Ecological and historical constraints on elevational ranges in birds

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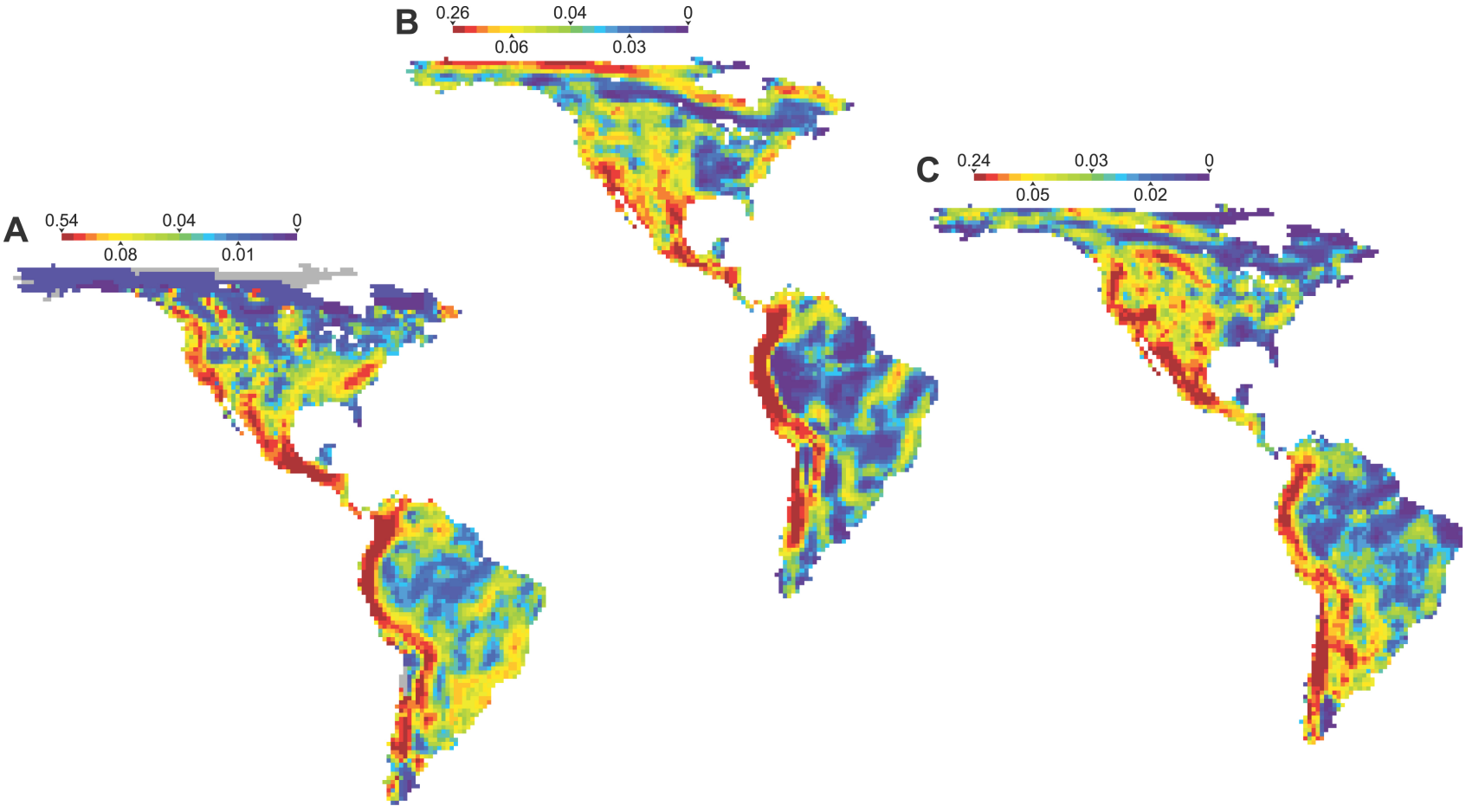
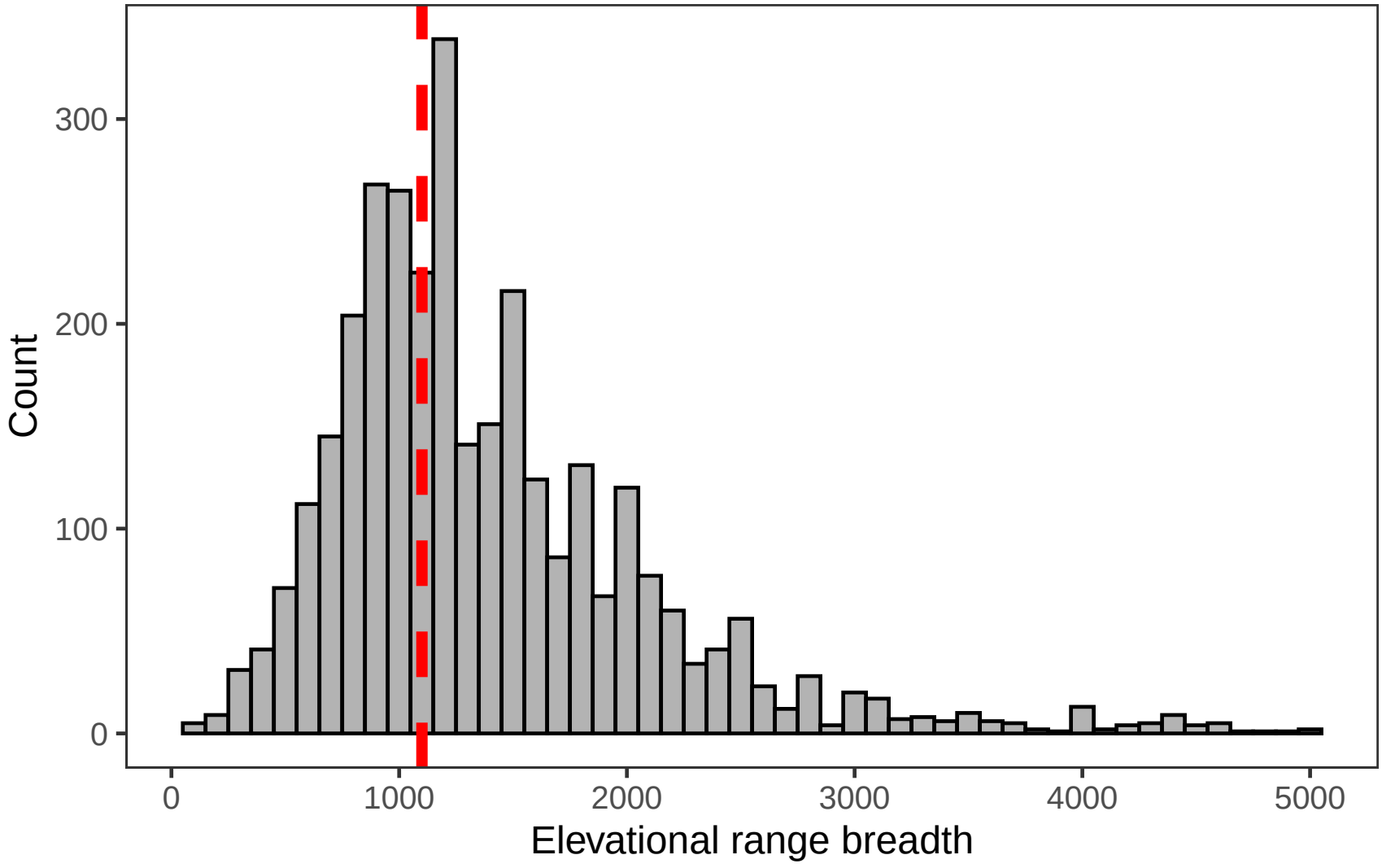
Big Pattern: β diversity and elevation



(McKnight et al. 2007 *PLoS ONE*)

Mountain biodiversity comes from elevational specialization

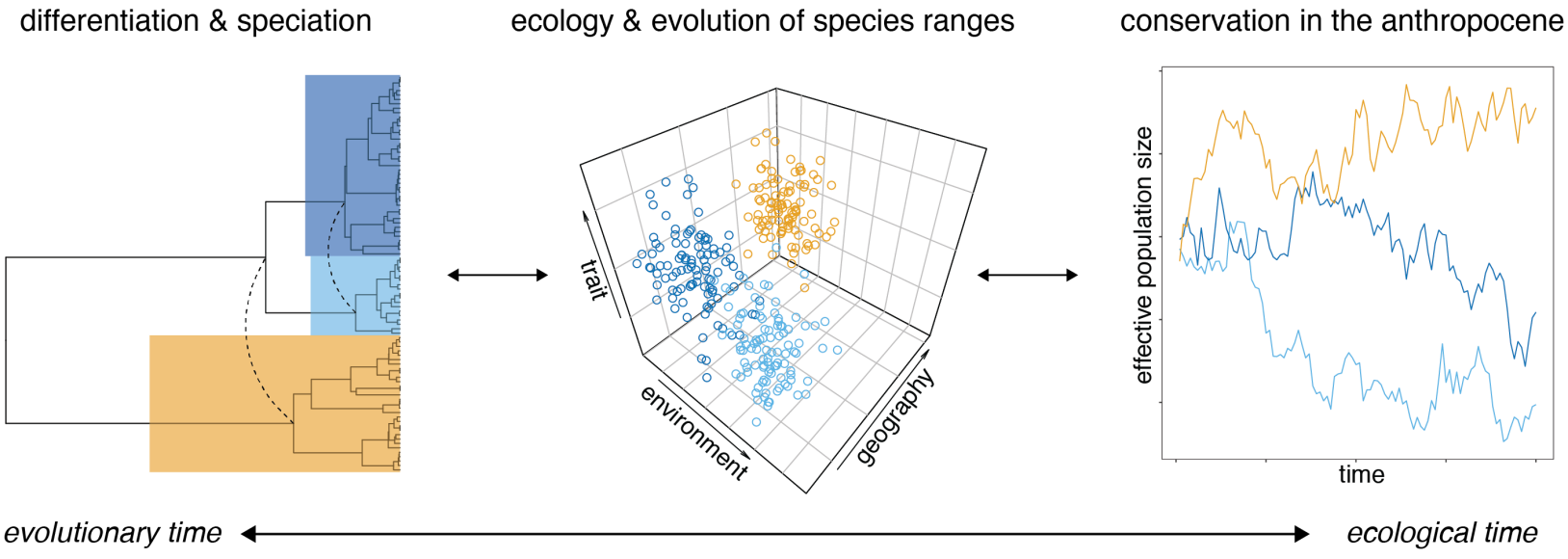


Birds and biogeography

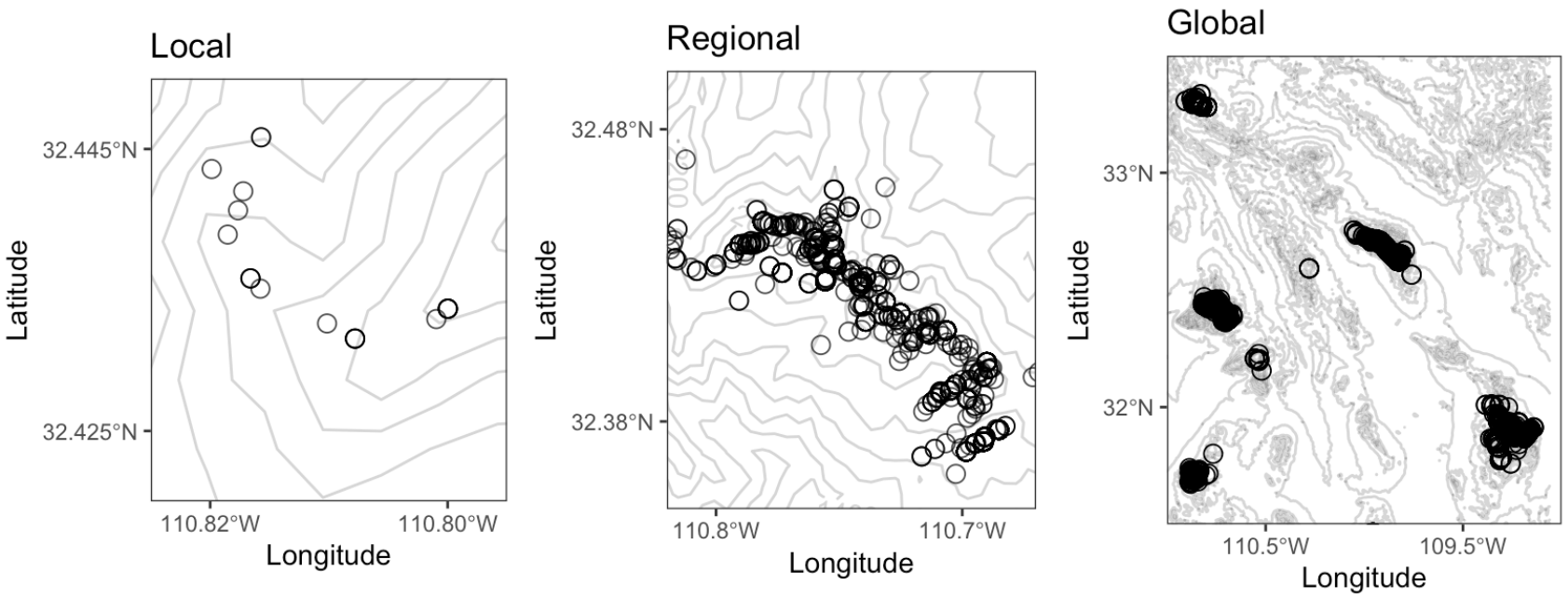
Birds and biogeography

(https://www.montana.edu/ecology/msu_researchers_capture_photos_of_new_britain-thrush.html)

Historical vs ecological biogeography



Range limiting processes are scale dependent

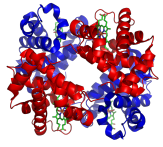


(Linck In Review *Am. Nat.*)

Talk outline

1) How does plasticity in respiratory traits relate to range breadth?

2) Are molecular adaptations to high altitude predictable?



3) How does speciation generate β diversity across elevation?

1) How does plasticity in respiratory traits relate to range breadth?

Acknowledgements:

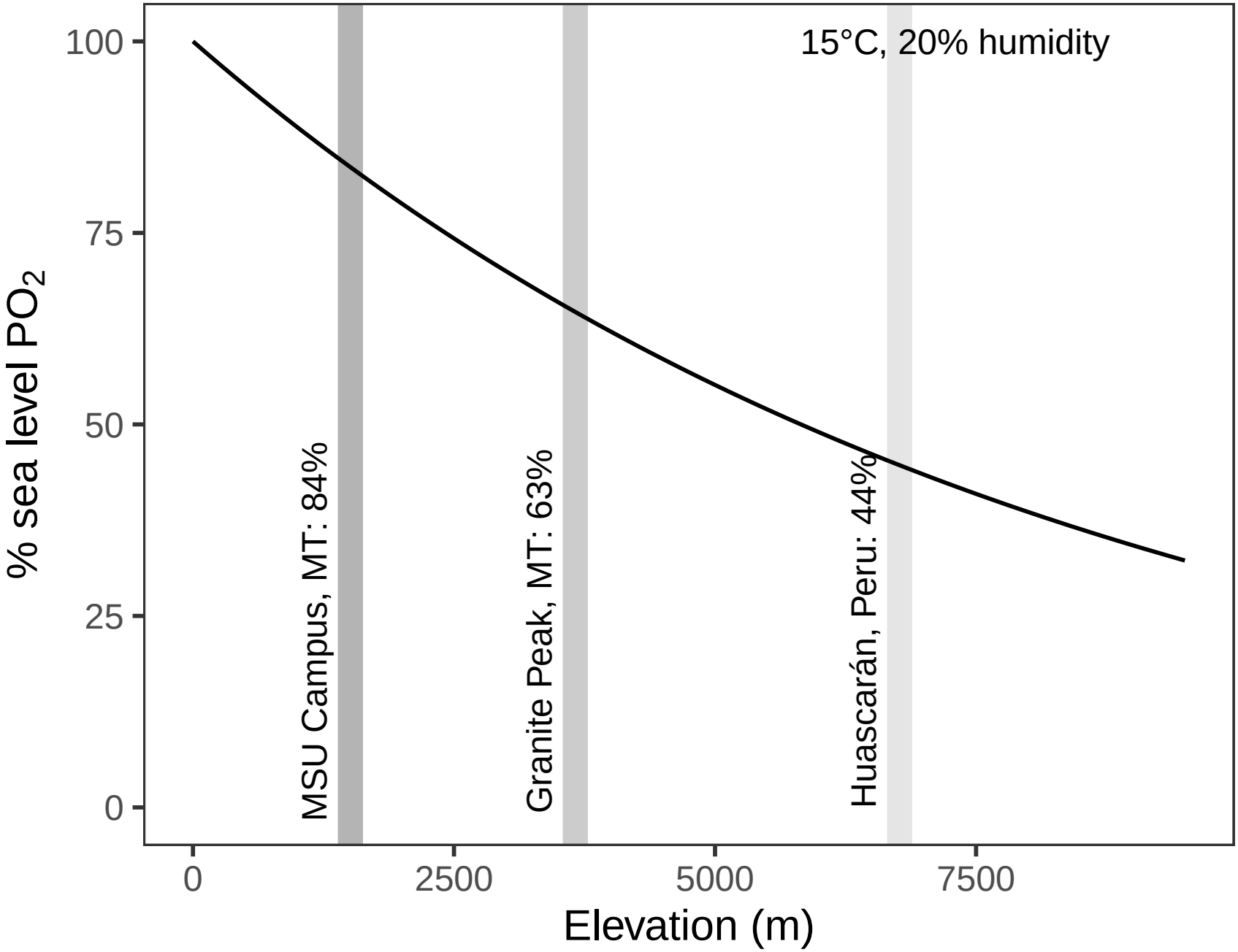
- **Coauthors**: Jessie L. Williamson, Emil Bautista, Elizabeth J. Beckman, Phred M. Benham, Shane G. DuBay, L. Monica Flores, Chauncey R. Gadek, Andrew B. Johnson, Matthew R. Jones, Jano Núñez-Zapata, Alessandra Quiñonez, C. Jonathan Schmitt, Dora Susanibar, Jorge Tiravanti C., Karen Verde-Guerra, Natalie A. Wright, Thomas Valqui, Jay F. Storz, Christopher C. Witt
- **Funding**: NSF DBI #1907353, DEB #1146491, and DEB #0543556

Distributions on environmental gradients

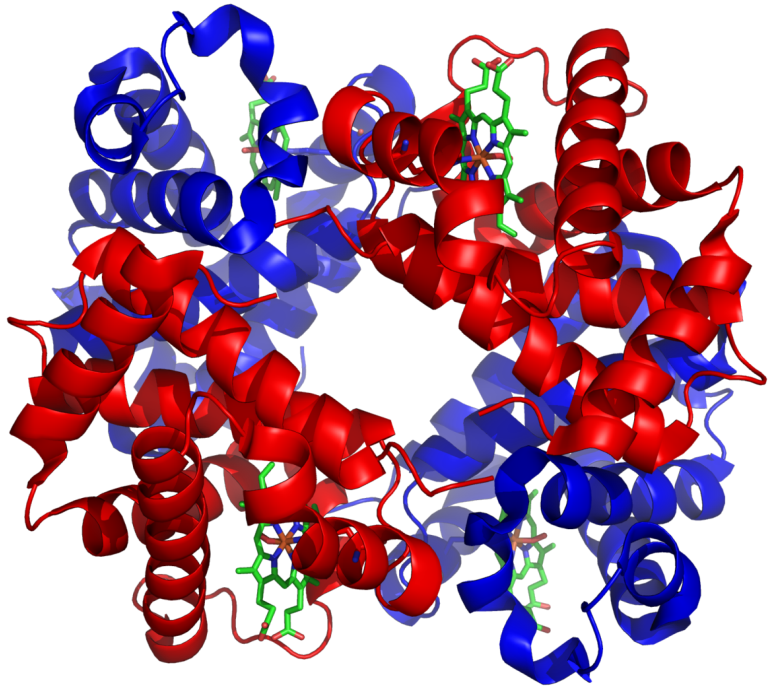
"In their simplest form the models state that the occurrence of species is limited respectively by: (i) physical or biological conditions that vary in parallel with the measured gradient, (ii) competitive exclusion and (iii) environmental discontinuities (ecotones)..." (Terborgh 1971 *Ecol.*)

Humid tropical elevational gradients lack ecotones

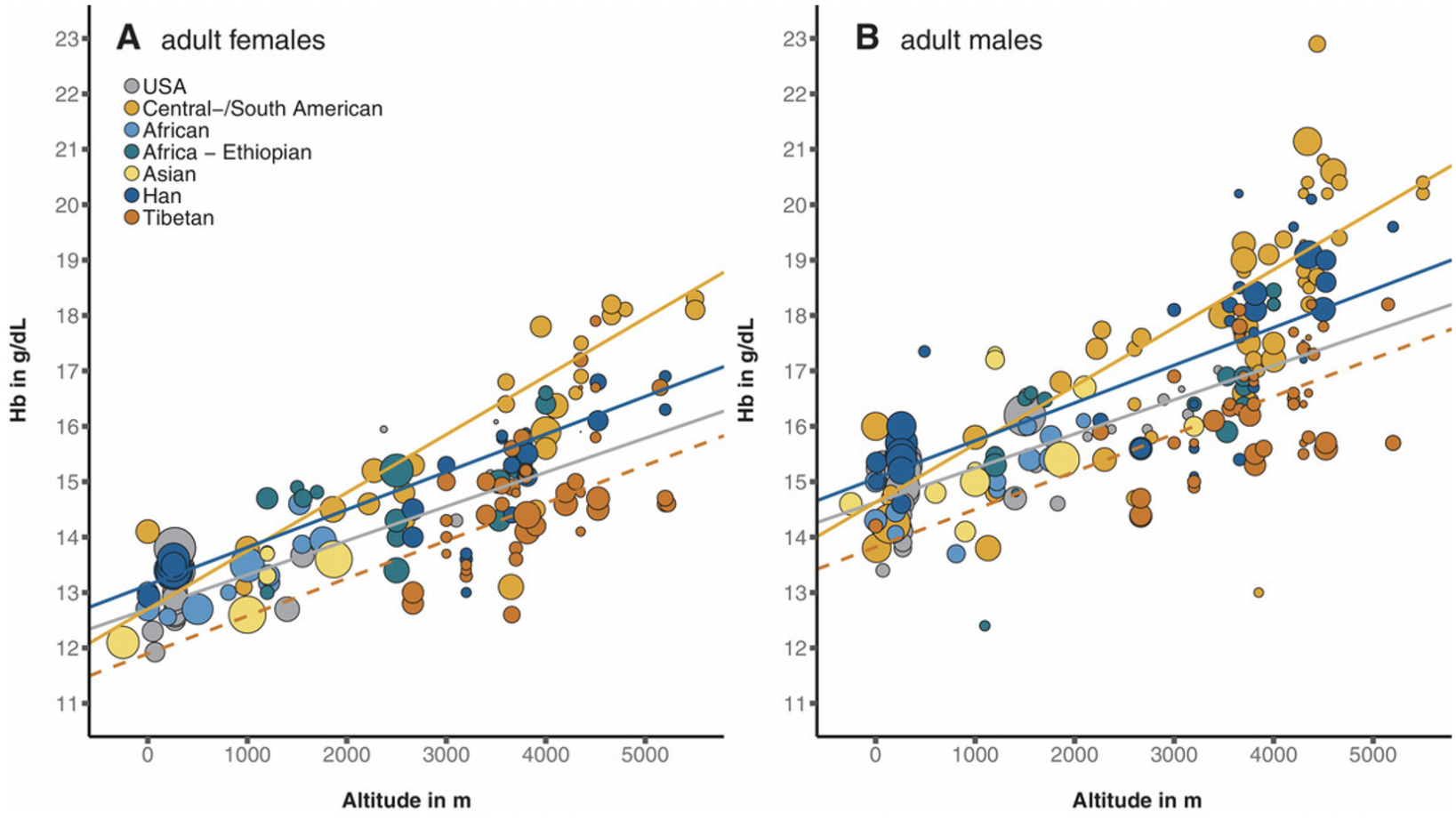
PO_2 varies in parallel with elevation



Hemoglobin facilitates oxygen transport for aerobic respiration

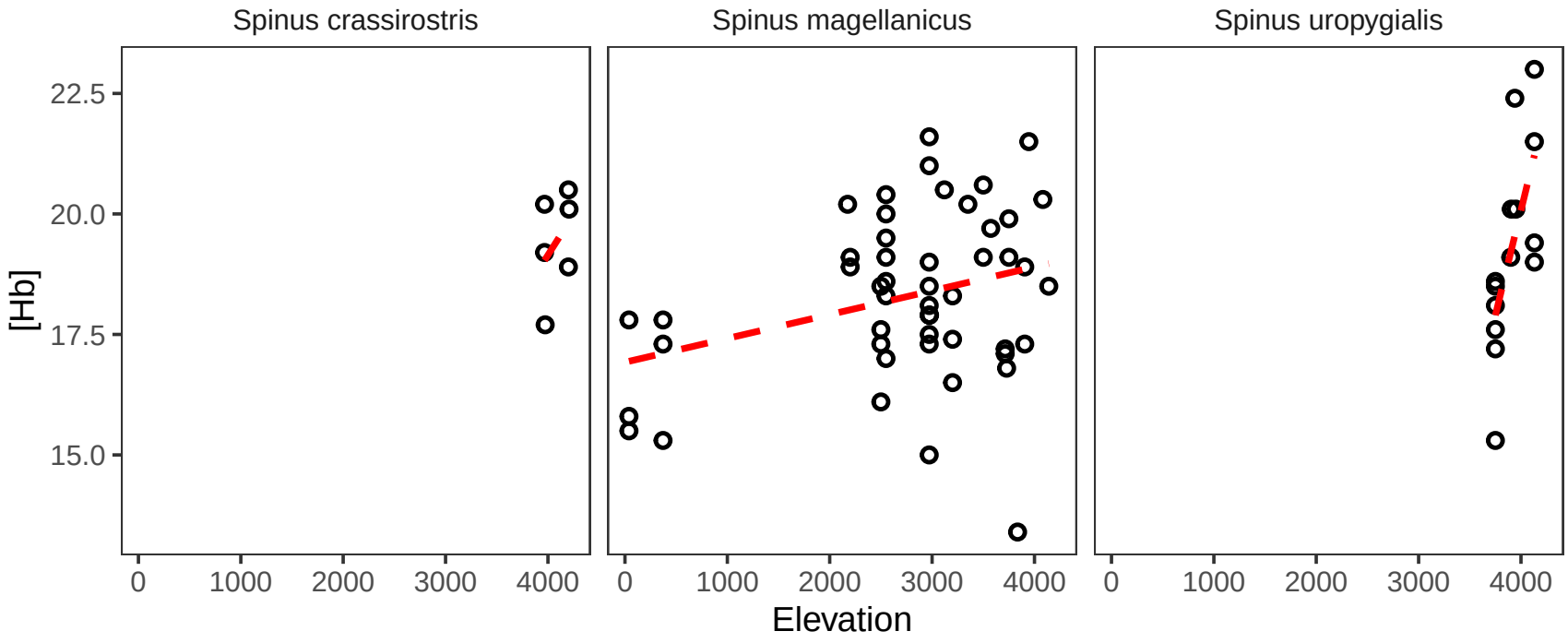


The increase in [Hb] with altitude varies among human populations

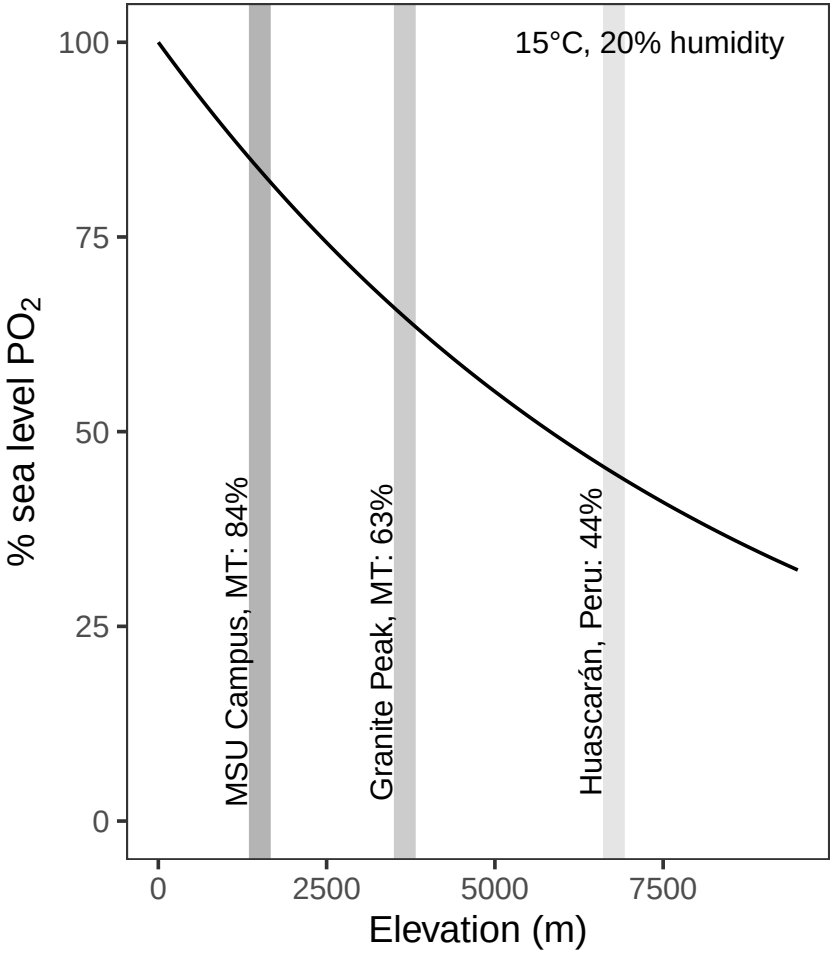


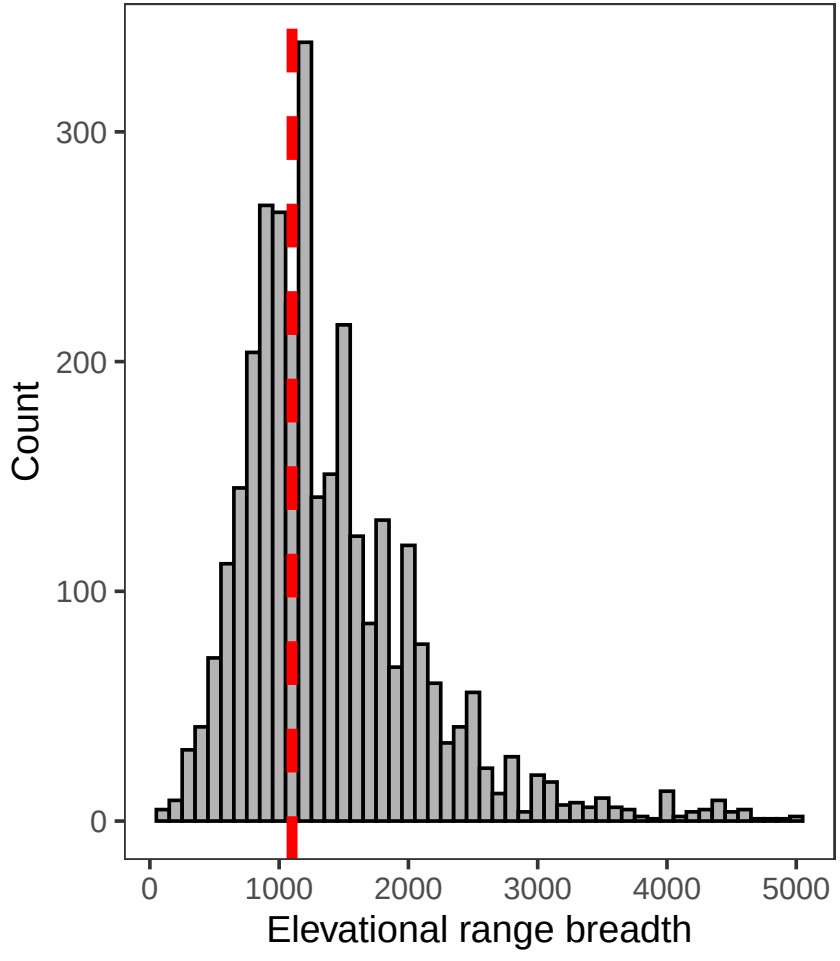
(Gassmann et al. 2019)

The increase in [Hb] concentration with altitude varies among Andean bird species



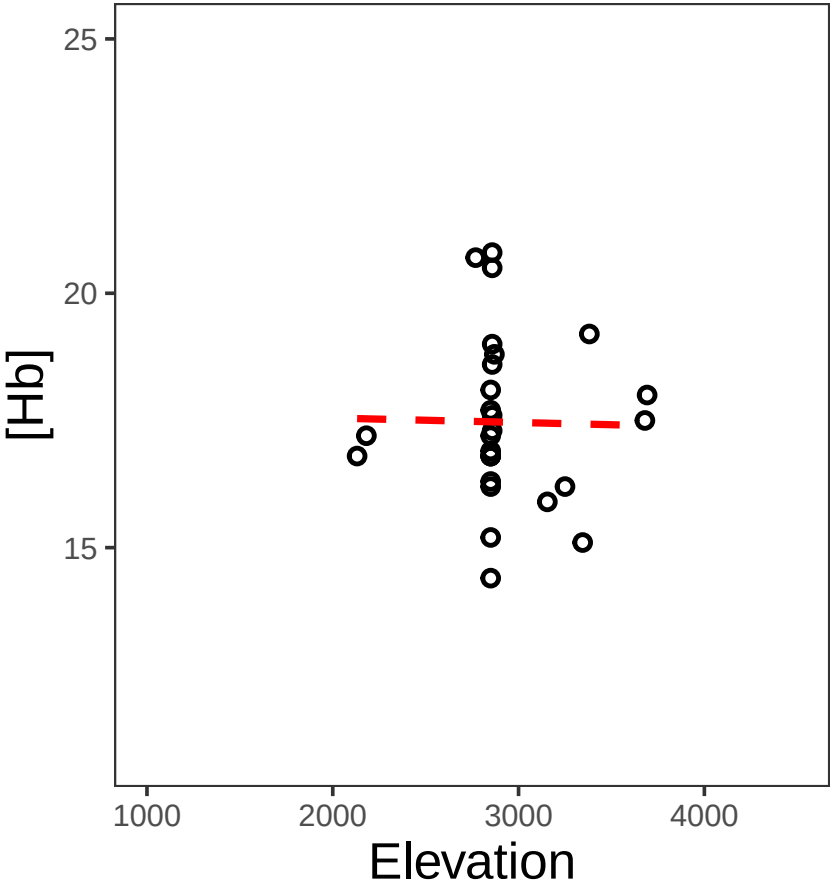
Does blood-O_2 carrying-capacity influence elevational specialization?



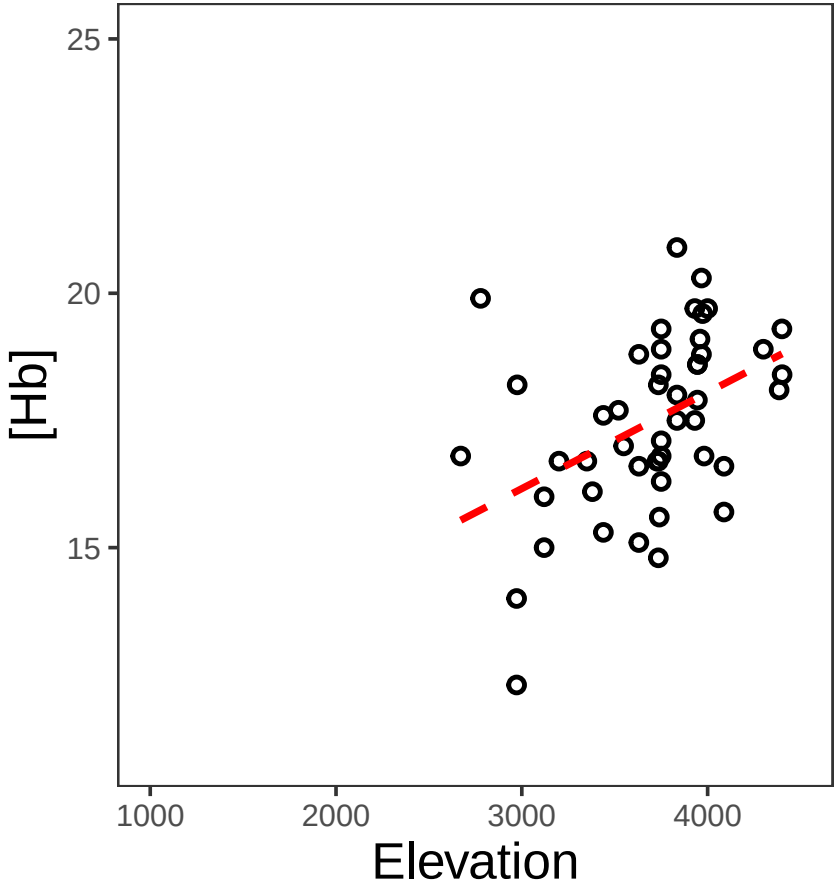


Metric: Respiratory "plasticity" ([Hb] sensitivity)

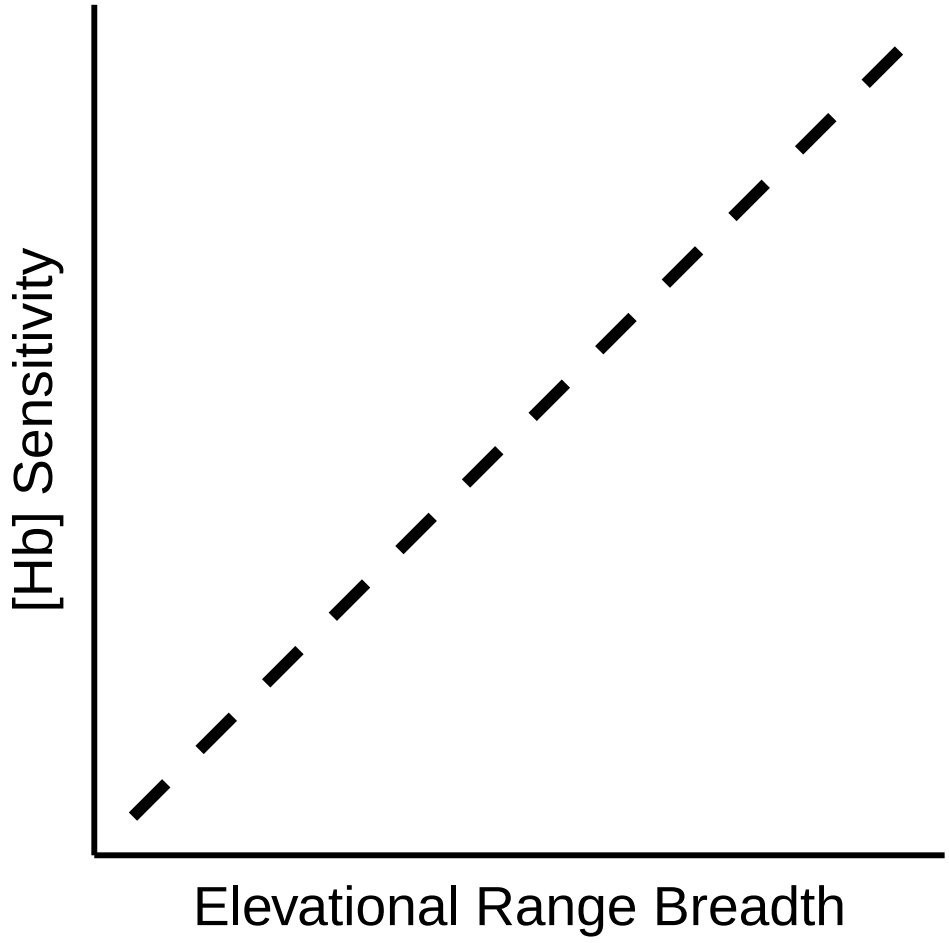
shallower slope, less sensitive



steeper slope, more sensitive

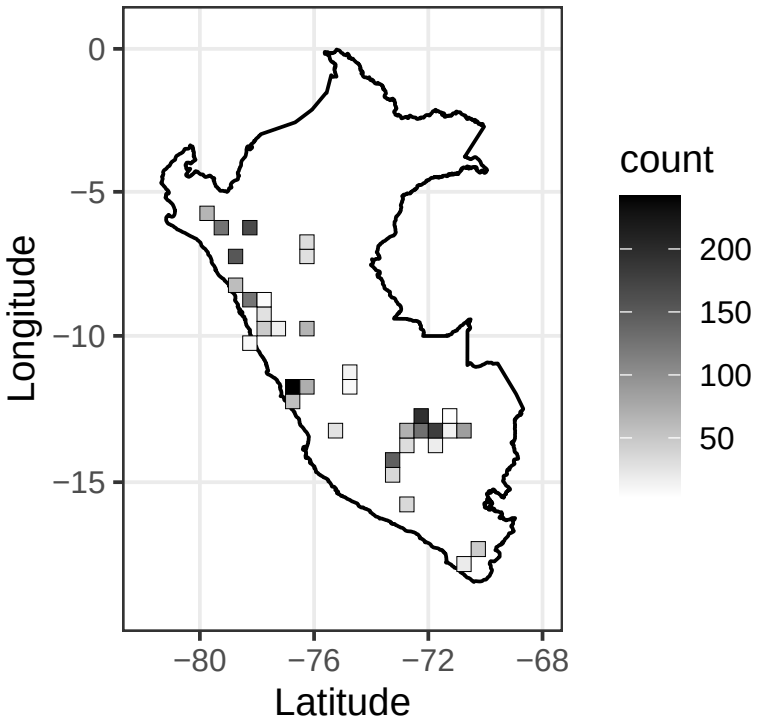


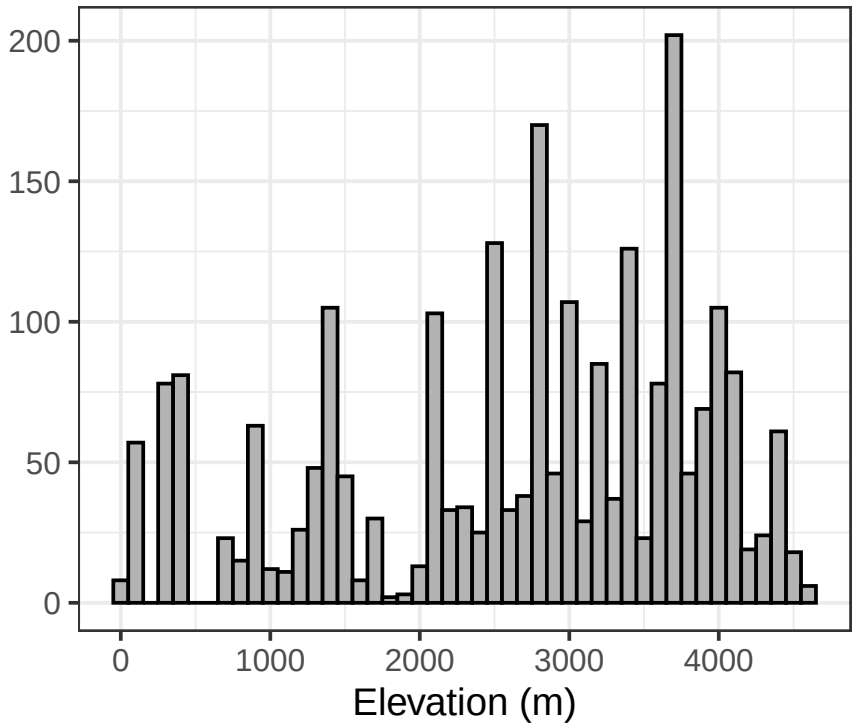
H_1: Respiratory plasticity influences niche breadth



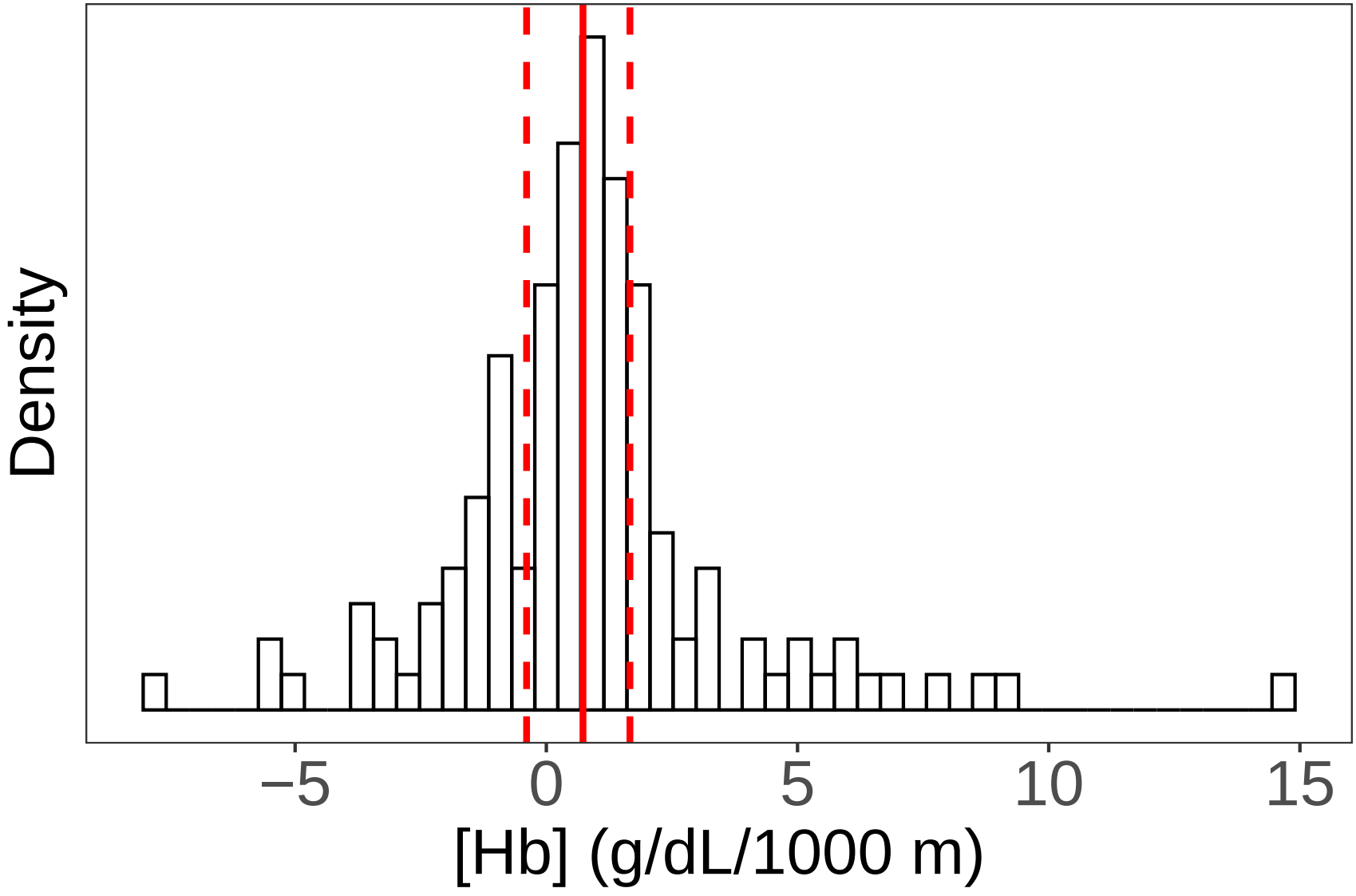
Methods

- **[Hb]** (+ other traits) from 2367 individuals, 136 species
- Bayesian linear models

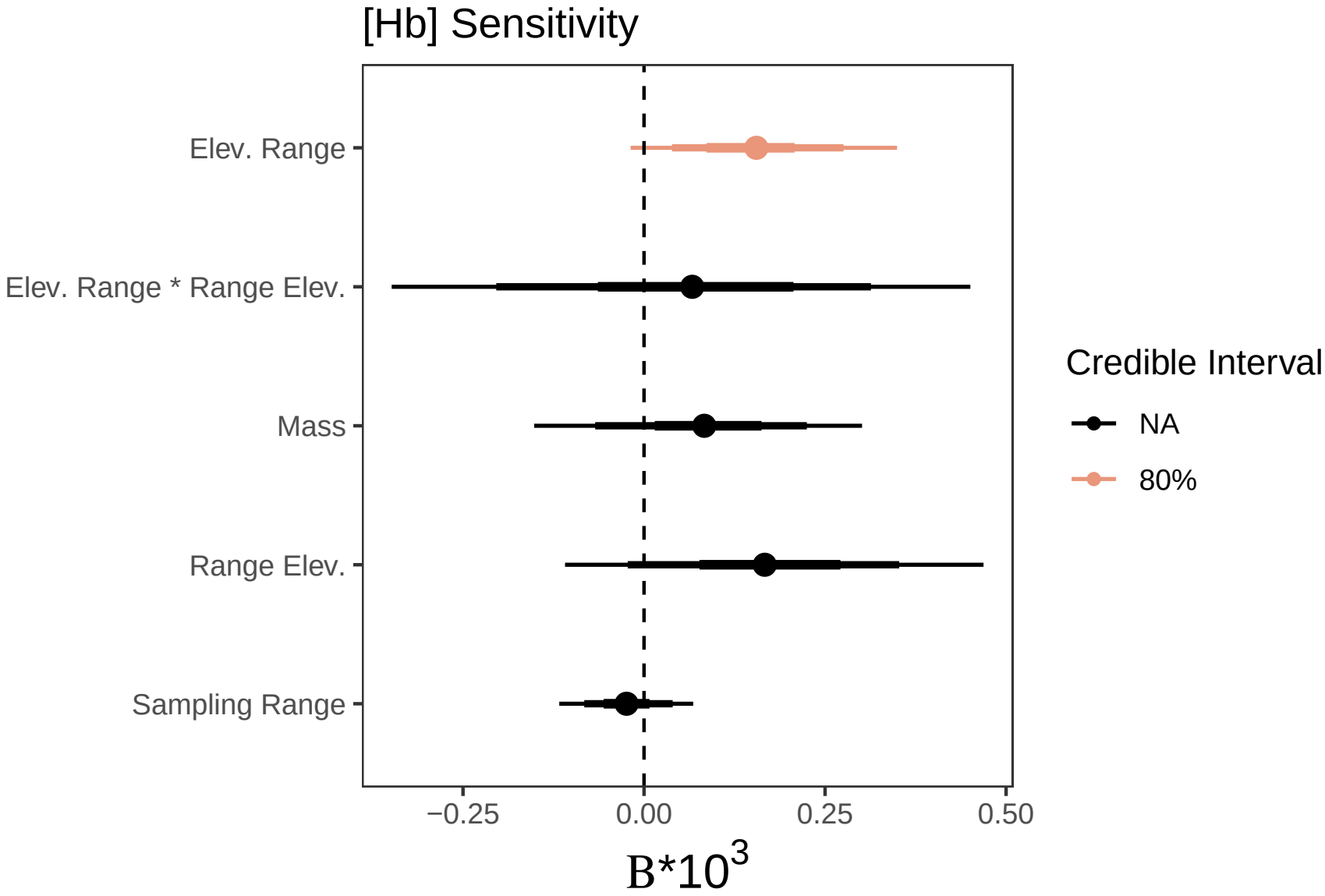




Respiratory plasticity varies but mostly positive



H_1: Elevational generalists have greater respiratory plasticity



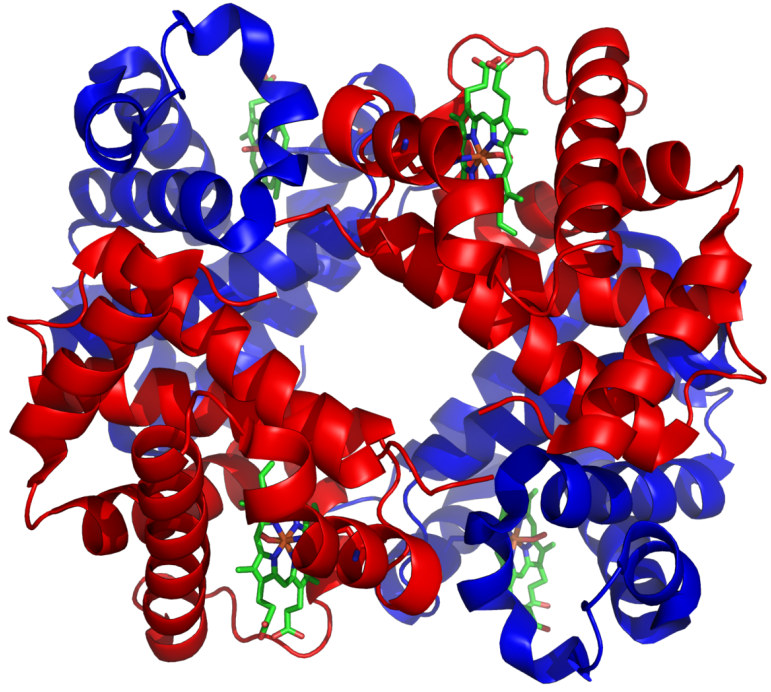
We suggest: Respiratory plasticity can facilitate elevational range expansion

2) Are molecular adaptations to high altitude predictable?

Acknowledgements:

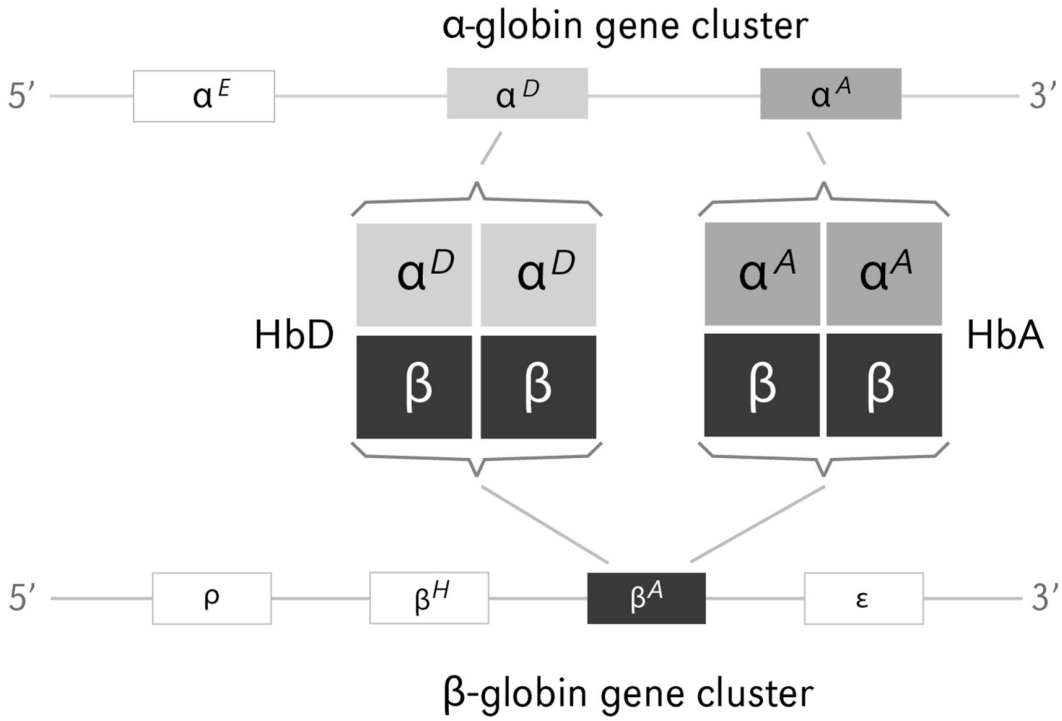
- **Coauthors**: Libby Beckman, Andrea Chavez, Chauncey Gadek, Jenna McCullough, Chandru Natarajan, Jay Storz, Christopher C. Witt
- **Funding**: NSF DBI #1907353, DEB #1146491, and DEB #0543556

Hemoglobin structure impacts oxygen transport



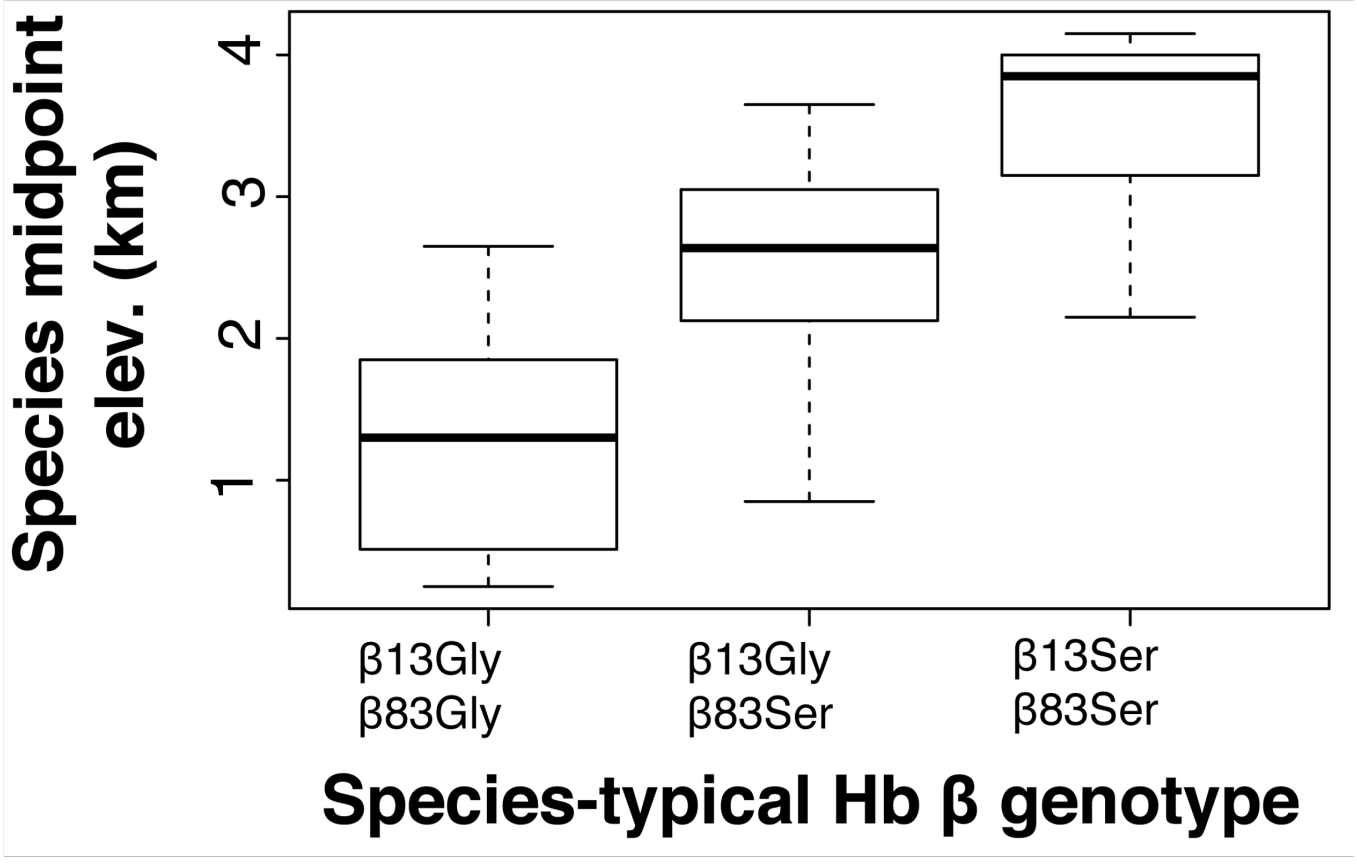
red=α-globin subunit, blue=β-globin subunit,
green=iron-containing hemes

Three genes code for adult avian hemoglobin isoforms



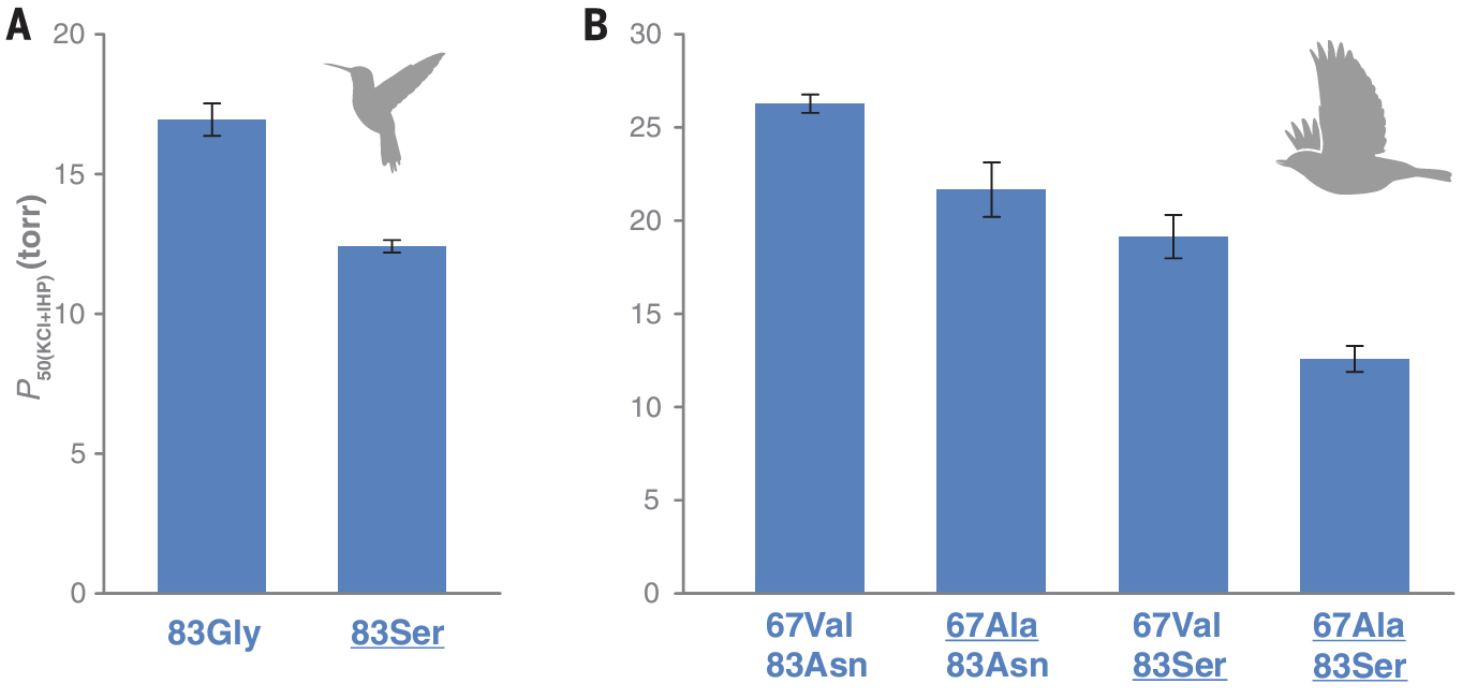
(Opazo et al. 2015 *Mol. Biol. Evol*)

β-Ser substitutions associated with elevation in hummingbirds



(Projecto-Garcia et al. 2013 *PNAS*)

β-Ser increases oxygen carrying capacity in hummingbirds and diglossine tanagers



(Natarajan et al. 2016 *Science*)

Diglossine tanagers

Conirostrum

Diglossa

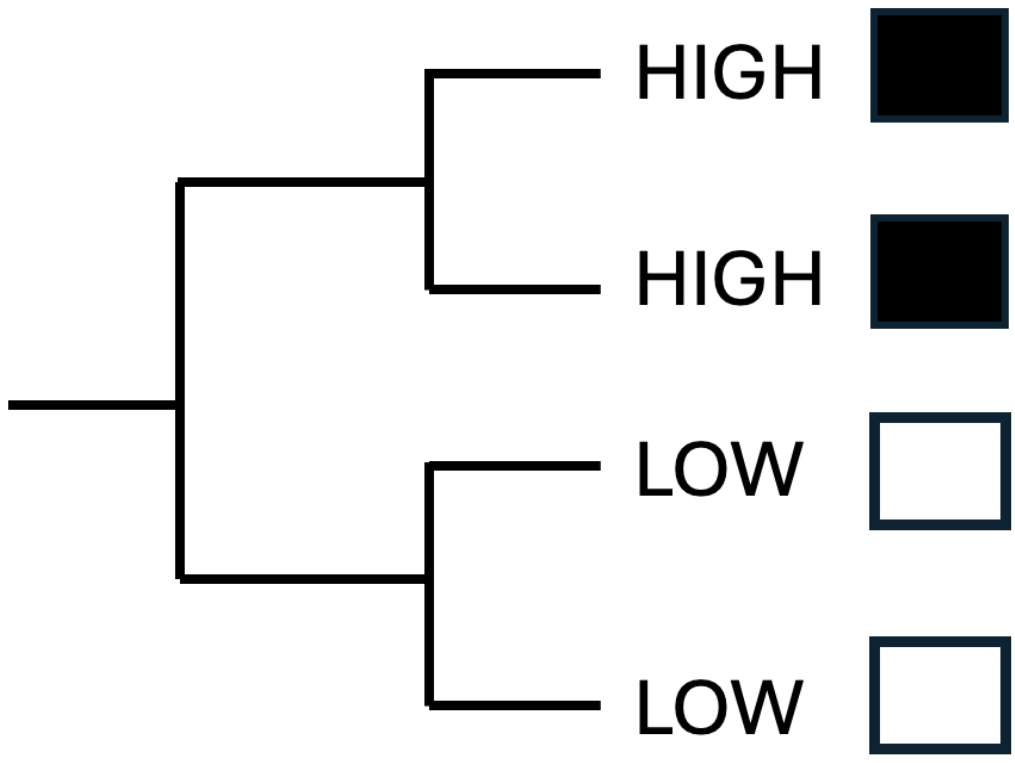
Diuca

Catamenia

Sicalis

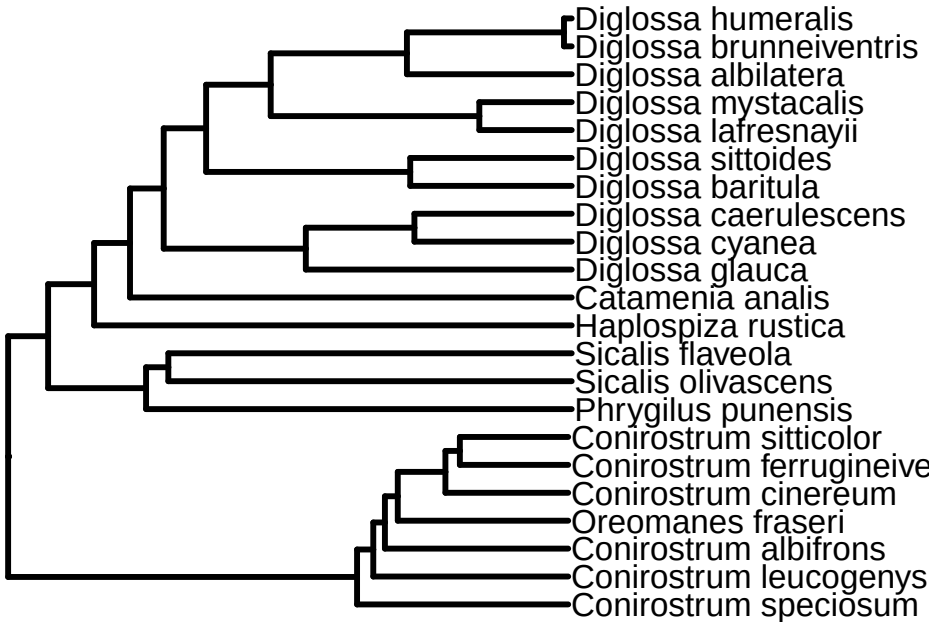
Xenodacnis

H_1: Functional substitutions to Hb are predictably associated with elevation in Diglossines, too

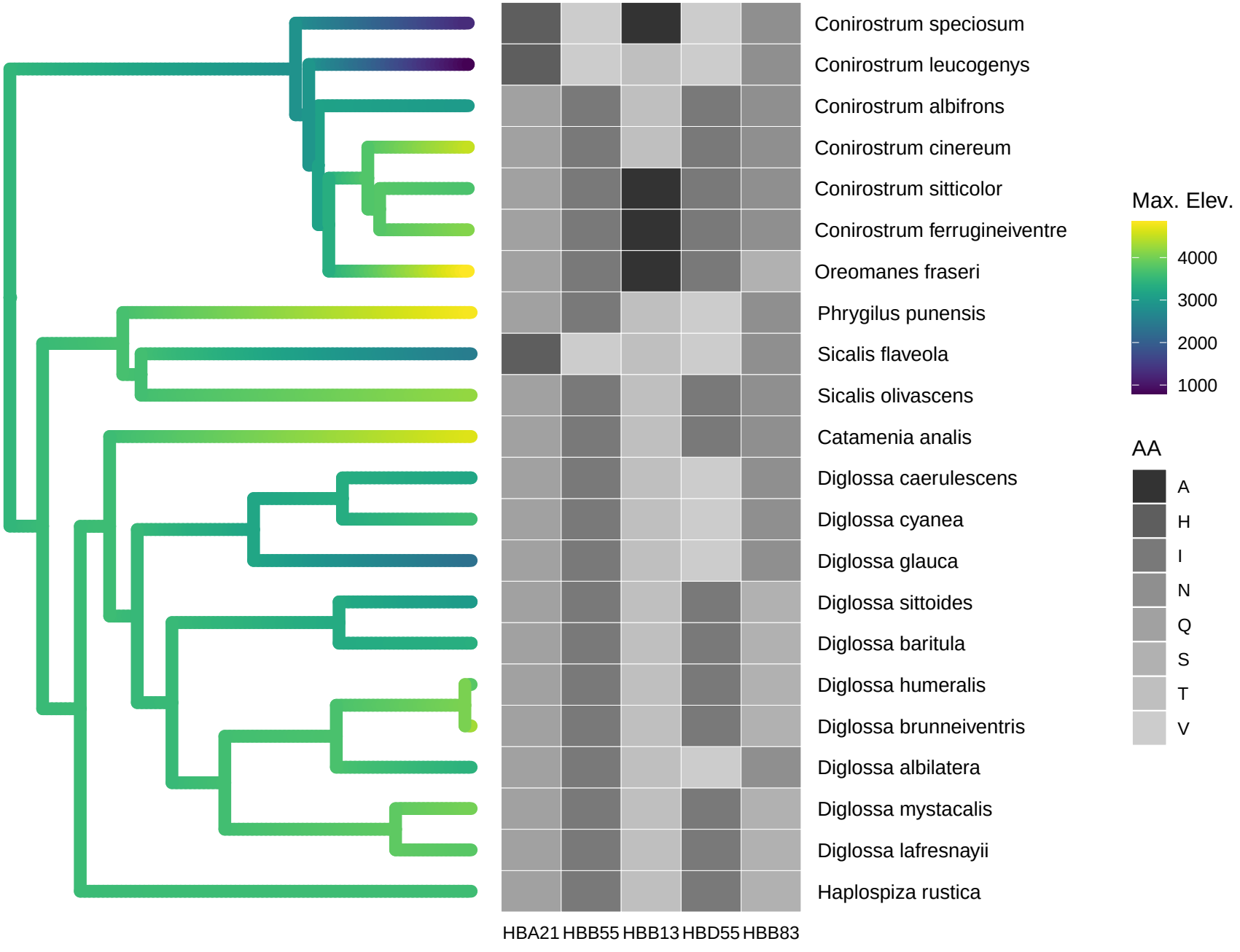


Methods

- Sequence capture of all 7 **Hb** genes for 88 individuals of 22 species
- CDS annotation and amino acid substitution
- Ancestral state reconstruction
- Phylogenetic linear mixed models with Brownian motion trait evolution



Repeated Hb substitutions (but not β-83Ser)



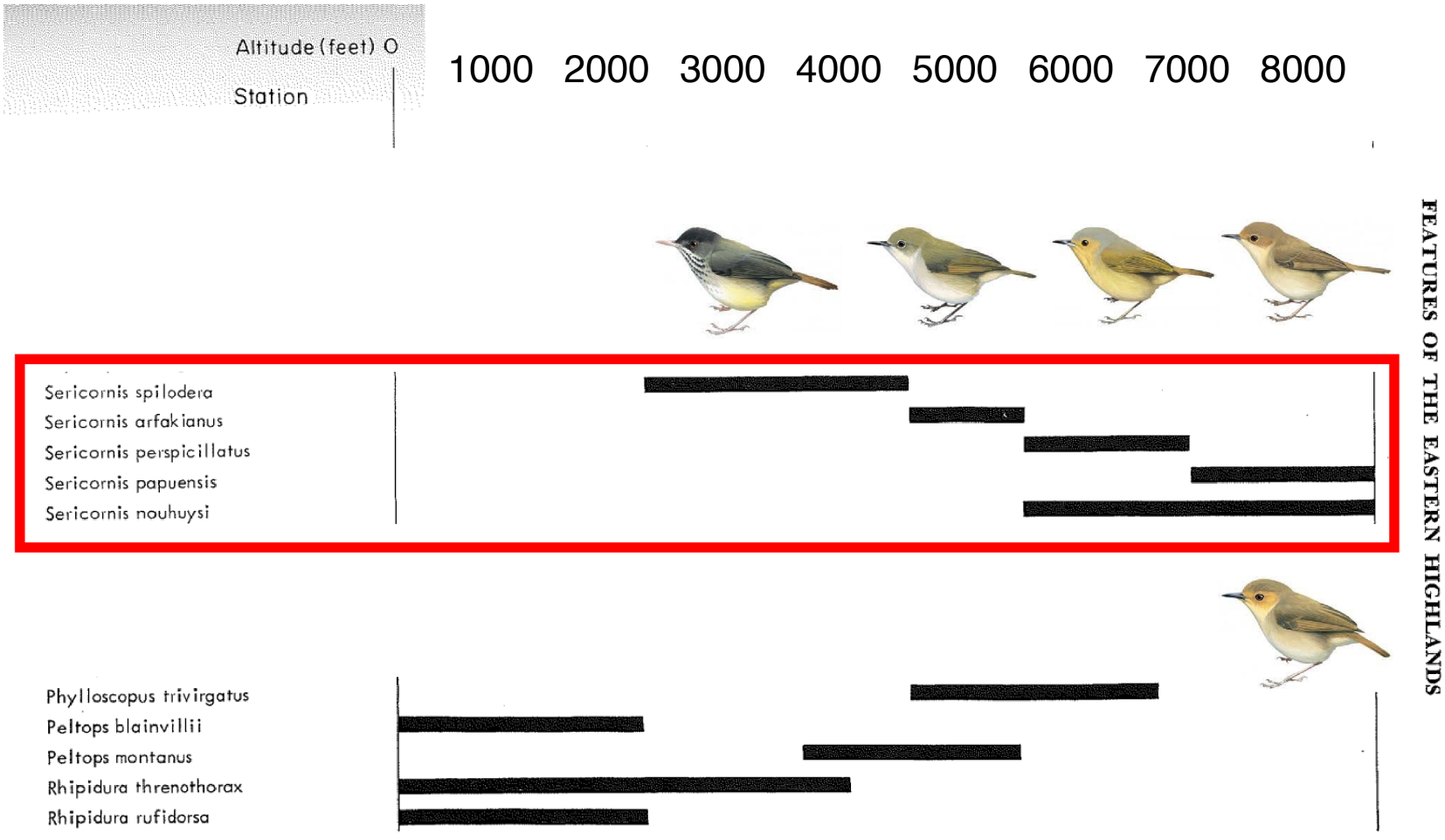
We conclude: evolution is both predictable and contigent (total cop out, lol)

3) How does speciation generate β diversity across elevation?

Acknowledgements:

- **Collaborators and Coauthors**: Salape Tulai, Bulisa Iova, Georgia Kapui, Ben Freeman, Jack Dumbacher, John Klicka, C.J. Battey, Kevin Epperly
- **Funding**: NSF DDIG #1701224, NSF DEB #0108247, and NDSEG and WRF-Hall Fellowships

Elevational replacements

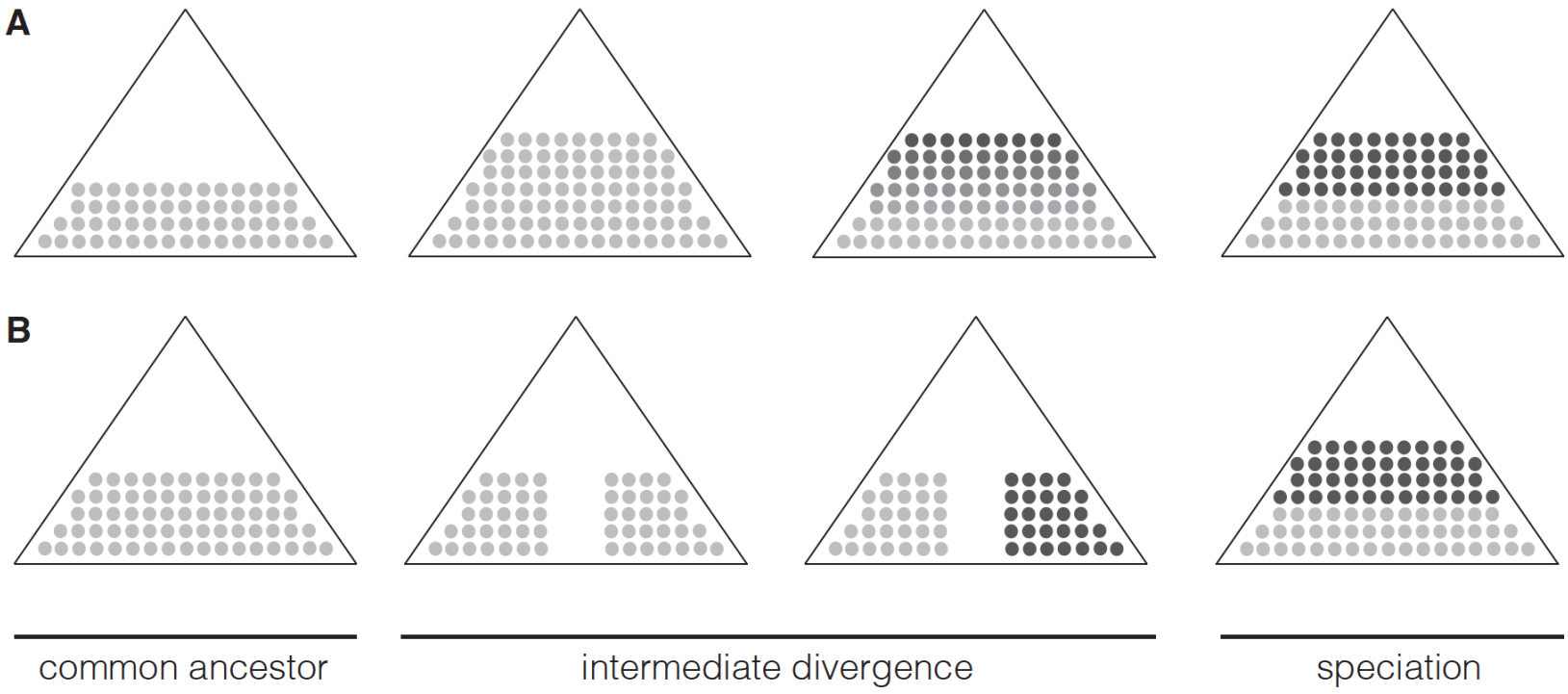


FEATURES OF THE EASTERN HIGHLANDS

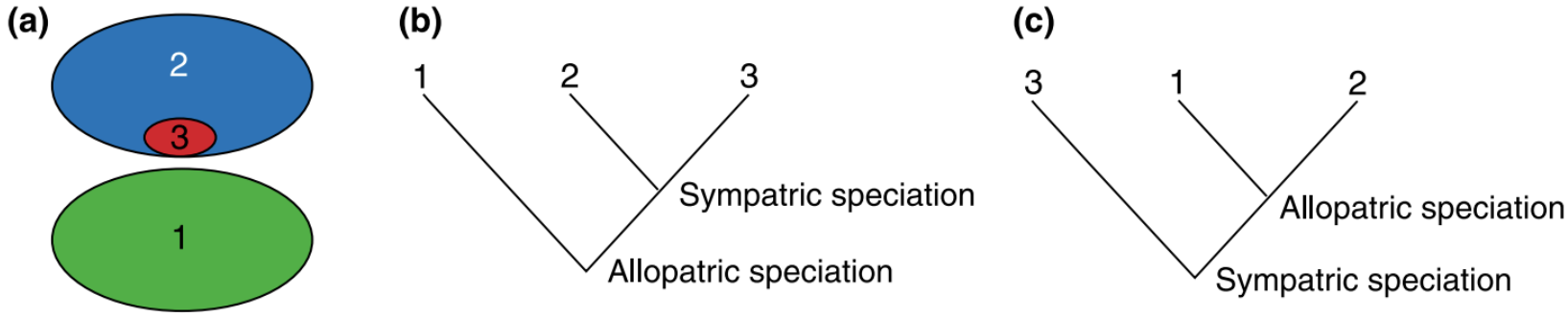
FIG. 4 (cont.). Altitudinal ranges of 166 species in the Karimui area.

(Diamond 1972)

Alternate paths to the same result

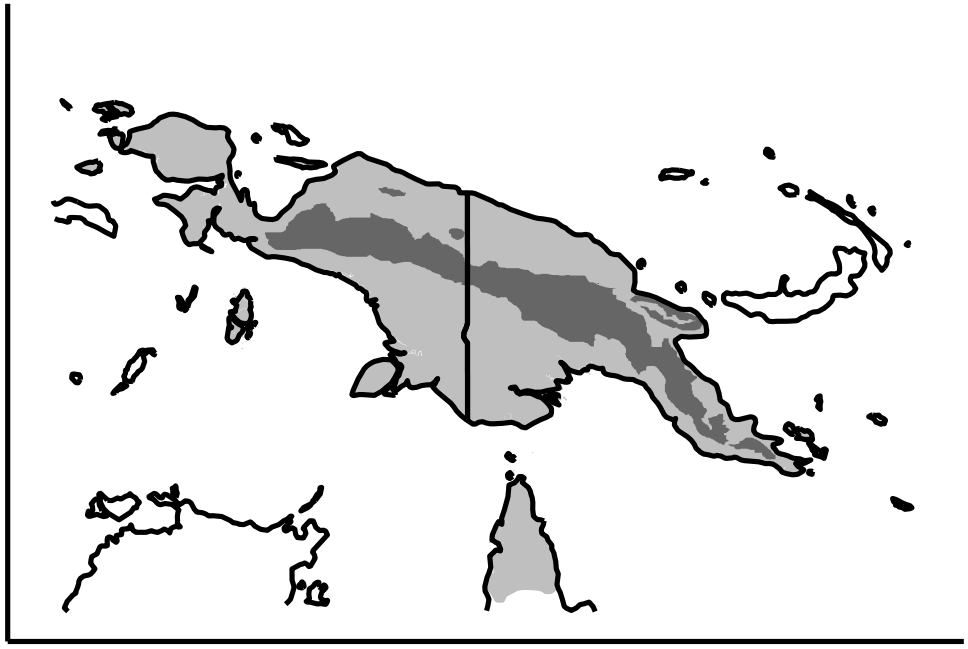


Phylogeny and the geography of speciation



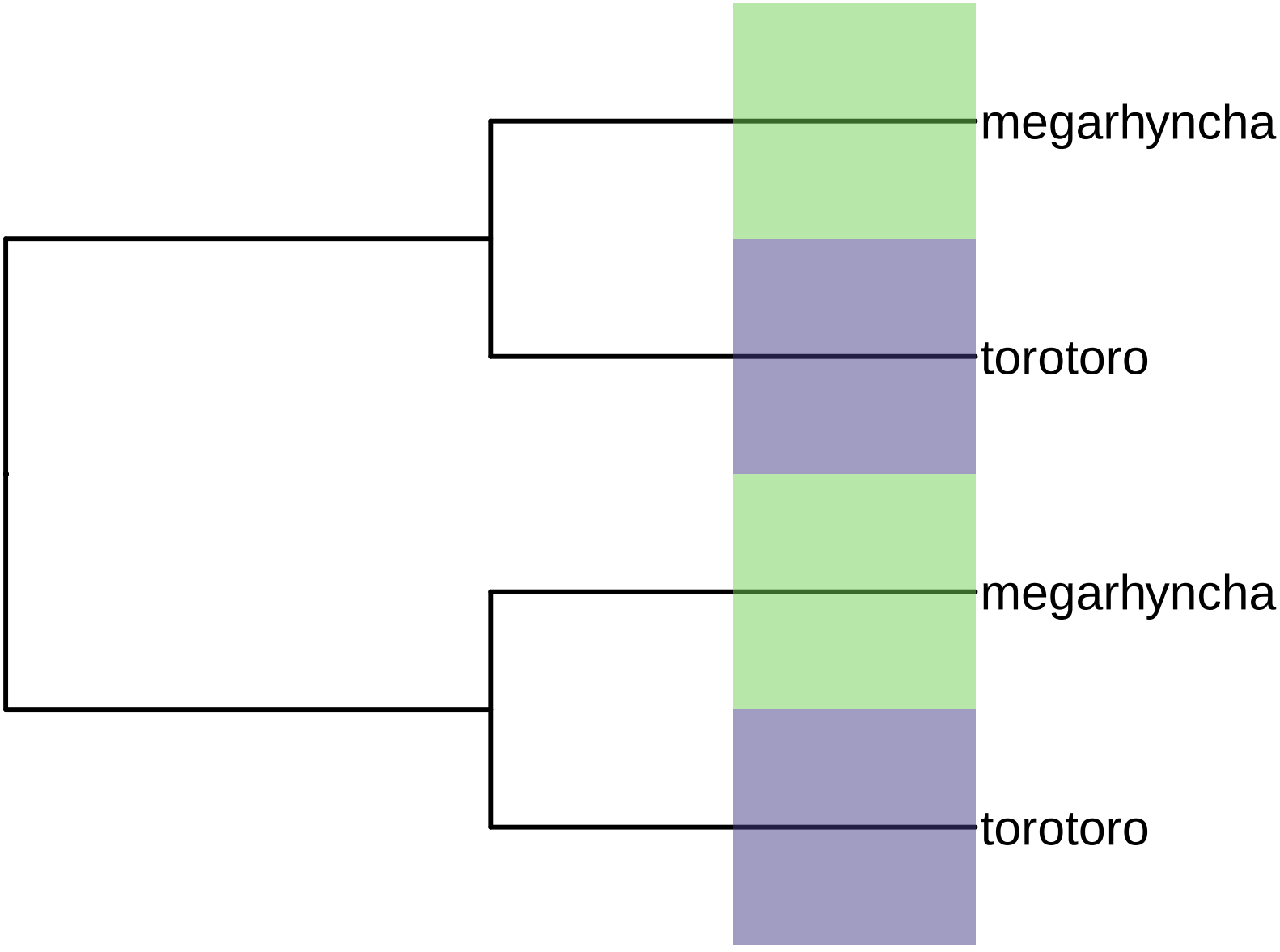
(Losos & Glor 2003)

Syma kingfishers as natural experiment

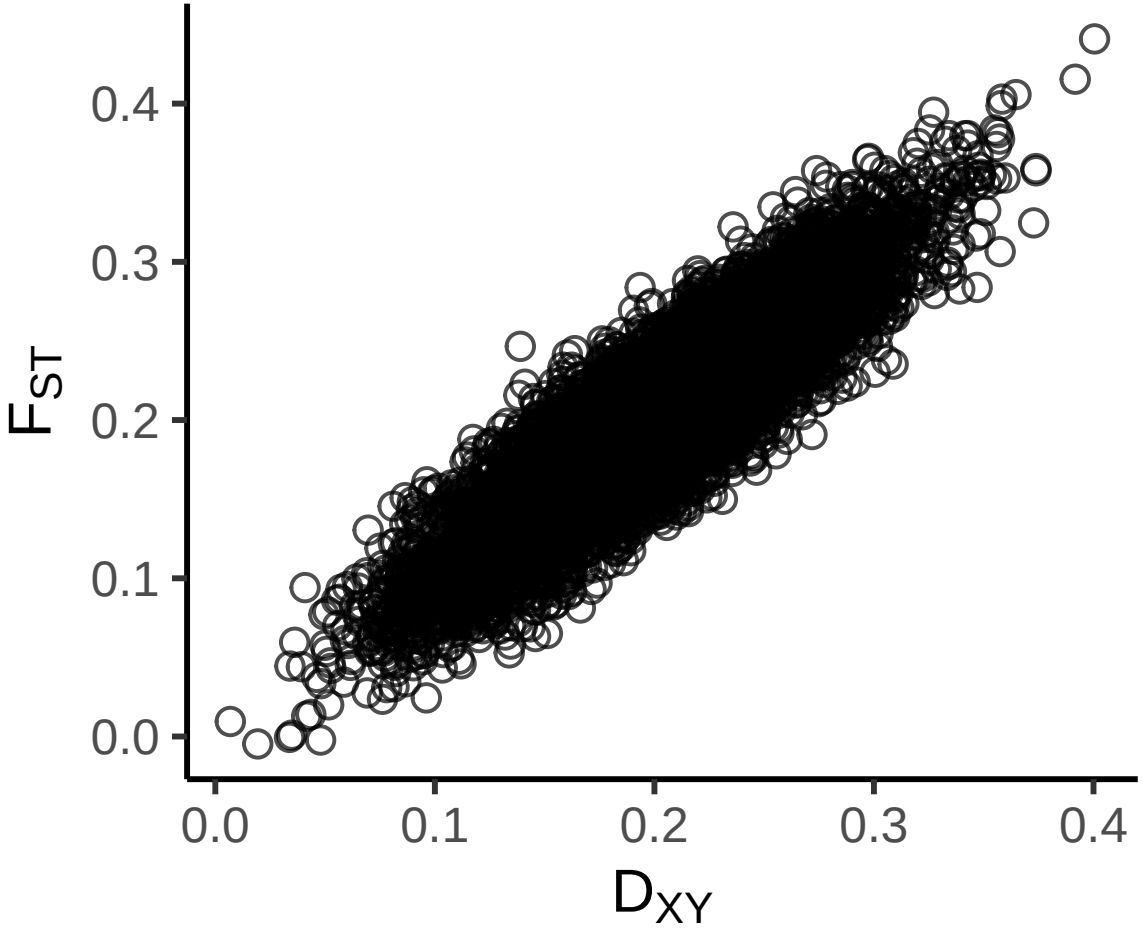


(art by Kevin Epperly)

H_1: Parallel parapatric (ecological) speciation



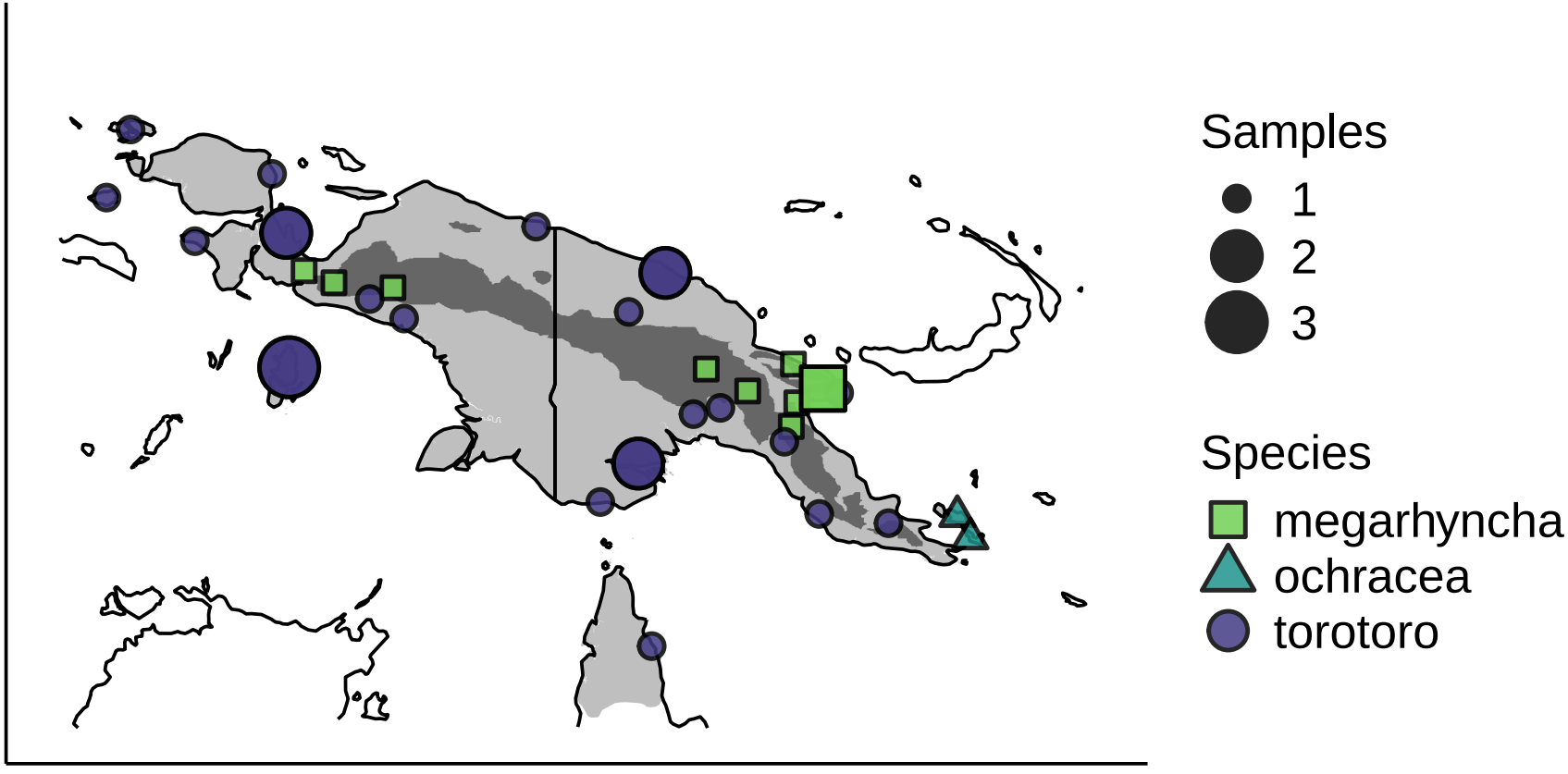
H_1: Parallel parapatric (ecological) speciation



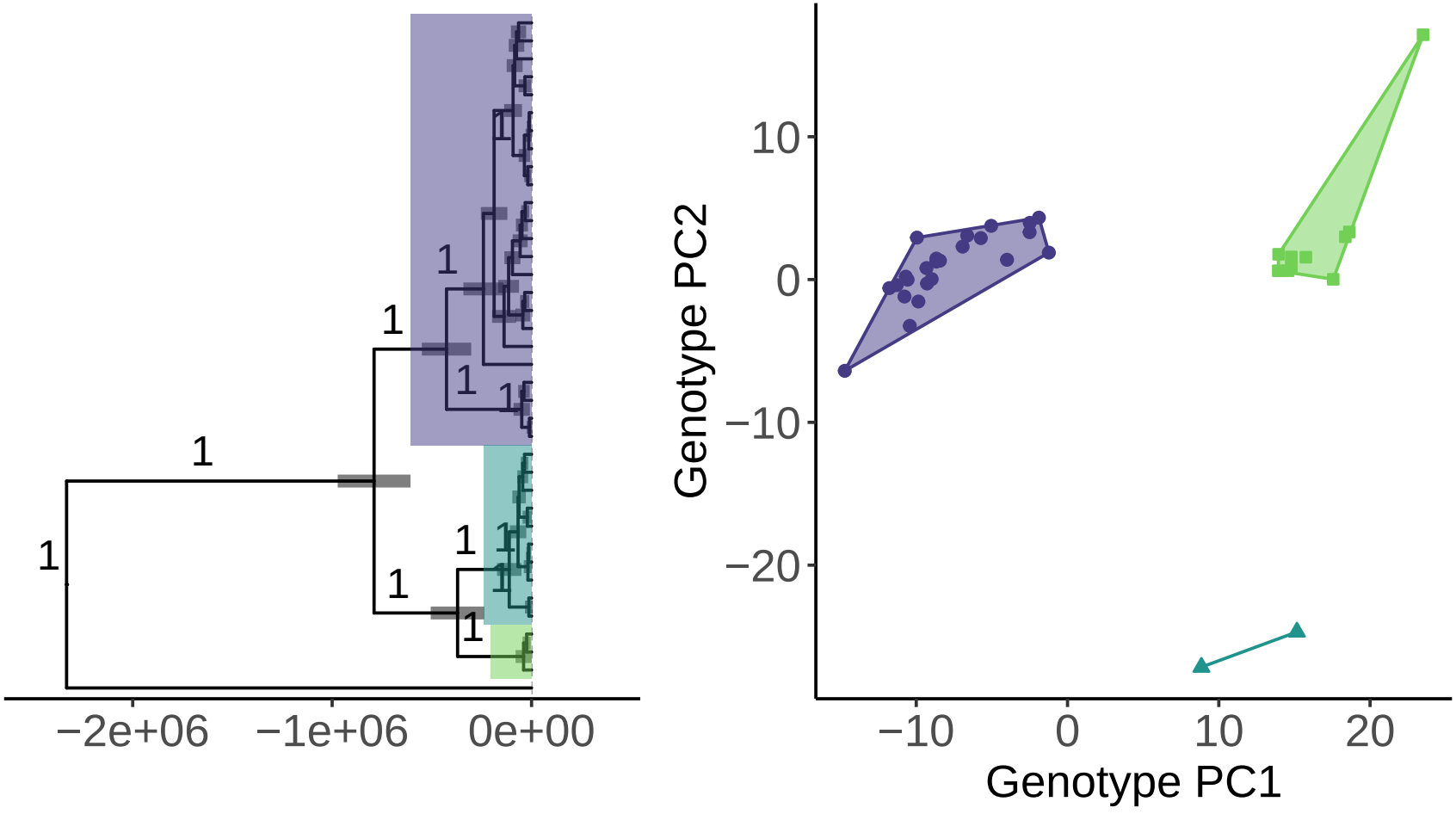
$$F_{ST} = \frac{\pi_{\text{Between}} - \pi_{\text{Within}}}{\pi_{\text{Between}}}; \; D_{XY} = \sum_{ij} x_i y_j d_{ij}$$

Methods

- mtDNA and nuclear DNA from fresh and historic tissues
- phylogenetic inference, clustering, and demographic modeling

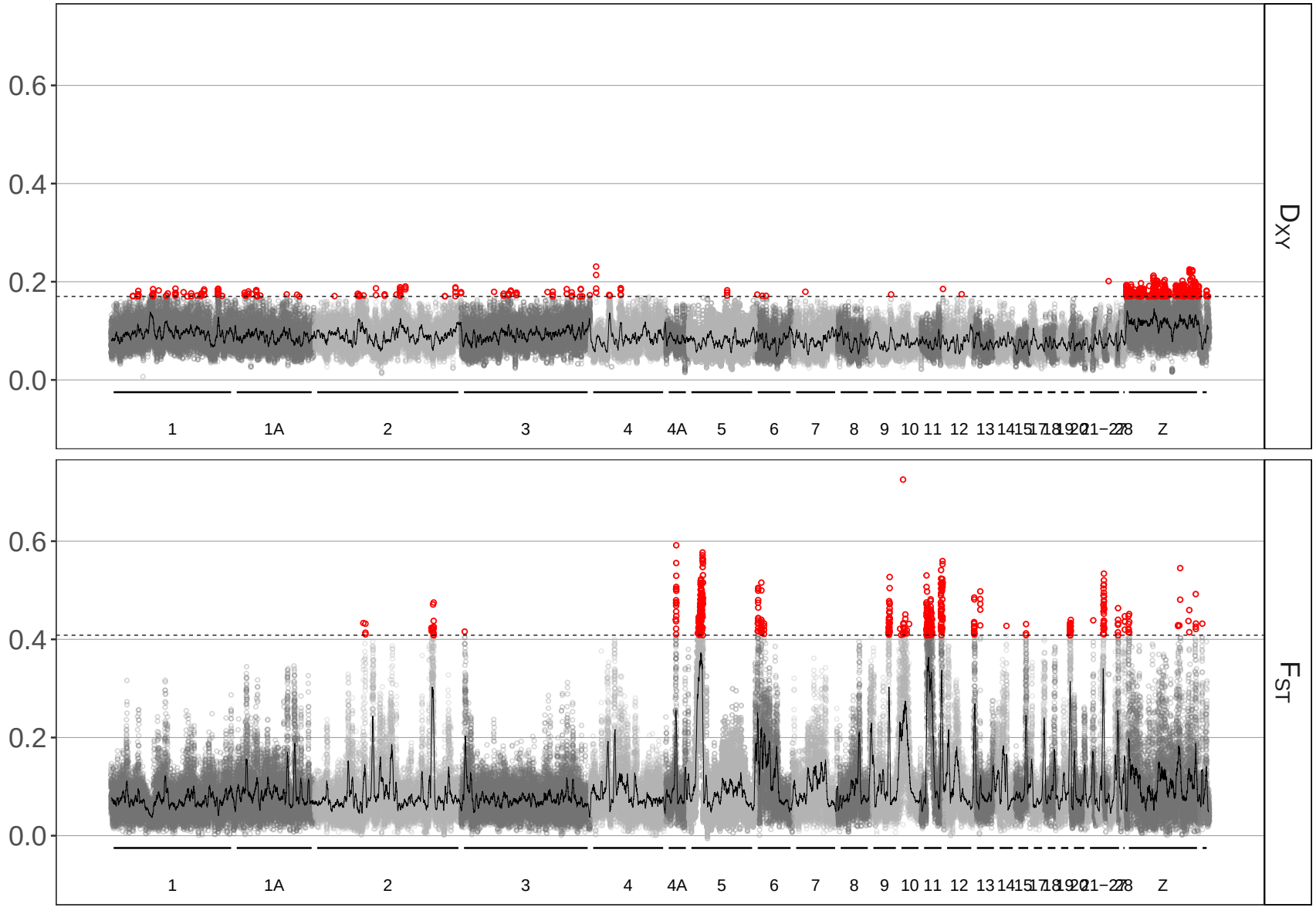


No evidence for parallel parapatric speciation

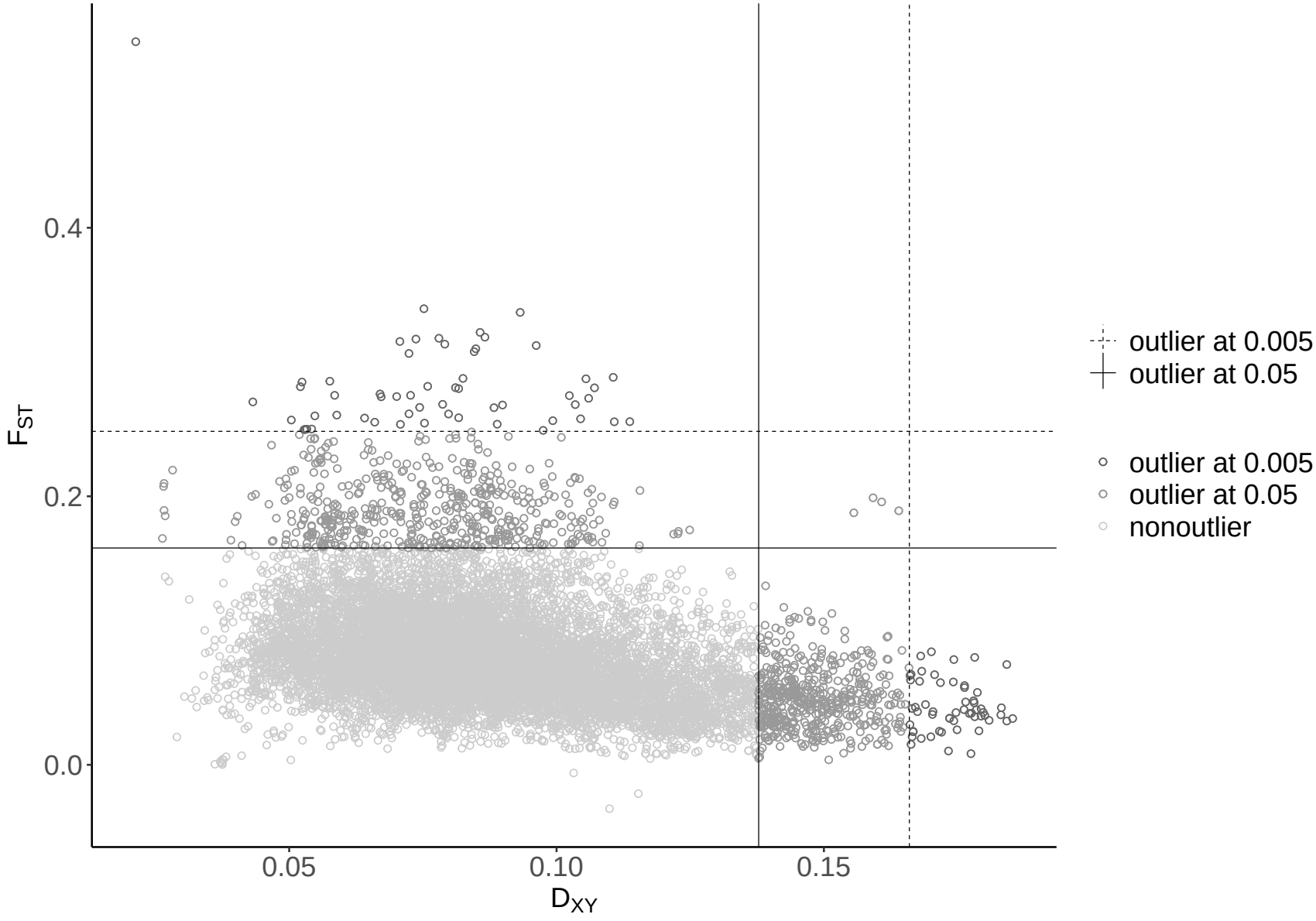


(Linck et al. 2020 *J. Evol. Biol*)

Heterogeneous divergence across the genome

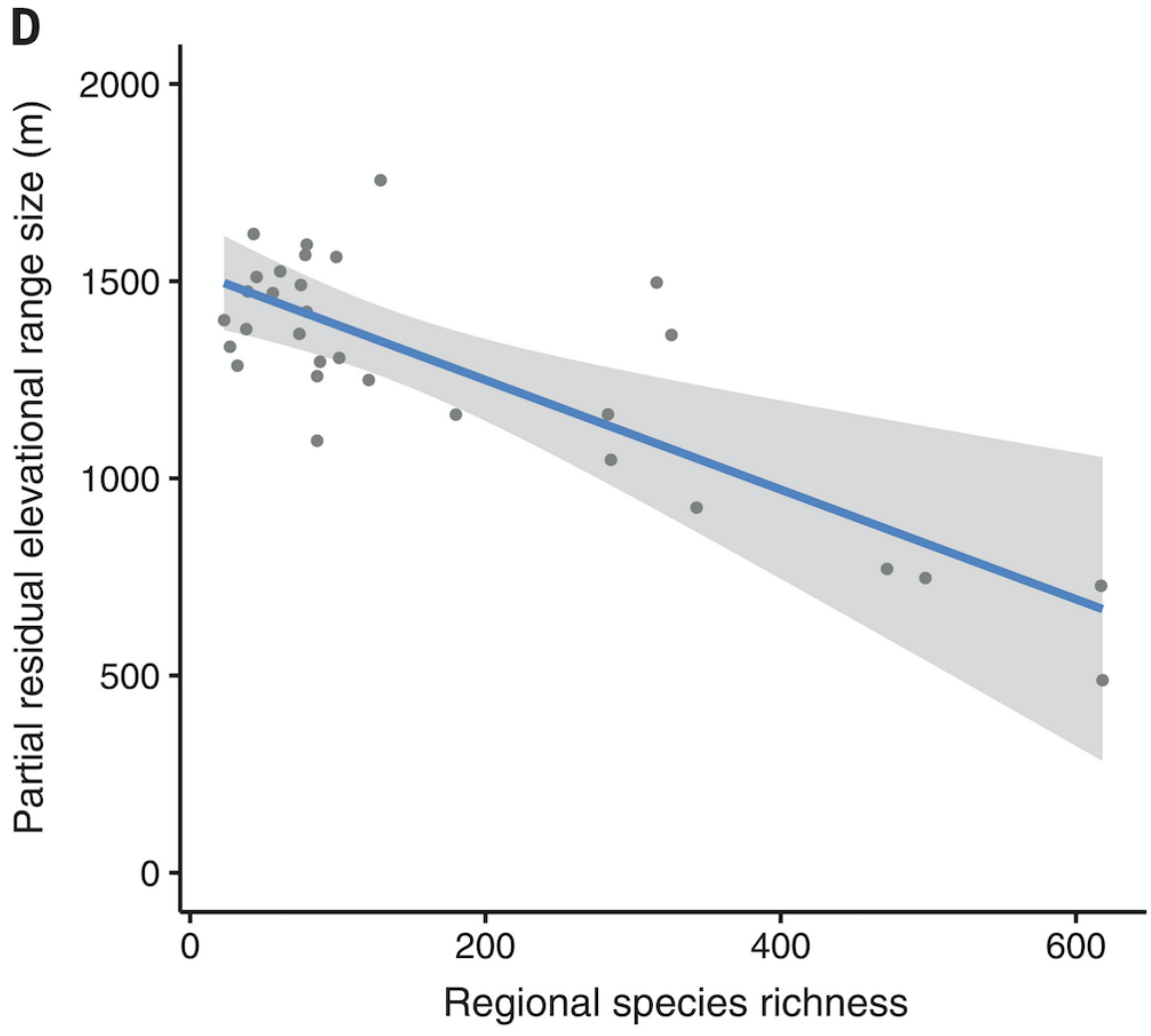


Absolute and relative divergence not correlated



We conclude: speciation in allopatry is more likely (but parapatric speciation is possible, and gene flow was involved)

The specter of other variables



(Freeman et al. 2022 *Science*)

Why this is all a little unsatisfying (or motivating?)

"However if many causes contribute to an observed pattern, none will be eliminated from consideration by a properly designed experiment. . . The objective of investigation in cases of this sort is not to determine the single cause of a pattern, as no such cause exists, but rather to assign relative importances to the contributions of, and interactions between, a number of processes, all known or reasonably suspected of operating to some degree" (Quinn & Dunham 1983 *Am. Nat.*)

Resources

- slides and code: https://github.com/elinck/misc_talks
- website: https://elinck.org/
- twitter: @ethanblinck

References

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- Freeman et al. 2022. *Science*, 377(6604), 416-420.
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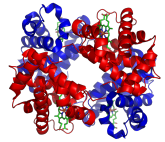
Thanks!

1) [Hb] sensitivity is correlated with range breadth

2) Adaptive Hb evolution is predictable but context dependent



3) Parapatric speciation is unlikely, but elevational gradients help maintain species limits