State-dependent diversification models

Introduction to phylogenetic comparative methods

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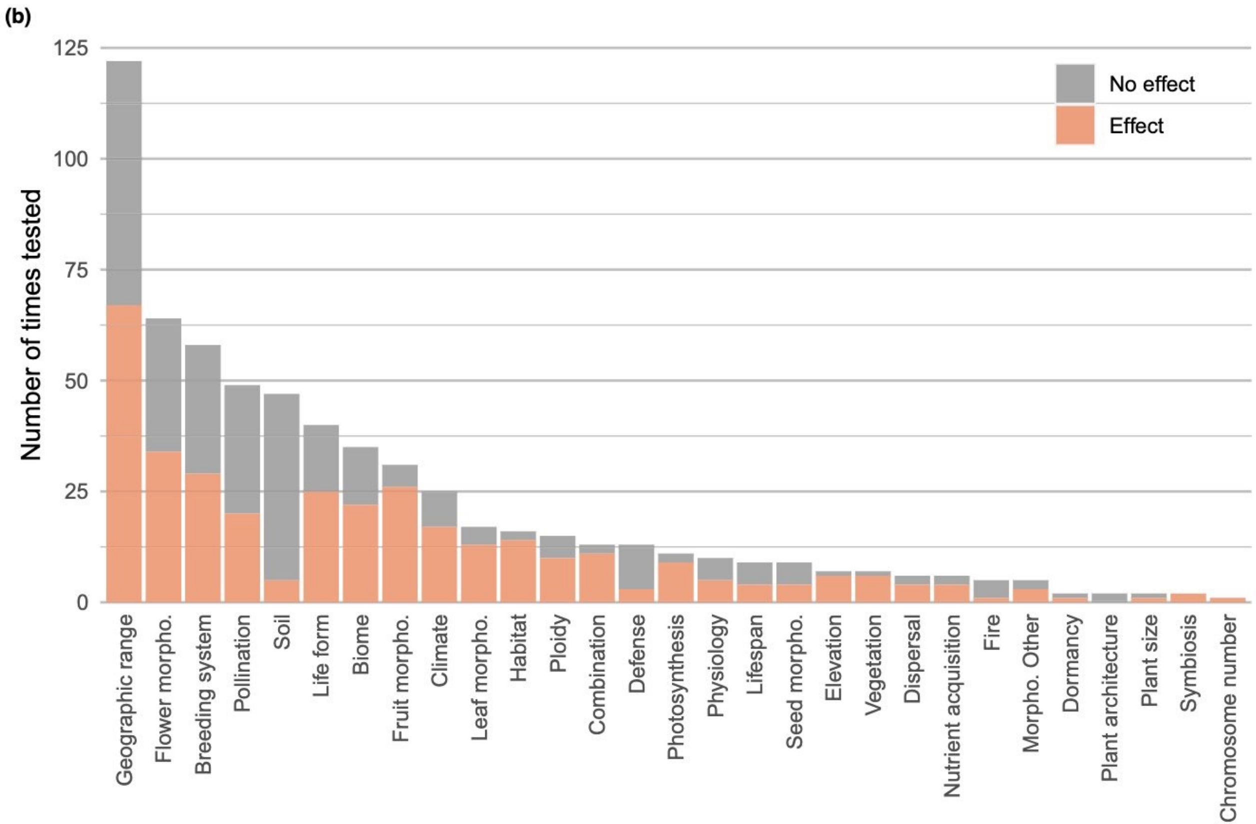
MOLE 2025 Workshop. Woods Hole, MA.

There are 400,000 vascular plants in the planet.

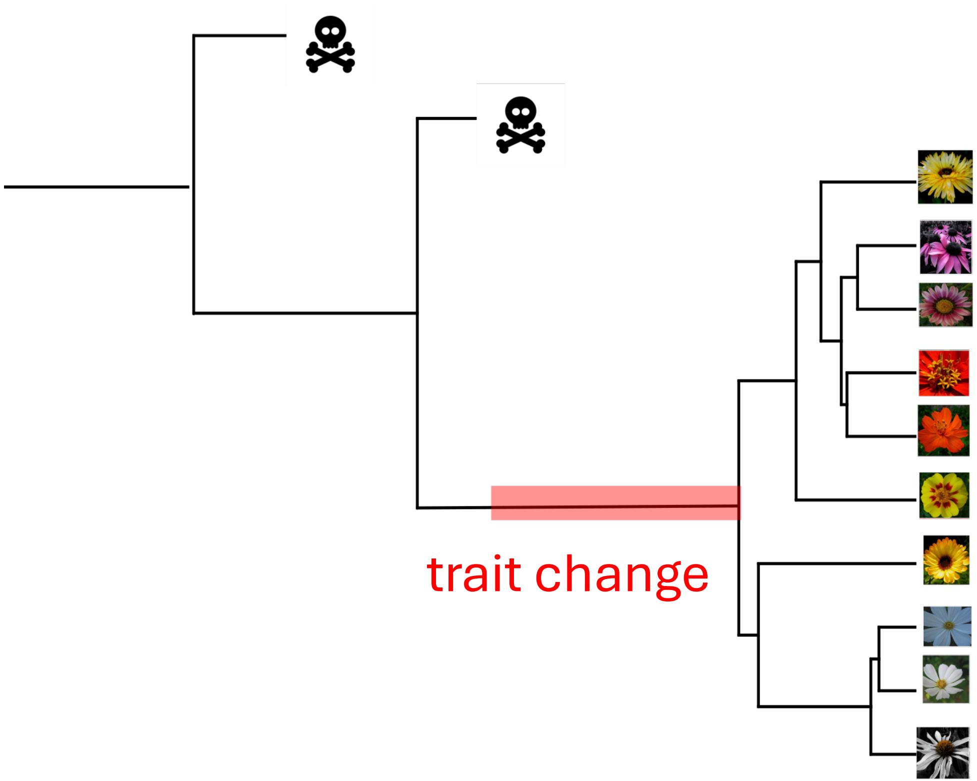
Volcanoes photography: Maria Costantini 2021
Plant photography: RZF and Carrie Tribble

152 studies linking plant traits to speciation and extinction using state-dependent diversification

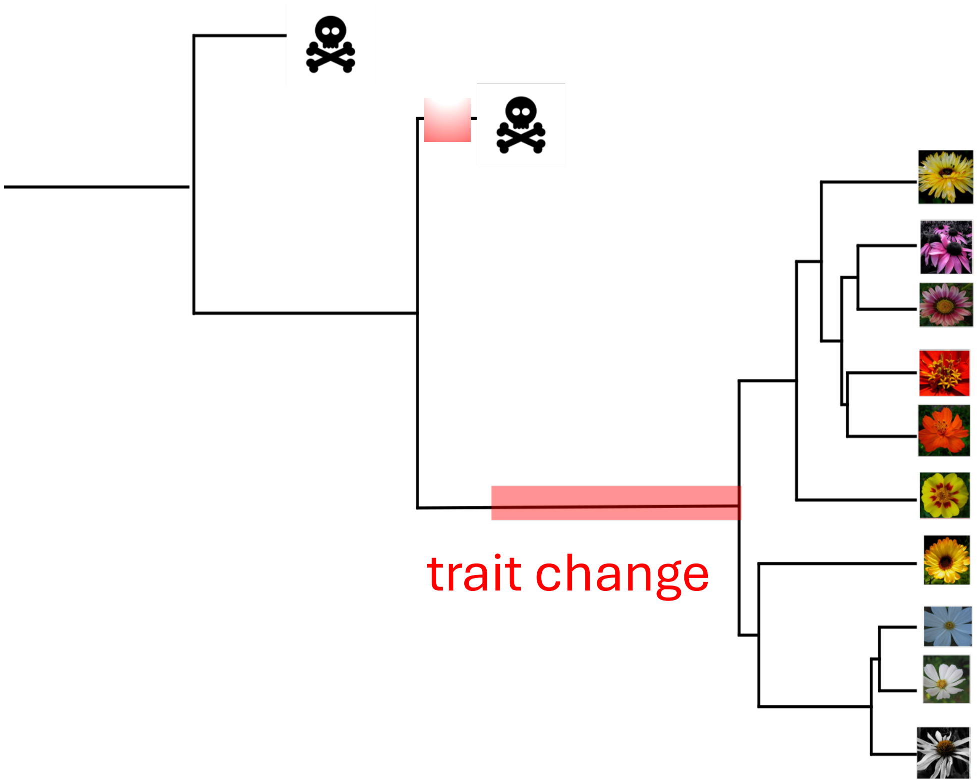


Helmstetter, A.J., Zenil-Ferguson, R., et al. 2022. *Ecology Letters*

Macroevolutionary consequences of trait change



Macroevolutionary consequences of trait change



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Perspective

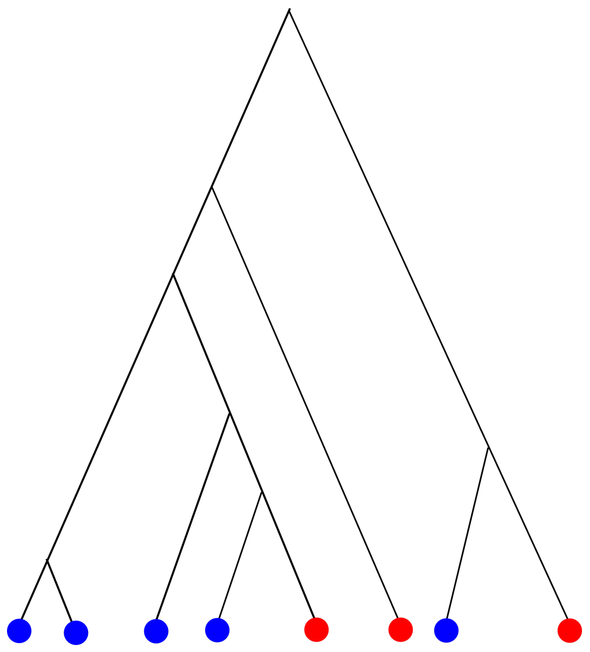
Opposing effects of plant traits on diversification

Bruce Anderson,[1,*] John Pannell,[2] Sylvain Billiard,[3] Concetta Burgarella,[4] Hugo de Boer,[5] Mathilde Dufay,[6] Andrew J. Helmstetter,[7] Marcos Méndez,[8] Sarah P. Otto,[9] Denis Roze,[10] Hervé Sauquet,[11,12] Daniel Schoen,[13] Jürg Schönenberger,[14] Mario Vallejo-Marin,[15] Rosana Zenil-Ferguson,[16] Jos Käfer,[17,*] and Sylvain Glémin[15,18,*]

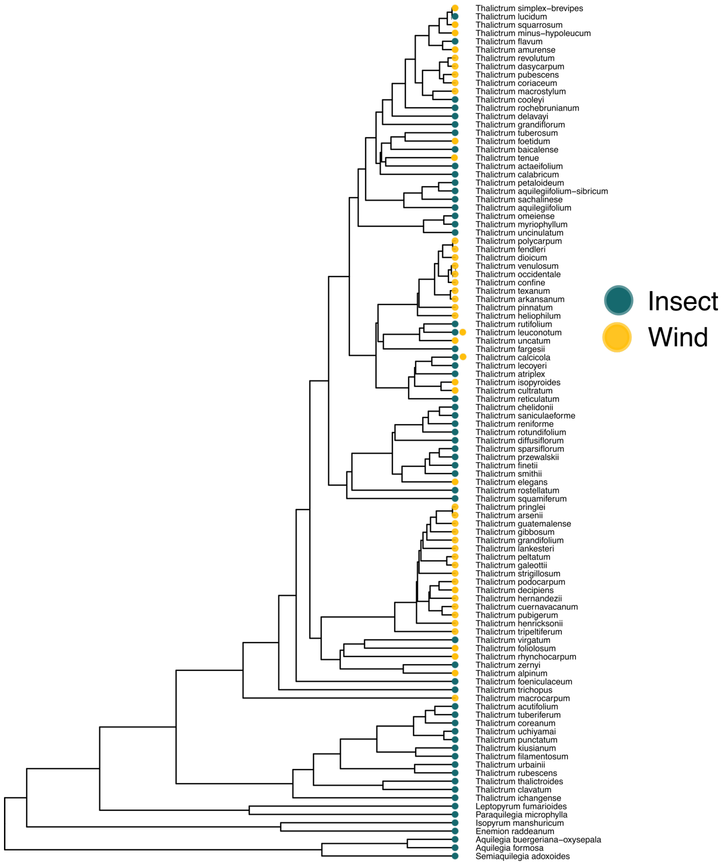
Polyploidy	↑	↑	↓	↑
	Gene redundancy allows evolution of new functions and facilitates divergence.	*Divergent resolution of gene redundancy leads to post-zygotic incompatibilities.*	*Instability in meiosis and minority cytotype disadvantage leads to mating difficulties*	*Gene redundancy buffers deleterious mutations and allows evolution of new functions, which increases adaptive potential in changing environments.*

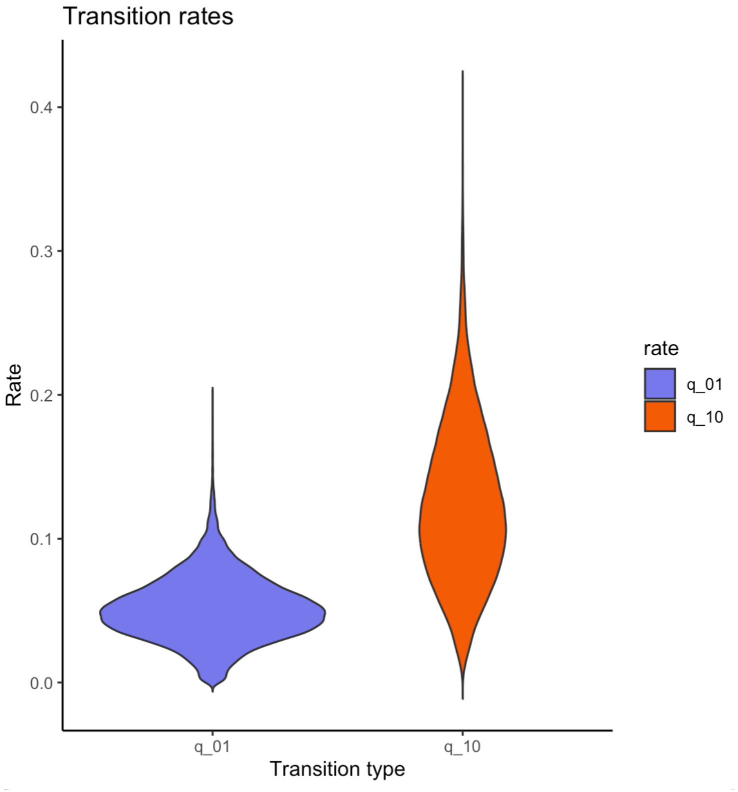
Stop and think

Where and how many transitions happened in this phylogeny?

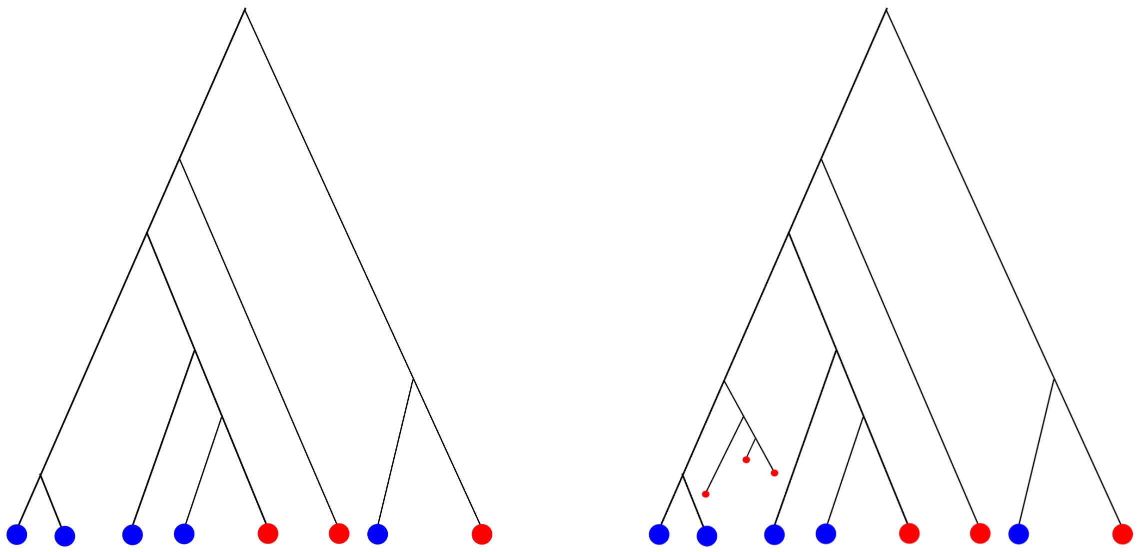


Under a Mk2 we estimated for our data



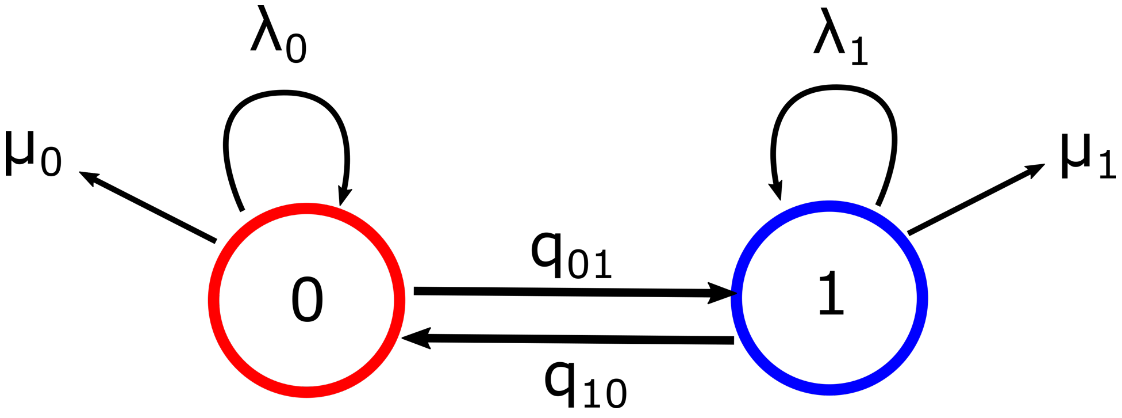


Why is state-dependent diversification so critical?



Maddison, 2007

¿How do we model state dependent diversification?
Two birth and death processes connected by transitions



SCAN ME

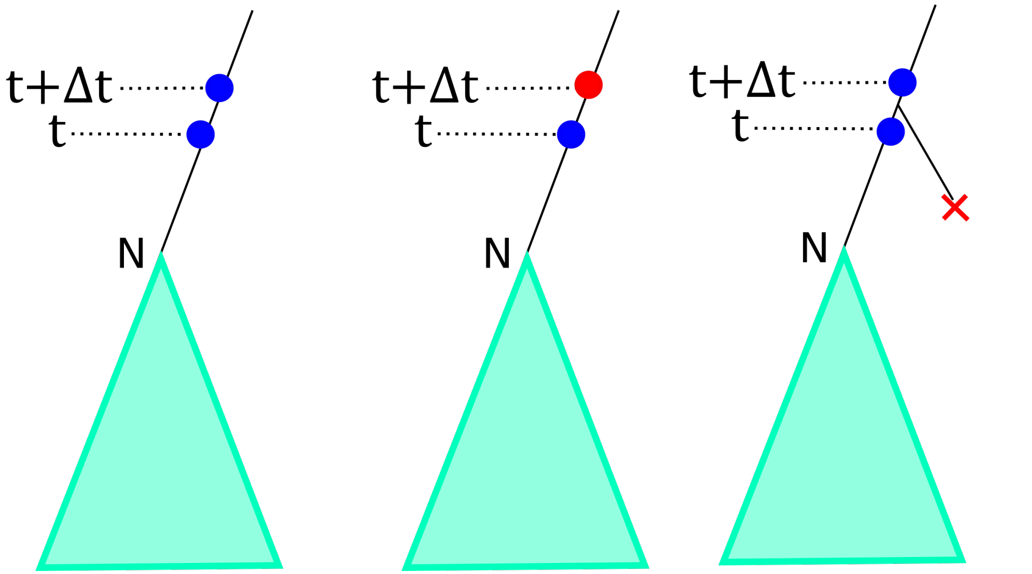
Phyloseminar
Dra. Sally Otto
BiSSE developer

How do we specify a Q-matrix for this?

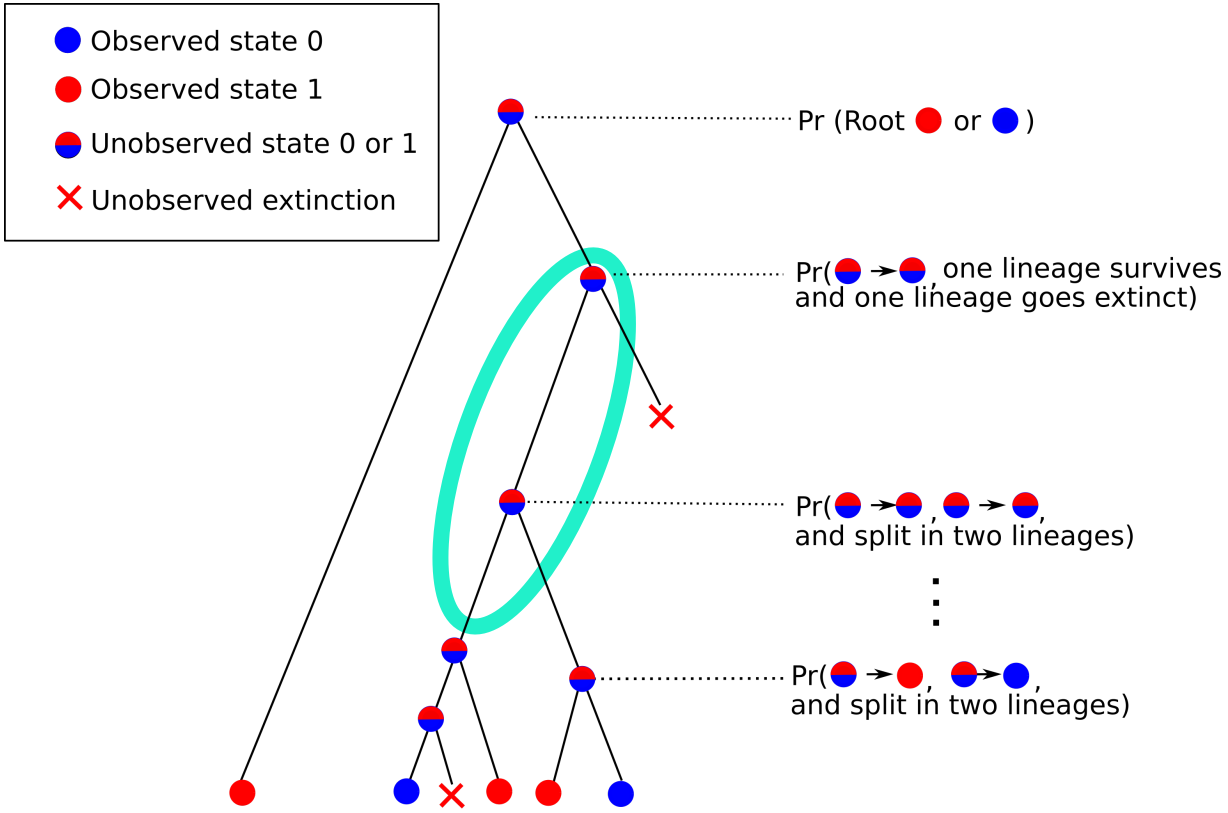
Binary state Speciation and Extinction Model (BiSSE)

Maddison et al. 2007. *Systematic Biology*

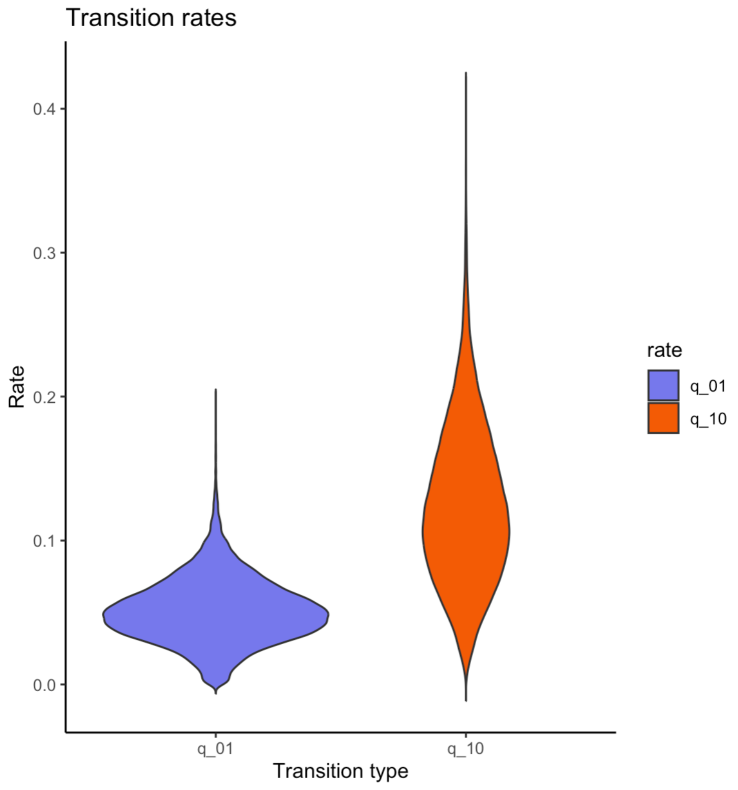
Stochastic differential equations (Kolmogorov-Forward)



The phylogenetic tree structure makes everything complicated

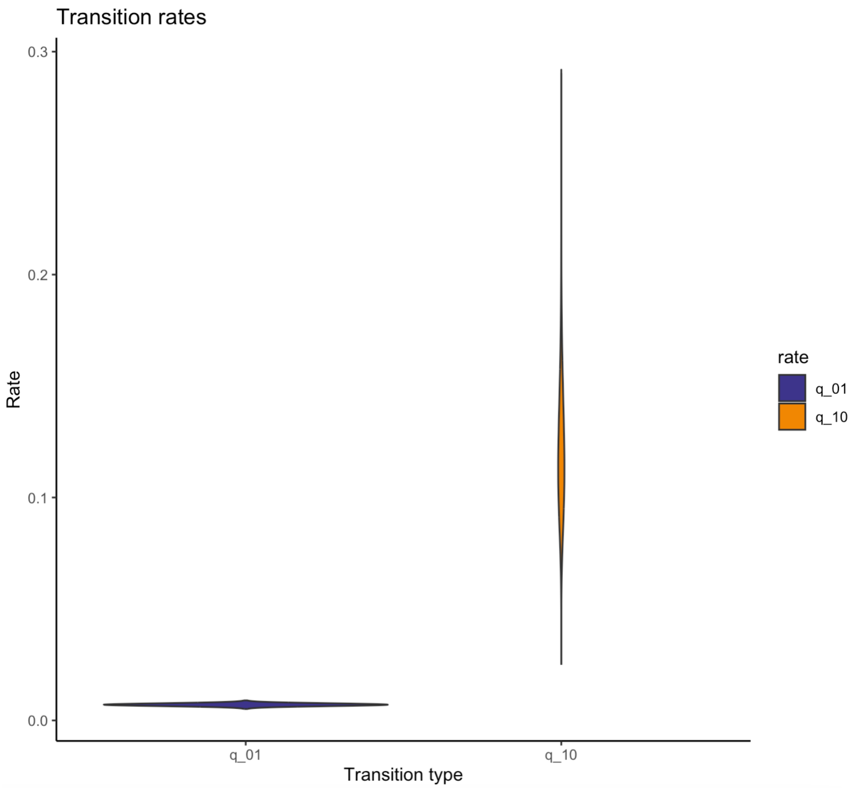


Zenil-Ferguson and Pennell. 2017. *Evolution*



Mk2

Equal transitions back and forth from pollination

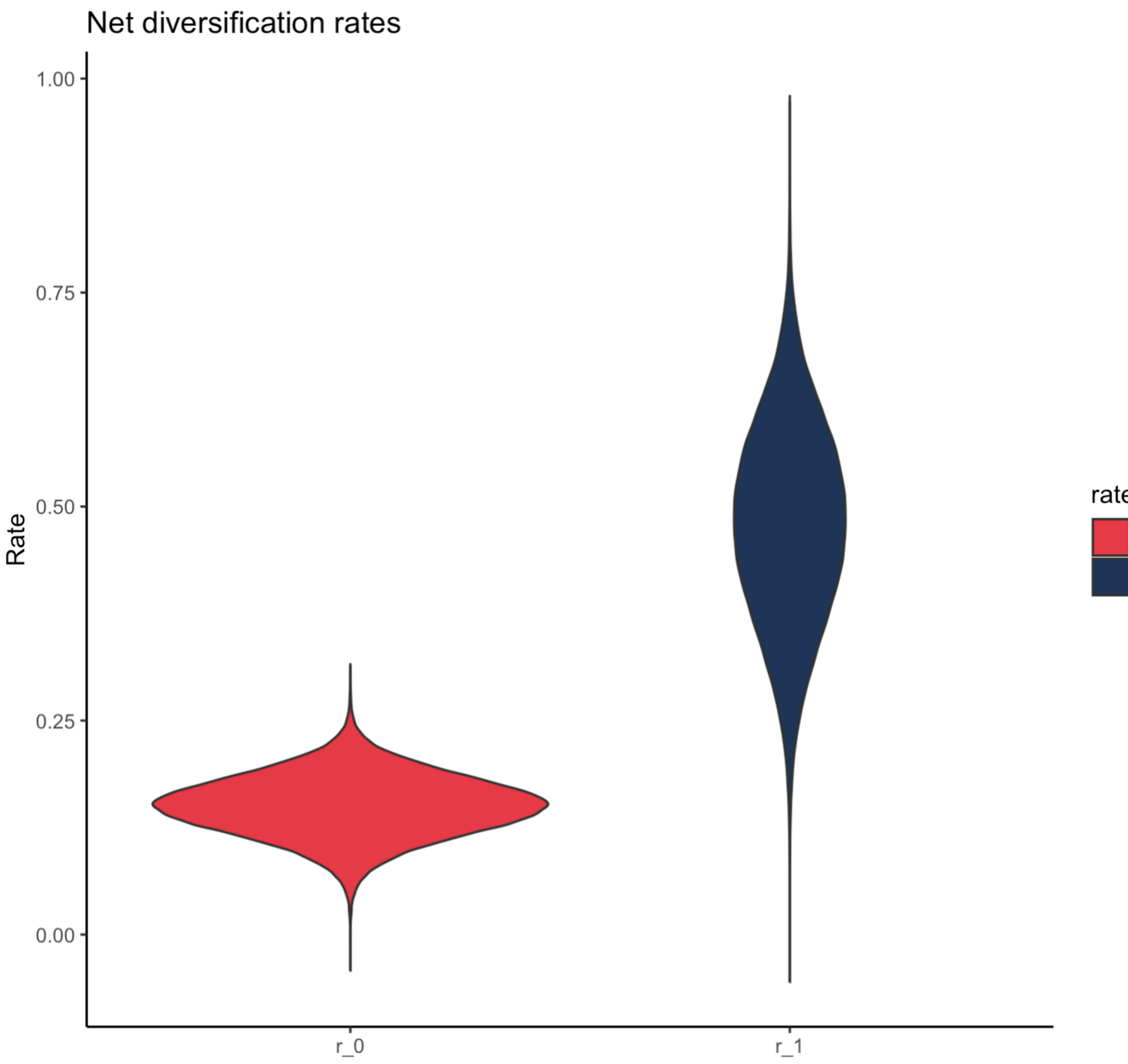


BiSSE

Easier to transition from Wind to Insect but uncertain

What about diversification?

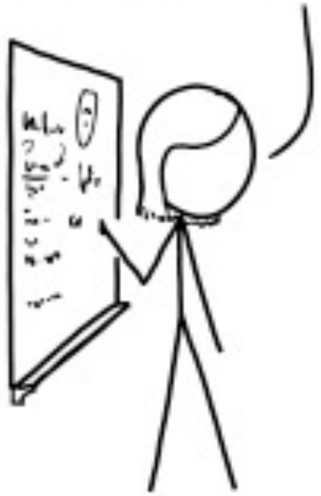
- Net diversification
- Turnover
- Extinction fraction

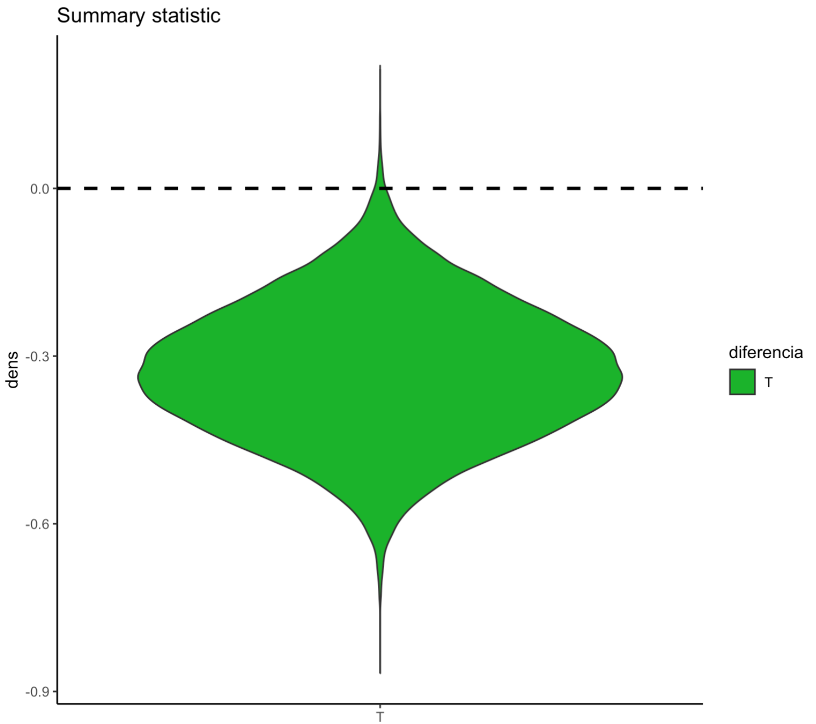


How do we know BiSSE is THE ONE?

H_0: $\lambda_0 = \lambda_1$ and $\mu_0 = \mu_1$

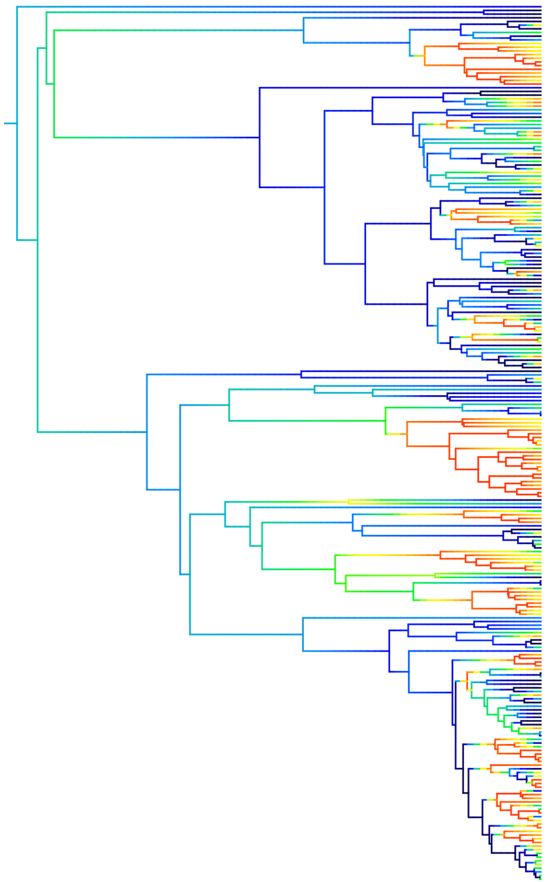
H_0: $r_0 = (\lambda_0 - \mu_0) = (\lambda_1 - \mu_1) = r_1$





Null hypothesis of BiSSE

$$H_0 : r_0 = r_1$$



BiSSE's Null Hypothesis is too simple

$$H_0\colon r_0 = r_1$$

Type I error 50%

Misspecification of null hypothesis

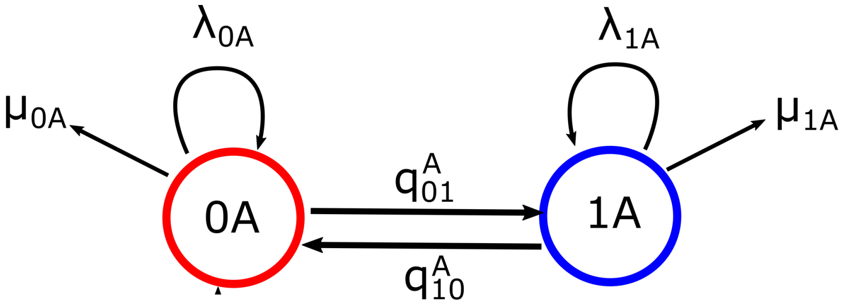
New null H_0:

Something else can be modifying diversification other than my trait

Davis et al. 2013. *BMC Evolutionary Biology*

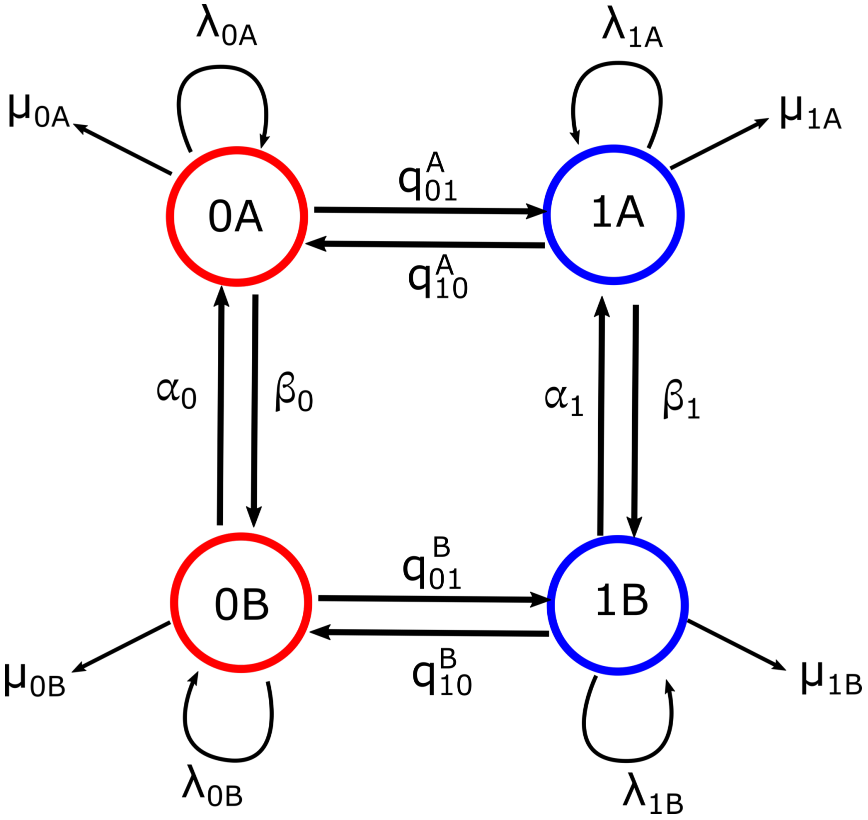
Rabosky and Goldberg 2015. *Sys Bio*

Better model (Heterogeneity in diversification)
HiSSE: Hidden State-dependent Speciation and Extinction



Beaulieu and O'Meara. 2016.

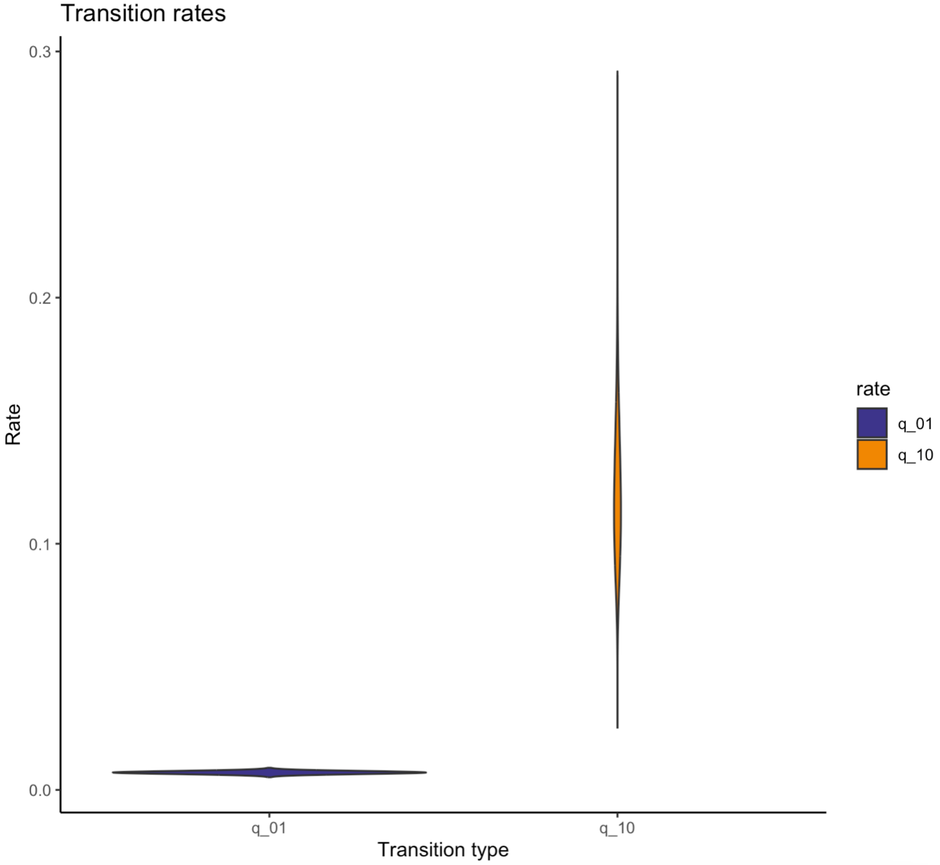
Full HiSSE



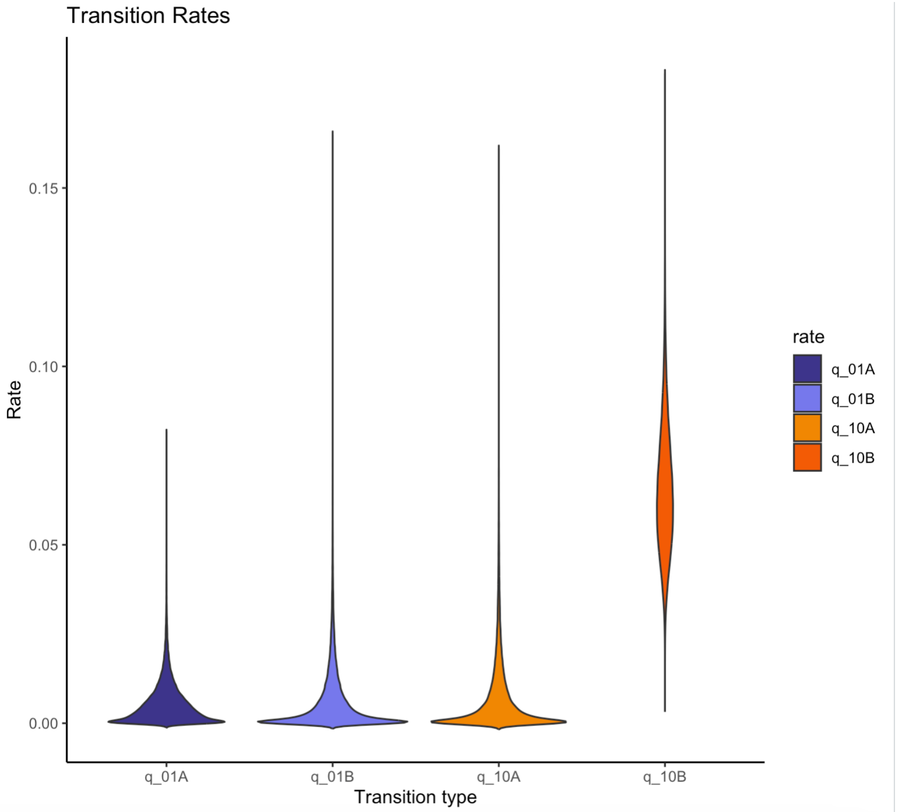
Important considerations:

Transition rates

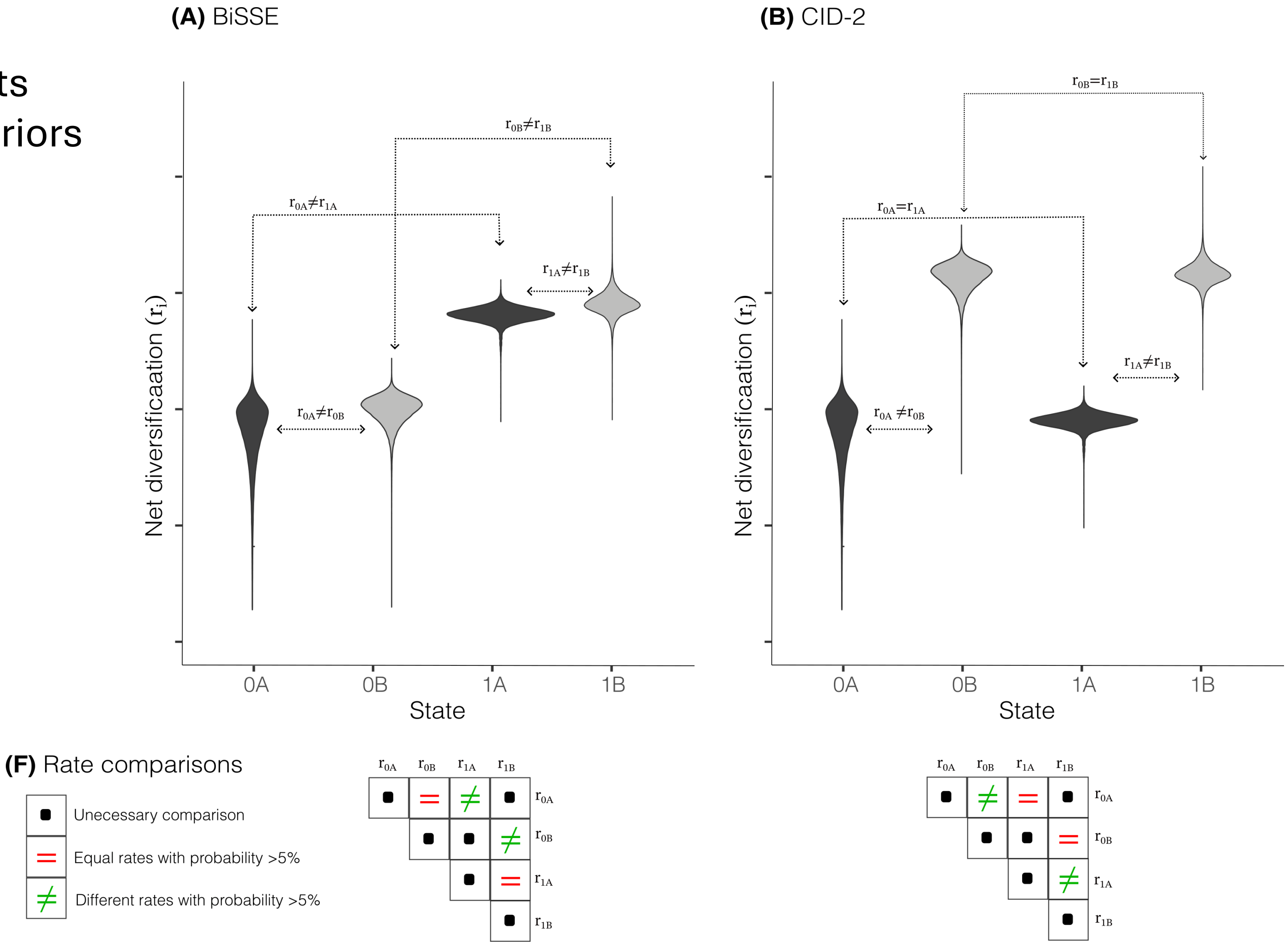
BiSSE



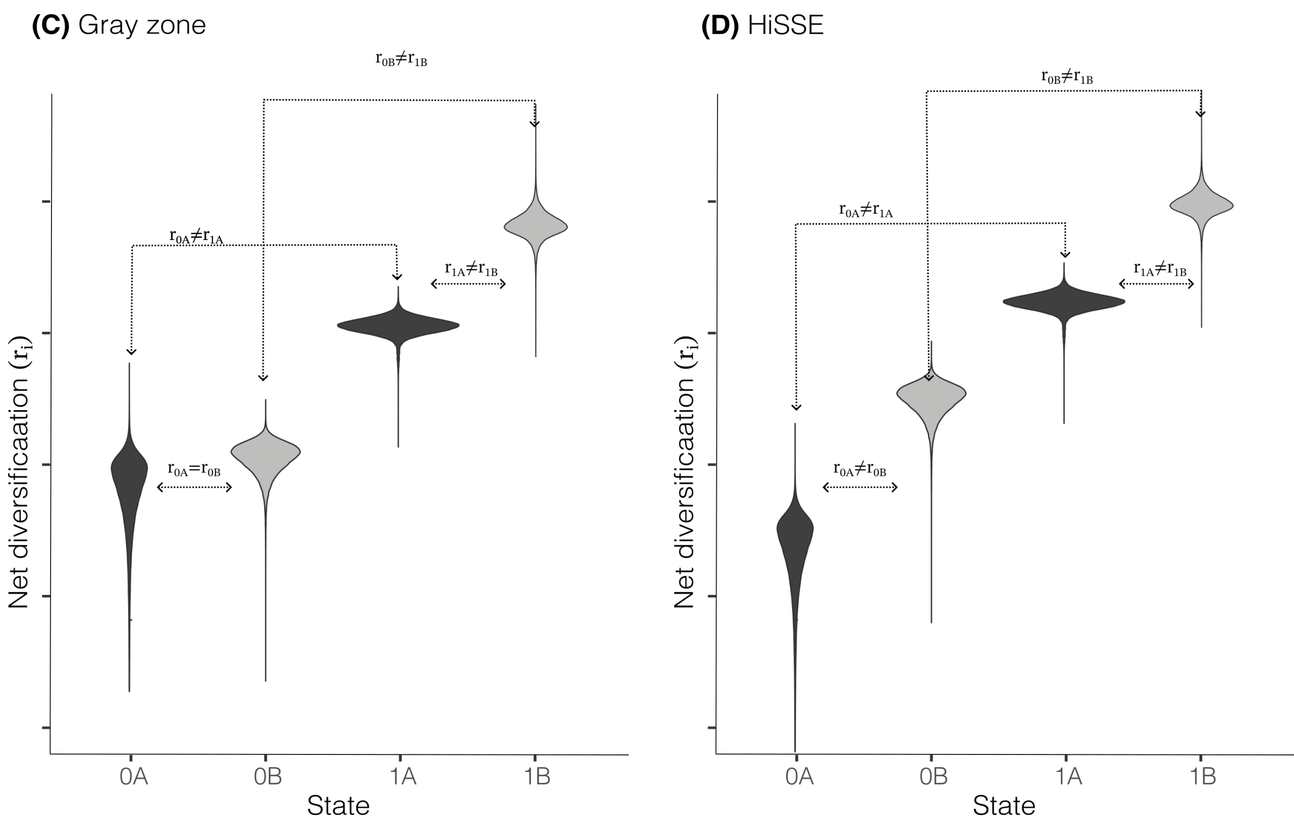
HiSSE



Interpreting results from HiSSE posteriors



Interpreting results from HiSSE posteriors



(F) Rate comparisons

■	Unecessary comparison
=	Equal rates with probability >5%
≠	Different rates with probability >5%

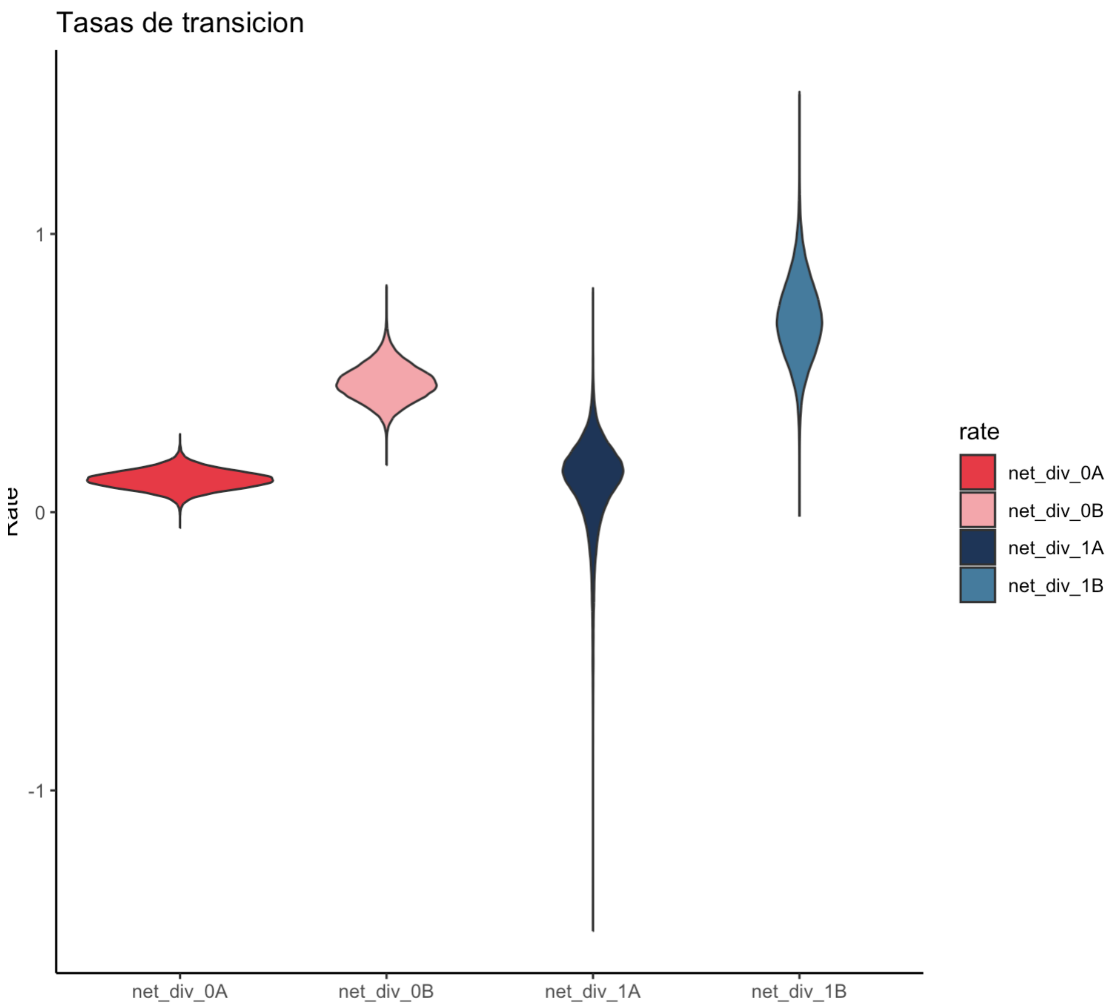
Gray zone:

r_{0A}	r_{0B}	r_{1A}	r_{1B}	
■	=	≠	■	r_{0A}
	■	■	≠	r_{0B}
		■	≠	r_{1A}
			■	r_{1B}

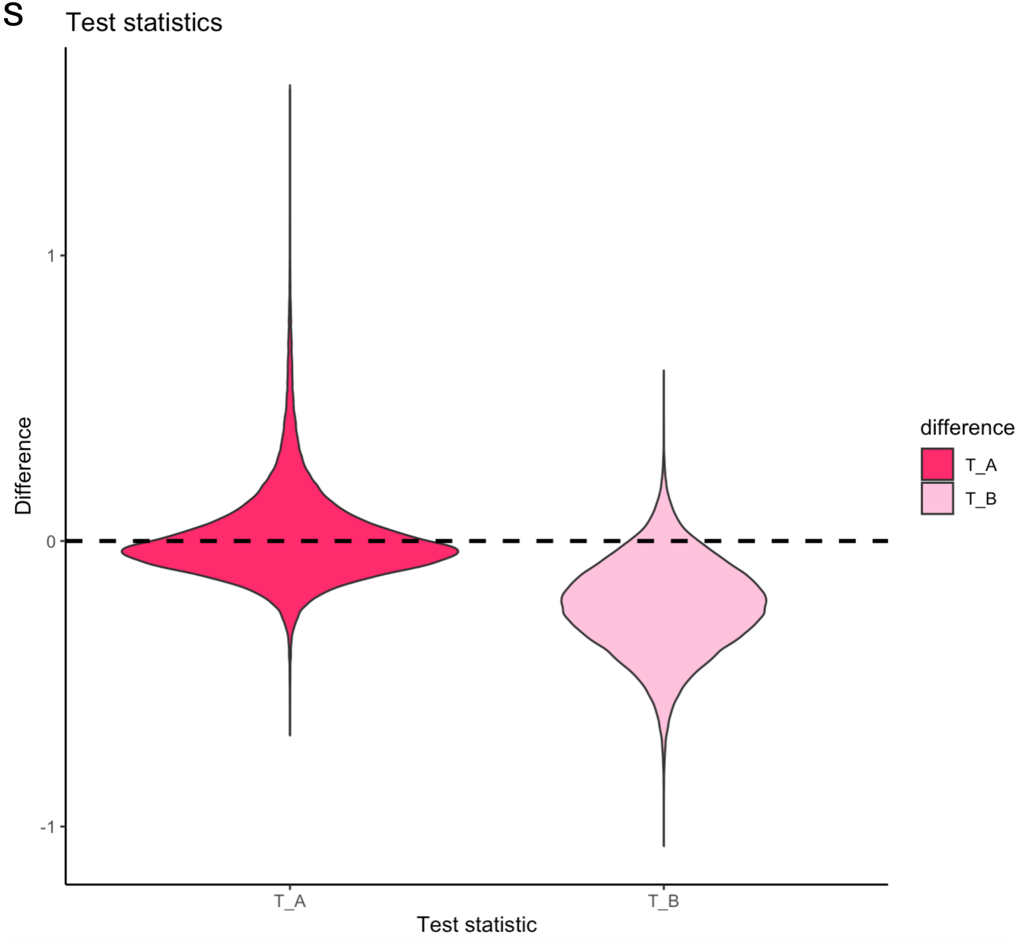
HiSSE:

r_{0A}	r_{0B}	r_{1A}	r_{1B}	
■	≠	≠	■	r_{0A}
	■	■	≠	r_{0B}
		■	≠	r_{1A}
			■	r_{1B}

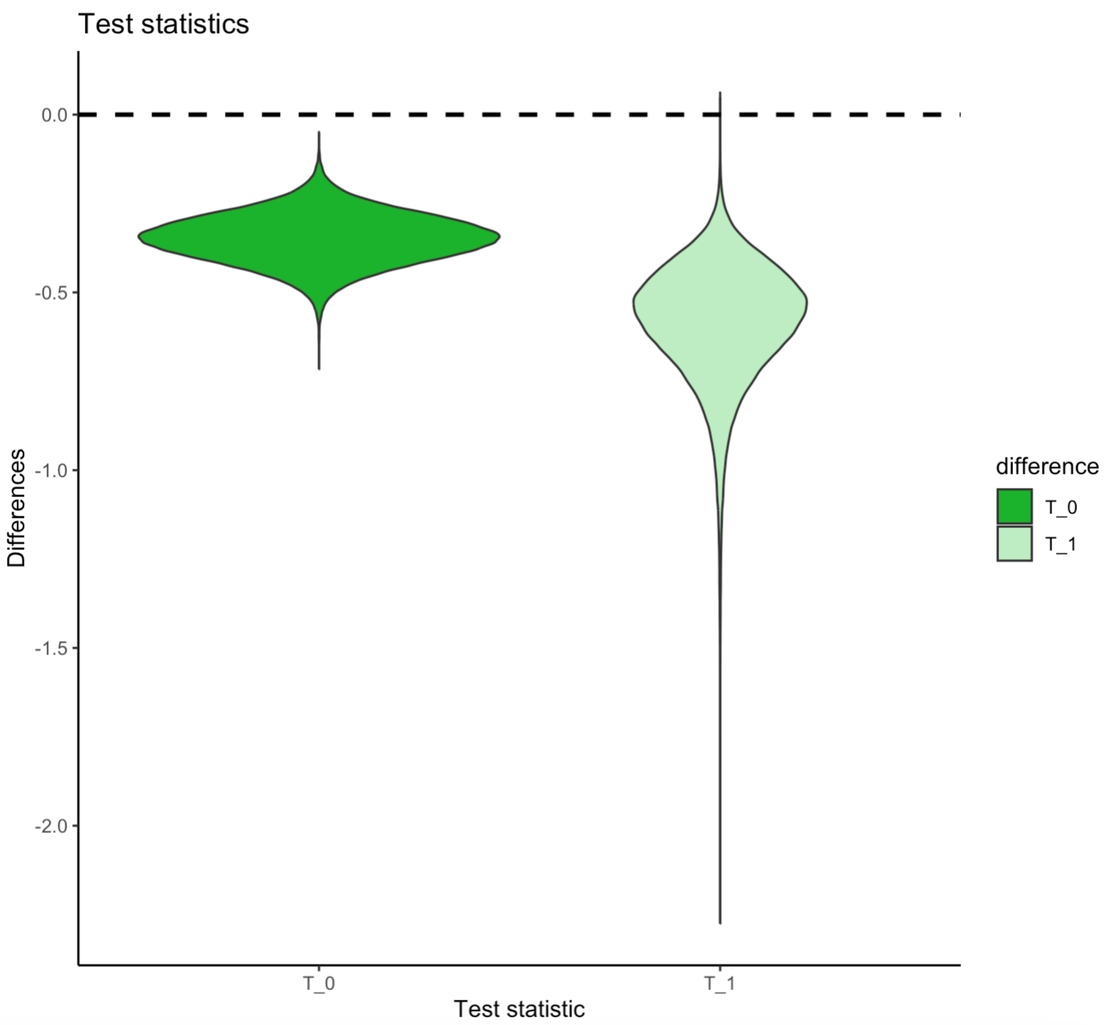
Quick conclusion?



Differences of net diversifications between 0 and 1.

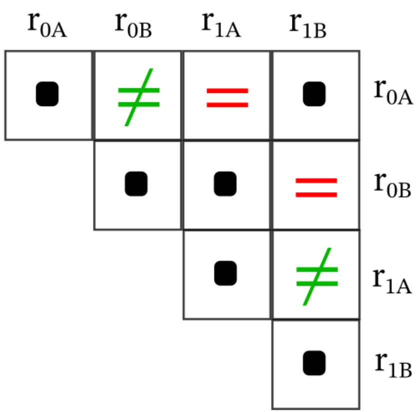


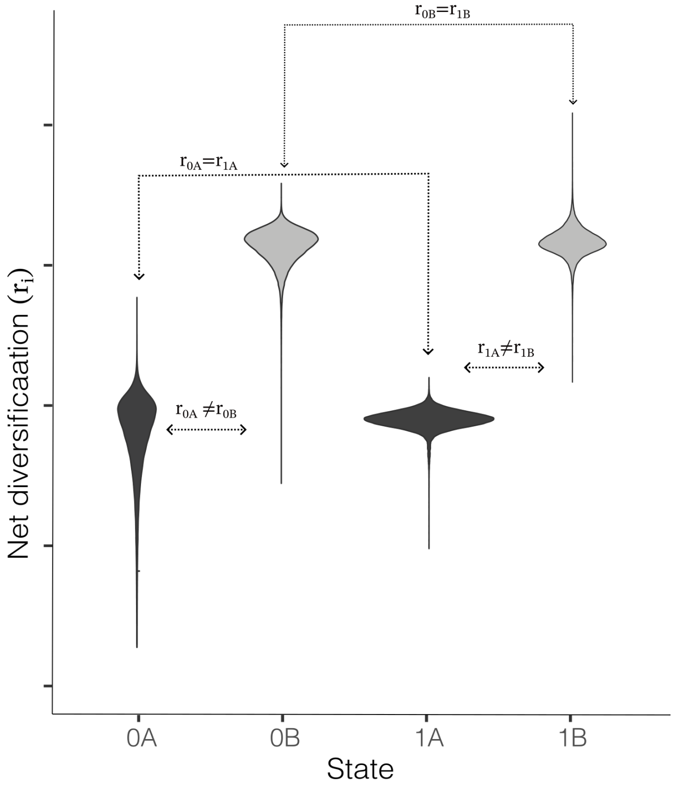
Differences of net diversifications between A and B



(**B**) CID-2

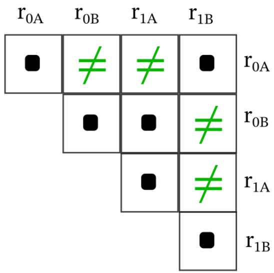
Conclusion



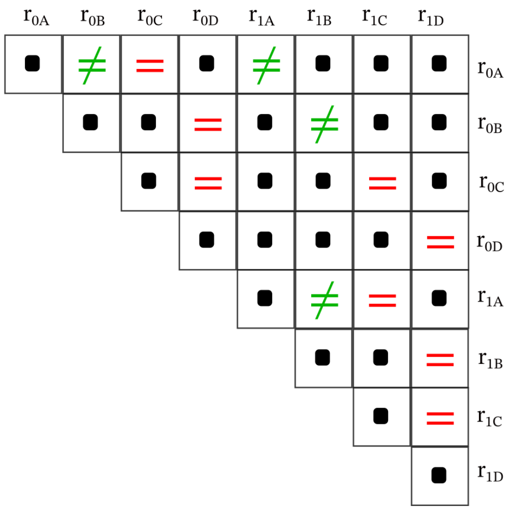


Fair comparisons

HISSE 2 hidden states



HISSE 4 hidden states



CID-4