellulose microfibril angle (degrees)</td>
<td>0.86</td>
</tr>
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- Validates in black spruce
- We have learned how GS works and what causes it not to work
Genomics – The Promise

• Accelerate the Outputs of Breeding
• Sitka spruce in the U.K.
Goal of Tree Improvement (TI): Select, breed and propagate trees that produce higher yield or quality outputs in plantations.

Forest Genetics: Tree Improvement

Genetic gain: 10-20% per cycle
Goal of Genomic Selection: Shortening the Tree Breeding Cycles by Reducing Testing Time

Expected impact of genomics on the duration of conifer breeding cycles.

Genetic gain:
2.5 – 3 times more gain per unit of time expected in white spruce study

Conventional breeding: > 29 years
Genomic selection: < 11 years
How could predictive genomics benefit species like Sitka Spruce in the U.K.?

Productivity, sustainability and adaptation impacts:

1. Accelerate breeding – short term
2. Intensification of production – short rotations while maintaining quality
3. Sustainability from improved genetic diversity management
4. Adaptation of the forest estate to changing conditions – long term

Novel tools and capacity impacts:

1. Next generation breeding tools
2. Novel capacity from genomic resource
3. Leverage global conifer genome resources
4. Update technical and scientific know-how
Summary and Conclusions

1. TI has increased productivity very substantially

2. Breeding for forest health is challenging but knowledge in this area is progressing rapidly

3. Genomics offers powerful tools to predict the outcomes of tree breeding

4. The tools of genomics hold much promise to accelerate outputs and address sustainability challenges

5. Next generation breeding is just around the corner for conifers like Sitka spruce
Questions?
Deploying Forward Genomic Selection with Somatic Embryogenesis

OP/CP seeds produced in breeding orchards → Somatic seedlings for multiclonal forestry

Genotyping → GEBV++ → Selected somatic lines

Cryobank → Pruning cryobank 20 yrs later → Clonal testing

High-quality plantations (10+ m³/ha/yr)
General scheme of tree improvement activities leading to forestation
Sustainable Forestry: Goals and Means

- Basic knowledge
- Management practices
- Technology
- Policy
- Markets

Sustainable Forestry

Healthy Forests | Productive Forestlands | Economic Value
21\textsuperscript{st} Century Forestry: New Challenges
Sustainable Forestry

Pressure on Land

Basic knowledge

Introduced Pests

Management practices

Invasive Species

Ecosystem Services

Markets

Policy

Technology

More Responsible Use

Climate Change

Public Expectations

Globalization
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<thead>
<tr>
<th>Life Habits:</th>
<th>Long-lived</th>
<th>Short-lived</th>
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<tbody>
<tr>
<td></td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Mating System:</td>
<td>Outbred</td>
<td>Inbred</td>
</tr>
<tr>
<td>Genetics:</td>
<td>Heterozygous*</td>
<td>Homozygous</td>
</tr>
<tr>
<td>Genome:</td>
<td>Large size</td>
<td>Small size</td>
</tr>
<tr>
<td></td>
<td>Slow evolving</td>
<td>Fast evolving</td>
</tr>
<tr>
<td>Ecological role:</td>
<td>Keystone or</td>
<td>???</td>
</tr>
<tr>
<td></td>
<td>Founder species</td>
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* Nearly all trees are diploid. Heterozygous: two different variants (alleles) of a given gene.