Causes and consequences of mountain pine beetle outbreaks: from genes to ecosystems
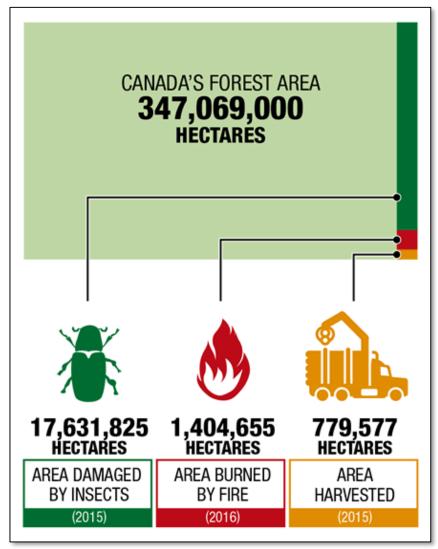
Patrick M. A. James

Université de Montréal
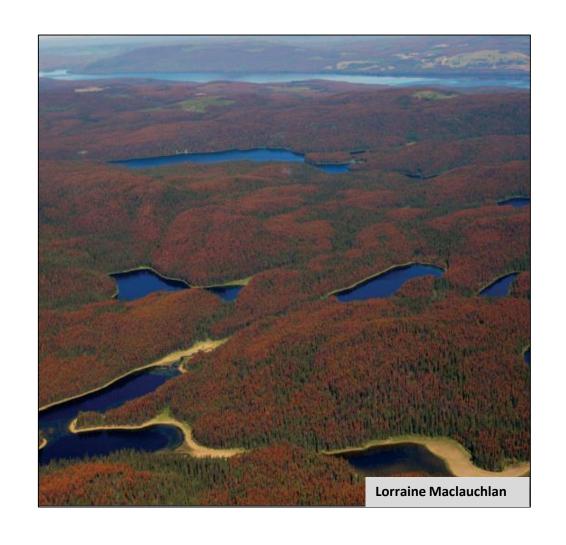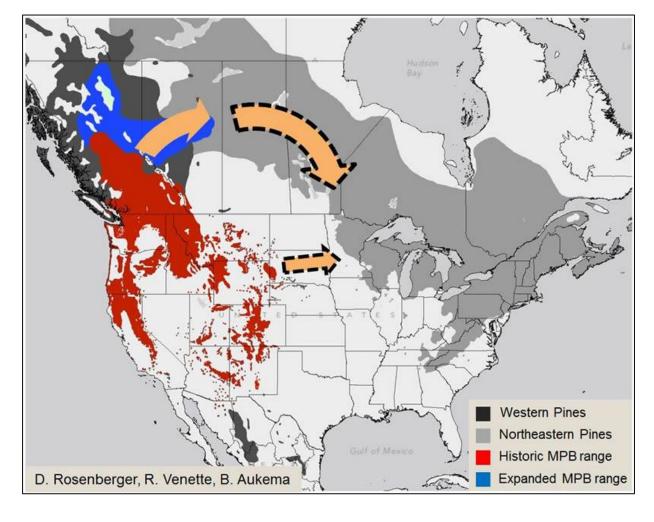
Forest health and disturbance

CANADA'S FOREST AREA
347,069,000
HECTARES

17,631,825
HECTARES

AREA DAMAGED
BY INSECTS
(2015)

1,404,655
HECTARES

AREA BURNED
BY FIRE
(2016)

779,577
HECTARES

AREA
HARVESTED
(2015)

Mountain Pine Beetle
> 18 × 10^6 ha affected in Canada; > 6 × 10^6 ha in the USA

Lorraine Maclauchlan

D. Rosenberger, R. Venette, B. Aukema

Western Pines
Northeastern Pines
Historic MPB range
Expanded MPB range

Mountain pine beetle outbreaks are episodic and natural

Alfaro et al 2009

Dendroctonus ponderosae

Forest health and disturbance

- **Outbreaks of native forest insects are an important agent of disturbance in the boreal forest**

Forest health and disturbance

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- However… the current MPB outbreak is larger than ever observed and the species appears to be undergoing a range expansion

- Climate change and the legacies of forest management are the likely cause (Raffa et al 2008; Bioscience)

Forest health and disturbance

- **Outbreaks of native forest insects are an important agent of disturbance in the boreal forest**

- However… the current MPB outbreak is larger than ever observed and the species appears to be undergoing a range expansion

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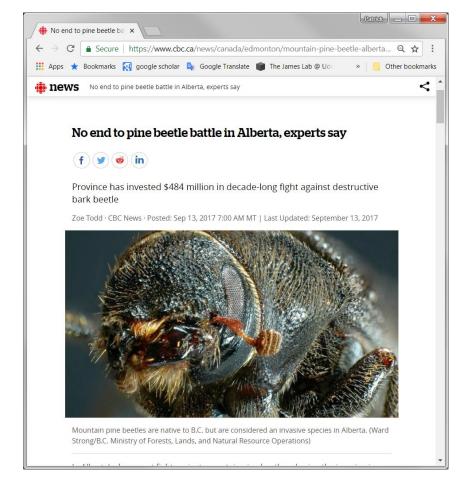- Downstream effects on timber, forest succession, carbon, fire risk, water quality, and **biodiversity** …
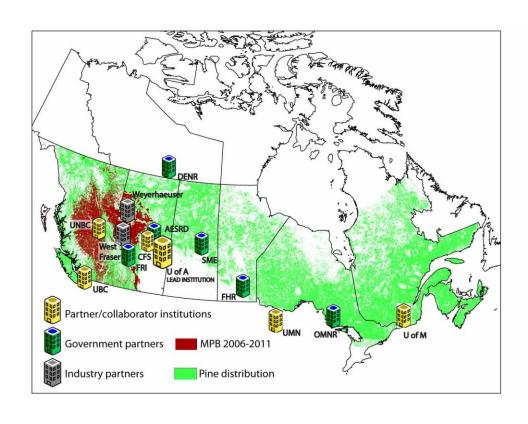
Forest insect outbreaks are costly

- ~ $500 million invested so far in Alberta to combat the MPB

- Estimated cumulative loss equal to ~$57 billion from 2009 to 2054 in British Columbia
  - Corbett et al 2015; *Forestry*

- Current spruce budworm outbreak in NB is expected to result in losses between $5 and $7 billion over the next 40 years
  - Healthy Forest Partnership, NB. 2017

- Similar losses expected in Quebec
  - Chang et al 2012; *CJFR*

No end to pine beetle battle in Alberta, experts say

Province has invested $484 million in decade-long fight against destructive bark beetle

Zoe Todd · CBC News · Posted: Sep 13, 2017 7:00 AM MT | Last Updated: September 13, 2017

Mountain pine beetles are native to B.C. but are considered an invasive species in Alberta. (Ward Strong/B.C. Ministry of Forests, Lands, and Natural Resource Operations)
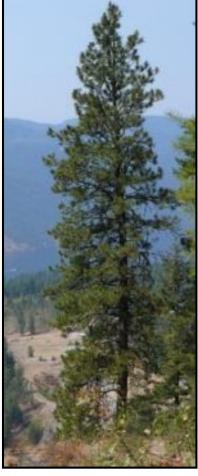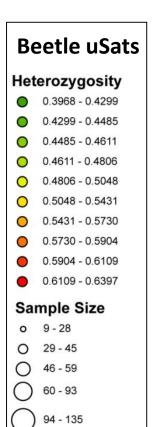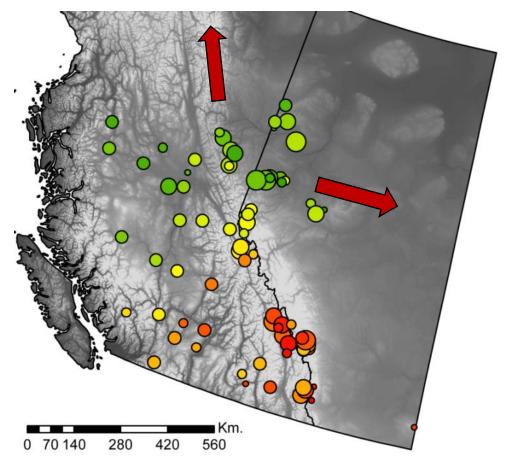
Mountain Pine Beetle Outbreak System
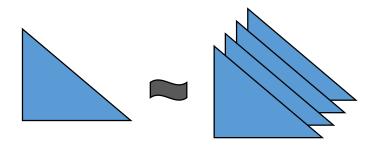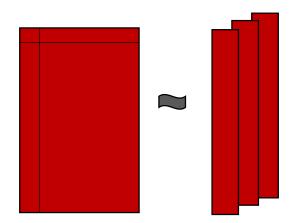
Ongoing Range Expansion

Landscape Genetics / Genomics

- **Landscape Genetics**: Combination of landscape ecology, spatial statistics, and population genetics to examine how **spatial heterogeneity** affects **gene flow and dispersal** (Manel *et al.* 2003).
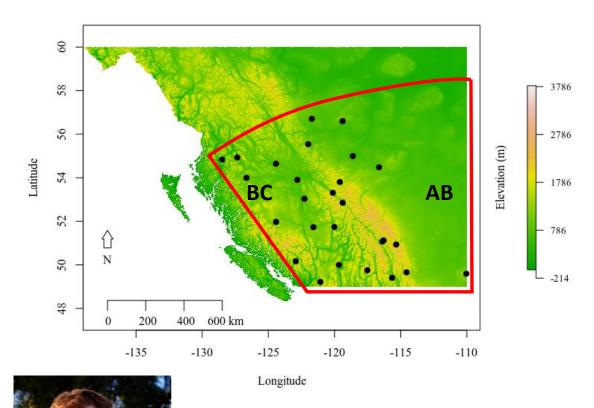
- **Landscape Genomics**: Combination of landscape ecology, spatial statistics, and population genomics to examine how **spatial heterogeneity** affects spatial patterns in **adaptive genetic variation**.

MPB Landscape Genetics

Julian Wittische

- **Question : What environmental features influence MPB genetic connectivity and gene flow?**

- Addressed using **532** beetles sequenced at **764** SNP loci (*Illumina GoldenGate*) collected from **27** sites across AB and BC.

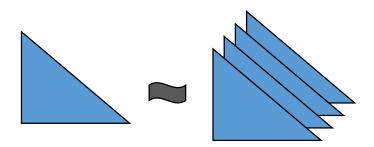- Predictors examined : elevation, pine volume, drought, and climate suitability

Why do we care about MPB movement?

- Movement is a fundamental but poorly understood aspect of MPB biology

- Understanding which landscape features **hinder** or **facilitate** MPB movement can help us develop and inform better spatial tools to **forecast** outbreak dynamics.

- Forecasting can help managers to **reduce risk** and limit the impacts of the outbreak on the economy and **ecosystem services**.
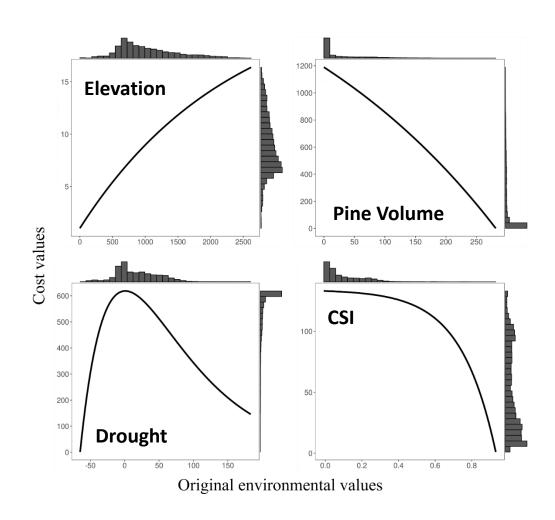
Specifying resistance surfaces is challenging

- **Modelling spatial environmental effects on gene flow requires specification of genetic and GEOGRAPHIC ecological distance matrices**

- Forms of relationships between landscape values of resistance to movement is typically unknown (Spear et al 2010)

- How to choose costs appropriately without *a priori* knowledge?
  - *Linear mixed effects model with a maximum likelihood population effects (**MLPE**)*
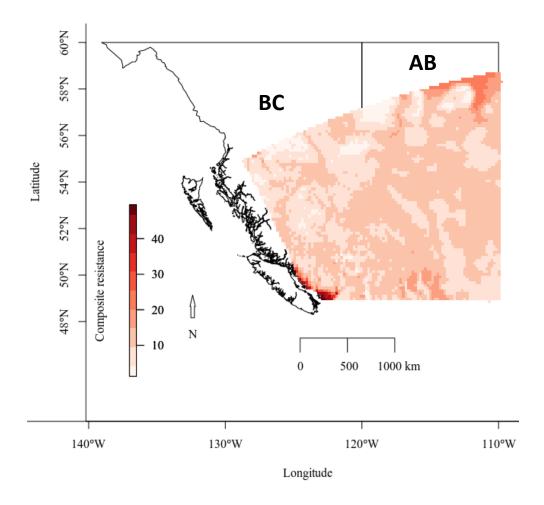 - *Machine Learning / Genetic Algorithms*
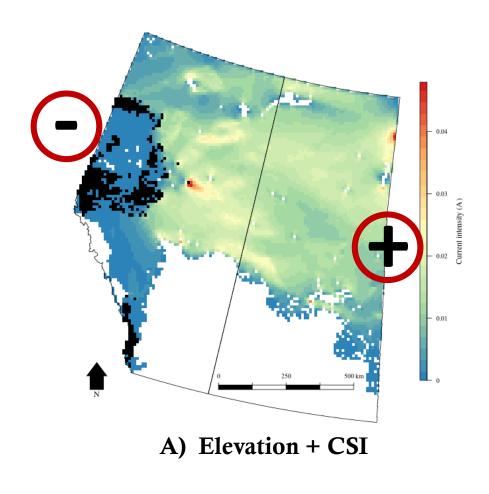
Single surface optimizations

- These curves represent the optimized functional relationships between each spatial variable and resistance to gene flow (movement) based on our SNP data set
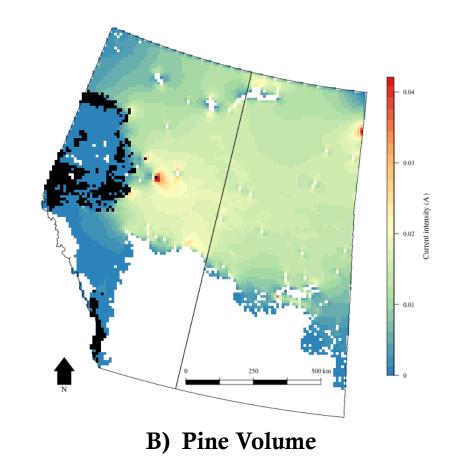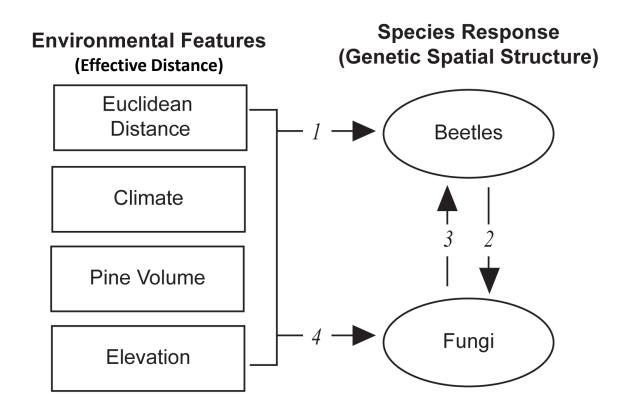
Optimized "best" composite surface

- **Elevation + Climate Suitability**

- Weighting: 69% climate; 31% elevation

- Large islands of less resistance

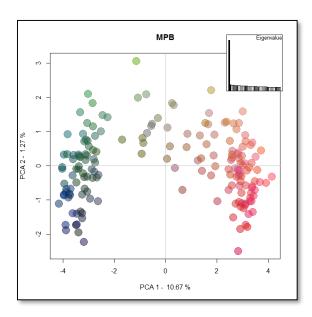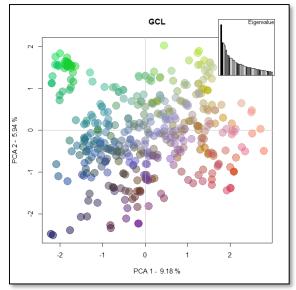- Cost heterogeneity decreases eastward: consequences for expansion?

Forecasting future spread risk using circuit theory...

A) Elevation + CSI

B) Pine Volume

Integrated landscape genetics

Environmental Features
(Effective Distance)

Species Response
(Genetic Spatial Structure)

James PMA *et al.* 2011. Spatial genetic structure of a symbiotic beetle-fungal system: Toward multi-taxa integrated landscape genetics. PLoS ONE 6(10): e25359

Integrated landscape genetics

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system: Toward multi-taxa integrated landscape genetics. PLoS ONE 6(10): e25359

Integrated landscape genetics

Environmental Features
(Effective Distance)

- Euclidean Distance
- Climate
- Pine Volume
- Elevation

Species Response
(Genetic Spatial Structure)

- Beetles
- Fungi

James PMA *et al*. 2011. Spatial genetic structure of a symbiotic beetle-fungal system: Toward multi-taxa integrated landscape genetics. PLoS ONE 6(10): e25359
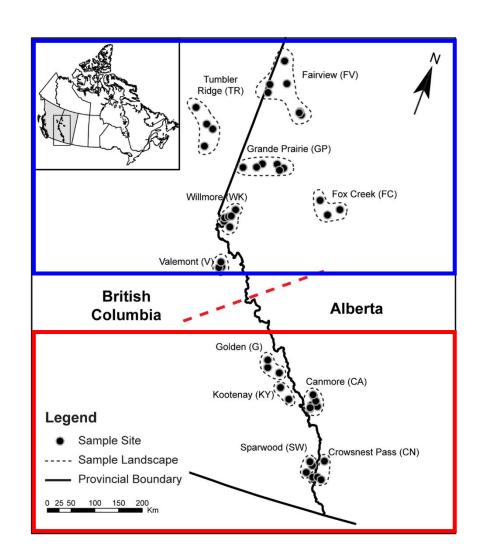
Landscape Community Genomics

Ecology, 84(3), 2003, pp. 559–573
© 2003 by the Ecological Society of America

COMMUNITY AND ECOSYSTEM GENETICS: A CONSEQUENCE OF THE EXTENDED PHENOTYPE

THOMAS G. WHITHAM,[1,3,6] WILLIAM P. YOUNG,[1,3] GREGORY D. MARTINSEN,[1,3] CATHERINE A. GEHRING,[1,3] JENNIFER A. SCHWEITZER,[1,3] STEPHEN M. SHUSTER,[1,3] GINA M. WIMP,[1,3] DYLAN G. FISCHER,[2,3] JOSEPH K. BAILEY,[1,3] RICHARD L. LINDROTH,[4] SCOTT WOOLBRIGHT,[1,3] AND CHERYL R. KUSKE[5]

OPEN ACCESS Freely available online   PLoS one

Spatial Genetic Structure of a Symbiotic Beetle-Fungal System: Toward Multi-Taxa Integrated Landscape Genetics
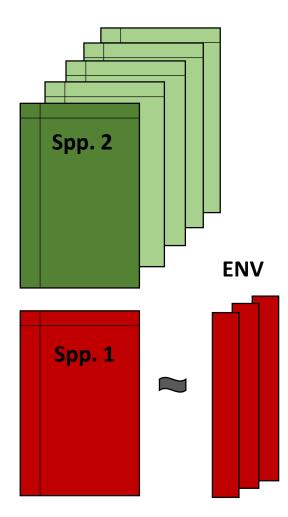
Patrick M. A. James[1*¤], Dave W. Coltman[1], Brent W. Murray[2], Richard C. Hamelin[3,4], Felix A. H. Sperling[1]

October 2011 | Volume 6 | Issue 10 | e25359

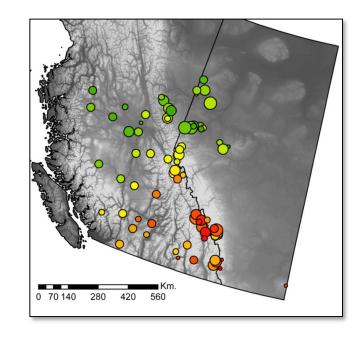## Landscape community genomics: understanding eco-evolutionary processes in complex environments

Brian K. Hand[1*], Winsor H. Lowe[2*], Ryan P. Kovach[1,3], Clint C. Muhlfeld[3], and Gordon Luikart[1]
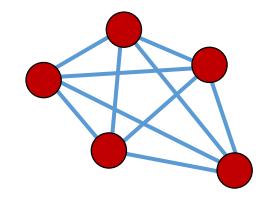
Trends in Ecology & Evolution   March 2015, Vol. 30, No. 3

Landscape Community Genomics

- Can we identify groups of potentially adaptive loci *among species* that cluster together?

- Search for **OUTBREAK SYNDROMES**

   ➔ **spatially structured**, inter-species associations of putatively adaptive alleles.
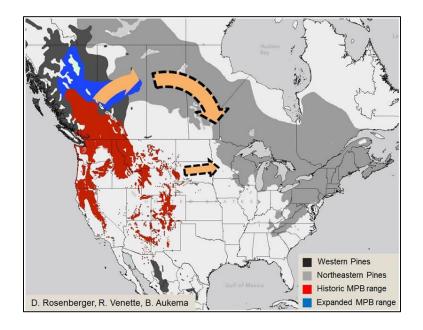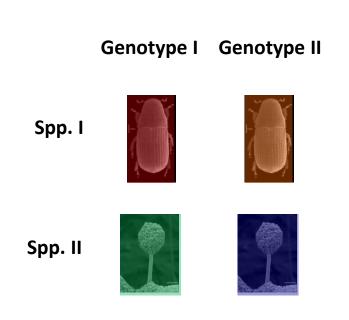

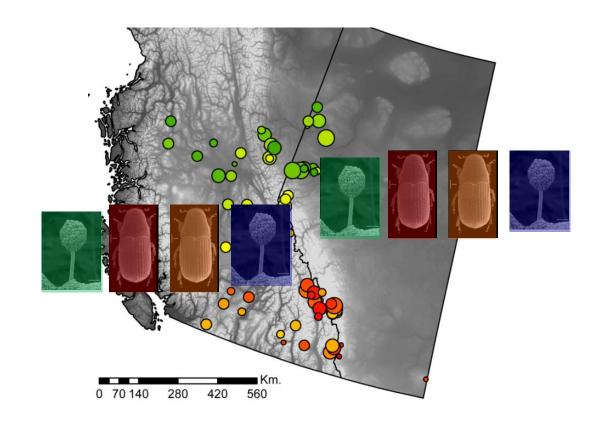**ADAPTIVE* VARIATION**

Landscape Community Genomics

Why do we care?

- Our goal is to improve understanding of spatial eco-evolutionary community and population dynamics of **outbreaks** and **range expansions**.

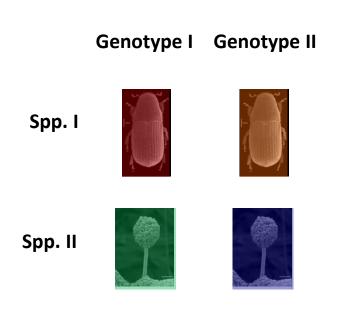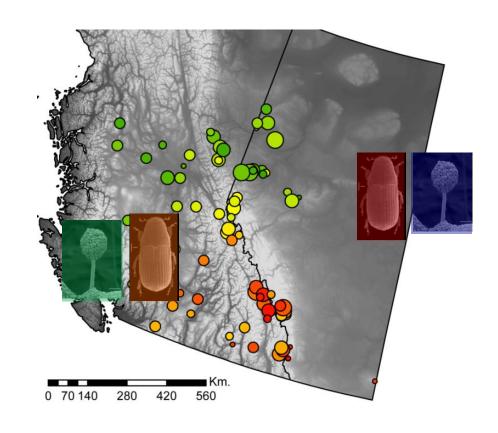 - Is rapid co-evolution driving system dynamics and outbreak expansion?

Legend:
- Western Pines
- Northeastern Pines
- Historic MPB range
- Expanded MPB range

D. Rosenberger, R. Venette, B. Aukema
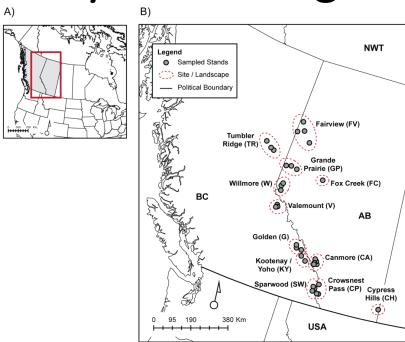
MPB Landscape Community Genomics

MPB Landscape Community Genomics

Study area and genomic data

A)

B)

- Samples collected in **2007/2008**
- Sequenced using Illumina (MPB) / Sequenome (fungi)
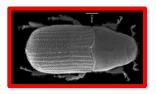- For beetle data, see Janes et al 2014. MBE

BEETLE
- *D. ponderosae* (MPB)
  - **175** individuals; **1532** loci

FUNGI
- *G. clavigera* (GCL)
  - **142** individuals; **242** loci
- *L. longiclavatum* (LLO)
  - **140** individuals; **254** loci
- *O. montium* (OMO)
  - **88** individuals; **112** loci

PINE
- *P. contorta* (LPP)
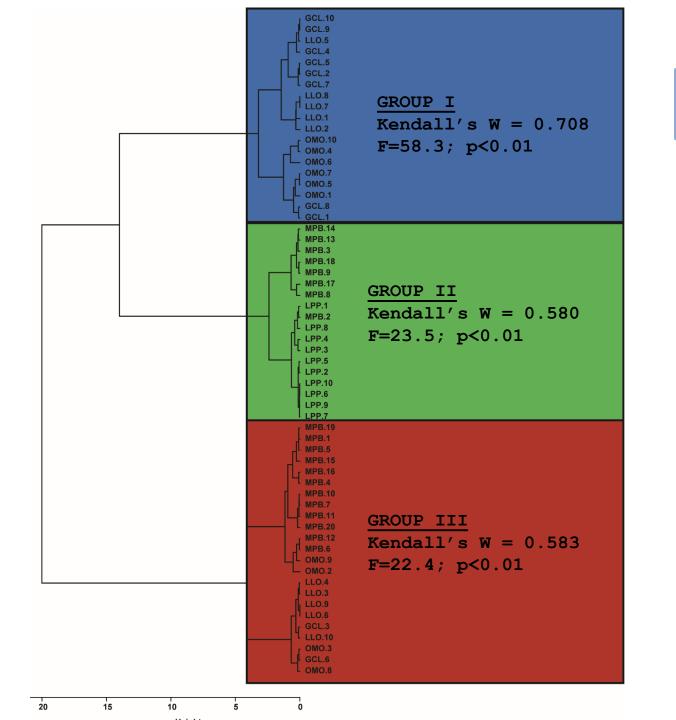 - **278** individuals; **367** loci

Analysis pipeline

1. Start with community genotypic data (SNPs).

2. Identify outlier loci using **Latent Factor Mixed Models** (Frichot et al 2015).

   - **Response**: top 10 putatively adaptive loci for each species (MPB = 20)
   - **Predictor**: Latitude*
   - *K*s (latent factors) selected on the basis on min. cross-entropy (**LEA**).

3. Merge individual species tables into a to single **genomic community** table

4. Cluster outlier loci based on frequency of co-occurrence among sites.

5. Assess significance of co-occurring loci clusters using *Kendall's W*.

   - Legendre 2005. Species Associations: The Kendall coefficient of Concordance Revisited. Journal of Agricultural, Biological, and Environmental Statistics. 10(2): 226-245.

6. Assess geographical distribution of clusters using PCA.

GROUP I
Kendall's W = 0.708
F=58.3; p<0.01

GROUP II
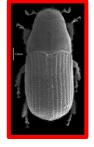Kendall's W = 0.580
F=23.5; p<0.01

GROUP III
Kendall's W = 0.583
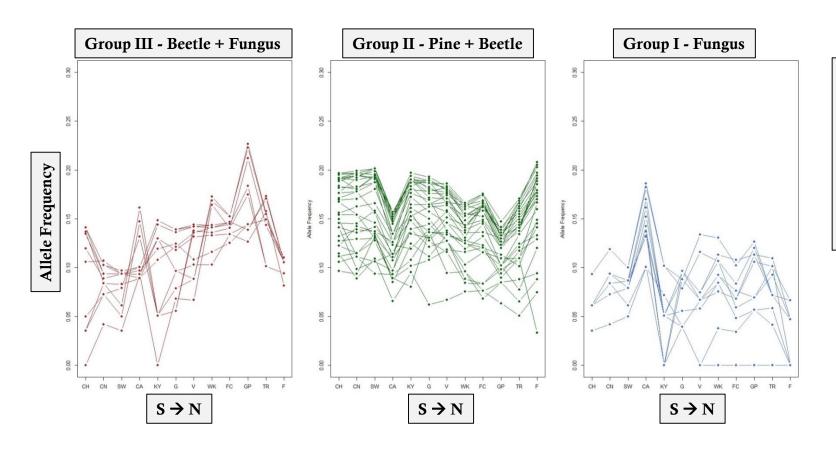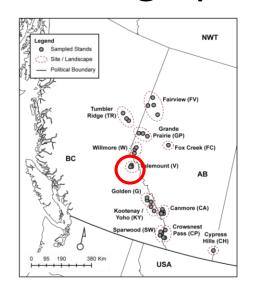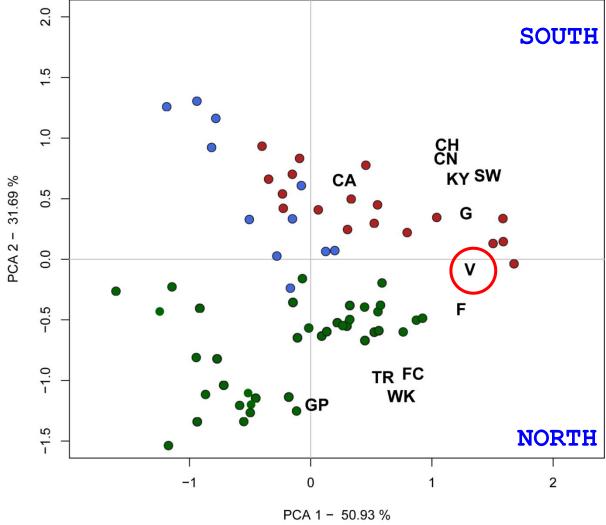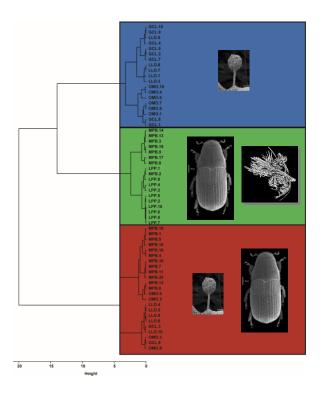F=22.4; p<0.01

Cluster behaviours (latitude)

- Tendencies in allele frequencies of the three adaptive groupings plotted against sites sorted from South to North
- Different patterns are what the clustering algorithm is picking up

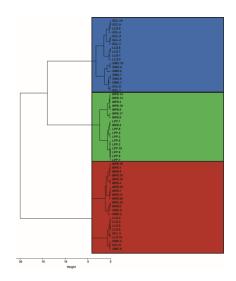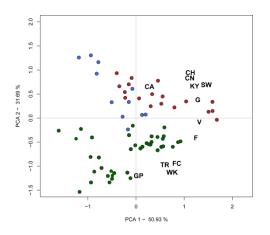# Geographic association of clusters?

Interpretations

1. We identified significant **inter** and **intra**-specific clusters of outlier loci at the community level.

2. These clusters show some fidelity to known expansion axes.

3. **Outbreak expansion *may* be in part due to spatial evolutionary dynamics among species.**

4. This community-genomics framework can be applied to other multi-taxa systems to better understand adaptive dynamics during outbreaks and range expansions.
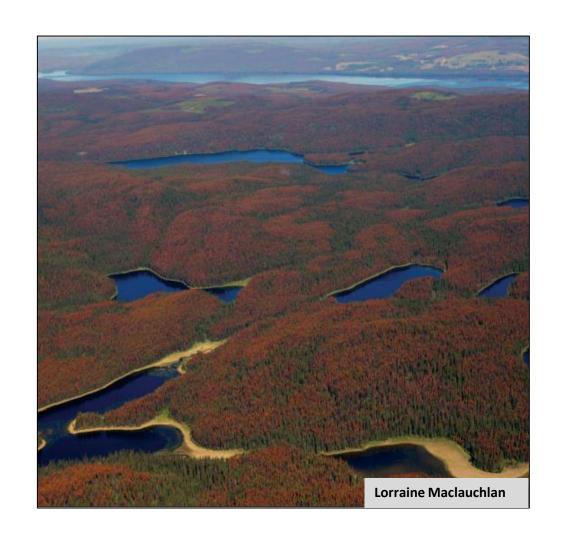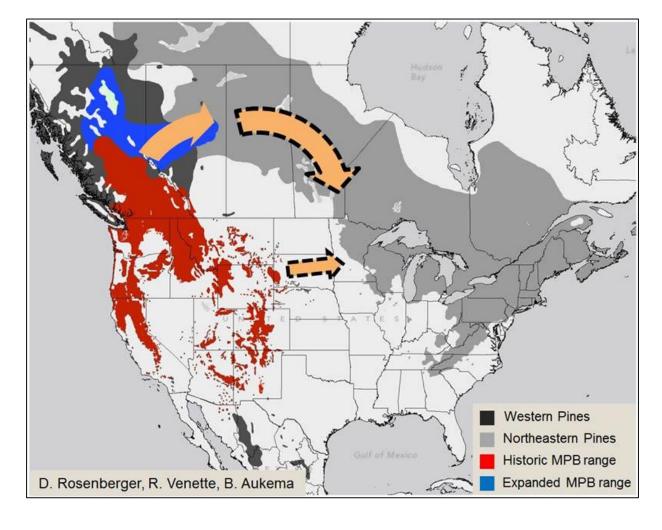
Caveats

- We don't know if the loci we used are really "**adaptive**".
  - Further functional characterization is still required to identify specific roles.
- Identifying loci under selection during range expansions can be biased due to allele surfing.
- Correlative results; we don't yet know the eco-evolutionary mechanisms connecting allele frequencies among species.
- We have not distinguished yet between simple induced spatial dependence vs species interactions...
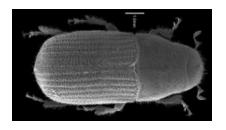
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Acknowledgements

- TRIA Net team
- Cathy Cullingham (UofA)
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- Jasmine Janes (UofA)
- Julian Wittische (UdeM)

NSERC CRSNG

TRIA-Net
Turning Risk Into Action for the Mountain Pine Beetle Epidemic

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