# Evolutionary paleoecology and the biology of extinction

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January 3, 2014

Introduction and theory

Brachiopods, environmental preference, and extinction

Ecology and survival in Cenozoic mammals

Community connectedness in Cenozoic mammals

# Framework

## Questions

- Why do certain taxa go extinct while others do not?
- How is emergence "formed?" When should it be invoked?
- Is extinction risk taxon–age independent?
- When should we expect global, regional, or local processes to dominate?

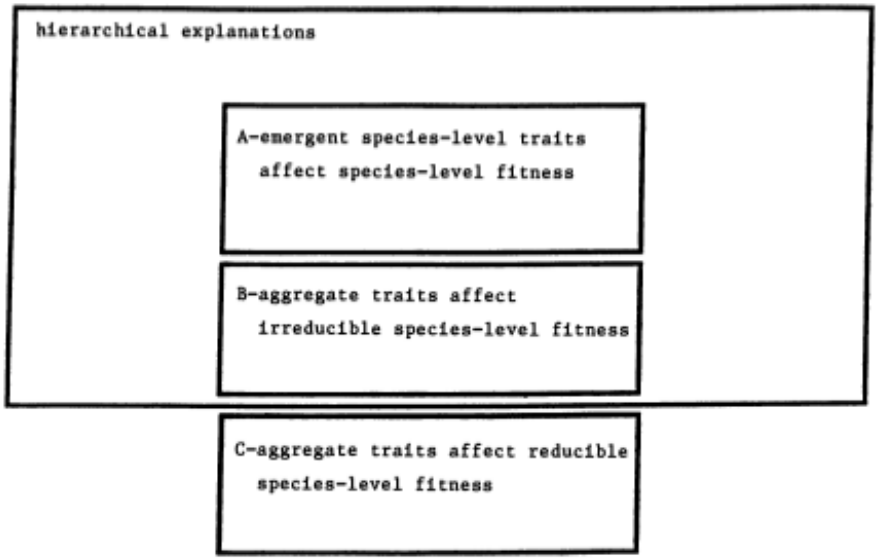
# Evolutionary paleoecology

*. . . the consequences of distinct ecological factors on differential rate dynamics, particularly rates of faunal turnover and diversification.*

*(Kitchell 1985 Paleobiology)*

ecological interactions $\rightarrow$ macroevolution

# Emergent properties



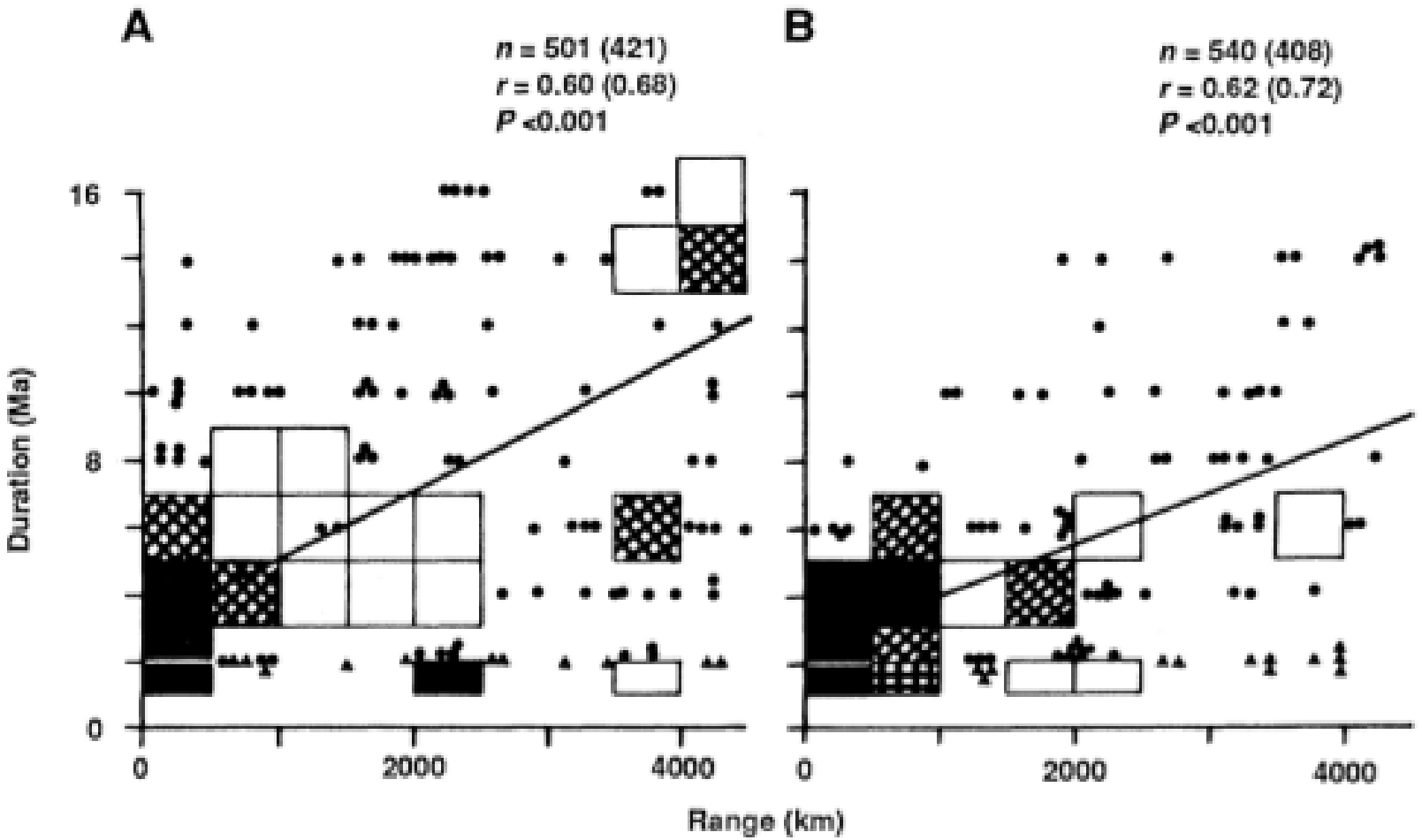

(Grantham 1995 *Ann. Rev. Ecol. Syst.*)

## Species level

Trait that cannot be reduced to organismal level

Product of one or more traits/factors

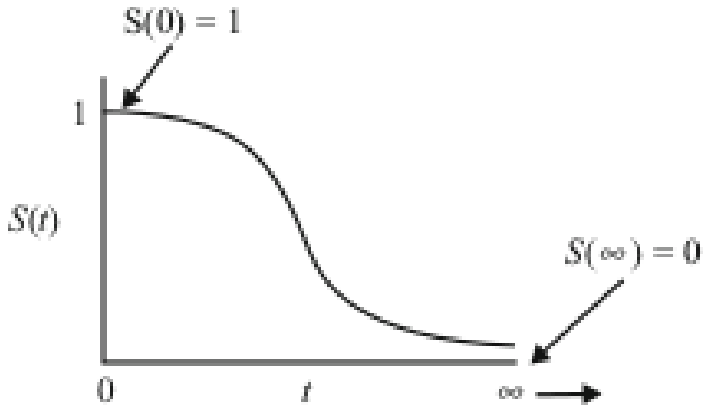
# Range size



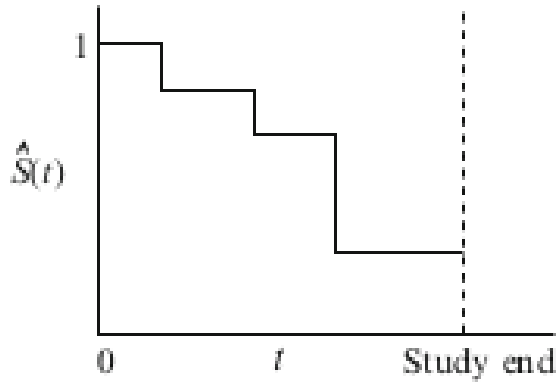

(Jablonski 1987 *Science*)

# Probability of survival

Theoretical $S(t)$:




$\hat{S}(t)$ in practice:




(Kleinbaum and Klein 2012)

## Survival function

$$S(t) = P(T > t)$$

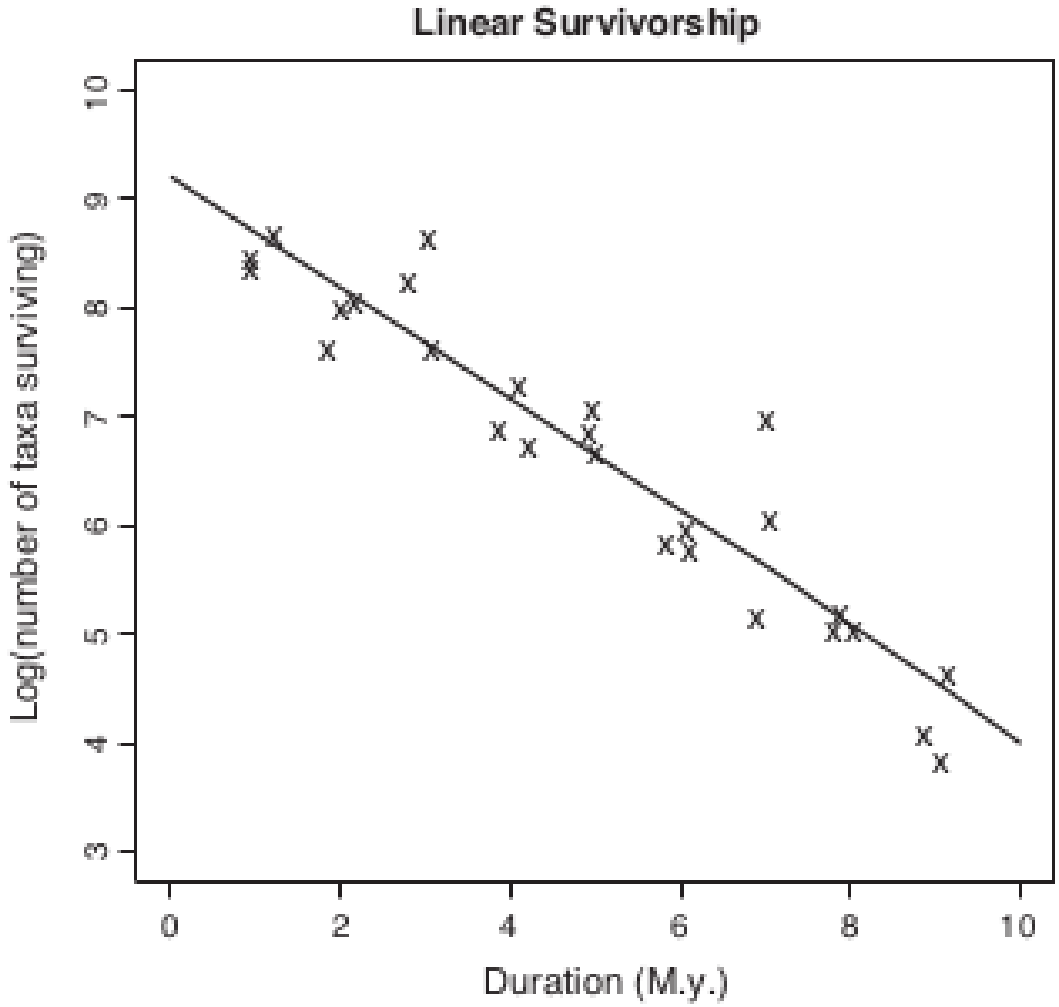
- $T$: survival time ($\geq 0$)
- $t$: specified time

# Instantaneous potential of failure (extinction)

**Hazard function $\equiv$ conditional failure rate**

$$h(t) = \lim_{\Delta t \to 0} \frac{P(t \leq T < t + \Delta t | T \geq t)}{\Delta t}$$

# Van Valen's observation of survival




(Liow et al. 2011 *TREE*)

# Law of Constant Extinction

**Definition**

Extinction risk in a given adaptive zone is taxon–age independent.

(Van Valen 1973 *Evol. Theory*)

translation: hazard is constant with respect to time (exponential)

$$h(t) = \lambda \iff S(t) = \exp^{-\lambda t}$$

# Brachiopods and mammals: a comparison

## brachiopods

- Permian ($\sim$ 47 My)
- marine
- Australasia
- global warming
- sessile

## mammals

- Cenozoic ($\sim$ 65 My)
- terrestrial
- North America, Europe, South America
- global cooling
- motile

# Series of related questions

- generic level survival in brachiopods
  - effect of ecological traits (emergence)
  - distribution of survival
- specific level survival in mammals
  - generic versus specific survival
  - anagenesis/species:genus simulation
  - distribution of survival
- community connectedness in mammals
  - global versus regional versus local scale processes
  - blocking on ecology

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# Traits relating to environment and range size

- substrate affinity
  - physical, chemical
  - availability
- habitat preference
  - energetics
  - availability
- affixing strategy
  - energetics
  - optimality

# Substrate affinity

- carbonates, clastics, mixed
- lithology/deposition environment
- Pharenozoic decrease in carbonates:clastics

# Habitat preference

- on-shore, off-shore, none
- sea-level and energetics
- Pharenozoic decrease in on-shore:off-shore

# Affixing strategy

- pedunculate, reclining, cementing
- pedunculate:on-shore, reclining:off-shore
- environmental energetics

# Assigning substrate and habitat

## Probability of assignment

$$P(H_1|E) = \frac{P(E|H_1)P(H_1)}{P(E|H_1)P(H_1) + P(E|H_2)P(H_2)}$$

$$P(E|H) = \binom{n}{k} p^k (1-p)^{n-k}$$

- $n$: total # of occ
- $k$: # (e.g.) carbonate occ

(Simpson and Harnik 2009 *Paleobiology*)

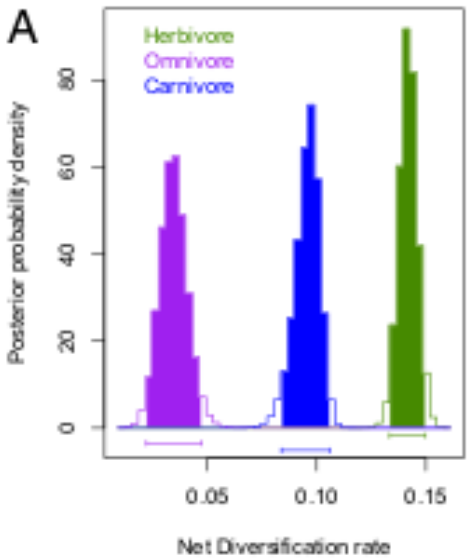
# Models

# Preliminary results

# Ecological traits

- dietary category
  - energetics
  - availability
- locomotor category
  - availability
  - dispersal
- body size
  - energetics
  - home range size

# Predictions: dietary category



# Predictions: locomotor category

# Predictions: body size

# Methodology

# Biases to survival: a simulation study

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# Community connectedness

**Definition**

The degree to which localities are composed of endemic versus cosmopolitan taxa, and how similar this ratio is across localities.

# Average relative number of endemics

$$E = \frac{\sum_{i=1}^{L} \frac{u_i}{n_i}}{L}$$

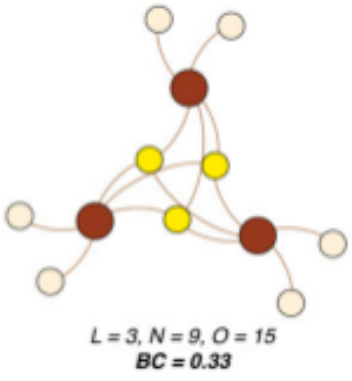
- $L$: number of localities
- $u$: number of taxa unique to a locality
- $n$: number of taxa at a locality
- $0 \leq E \leq 1$

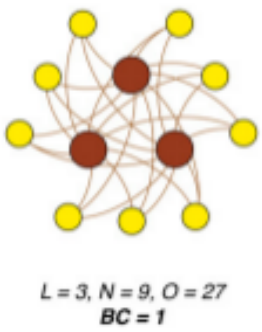
# Average relative occupancy per taxon

$$Occ = \frac{\sum_{i=1}^{N} \frac{l_i}{L}}{N}$$

- $N$: total number of taxa
- $l$: number of localities a taxon occurs at
- $L$: number of localities
- $0 \leq Occ \leq 1$

# Biogeographic connectedness

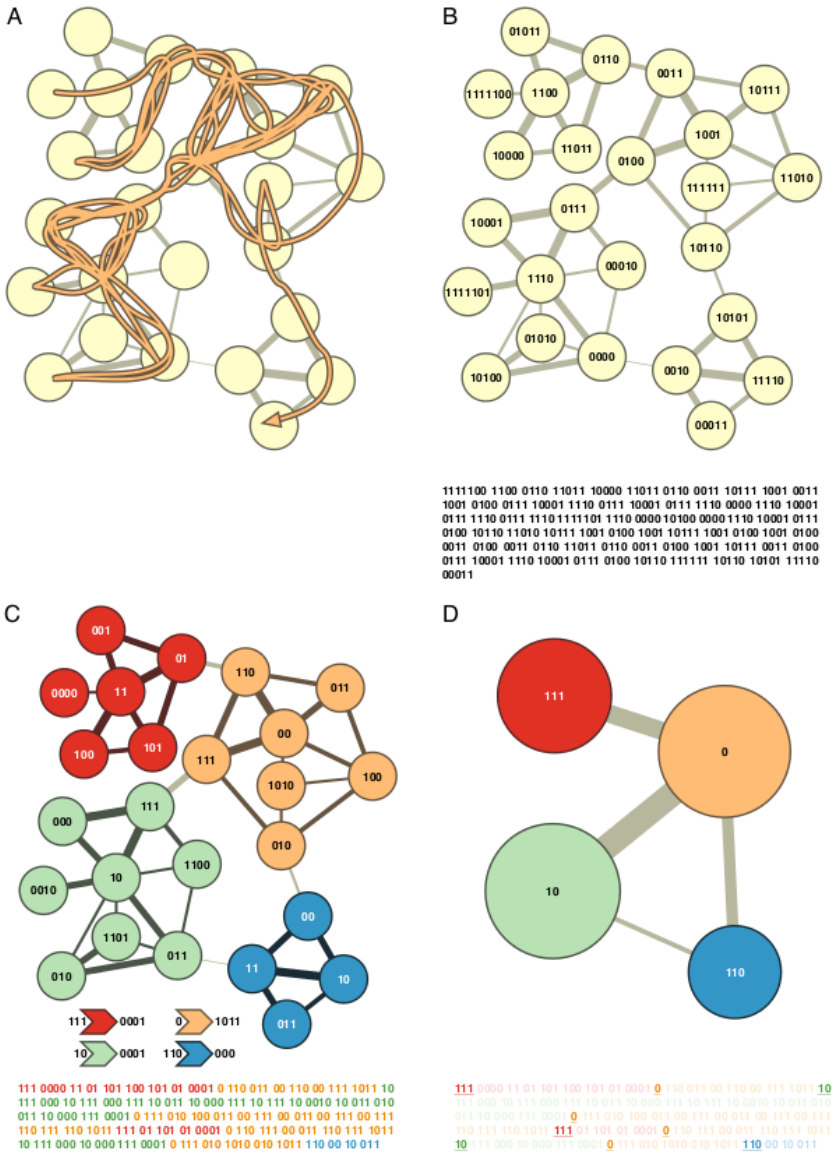




(Sidor et al. 2013 *PNAS*)

$$BC = \frac{O - N}{LN - N}$$

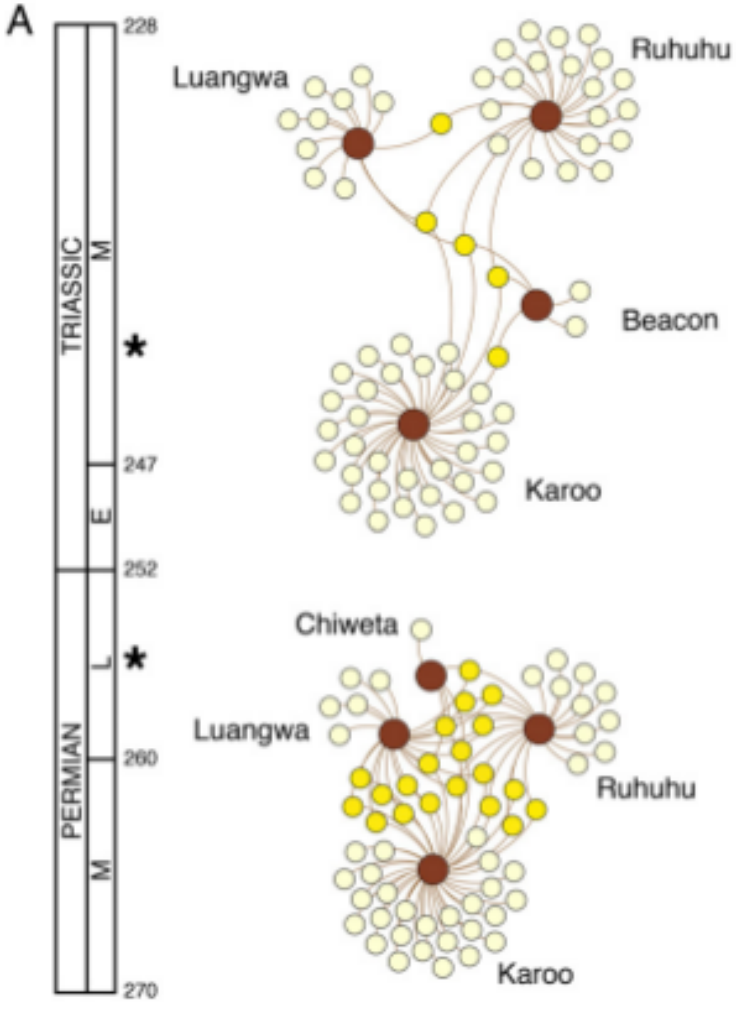
- $O$: number of occurrences
- $N$: total number of taxa
- $L$: number of localities
- $0 \leq BC \leq 1$

# Code length




(Rosvall and Bergstrom 2008 *PNAS*)

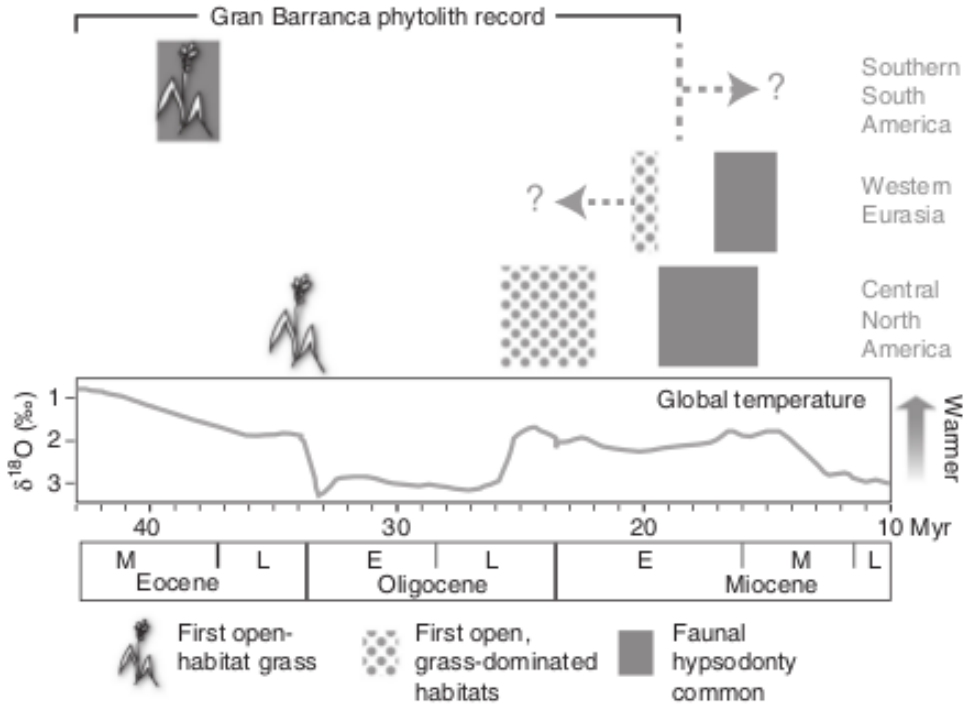
# Global versus regional versus local scale processes




(Sidor et al. 2013 *PNAS*)

- global
  - corr w/ global climate
  - multiple regions corr
- regional
  - $\downarrow E$, $\uparrow Occ$, $\uparrow BC$, $\uparrow$ code
- local
  - $\uparrow E$, $\downarrow Occ$, $\downarrow BC$, $\downarrow$ code
- not mutually exclusive

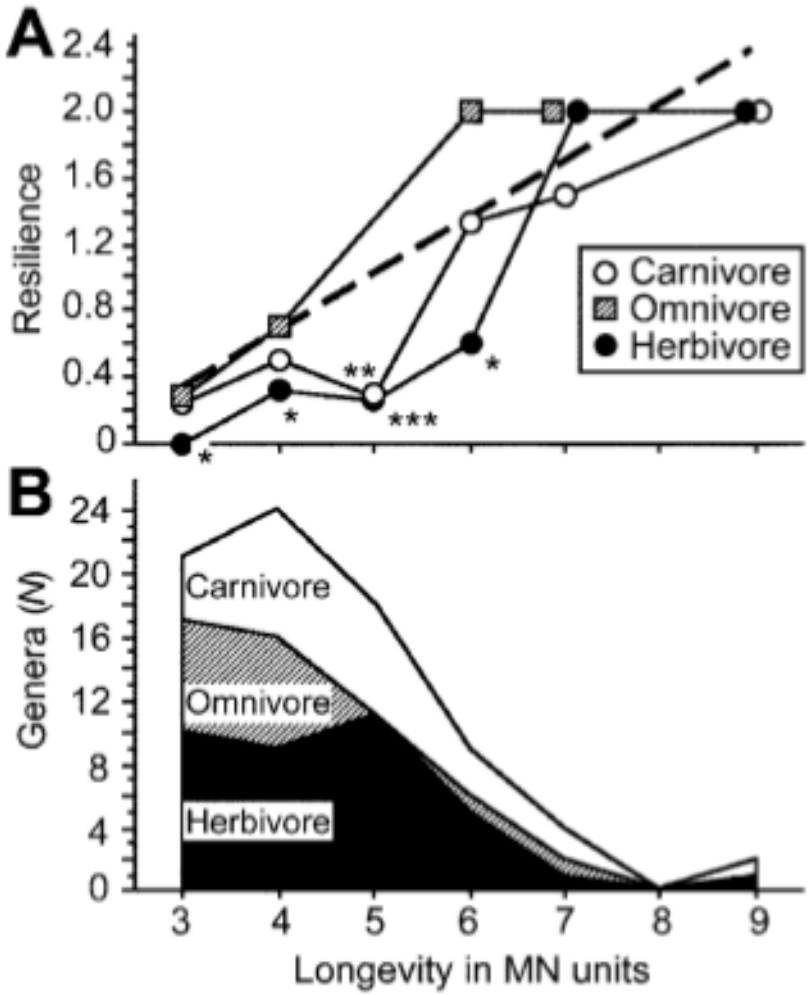
# Expectations: locomotor category




(Strömberg *et al.* 2013 *Nature Com.*)

- arboreal
  - $\uparrow E$, $\uparrow$ code
  - $\downarrow BC$, $\downarrow Occ$
- ground dwelling
  - $\downarrow E$, $\downarrow$ code
  - $\uparrow BC$, $\uparrow Occ$
- scansorial
  - constant $\vee$ random

# Expectations: dietary category




(Jernvall and Fortelius 2004 *Am. Nat.*)

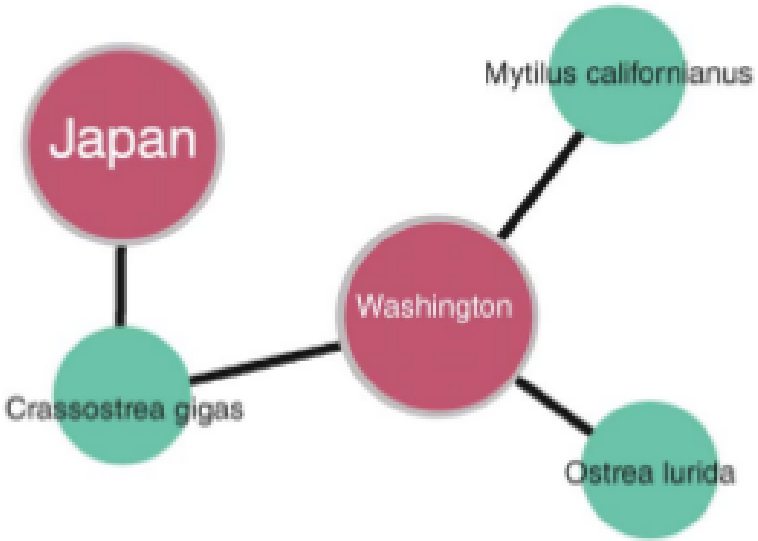
- herbivore
  - most like all taxa
- carnivore
  - constant $\vee$ corr w/ herbivores
- omnivore
  - constant $\vee$ random

# Community connectedness of North America

# Community connectedness of Europe

# Community connectedness of South America

# Methodology




(Vilhena *et al.* 2013 *Sci. Reports*)

- biogeographic network
  - taxa: species
  - locality: 2x2 equal–area map projection grid
- 2 My intervals
- PBDB, NOW, museum collections, compilations

# Preliminary results

# Questions

## Questions

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# Summary of proposed research

## Studies

- Permian brachiopod trait based survival
- Cenozoic mammal trait based survival
- Cenozoic mammal community connectedness

# Acknowledgements


- **Committee**
  - Kenneth D. Angielczyk (co-advisor)
  - Michael J. Foote (co-advisor)
  - P. David Polly
  - Richard H. Ree
- Discussion
  - David Bapst, Megan Boatright, Ben Frable, Colin Kyle, Darcy Ross, Liz Sander
  - John Alroy, Graeme Lloyd, Carl Simpson, Graham Slater



The Field Museum