Spatial heterogeneity in landscape structure influences dispersal and genetic structure: empirical evidence from a grasshopper in an agricultural landscape

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Landscape connectivity

• The degree to which the landscape facilitates or impedes movement (Taylor et al. 1993)
  – Structural connectivity: the spatial structure of a landscape
  – Functional connectivity: the response of individuals to landscape features

Important to assess for conservation and management of biodiversity in fragmented landscapes
Landscape genetics
A framework to study connectivity (Manel et al. 2003)

- Individual-based sampling / analyses
- Discriminate between the effect of:
  - Geographic distance
  - Isolation-by-distance (Rousset 2000)
  - Landscape boundaries
  - Isolation-by-barrier
  - Clustering methods (Geneland/Structure/DAPC)

Landscape structure and environmental features

Genetic diversity, differentiation and contemporary gene flow
Landscape genetics
A framework to study connectivity (Manel et al. 2003)

Computer simulations (Epperson et al. 2010)

- IBDsim (Leblois et al. 2009)
- CDpop (Landguth et al. 2010)

- Compare statistical methods and investigate ability/power to
detect landscape genetics relationships: sample size/markers… (Landguth et al. 2012)
- Applications to real systems
  - Determine contemporary vs historical isolating events (+ lag time)
  - Understanding causal relationships between landscape resistance and dispersal (Landguth et al. 2010)

Context of the study
Pezotettix giornae

- Small-sized unwinged grasshopper (reduced dispersal capacities).
- A single generation each year
- subservient to grassland habitats for reproduction (Hill & al., 1995).

- How landscape heterogeneity affects P. giornae gene flow?
- How this species subsist in farmlands in the context of agricultural intensification?

- Loss of grassland habitats and their connectivity (Benton 2003)
- Intensification of agricultural practices (eg, artificial/temporary grasslands)
Aim of the study

1) Assess the influence of landscape structure and grasslands characteristics on *P. giornae* dispersal and gene flow

2) Assess the scale of spatial and genetic structure of *P. giornae* to gain insight on its dispersal patterns in farmlands

Material

- 11 microsatellites loci
- Individual based sampling: -> 377 individuals from 190 grasslands
- Genetic sampling
  - 11 microsatellites loci
Results
Microsatellites characteristics

<table>
<thead>
<tr>
<th>Locus</th>
<th>A</th>
<th>He</th>
<th>Ho</th>
<th>Fis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pezo_3</td>
<td>3</td>
<td>0.152</td>
<td>0.085</td>
<td>0.439***</td>
</tr>
<tr>
<td>Pezo_8</td>
<td>2</td>
<td>0.417</td>
<td>0.592</td>
<td>0.419***</td>
</tr>
<tr>
<td>Pezo_9</td>
<td>3</td>
<td>0.241</td>
<td>0.111</td>
<td>0.538***</td>
</tr>
<tr>
<td>Pezo_13</td>
<td>2</td>
<td>0.473</td>
<td>0.366</td>
<td>0.227***</td>
</tr>
<tr>
<td>Pezo_19</td>
<td>2</td>
<td>0.223</td>
<td>0.207</td>
<td>0.07†</td>
</tr>
<tr>
<td>Pezo_24</td>
<td>3</td>
<td>0.264</td>
<td>0.043</td>
<td>0.839***</td>
</tr>
<tr>
<td>Pezo_27</td>
<td>2</td>
<td>0.307</td>
<td>0.271</td>
<td>0.116**</td>
</tr>
<tr>
<td>Pezo_29</td>
<td>6</td>
<td>0.304</td>
<td>0.311</td>
<td>-0.024†</td>
</tr>
<tr>
<td>Pezo_31</td>
<td>3</td>
<td>0.482</td>
<td>0.264</td>
<td>0.453***</td>
</tr>
<tr>
<td>Pezo_32</td>
<td>3</td>
<td>0.494</td>
<td>0.501</td>
<td>-0.016†</td>
</tr>
<tr>
<td>Pezo_37</td>
<td>2</td>
<td>0.497</td>
<td>0.449</td>
<td>0.096</td>
</tr>
</tbody>
</table>

- Low levels of genetic diversity (from 2 to 6 alleles per locus)
- Overall heterozygosity deficit (Fis = 0.169)
- Presence of null alleles (Dakin & Avise 2004; Chapuis et al. 2005)
  - At 6 loci
- Spatial genetic structure

Results
Spatial genetic structure

Bayesian genetic clustering (Geneland, Guillot et al. 2005)

- Correlated allele frequencies model + presence of null alleles

- Medium differentiation prior
- No prior
- Low differentiation prior

- 2 genetic clusters separated by the linear hedged farmland
  - 90% individuals unambiguously assigned to their cluster

- A third cluster not strongly supported
  - No individuals unambiguously assigned to the 2 Western clusters
Results
Spatial genetic structure

- 40 – 90 generations
- $H_0 = 0.88$
- $Fst = 0.0019$

- 30 generations
- $H_0 = 0.3$
- $Fst = 0.007^{**}$

Results
Bayesian genetic clustering (Geneland, Guillot et al. 2005)

- $Fst = 4.5\%$
- Individuals from the linear hedged farmland mainly assigned to the Eastern cluster (70\%)

Isolation-by-distance (IBD)

- Genetic differentiation increases with distance
- IBD can generate erroneous inference of genetic clusters (Guillot & Santos 2008)
### Results

#### Landscape characteristics

<table>
<thead>
<tr>
<th></th>
<th>Western side</th>
<th>Hedgered farmland</th>
<th>Eastern side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassland</td>
<td>~ 10 %</td>
<td>~ 25 %</td>
<td>~ 10 %</td>
</tr>
<tr>
<td>Grassland &lt;2 years</td>
<td>43 %</td>
<td>33 %</td>
<td>52 %</td>
</tr>
<tr>
<td>Permanent Grassland</td>
<td>32 %</td>
<td>45 %</td>
<td>23 %</td>
</tr>
<tr>
<td>Distance among 10 closest grassland (m)</td>
<td>340</td>
<td>240</td>
<td>445</td>
</tr>
<tr>
<td>Hedgerow index</td>
<td>~ 3</td>
<td>~ 10</td>
<td>~ 2</td>
</tr>
</tbody>
</table>

- The linear hedged farmland contains more favorable and persistent habitat and hedgerows.
- *P. giornae* density did not vary significantly among zones.

#### Hypothesis: gene flow is...

- Reduced in the linear hedged farmland
  - Dispersal limited by hedgerows
  - Persistent habitats
- Enhanced in its Western and Eastern sides
  - No physical barriers
  - Disturbed habitats

Q1: Could spatial heterogeneity in dispersal lead to inference of 2 genetic clusters?
Q2: Why only two clusters?
Q3: Why individuals from the hedged farmland were assigned to the eastern cluster?

Computer simulations
Results

Computer simulations

- Q1: Could spatial heterogeneity in dispersal lead to inference of 2 genetic clusters?

Simulation of a single IBD population (IBDsim, Leblois & al. 2006)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>High disp. zone</th>
<th>Low disp. zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate contrast</td>
<td>$e = 0.6$  $g = 0.75$</td>
<td>$e = 0.4$  $g = 0.67$</td>
</tr>
<tr>
<td>Strong contrast</td>
<td>$e = 0.8$  $g = 0.75$</td>
<td>$e = 0.2$  $g = 0.5$</td>
</tr>
</tbody>
</table>

$e =$ dispersal rate
$g =$ parameter of the geometric law
Results
Computer simulations

Q1: Could spatial heterogeneity in dispersal lead to inference of 2 genetic clusters?

- Moderate contrast
  - High disp. zone: $e = 0.6$, $g = 0.75$
  - Low disp. zone: $e = 0.4$, $g = 0.67$

- Strong contrast
  - High disp. zone: $e = 0.8$, $g = 0.75$
  - Low disp. zone: $e = 0.2$, $g = 0.5$

Strong contrast can lead to the erroneous detection of 2 clusters.

Q2: Why only 2 clusters?

High dispersal
Low dispersal
Constant density
Results
Computer simulations

- Q1: Could spatial heterogeneity in dispersal lead to inference of 2 genetic clusters?
- Q2: Why only 2 clusters?

Scenario 3: strong contrast + wider low dispersal zone

Q1: Could spatial heterogeneity in dispersal lead to inference of 2 genetic clusters?

IBD slope: 4 times larger than in real dataset / others scenario

3 clusters!

14/26 sim dataset
Results

Computer simulations

- Q1: Could spatial heterogeneity in dispersal lead to inference of 2 genetic clusters?
- Q2: Why only 2 clusters?
- Q3: Why individuals from the hedged farmland are assigned to the eastern cluster?

Scenario 4: strong contrast + central low dispersal zone

- 63% b)
- 52% d)

Q1: Could spatial heterogeneity in dispersal lead to inference of 2 genetic clusters?
Q2: Why only 2 clusters?
Q3: Why individuals from the hedged farmland are assigned to the eastern cluster?

Scenario 4: strong contrast + central low dispersal zone
Discussion

Hedged farmland

- Dispersal slowed down

⇒ Reduced dispersal rates and distance
  - Hedgerows (physical barrier)
  - Grasslands: Circe principle? (Landers et al. 2008)

Intensive open areas

- Dispersal rate and distance enhanced

⇒ Small scale intense dispersal
  Promoted by habitat instability
  (Travis et al. 1999, Denno et al. 2001)

Hedged farmland

- Dispersal slowed down

⇒ Reduced dispersal rates and distance
  - Hedgerows (physical barrier)
  - Grasslands: Circe principle? (Landers et al. 2008)
Results
Scale of spatial and genetic structure

Spatial autocorrelation of abundances: up to 1 km

Spatial genetic autocorrelation based on relatedness: up to 1 km

► Both results suggest intense small scale dispersal

Discussion

Poecilus cupreus

Microtus arvalis

► Homogénéité génétique à grande échelle + IBD
► Autocorrélation spatiale des abondances à faible distance
► Dispersion biaisée vers les mâles

► « Syndrome Agroécosystème »
Forçage paysager ? Perturbations => dispersion

Marrec & al. In prep
Gaufre et al. 2008/2009
Conclusion

• Importance of computer simulations in landscape genetics
  – Analysis of empirical data -> hypotheses about pattern-process relationships governing population genetic substructure
  – Simulations -> evaluate the conditions under which inferred process correctly re-create the observed genetic pattern (Landguth et al. 2010)

• Importance of addressing landscape genetics processes in terms of isolation by differential resistance

Thank you!