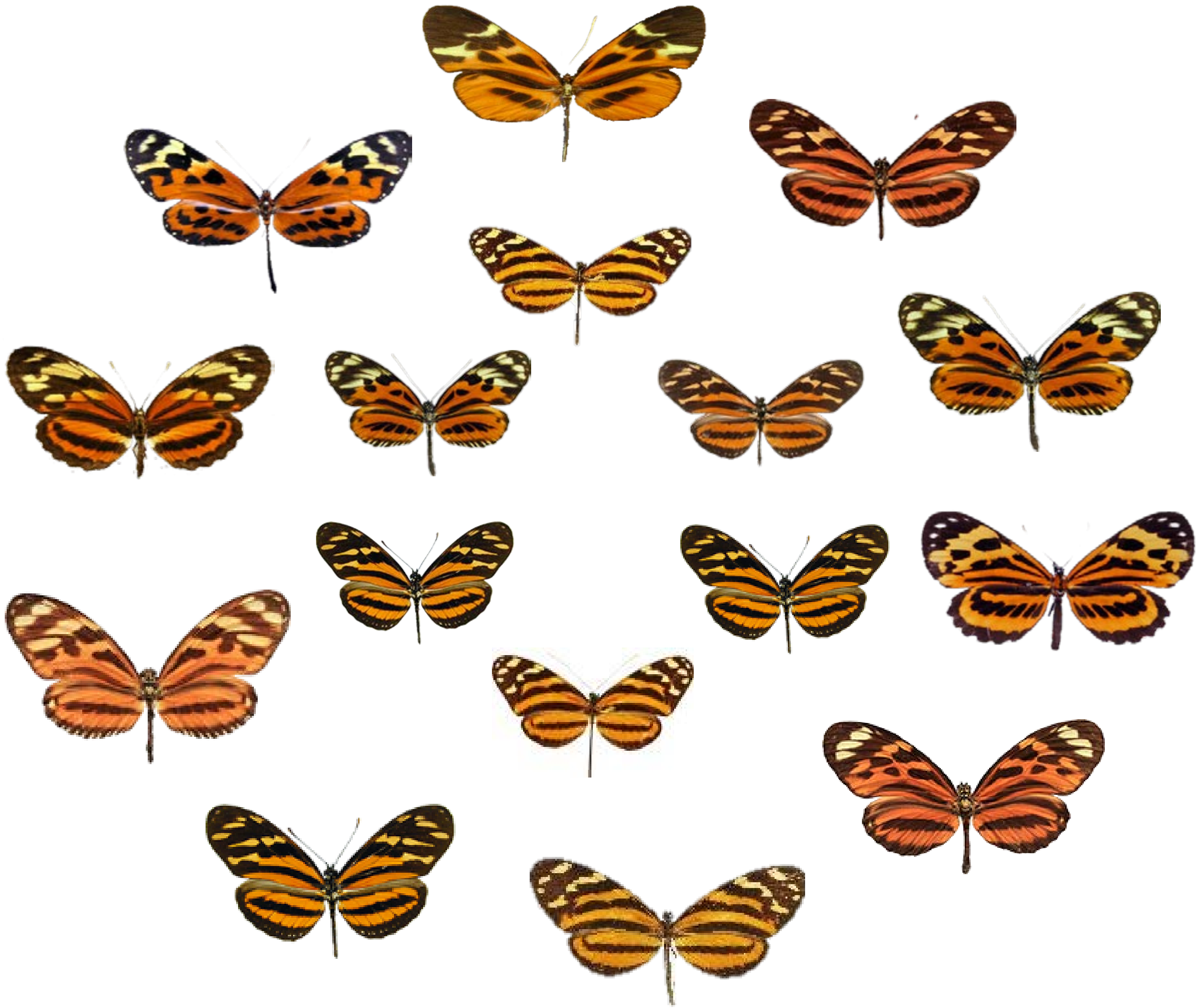
Müllerian mimicry in neotropical butterflies

“One ring to bring them all, and in the jungle bind them”

Maël Doré

Eddie Perochon, Keith Willmott, Sébastien Lavergne, Nicolas Chazot, André VL Freitas, Colin Fontaine, Krzysztof Kozak, Neil Rosser, Marianne Elias

GTOE 2023



Credit photos: C. Jiggings

MUSÉUM NAL HIST NATURELLE

ISYEB Institut de Systématique, Evolution, Biodiversité

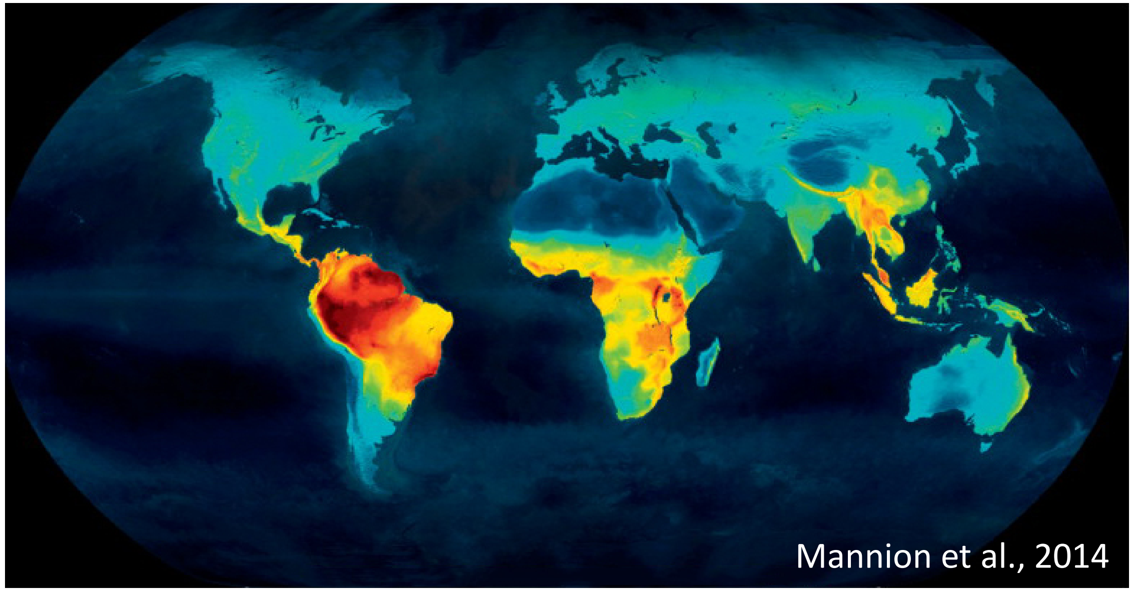
cnrs

CESCO Centre d'Écologie et des Sciences de la Conservation

Context

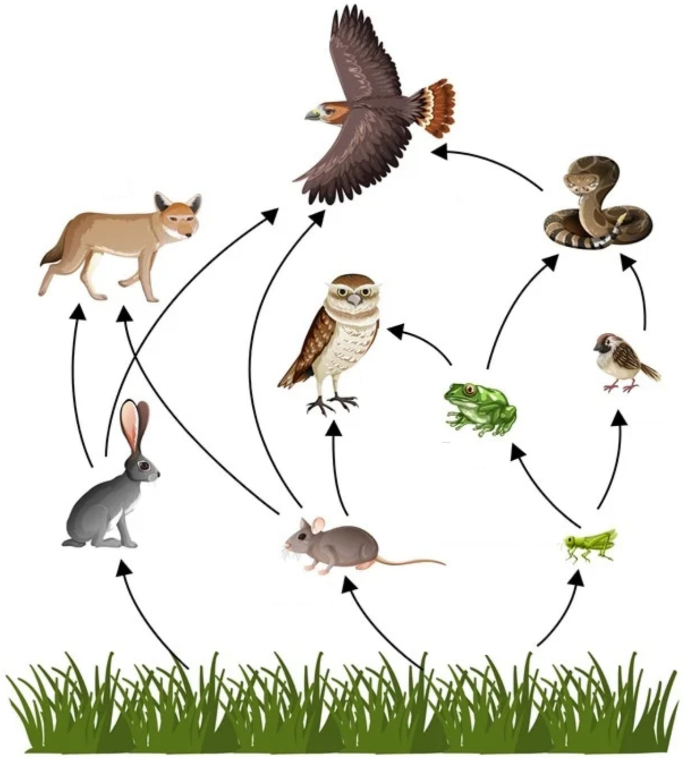
Biodiversity

Biological units



+

Interactions



Credit: Shutterstock.com

Context

Mutualistic interactions:

- Cooperative hunting
- Plant facilitation
- Müllerian mimicry

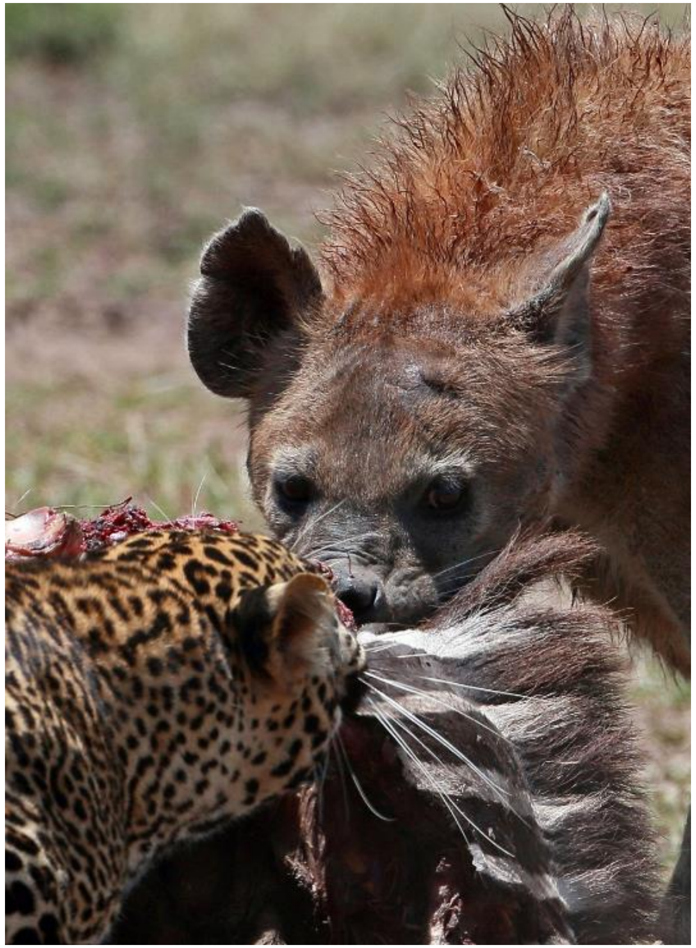
Credits: Thomas Kline

Credits: Amanda R. Liczner

Credits: Jason L. Brown

Context

Credit: Campillo Rafael



Credit: Caters News Agency

Credits: Anytka Olkova & Larry Myers

Exploitative competition:

- for local resources
- for habitats
- for space

Context

Competition / Mutualism

Spatial pattern

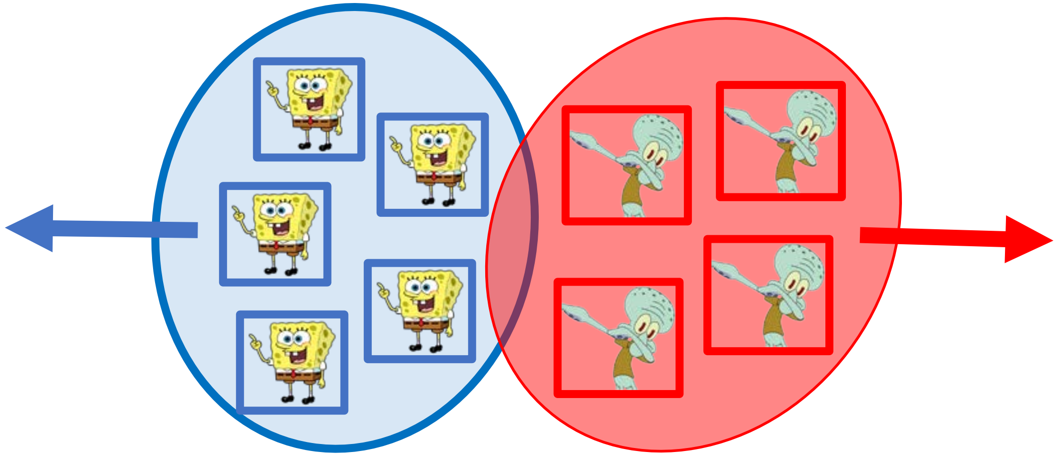
Niche evolution

Context

Competition –/–

Mutualism +/+

Spatial pattern



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Context

Competition −/−

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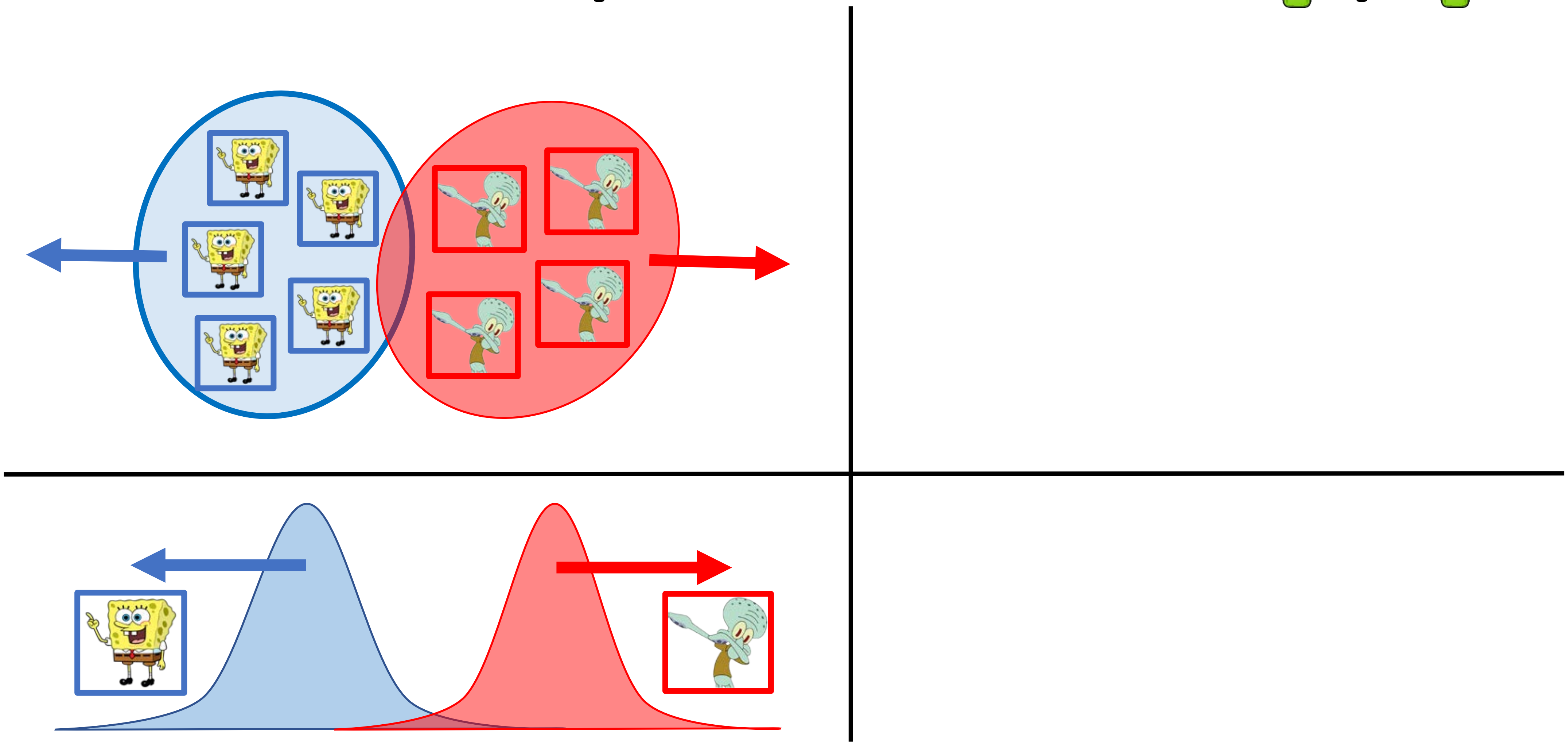

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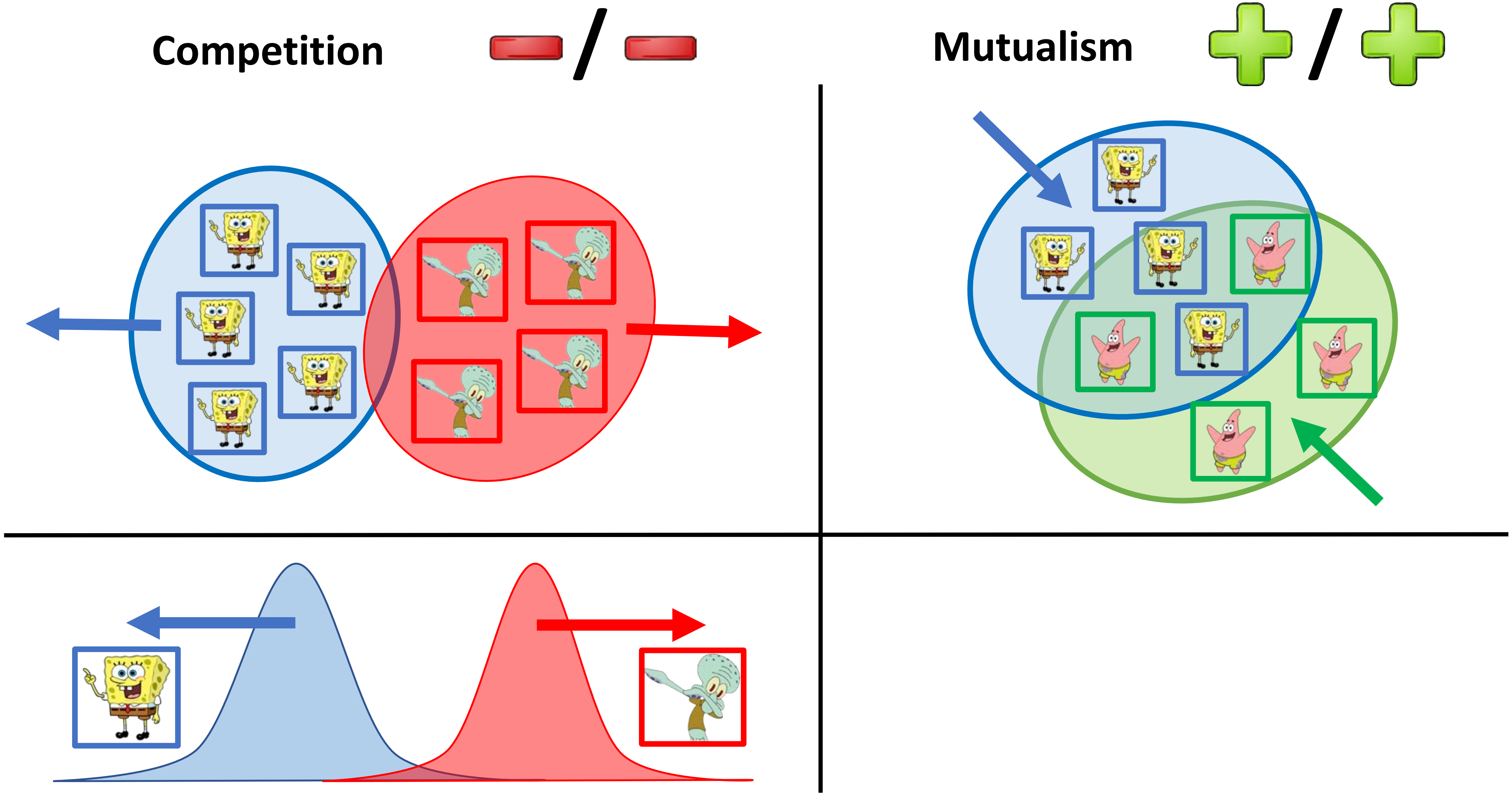

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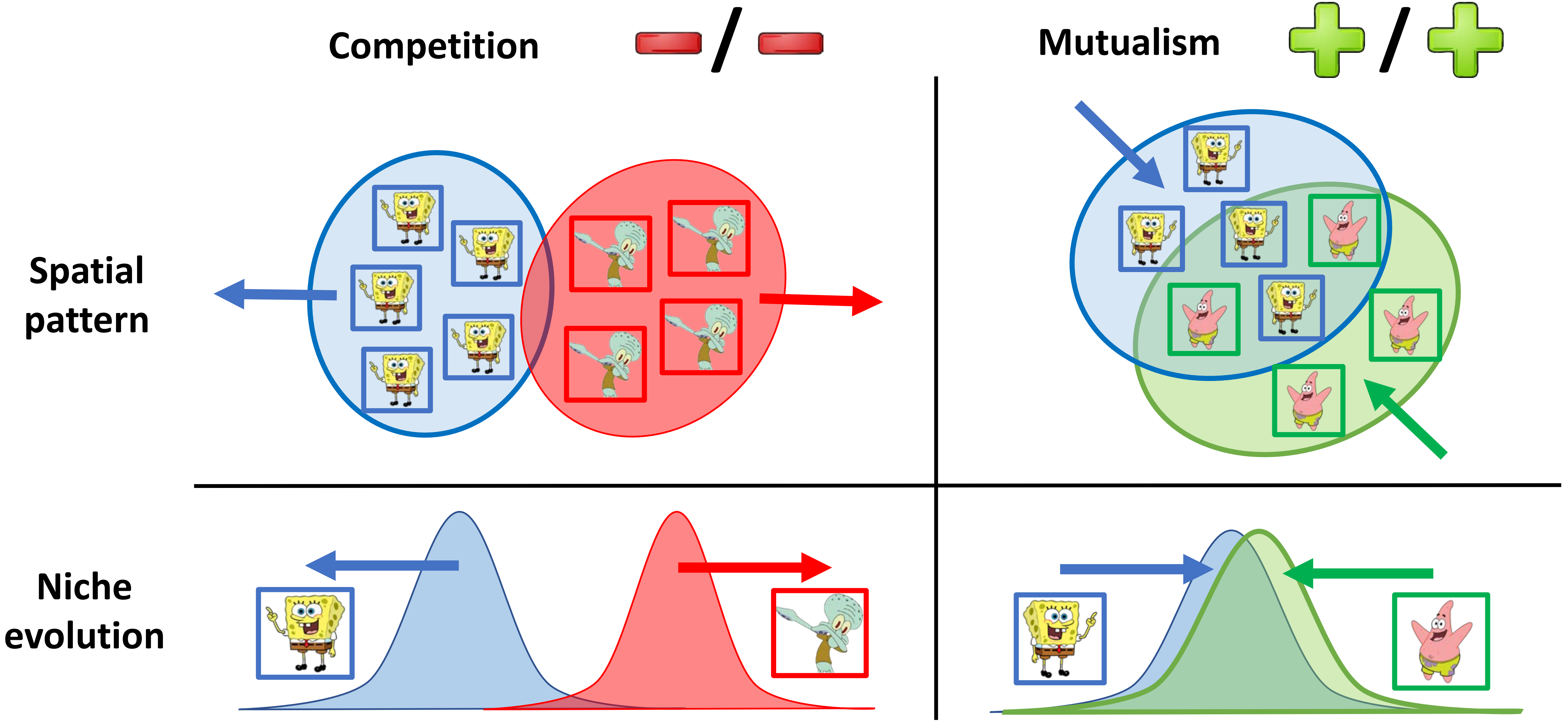


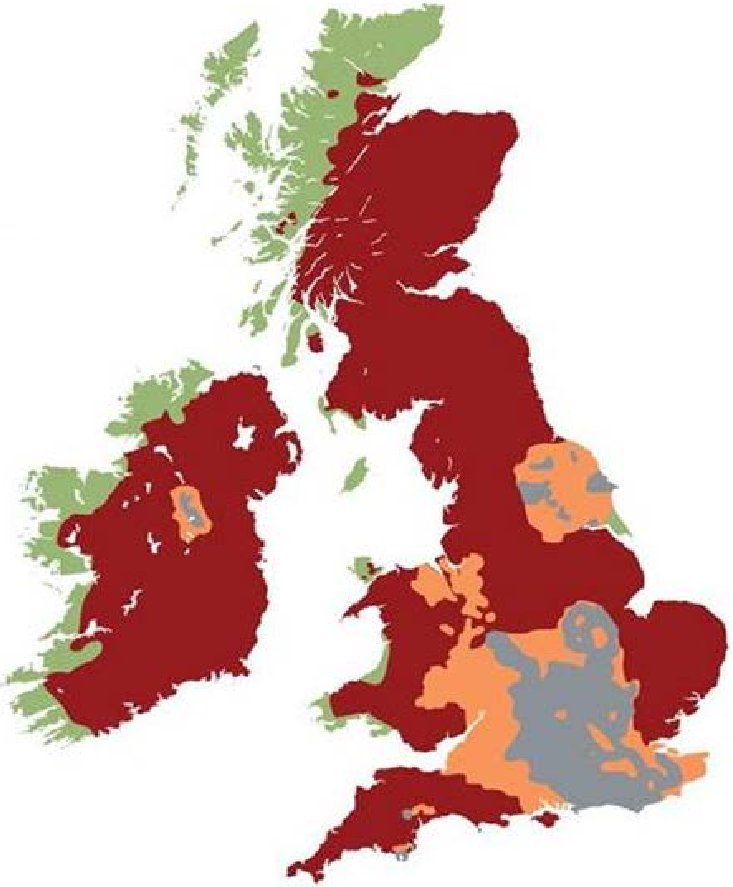
Context

Grey squirrel
Sciurus carolinensis

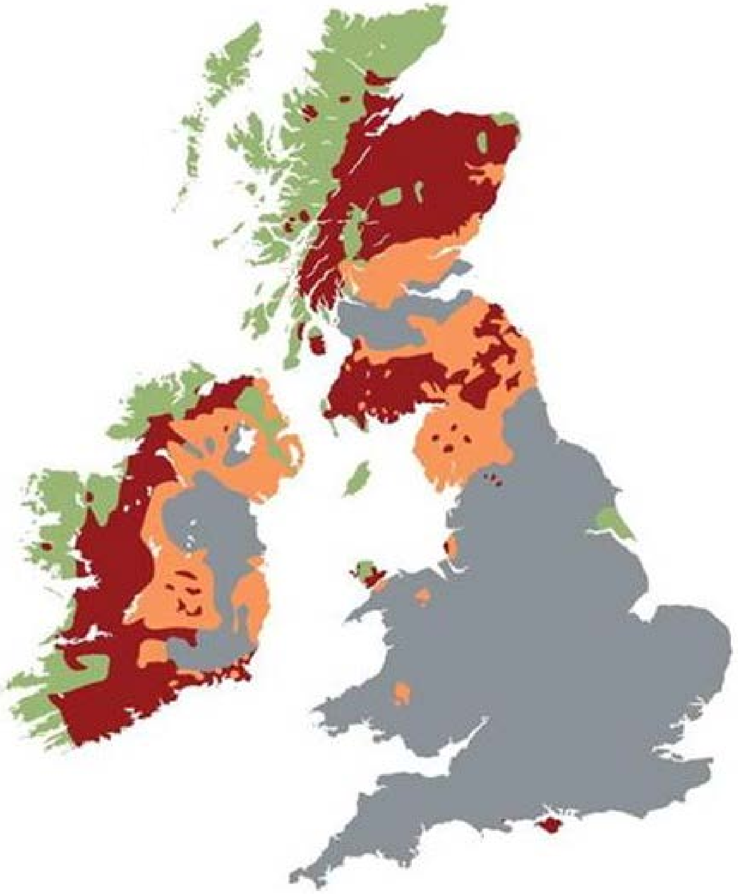
Both species

Red squirrel
Sciurus vulgaris

Year 1945



Year 2010



Source: WTSWW

Question & Hypotheses

How **mutualistic interactions** affect the **structure** and **evolution** of biodiversity at the **macroecological scale**?

Spatial pattern

Promote the large-scale **cooccurrence** of mutualistic species

Niche evolution

Drive the **convergence** of the niche of mutualistic species

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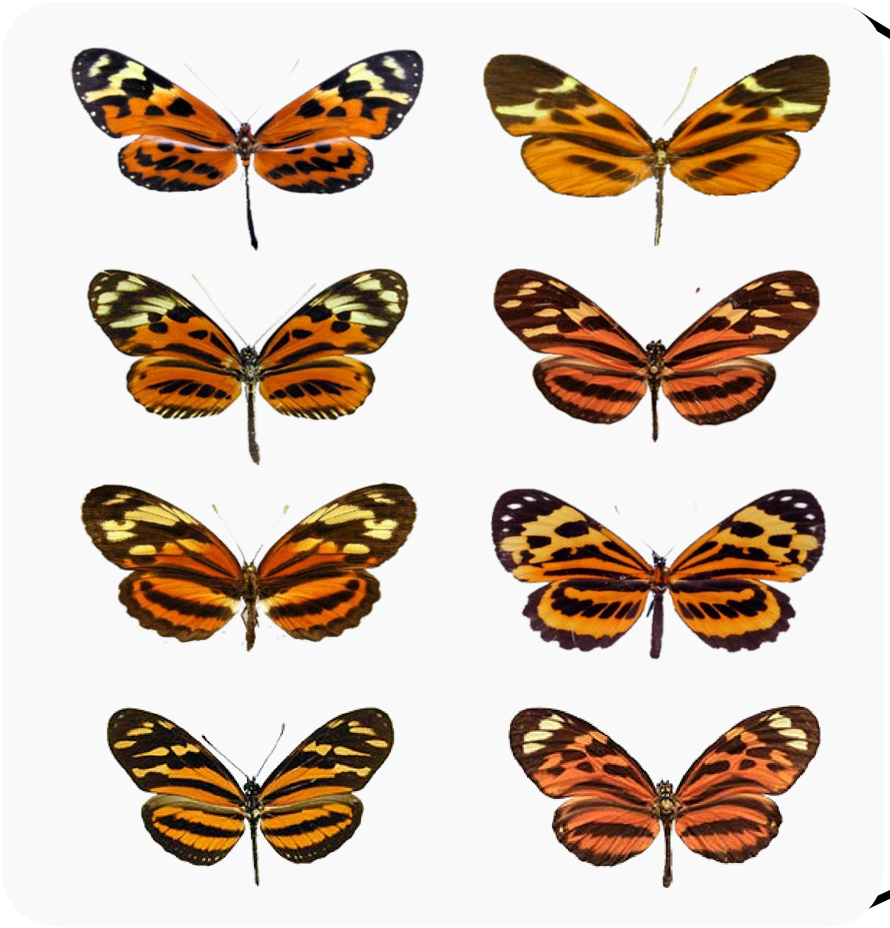
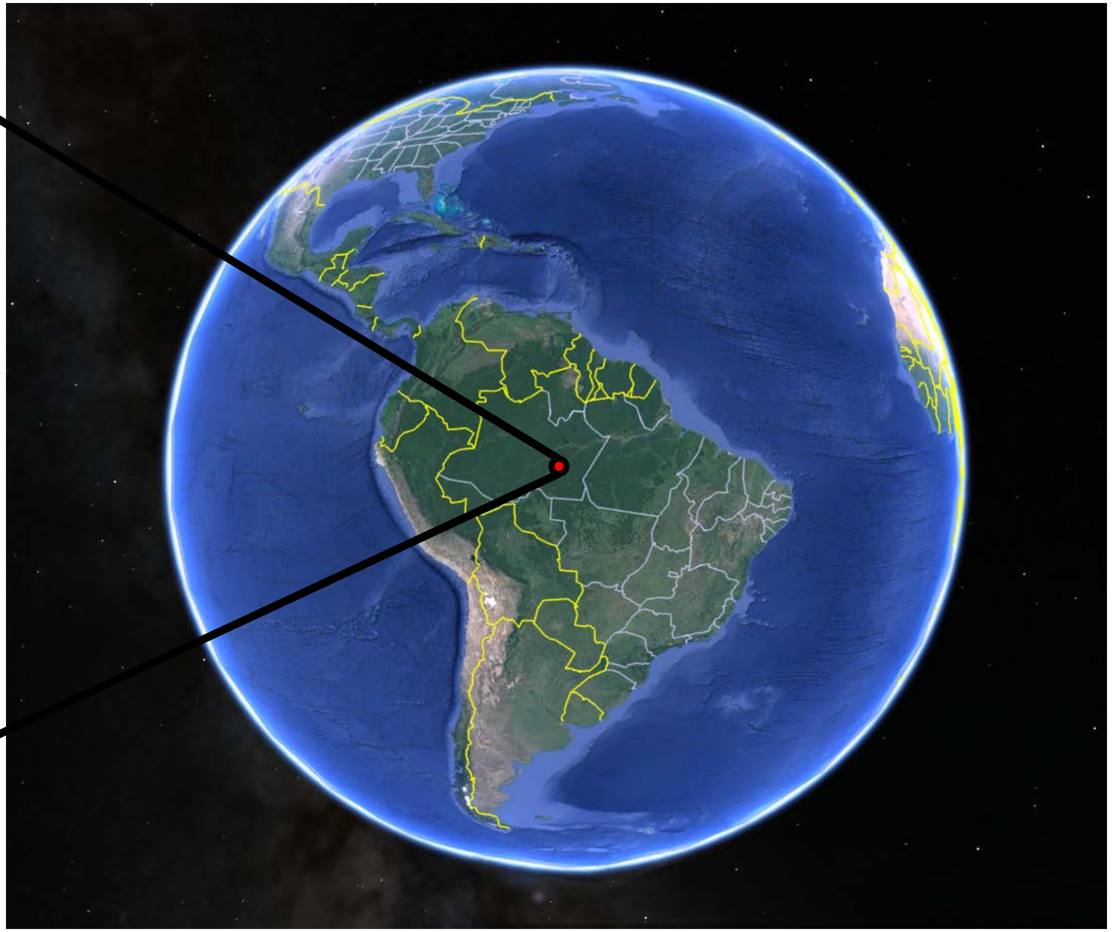


A mimicry ring



Credits: Google Earth

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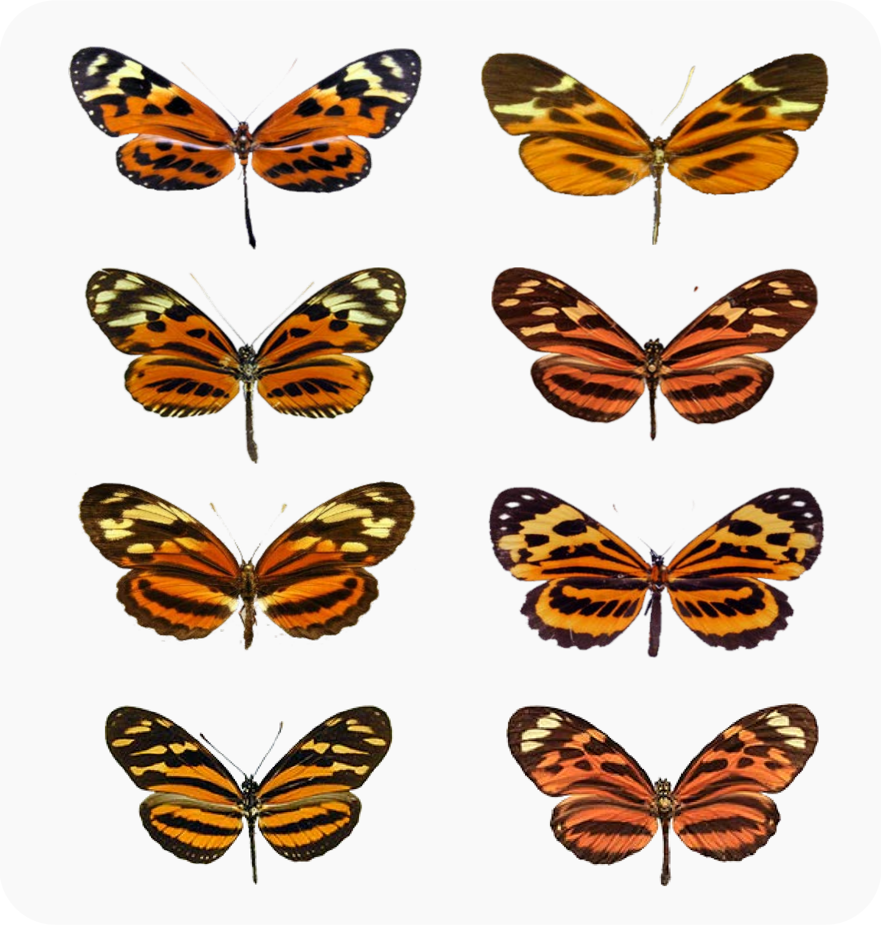

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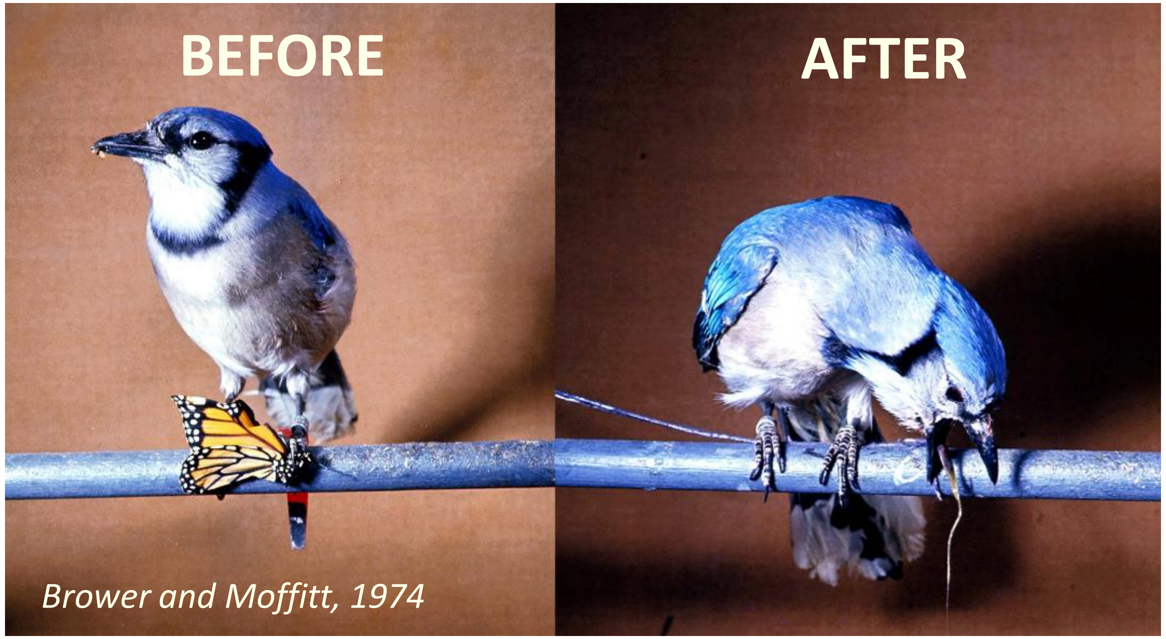

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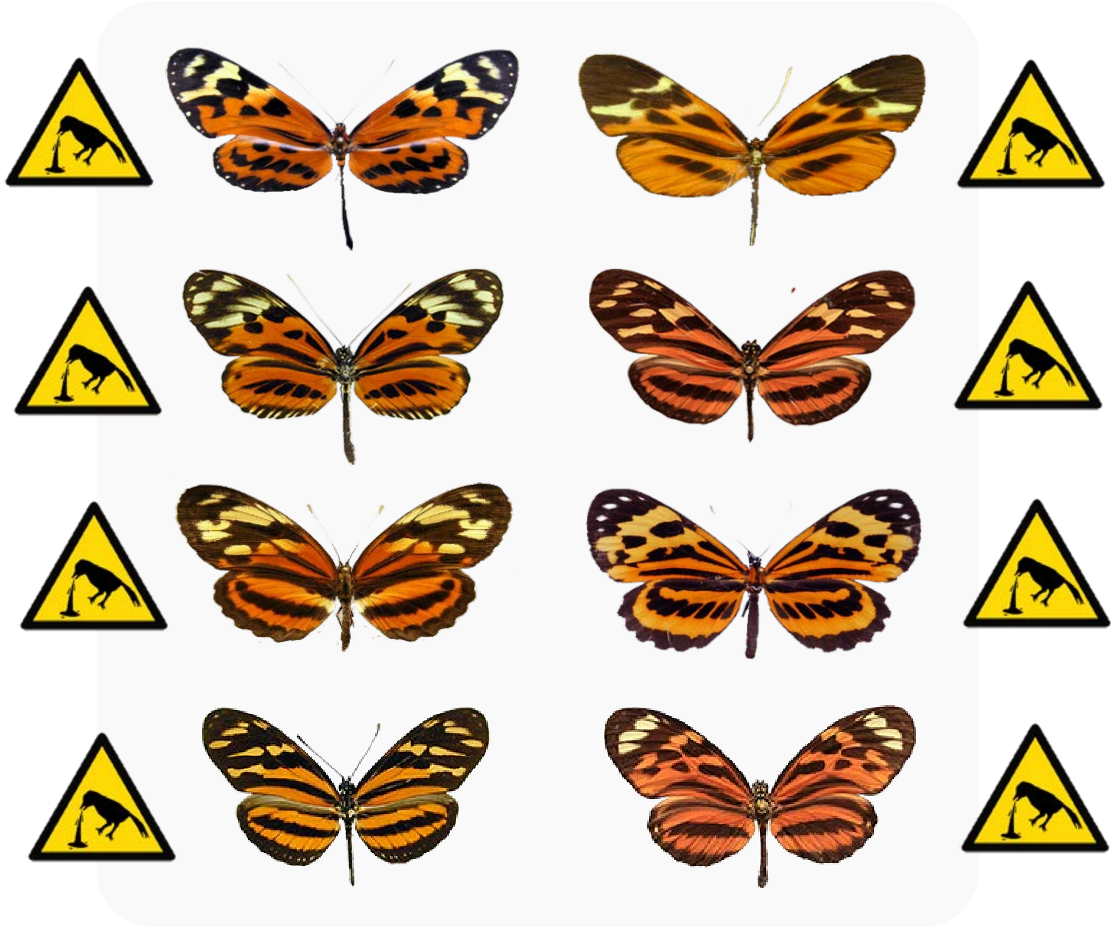

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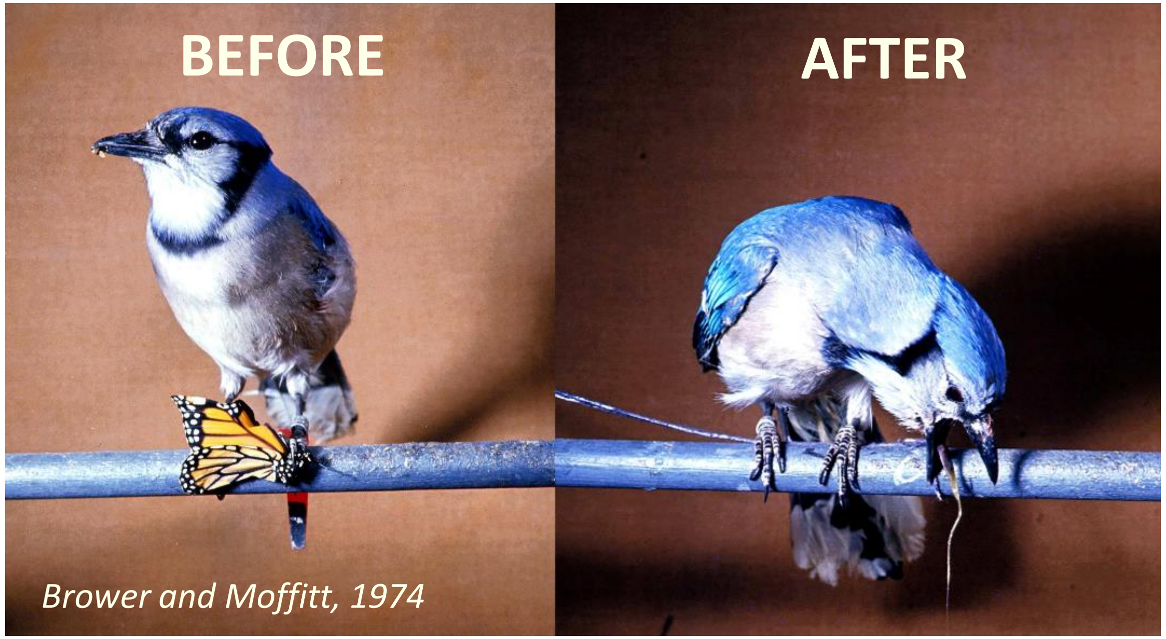


Study system: Müllerian mimicry

† Let a_1 and a_2 be the numbers of two distasteful species of butterflies in some definite district during one summer, and let n be the number of individuals of a distinct species which are destroyed in the course of a summer before its distastefulness is generally known. If both species are totally dissimilar, then each loses n individuals. If, however, they are undistinguishably similar, then the first loses $\frac{a_1 n}{a_1 + a_2}$, and the second $\frac{a_2 n}{a_1 + a_2}$. The absolute gain by resemblance is therefore for the first species $n - \frac{a_1 n}{a_1 + a_2} = \frac{a_2 n}{a_1 + a_2}$; and in a similar manner for the second, $\frac{a_1 n}{a_1 + a_2}$. This absolute gain, compared with the occurrence of the species, gives for the first, $1_1 = \frac{a_2 n}{a_1 (a_1 + a_2)}$, and for the second species, $1_2 = \frac{a_1 n}{a_2 (a_1 + a_2)}$, whence follows the proportion, $1_1 : 1_2 = a_2^2 : a_1^2$.

Müller, 1879

Fritz Müller
(1821 – 1897)

Study system: Müllerian mimicry

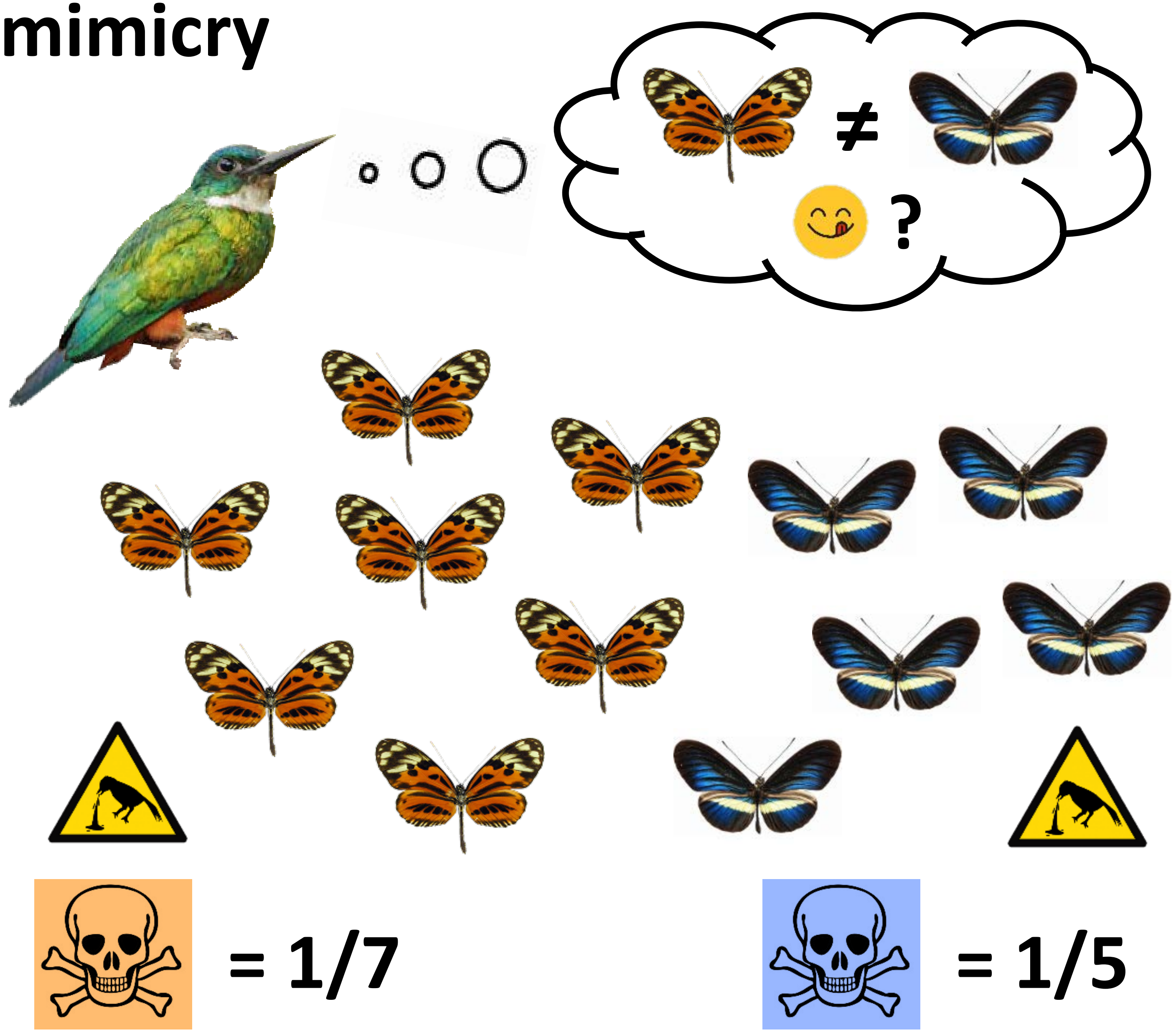
1/ **Positive frequence-dependent** selection

2/ Advantage for **similarity**

Consequences:

- Local pattern **convergence**
  => **mimicry rings**

- Mutual benefit from cooccurrence
  => **mutualistic interactions**



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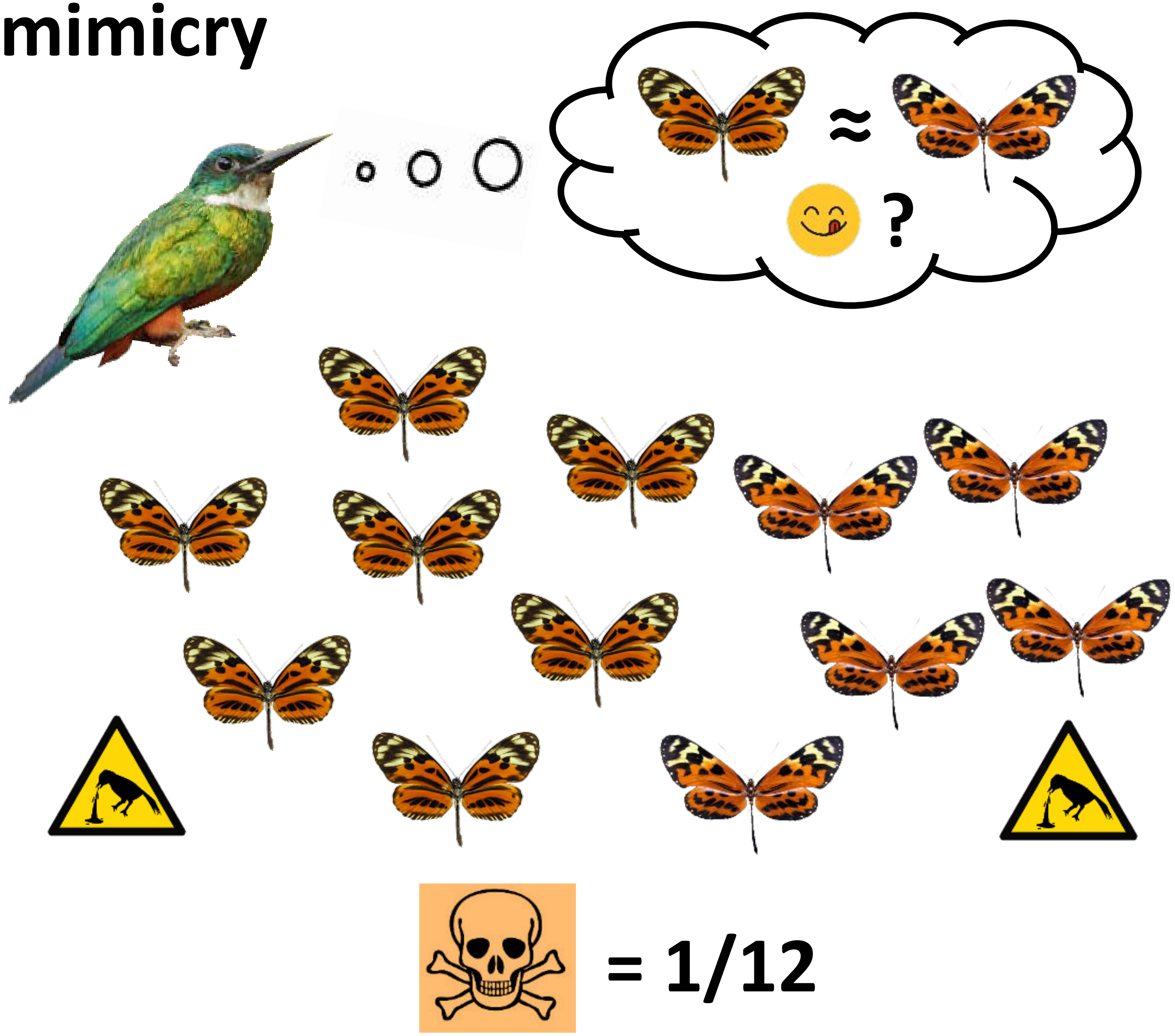

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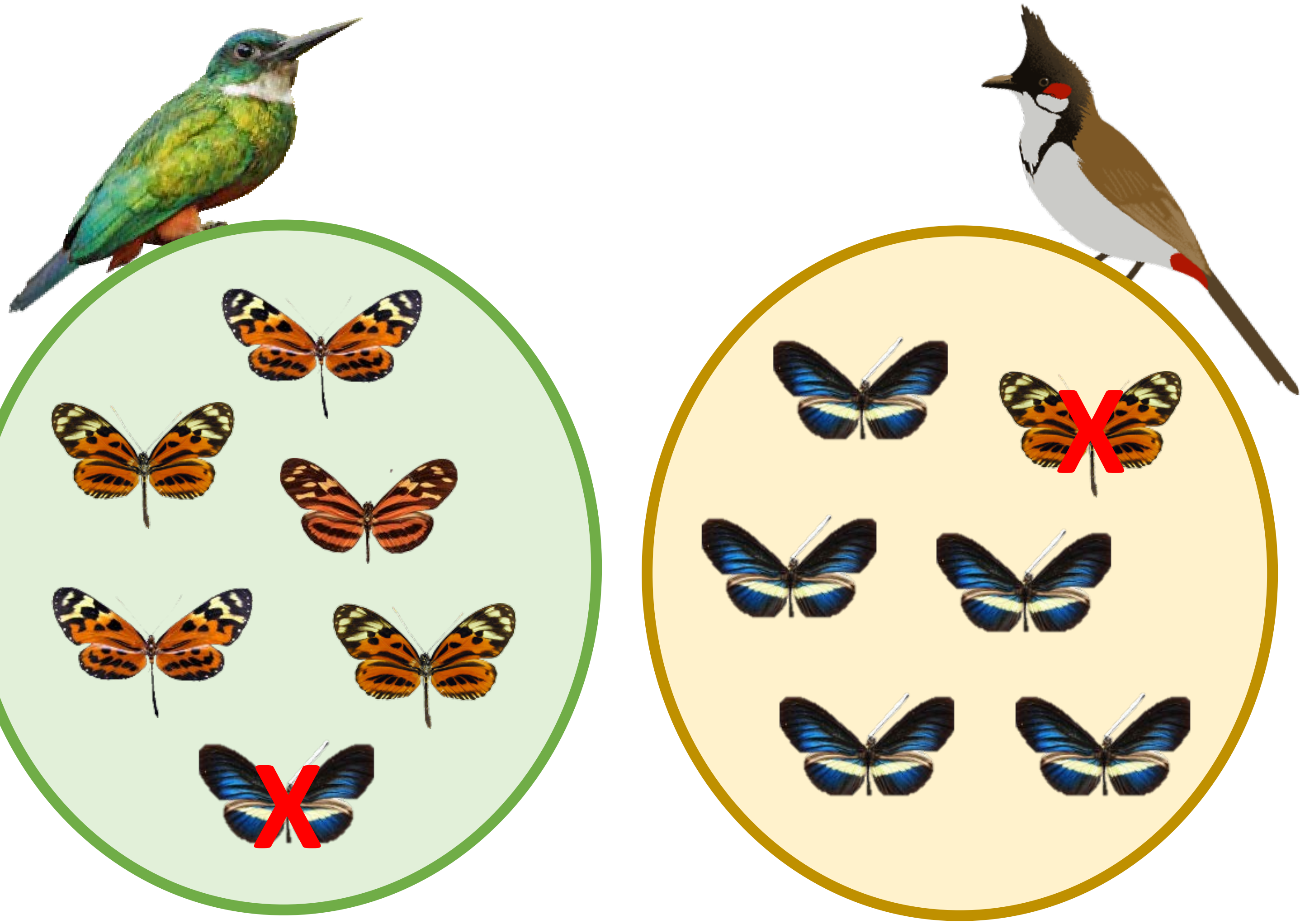


Study system: Neotropical butterflies

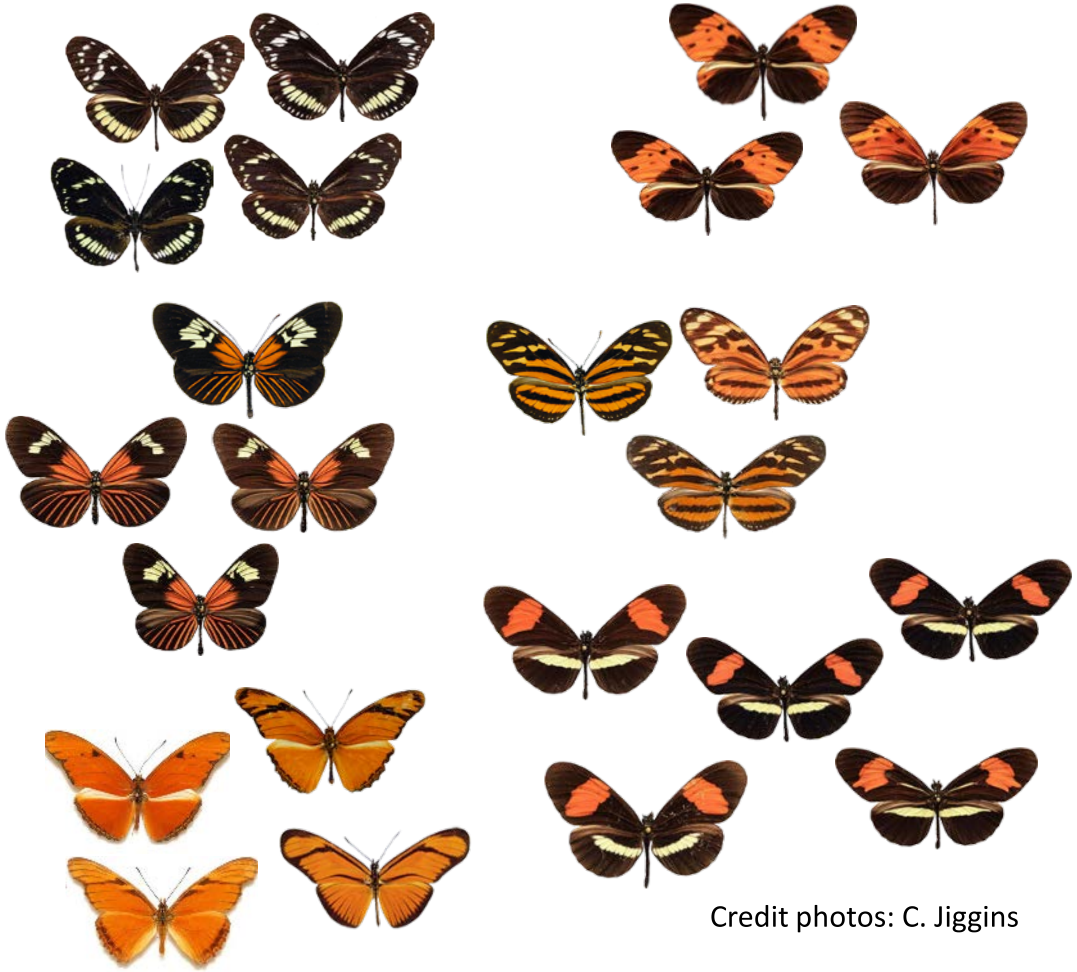
	Ithomiini tribe	Heliconiini tribe

Mimicry

Phylogeny

Geography

Credit photos: N. Chazot



Credit photos: C. Jiggins

Study system: Neotropical butterflies

Ithomiini tribe | Heliconiini tribe

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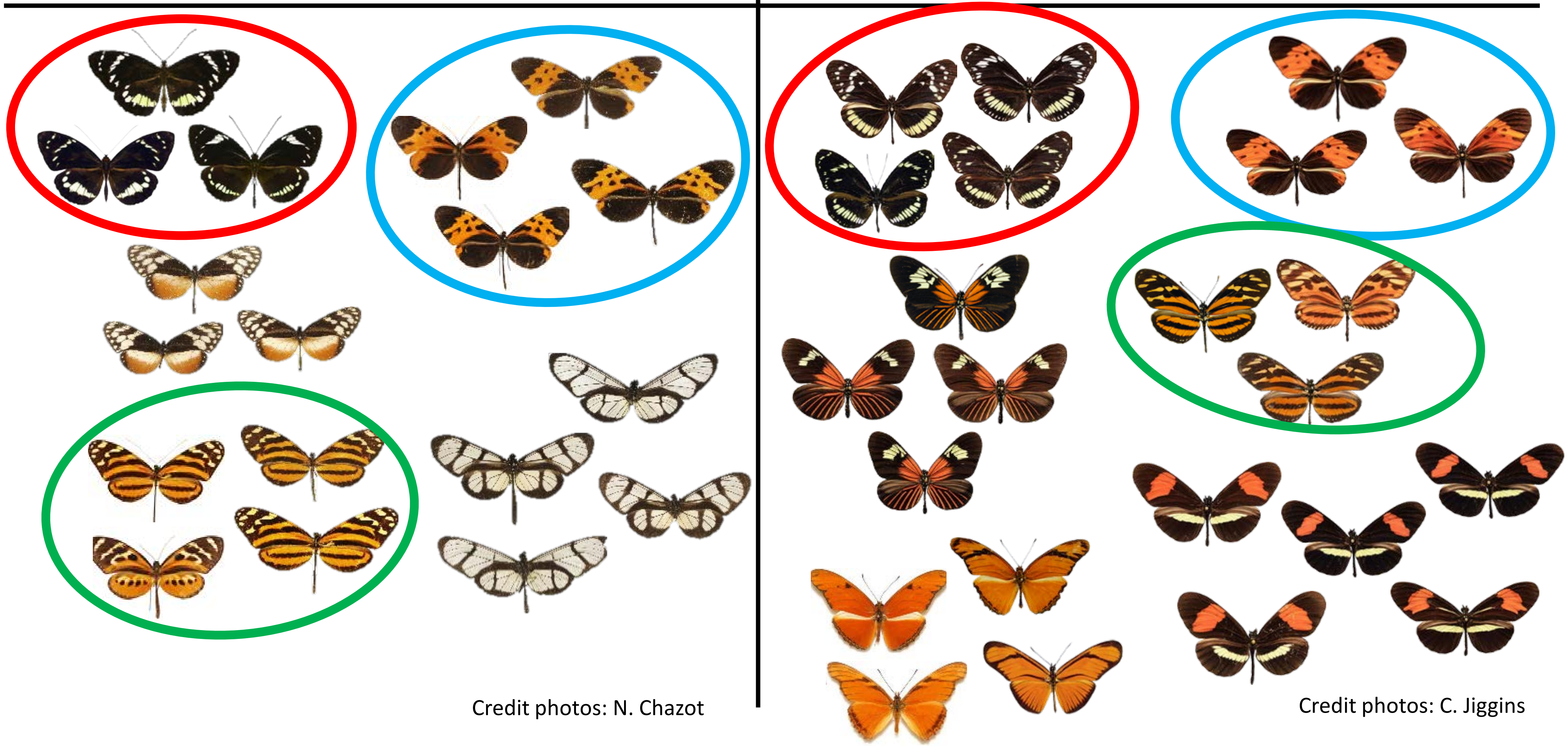

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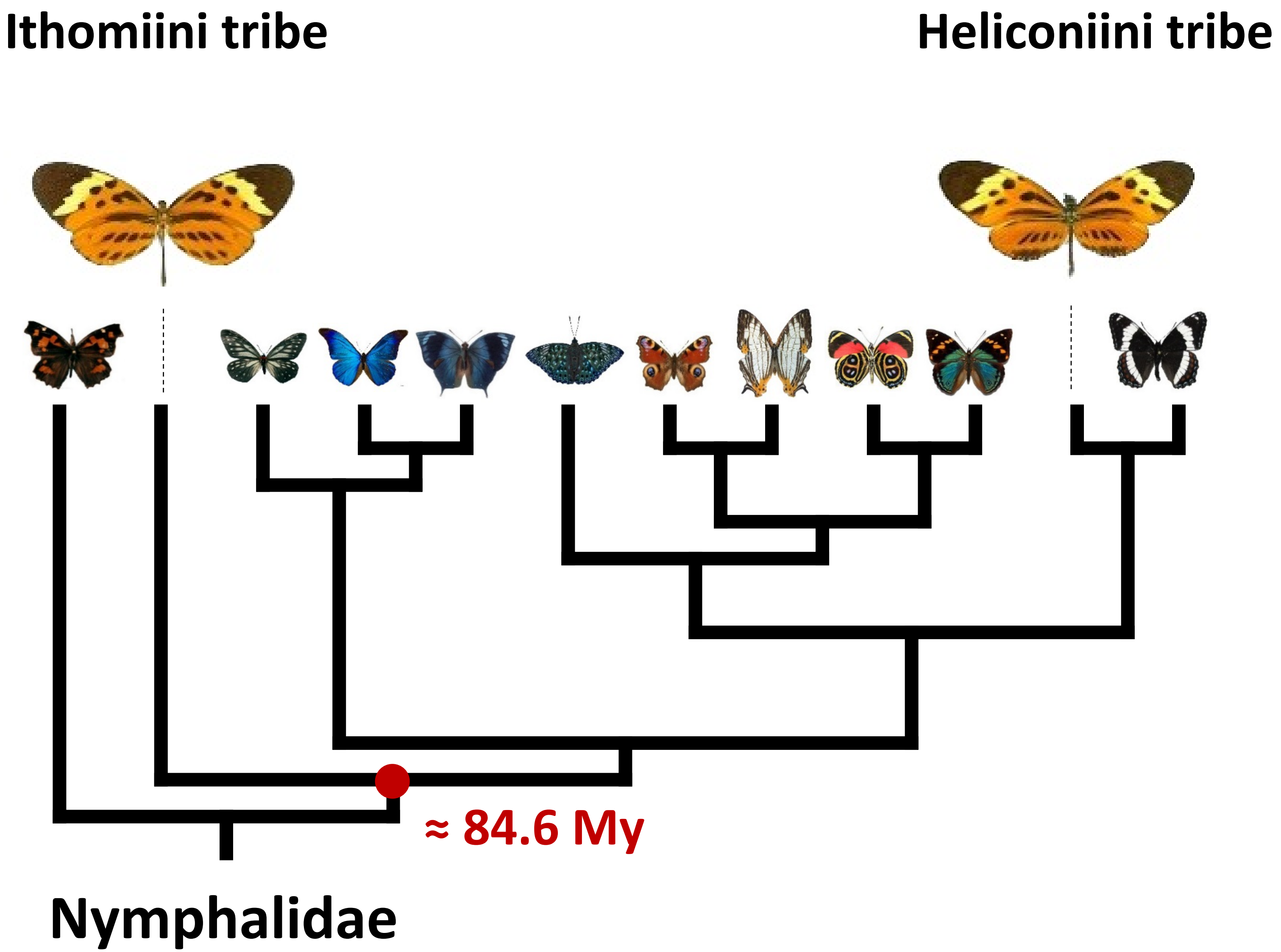

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Heliconiini tribe

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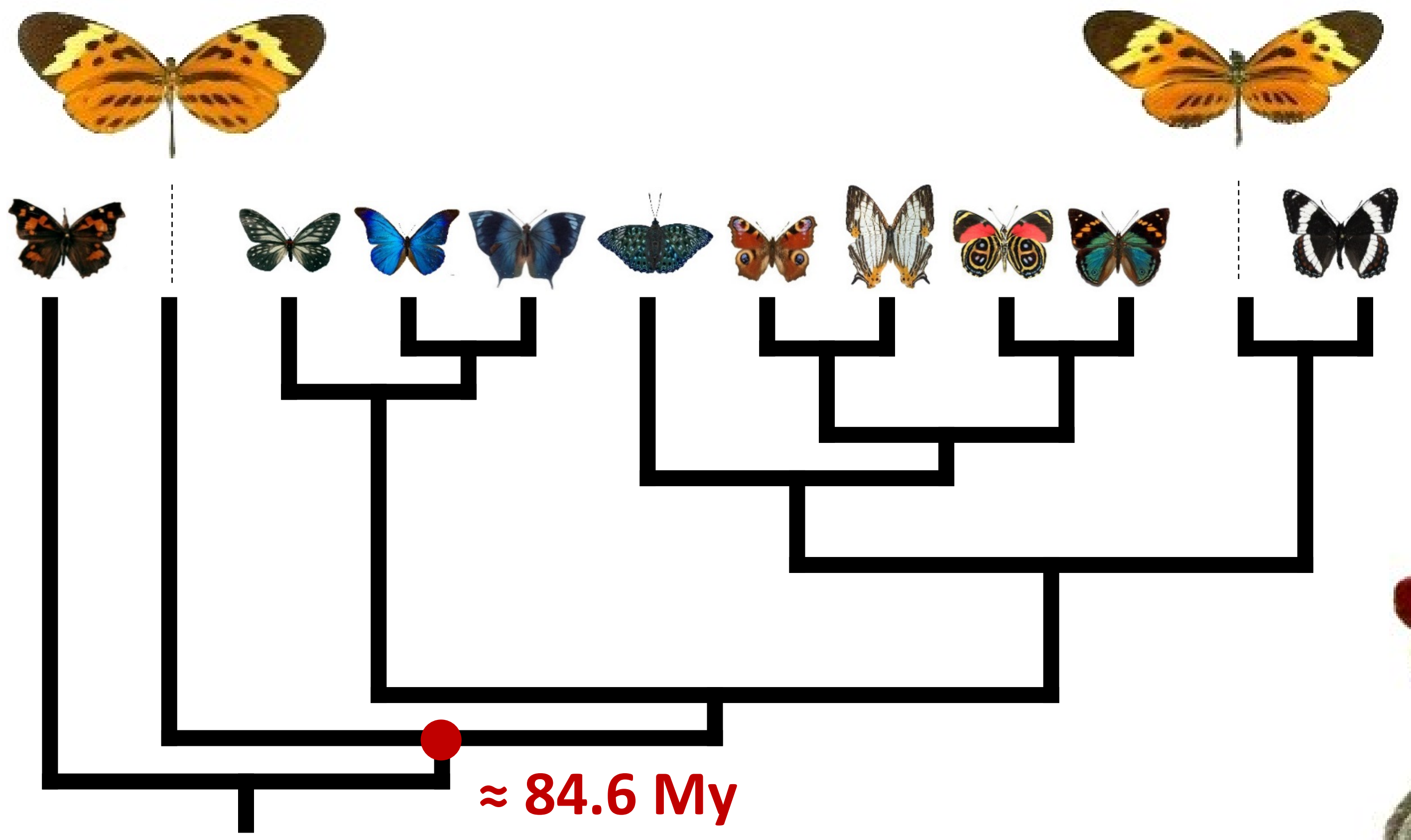


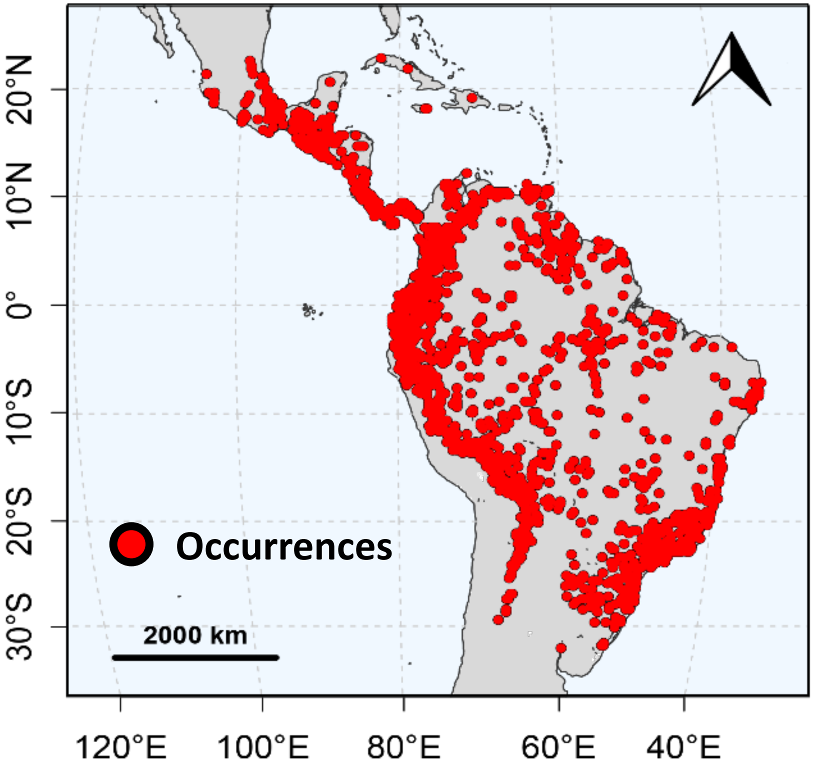
Nymphalidae

Study system: Neotropical butterflies

	Ithomiini tribe	Heliconiini tribe
Mimicry Phylogeny Geography	Occurrence map	Occurrence map

Ithomiini tribe

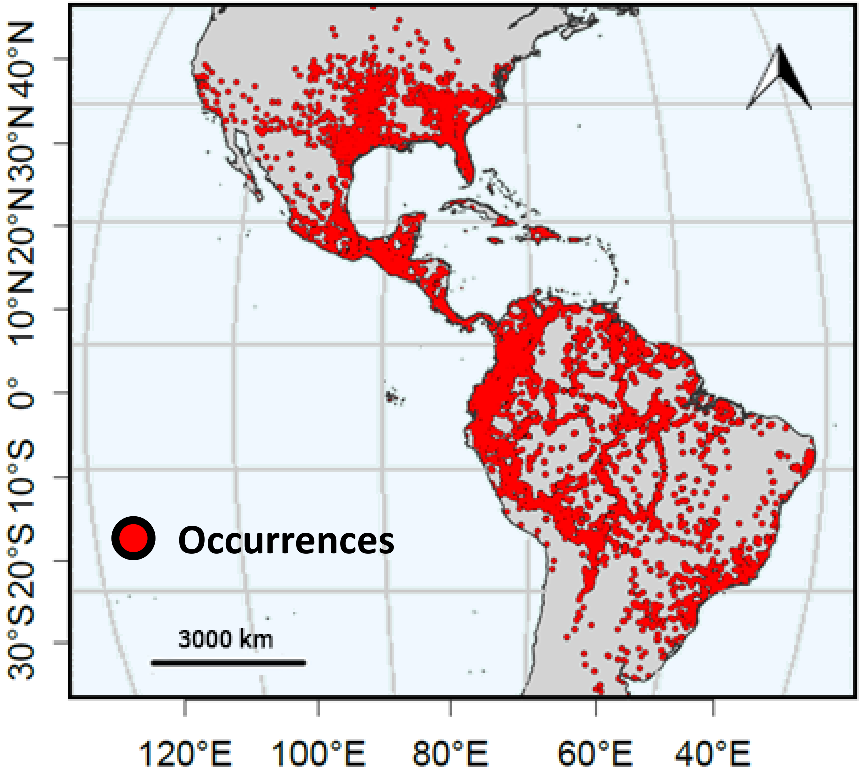
Occurrence map



Doré et al., 2022

Heliconiini tribe

Occurrence map



Perochon et al., in prep

Study system: Neotropical butterflies

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Mimicry

Phylogeny

Geography

State-of-the-art

Structuration of mimetic communities by:

- **flight height** *(Beccaloni, 1997)*
- **microhabitats** *(Elias et al., 2008)*
- **host plants** *(Willmott & Mallet, 2004)*
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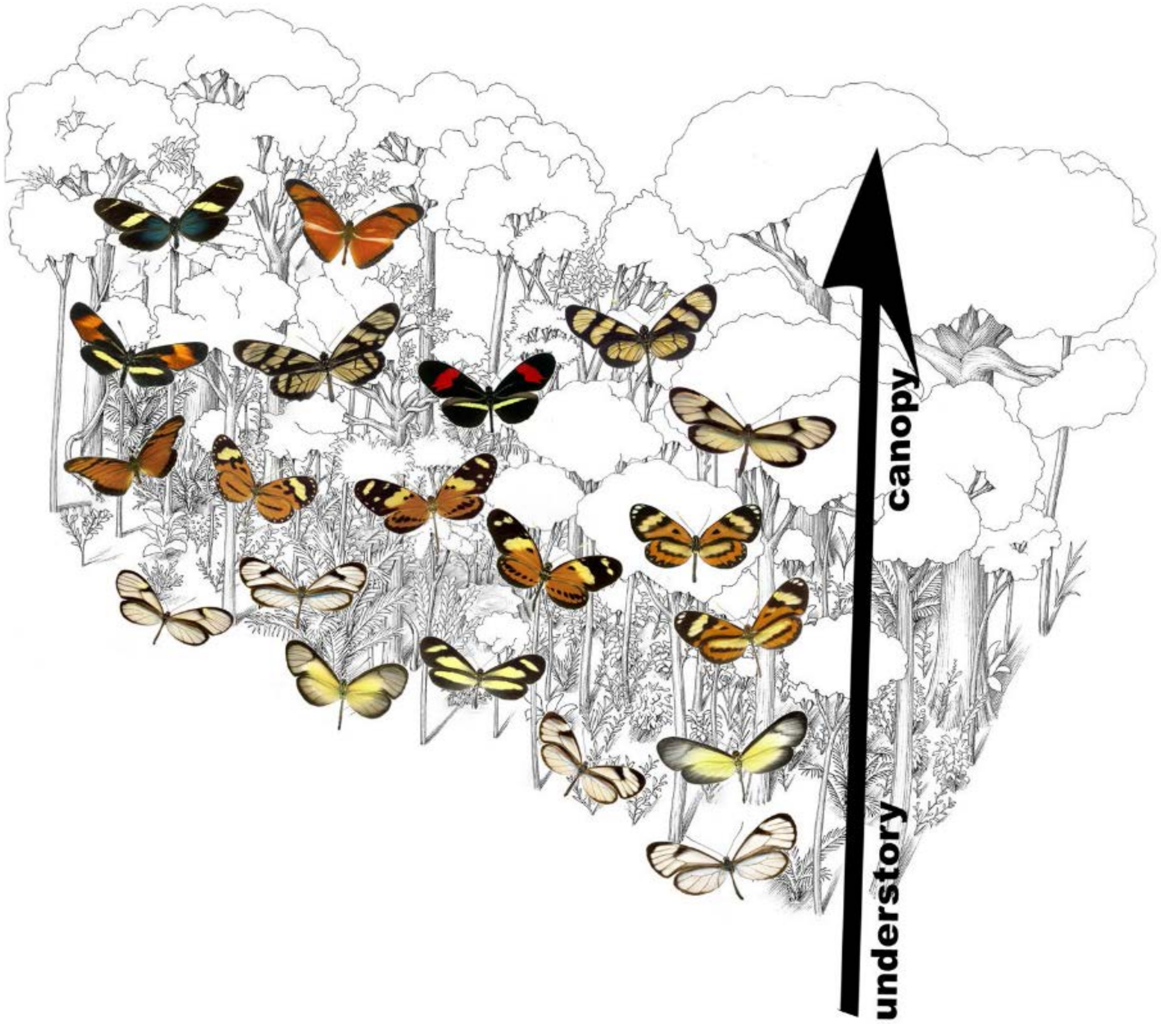
Limits :

- **Spatial**: local to regional
- **Taxonomic**: few genera



Adapted from Birskis-Baros et al., 2021

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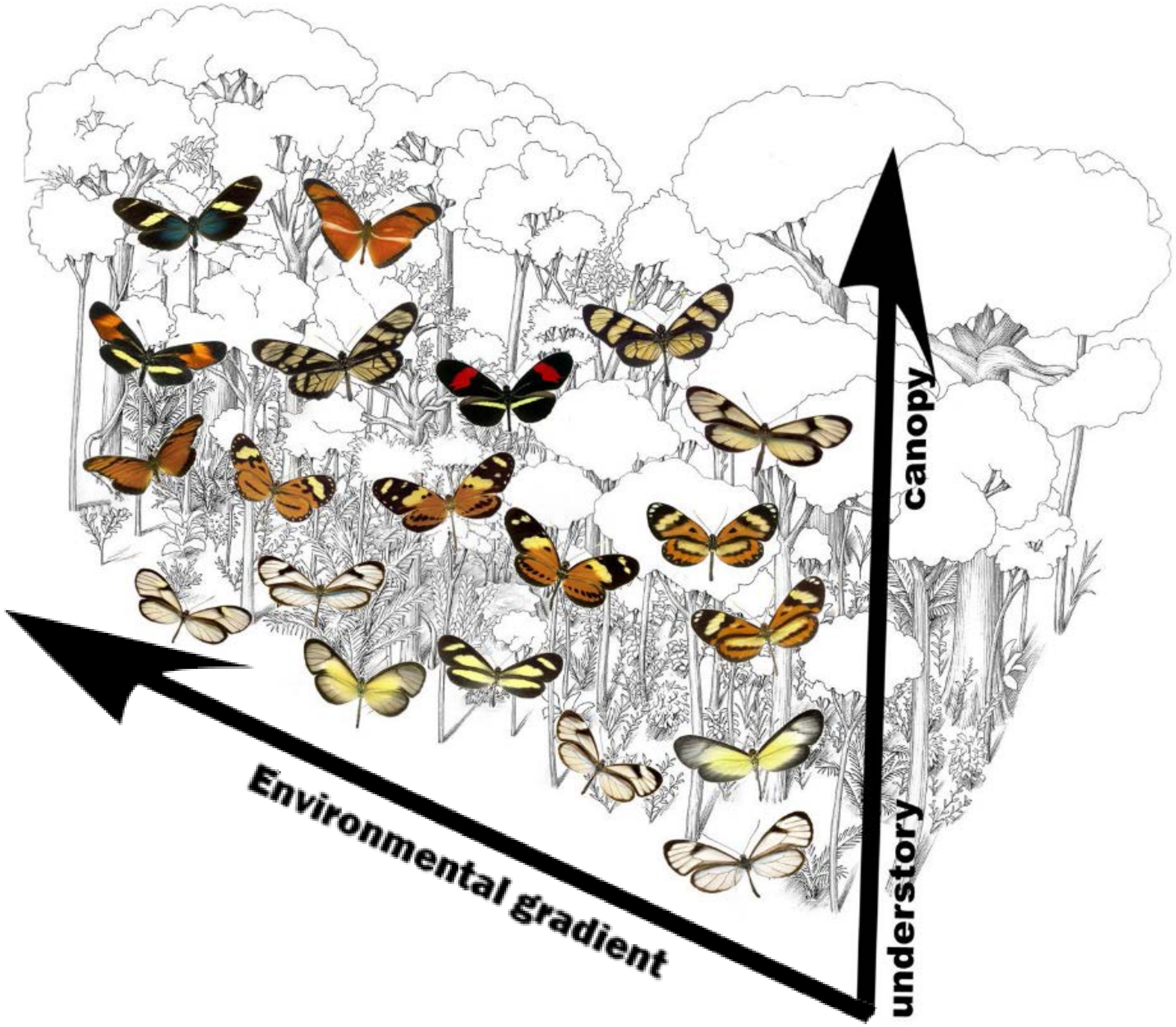

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Credits: Arthur Anker

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This study: **macroecological scale** for the **whole tribes**
Dimensions = **climatic niche**

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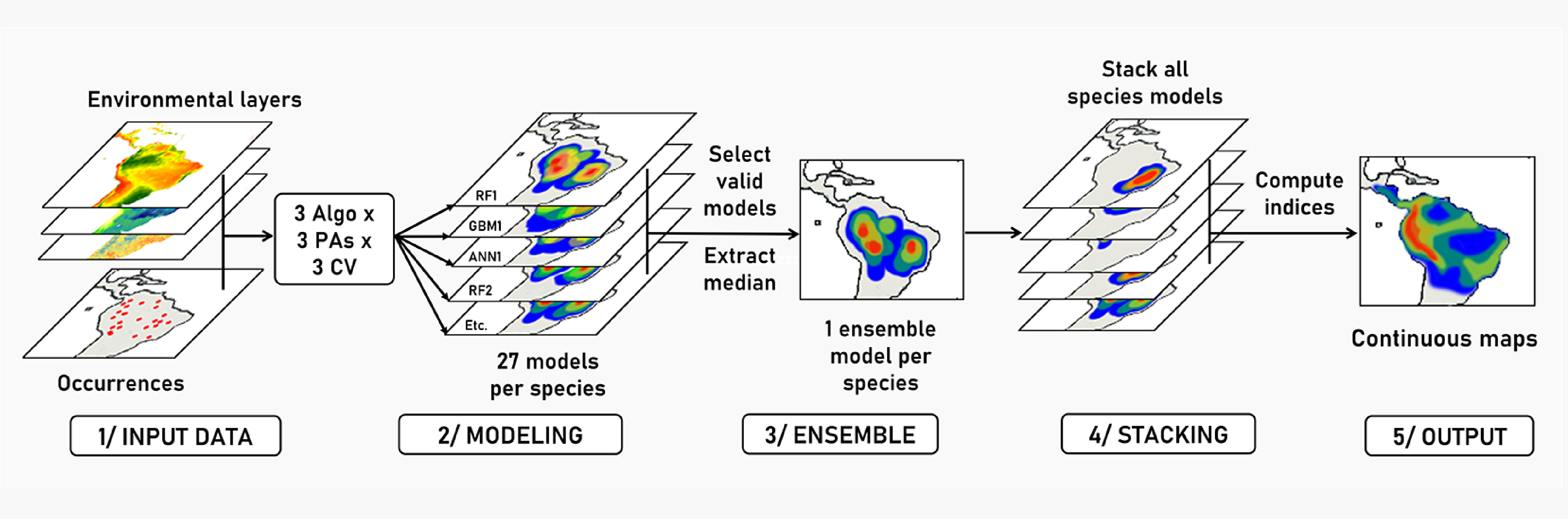
Objectives

How **mutualistic interactions** affect the **structure** and **evolution** of biodiversity at the **macroecological scale**?

1. **Biodiversity patterns**: Are large-scale **biodiversity patterns** different between tribes?
2. **Spatial congruence**: Do phenotypically similar species **cooccur** more than expected at random?
3. **Niche similarity**: Do phenotypically similar species have **similar climatic niche**?
4. **Niche convergence**: Is the climatic niche of phenotypically similar species **more similar** than expected from **shared ancestry**?

Species Distribution Modeling (SDM)

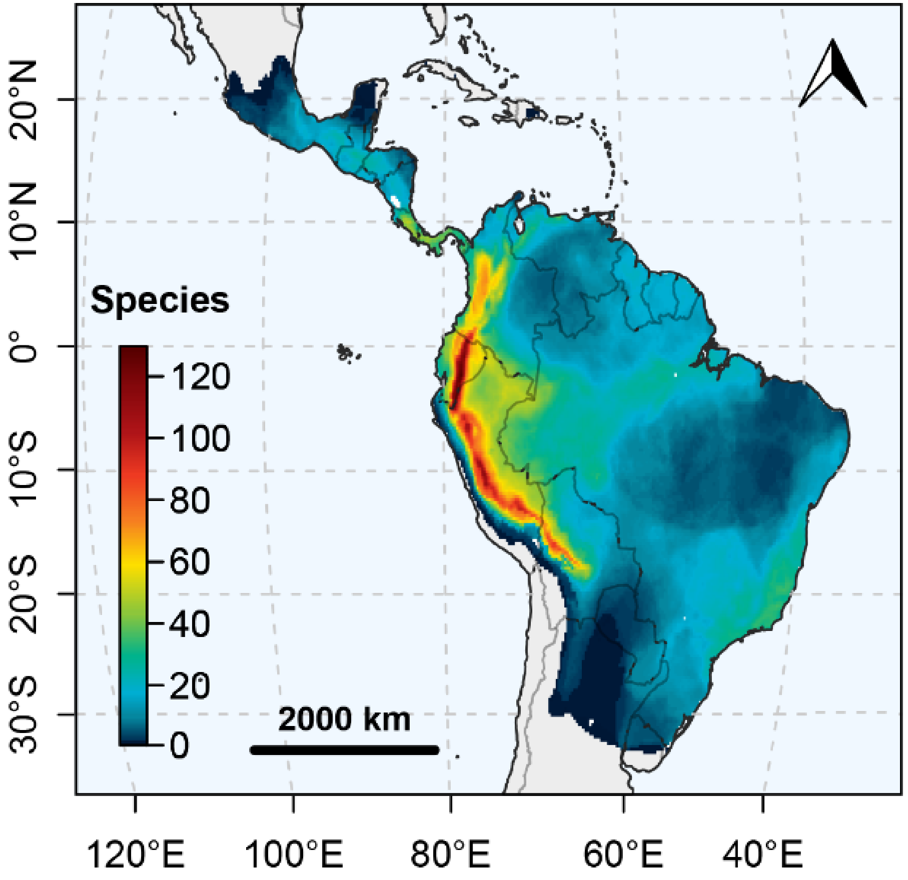


SDM → Species distribution maps → Diversity indices

Biodiversity patterns

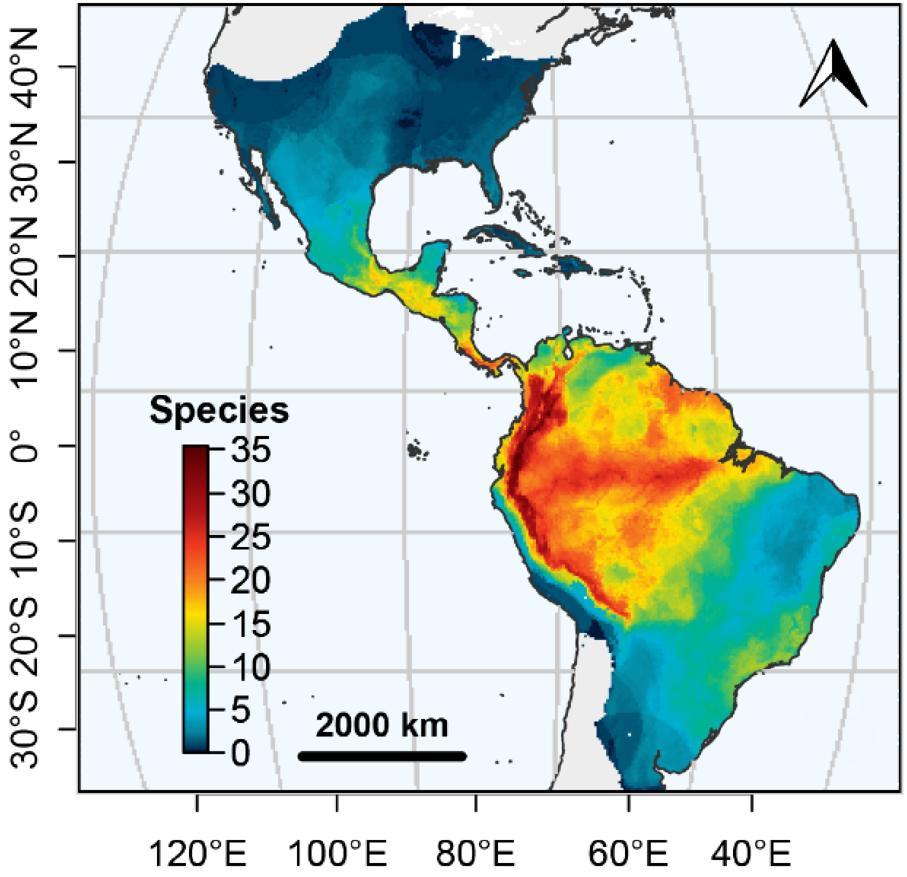
Species richness

Ithomiini
(396 species)



Doré et al., 2022

Heliconiini
(77 species)



Pérochon et al., in prep

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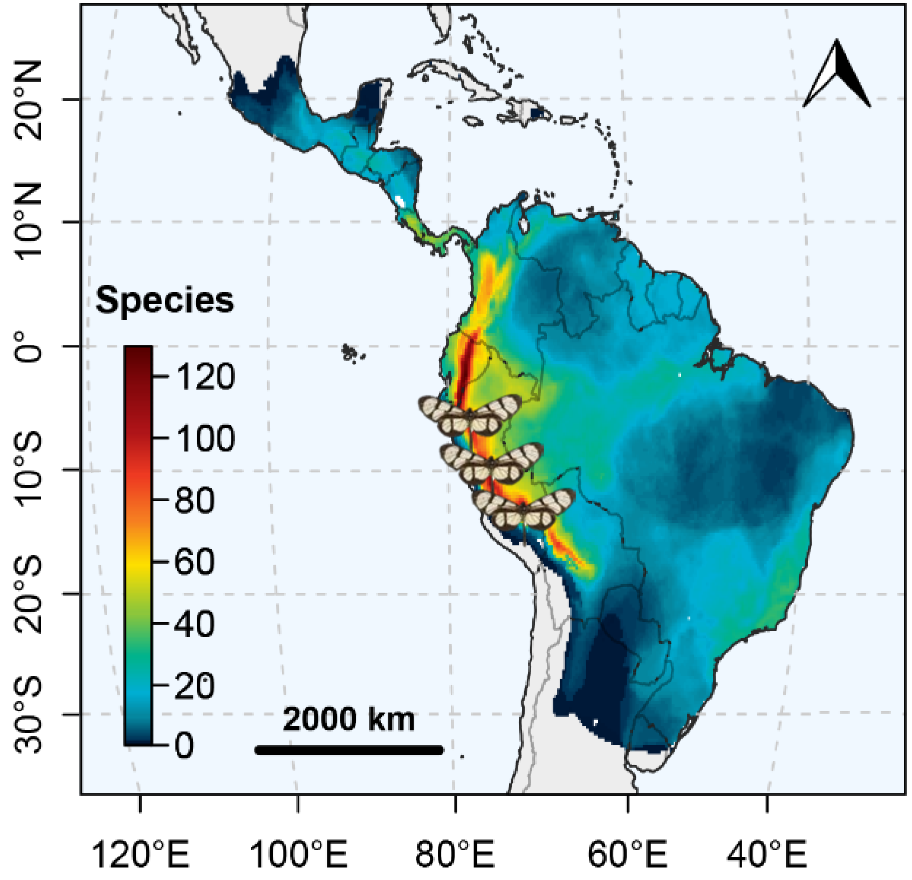

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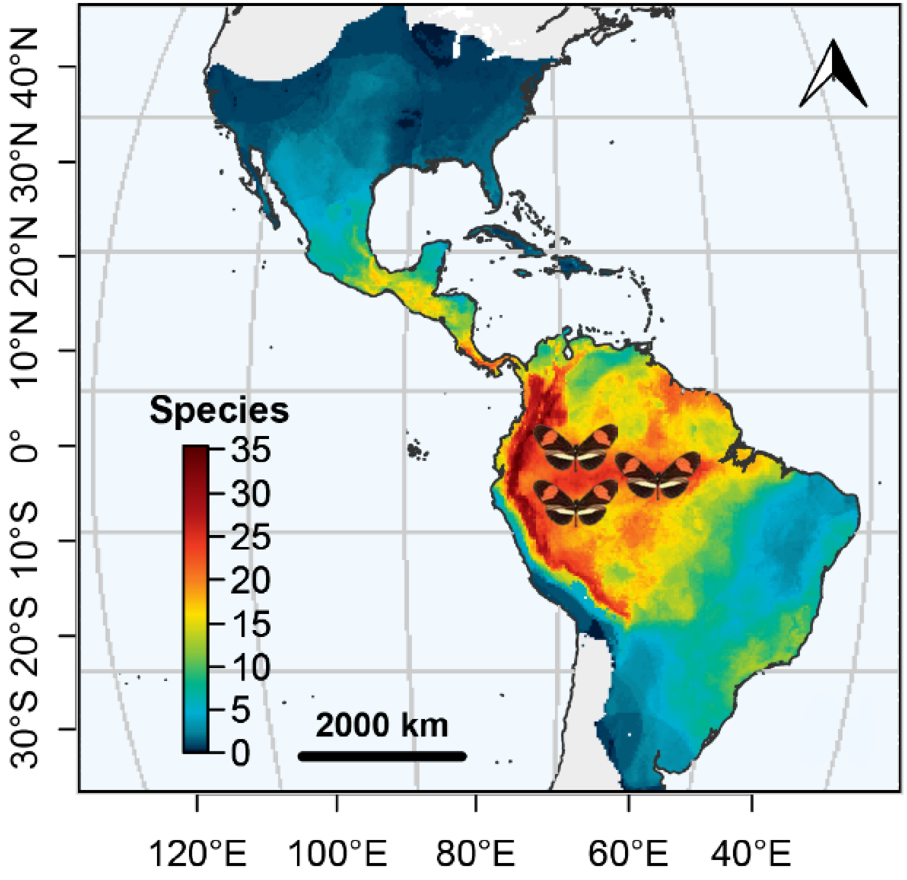

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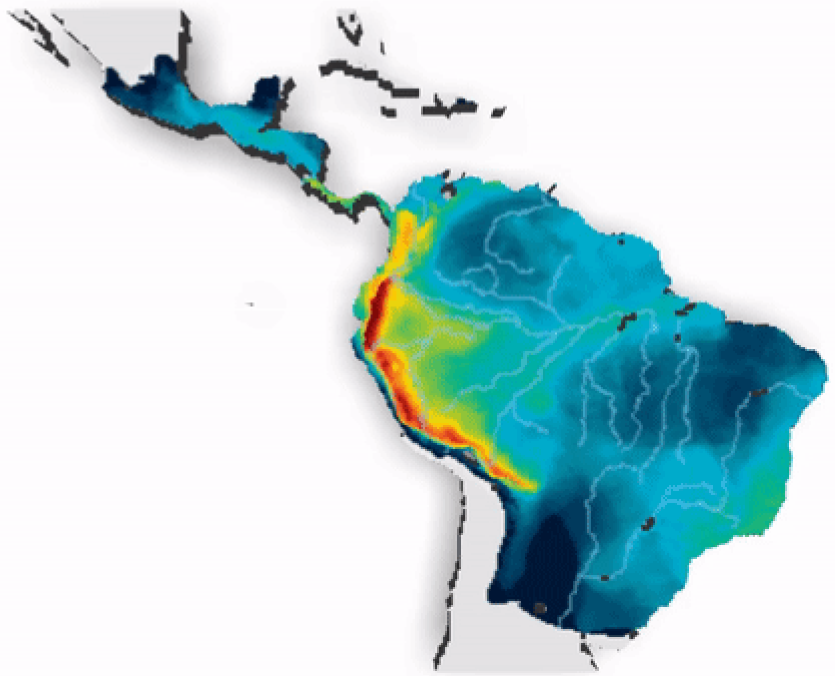

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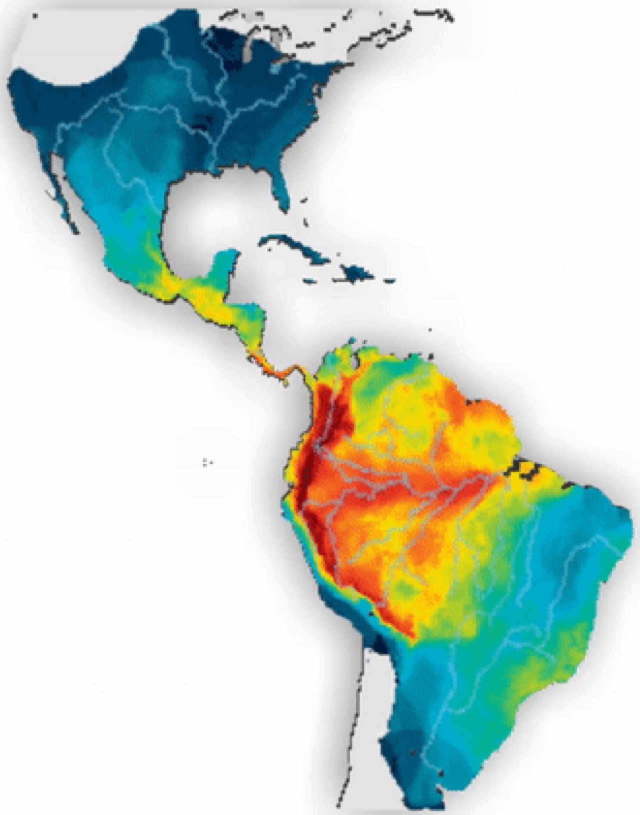

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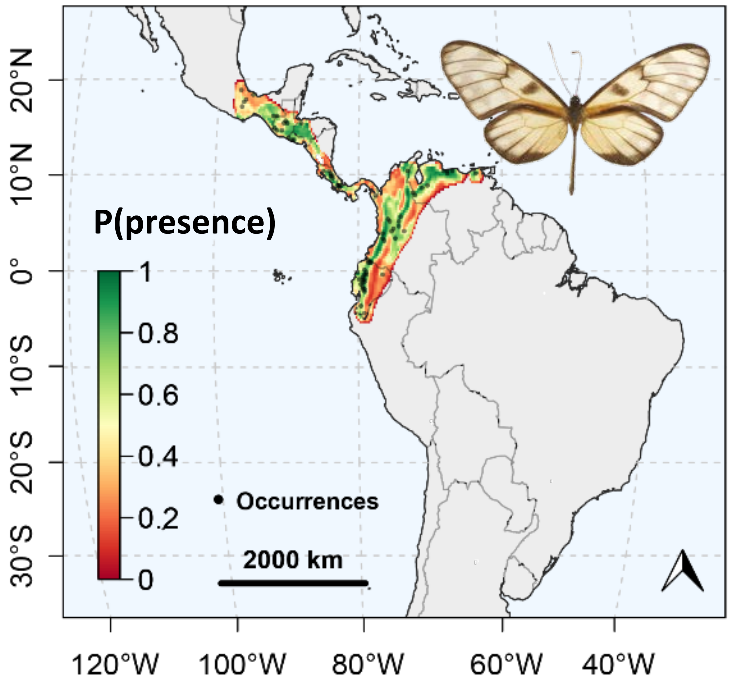
Spatial congruence

Question: Do phenotypically similar species **cooccur** more than expected at **random**?

Hypothesis: Lower **spatial dissimilarity** for comimetic species

$$BC_{ij} = 1 - \frac{2\sum \min(P_i, P_j)}{\sum P_i + P_j}$$

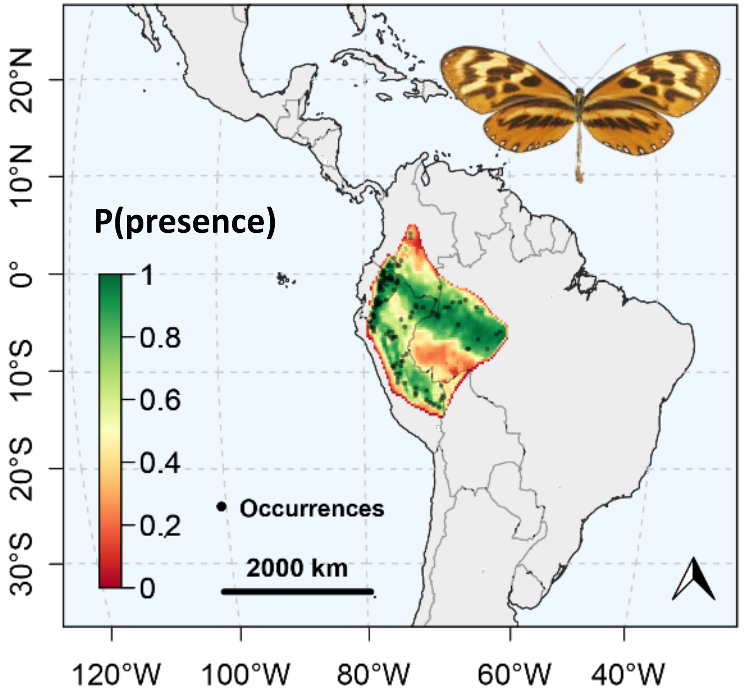
Dircenna jemina **(DILUCIDA)**



No mimicry

BC = 0.9

Mechanitis mazaeus **(MAELUS)**



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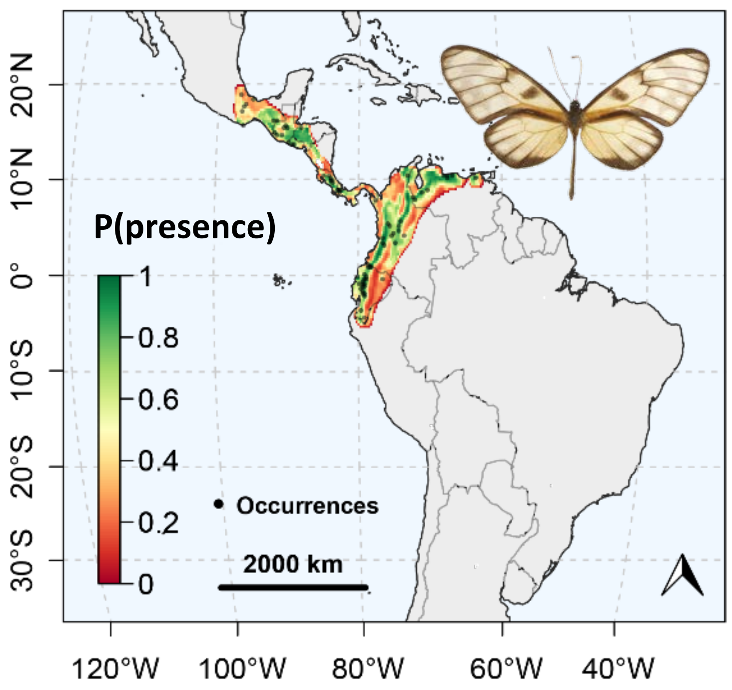
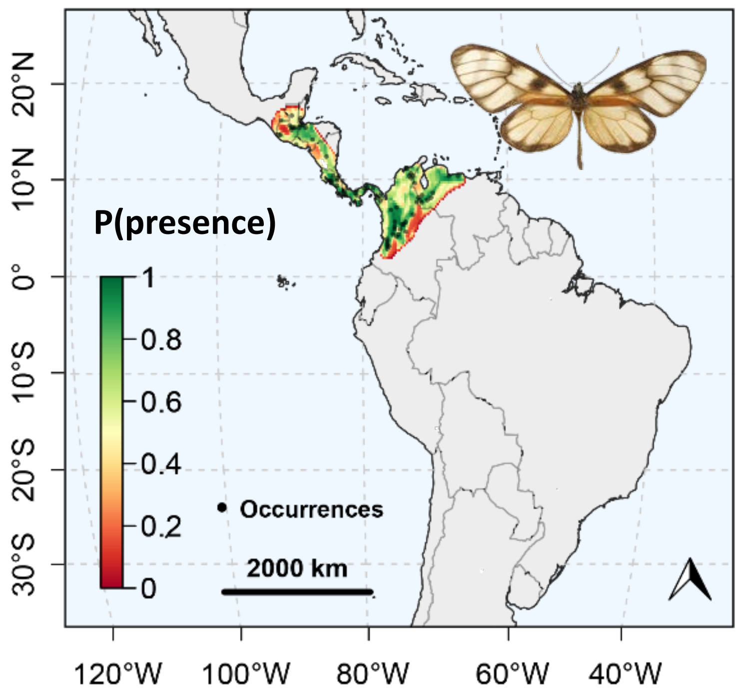


Mimicry

BC = 0.2

Dircenna dero **(DILUCIDA)**



Spatial congruence

Question: Do phenotypically similar species **cooccur** more than expected at **random**?

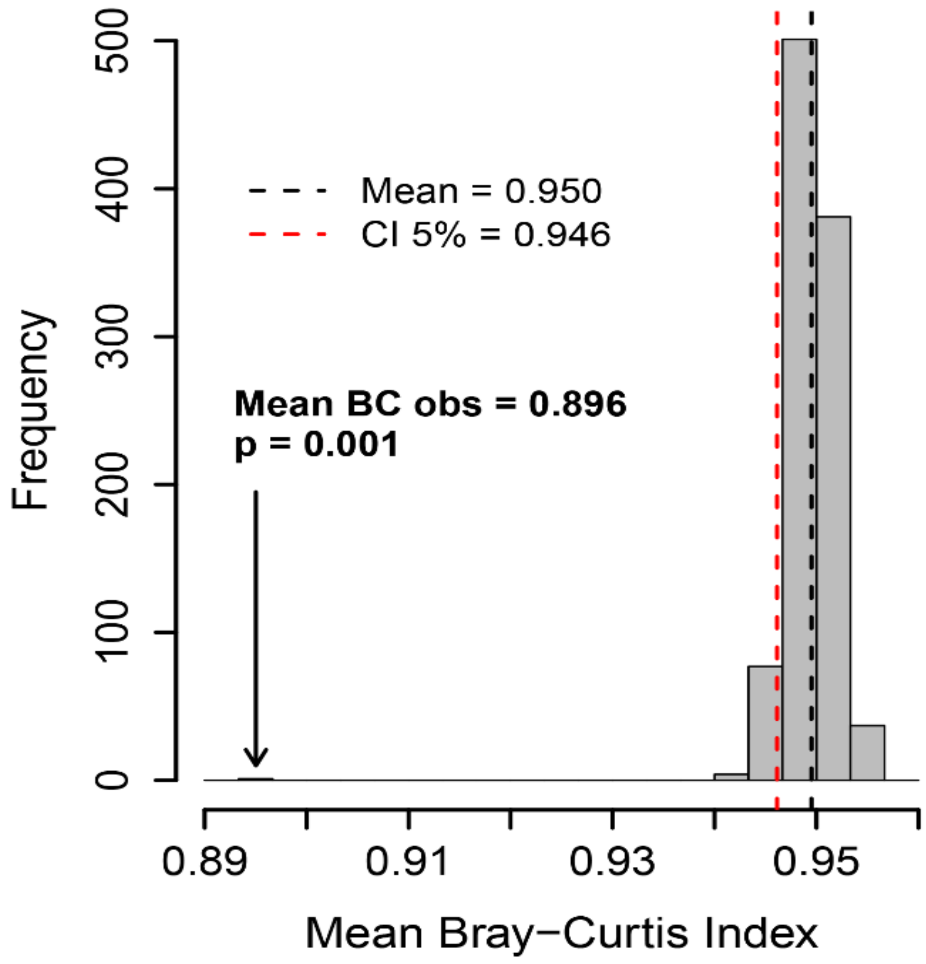
Global: Mean BC_{obs} << Mean BC_{perm} ✓

Per phenotypic group: 85% of putative rings

- Non-significant rings = low N

Results: Mimicry promotes the **spatial congruence** of phenotypically similar species at **large-scale**

Next: What happens between tribes?



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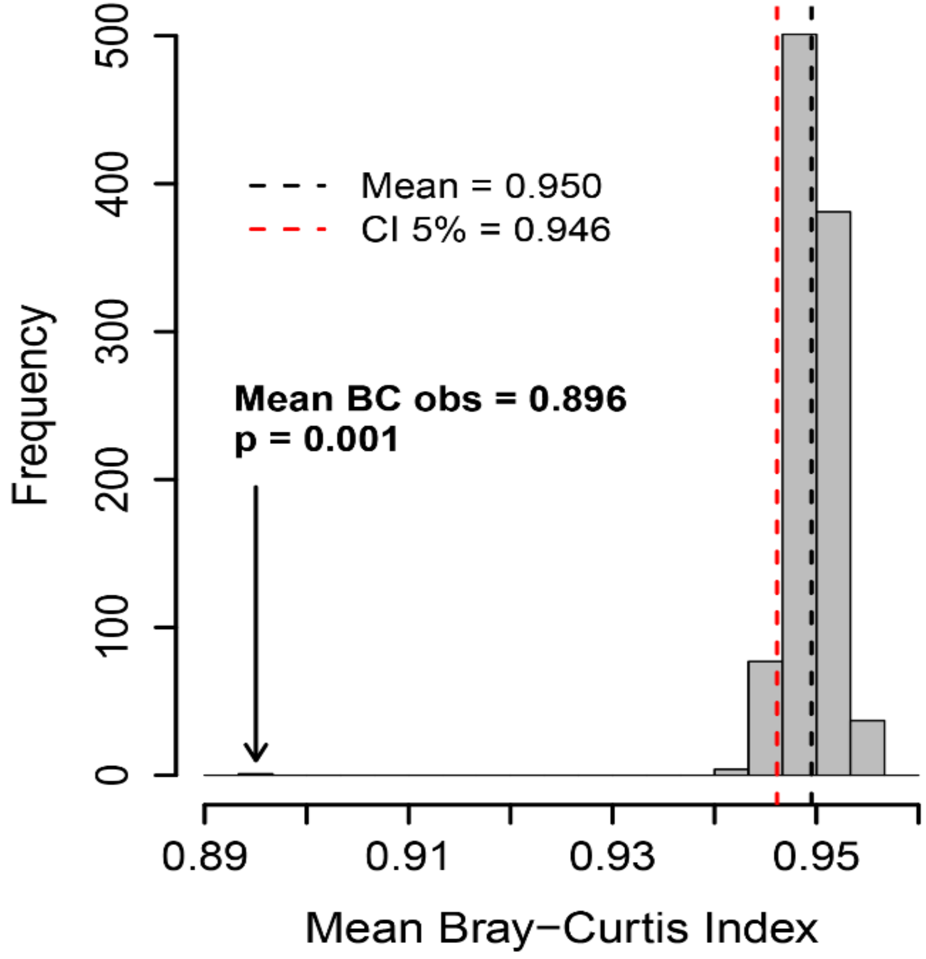

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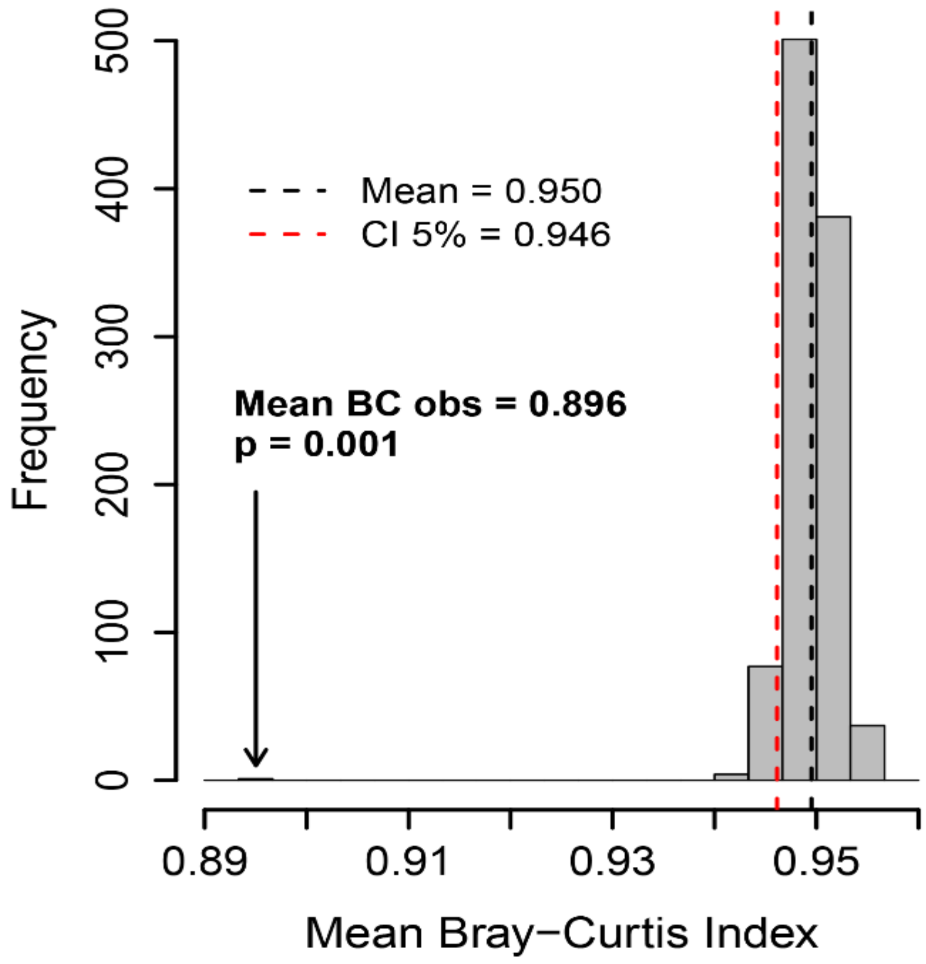

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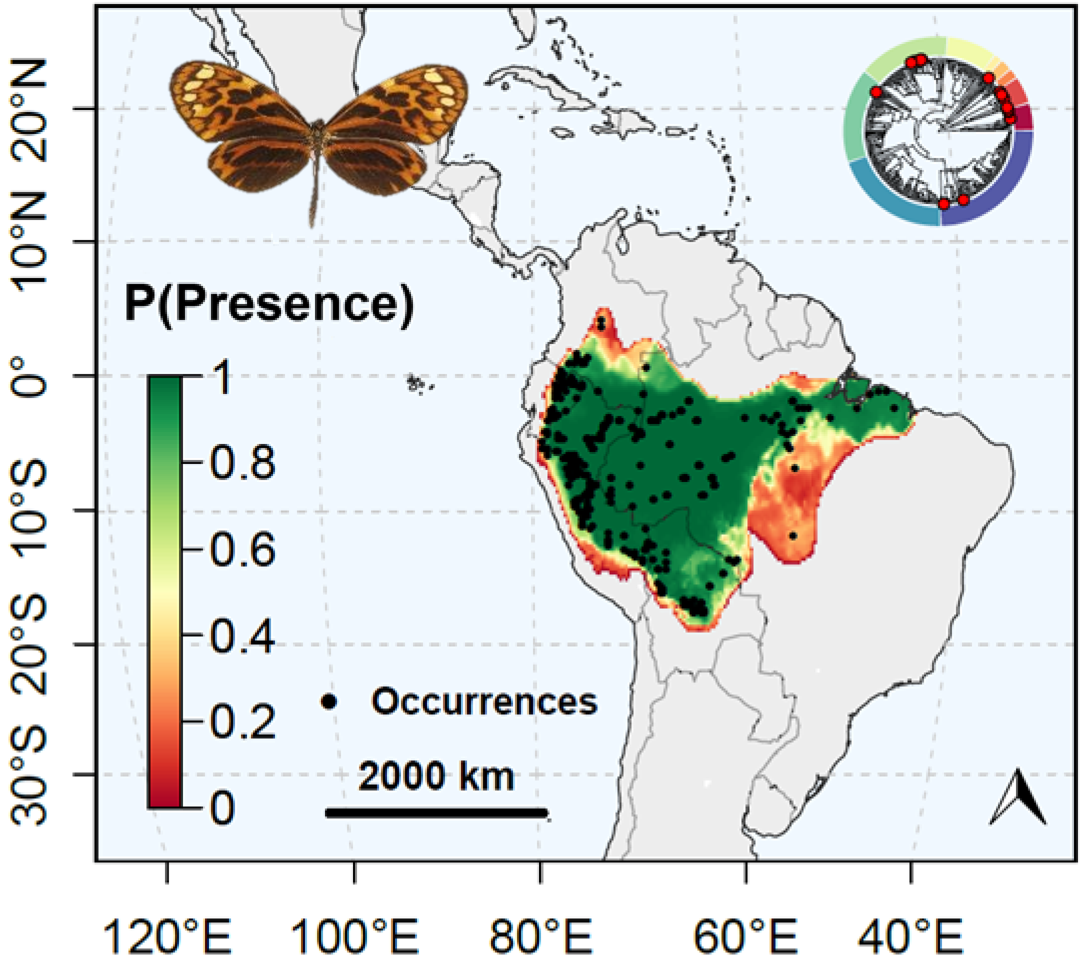
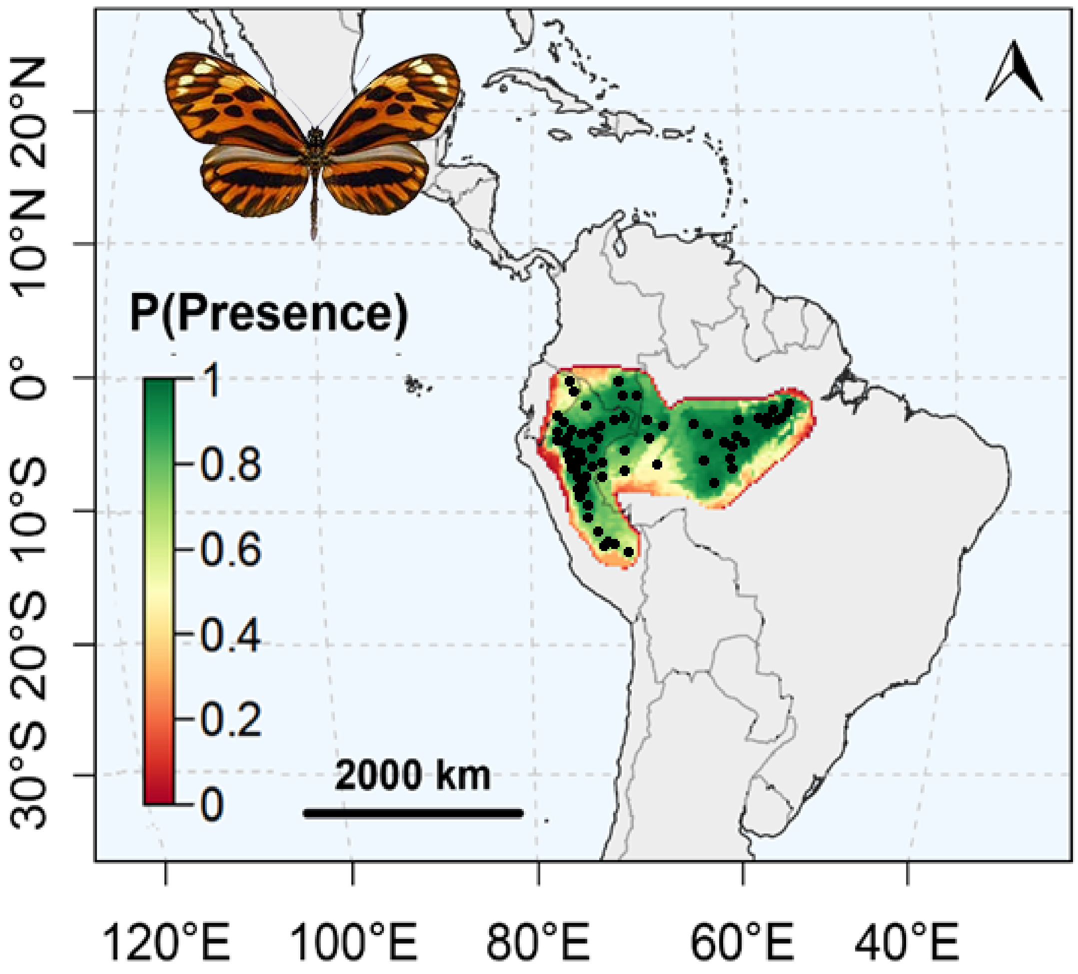
Spatial congruence

Ithomiini: pattern MAELUS (16 species)

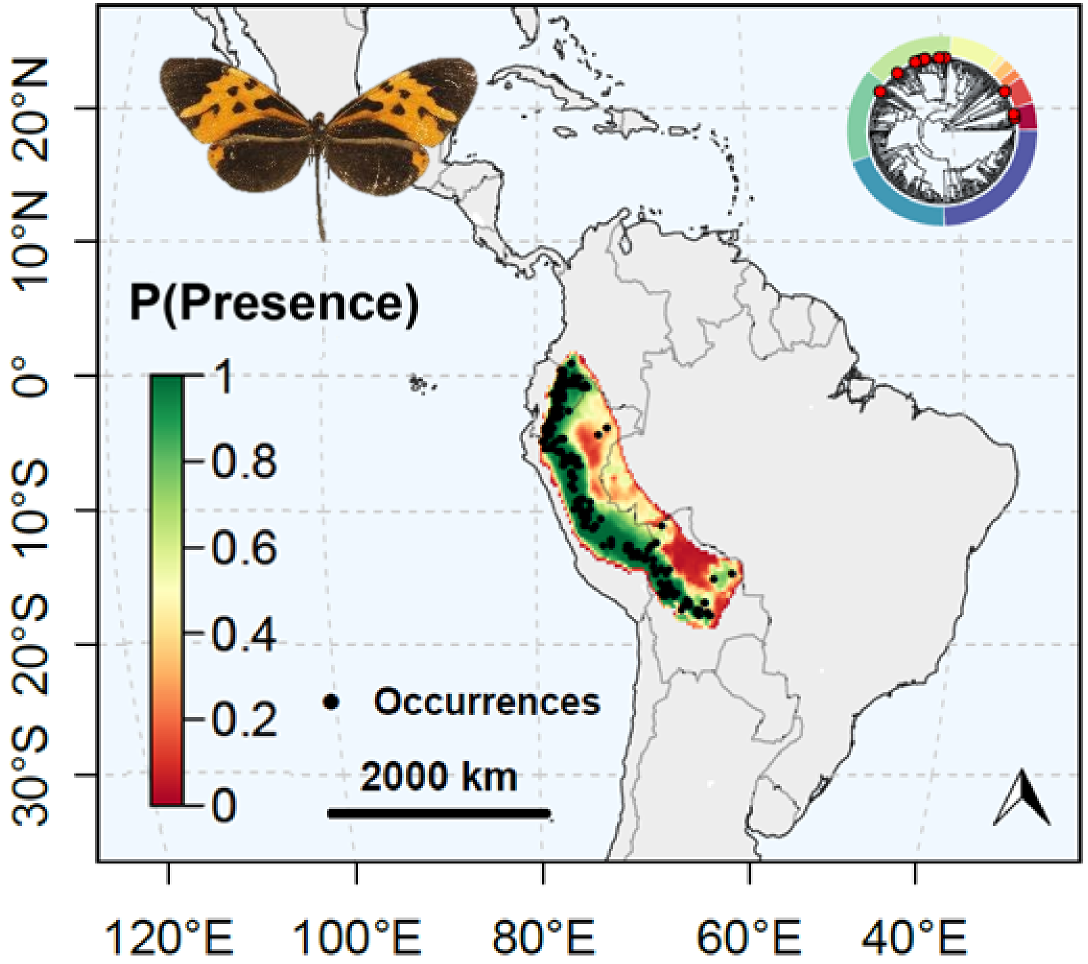


Heliconiini: pattern MAELUS (5 species)

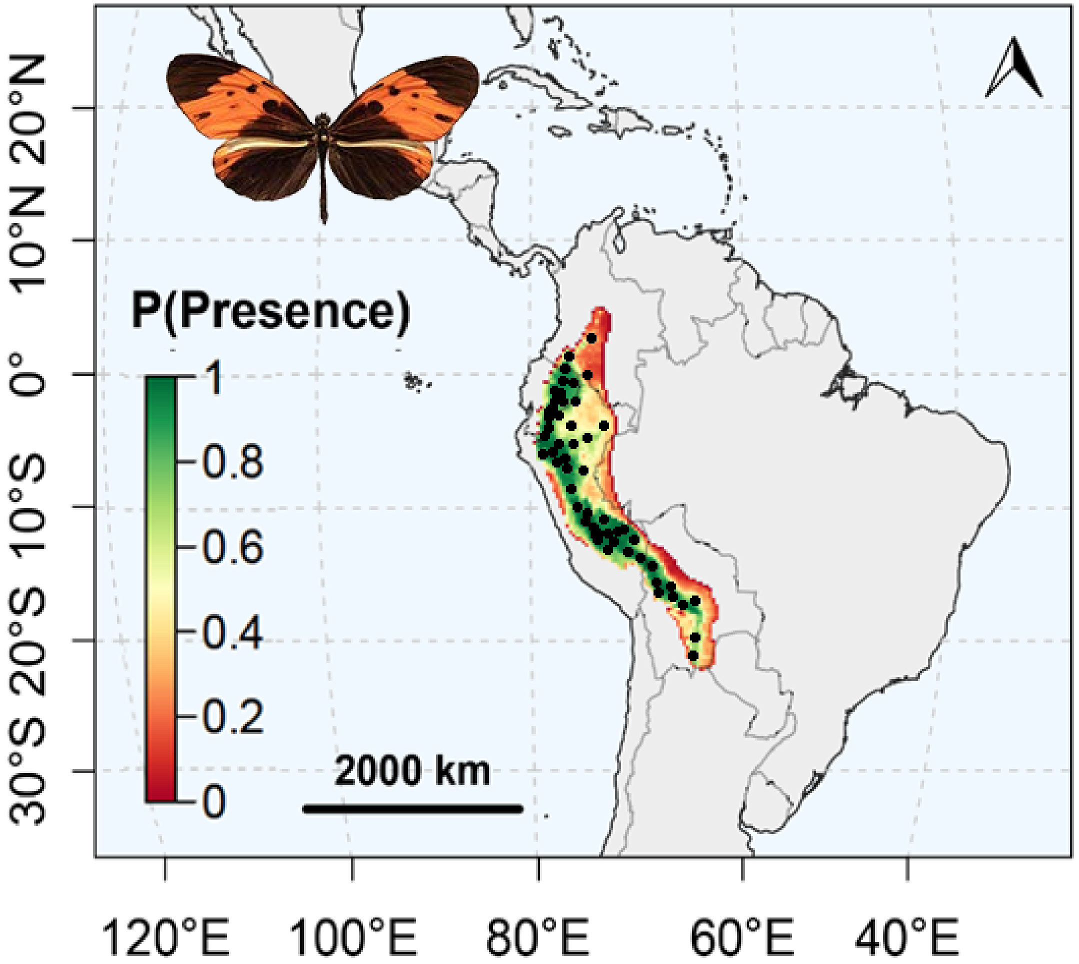


Spatial congruence

Ithomiini: pattern MOTHONE (14 species)

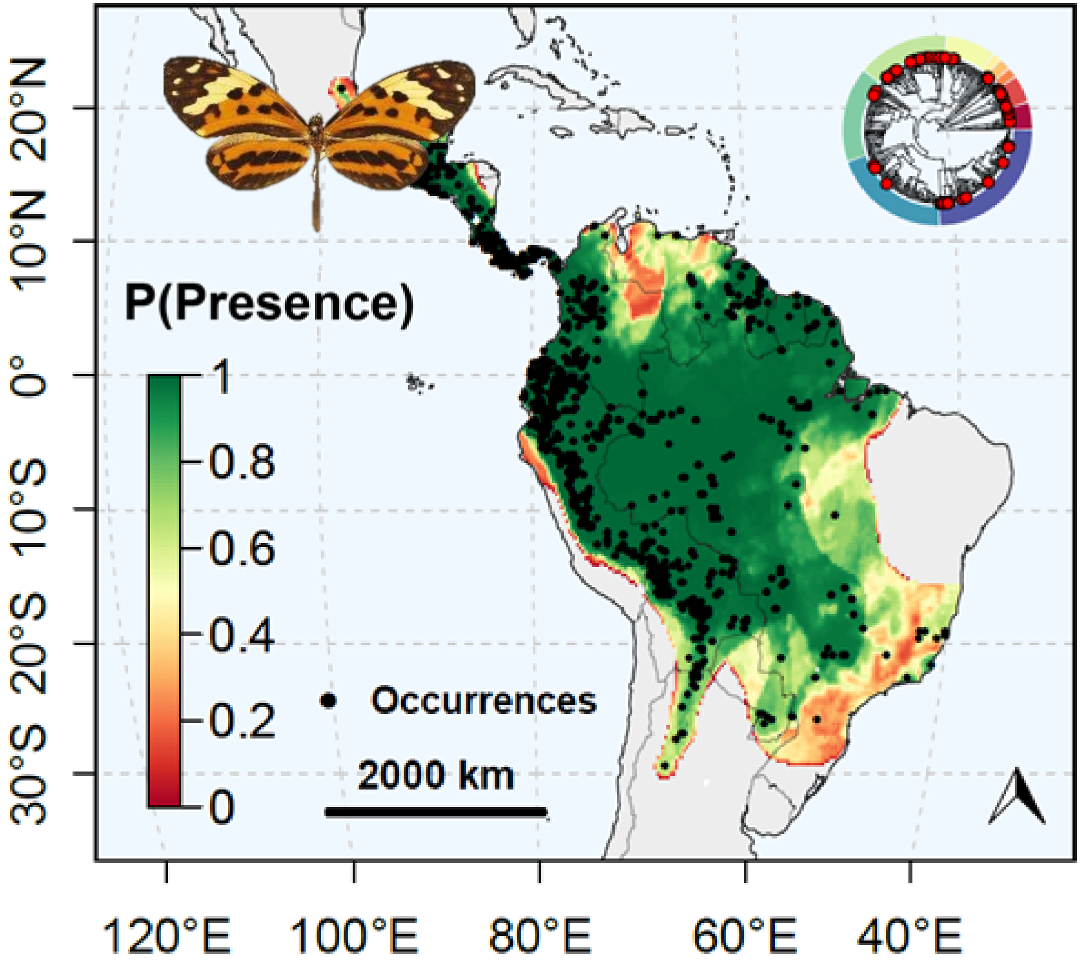


Heliconiini: pattern MOTHONE (3 species)

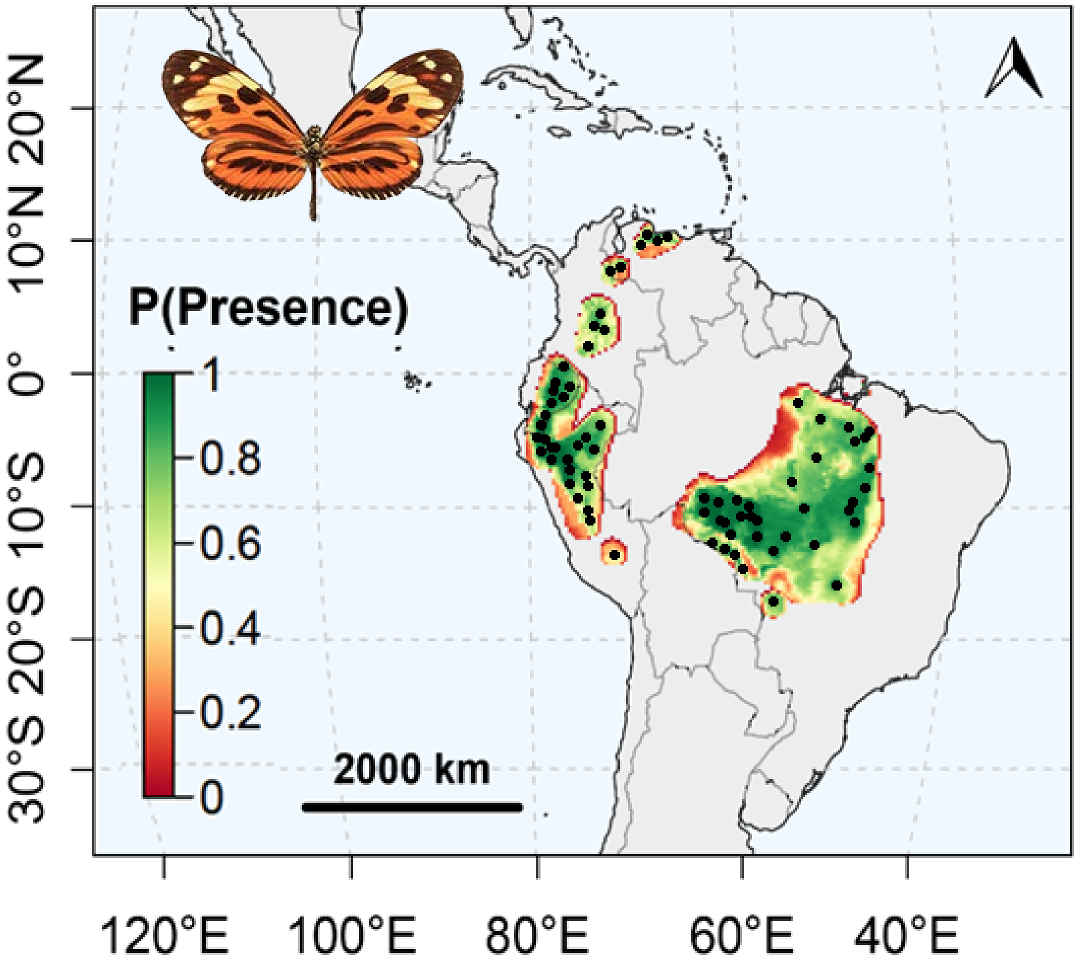


Spatial congruence

Ithomiini: pattern MAMERCUS (64 species)



Heliconiini: pattern MAMERCUS (10 species)



Objectives

How **mutualistic interactions** affect the **structure** and **evolution** of biodiversity at the **macroecological scale**?

1 **Biodiversity patterns**: Are large-scale **biodiversity patterns** different between tribes?

2 **Spatial congruence**: Do phenotypically similar species **cooccur** more than expected at random?

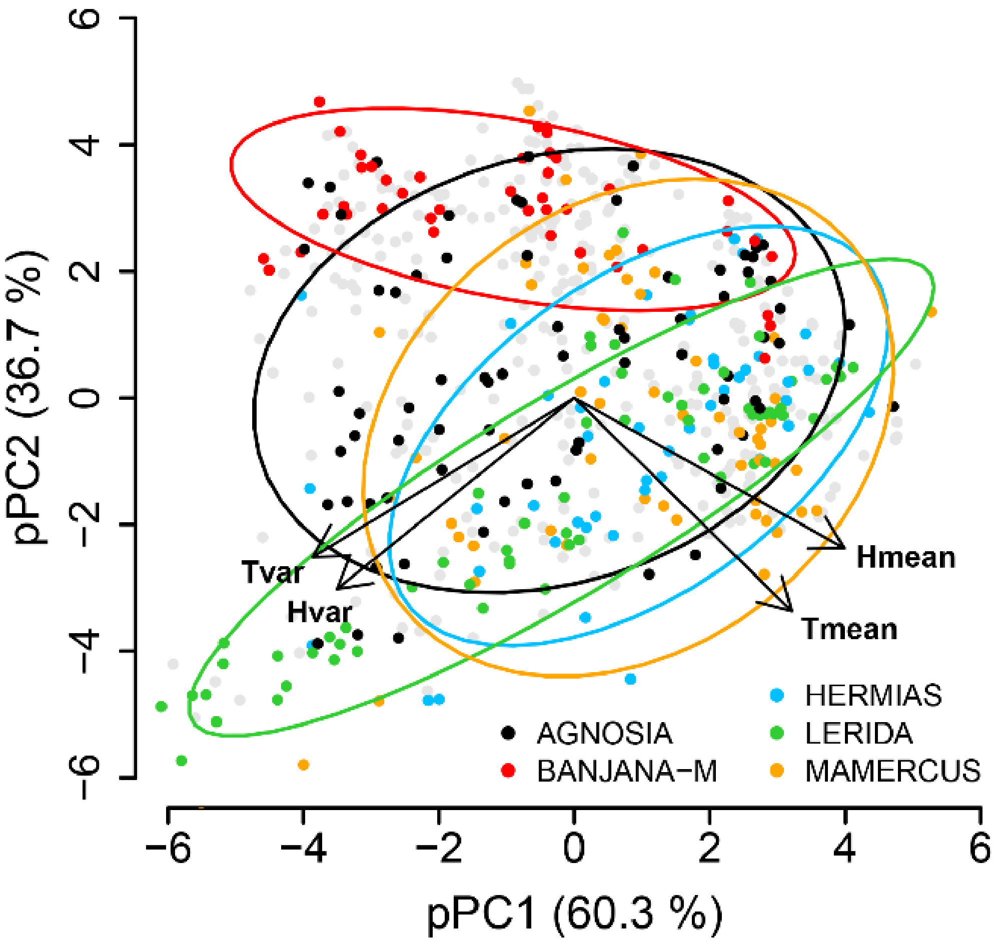
3 **Niche similarity**: Do phenotypically similar species have **similar climatic niche**?

4 **Niche convergence**: Is the climatic niche of phenotypically similar species **more similar** than expected from **shared ancestry**?

Climatic niche similarity

Question: Do **phenotypic groups** occupy different **climatic niche**?

Global: perMANOVA, $R^2 = 0.41$, $p = 0.001$



Per phenotypic group:

- 81.0% pairs with $p < 0.05$
- 66.4% pairs with $p < 0.001$

Next: Is this pattern due to **shared ancestry** or **evolutionary convergence**?

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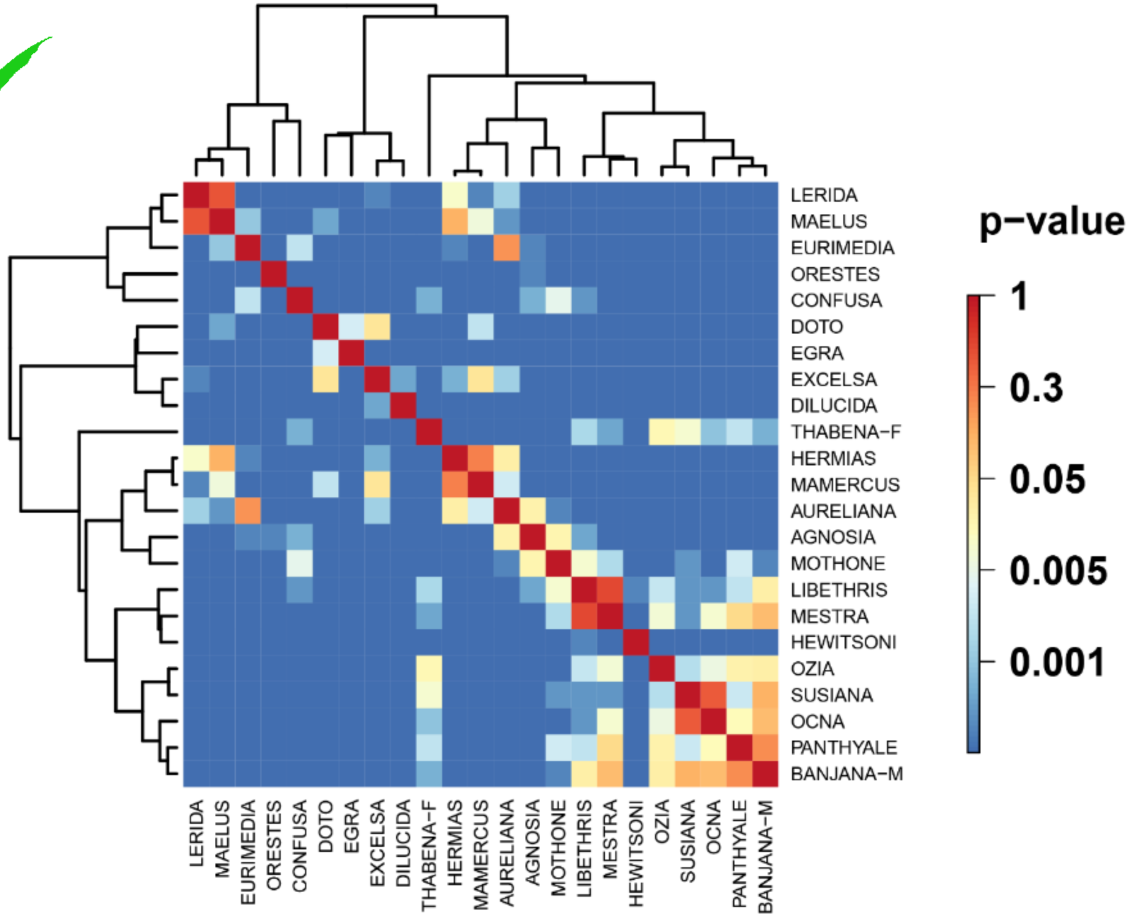

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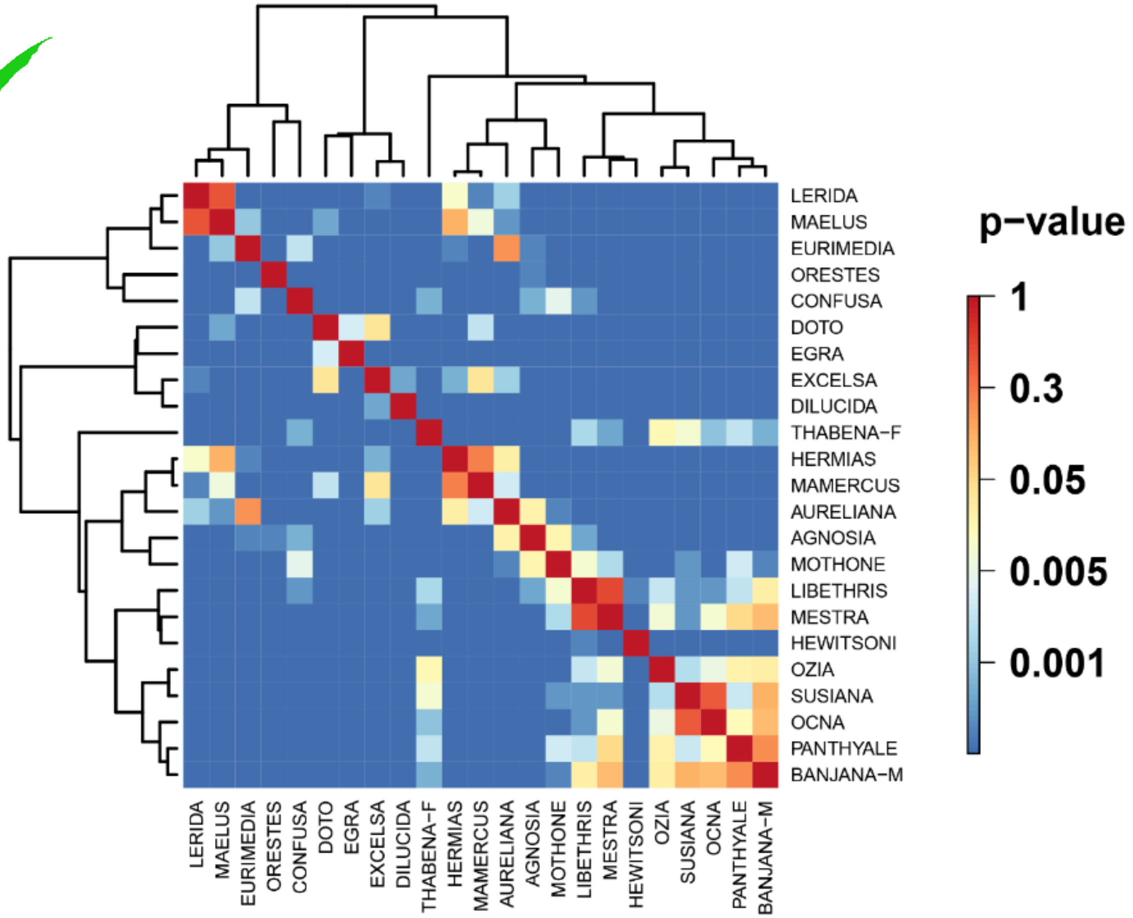

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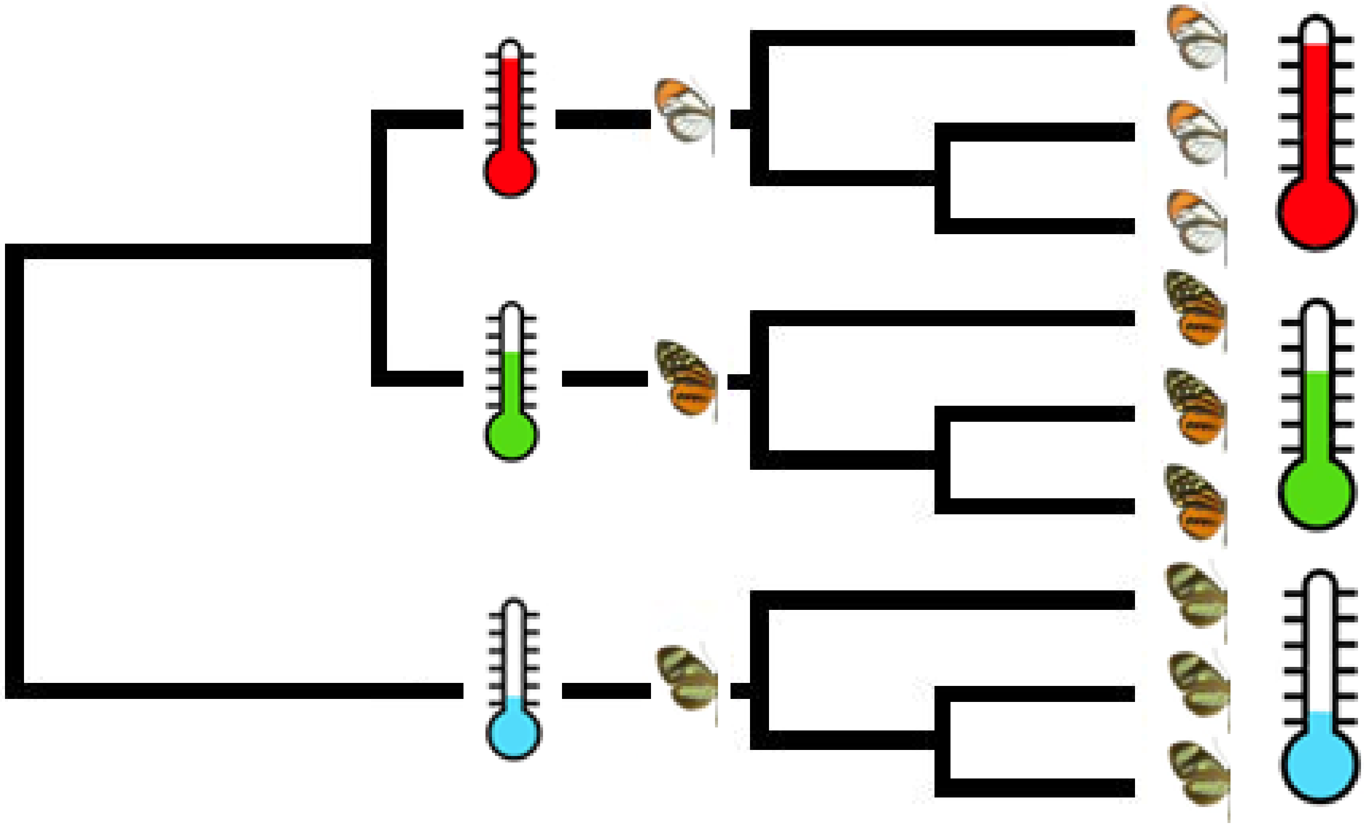
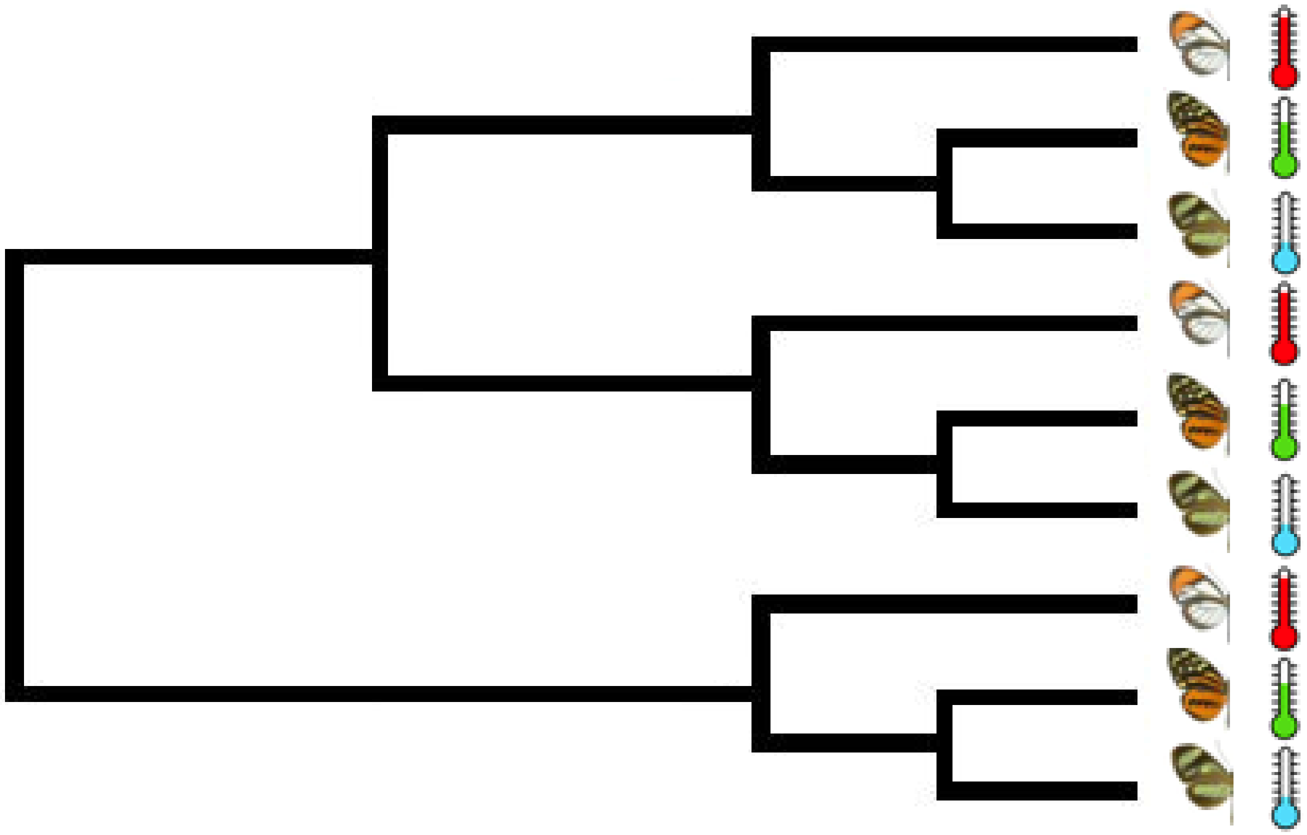
Climatic niche evolution

Question: Is this pattern due to **shared ancestry** or **evolutionary convergence**?



Climatic niche evolution

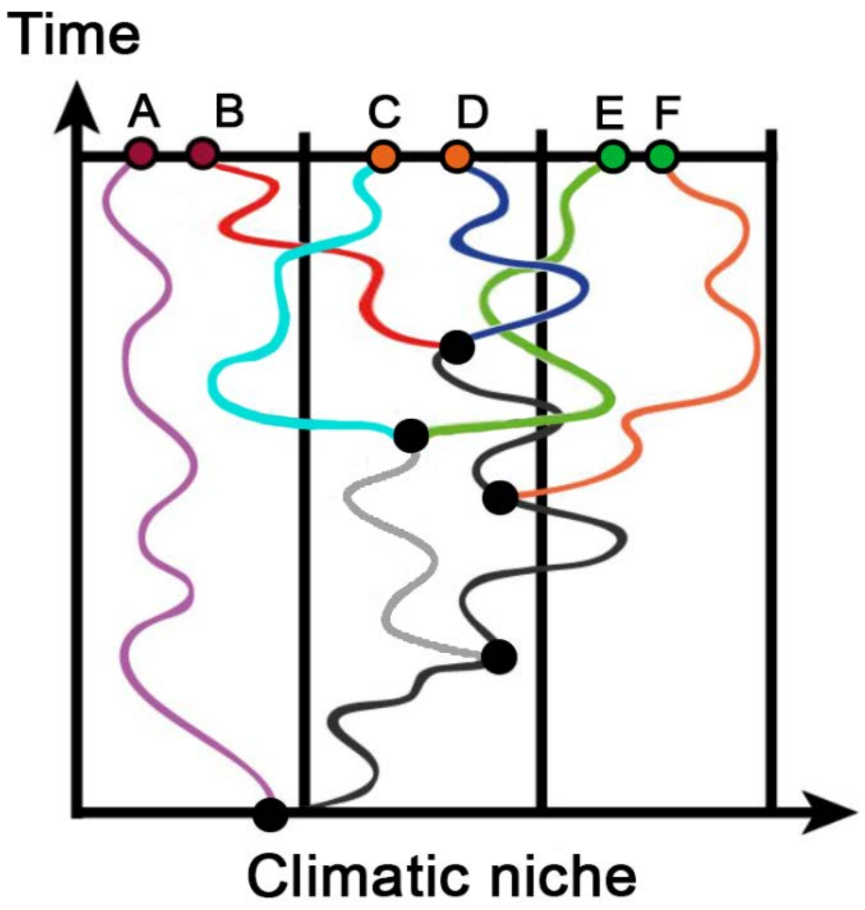
Question: Is this pattern due to **shared ancestry** or evolutionary convergence?



Climatic niche evolution

Question: Is the **climatic niche** of phenotypically similar species more similar than expected from the **phylogeny**?

Simulate the evolution of climatic niche under multivariate **neutral evolutionary model**



phyloMANOVA: $\lambda_{obs} << \lambda_{simul}$

Results: Evolutionary association between **climatic niche** and **color patterns**

Climatic niche evolution

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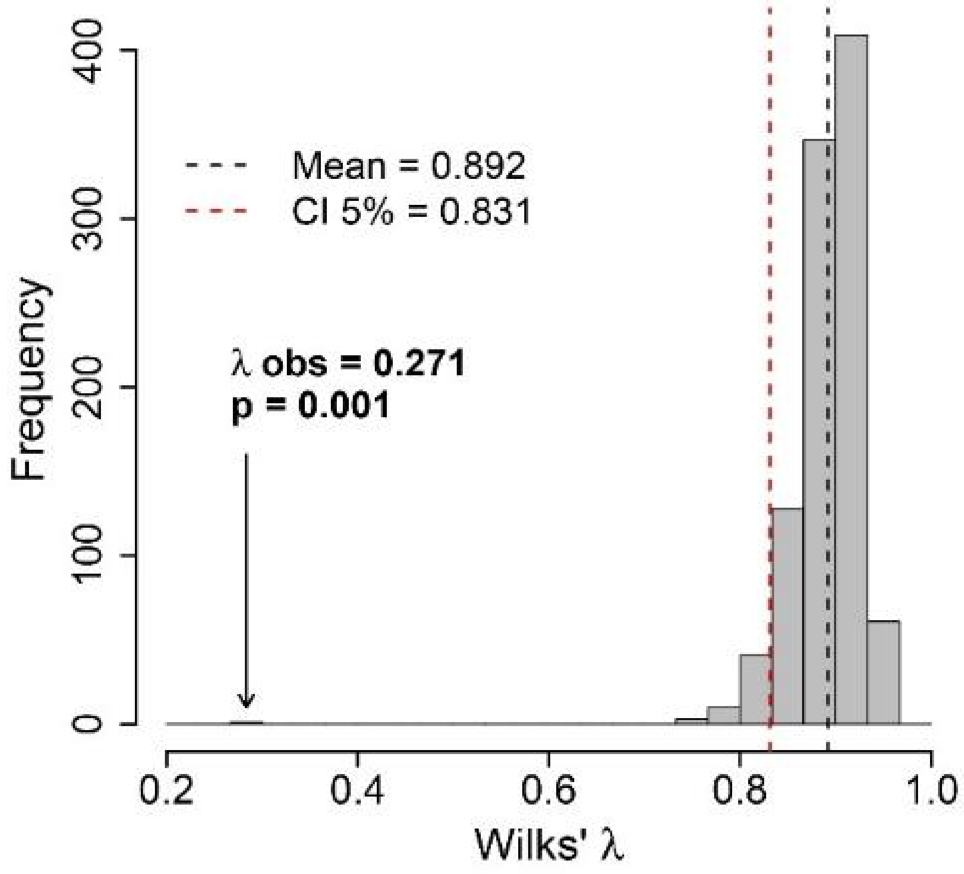

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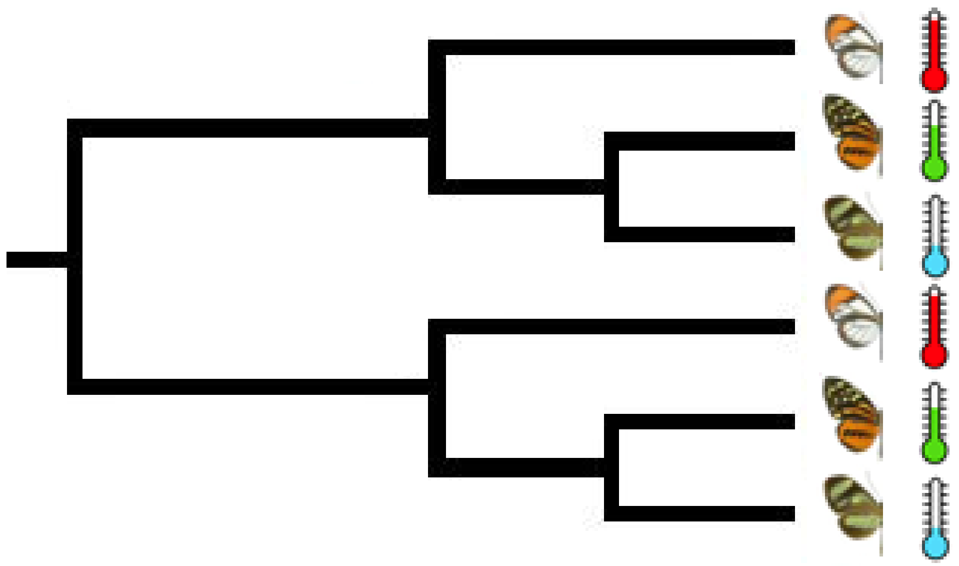
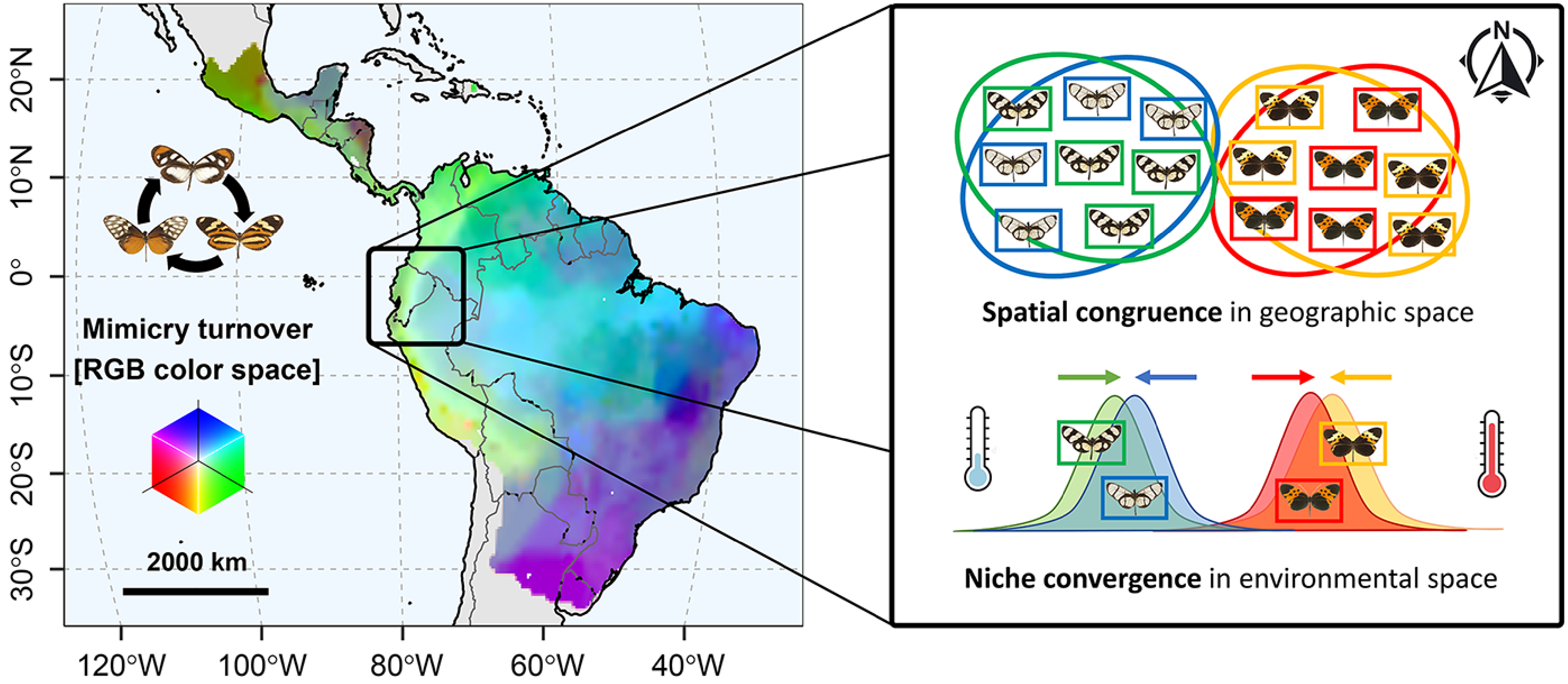
Results: Evolutionary convergence between **climatic niche** and **color patterns**

Evolutionary convergence



Conclusion

How **mutualistic interactions** affect the **structure** and **evolution** of biodiversity at the **macroecological scale**?



Research team

Advisors: Marianne Elias (ISYEB) & Colin Fontaine (CESCO)

Funding: PhD Grant (French MESR) & Marianne Elias (HFSP Grant)

Main collaborators:

- Eddie Pérochon, Université de Lausanne, Switzerland
- Keith Willmott, Florida University, USA
- Andre Freitas, Campinas State University, Brazil
- Nicolas Chazot, SUAS, Sweden
- Sébastien Lavergne, LECA, France
- Neil Rosser, Harvard University, USA
- Krzysztof Kozak, STRI, Panama

MaelDore

Mael_Dore

SCAN ME

Thanks for your attention

Hypomenitis enigma (Ithomiini). Credits: M. Elias

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