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Integrated Population Genomics of the Mountain Pine Beetle System

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MPB System
MPB System

- Complex and dynamic system controlled by multiple factors at multiple scales
- Multiple interacting species
- What are the similarities and differences in their responses to spatial heterogeneity?
- What do genomic interactions among taxa and landscape features mean to future outbreaks?
Outline

• MPB - Isolation by Distance
  • Geographical genetics
  • Mantel test – Euclidean distance
• MPB - Isolation by Resistance
  • Landscape genetics
  • Partial Mantel tests - Effective distance / resistance surfaces
• Integrated Genomic Landscape Map
  • Genetic information as resistance surface
• MPB Sex-Ratio Variability
Spatial Genetic Variation

MPB Heterozygosity

- What drives observed MPB genetic structure?
  - Distance (IBD)
  - Landscape features?
- Do intervening landscape features affect genetic connectivity?
- What does this mean for beetle dispersal and outbreak spread?
Elevation
(1:250 000 DEM)

Legend
- MPB Sample Sites

Elevation
- High
- Low

Kilometers
0 75 150 300 450 600
MPB Climatic Suitability Index (1970-2000)

Legend
Sample Sites

CSI
- Very Low
- Low
- Moderate
- High
- Extreme

Carroll et al. 2003
Because we are examining neutral variation (i.e., microsatellites) we are interested in the features between sampling locations (Nodes) rather than environmental variation at the sampling locations (Links).
Mantel Test

• Tests for significant correlation between distance matrices.

→ Are genetic distances correlated with Euclidean spatial distances?

Genetic Distances ($D_S$)                  Spatial Distances
Euclidean Distance

$D_{Eucl} = \sum_{i=1}^{j} d_i$

$\Rightarrow D_S \sim D_{Eucl}$
Complete Graph
Minimum Planar Graph
Mantel Results

Euclidean vs. Genetic Distance (Ds)

Mantel’s $r$: 0.7880
$p < 0.0001$
Partial Mantel Test

• Tests for significant correlation between distance matrices while accounting for the influence of a third matrix.

→ Are genetic distances correlated with effective (cost) distances when Euclidean distances are removed?

<table>
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<tr>
<th>Genetic Distances ($D_s$)</th>
<th>Cost Distances</th>
<th>Spatial Distances</th>
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Effective Distance

\[ D_{\text{Eff}} = \sum_{i=1}^{j} d_i w_i \]

\[ \Rightarrow D_S \sim D_{\text{Eff}} \ | \ D_{\text{Eucl}} \]
Partial Mantel Results

Elevation vs. Genetic Distance

Mantel’s $r$: 0.2729
$p < 0.0001$

CSI vs. Genetic Distance (Ds)

Mantel’s $r$: 0.2193
$p < 0.0001$

Pine vs. Genetic Distance (Ds)

Mantel’s $r$: 0.0575
$p = 0.0854$
Partial Mantel Results

• Positive correlation between genetic and effective distances
  – Sites separated by high cost are less genetically similar

• Significant effect of Elevation and CSI

• Positive, but non-significant influence of pine

• Parameterization of cost surfaces is not trivial
  – Relative values?
  – Integrated cost surfaces?
  – Landscape + Genetic features.
Circuit theory to assess landscape connectivity

- Calculates “flow” of current between pairs of nodes.
- Transition from linear links to more realistic two-dimensional paths.
- Can identify potential dispersal corridors.
- Integrated resistance surfaces?
Integrated Landscape Genomics

• Are fungal and pine spatial structure affected by the same features as MPB?
• Does genetic information from fungi and pine help explain the genetic structure of MPB?
• Genetic structure of MPB, fungi, and pine as resistance surfaces
  – “Genetic Resistance Topographies”
  – Does the genetic structure in the other species facilitate or impede MPB dispersal among populations?
  – How does connectivity among fungal and MPB populations vary as a function of pine?
Further Work

- Identify markers under selection; adaptive variation
- Spatially explicit modelling of interactions among species genetic structure and landscape heterogeneity
  - Landscape Genomics
  - SNPs
- Genomics-enhanced MPB and pine fitness surfaces
- Genomics-informed parameters for forecasting future outbreak risk
Spatial Variation in MPB Sex-Ratio
Importance of understanding sex-ratio

• Application to economic and ecological risk models.
• Sex-ratio influences effective population size and hence rate of population growth.
• Novel opportunity to examine sex-ratio variability in an outbreaking forest pest insect.
Role of Tree Size? Outbreak Stage?

Figure 17.—Change in percent female of mountain pine beetle populations for the two extremes in lodgepole pine diameter classes during the life of an infestation, Wasatch-Cache National Forest, Utah.

Amman and Cole 1983
Modelling Framework

• Logistic Mixed-Effects Model
• Determine probability of male or female under different conditions.
• Fixed Effects
  – DBH
  – Host type (Lodgepole vs. hybrid)
• Random Effects
  – Site, Tree
• Control for larval instar
Initial Results

- SEX ~ DBH + Host + (1|SITE)

Fixed effects:

|                | Estimate | Std. Error | z value | Pr(>|z|) |
|----------------|----------|------------|---------|----------|
| (Intercept)    | 1.066836 | 0.184695   | 5.776   | 7.64e-09 *** |
| DBH            | -0.015318| 0.005583   | -2.744  | 0.00608 **  |
| HOST           | -0.059315| 0.087288   | -0.680  | 0.49680   |

- Globally, larger trees produce fewer females
- Host does not influence sex ratio
Further Work

• Inclusion of additional predictors
  – Outbreak status
  – Further forest composition data
• Sex-ratio skew as indicator of developing outbreak?
• Influence of tree and fungal genomics
• Integration of sex-ratio dynamics and genomics-enhanced risk models to forecast future outbreak potential