Overview of the Tria Mountain Pine Beetle Project

Janice Cooke, Joerg Bohlmann and the Tria Consortium
Unprecedented spread of mountain pine beetle during the current outbreak
Unprecedented spread of mountain pine beetle during the current outbreak

Data: Little (1971); S. Taylor, G. Thandi, D. Yemshinov (Canadian Forest Service)
Mountain pine beetle range expansion into jack pine
Mountain pine beetle range expansion into jack pine

Mountain pine beetle host-range expansion threatens the boreal forest

Catherine I. Cullingham,* Janice E. K. Cooke,* Sophie Dang,* Corey S. Davis,* Barry J. Cooke† and David W. Coltman*

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doi: 10.1111/j.1365-294X.2011.05086.x
Mountain pine beetle at the leading edge of the outbreak: new surprises at every turn

Lorraine Maclauchlin, BC Ministry of Forests and Range
Rory McIntosh, Saskatchewan Environment
The Tria Project: A large-scale multidisciplinary collaborative effort

Physiological & Functional Genomics

Ecology

Population Genomics

Fungal pathogen

Pine host

MPB vector
The Tria Project: A large-scale multidisciplinary collaborative effort

Physiological & Functional Genomics

Ecology

Population Genomics

How gene products work

Genetic variation across landscapes

MPB vector

How organisms function & interact in nature

Pine host

Fungal pathogen

Janice Cooke

Jack Scott

Adrianne Rice

Mountain Pine Beetle System Genomics
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How gene products work

How organisms function & interact in nature

Stakeholders & End Users

Policy development; Forest management and spread control programme planning

Pine host

Fungal pathogen

Janice Cooke

Jack Scott

Adrianne Rice

10
Genomes and Genomic Resources

Chromosomes

Genetic linkage map (relative positions of gene-based or anonymous markers)

Genome sequence

Expressed gene sequences

...AAGAGAGCCTGTCGCTAAATGCAAGCCTTGAATCC...

(Adapted from Paul & Ferl, 2000)
Sequence data enables high-throughput analyses of many genes and/or many individuals simultaneously.

Monitoring large numbers of genes simultaneously for gene activity levels.
Sequence data enables high-throughput analyses of many genes and/or many individuals simultaneously.

Assessing genetic variation in large numbers of individuals simultaneously.

<table>
<thead>
<tr>
<th>Individuals</th>
<th>Gene Markers</th>
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The Tria Project:
A large-scale multidisciplinary collaborative effort

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University of Northern British Columbia
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Defense of Pines and other Conifers

Joerg Bohlmann and Janice Cooke
Overview: Pine and Conifer Defenses

1) Why pine trees *should* never have been attacked
2) Why pine trees *are* being killed
3) Take home message:
   - Trees and bark beetles are in a *never ending arms race*
   - Trees and bark beetles are in a state of *balanced weapons*
   - Changing environments can *disturb the balance*
Overview: Pine and Conifer Defenses

1) Why pine trees *should* never have been attacked
   - Most insects don’t eat pines

2) Why pine trees *are* being killed
   - *Tree killing bark beetles are specialists*

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1) Why pine trees *should* never have been attacked
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   - Pines can be very hostile

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   - Tree killing bark beetles are specialists, who fought for the last available seat at the table

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- Pines can be very hostile

Life as a conifer tree

- Hundreds of years with no escape
- Hundreds of years of exposure
- Need for diverse defenses
- Need for dynamic defenses
1) Why pine trees *should* never have been attacked

Most insects don’t eat pines

Pines can be very hostile

Imaginary journey as a bark beetle

- Long exhausting flight
- Solid outer wall of bark
- Minefield of traps and weapons

White spruce (*Picea glauca*, pine family)
Tristan Gillan, UBC
1) Why pine trees *should* never have been attacked

Most insects don’t eat pines

Pines can be very hostile

Imaginary journey as a bark beetle

- Long exhausting flight
- Solid outer wall of bark
- Minefield of traps and weapons

... and the same for the brood
Pine and Conifer Defenses

1) Why pine trees *should* never have been attacked

Conifer Bark is a Minefield of Traps and Weapons

- Sharp objects and shrapnels
- Chemical weapons
- Biochemical warfare

Franceschi et al. (2005)
New Phytologist 167: 353–376
Pine and Conifer Defenses

1) Why pine trees *should* never have been attacked

Conifer Bark is a Minefield – Trapped in Resin – Drowned in Turpentine

- Sharp objects and shrapnels
- Chemical weapons
- Biochemical warfare

Keeling and Bohlmann (2006)
New Phytologist 170: 657–675
Pine and Conifer Defenses

1) Why pine trees *should* never have been attacked

Conifer Bark is a Minefield – **Encoded by Pine Genes**

- Sharp objects and shrapnels
- Chemical weapons
- Biochemical warfare

Keeling and Bohlmann (2006)
New Phytologist 170: 657–675
Pine and Conifer Defenses

2) Why pine trees *are* being killed

**Tree killing bark beetles are specialists**
- Exhaust tree defenses by mass attack
- Turn pine defenses into beetle perfumes
- Use the help of fungi
Overview: Pine and Conifer Defenses

1) Why pine trees should never have been attacked
   Most insects don’t eat pines
   Pines can be very hostile

2) Why pine trees are being killed
   Tree killing bark beetles are specialists, who fought for the last available seat at the table

3) Take home message
   ● Trees and bark beetles are in a never ending arms race
   ● Trees and bark beetles are in a state of balanced weapons
   ● Changing environments can disturb the balance
Overview: Pine and Conifer Defenses

**Efficacy of tree defense physiology varies with bark beetle population density: a basis for positive feedback in eruptive species**

Celia K. Boone, Brian H. Aukema, Jörg Bohlmann, Allan L. Carroll, and Kenneth F. Raffa

Canadian Journal of Forest Research 41: 1174-1188 (2011)

**Take home message**

- Trees and bark beetles are in a *never ending arms race*
- Trees and bark beetles are in a state of *balanced weapons*
- Changing environments can *disturb the balance*
Factors Affecting Pine Defense against MPB

Janice Cooke and Joerg Bohlmann
Mountain pine beetles overcome pine defenses through mass-attack

This part of the curve is affected by host genetics and environment.
Mountain pine beetles overcome pine defenses through mass-attack

Environment: Stressed trees seem to be favourite targets under lower MPB attack densities, while healthy trees appear to be favoured under higher MPB densities.
Getting a handle on genetic variation in defense: do lodgepole pine and jack pine defenses differ?
Measuring the effect of climate on defense: does drought affect pine defenses?

Climate Moisture Index (Hogg, 1997) output using BioSim (Barry Cooke)
### Dissecting pine defense responses

#### Growth chamber studies
- lodgepole & jack pine seedlings

#### Mature tree field studies
- Hybrids, lodgepole & jack pine

<table>
<thead>
<tr>
<th>Species</th>
<th>Water availability</th>
<th>Inoculation treatment</th>
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<tbody>
<tr>
<td>Lodgepole pine</td>
<td>Well watered</td>
<td>Wound (seedlings only)</td>
</tr>
<tr>
<td>Jack pine</td>
<td>Water deficit</td>
<td>Wound/Inoculation with MPB fungus</td>
</tr>
<tr>
<td>Hybrids</td>
<td></td>
<td>Control</td>
</tr>
</tbody>
</table>

- **Water availability**
  - Well watered
  - Water deficit

- **Inoculation treatment**
  - Wound (seedlings only)
  - Wound/Inoculation with MPB fungus
  - Control
Water deficit causes lodgepole and jack pine to close their stomata.

**Lodgepole pine**

![Graph showing gs (mmol m⁻² s⁻¹) for Lodgepole pine on Day 14 and Day 28.]

**Jack pine**

![Graph showing gs (mmol m⁻² s⁻¹) for Jack pine on Day 14 and Day 28.]

Legend:
- **Well watered**
- **Water deficit**
Water deficit reduces photosynthesis in lodgepole and jack pine, decreasing carbon gain.
Lesion development differs in lodgepole and jack pine, and is also affected by drought.

**Seedlings**

- **Lodgepole**
  - Well Watered
  - Water Deficit

- **Jack**
  - Well Watered
  - Water Deficit

**Mature trees**

- **Lodgepole**
  - Well Watered
  - Water Deficit

- **Jack**
  - Well Watered
  - Water Deficit

Lesion development differs in lodgepole and jack pine, and is also affected by drought.
Drought affects gene expression associated with both pre-formed and induced defenses.

**Pbc chitinase2.1**

![Bar chart showing gene expression levels for Pbc chitinase2.1 under well watered and water deficit conditions, with significant changes indicated by p-values: Water p=0.0008, Fungi p=0.08, W*F p=0.73.]

**Pbc(+)-3-carene-synthase**

![Bar chart showing gene expression levels for Pbc(+)-3-carene-synthase under well watered and water deficit conditions, with significant changes indicated by p-values: Water p=0.01, Fungi p=0.002, W*F p=0.26.]

**Pbc chitinase1**

![Bar chart showing gene expression levels for Pbc chitinase1 under well watered and water deficit conditions, with significant changes indicated by p-values: Water p=0.0006, Fungi p<0.0001, W*F p=0.005.]

**Pbc(E)-β-farnesene-synthase**

![Bar chart showing gene expression levels for Pbc(E)-β-farnesene-synthase under well watered and water deficit conditions, with significant changes indicated by p-values: Water p=0.01, Fungi p=0.02, W*F p=0.49.]

*Increased constitutive expression*

*Decreased induced expression*

**Lodgepole pine**
- Jasmonic acid (ng/g FW): n.d.
- Salicylic acid (ng/g DW): 200-400

**Jack pine**
- Jasmonic acid (ng/g FW): n.d.
- Salicylic acid (ng/g DW): 50-100

*Well watered vs. Water deficit*
In progress: analyses to look at networks of gene expression in these experiments

Lodgepole Pine
Inoculated vs control &
Inoculated vs wounded

- Well Watered
- Water Deficit

Jack Pine
Inoculated vs control &
Inoculated vs wounded

- Well Watered
- Water Deficit

<table>
<thead>
<tr>
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<th>Water Deficit</th>
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Summary

- Trees and bark beetles are in a *never ending arms race*

- Trees and bark beetles are in a state of *balanced weapons*

- Changing environments can *disturb the balance*

- How will the arms race play out as beetles continue to move into novel habitats?
Acknowledgements

Adriana Arango
Celia Boone
Charles Copeland
Leonardo Galindo
Dawn Hall
Miranda Meents
Dominik Royko

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