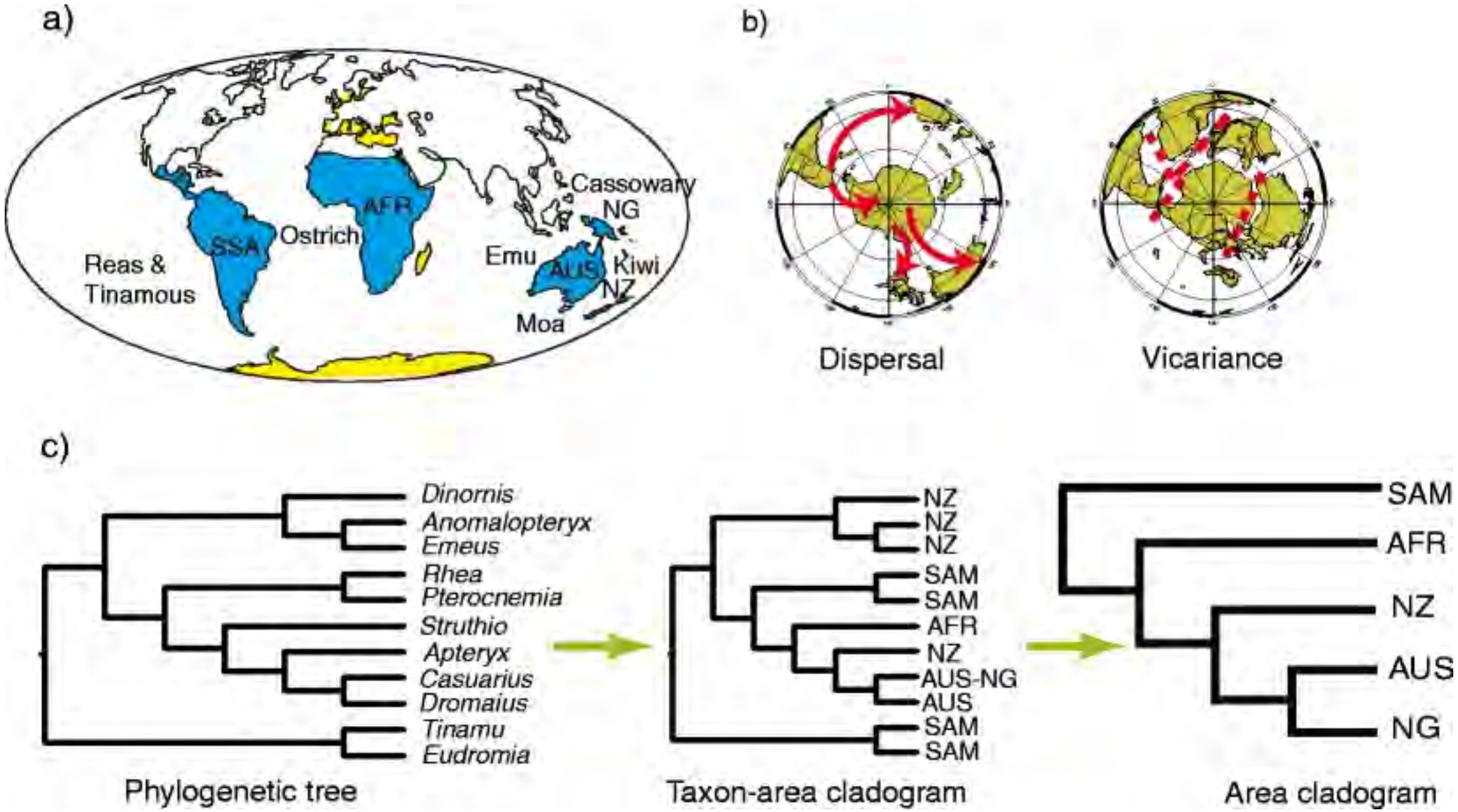
Historical Biogeography

Historical Biogeography

Understanding the geographic distributions of species in the context of their evolutionary history and the geological histories of the regions they occupy



(figure from Sanmartín 2012)

Historical Biogeography

Discrete areas (character states)

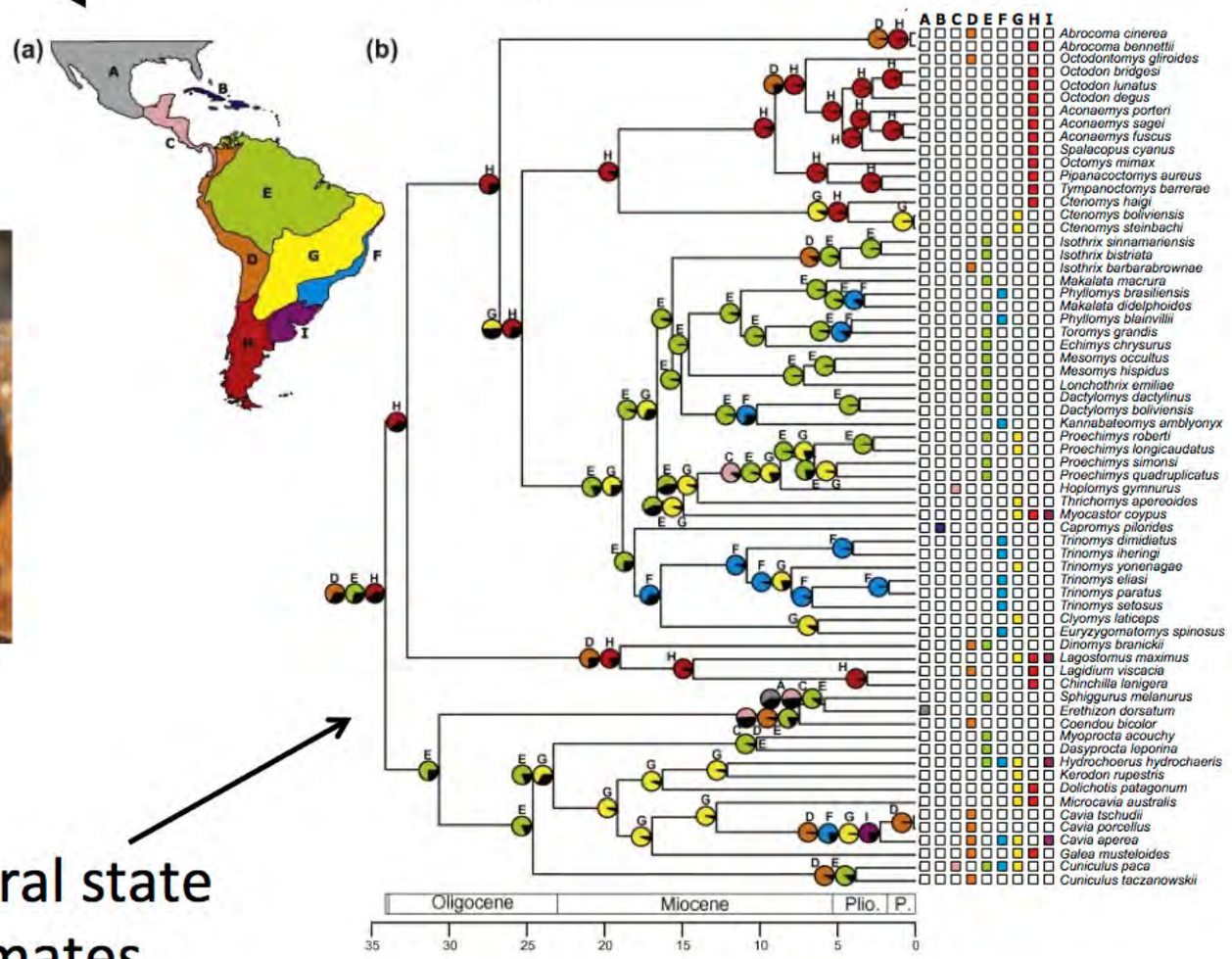
Time-calibrated phylogeny

Data matrix

Octodon degus

Photo, José Cañas

Ancestral state estimates

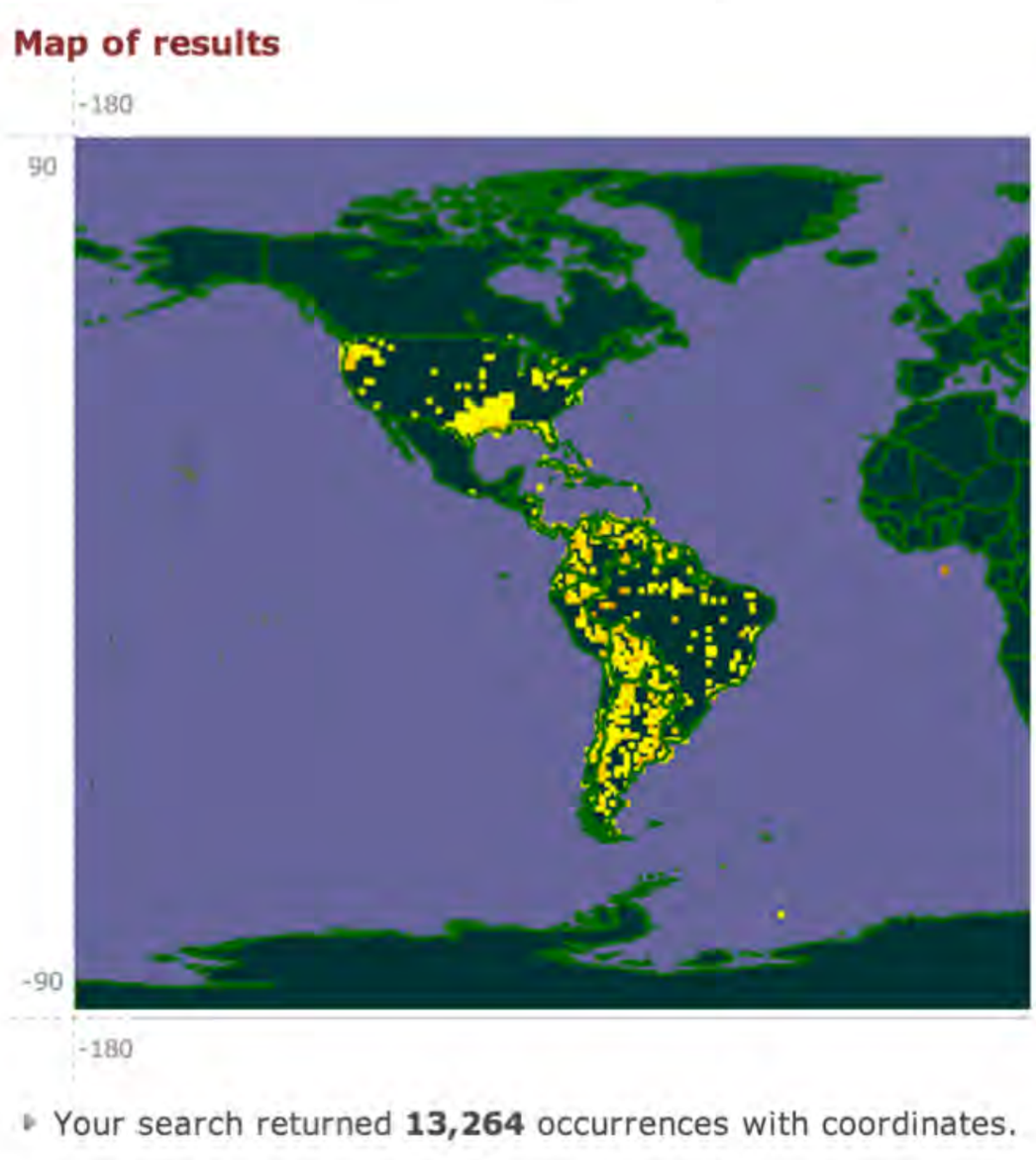


(figure from Upham & Patterson 2012)

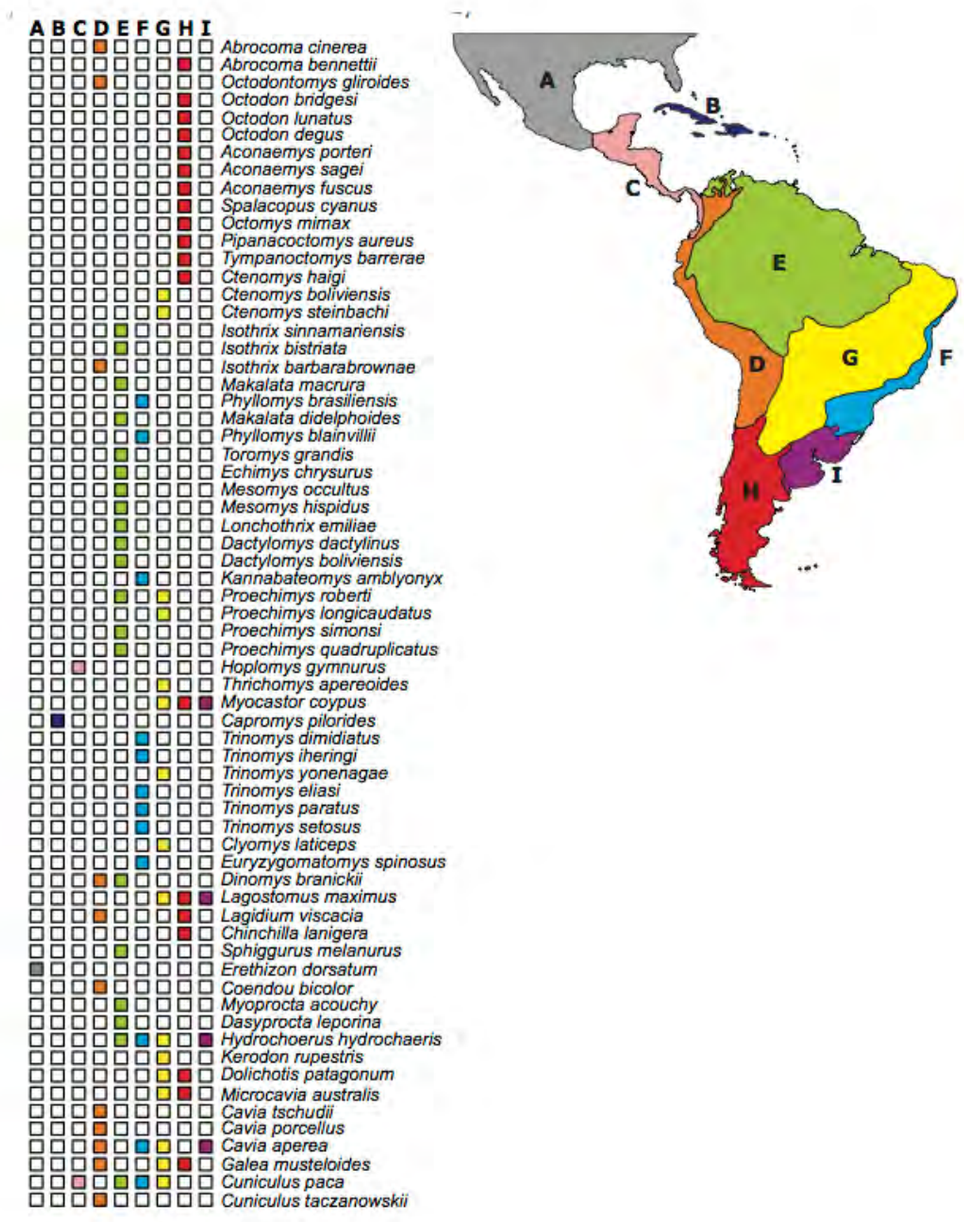
(based on slides by Michael Landis https://github.com/ssb2017/revbayes_biogeography)

Historical Biogeography

Species occurrence data
(https://www.gbif.org, 2013)

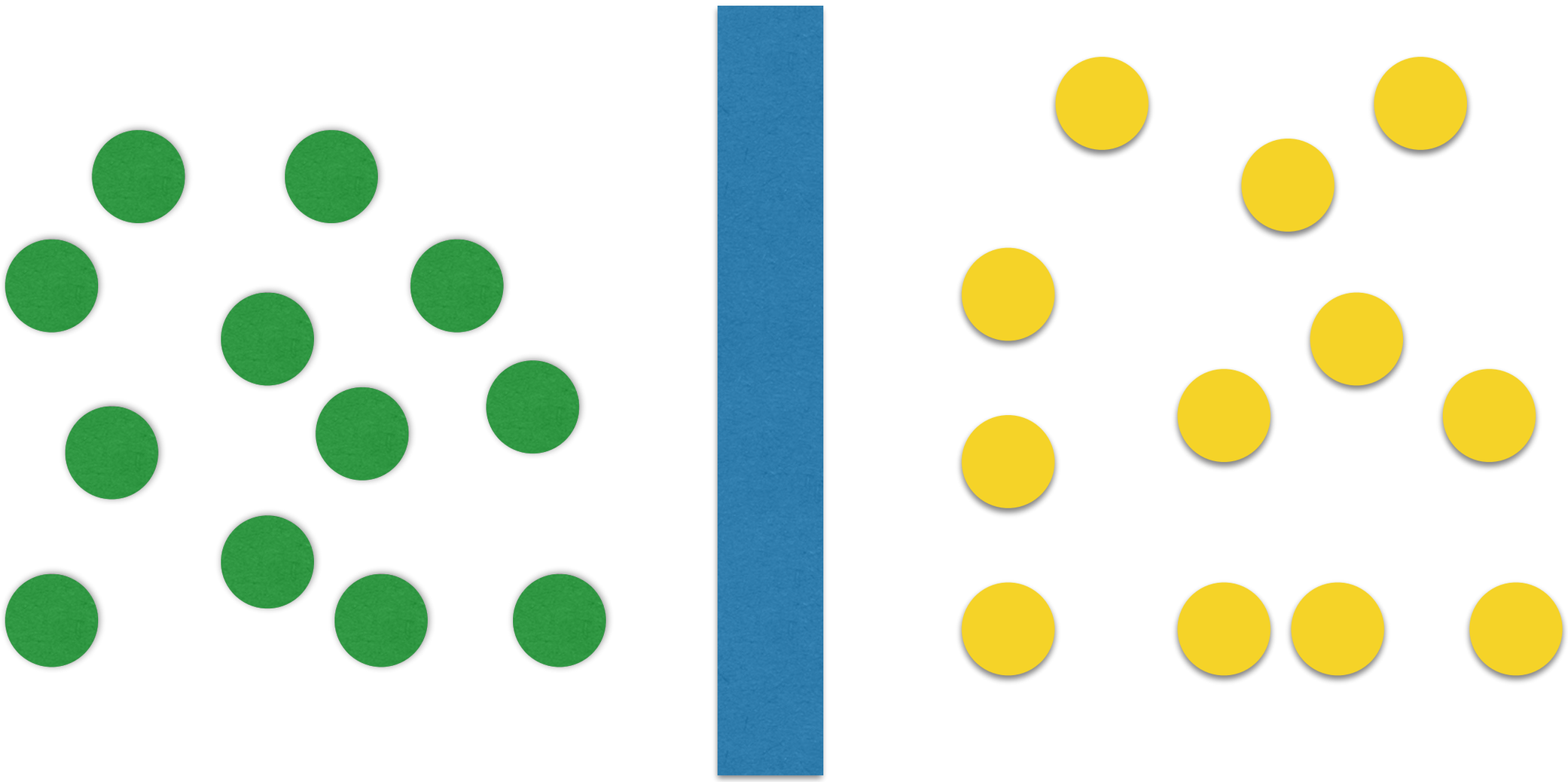


Discrete presence-absence
(Upham & Patterson 2012)

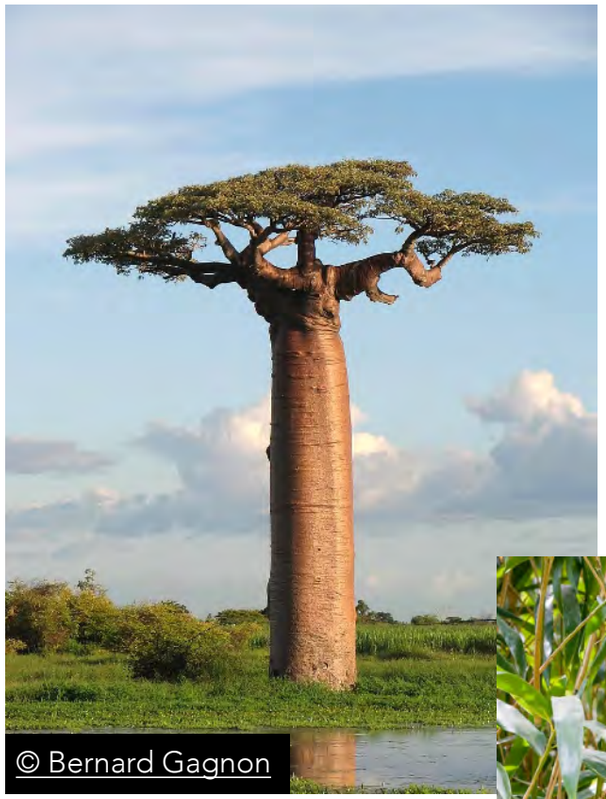


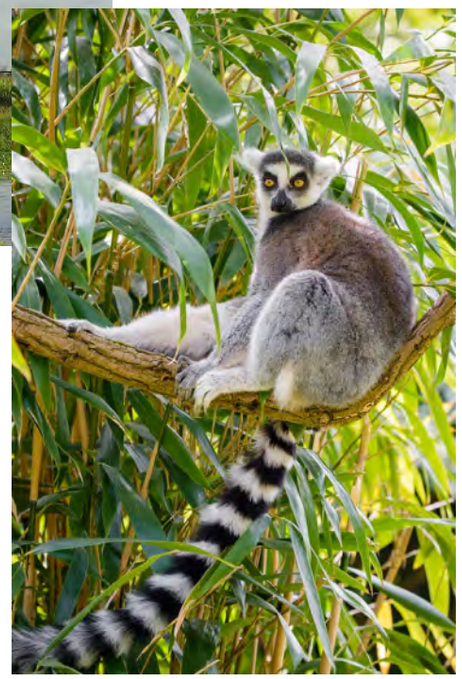
(based on slides by Michael Landis https://github.com/ssb2017/revbayes_biogeography)

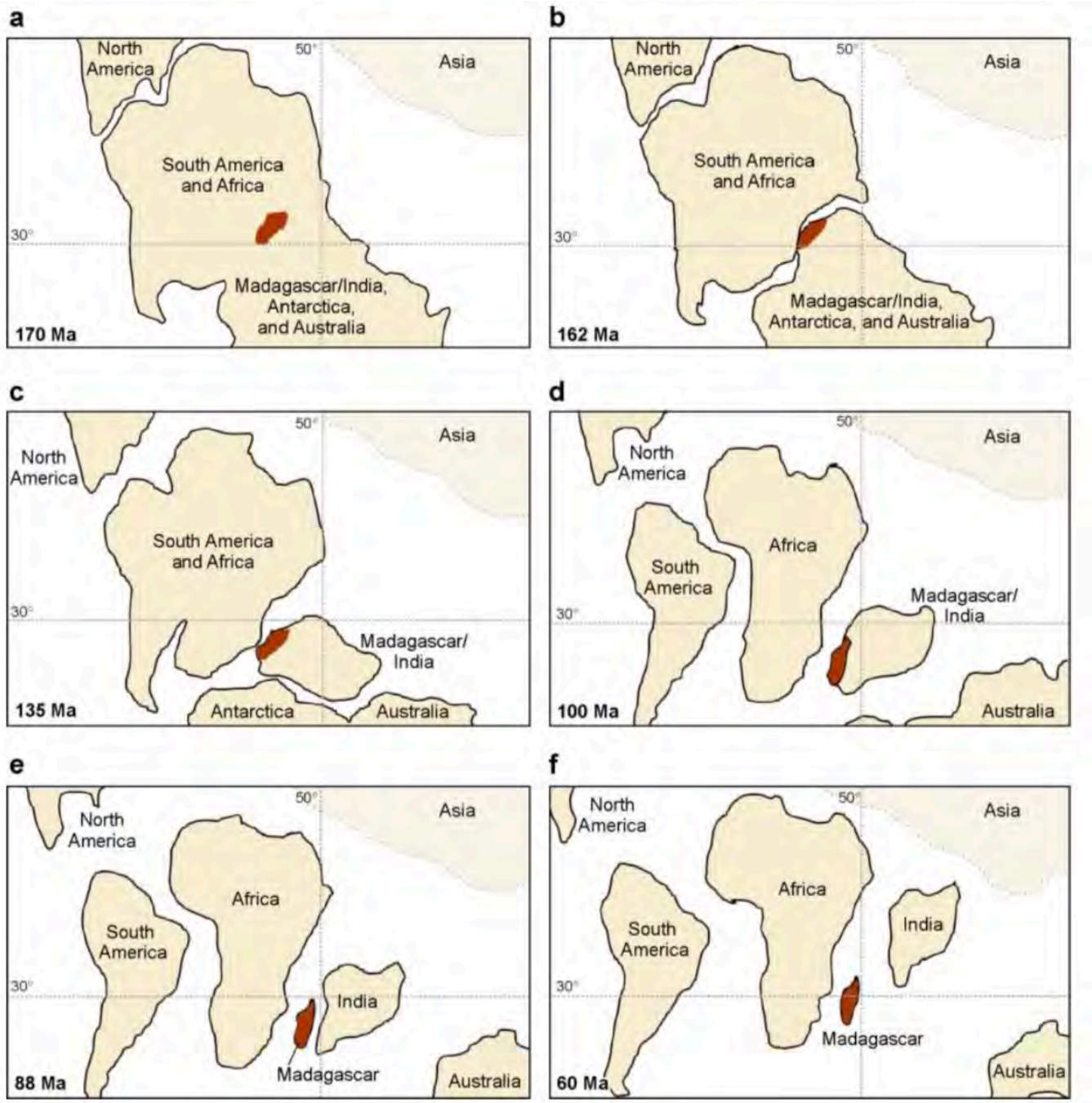
Patterns of Observed Species Ranges



Dispersal







Madagascar has many species of plants and animals that have evolved in isolation. How did they get there?

(Yoder & Nowak 2006)

Dispersal

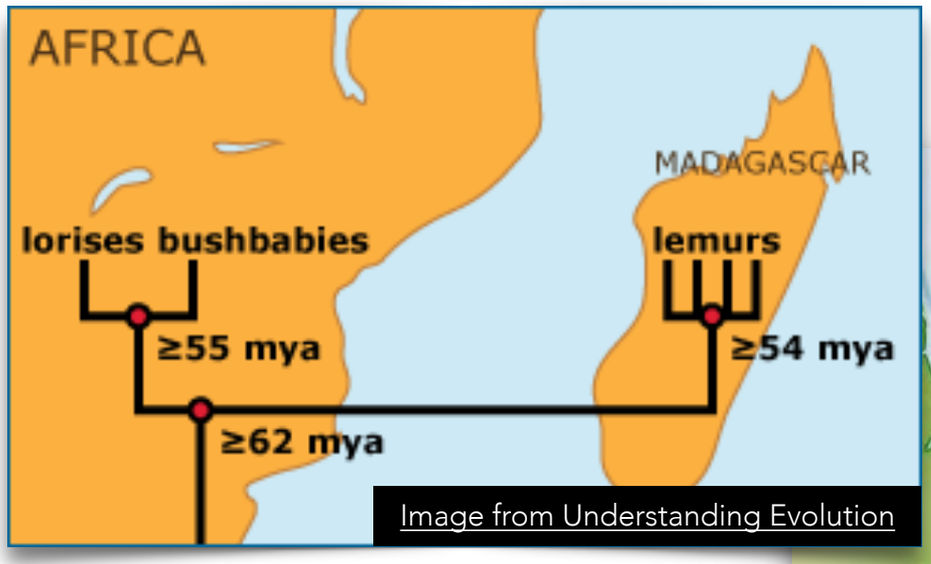


Image from Understanding Evolution

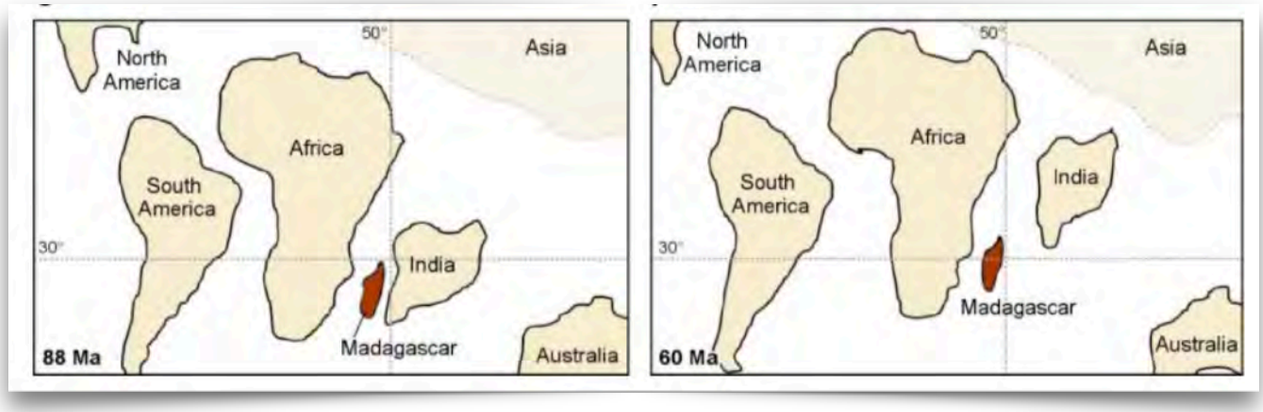
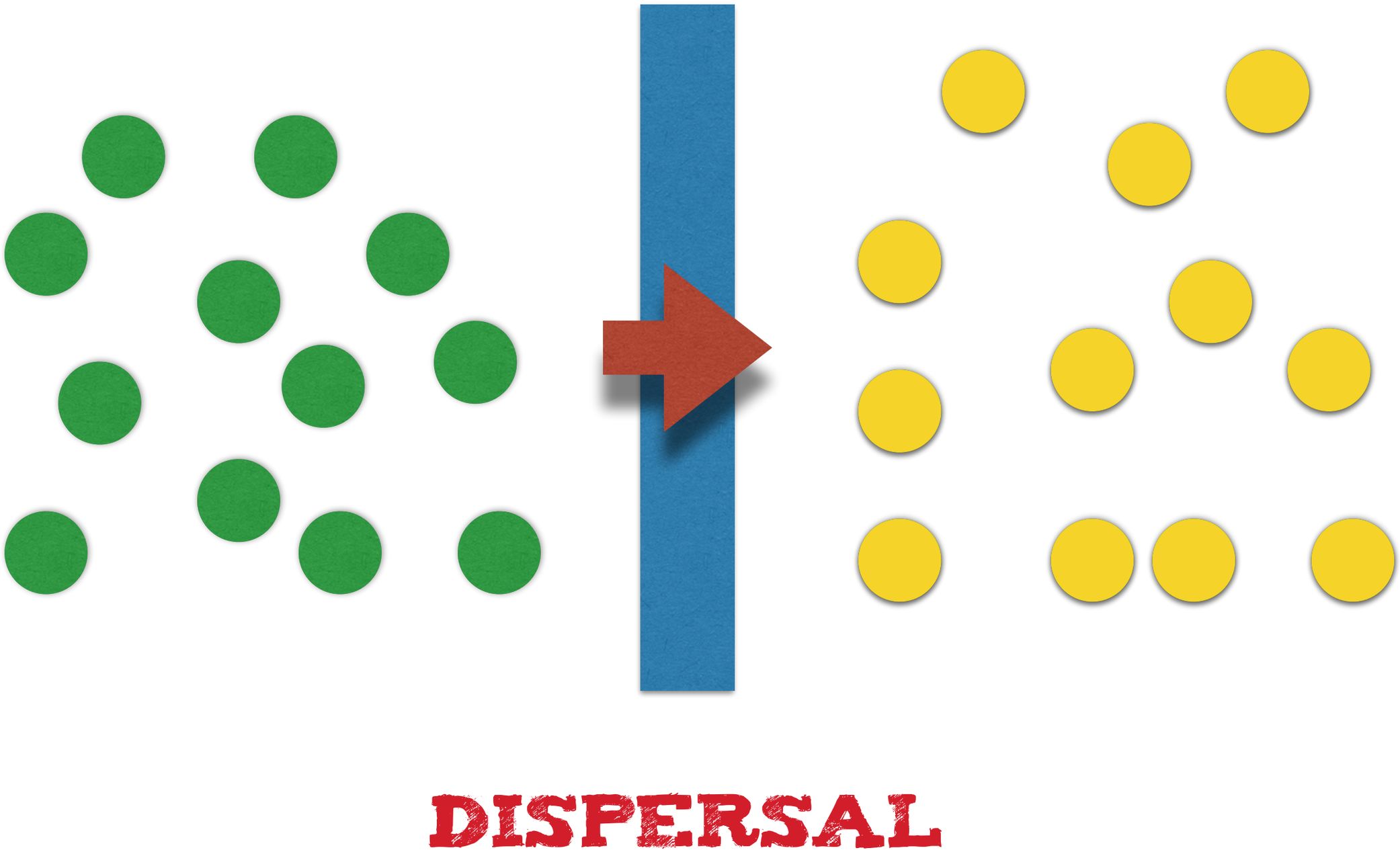


Image from Krause 2010

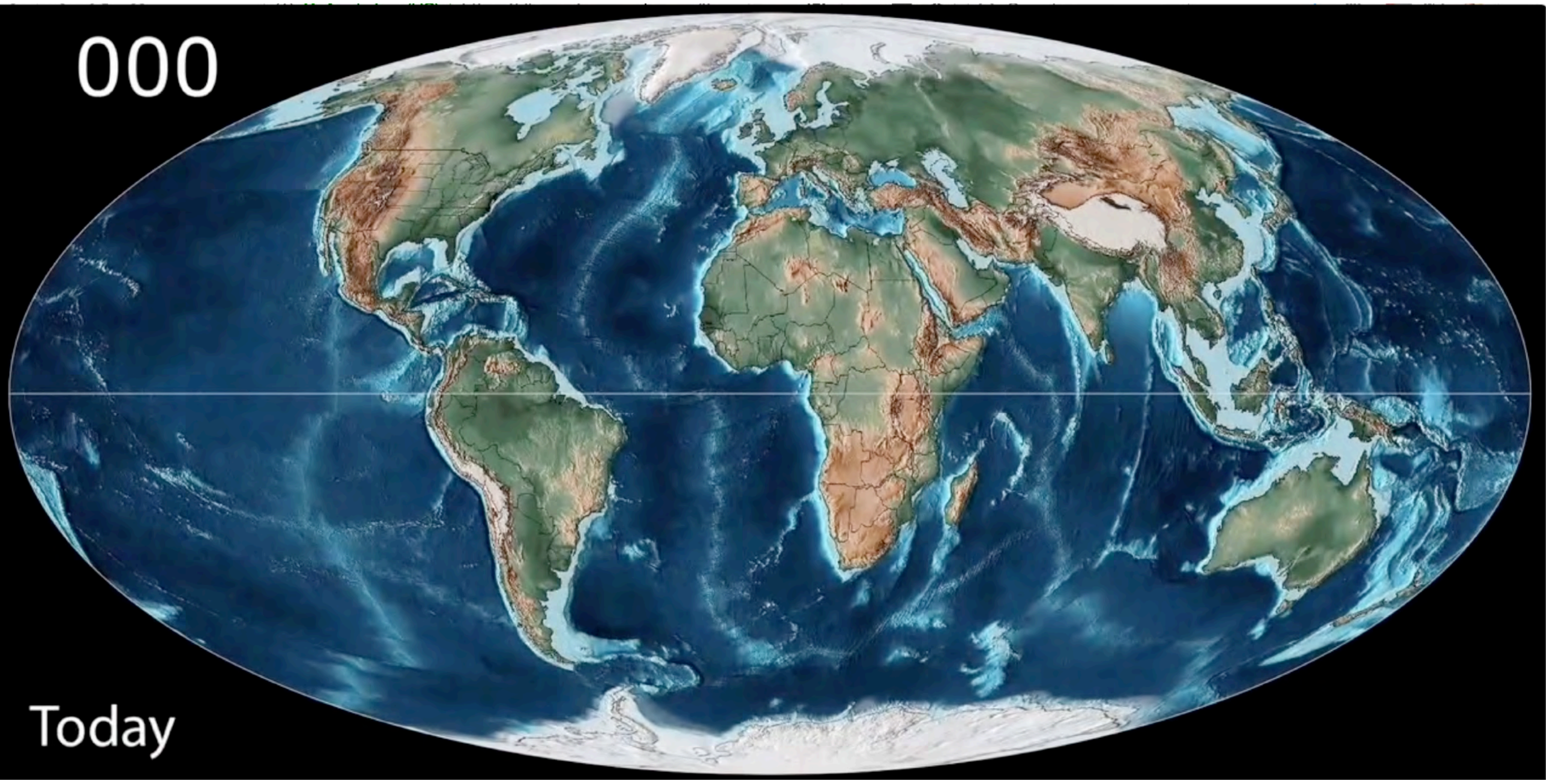
Most of the present-day species of Madagascar are descended from ancestors that dispersed, primarily from Africa, during the Cenozoic

(Yoder & Nowak 2006)

Patterns of Observed Species Ranges

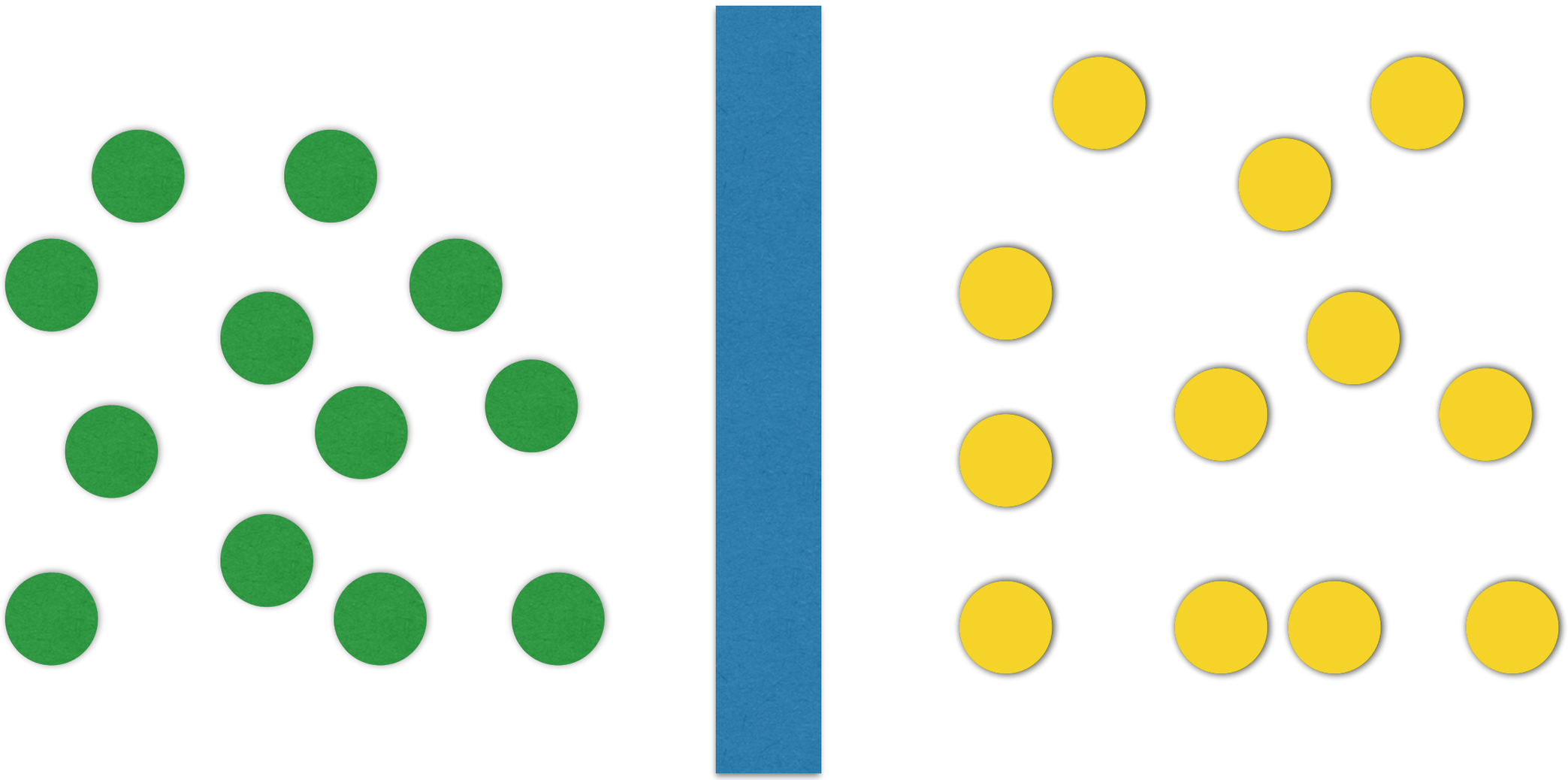


Vicariance



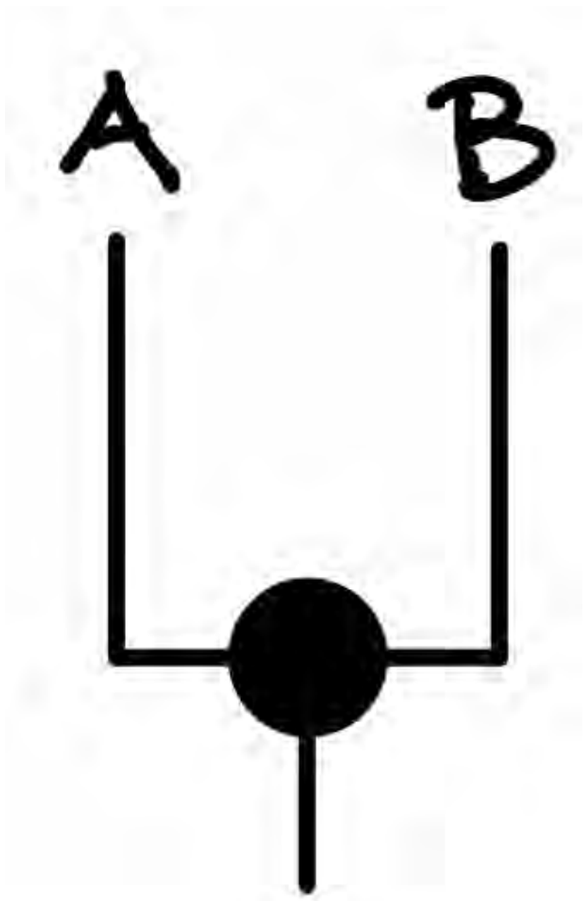
(video source: https://youtu.be/g_iEWvtKcuQ)

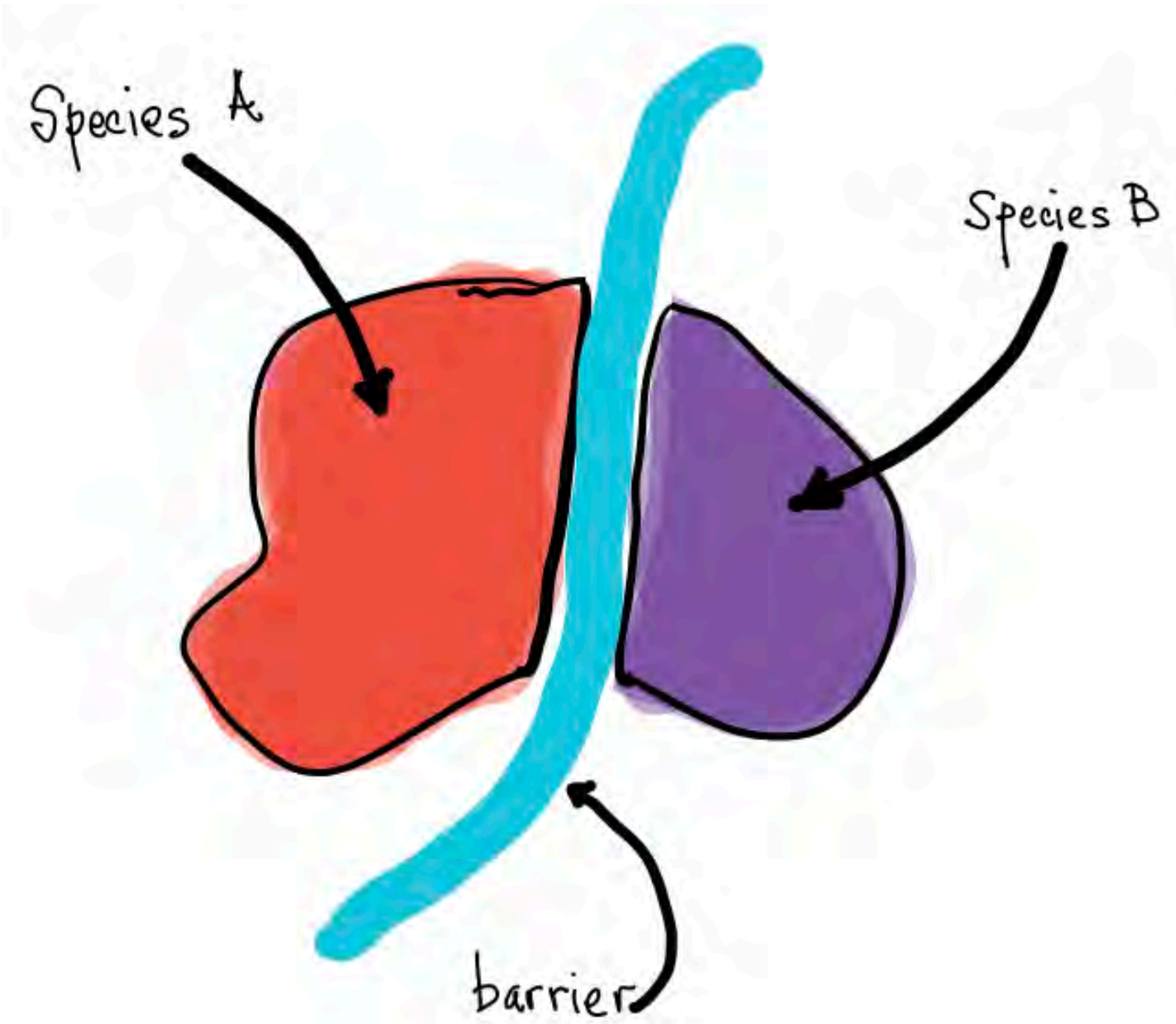
Patterns of Observed Species Ranges



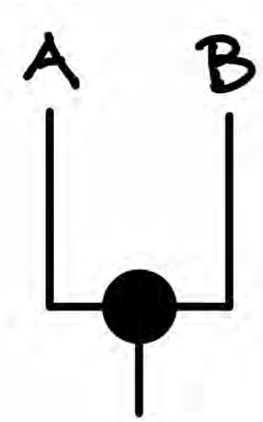
VICARIANCE

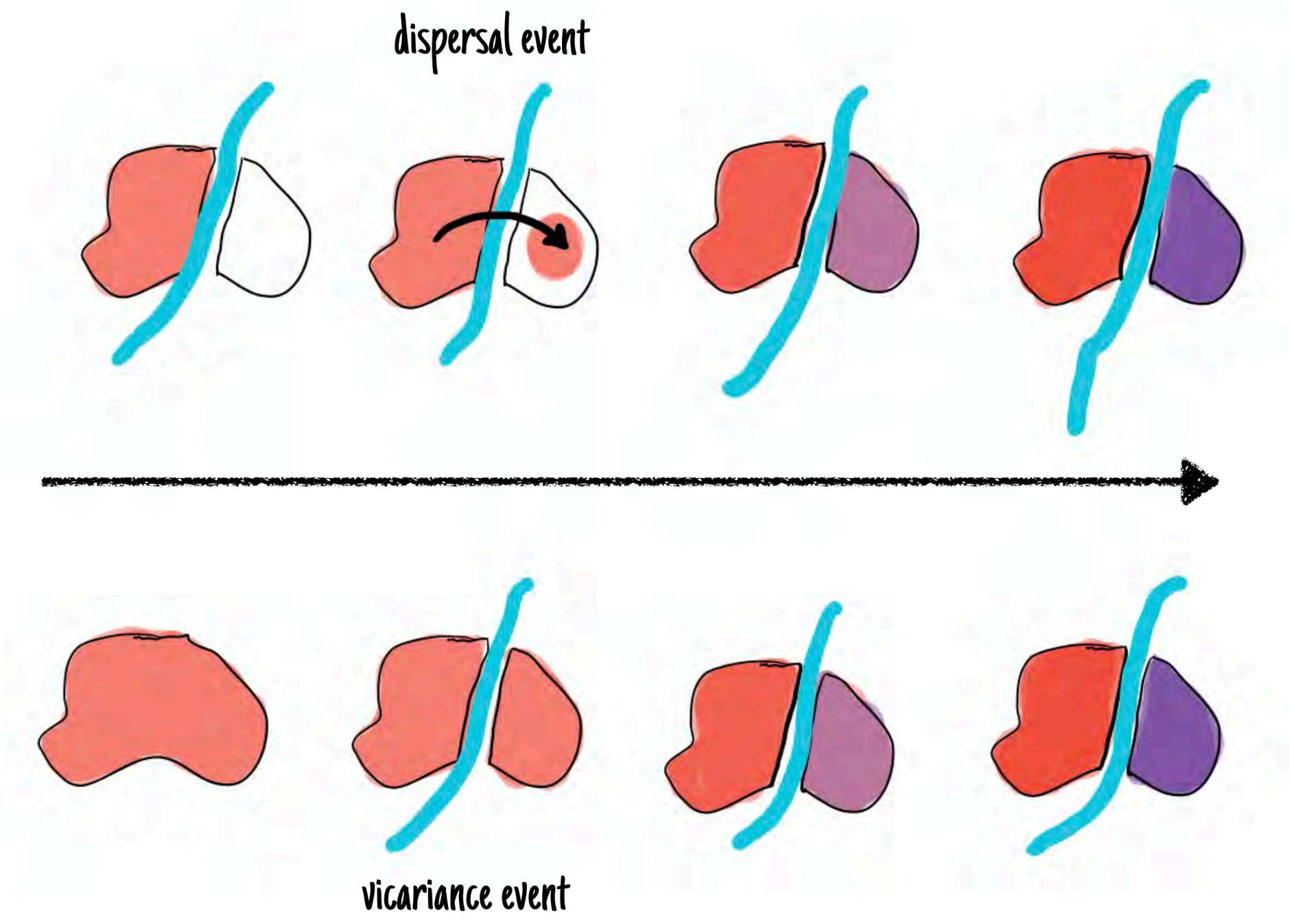
Dispersal or Vicariance?



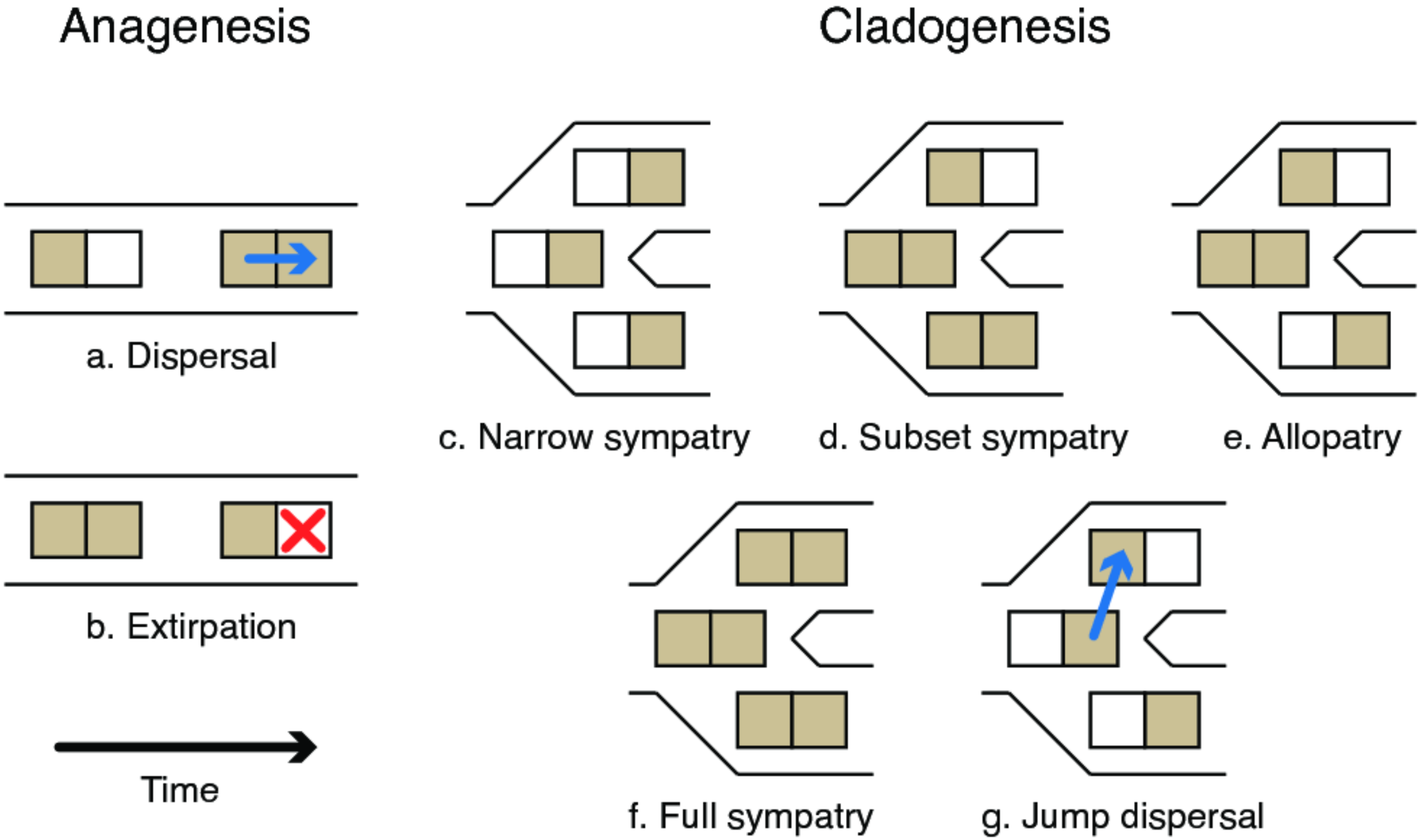


Dispersal or Vicariance?



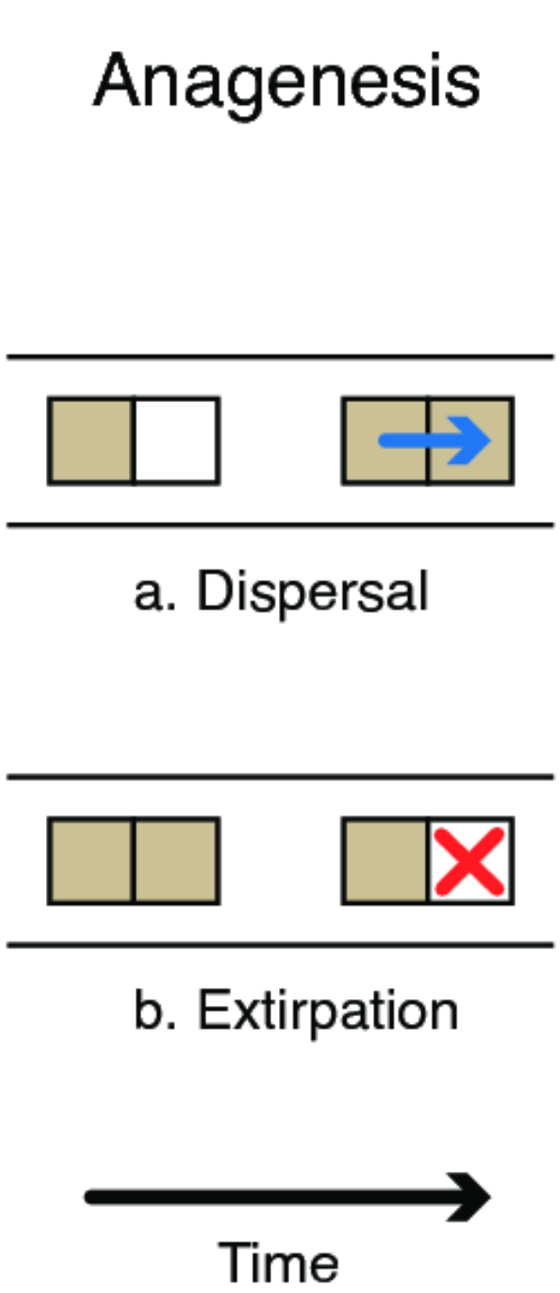


Modeling Species Range Evolution



(image source: https://revbayes.github.io/tutorials/biogeo/biogeo_intro.html)

Modeling Species Range Evolution



Anagenesis is when there is a change that is not associated with a speciation event

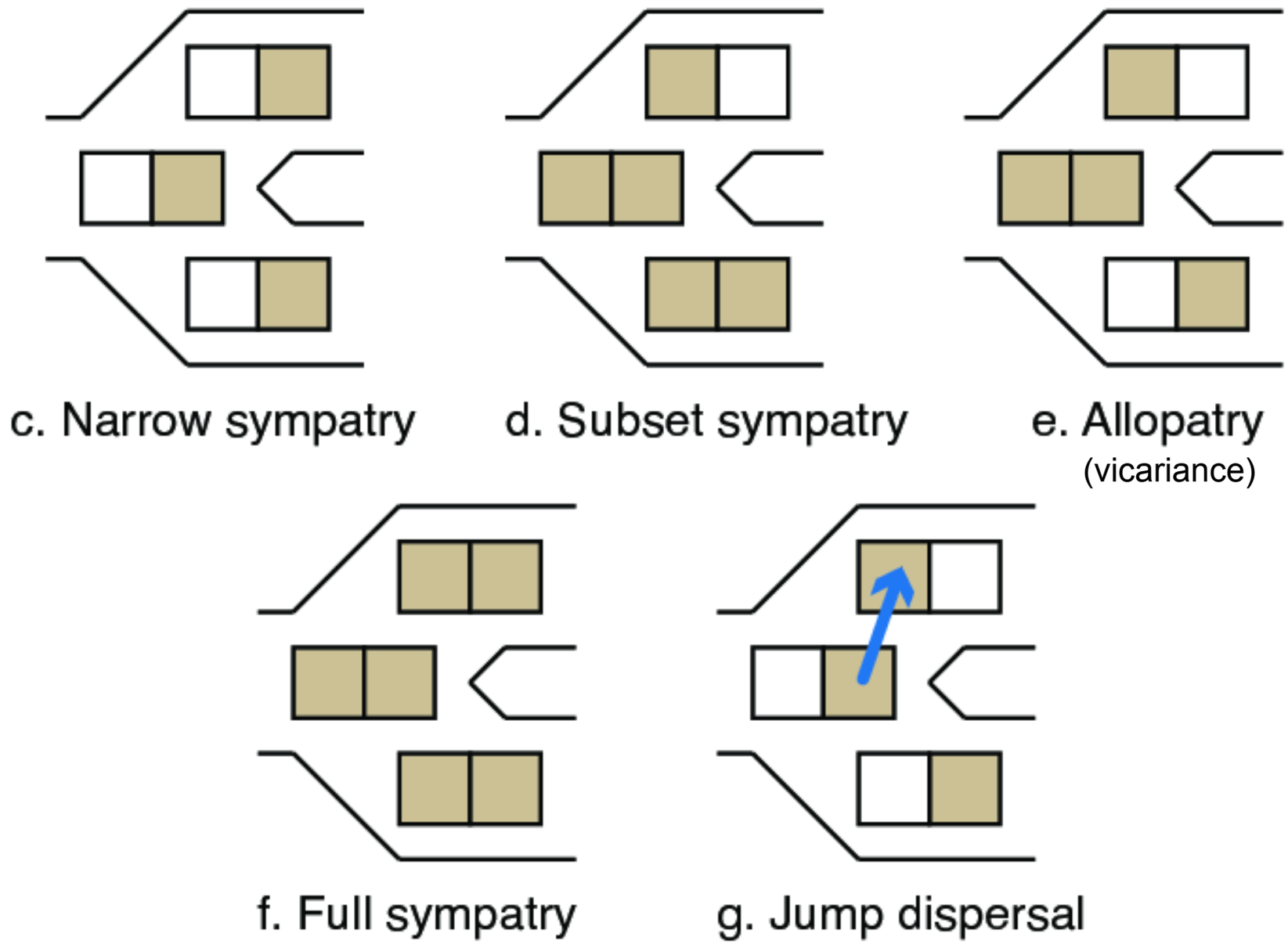
A species can expand its range by dispersing to a new area

Or it may have been widespread, but then became extirpated in part of its range

(image source: https://revbayes.github.io/tutorials/biogeo/biogeo_intro.html)

Modeling Species Range Evolution

Cladogenesis is speciation, which may or may not be associated with a change in the species ranges

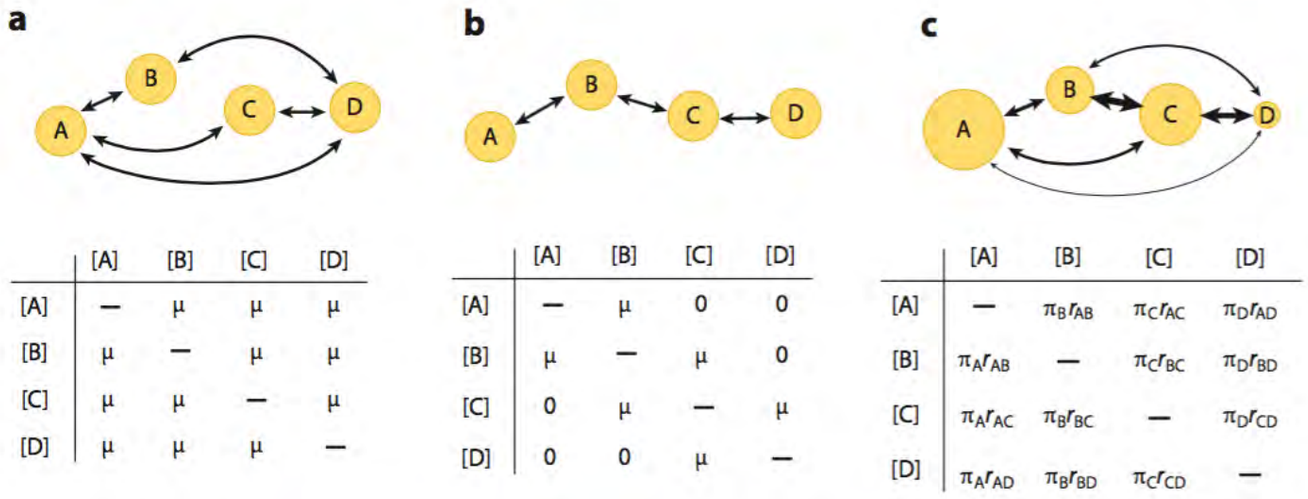


(image source: https://revbayes.github.io/tutorials/biogeo/biogeo_intro.html)

Probabilistic Dispersal

Geographic range can be modeled as a character that is inherited by daughter lineages at the time of speciation

This is a CTMC and directly analogous to discrete character change



	[A]	[B]	[C]	[D]
[A]	—	μ	μ	μ
[B]	μ	—	μ	μ
[C]	μ	μ	—	μ
[D]	μ	μ	μ	—

	[A]	[B]	[C]	[D]
[A]	—	μ	0	0
[B]	μ	—	μ	0
[C]	0	μ	—	μ
[D]	0	0	μ	—

	[A]	[B]	[C]	[D]
[A]	—	$\pi_B r_{AB}$	$\pi_C r_{AC}$	$\pi_D r_{AD}$
[B]	$\pi_A r_{AB}$	—	$\pi_C r_{BC}$	$\pi_D r_{BD}$
[C]	$\pi_A r_{AC}$	$\pi_B r_{BC}$	—	$\pi_D r_{CD}$
[D]	$\pi_A r_{AD}$	$\pi_B r_{BD}$	$\pi_C r_{CD}$	—

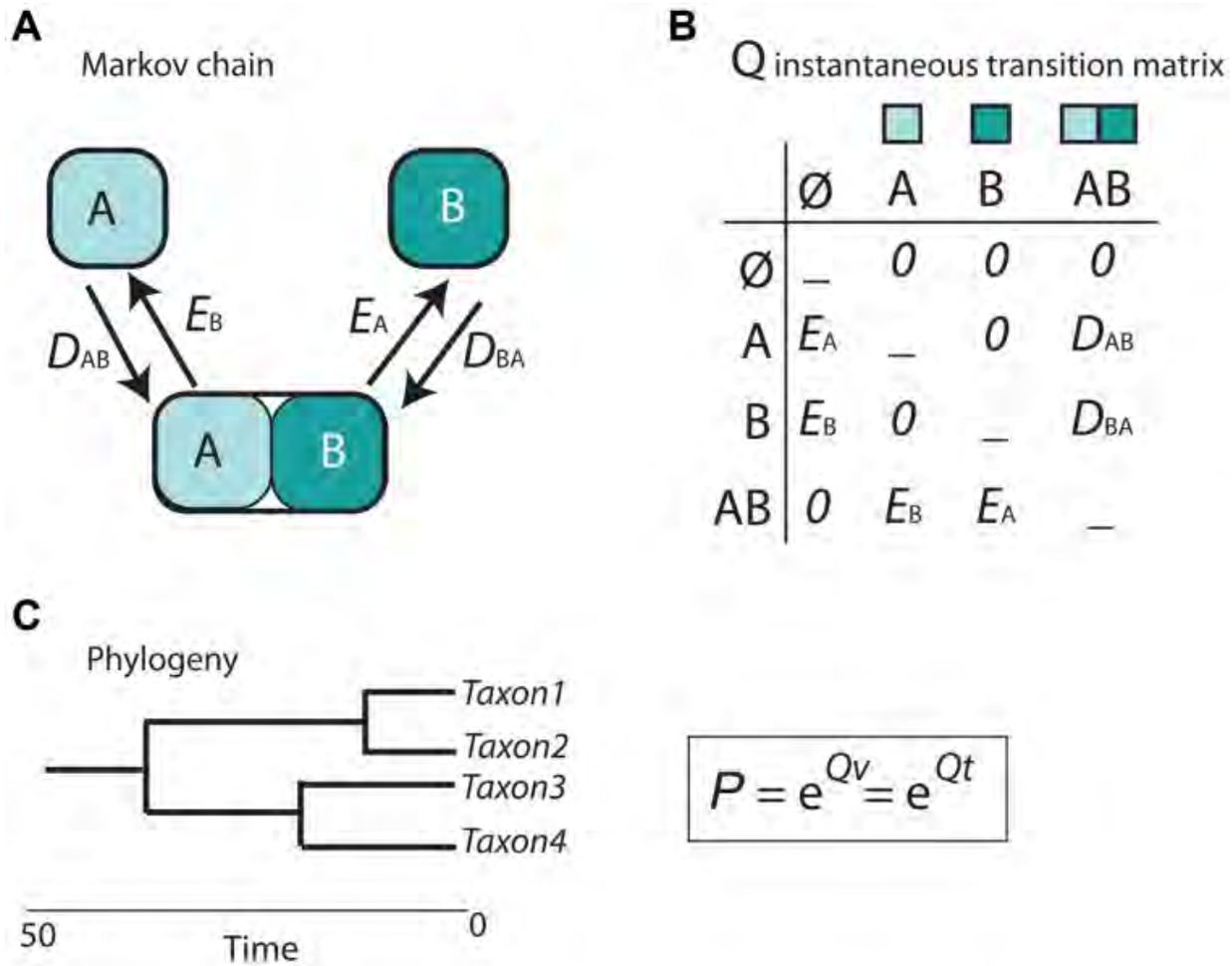
(figure from Ronquist & Sanmartín 2011)

The DEC Model

Dispersal-extinction-cladogenesis model (Ree et al. 2005; Ree & Smith 2008) models geographic range evolution as a continuous time Markov chain

Accounts for dispersal, extirpation (local extinction), and cladogenesis

The states are pre-defined discrete geographic areas



(figure from Sanmartín & Sanchez Meseguer 2016)

The DEC Model Assumptions

Anagenetic change follows a CTMC

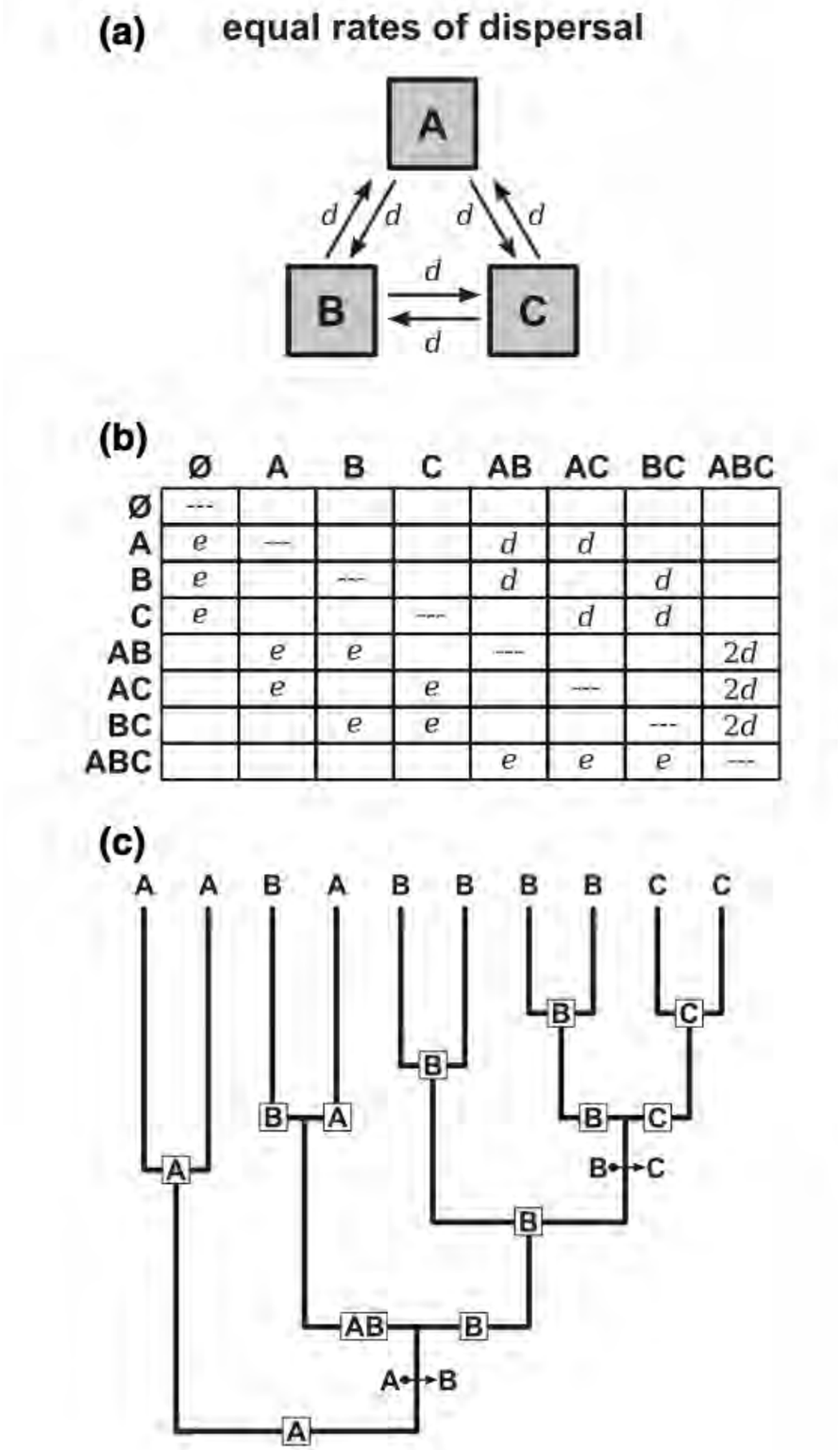
After speciation, daughter lineages do not necessarily have identical ranges

Speciation is dichotomous

Lineage divergence can occur within an area, or, for widespread ancestral ranges, between areas

Cladogenesis results in one of the two daughter species arising in, and inheriting a range of, a single area

The DEC Model



An instantaneous rate matrix for geographic range evolution when dispersal between areas is equal

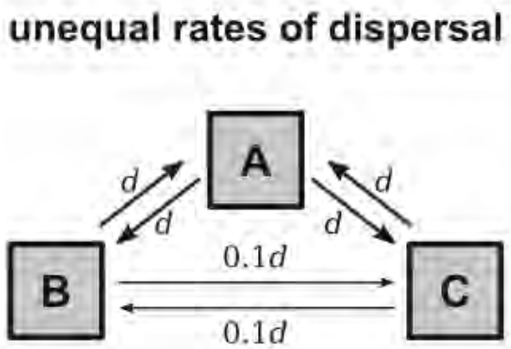
d is the rate of dispersal

e is the rate of extirpation

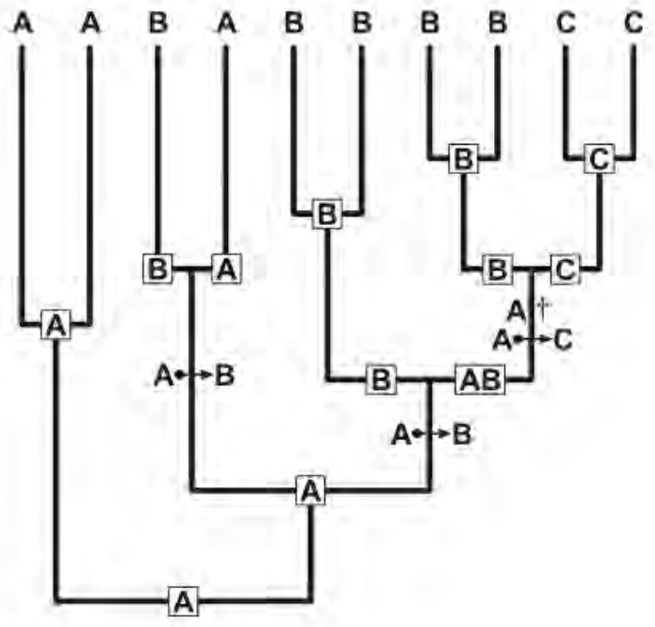
empty cells are 0

(figure from Ree & Sanmartín 2009)

The DEC Model



	Ø	A	B	C	AB	AC	BC	ABC
Ø	---							
A	e	---			d	d		
B	e		---		d		$0.1d$	
C	e			---		d	$0.1d$	
AB		e	e		---			$1.1d$
AC		e		e		---		$1.1d$
BC			e	e			---	$2d$
ABC					e	e	e	---



Unequal rates can also be modeled

In this case some areas may be more distant or difficult to travel to

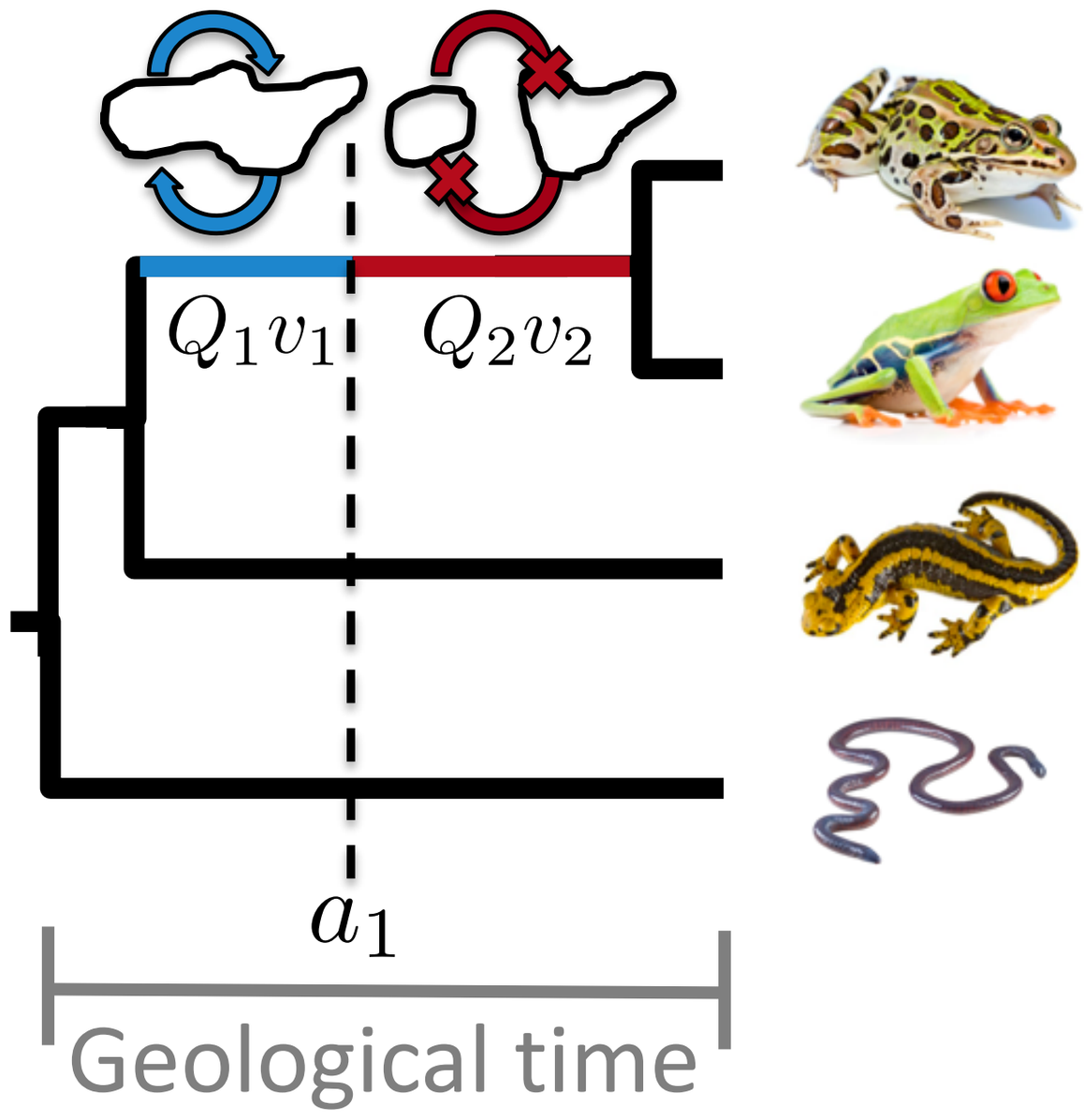
(figure from Ree & Sanmartín 2009)

The DEC Model w/ Paleogeography

The model can be adapted to account for known changes in geographical areas over time

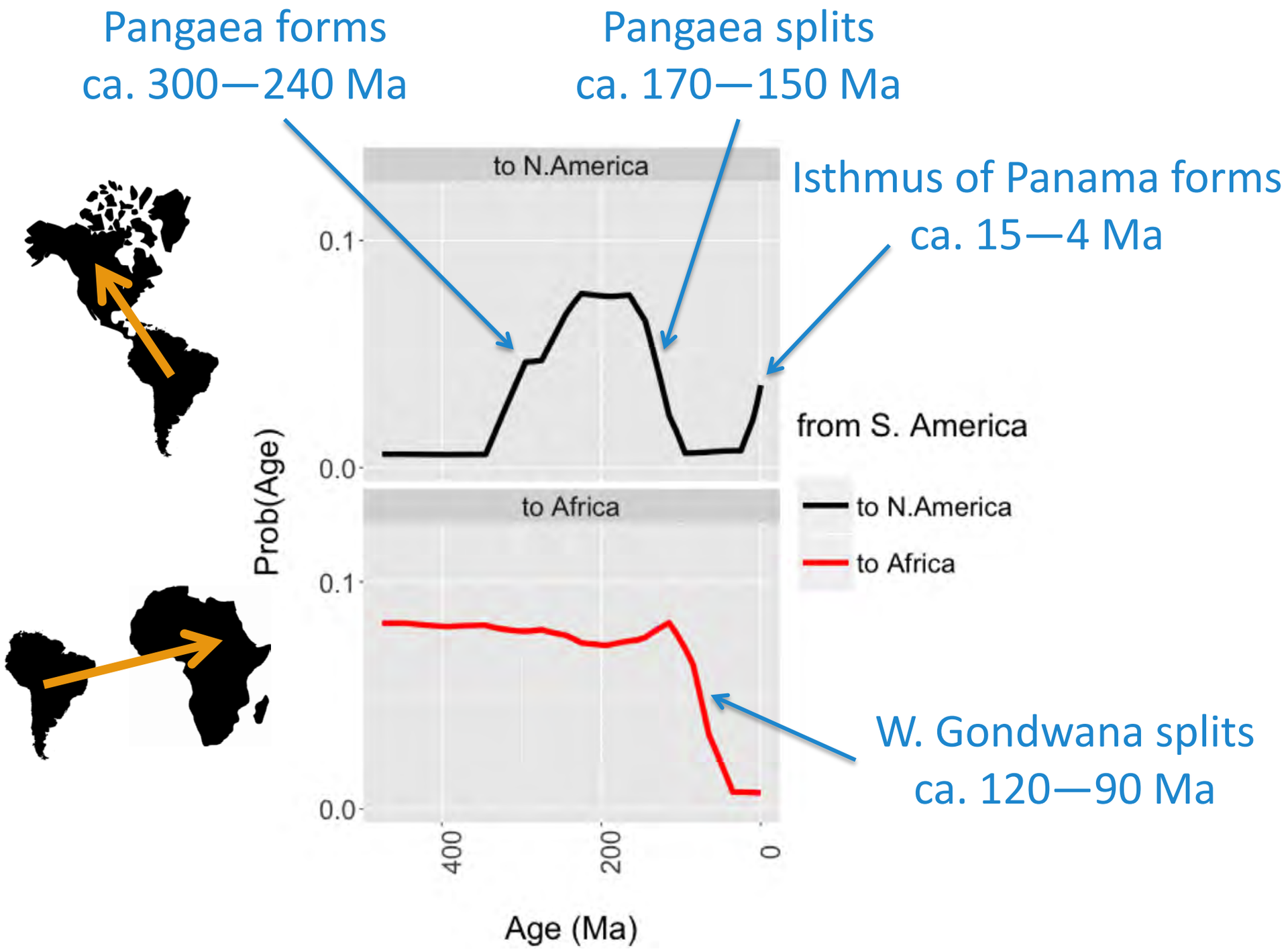
This is an "epoch" model that applies different rate matrices to different time intervals

$$\mathbf{P}_{ij}(\mathbf{v}) = \prod \exp\{Q_k v_k\}$$



(figure by M. Landis)

The DEC Model w/ Paleogeography



(figure by M. Landis)

Methods for Biogeographic Analysis

Lagrange — Maximum likelihood analysis under the DEC model
https://github.com/rhr/lagrange-python

BioGeoBEARS — Maximum likelihood model testing under biogeographic models
https://github.com/nmatzke/BioGeoBEARS

RevBayes — Bayesian inference of ancestral areas and divergence-time estimation under biogeographic models
http://revbayes.com