

Historical biome shifts in the Sahara region since the Miocene

A macrogenetic perspective

André Vicente Liz (*et al.*)

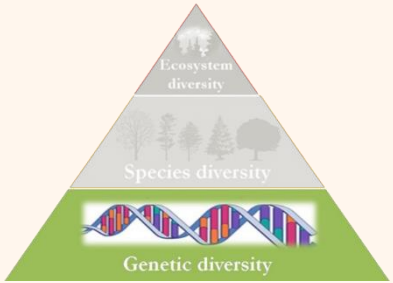
CIBIO – Research Centre in Biodiversity and Genetic Resources, Portugal

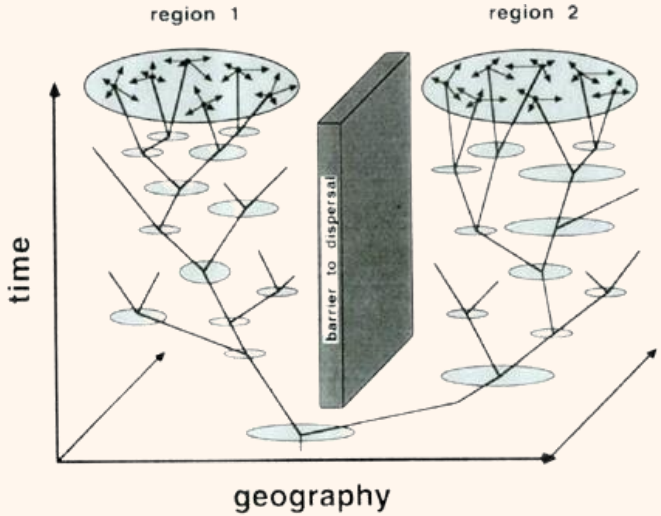
3rd Joint Congress on Evolutionary Biology
27th July 2024
Montreal, Canada

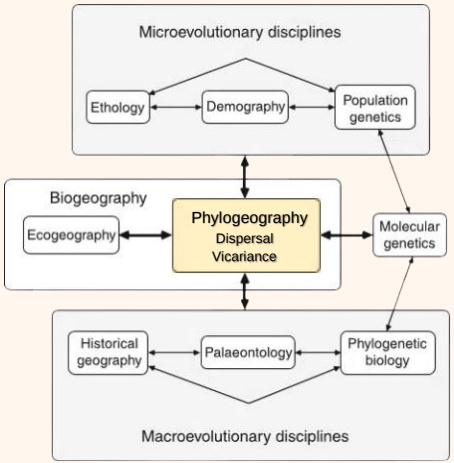
Phylogeography

The integration of space and time in the study of biological diversity

- **Biogeography + evolutionary biology**
- **Spatial patterns** of genealogical **lineages** and their **geo/eco/evolutionary drivers**







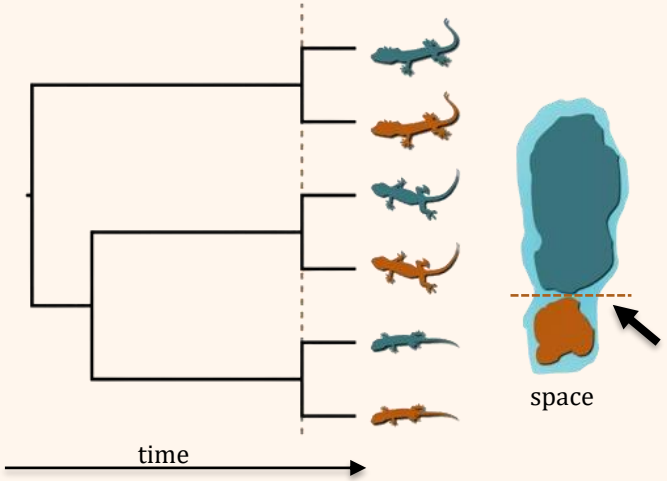
References: Avise, 2000, 2009

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- **Comparative phylogeography**

  "evolutionary and biogeographic histories of co-distributed species or populations"



References: Gutiérrez-García & Vázquez-Domínguez, 2011; Oaks, 2018

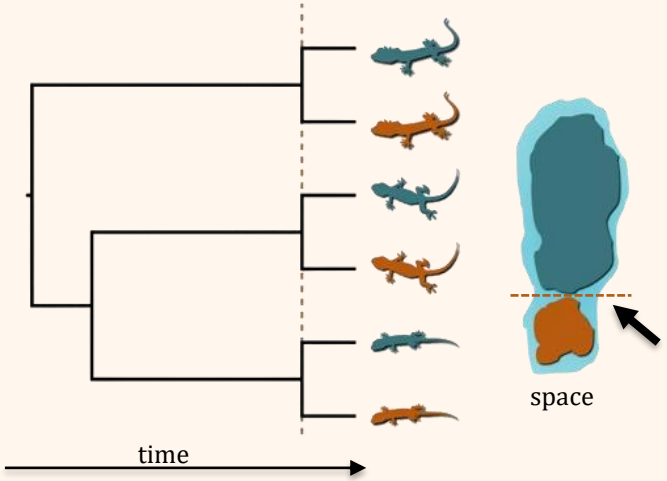
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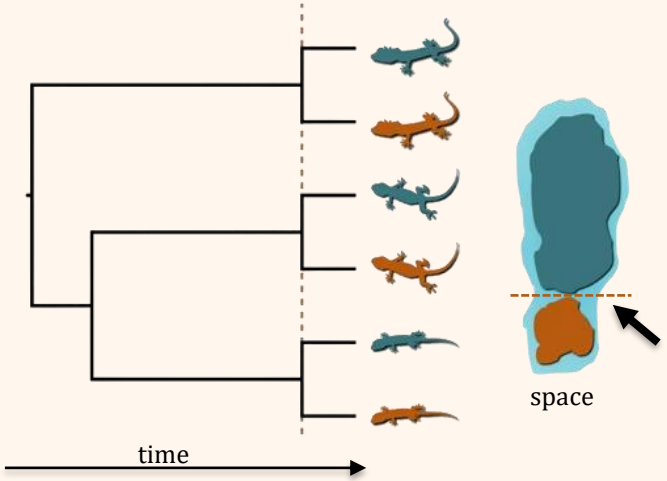
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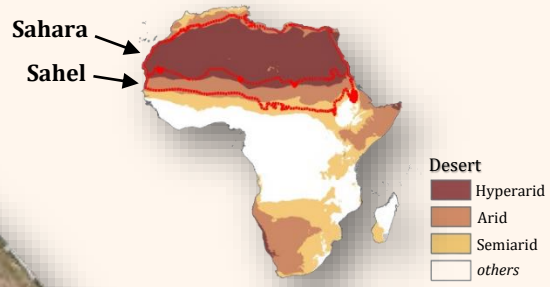
References: Gutiérrez-García & Vázquez-Domínguez, 2011; Oaks, 2018

The Sahara-Sahel

Setting the scene

- **Vast** and **remote warm desert**



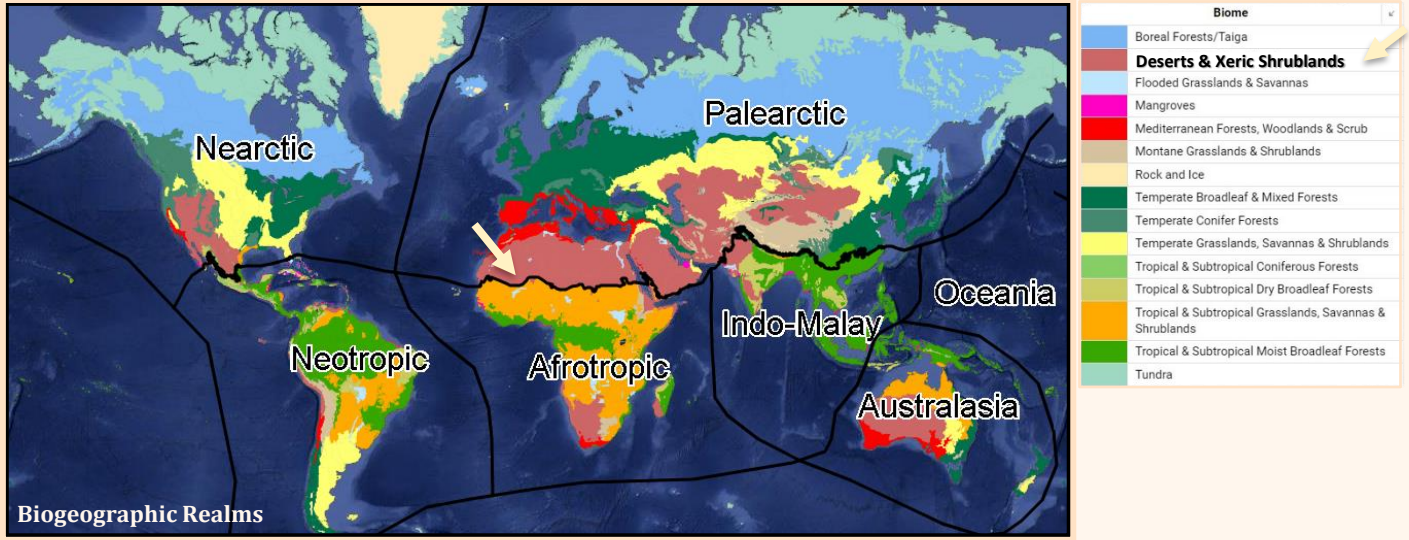


References: Brito *et al*, 2014

The Sahara-Sahel

Setting the scene

- Vast and remote warm desert
- **Palaearctic–Afrotropical transition**



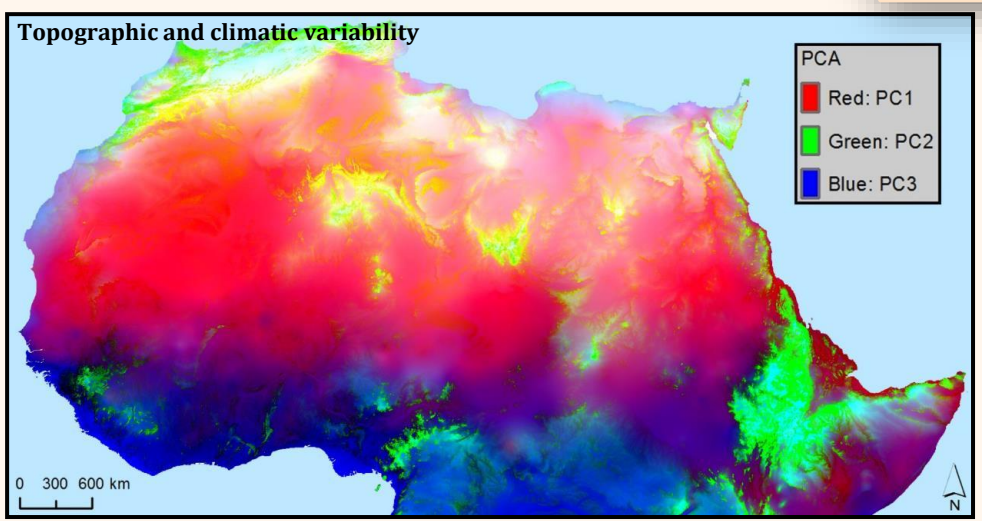
References: Brito *et al*, 2014; Dinerstein *et al*, 2017

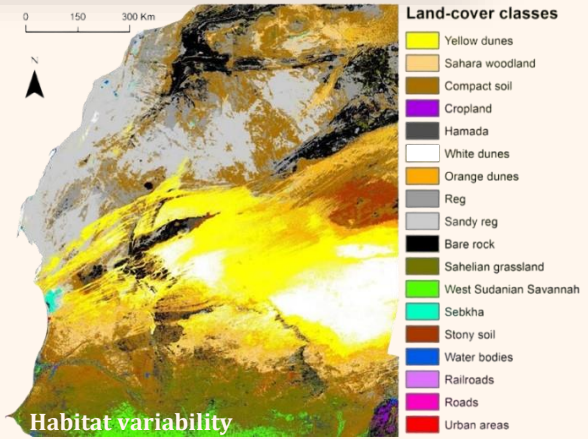
The Sahara-Sahel

Setting the scene



- Vast and remote warm desert
- Palaearctic–Afrotropical transition
- **Abiotic** and biotic **diversity**

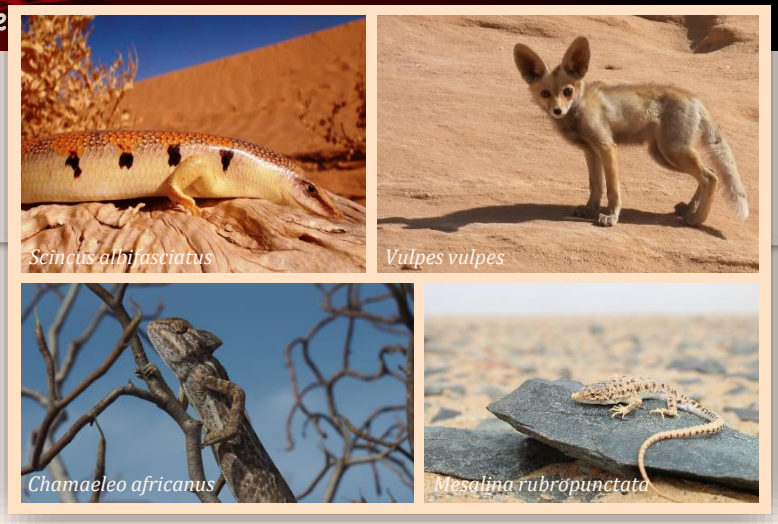




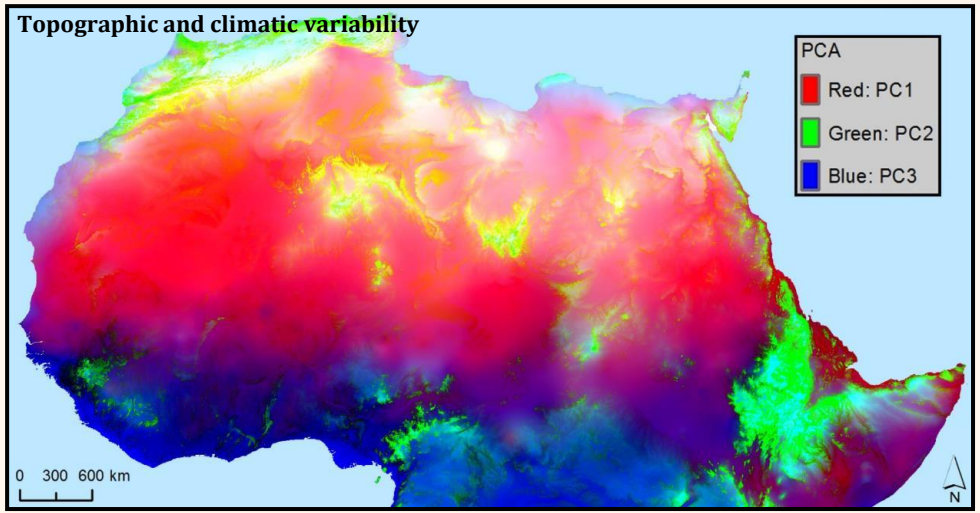
References: Brito *et al*, 2014; Campos & Brito, 2018

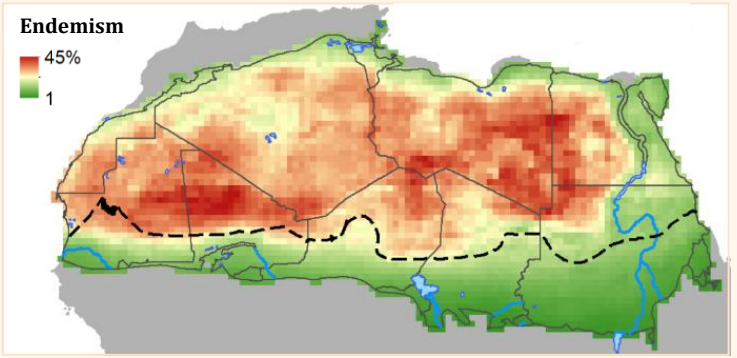
The Sahara-Sahel

Setting the scene



- Vast and remote warm desert
- Palaearctic–Afrotropical transition
- Abiotic and **biotic diversity**





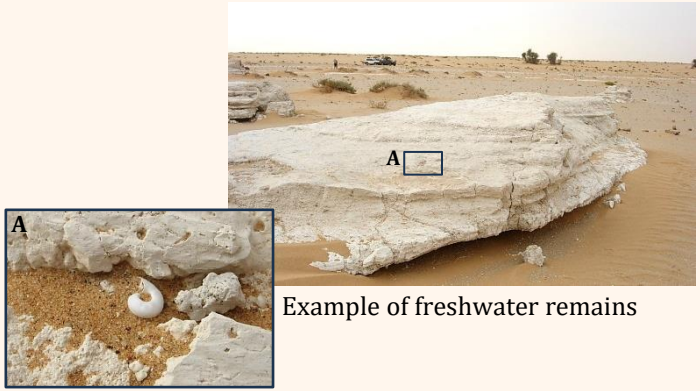
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The Sahara-Sahel

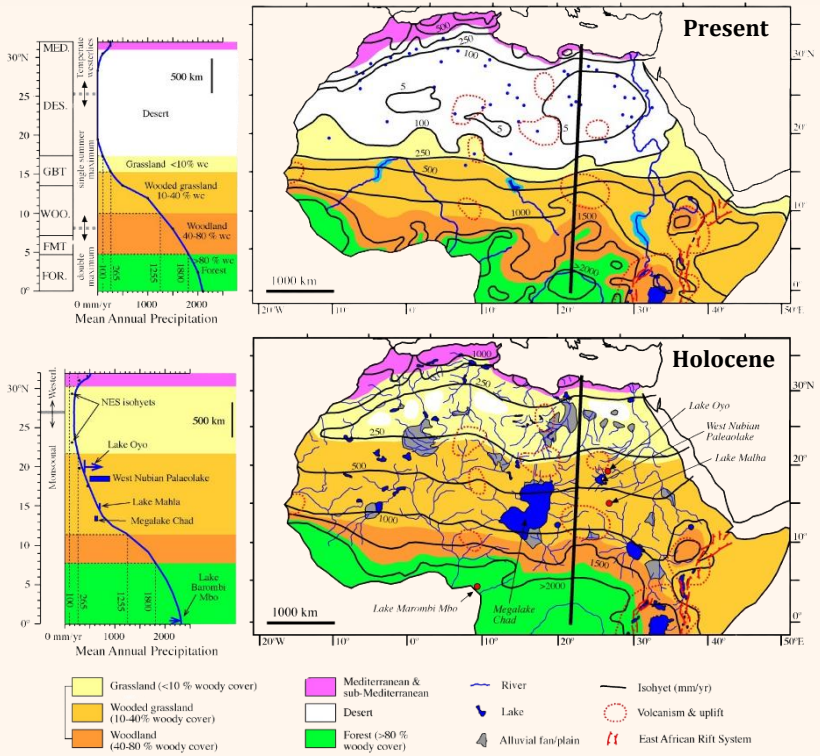
Setting the scene

Palaeoclimatic oscillations → Hydrological / land-cover shifts

- Vast and remote warm desert
- Palaearctic–Afrotropical transition
- Abiotic and biotic diversity
- **Unique natural history**



Example of freshwater remains



References: Larrasoaña *et al*, 2013; Brito *et al*, 2014; Crocker *et al*, 2022

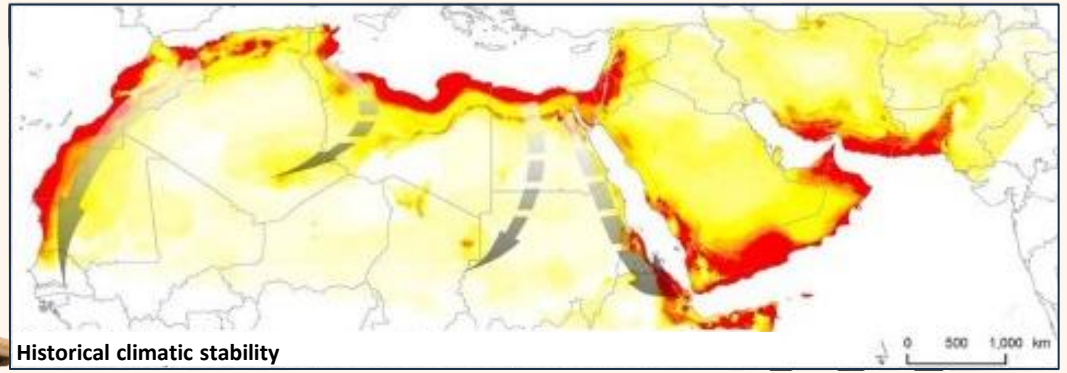
The Sahara-Sahel

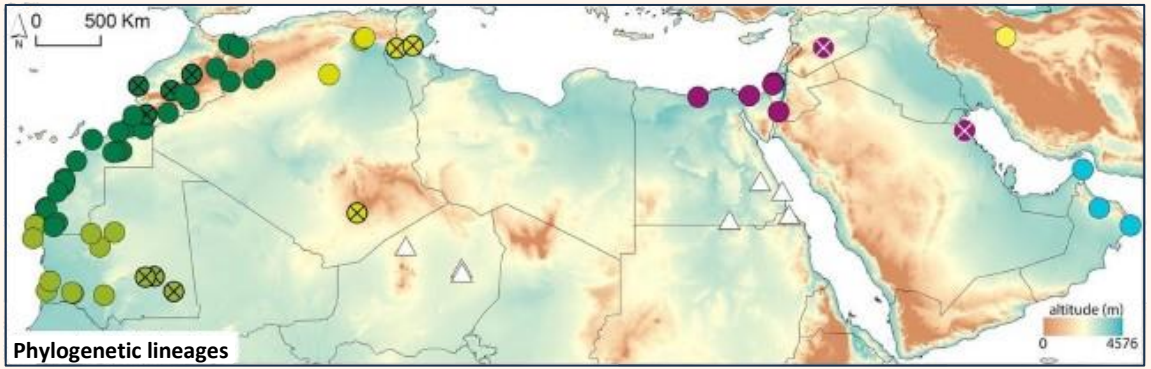
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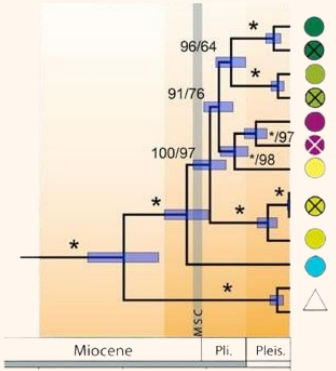
Biodiversity imprints

Palaeoclimatic oscillations → Hydrological / land-cover shifts

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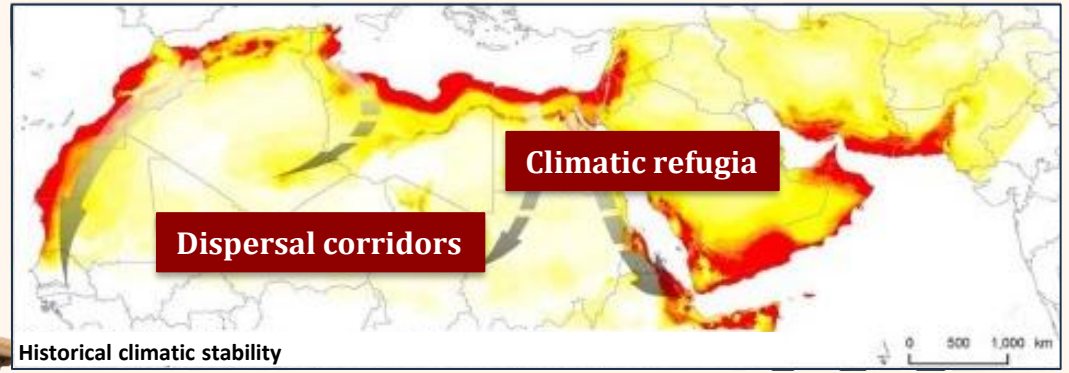
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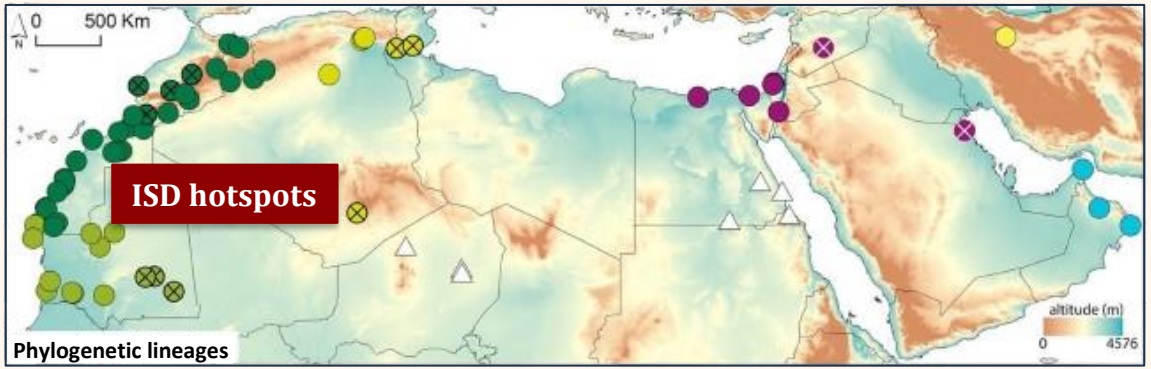
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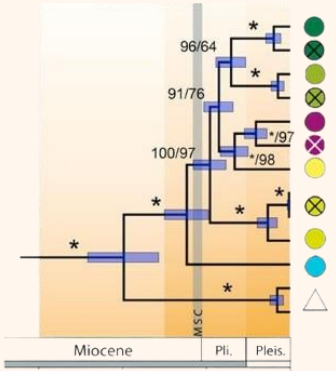
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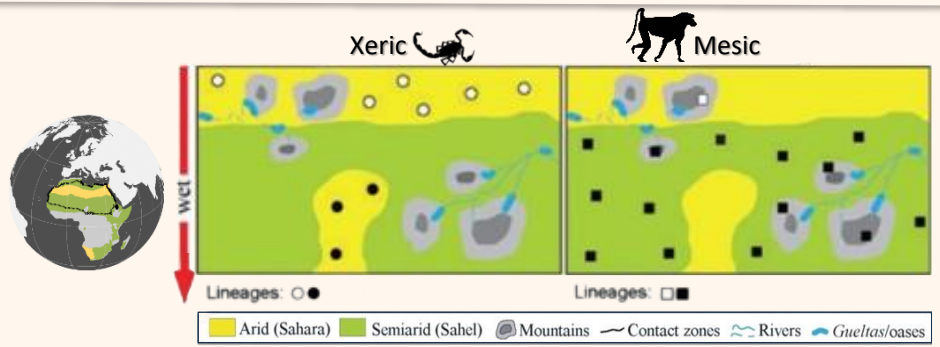
The Sahara-Sahel

Setting the scene

Biodiversity responses driven by taxa habitat requirements

Palaeoclimatic oscillations → Hydrological / land-cover shifts

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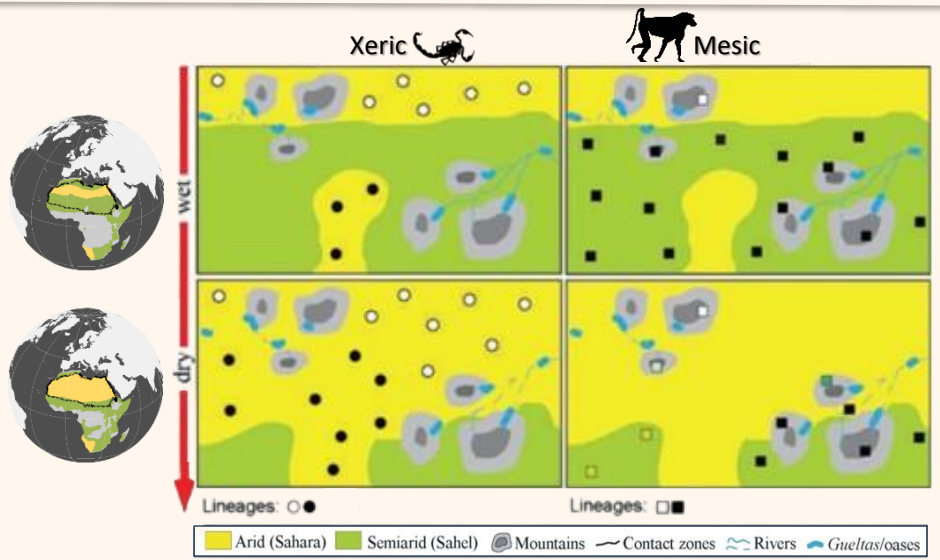
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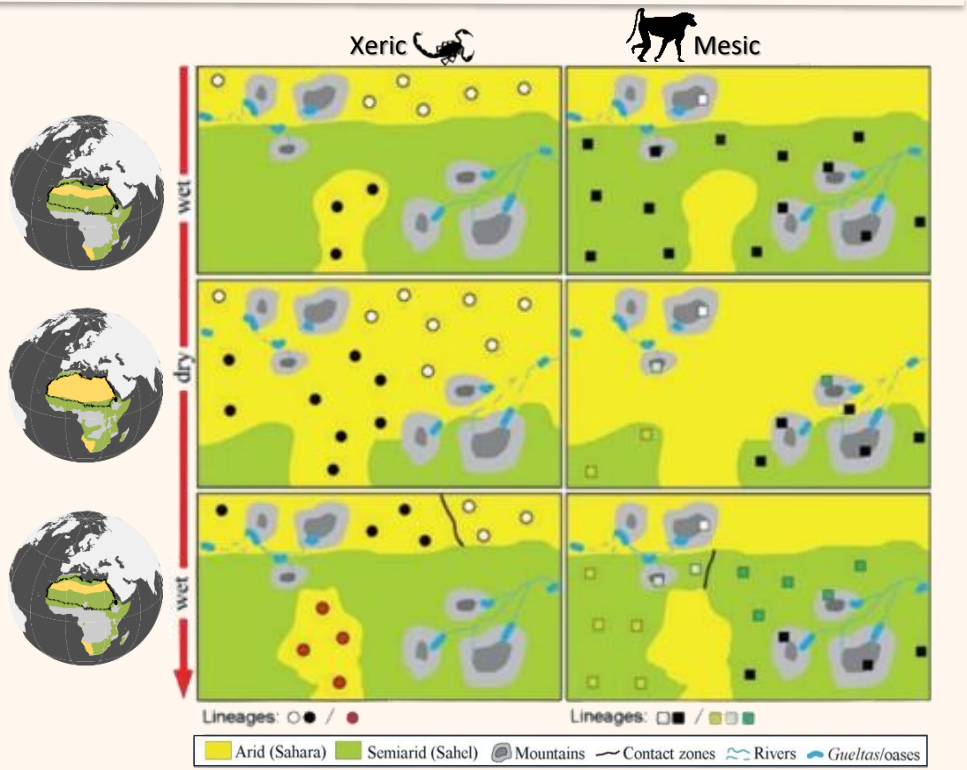
The Sahara-Sahel

Setting the scene

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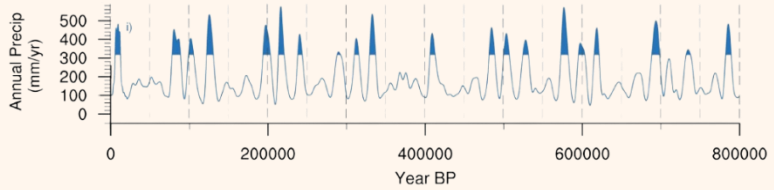
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Research agenda

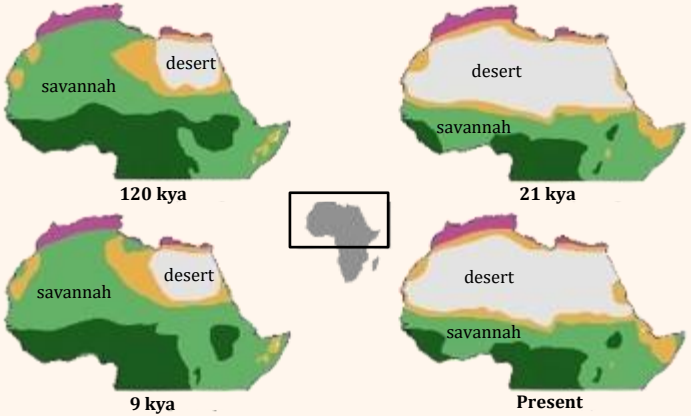
Biogeographic hypotheses

- **High intra-specific diversity (ISD) within refugia**
  - Long-term population persistence
  - Confounding effect

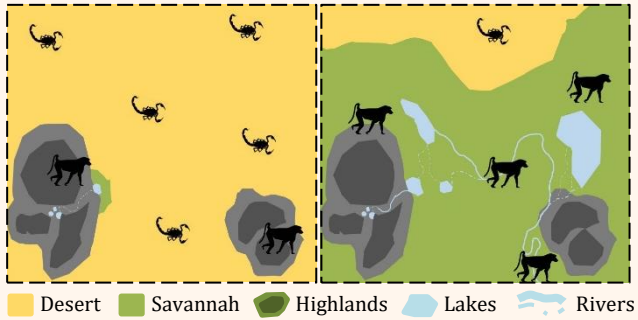
Historical rainfall variation in North Africa

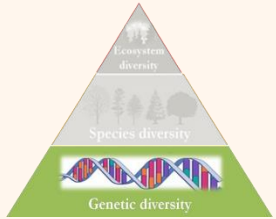


Desert/savannah biome cycles



Arid Sahara **_Green_ Sahara**





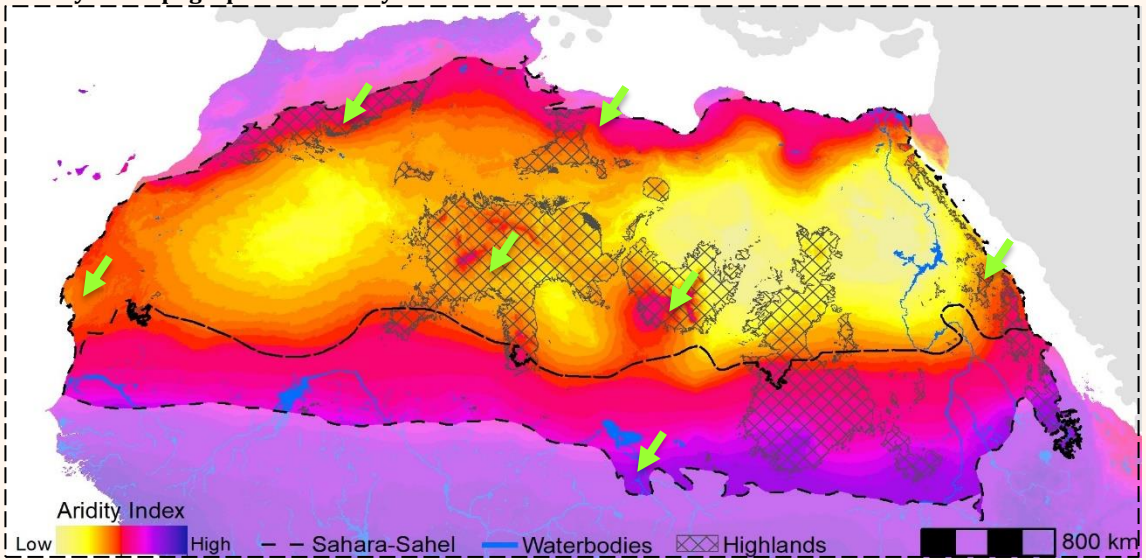
References: Brito *et al*, 2014; Armstrong *et al*, 2023

Research agenda

Biogeographic hypotheses

- High intra-specific diversity (ISD) within refugia
- **Hypotheses of ecological refugia and dispersal corridors**

Aridity and topographic variability



Mesic taxa



- **Refugia:** arid mountains and desert fringes
- **Trans-Saharan corridors:**
  1) Atlantic Sahara
  2) Central Sahara
  3) Nile River valley

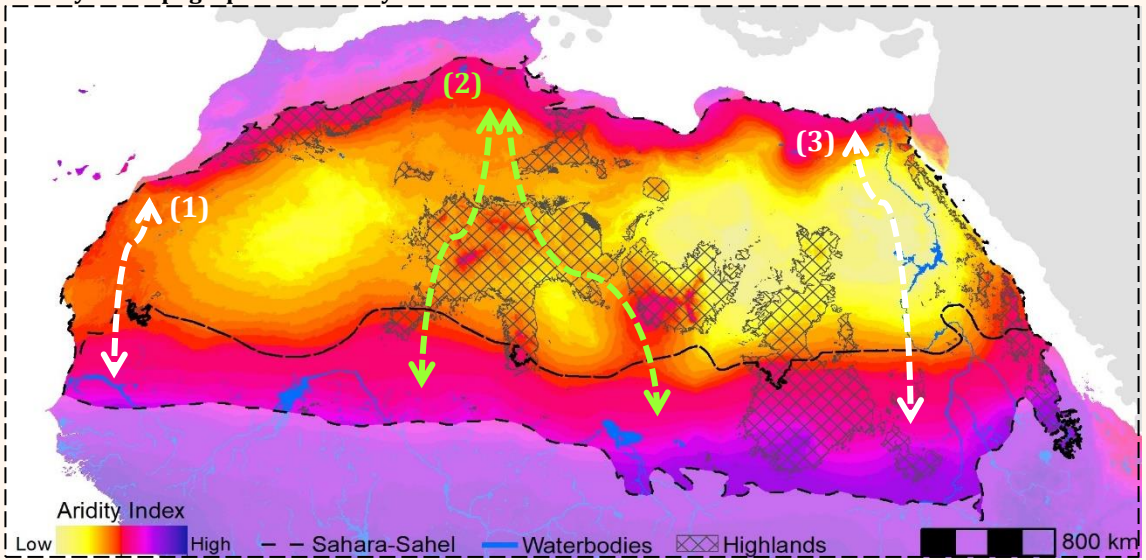
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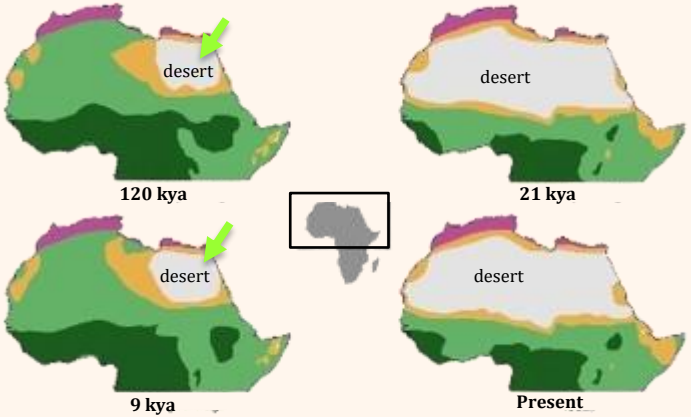
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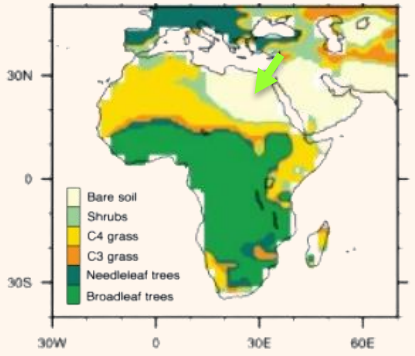
Desert/savannah biome cycles



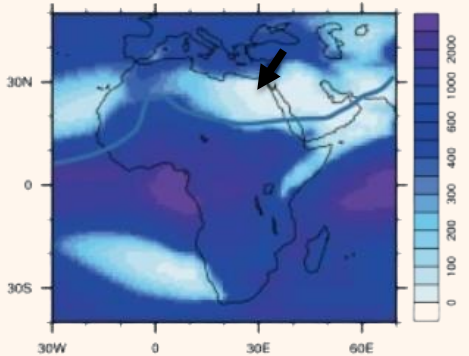
Xeric taxa → poorly known

- **Refugia:** northern Sahara
- **Trans-Saharan corridors:** southern Sahara

Green Sahara vegetation



Green Sahara rainfall



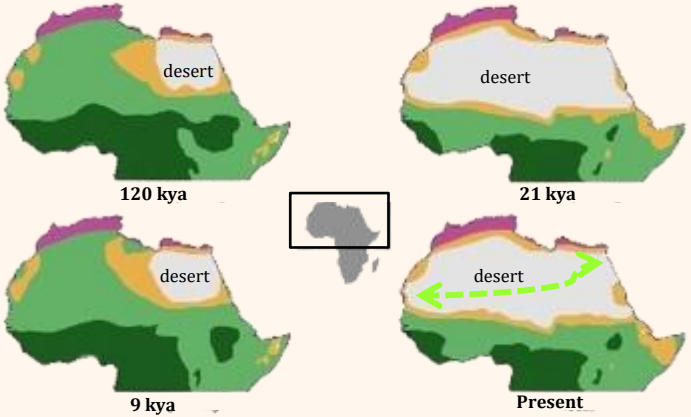
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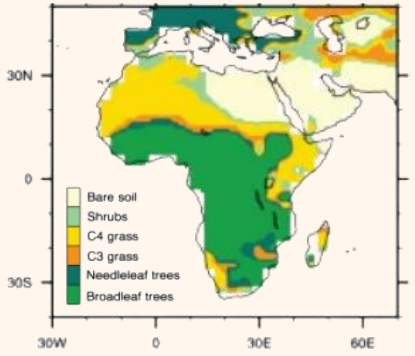
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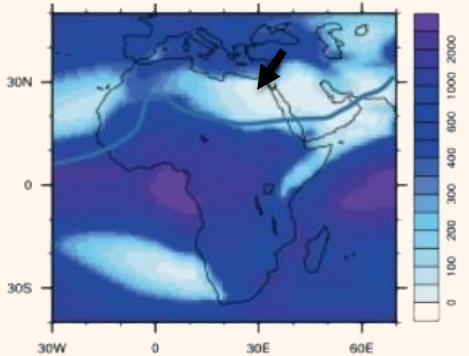
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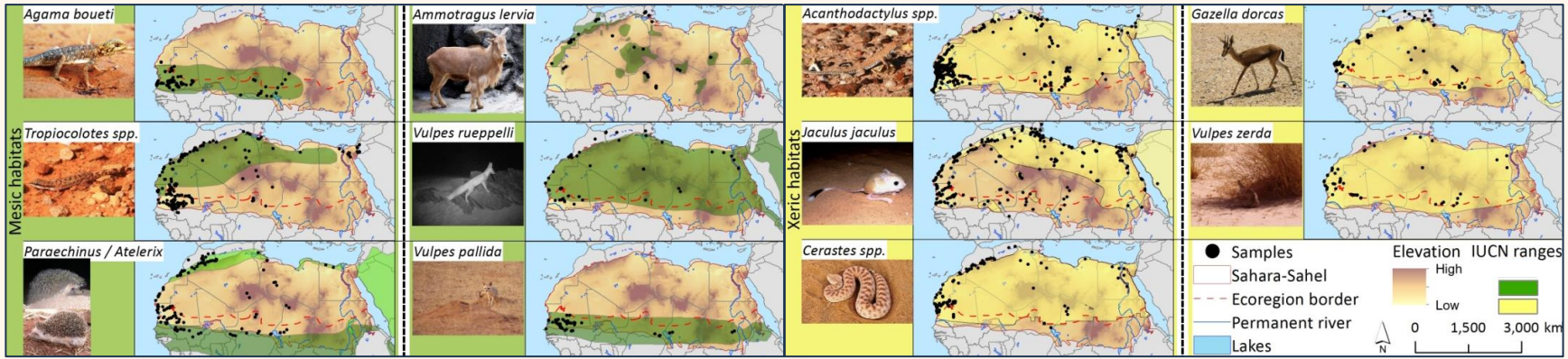
Methods

Study taxa

- **104 vertebrate species (monophyletic clades)**



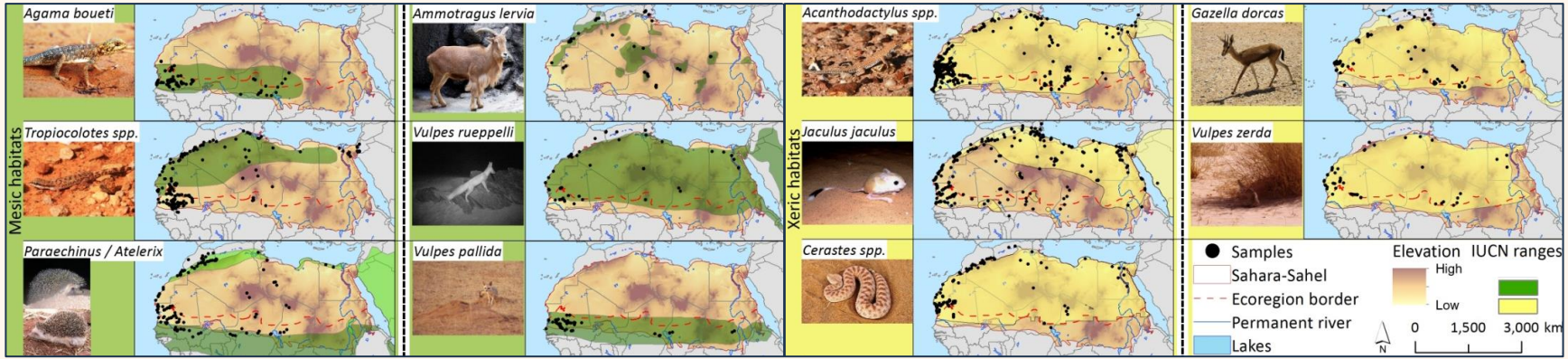
  - Candidate species → >20% Sahara-Sahel distribution
    → ≥5 georeferenced DNA sequences from unique Sahara-Sahel localities
  - Mesic/xeric habitat defined by hyperarid distribution (threshold: 65%)



Methods

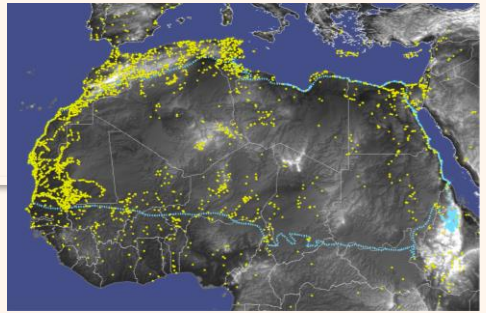
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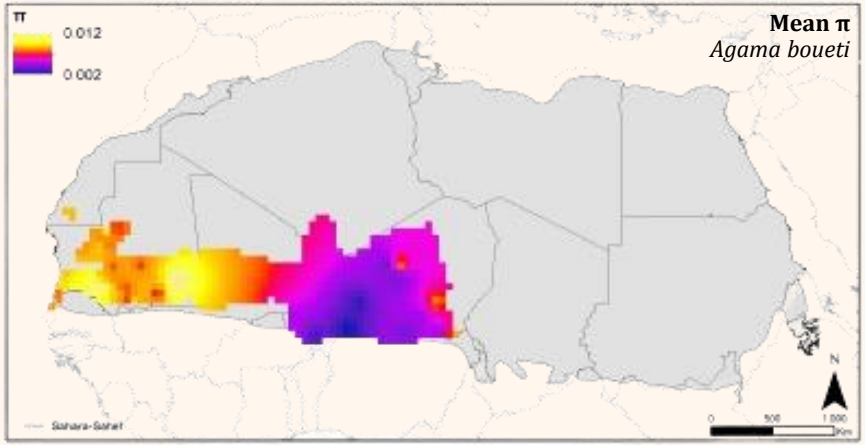
Methods

Genetic approach



>8.500 georeferenced DNA sequences

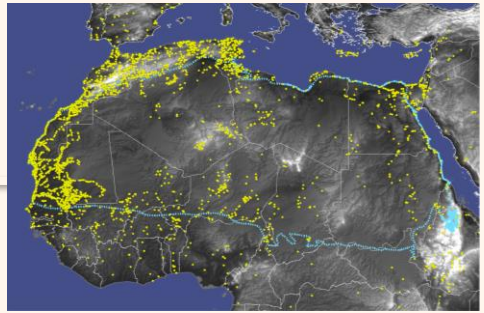
- **ISD hotspots**: geostatistics
  - Species' π interpolations (mtDNA) → Averaged for mesic/xeric



References: Tarroso *et al*, 2019

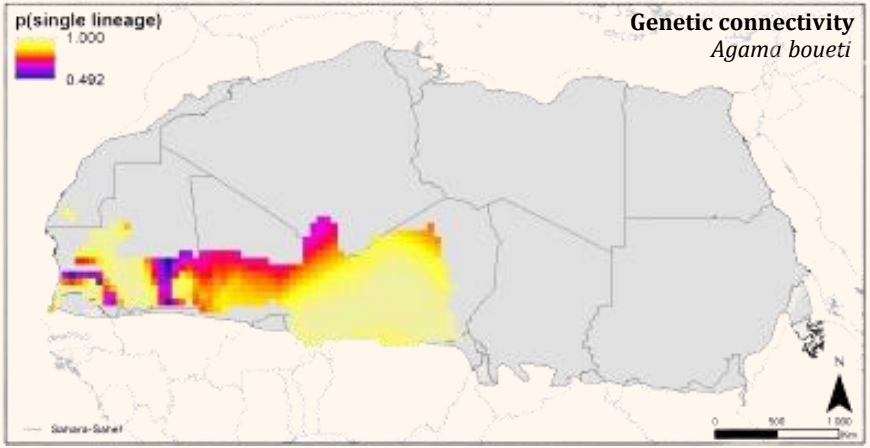
Methods

Genetic approach



>8.500 georeferenced DNA sequences

- **ISD hotspots**: geostatistics
- **Genetic connectivity**: phylogeographic analyses + geostatistics
  - Time-calibrated Maximum Likelihood multi-locus trees (mtDNA + nuDNA)
  - Species' single-lineage distribution interpolations → Averaged for mesic/xeric

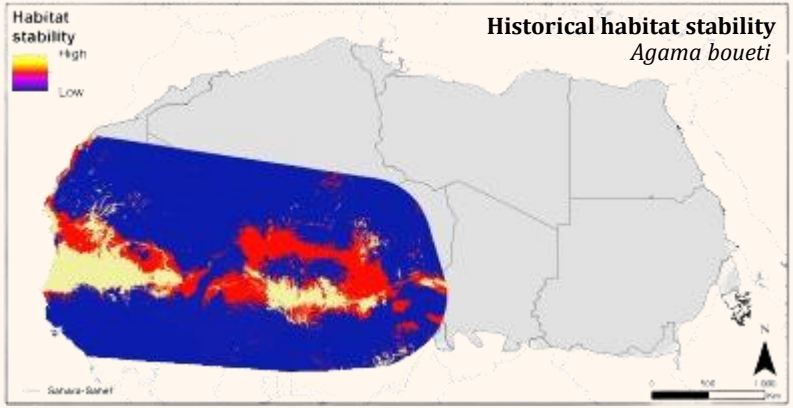


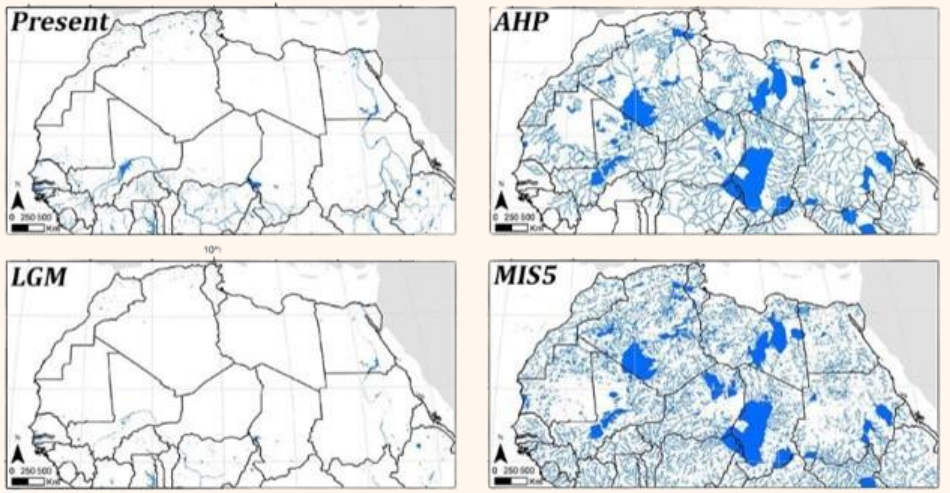
References: Tarroso *et al*, 2019

Methods

Ecological approach

- **Historical habitat stability**: ENMs and palaeoprojections → Averaged for mesic/xeric
  - Predictors → (palaeo)climate + (palaeo)vegetation + (palaeo)hydrology + topography + dunes
  - Presence data → GBIF + articles + unpublished
  - Dataset 1 (1°) + Dataset 2 (2.5')

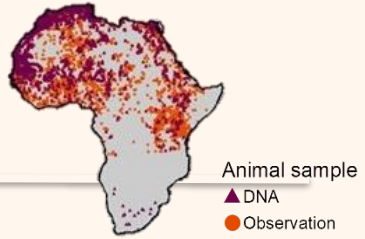




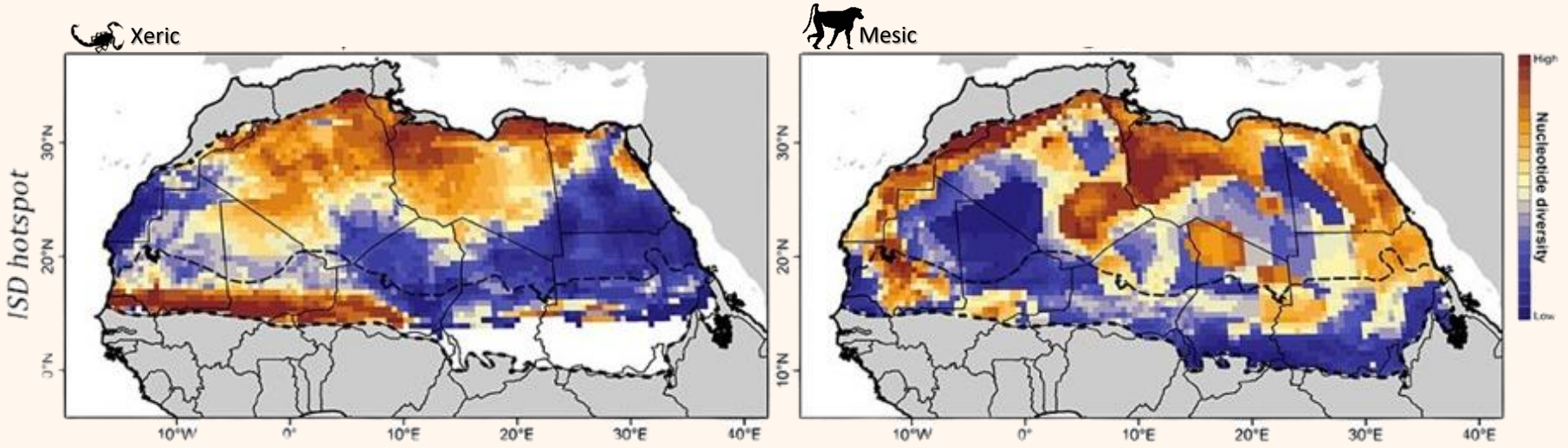
References: Drake *et al*, 2011; Scerri *et al*, 2014; Pekel *et al*, 2016; Fick & Hijman, 2017; Armstrong *et al*, 2023

Results

Genetic insights



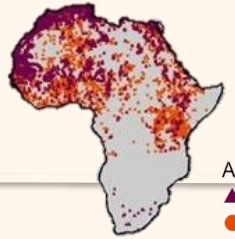
- ISD hotspots



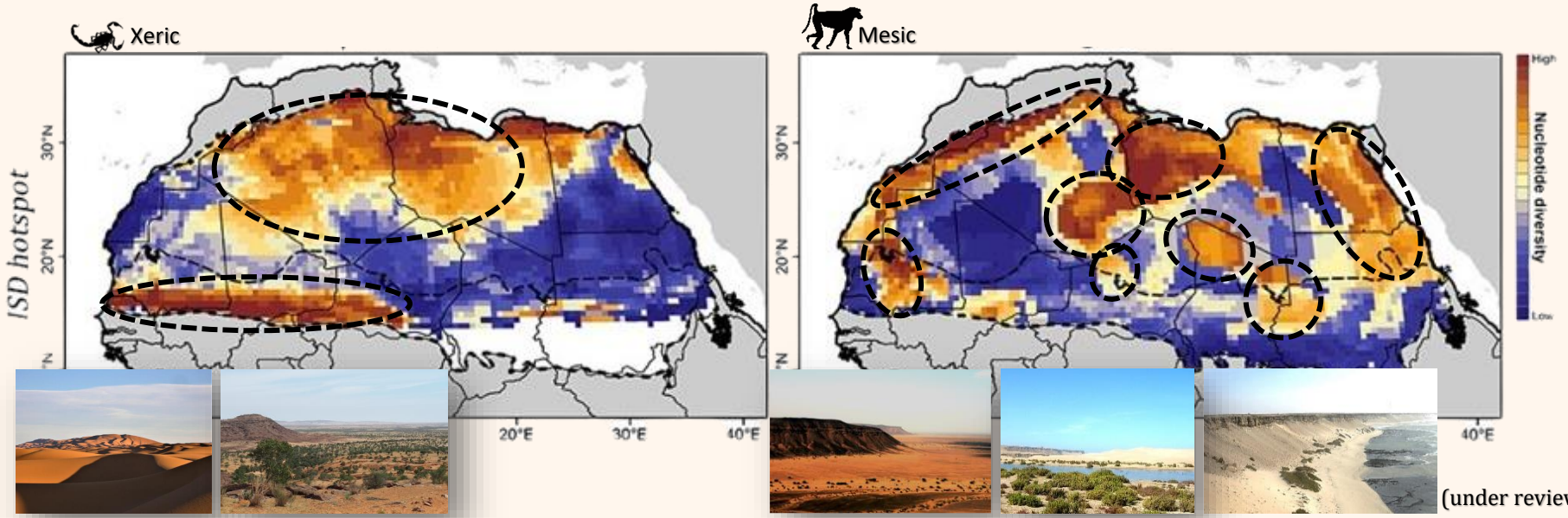
Liz *et al* (under review)

Results

Genetic insights



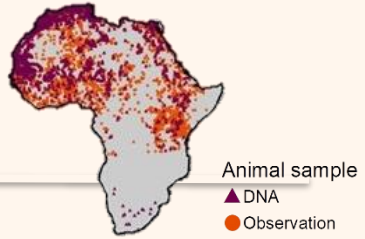
- ISD hotspots
  - **Xeric** taxa: **northern Sahara** and **western Sahel**
  - **Mesic** taxa: **mountains**, **Nile Valley** and **coasts**



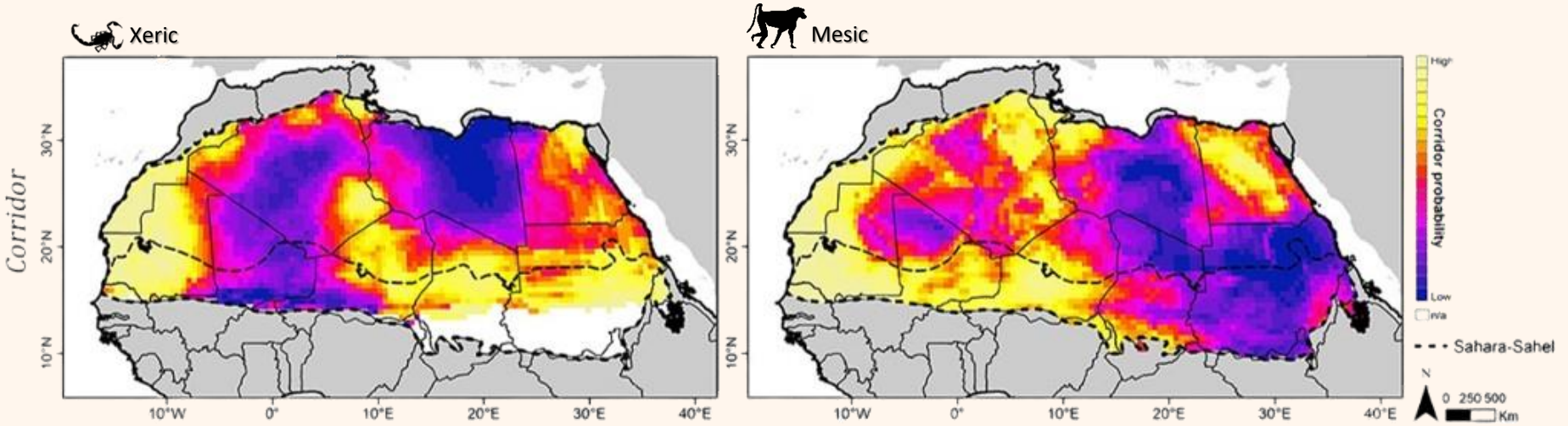
(under review)

Results

Genetic insights



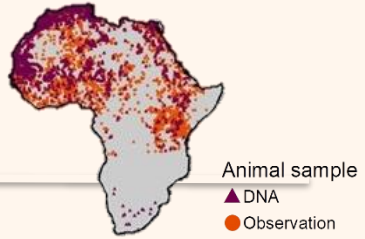
- Genetic connectivity



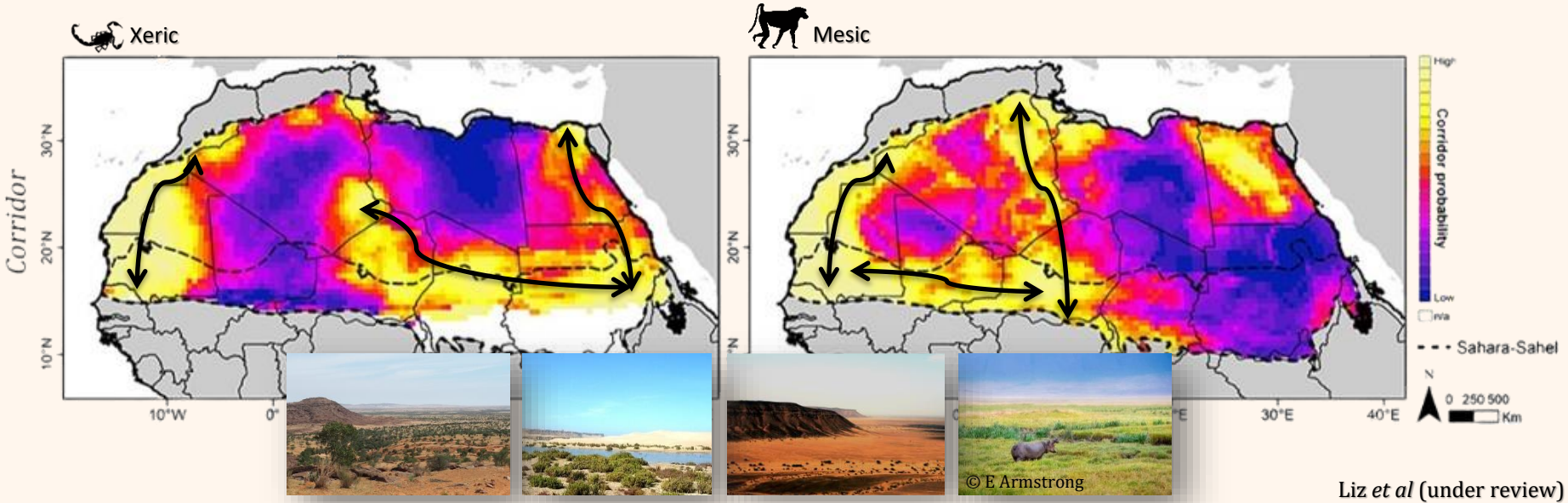
Liz *et al* (under review)

Results

Genetic insights



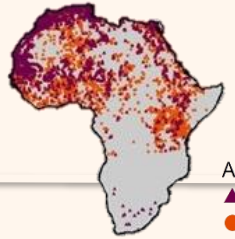
- Genetic connectivity
  - **Xeric**: **Atlantic Sahara** and **Nile Valley–eastern Sahel–Central Sahara**
  - **Mesic**: **Atlantic Sahara** and **Central Sahara**



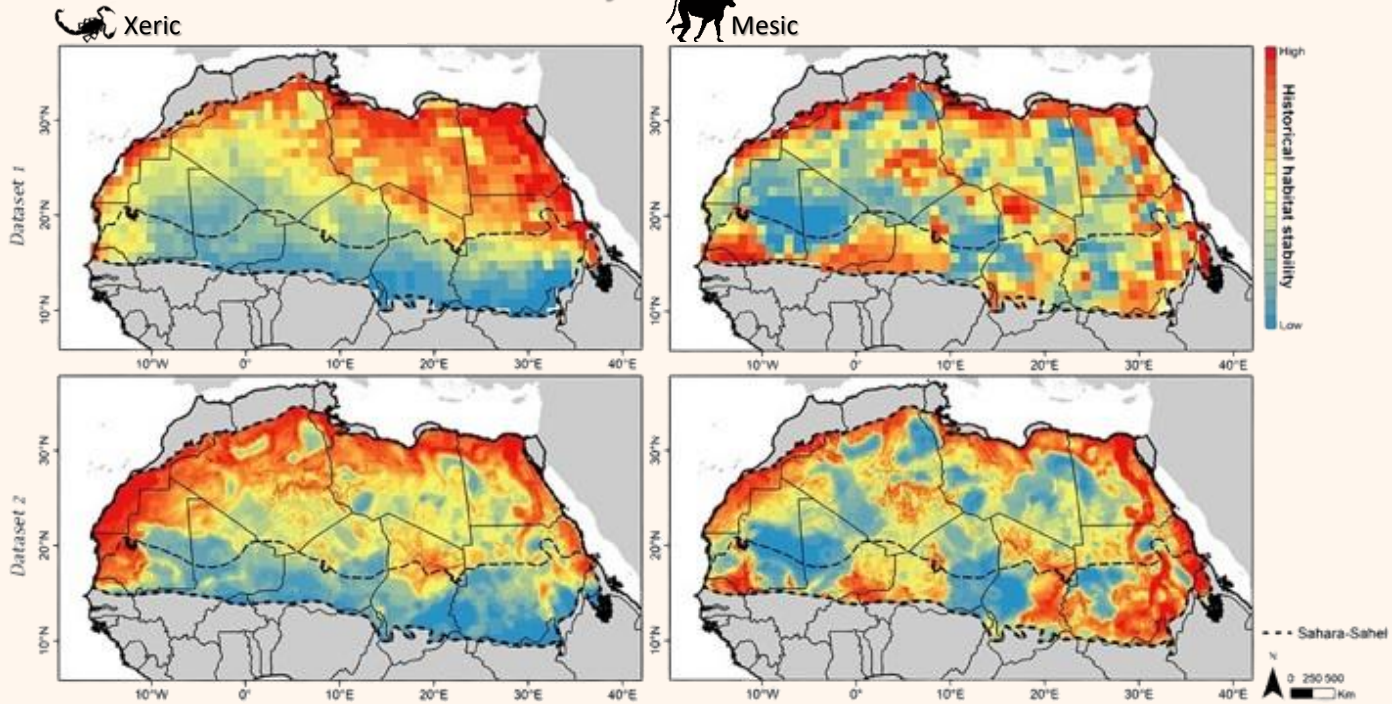
Liz *et al* (under review)

Results

Ecological insights



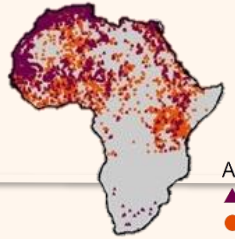
- Historical habitat stability



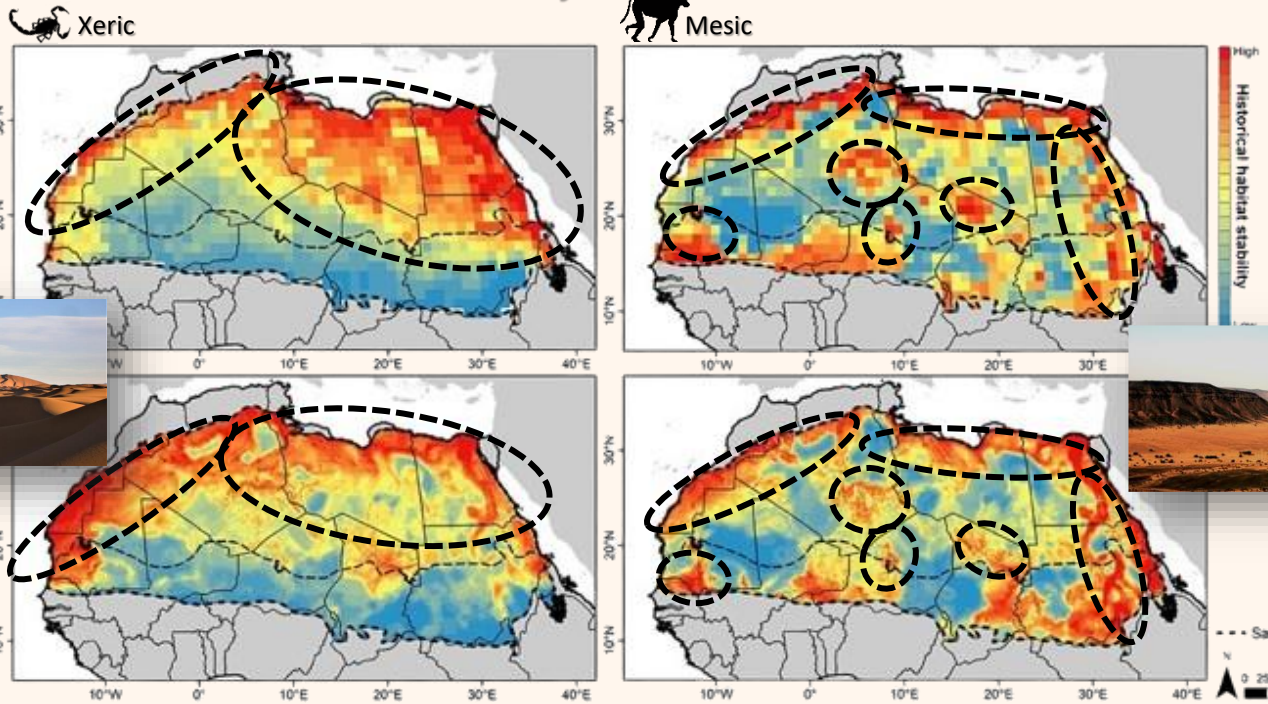
Liz *et al* (under review)

Results

Ecological insights



- Historical habitat stability









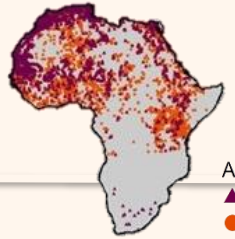
Refugia

- **Xeric**: **northern Sahara**
- **Mesic**: **mountains**, **coasts**, and **Nile Valley**

Liz *et al* (under review)

Results

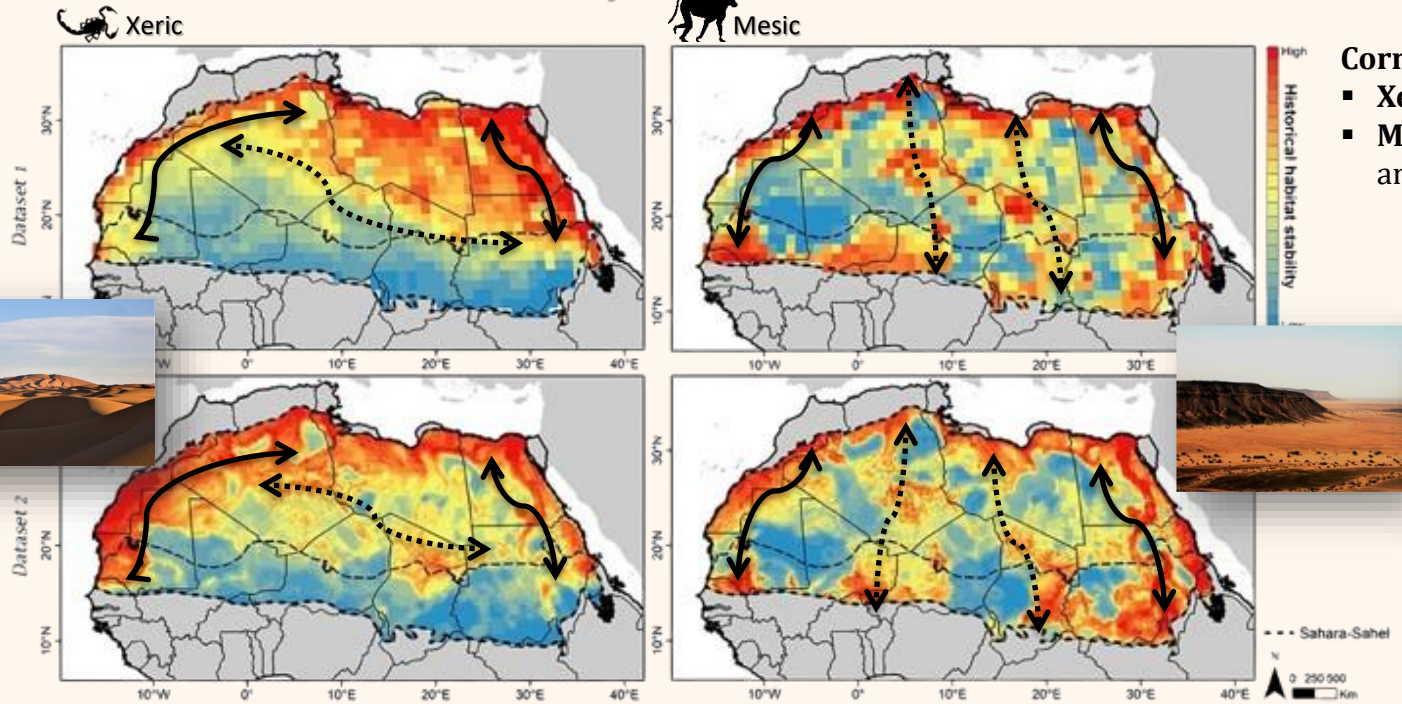
Ecological insights



➢ Historical habitat stability

Xeric

Mesic







Corridors

- **Xeric**: **Pan-Saharan**
- **Mesic**: **Central Sahara**, **coasts** and **Nile Valley**

Liz *et al* (under review)

Major conclusions

Integrative phylogeography of Sahara-Sahel fauna

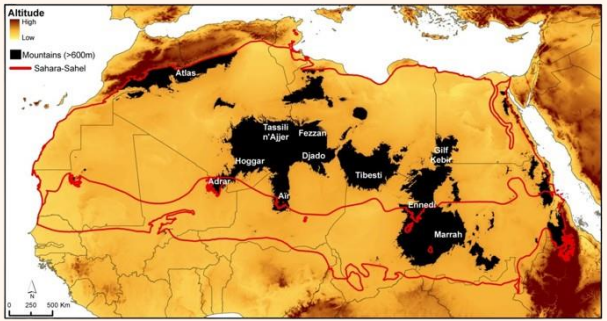
- Concordant ISD and habitat stability

References: Drake *et al*, 2011; Brito *et al*, 2014; Gonçalves *et al*, 2018; Velo-Antón *et al*, 2018; Armstrong *et al*, 2023

Major conclusions

Integrative phylogeography of Sahara-Sahel fauna

- **Concordant ISD and habitat stability**
- **Arid mountains:** ISD hotspots and ecological refugia for mesic communities

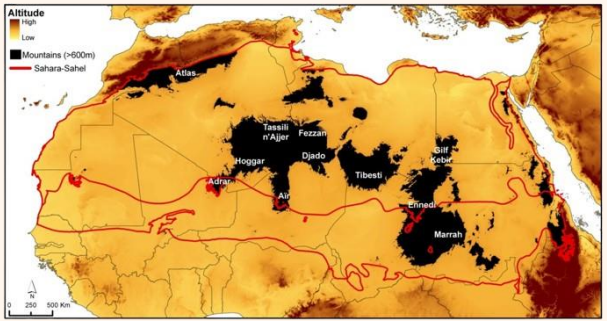


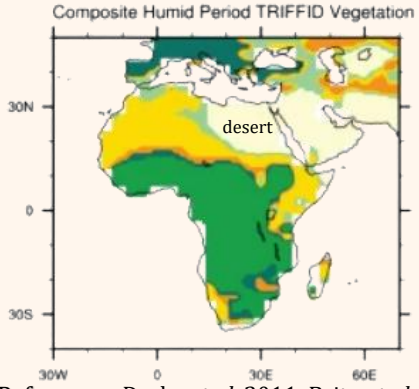
References: Drake *et al*, 2011; Brito *et al*, 2014; Gonçalves *et al*, 2018; Velo-Antón *et al*, 2018; Armstrong *et al*, 2023

Major conclusions

Integrative phylogeography of Sahara-Sahel fauna

- **Concordant ISD and habitat stability**
- **Arid mountains:** ISD hotspots and ecological refugia for mesic communities
- **The Northern Sahara:** ISD hotspot and ecological refugia for xeric communities



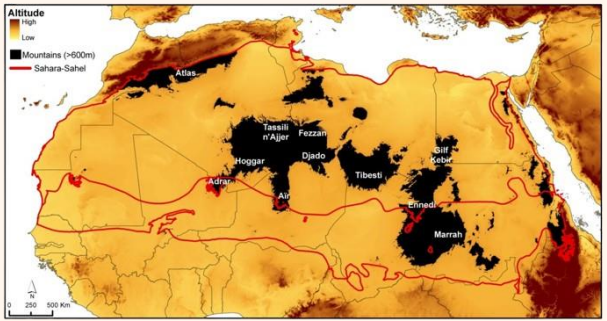


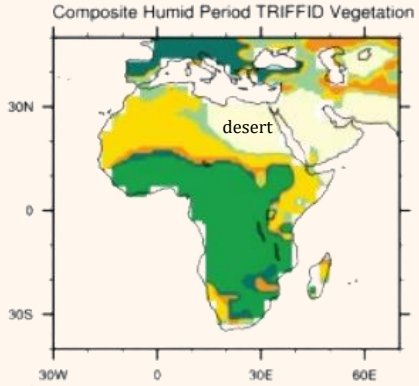
References: Drake *et al*, 2011; Brito *et al*, 2014; Gonçalves *et al*, 2018; Velo-Antón *et al*, 2018; Armstrong *et al*, 2023

Major conclusions

Integrative phylogeography of Sahara-Sahel fauna

- **Concordant ISD and habitat stability**
- **Arid mountains:** ISD hotspots and ecological refugia for mesic communities
- **The Northern Sahara:** ISD hotspot and ecological refugia for xeric communities
- **Atlantic Sahara:** refugia and corridor for both mesic and xeric communities



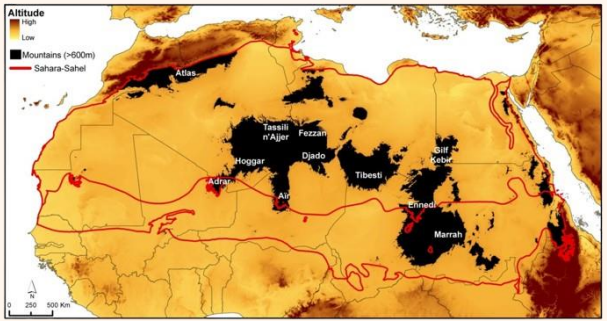


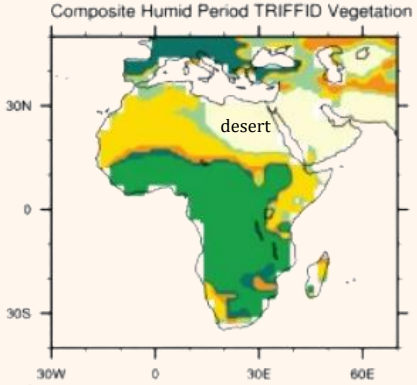
References: Drake *et al*, 2011; Brito *et al*, 2014; Gonçalves *et al*, 2018; Velo-Antón *et al*, 2018; Armstrong *et al*, 2023

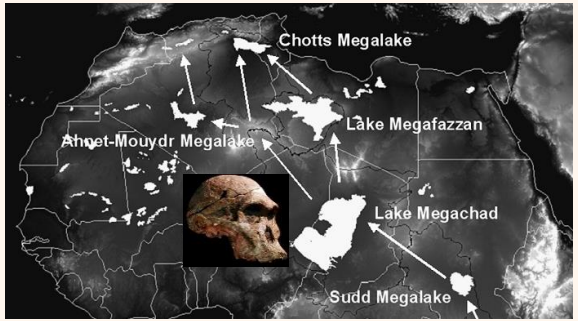
Major conclusions

Integrative phylogeography of Sahara-Sahel fauna

- **Concordant ISD and habitat stability**
- **Arid mountains:** ISD hotspots and ecological refugia for mesic communities
- **The Northern Sahara:** ISD hotspot and ecological refugia for xeric communities
- **Atlantic Sahara:** refugia and corridor for both mesic and xeric communities
- **Central Sahara mountain corridors:** intermittent mesic routes but comparable to stable ones







References: Drake *et al*, 2011; Brito *et al*, 2014; Gonçalves *et al*, 2018; Velo-Antón *et al*, 2018; Armstrong *et al*, 2023

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Work co-authors : Dennis Rödder, Duarte Vasconcelos Gonçalves, Guillermo Velo-Antón, José Carlos Brito, Maria João Paul, Nick Drake, Paul Breeze, Pedro Tarroso, Peter Hopcroft, Pierre-André Crochet, Raquel Godinho, Silvia B. Carvalho.

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