

Evolutionary paleoecology and the biology of extinction

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Introduction and theory

Brachiopods, environmental preference, and extinction

Ecology and survival in Cenozoic mammals

Community connectedness in Cenozoic mammals

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Questions

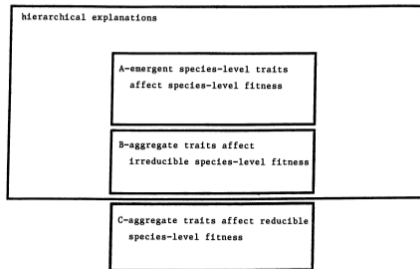
- ▶ Why do certain taxa go extinct while others do not?
- ▶ How is emergence “formed?” When should it be invoked?
- ▶ Is extinction risk taxon–age independent?
- ▶ When should we expect global, regional, or local processes to dominate?

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

(Kitchell 1985 Paleobiology)

environmental interactions → macroevolution

Emergent properties



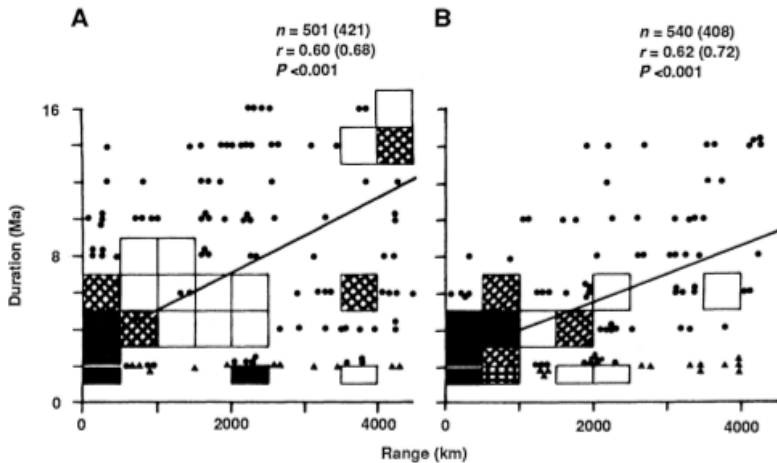
(Grantham 1995 *Ann. Rev. Ecol. Syst.*)

Species level

Trait that cannot be reduced to organismal level

Product of one or more traits/factors

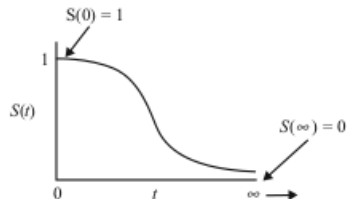
Range size



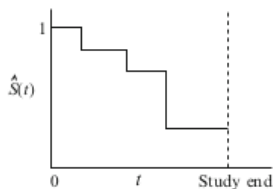
(Jablonski 1987 *Science*)

Probability of survival

Theoretical $S(t)$:



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



(Kleinbaum and Klein 2012)

Survival function

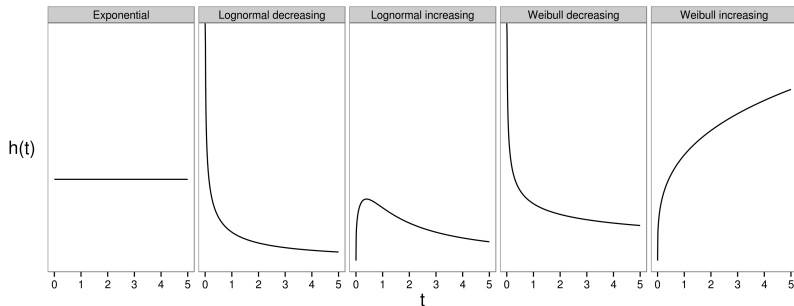
$$S(t) = P(T > t)$$

- ▶ T : survival time (≥ 0)
- ▶ t : specified time

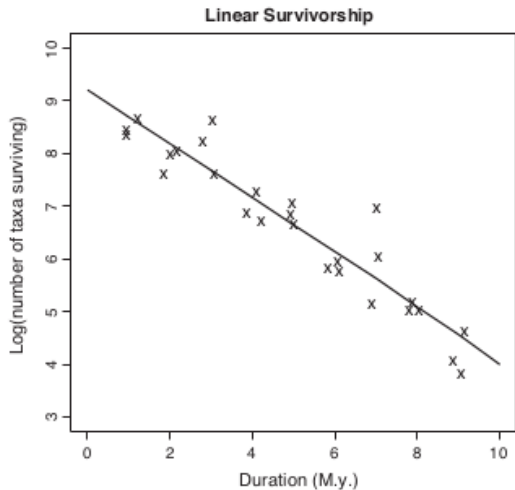
Instantaneous potential of failure (extinction)

Hazard function \equiv conditional failure rate

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



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 survival**)

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

Brachiopods and mammals: a comparison

brachiopods

- ▶ Permian (~ 47 My)
- ▶ marine
- ▶ Australasia
- ▶ global warming
- ▶ sessile

mammals

- ▶ Cenozoic (~ 65 My)
- ▶ terrestrial
- ▶ North America, Europe, South America
- ▶ global cooling
- ▶ motile

Series of related questions

- ▶ generic level survival in brachiopods
 - ▶ ecological traits re. environmental pref. (emergence)
 - ▶ survival distribution
- ▶ specific level survival in mammals
 - ▶ ecological traits re. range size (emergence)
 - ▶ generic versus specific survival
 - ▶ anagenesis/species:genus simulation
 - ▶ survival distribution
- ▶ community connectedness in mammals
 - ▶ global versus regional versus local scale processes
 - ▶ ecological traits (trophic/locomotion)

Introduction and theory

Brachiopods, environmental preference, and extinction

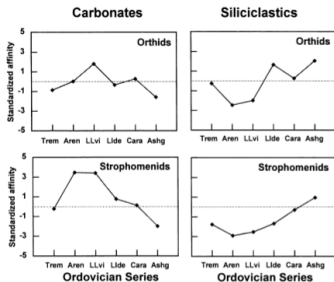
Ecology and survival in Cenozoic mammals

Community connectedness in Cenozoic mammals

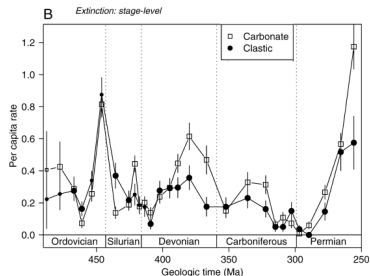
Traits relating to environment and range size

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

Substrate affinity



(Miller and Connolly 2001 *Paleobio.*)



(Foote 2006 *Paleobio.*)

- ▶ 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: model comparison

Preliminary results: best substrate

Preliminary results: best habitat

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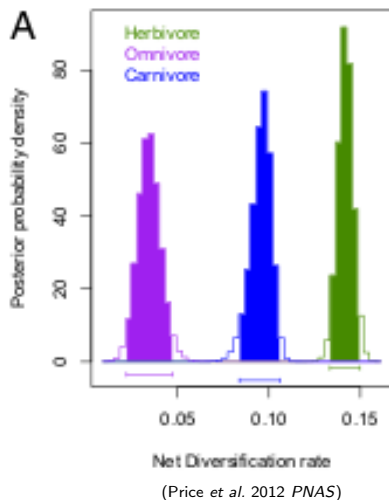
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Ecological traits

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

Predictions: dietary category

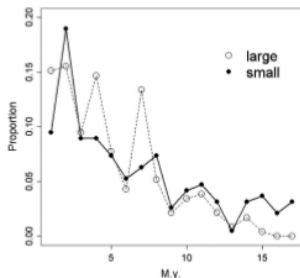


- ▶ trophic hierarchy (stability \rightarrow duration)
 - ▶ herb: most stable, longest duration
 - ▶ carni: least stable, shortest duration
 - ▶ omni: avg. stability, avg. duration
- ▶ \uparrow diversification
 - ▶ \uparrow origination; \simeq extinction
 - ▶ \simeq origination; \downarrow extinction

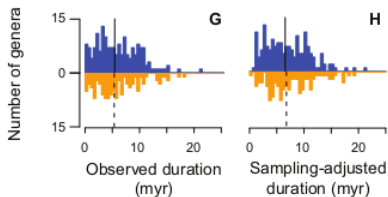
Predictions: locomotor category

- ▶ Paleogene → Neogene
 - ▶ open → closed environment

Predictions: body size



(Liow et al. 2008 *PNAS*)



(Tomiya 2013 *Am. Nat.*)

- ▶ \uparrow body size, \uparrow energy req,
 \uparrow range size, \downarrow extinction
- ▶ Europe
 - ▶ lrg body size genera:
 \uparrow extinction
- ▶ North America
 - ▶ generic body size:
 \simeq extinction

Methodology

Biases to survival: a simulation study

- ▶ bias away from $h(t) = \lambda$
 - ▶ species:genus
 - ▶ anagenesis/cryptic speciation
- ▶ time-homogeneous birth-death model
 - ▶ common phylogenetic model
 - ▶ constant p, b
 - ▶ expected $S(t) = \exp^{-\lambda t}$
 - ▶ vary (cryptic) anagenesis

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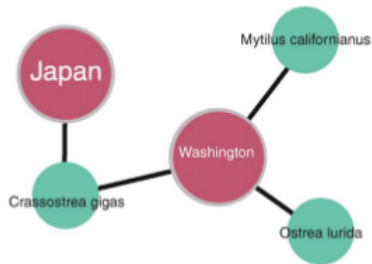
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Community connectedness in Cenozoic mammals

Definition

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

Biogeographic networks



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

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

Average relative number of endemics

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

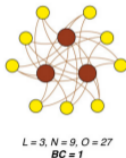
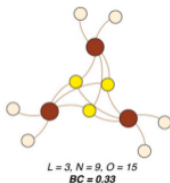
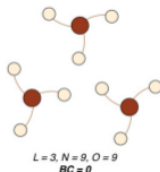
- ▶ L : number of localities
- ▶ u : number of taxa unique to a locality
- ▶ n : number of taxa at a locality
- ▶ $0 \leq E \leq 1$

Average relative occupancy per taxon

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

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

Biogeographic connectedness

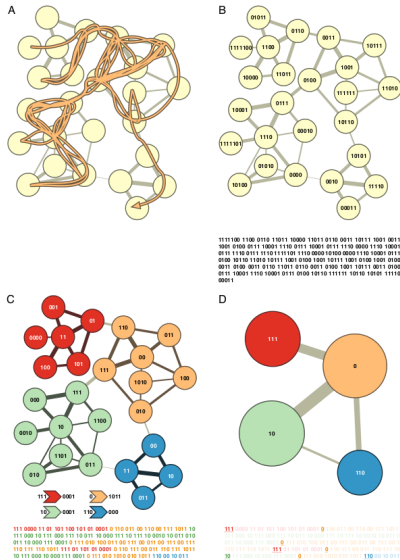


(Sidor et al. 2013 *PNAS*)

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

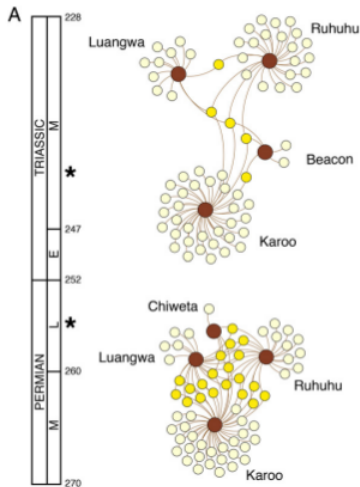
- ▶ O : number of occurrences
- ▶ N : total number of taxa
- ▶ L : number of localities
- ▶ $0 \leq BC \leq 1$

Code length



(Rosvall and Bergstrom 2008 *PNAS*)

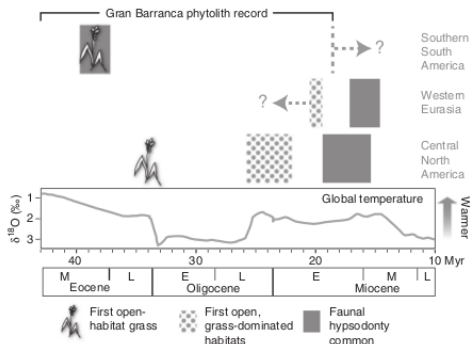
Global versus regional versus local scale processes



(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

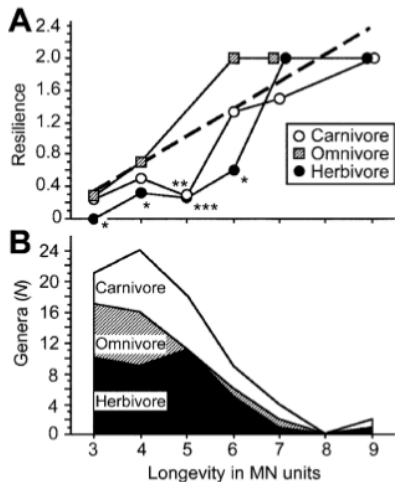
Expectations: locomotor category



(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.*)

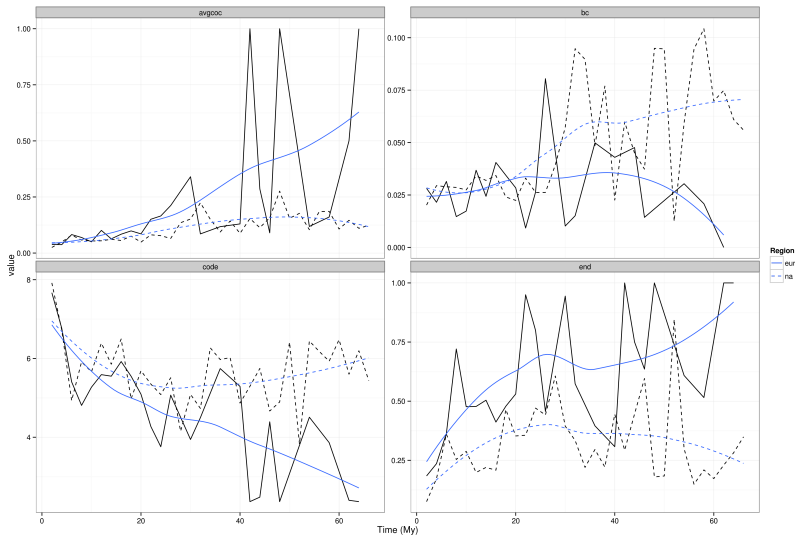
- ▶ herbivore
 - ▶ most like all taxa
- ▶ carnivore
 - ▶ constant \vee corr w/
herbivores
- ▶ omnivore
 - ▶ constant \vee random

Community connectedness of North America

Community connectedness of Europe

Community connectedness of South America

Preliminary results: NA, Eur



Preliminary results: locomotor category

Preliminary results: dietary category

Questions

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- ▶ How is emergence “formed?” When should it be invoked?
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Summary of proposed research

Studies

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

Acknowledgements

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The **Field**
Museum