Markov Chains in Diversification

Introduction to state-dependent diversification

NSF-DEB 2323170

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SSB Brekout Meeting 2026

Download slides and files

https://roszenil.github.io/mytutorials

SCAN ME

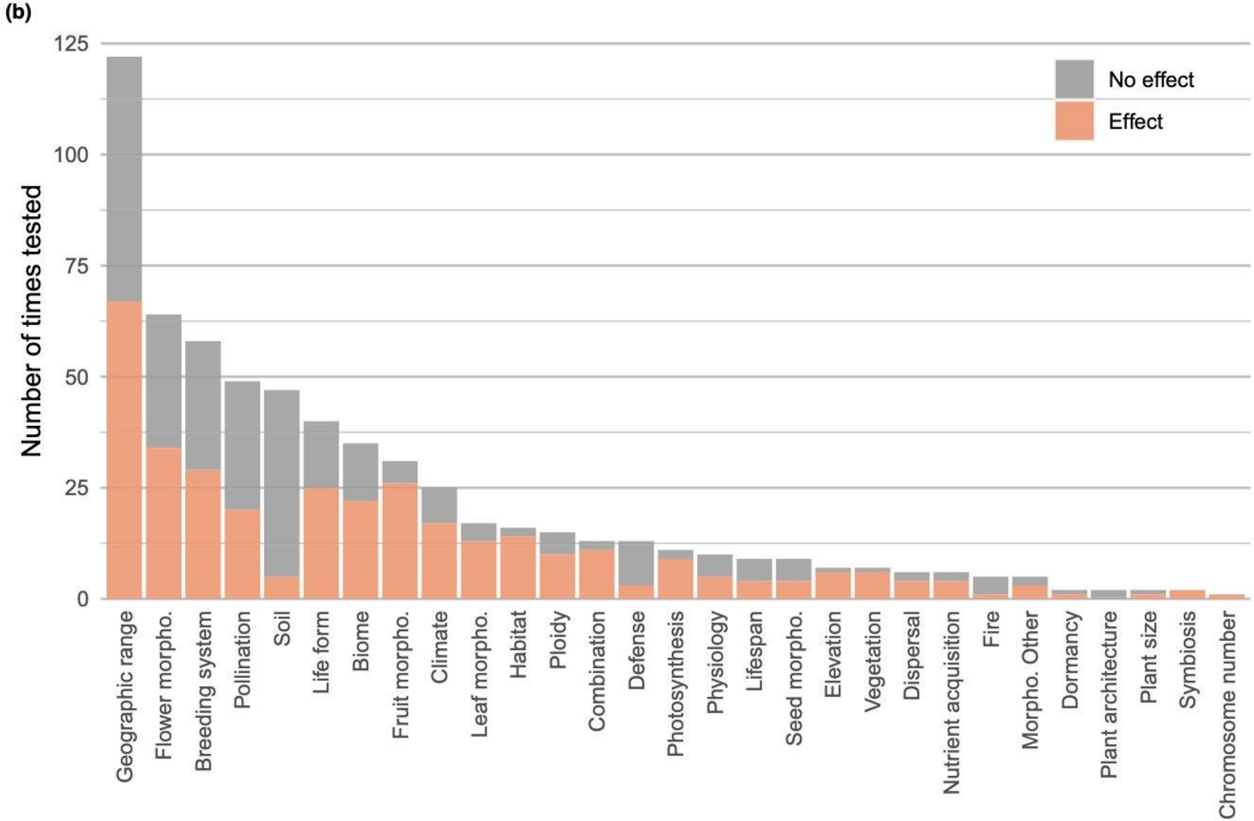
There are 400,000 vascular plants in the planet.





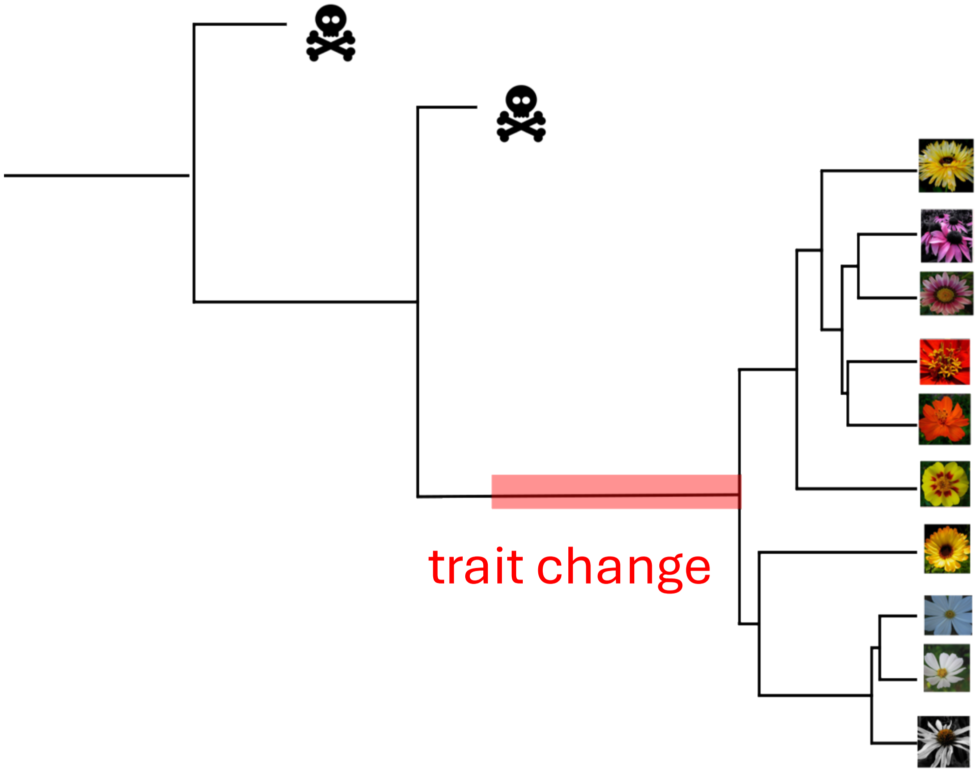

Volcanoes photography: Maria Costantini 2021
Plant photography: RZF and Carrie Tribble

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

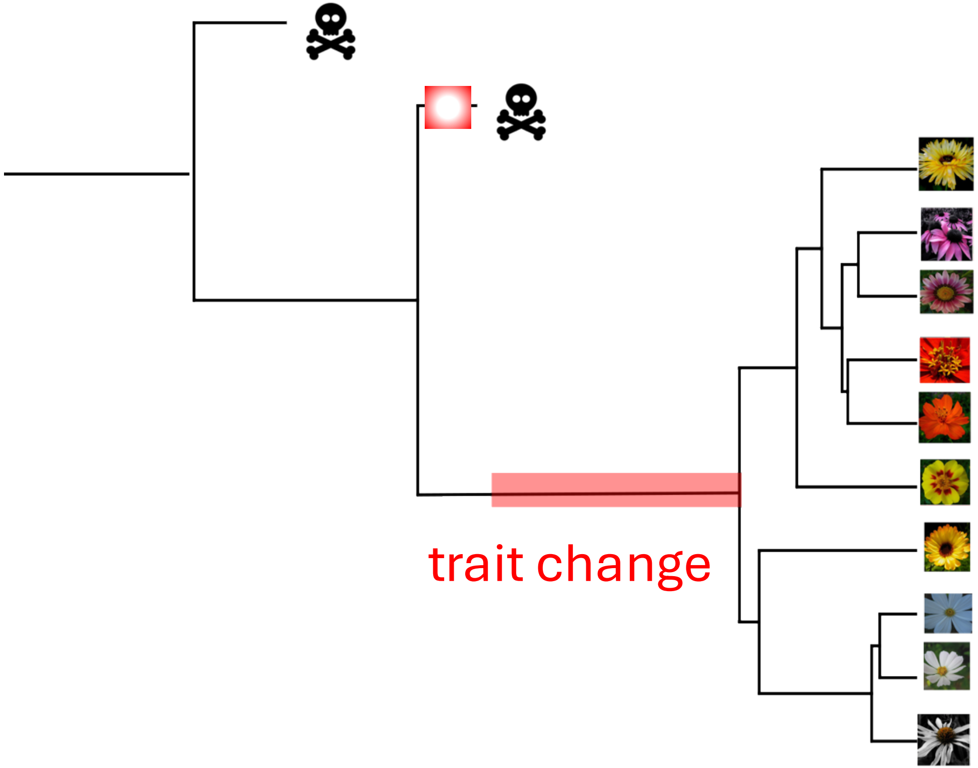


Helmstetter, A.J., Zenil-Ferguson, R., et al. 2022. *Ecology Letters*

Macroevolutionary consequences of trait change



Macroevolutionary consequences of trait change



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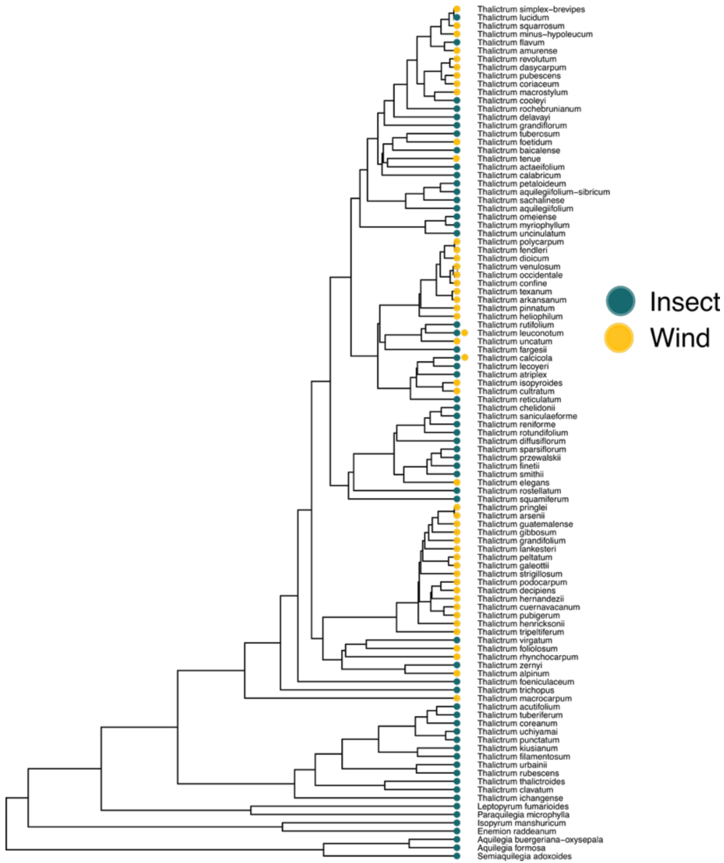
Perspective

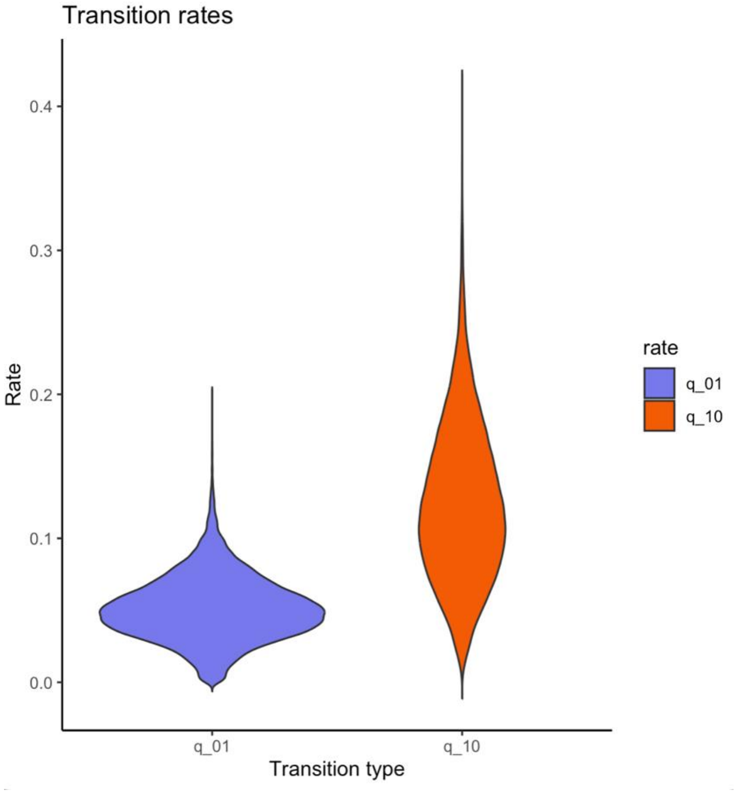
Opposing effects of plant traits on diversification

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,*]

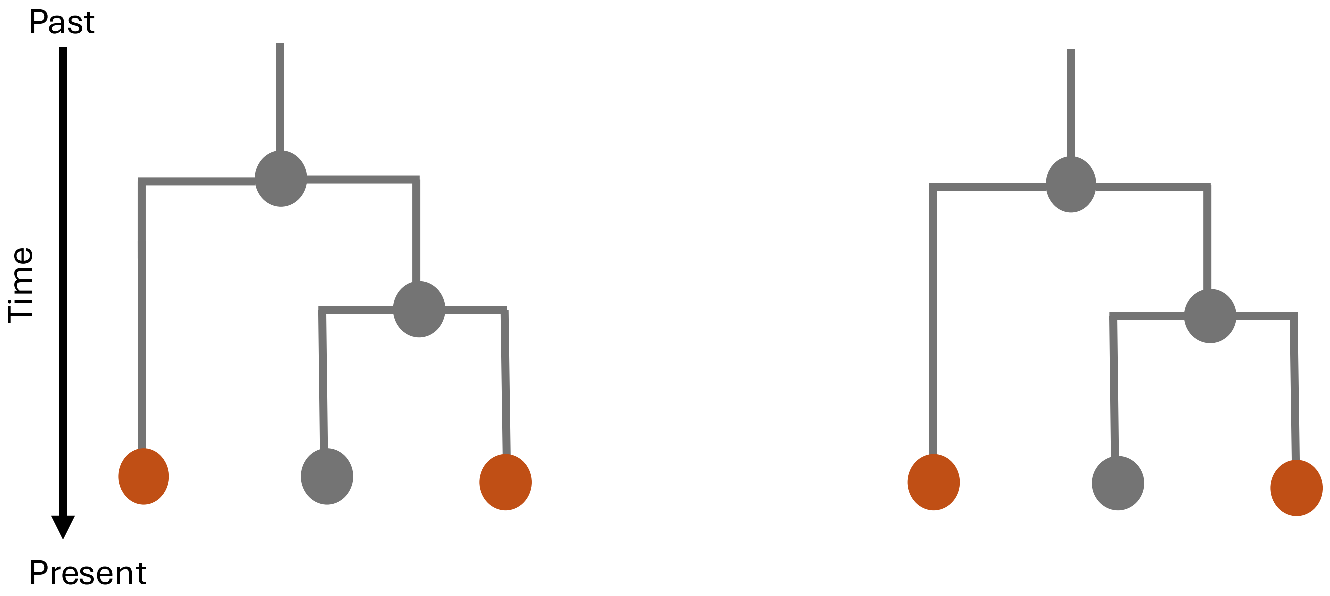
Polyploidy	↑	↑	↓	↑
	Gene redundancy allows evolution of new functions and facilitates divergence.	*Divergent resolution of gene redundancy leads to post-zygotic incompatibilities.*	*Instability in meiosis and minority cytotype disadvantage leads to mating difficulties*	*Gene redundancy buffers deleterious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

Under a Mk2 we estimated for our data





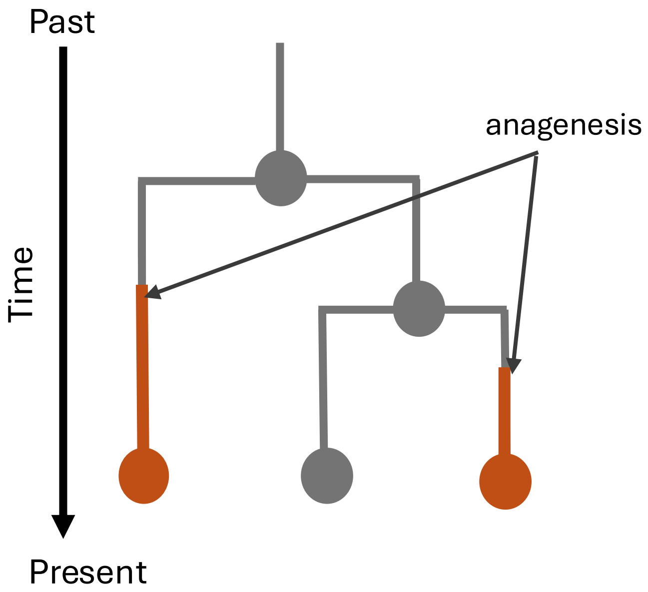
Trait evolution is biased without understanding the role of speciation and extinction events



Maddison. 2006. *Sys Bio*.

Considering speciation and extinction is necessary to decrease biases in ancestral reconstruction and estimates of transition rates

Trait evolution is biased without understanding the role of speciation and extinction events



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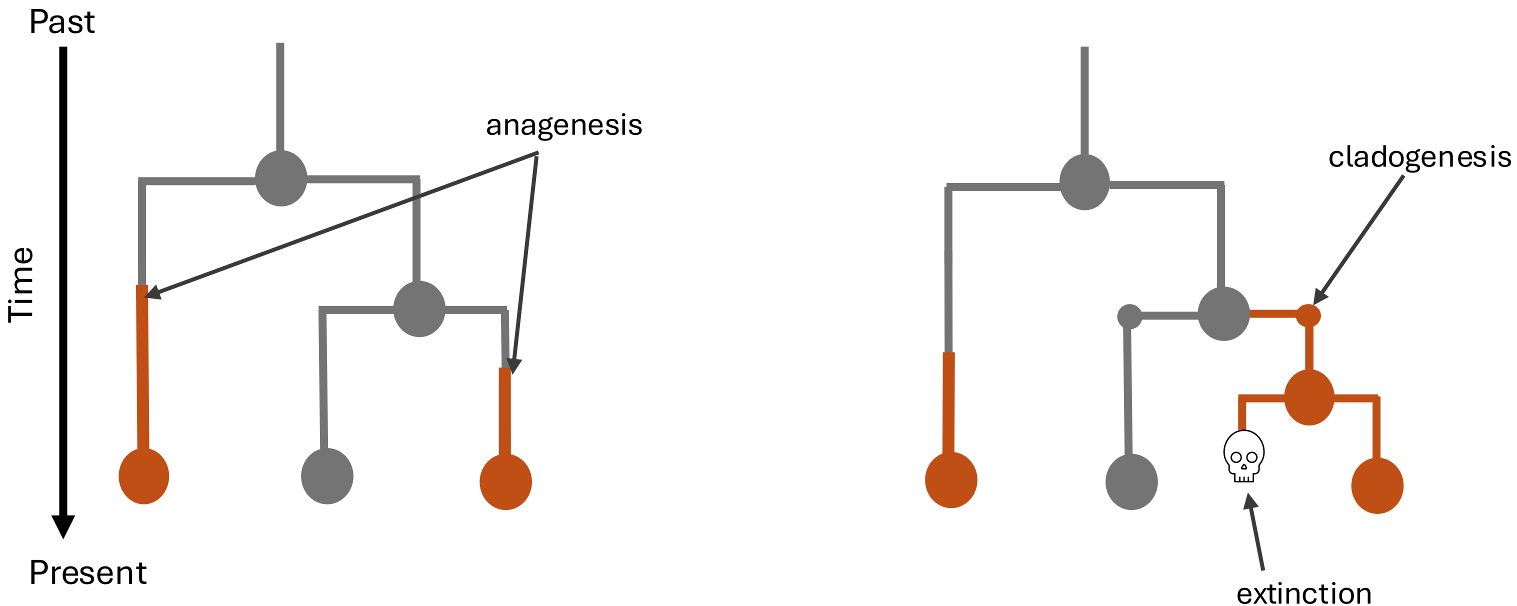
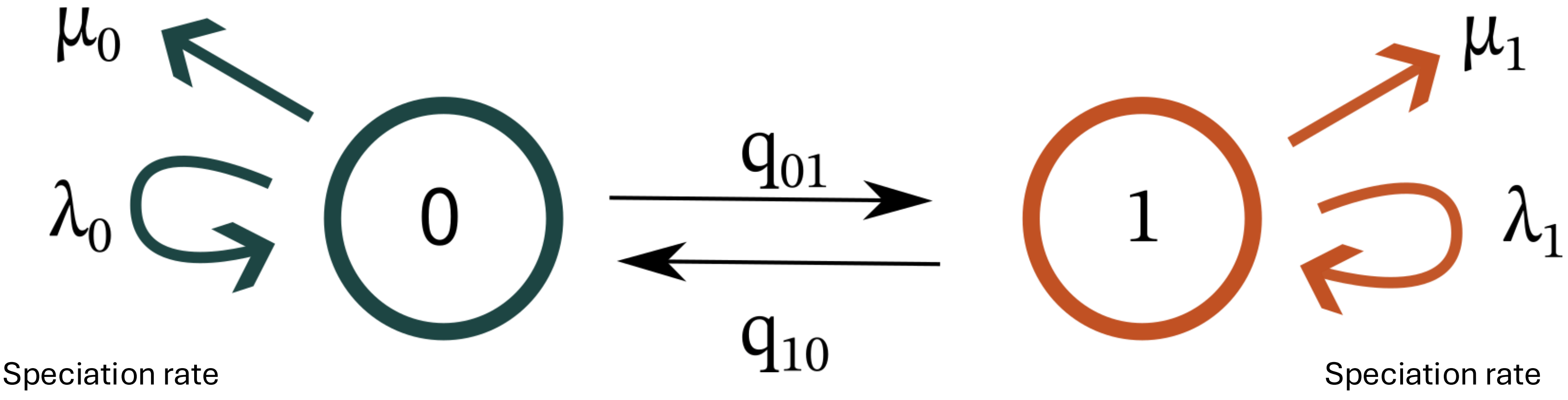


Maddison. 2006. *Sys Bio*.

Considering speciation and extinction is necessary to decrease biases in ancestral reconstruction and estimates of transition rates

Binary state speciation and extinction model (BiSSE)



Extinction rate

Extinction rate

Speciation rate

Speciation rate

Transition rates

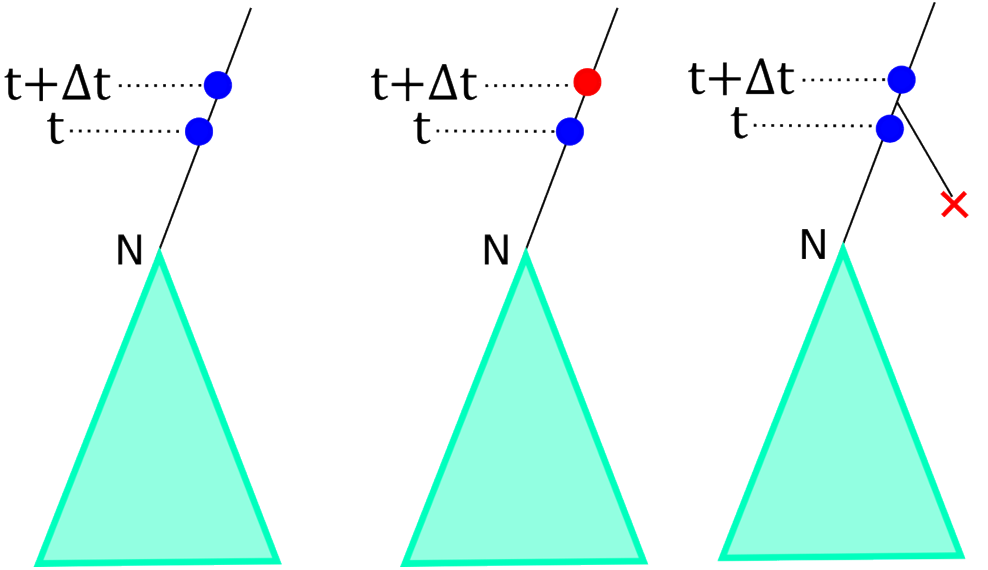
Maddison et al. 2007. *Sys Bio*

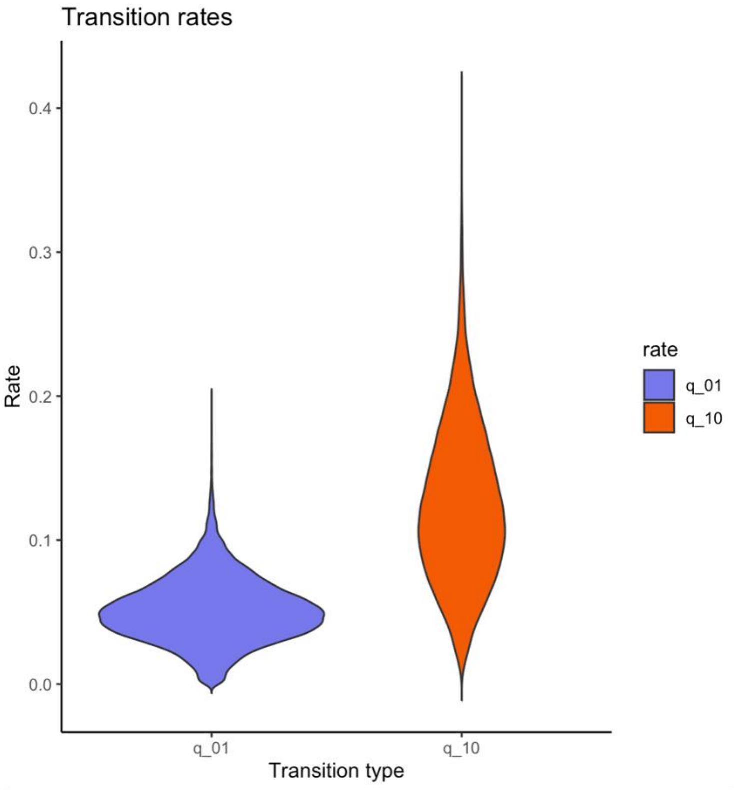
SCAN ME

Phyloseminar
Dra. Sally Otto
BiSSE
developer

How do we specify a Q-matrix for this?

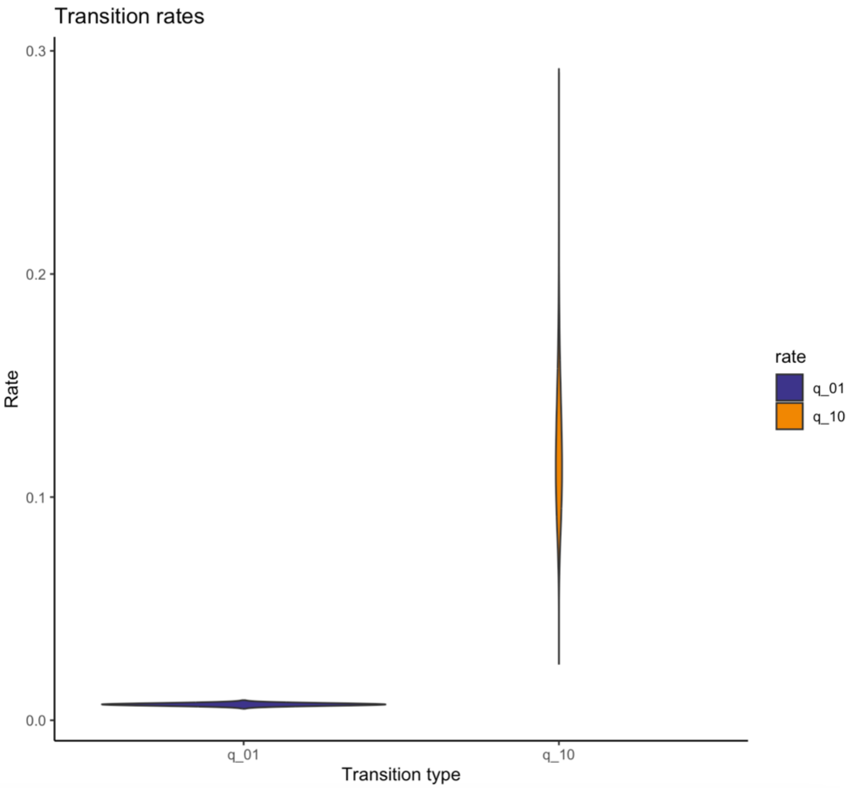
Stochastic differential equations (Kolmogorov-Forward)





Mk2

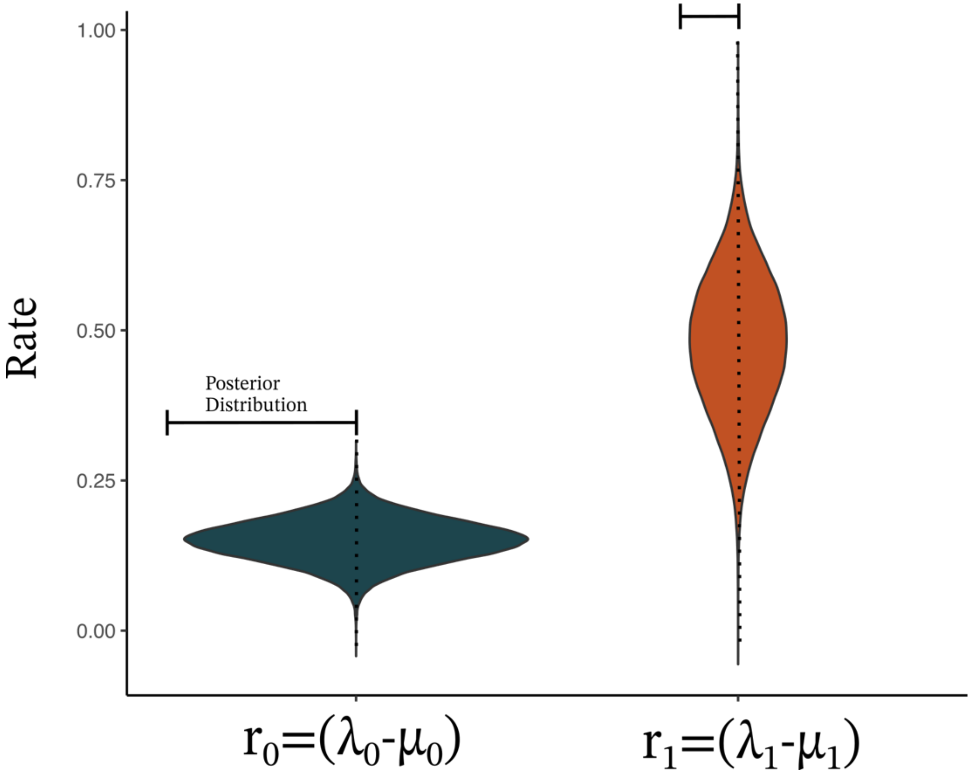
Equal transitions back and forth from pollination



BiSSE

Easier to transition from Wind to Insect but uncertain

Checking for differences in diversification correlated to a discrete trait

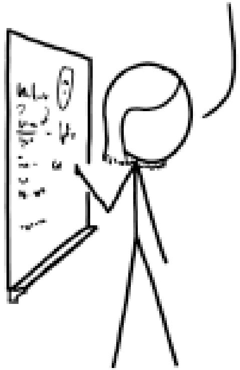


Net diversification rate (r) =
Speciation rate (λ) – Extinction rate (μ)

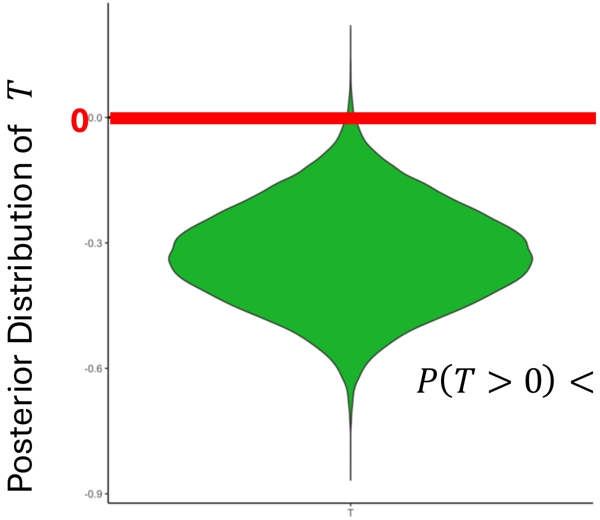
Is it probable
that they are different?

Developing a hypothesis testing framework to find differences in net diversification

$H_0: r_0 = r_1$



Test statistic $T = r_0 - r_1$

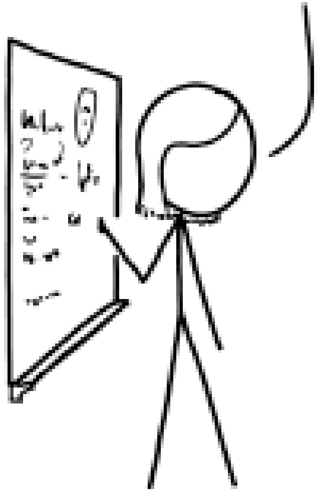


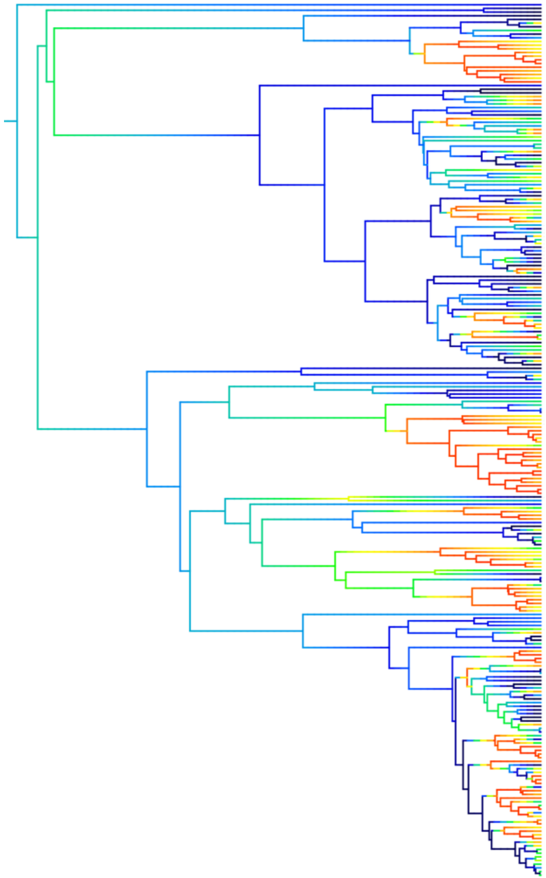
$P(T > 0) < 0.05$

The probability that 0 and 1 being equal is less than 5%

Null hypothesis of BiSSE

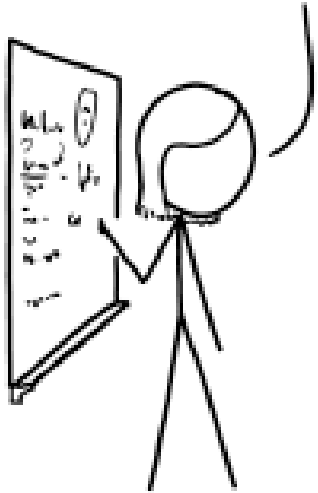
$H_0 : r_0 = r_1$





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

Hidden states
A and B
represent other
unmeasured sources
of diversification

HiSSE
- 4 speciations
- 4 extinctions
- 8 transition rates

Beaulieu and O'Meara. 2016. *Sys Bio*

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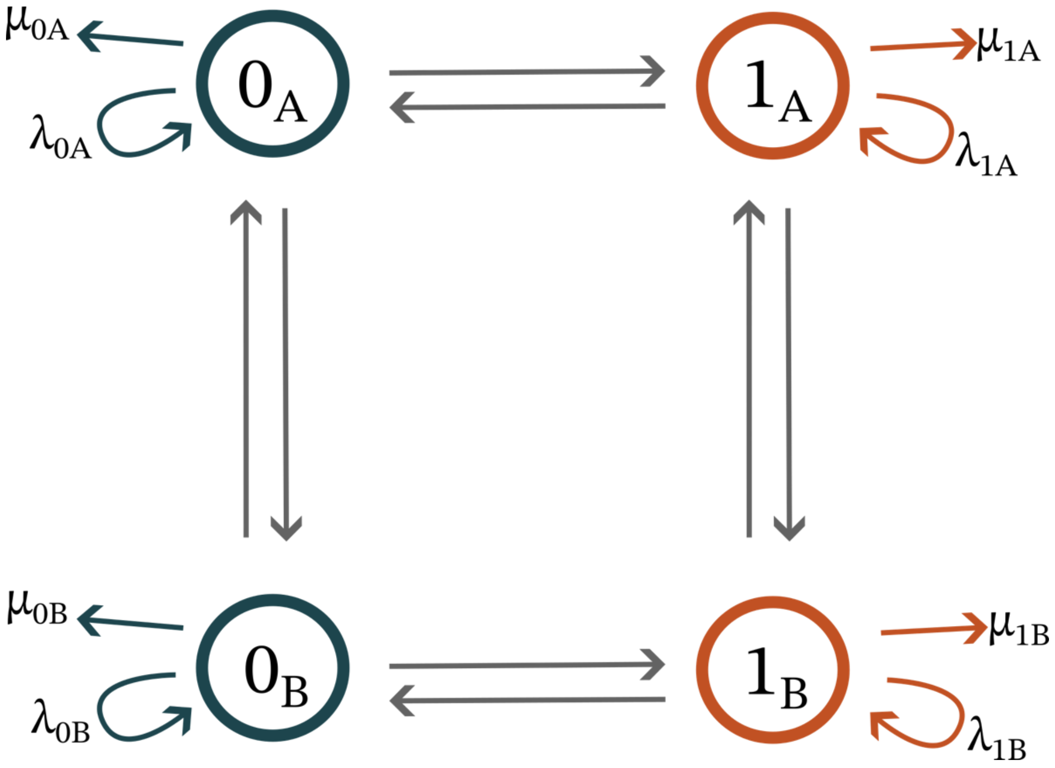
HiSSE: Hidden State-dependent Speciation and Extinction



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HiSSE
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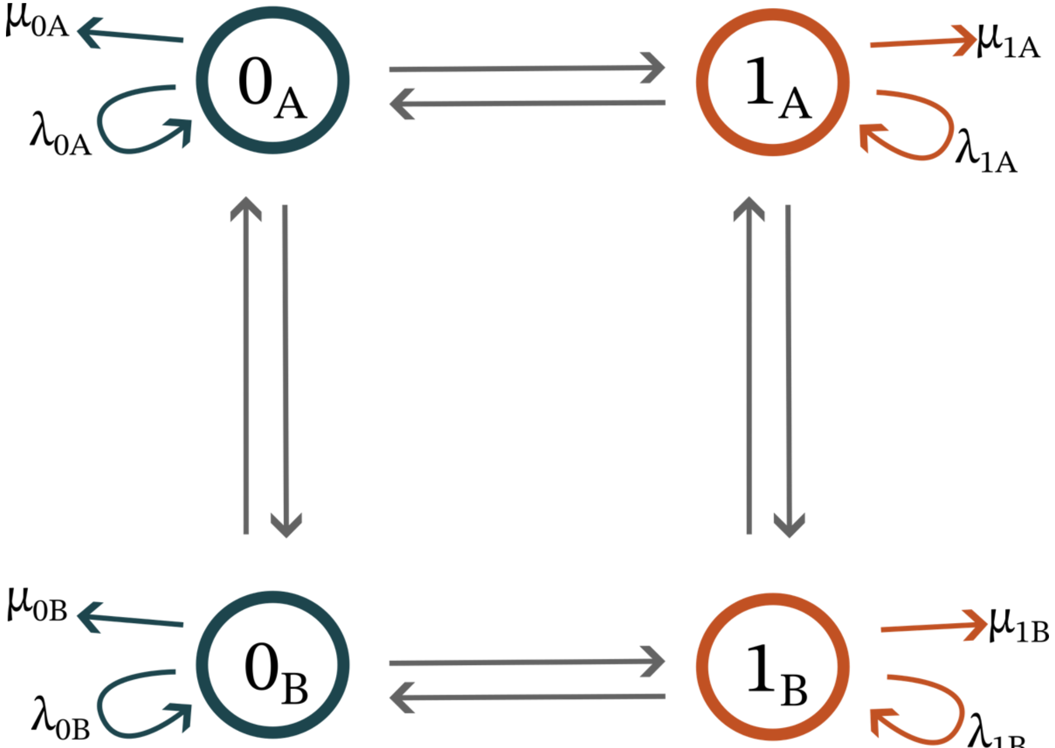
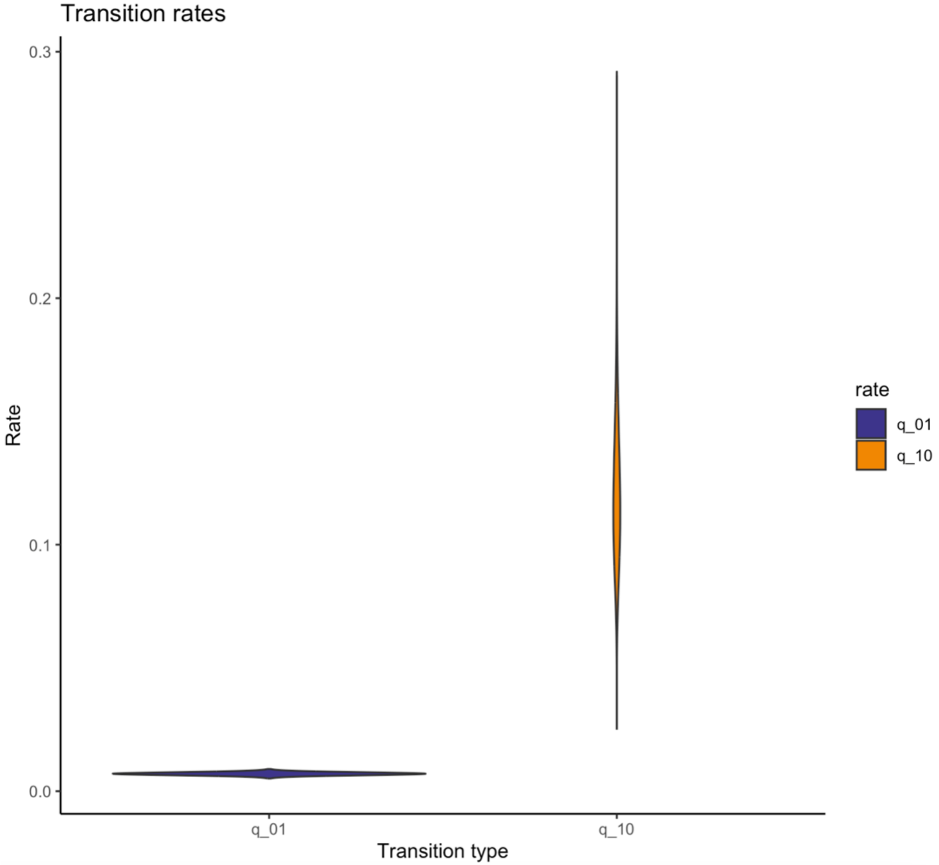
Transition Rates

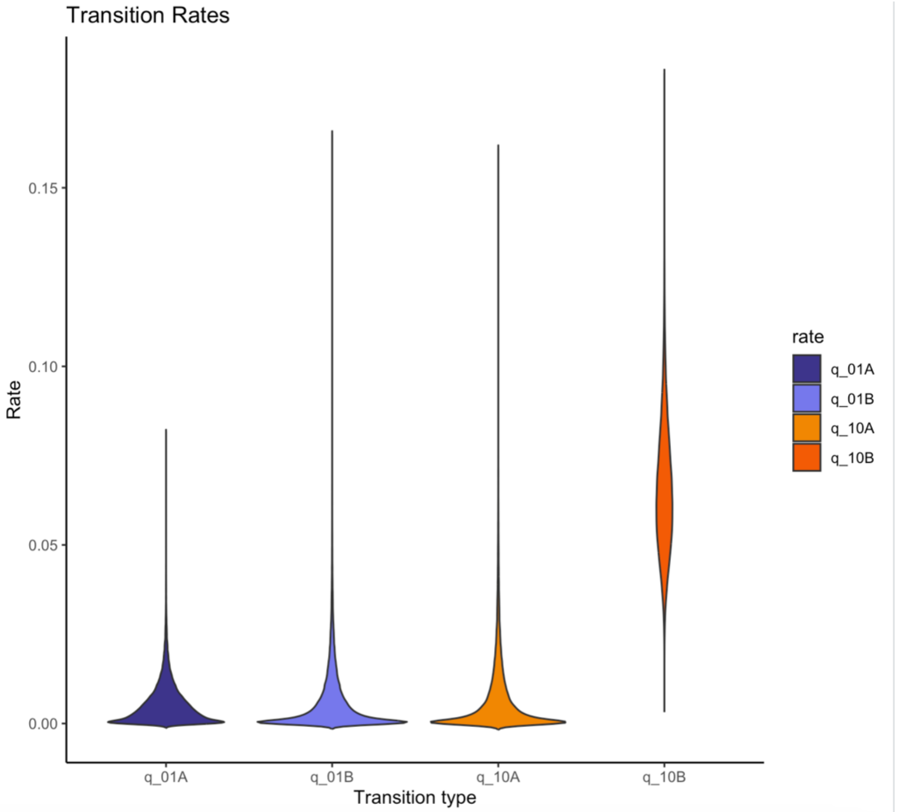


Transition rates

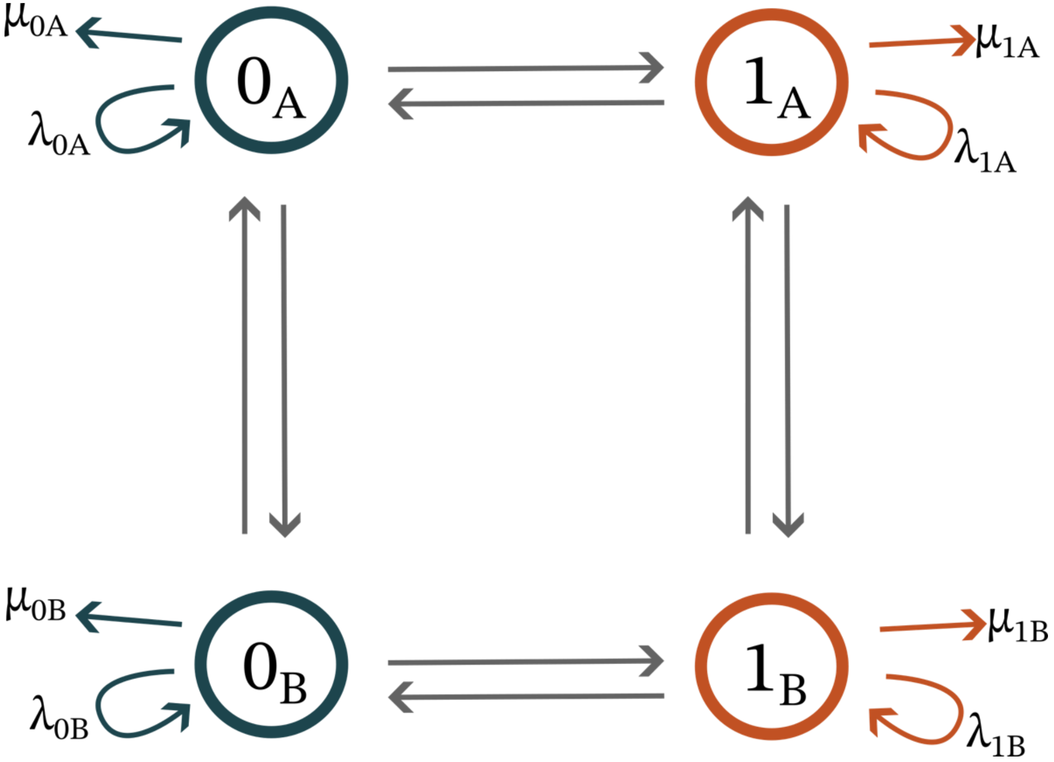
BiSSE



HiSSE



New null hypothesis: Diversification does not come from main trait…



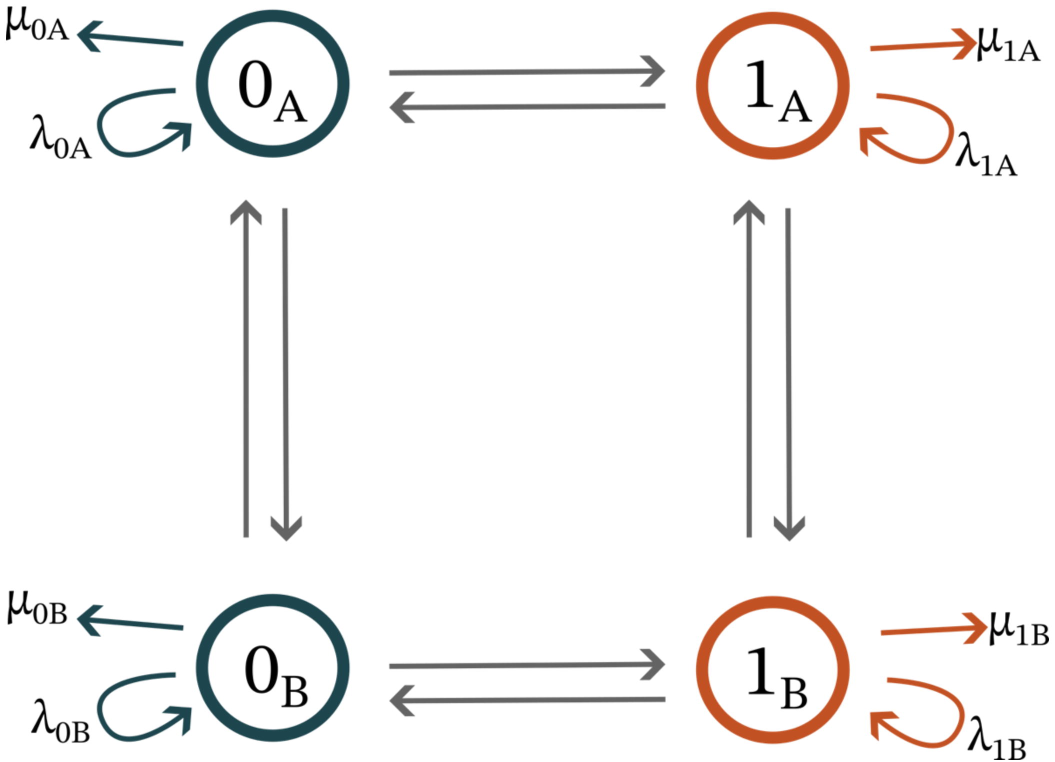
$$r_{0A} = r_{1A}$$

$$0 = 1$$

$$r_{0B} = r_{1B}$$

Beaulieu and O'Meara. 2016. *Sys Bio*

$r_{0A} \neq r_{0B}$ $A \neq B$ $r_{1A} \neq r_{1B}$



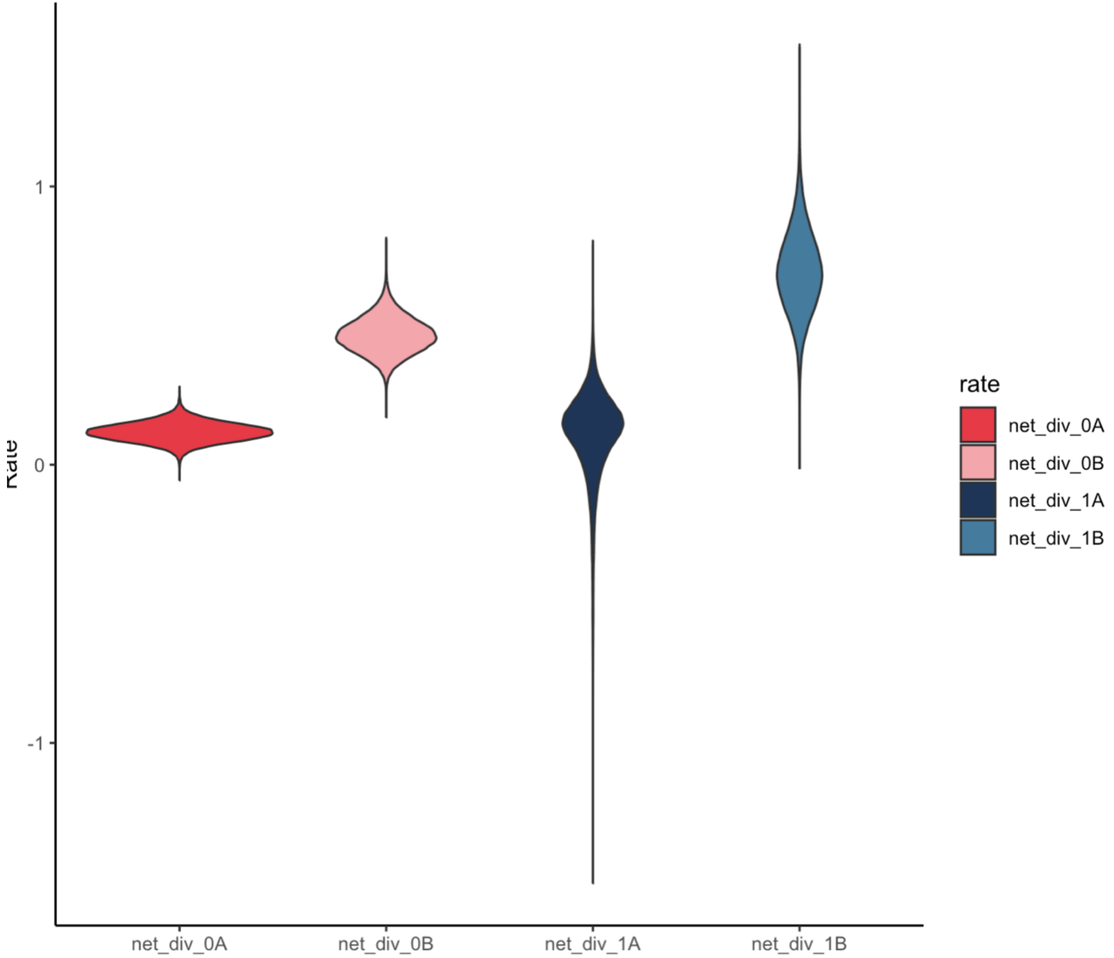
New null hypothesis:

..but diversification can come from other factors

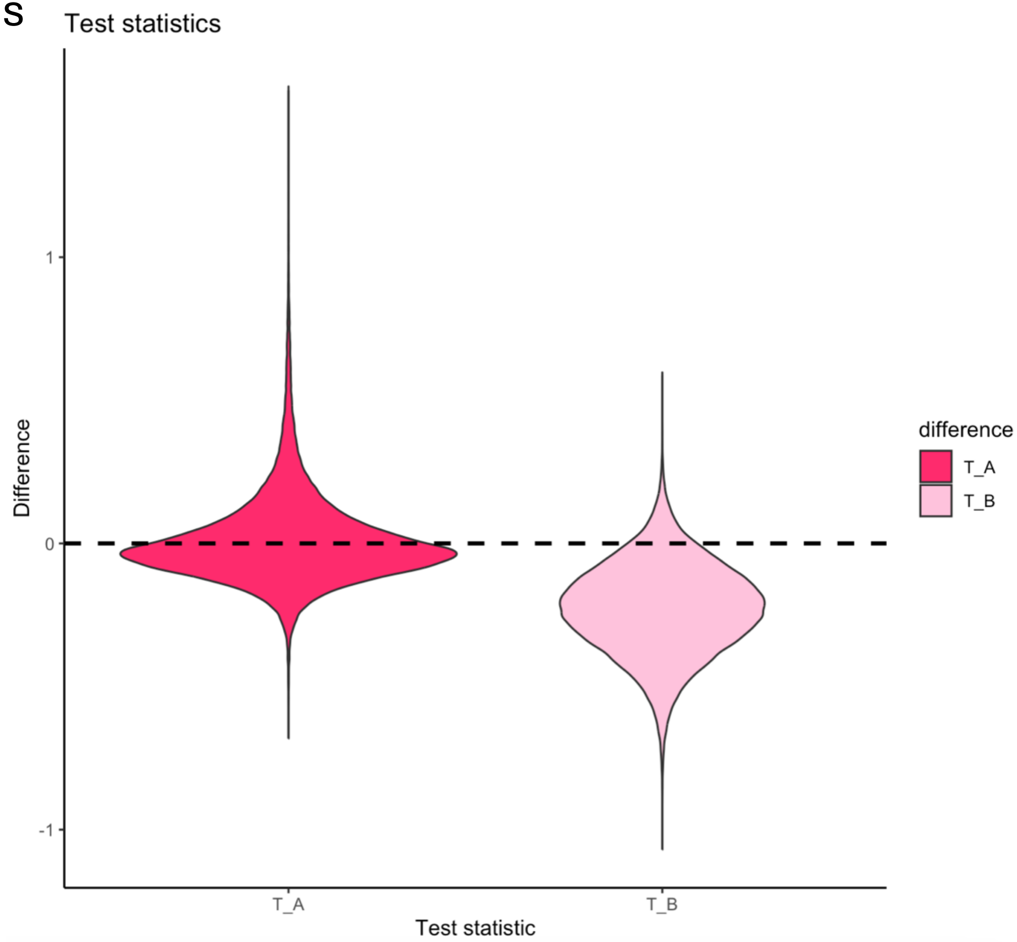
A new “model”
Character
Independent
(CID)

Beaulieu and O’Meara. 2016. *Sys Bio*

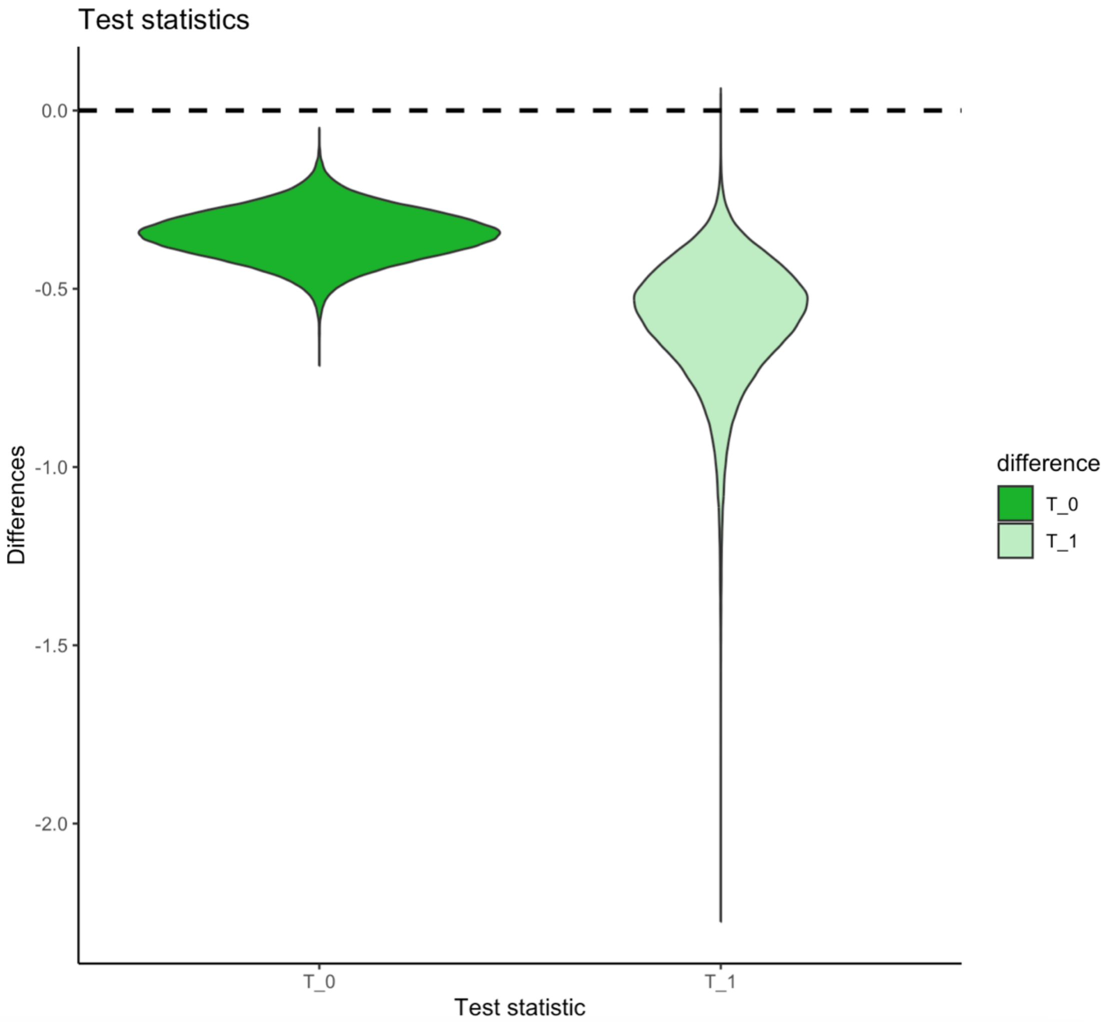
Quick conclusion?



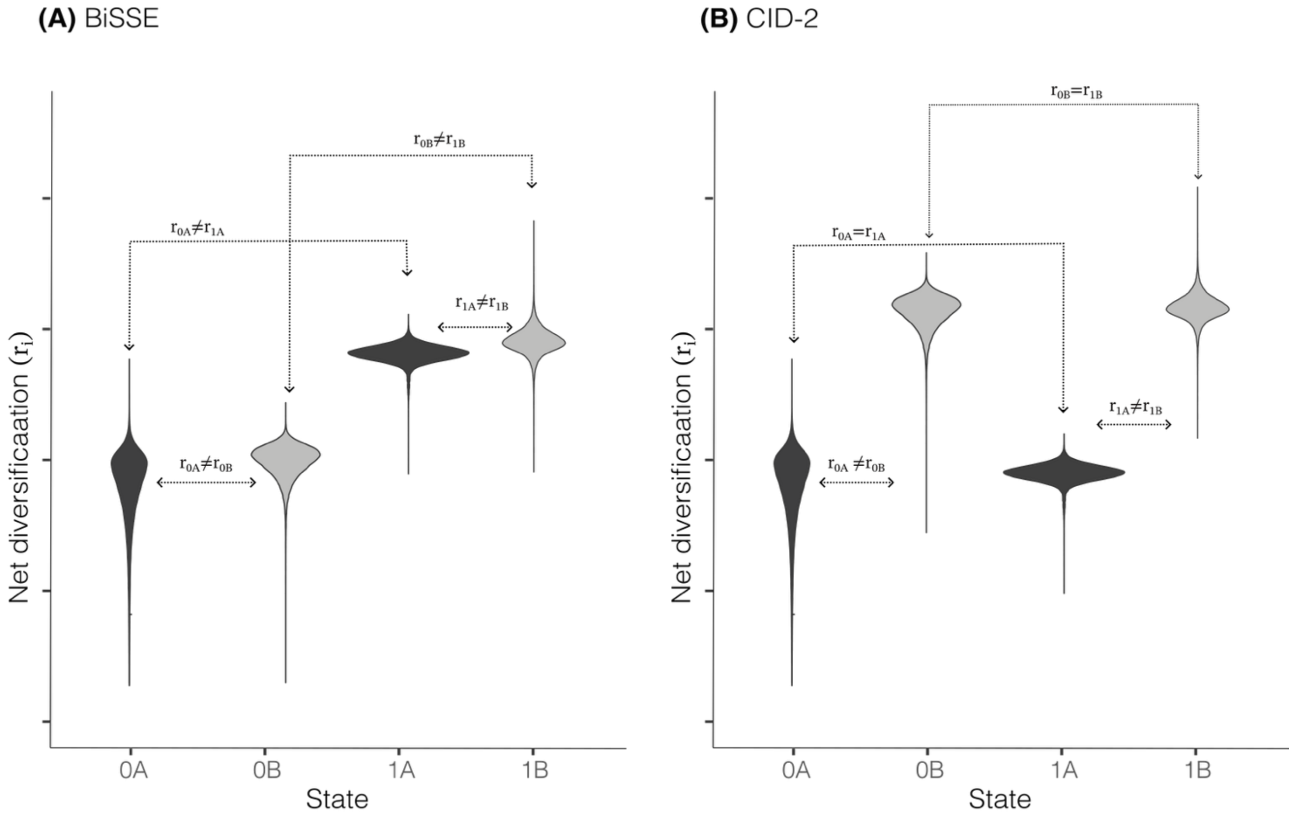
Differences of net diversifications between 0 and 1.



Differences of net diversifications between A and B



Interpreting results from HiSSE posteriors



(F) Rate comparisons

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

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

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

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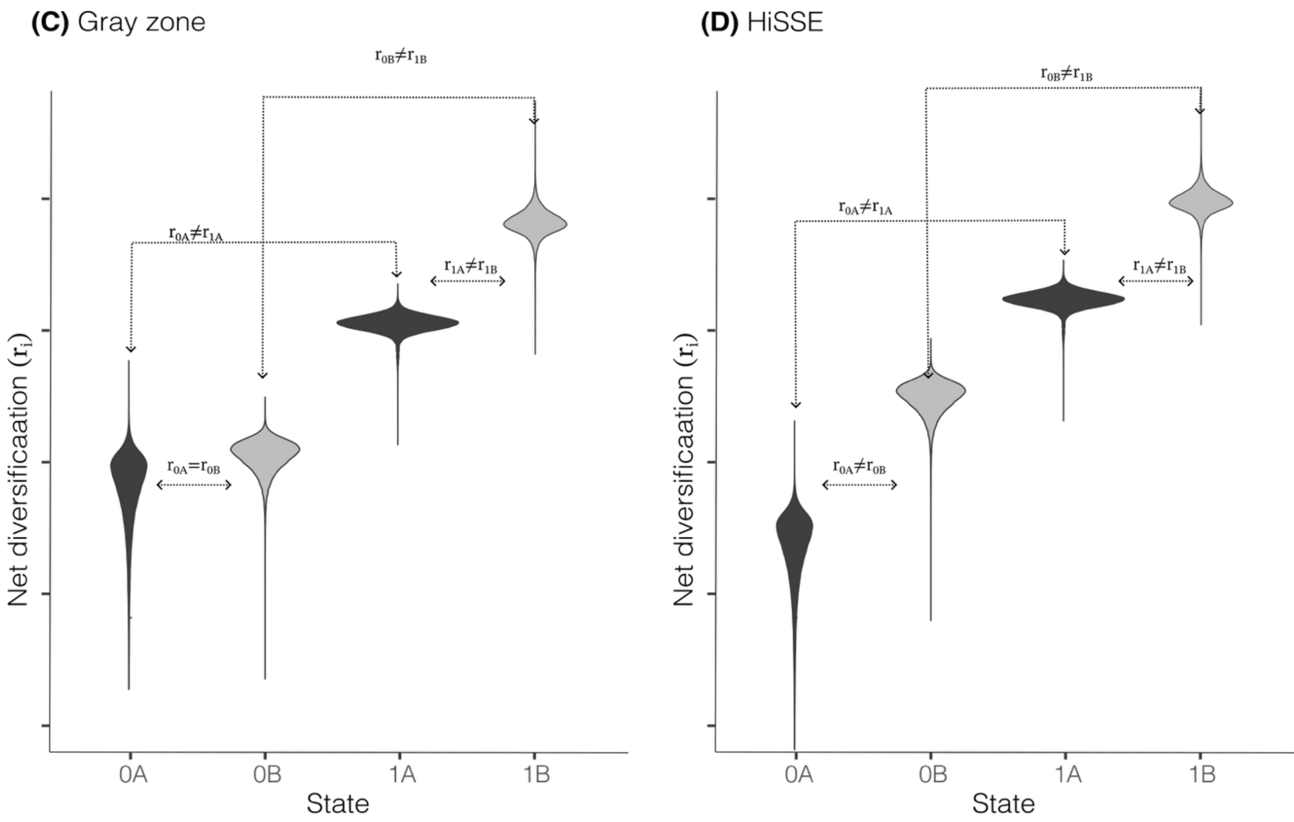

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r_{0A}	r_{0B}	r_{1A}	r_{1B}	
■	=	≠	■	r_{0A}
	■	■	≠	r_{0B}
		■	≠	r_{1A}
			■	r_{1B}

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