Biotechnology and tree breeding

John MacKay
Wood Professor of Forest Science

INNOVATION FOR CHANGE
New drivers for tomorrow’s forestry

INSTITUTE OF CHARTERED FORESTERS
National Conference
Edinburgh • 2 – 3 May 2018
Eucalyptus yields from intensive Tree Improvement and silviculture

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<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>
</tr>
</tbody>
</table>
Sequencing of Forest Tree Genomes

Next Generation Sequencing Technologies

2000
- Arabidopsis
- Rice

2006
- Poplar

2012
- White spruce
- Norway spruce
- Eucalyptus
- Loblolly Pine

2016
- Oak, ash

Broadleaf trees
Conifer trees
Herbaceous plants
Outline

• Recent Developments in Forest Genomics
• Matching Technology with Needs
• Conclusions
Recent Developments in Forest Genomics

- Knowledge creation
- Research and impacts in forest productivity and health
Whole Genome Duplications (WGD) in Conifers

Ovals correspond to inferred locations of WGD events;

• black, seed plant;
• gray, angiosperm;
• purple, *Welwitschia*;
• green, Pinaceae (Pine family);
• red, cupressacea (cypress family).

Zheng Li et al. Sci Adv 2015;1:e1501084
Evolution of Disease Resistance genes

- **ANGIOSPERMS**
  - Basal Angiosperms (Amborellaceae)
  - Basal monocots (Phoenix dactylifera)
  - Rosaceae
  - Solanaceae

- **DICOTYLEDONS**
  - Basal dicotyledon (Aquilegia)
  - Rosales

- **GYMNOSPERMS**
  - Liverworts (Marchantiidae)
  - Mosses (Bryiidae)
  - Lycopodes (Lycopodiidae)
  - Ginkgo

- **MONOCOTS**
  - Poaceae

- **ASTERIDS**
  - Lamiales

- **ROSIDS**

- **T C R**
  - Pre-RNL
  - RNL ADR1-like
  - RNL NRG1-like
  - RNL gymnosperm group 1-like
  - RNL gymnosperm group 2-like
  - TNL
  - CNL or XNL

- **Emergence**
- **Loss**
Genomic Selection to Accelerate Tree Breeding

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

Genetic gain: 2.5 – 3 times more gain per year is expected (study in white spruce)

Conventional breeding: > 29 years

Genomic selection: < 11 years

First generation
4 yrs 1-2 yrs 5 yrs

Second generation
20 yrs

Third generation
5 yrs

Processes:
- Crosses
- Evaluation
- Propagation
A Case Study: Genomic Selection in White Spruce

<table>
<thead>
<tr>
<th>Trait</th>
<th>Advanced-Breeding Population</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Accuracy</td>
<td>Gain (5% S.I.)</td>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>GS</td>
<td>Conventional</td>
<td>GS</td>
<td>GS/C (%)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.80</td>
<td>0.71</td>
<td>106</td>
<td>100</td>
<td>94%</td>
</tr>
<tr>
<td>Diameter (DBH) (cm)</td>
<td>0.84</td>
<td>0.73</td>
<td>7.98</td>
<td>7.28</td>
<td>91%</td>
</tr>
<tr>
<td>Wood density (Kg/m$^3$)</td>
<td>0.88</td>
<td>0.80</td>
<td>23.8</td>
<td>21.2</td>
<td>89%</td>
</tr>
<tr>
<td>Cellulose microfibril angle (degrees)</td>
<td>0.86</td>
<td>0.77</td>
<td>2.62</td>
<td>2.48</td>
<td>95%</td>
</tr>
</tbody>
</table>

- Validates in black spruce
- We have learned the parameters that determine GS performance
Genomics Informed Breeding in Sitka Spruce
A 3 year project funded by the BBSRC
(Biotechnology and Biological Sciences Research Council of the UK)

PROJECT OVERVIEW

The Sitka Spruced project aims to create novel capacity to increase the rates of genetic gain in the UK's breeding programme. Selective breeding is effective for increasing yields in Sitka spruce but it takes 30 years to select and propagate new varieties. Sitka Spruced will develop Genomic Selection methods aiming to shorten the breeding process and increase the rate of yield gains more than two-fold. The proposed research will develop large-scale genotyping capacity, a genetic linkage map for Sitka spruce, and large training set for predictive genomics model development. We will use this platform to investigate issues of genomic prediction accuracy, models for both yield and wood quality traits, genotype imputation, resistance to damaging insects.

PROJECT PARTNERS

Sitka Spruced is a collaboration of the University of Oxford, the University of Edinburgh (Roslin Institute) and Forest Research (an Agency of the Forestry Commission). It is funded by BBSRC and a group of forest and wood processing industries.
Spruce Budworm: Resistance compounds

<table>
<thead>
<tr>
<th></th>
<th>Piceol</th>
<th>Pungenol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritability</td>
<td>0.66 ± 0.07</td>
<td>0.60 ± 0.08</td>
</tr>
</tbody>
</table>

Weevil resistance in Sitka
Predicted Ash Dieback damage scores in Great Britain and Denmark

Matching Technology with Needs

- 21st century challenges
- Forest Genetic Resources
- Other Technologies
21st Century Forestry: New Challenges

Sustainable Forestry

- Basic knowledge
- Introduced pests
- Management practices
- Invasive species
- Technology
- Policy
- Markets
- Pressure on land
- Ecosystem services
- More responsible use

Ecosystem services

21st Century Forestry: New Challenges

- Basic knowledge
- Introduced pests
- Management practices
- Invasive species
- Technology
- Policy
- Markets
- Pressure on land
- Ecosystem services
- More responsible use

Ecosystem services
Forest Genetic Resources for Resilience and Sustainability

- Species and genetic diversity are the key
- Forest Genetic Resources (FGRs)
  - Ensure adaptability
  - Need better knowledge, management, and conservation
  - Several organisations are involved
- Role of DNA databases and marker technologies
Forest Genetic Resources & DNA Markers

Species are diverse and needs are varied
- Mapping diversity, population structures, gene flow, tracing and tracking origins, conservation

Existing technologies enable:
- More efficient development of the knowledge base
- Flexible and efficient DNA testing
Other Technologies – Gene Editing

**Genetic Modification** for insect resistance by introduction of bacterial gene (Bt toxin gene)

- Control
- GM

**CRISP/Cas for Gene Editing**
- Potential for transgene-free plants
- **Trees**: demonstration studies; tests in disease resistance in poplar

[Diagram of CRISP/Cas system]
Summary and Conclusions

1. Developments in genomics: rapid changes in tree breeding and forest health research
2. Next generation breeding: UK Sitka spruce
3. Increasing focus on adaptability and resilience: new opportunities from genomic technologies
4. UK organisations working together: coordination and adoption of new methods
Questions?