Adaptation of rodents to arid environments: Jaculus, colour and remote sensing data

Zbyszek Boratynski

BIODESERTS, Biodiversity of Deserts and Arid Regions Research Group, CIBIO/InBio, University of Porto

Department of Biological and Environmental Science, University of Jyväskylä, Finland
BIODESERTS and rodents from Sahara-Sahel

Overview

1. BIODESERTS (Biodiversity of Deserts and Arid Regions Research Group):
   interests, aims, practices

2. Rodents in BIODESERTS:
   Jaculus, Felovia, Gerbillus

3. Prospects (plans, team, founds)
Research group - location:

Biodiversity of Deserts and Arid Regions
- assessing biodiversity patterns in deserts and arid regions

http://biodeserts.cibio.up.pt
Research group – main research lines:

**Biodiversity of Deserts and Arid Regions**
- assessing biodiversity patterns in deserts and arid regions

1. **Biodiversity distribution:**
distribution of species and identification of biodiversity hotspots, identification of environmental and physiological factors related to distribution, and multi-time scale modeling of biodiversity distribution

2. **Evolutionary and Landscape processes:**
determination of biogeographical relationships and spatial patterns in morphological and genetic variation, identification of barriers to gene flow, and investigation of the role of paleogeographical mechanisms in diversification events

3. **Conservation planning:**
identification of threatened taxa and of factors making populations prone to extinction, designing optimized reserve solutions for biodiversity conservation, simulation of climate change effects on biodiversity distribution.

Research group – main research lines:

*Biodiversity of Deserts and Arid Regions*
- assessing biodiversity patterns in deserts and arid regions

http://biodeserts.cibio.up.pt
Research group – main research lines:
*Biodiversity of Deserts and Arid Regions*
- assessing biodiversity patterns in deserts and arid regions

http://biodeserts.cibio.up.pt
Research group – main research lines:

**Biodiversity of Deserts and Arid Regions**
- assessing biodiversity patterns in deserts and arid regions

http://biodeserts.cibio.up.pt

---

**Challenges!**

9 400 000 km² (Australia is only 7 600 000)
Research group – main research lines:
*Biodiversity of Deserts and Arid Regions*
- assessing biodiversity patterns in deserts and arid regions

http://biodeserts.cibio.up.pt

Research group – main research lines:
Biodiversity of Deserts and Arid Regions
- assessing biodiversity patterns in deserts and arid regions

25 expeditions (2000 -2014):
10 countries
600 work days
100 000 km
Research group - main aim:  
*Biodiversity of Deserts and Arid Regions*  
- assessing biodiversity patterns in deserts and arid regions

Geographical Information Systems, environmental data, inter- and intraspecific variation (e.g. genetic):  
1. describe/predict biodiversity distribution  
2. detect mechanisms affecting diversity distribution  
3. find threats to diversity

Research group - main aim:

*Biodiversity of Deserts and Arid Regions*
- assessing biodiversity patterns in deserts and arid regions

Mechanisms behind biodiversity patterns in Saharo-Saharan rodents
Sahara – spatial variation

Altitude: -133 to 3415 m.n.p.m.
Topography: mountains, sand seas, rivers
Rainfall (aver. annual): ≈ 0 to 981 mm of rainfall
T. (aver. annual): 9.4 to 30.8 °C
**Sahara – spatial variation**

Altitude: -133 to 3415 m.n.p.m.
Topography: mountains, sand seas, rivers
Rainfall (aver. annual): ≈ 0 to 981 mm of rainfall
T. (aver. annual): 9.4 to 30.8 °C
Sahara – temporal variation

Oscillating climate:
- since Pliocene eight to ten major dry-wet cycles
- least climate switch around 5000 year ago
- switches of habitat extend of about 1000 km

Ancient climate fluctuations: 0-100 000 B.P.

Ongoing fluctuation in precipitation:
1900-2000

Saharan arid periods
Green Sahara, wet periods
Oscillating climate:
- since Pliocene eight to ten major dry-wet cycles
- least climate switch around 5000 year ago
- switches of habitat extend of about 1000 km
Sahara – temporal variation

Oscillating climate:
- since Pliocene eight to ten major dry-wet cycles
- least climate switch around 5000 year ago
- switches of habitat extend of about 1000 km
Sahara consist spatially and temporally variable mosaic of habitats
Sahara consist spatially and temporally variable mosaic of habitats. How do organisms respond to those variations?
Research group - main aim:

*Biodiversity of Deserts and Arid Regions*
- assessing biodiversity patterns in deserts and arid regions

How spatial variation influence diversity within Saharan species?
How spatial variation influence diversity within Saharan species, lesser Egyptian jerboa (*Jaculus jaculus*)?

Available samples (298):
- 130 specimens, own samples (West Africa)
- 79 specimens, NMNH, Washington D.C. (Sahara)
- 11 specimens, HNHM, Hungary (East Africa)
- 8 specimens, Krakow, Poland (Algeria)
- 7 Natural History Museum, Vienna (East Africa)
- 16 Royal Belgian Institute of Natural Sciences (Sahara)
- 24 Royal Museum of Central Africa (Sahara)
- 23 La Specola, Florence, Italy (Somalia)

Field expeditions:
Algeria, Niger, Morocco, Tunisia, Mauritania, Mali


Genetic polymorphism

*Jaculus jaculus* (Linnaeus 1758)

- West Sahara (Mauritania, Morocco, Tunisia)
- 2 distinct and sympatric clades
- genetic variation on both mitochondrial and nuclear levels

Genetic polymorphism

*Jaculus jaculus* (Linnaeus 1758)

- West Sahara (Mauritania, Morocco, Tunisia)
- 2 distinct and sympatric clades
- genetic variation on both mitochondrial and nuclear levels

Geographical syzygy but ecological separation of distinct genetic lineages?

Habitat

Habitat and phenotypic variation

![Graphs showing annual average temperature, annual total precipitation, and land-cover distribution.]

Habitat and phenotypic variation

Variations in phenotype and habitat, but is there covariation?

Covariation between genetic, habitat and phenotypic variation

QUESTIONS

Is evolution of camouflage involved?

Covariation between genetic, habitat and phenotypic variation

QUESTIONS

Is evolution of camouflage involved?
Did it promote divergence?

Covariation between genetic, habitat and phenotypic variation

QUESTIONS

Is evolution of camouflage involved?

Did it promote divergence?

PREDICTIONS

Phenotypic and genetic divergence

Colors matching between soil and animal fur
Covariation between genetic, habitat and phenotypic variation

Data 1: Genetic polymorphism
Data 2: Phenotypic polymorphism
Data 3: Habitat polymorphism
Covariation between genetic, habitat and phenotypic variation

Data 1: Genetic polymorphism
Data 2: Phenotypic polymorphism
Data 3: Habitat polymorphism
Covariation between genetic, habitat and phenotypic variation

Data 1 - Genetic polymorphism
Data 2 - Phenotypic polymorphism
Data 3 - Habitat polymorphism

Habitat luminosity and RGB colors
Phenotype luminosity and RGB
Genetic clade affiliations

SATELLITE PHOTOGRAPHY
DIGITAL PHOTOGRAPHY
DNA SEQUENCING

Remote sensing
Color analyses
Phylogenetic reconstructions

Soil / rock color
Dorsal fur color
Relatedness between samples
Geographic distribution of genetic polymorphism

Result 1: Sympatric distribution of two divergent genetic clades over North Africa
Result 2: Correlation between animal and habitat coloration

Phenotype-habitat correlation

<table>
<thead>
<tr>
<th>Correlations between habitat and animal colors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
</tr>
<tr>
<td>All</td>
</tr>
</tbody>
</table>

* p < 0.05
Clade specific phenotype-habitat mismatch

Levels of mismatch between animal and habitat colors

Correlations between habitat and animal colors

<table>
<thead>
<tr>
<th></th>
<th>Luminosity</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clade 1</td>
<td>0.45*</td>
<td>0.44*</td>
<td>0.31*</td>
<td>0.33*</td>
</tr>
<tr>
<td>Clade 2</td>
<td>0.40*</td>
<td>0.39*</td>
<td>0.41*</td>
<td>-0.16</td>
</tr>
</tbody>
</table>

* p < 0.05

Result 3: Animals from clade 1 match closer to their habitat colors
Phenotype divergence between lineages

**Differences between clades in coloration**

<table>
<thead>
<tr>
<th></th>
<th>Luminosity</th>
<th>Red</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>3.91</td>
<td>4.45</td>
<td>3.5</td>
<td>2.44</td>
</tr>
<tr>
<td>p</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Result 4: Clades differed in the level of expressed coloration.
Covariation between genetic, habitat and phenotypic variation

QUESTIONS

Is evolution of camouflage involved?

Did it promote divergence?

Mixed model results

<table>
<thead>
<tr>
<th>Clade affiliation</th>
<th>-13.1</th>
<th>3.35</th>
<th>73</th>
<th>-3.91</th>
<th>0.0002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat coloration</td>
<td>113.0</td>
<td>28.6</td>
<td>73</td>
<td>3.95</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

PREDICTIONS

Phenotypic and genetic divergence

Matching between soil and animal fur colors
Covariation between genetic, habitat and phenotypic variation

QUESTIONS

Is evolution of camouflage involved?

Did it promote divergence?

Mixed model results

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>SE</th>
<th>df</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fur luminosity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clade affiliation</td>
<td>-13.1</td>
<td>3.35</td>
<td>73</td>
<td>-3.91</td>
<td>0.0002</td>
</tr>
<tr>
<td>Habitat coloration</td>
<td>113.0</td>
<td>28.6</td>
<td>73</td>
<td>3.95</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

PREDICTIONS

Phenotypic and genetic divergence

Matching between soil and animal fur colors
SUMMARY

Dorsal fur coloration matching coloration of the habitat

Phenotypic differences between genetic clades

Clades, that occurs in sympatry over vast area of North Africa

Importance of an ecological mechanism

PERSPECTIVES

Ecological bases for reproductive isolation - ecological speciation?

Ecological factors in limiting distribution - habitat specialization?
SUMMARY

Dorsal fur coloration matching coloration of the habitat

Phenotypic differences between genetic clades

Clades, that occurs in sympatry over vast area of North Africa

Importance of an ecological mechanism

PERSPECTIVES

Ecological bases for reproductive isolation - ecological speciation?

Ecological factors in limiting distribution - habitat specialization?

ONGOING PROJECTS

1. Genomic regions of divergences and phenotype variation
2. Level of reproductive isolation / hybridization
3. Ecological niche divergence / overlap
SUMMARY

Dorsal fur coloration matching coloration of the habitat

Phenotypic differences between genetic clades

Clades, that occurs in sympatry over vast area of North Africa

Importance of an ecological mechanism

PERSPECTIVES

Ecological bases for reproductive isolation - ecological speciation?

Ecological factors in limiting distribution - habitat specialization?
Phylogeography in a Sahara-Sahel mountain specialist, the Felou gundi

Endemic family (Ctenodactylidae) from North Africa

Genera:
- *Ctenodactylus gu*
- and *C. vali*
- *Massoutiera mzal*
- *Pectinator spekei*
- *Felovia (Felovia v*

Sousa, Silva, Brito and Boratyński. Phylogeographic structuring in a Sahara-Sahel mountain specialist, the *Felou gundi*. Submitted
Phylogeography in a Sahara-Sahel mountain specialist, the Felou gundi

Endemic family (*Ctenodactylidae*) from North Africa

**Genera:**

*Ctenodactylus gu* - Red
*Massoutiera mzali* - Blue
*Pectinator spekei* - Purple
*Felovia (Felovia var.)* - Yellow

![Map showing distribution of Felou gundi](image)
Phylogeography in a Sahara-Sahel mountain specialist, the Felou gundi

Ecological models predicted occurrence in 8 suitable habitat areas:
- with high slope
- around gueltas
- bare and rocky deserts areas.

Felovia (*Felovia vae*)

Phylogeography in a Sahara-Sahel mountain specialist, the Felou gundi

Ecological models predicted occurrence in 8 suitable habitat areas:
-with high slope

Phylogeography in a Sahara-Sahel mountain specialist, the Felou gundi
Phylogeography in a Sahara-Sahel mountain specialist, the Felou gundi
Diversity patterns in North Africa - the case of specious Gerbillus rodents

Available samples (632):
- 230 specimens, own samples (West Sahara)
- 10 specimens, HNHM, Hungary
- 104 specimens, Krakow, Poland
- 52 Natural History Museum, Vienna
- 65 Royal Belgian Institute of Natural Sciences
- 115 Royal Museum of Central Africa
- 56 La Specola, Florence, Italy

Field expeditions:
Algeria, Niger, Morocco, Tunisia, Mauritania/Mali/Senegal

Main interest:
- Mechanisms of speciation/diversification in *Gerbillus*
- Genomic regions of diversification and speciation

Ongoing work:
1. Phenotype - habitat linkage, colour variation between and within species
2. Phylogenetic reconstruction and sample barcoding
3. Ecological niche evolution
Diversity patterns in North Africa - the case of specious Gerbillus rodents

Available samples (632):
- 230 specimens, own sample
- 10 specimens, HNHM, Paris
- 104 specimens, Krakow
- 52 Natural History Museum
- 65 Royal Belgian Institute
- 115 Royal Museum of Central Africa
- 56 La Specola, Florence

Field expeditions:
Algeria, Niger, Morocco, Tunisia, Libya, Mali, Senegal, Sudan

New 218 skins

Main interest:
- Mechanisms of speciation
- Genomic regions of diversity

Ongoing work:
1. Phenotype - habitat linkage, colour variation between and within species
2. Phylogenetic reconstruction and sample barcoding
3. Ecological niche evolution
Thank you for your attention!