Starting Causal Inference for Macroevolution

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Background

- SSE models are popular tools to study adaptive radiations but can be misled (Rabosky & Goldberg 2015).
- Hidden states (HiSSE; Beaulieu & O'Meara, 2016) detect confounding factors to rate heterogeneity.
- "Phylogenetic Natural History" (Uyeda, Zenil-Ferguson & Pennell, 2018) combines hypothesis-testing and data-driven approaches to disentangle the impact of observed and latent factors.

How much of the **rate heterogeneity** in the data can really be **explained by the focal trait**?

Check out our Preprint!

Advantages of Causal Inference Approach:

- Consider additional, **latent rate shifts**
- Distinguish clades with different dynamics (*e.g.*, absence of **ecological opportunity**)
- Infer **relative importance** of different factors

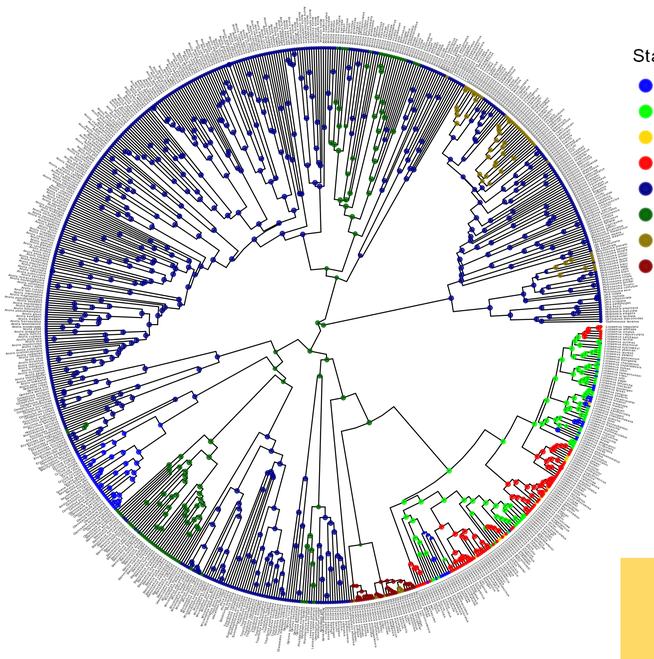
Methods I

Data:

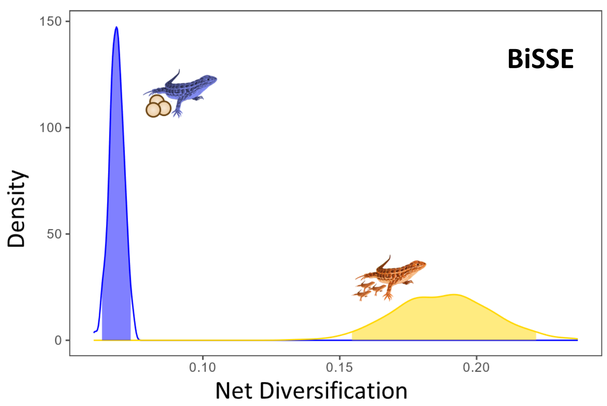
- Phylogeny of Pleurodonta, 733 out of 1111 spp. (Tonini *et al.,* 2016)
- Reproductive mode (ovip./vivip.), occurrence in Andean mountains.

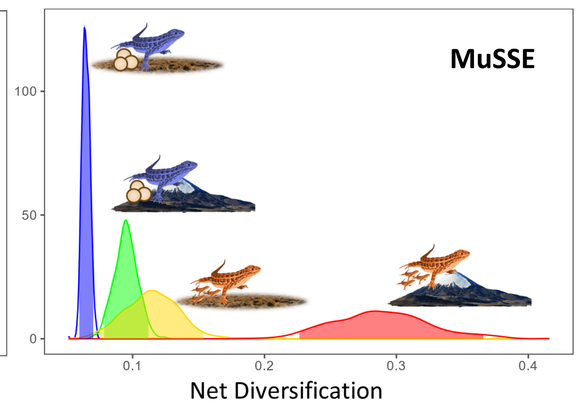
Diversification Analyses:

- *Standard:* BiSSE/MuSSE (HiSSE/MuHiSSE) in RevBayes.
- *Causal*: MiSSE in R (hidden states only), AIC for best #states, then MuSSE with combined MiSSE-states & trait



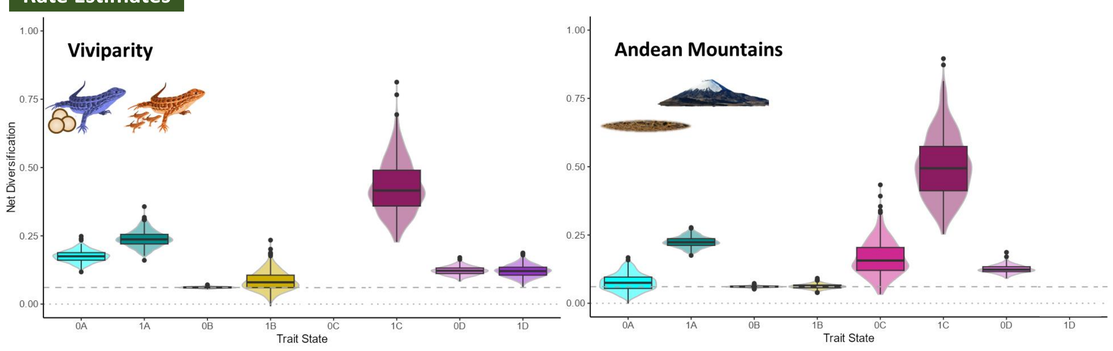
SSE Rate Estimates

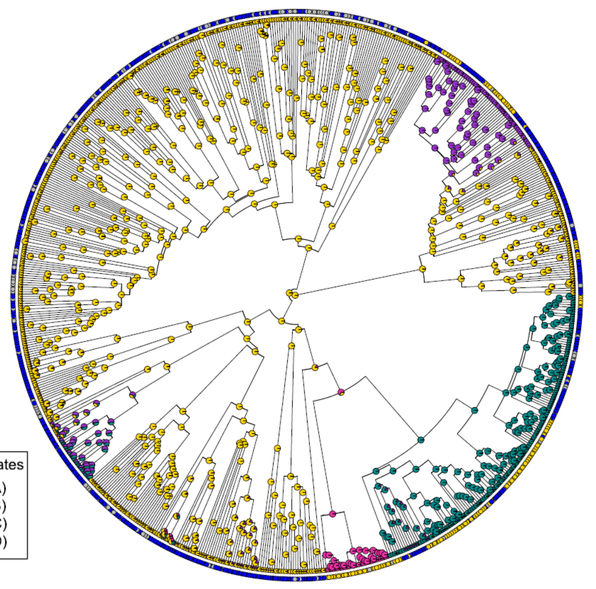




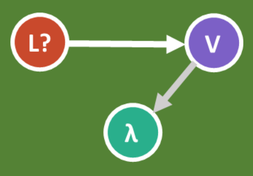
Viviparity seems to have little to **no additional explanatory power**!

MuSSE*MiSSE Rate Estimates



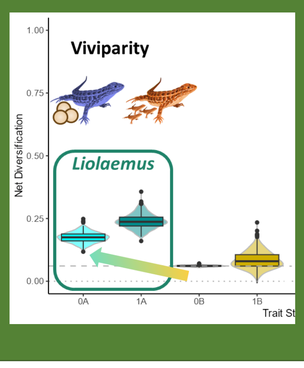


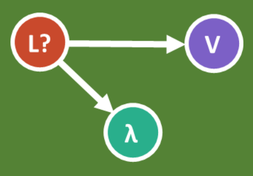
Testing Causal Relations



λ|V ⊥ L

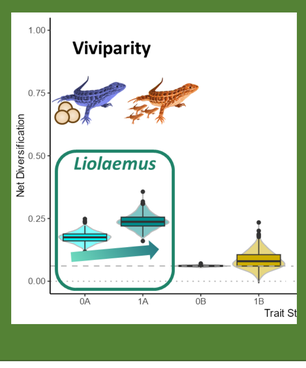
After conditioning on viviparity, diversification and clade shift are uncorrelated

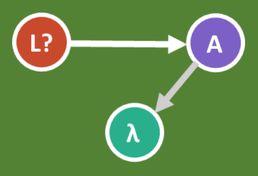




V|L ⊥ λ|L

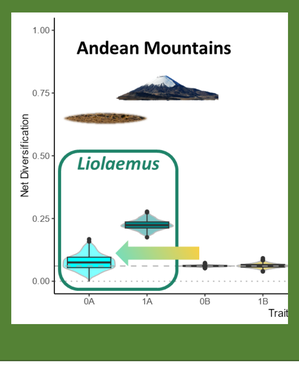
After conditioning on clade shift, viviparity and diversification are uncorrelated

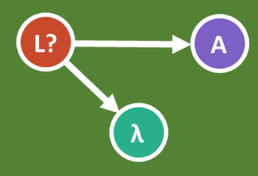




λ|A ⊥ L

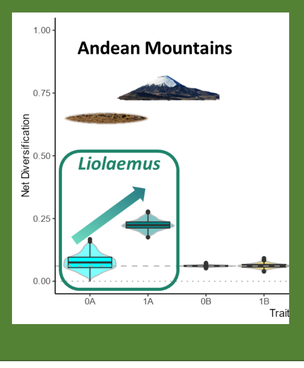
After conditioning on the Andes, diversification and clade shift are uncorrelated





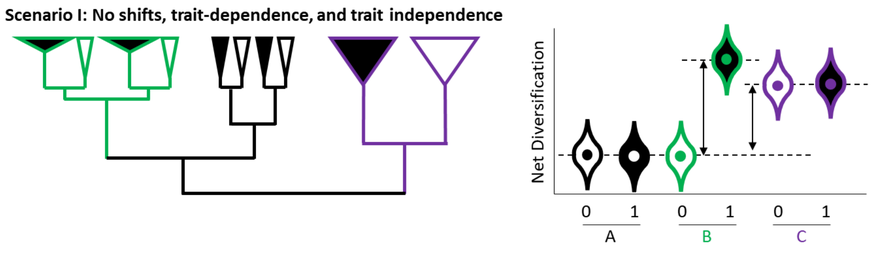
A|L ⊥ λ|L

After conditioning n clade shift, viviparity and diversification are uncorrelated

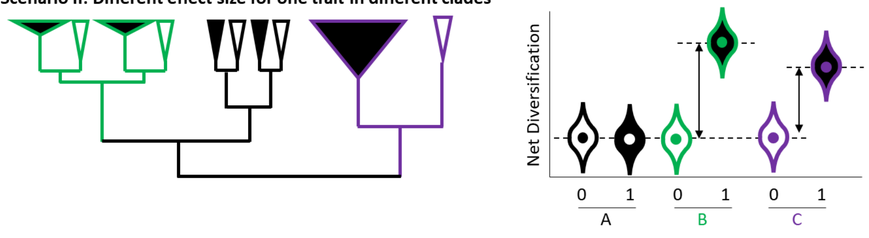


Under what scenarios is just **adding hidden states** insufficient?

Scenario I: No shifts, trait-dependence, and trait independence



Scenario II: Different effect size for one trait in different clades



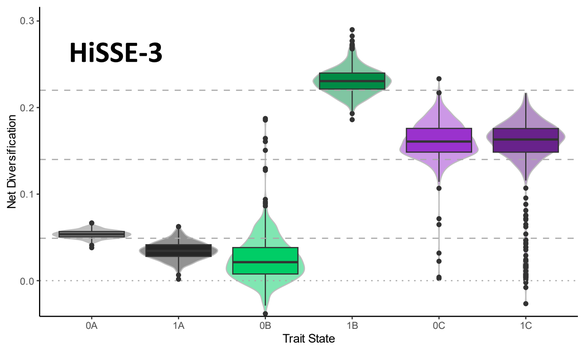
Methods II

Phylogenetic Natural History:

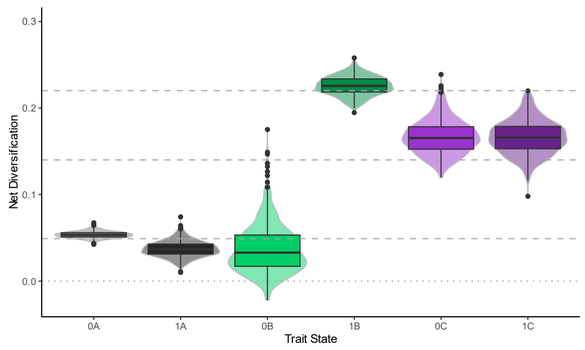
- Simulate diversification scenarios with known causal relations
- Infer using BiSSE, HiSSE-2, HiSSE-3, and new Causal Inference approach

- **Causal Inference** reliably recovers trait and clade effects
- **HiSSE** succeeds when correct number of hidden states specified
- **HiSSE** fails when overparametrised

Best Conventional Model (AIC)



Causal Inference



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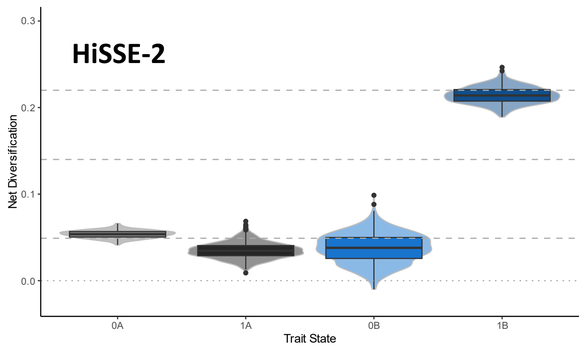

Causal Inference

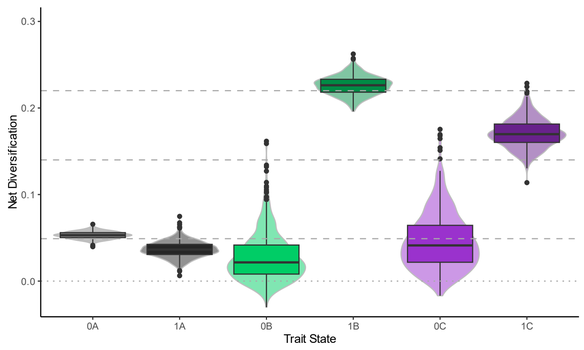

Photo: Marcio Borges-Martins

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Swiss National Science Foundation

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