

Macroevolution: Introduction and Preliminary Concepts

Course Particulars

Class: Tuesday/Thursday: 2:10 – 3:30, 203 Bessey Hall

Office Hours: By appointment

Course Format: This course is a combination of lecture, discussion, and computer practicals

Goal: learn concepts; then apply them in research

Weeks 1-7: macroevolutionary theory (lecture and discussion)

Weeks 8-15: methods application (lecture and computer exercises)

Course Materials

Website: Most information found on the course website:

<https://eeob-macroevolution.github.io>

Canvas: Used for submitting materials (and for content that cannot be shared publicly)

Readings: Links on website (some on Canvas as noted)

Lectures: Posted on website

Practicals: Links from website

Course Goals

- Understand patterns of diversity in the fossil record, and changes in that diversity over time
- Understand macroevolutionary patterns and processes, and the difference between gradualism, stasis, and punctuated equilibrium
- Become familiar with ‘tree thinking’, and understand the principles of using a phylogenetic perspective to address evolutionary questions in biology
- Gain experience in applying cutting-edge phylogenetic methods for testing hypotheses in macroevolution

How will grades be assigned?

Midterm: 20%

Participation: 40%

-*Undergraduates*: Submit 1 question per discussion, participate in discussion

-*Graduate students*: actively participate and assist in leading discussions

-All students will participate in the computational exercises and submit (via Canvas) responses to the synthesis questions provided with each exercise

Project and Presentation: 40%

-Design project, conduct analyses, give 10-minute presentation on project the last week of class

Introduction to Macroevolution

Explaining Biodiversity

Biologists observe wondrous diversity in taxa and traits



C. Kelly



Butterflyworld.com



Wikimedia commons



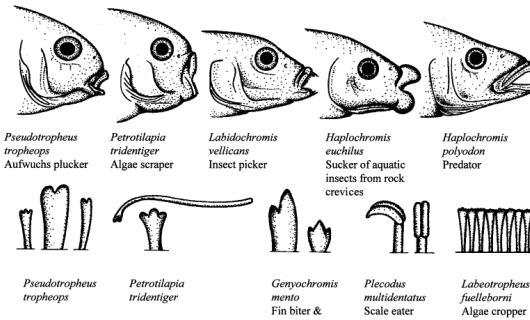
itsnature.org



www.mnh.si.edu



animals.nationalgeographic.com



Fryer and Iles 1972



Freed et al. 1987



dbs.umt.edu/research_labs/fishmanlab

How can we explain the evolution of this diversity?

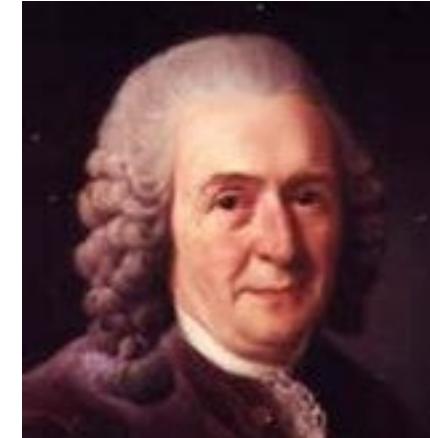
History of Biological Thought

Prior to 1859:

- Biological diversity understood via **Aristotelian essentialism**
- Species were considered eternal, immutable, and discrete
- ‘Essential’ morphological traits used to describe species
- Observed variation among individuals treated as aberrations around a **type** (idealized) form for the species
- Combined with Linnaean hierarchy (1700’s), this approach generated species classifications and taxonomy, used to categorize and understand biodiversity



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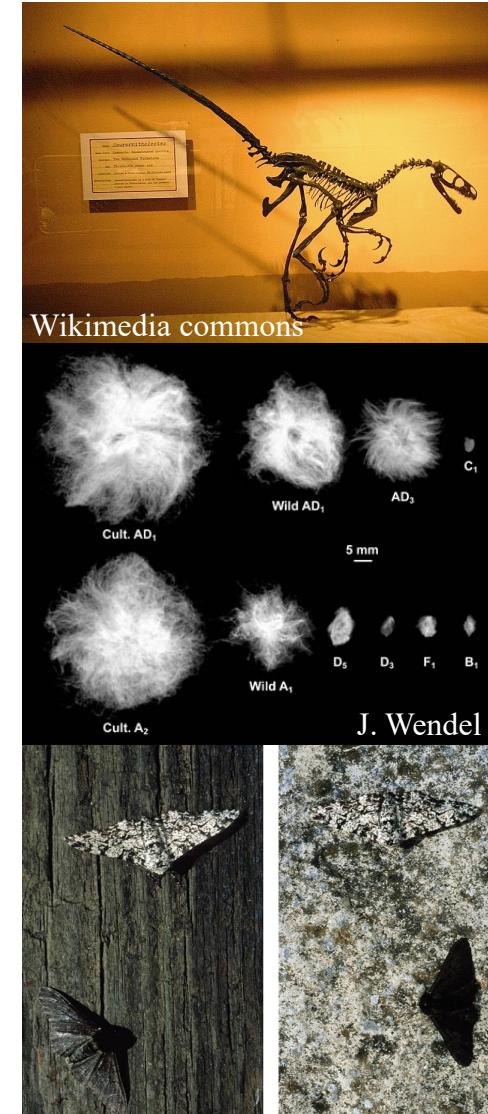
Shift Biological Thought

Radical shift in thinking during 19th century

As the science of biology progressed, it was discovered that:

- Species were not eternal (fossils discovered)
- Species were not immutable (plant/animal breeding = artificial selection)
- Variation in nature is common and seemed important for survival (not aberrations)

These observations required a re-evaluation of the tenets of biological thought



from Futuyma & Kirkpatrick (2017)

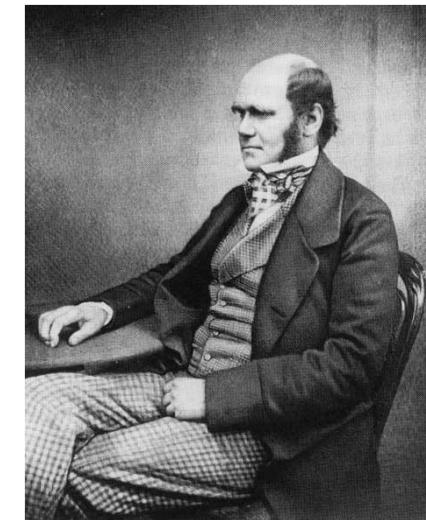
Darwinian Evolution

Darwin proposed mechanism that explained these observations: **Evolution by natural selection**

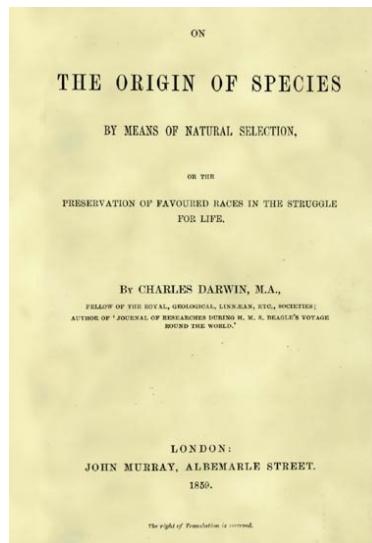
-Evolution by natural selection:

- Changes the variation of traits within populations across generations (evolution = change through time)

-Can drive change between populations (population divergence, which can lead to speciation)



Wikimedia commons



NOTE: Natural selection was Darwin's first big idea in the *Origin*; the second was Descent with Modification, which initiated 'tree thinking' and later phylogenetics

Wikimedia Commons

Evolution by Natural Selection

Evolution by natural selection

-Several simple requirements:

- More individuals are born each generation than can survive
- Individuals within a population vary in their traits
- Some of this variation is **heritable**
- Trait differences are tied to fitness

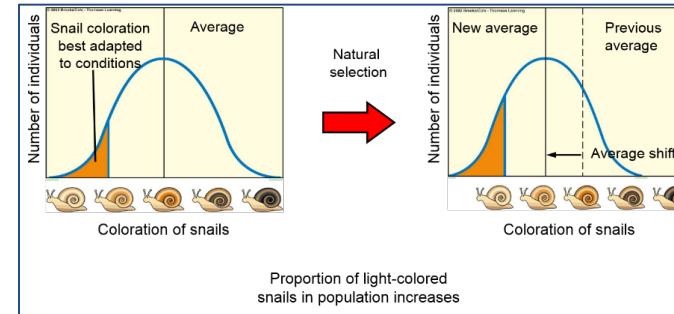
-Individuals with the most favorable trait values have a better chance of surviving and reproducing: they are ‘naturally selected’

-Natural selection is one of the major mechanisms of **microevolution** (evolutionary change within species and populations)

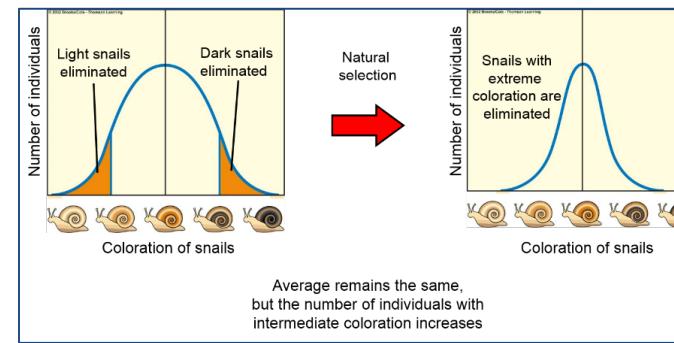
Common Patterns of Natural Selection

Across generations, natural selection changes trait distributions (as well as the frequencies of the genes encoding them)

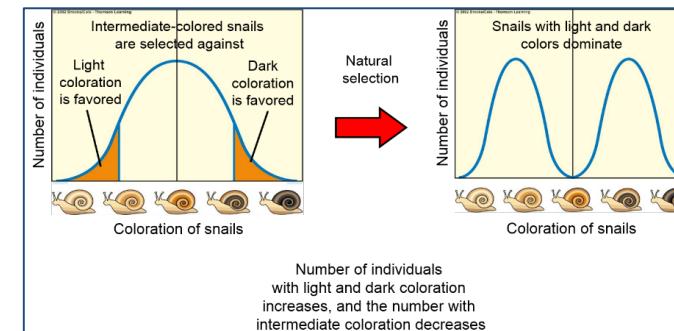
Directional selection:
phenotypic shifts in a particular direction



Stabilizing selection:
intermediate phenotypes selected



Diversifying selection:
extreme phenotypes selected



Consequences of Natural Selection

Across generations, traits change due to natural selection: a process that can lead to adaptations

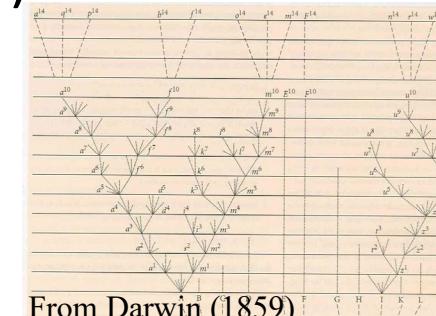
-Selective change over time is called descent with modification

-Darwin argued that this process could generate discontinuities resulting in new species

-Insights emerging from descent with modification:

- Species share traits due to common ancestry, so similarities in structure imply evolutionary relationships
- This similarity implies a tree of life describing the relationships among species (evolutionary tree = phylogeny)

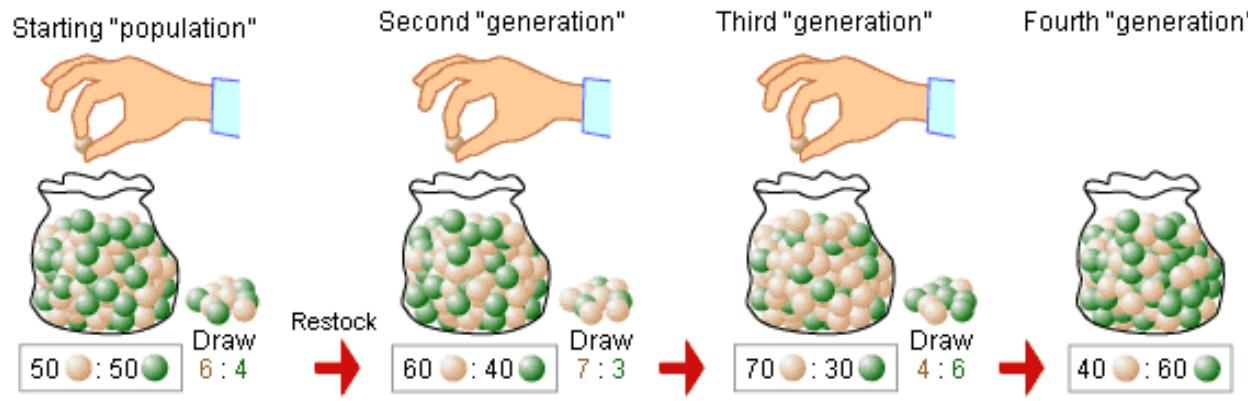
- Descent with modification leads to tree thinking!



Random Genetic Drift

Microevolution also occurs via Genetic Drift, the random sampling of organisms

-The effects of drift are most evident in smaller populations



<https://evolution.berkeley.edu/>

IMPORTANT MICROEVOLUTIONARY DISTINCTION

- Natural selection is differential survival &/or reproduction of genotypes based on the phenotypes being selected
- Genetic drift is differential survival &/or reproduction of genotypes and phenotypes unrelated to selection

Back to Biodiversity

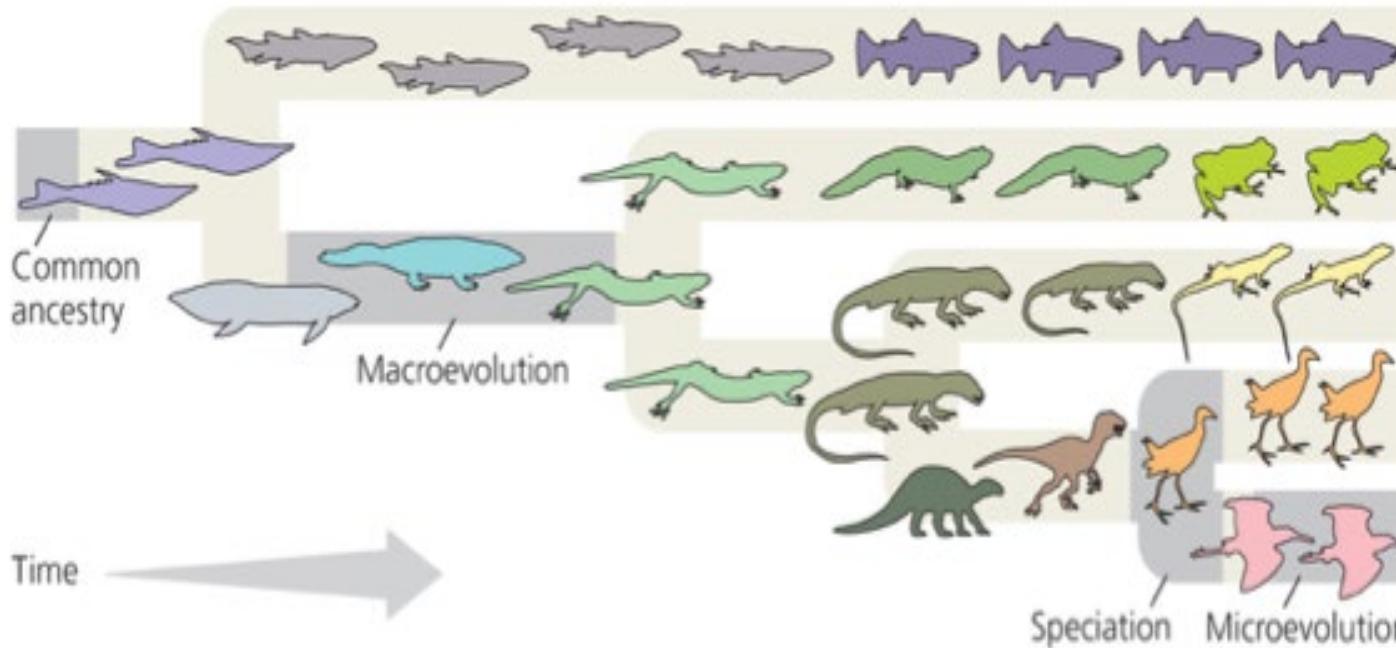
How does microevolution help us explain biodiversity?

-Descent with modification and *LOTS* of time

-Species change over time (microevolution)

-Lineages split to form new species (speciation)

-New life forms derive from older life forms (macroevolution)

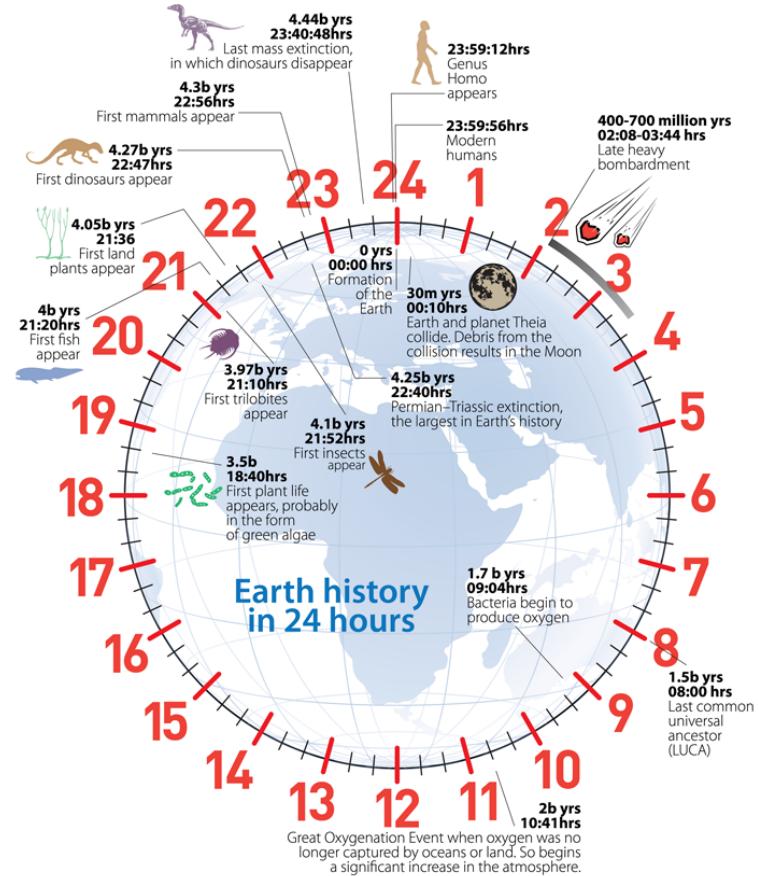
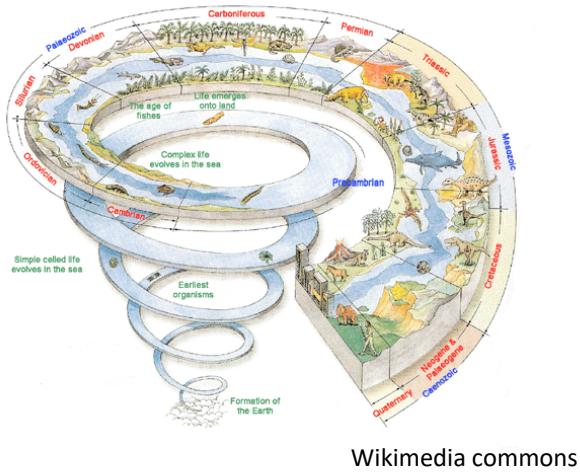
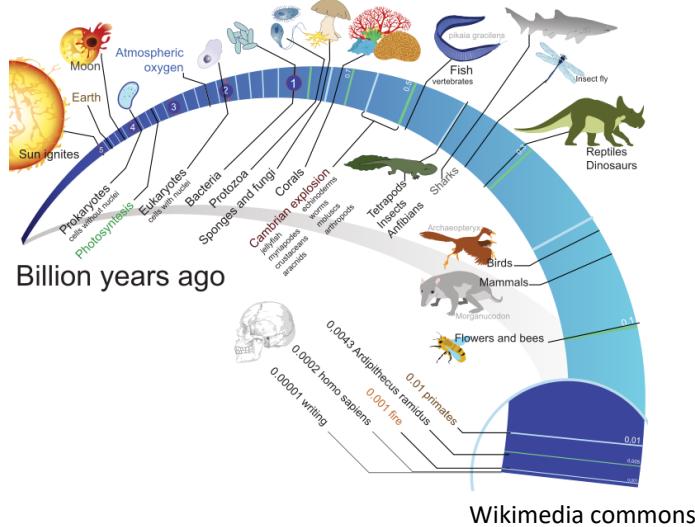


-View espouses that microevolution + time = macroevolution*

*Gould and others have a more nuanced view (see lecture 4)

The Importance of Time

-The earth's history has provided lots of time for evolution



What is macroevolution?

- Evolution above the species level
- Describes patterns and processes in the over-arching history of life

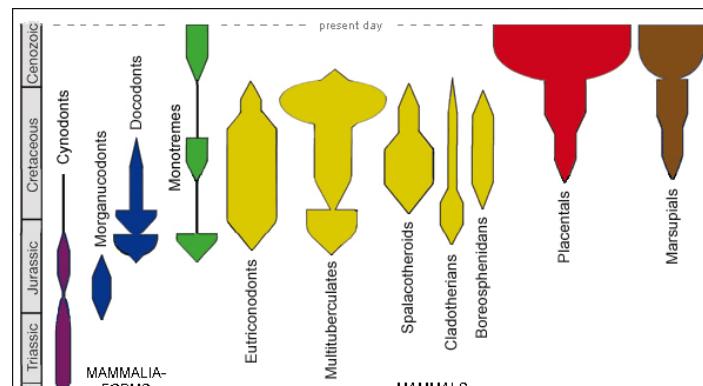
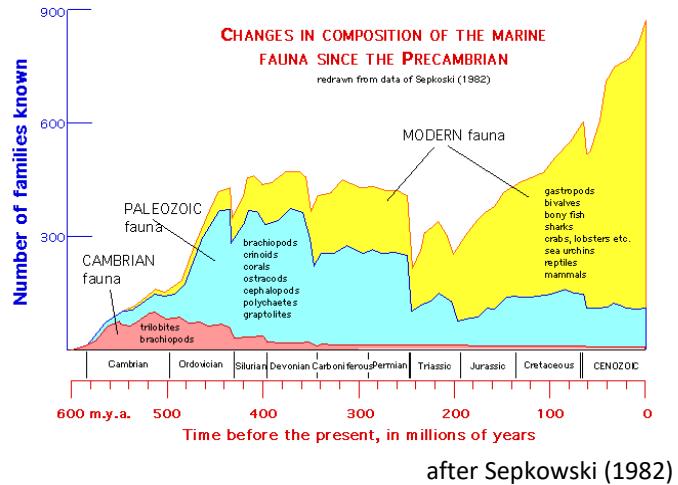
Macroevolution encompasses the study of:

- Deep time patterns of the origins of diversity
- The splitting of lineages (speciation / cladogenesis)
- The changing of lineages (anagenesis)
- Patterns of biodiversity (diversification rates, mass extinctions, etc.)
- Patterns of trait variation (morphological disparity)
- Rates of trait change (gradual, punctuated, early-burst, etc.)
- Modes of trait change (Brownian, Ornstein-Uhlenbeck, etc.)
- Trends of trait change over time and space (Cope's rule, Bergmann's rule, Foster's [island] rule, etc.)

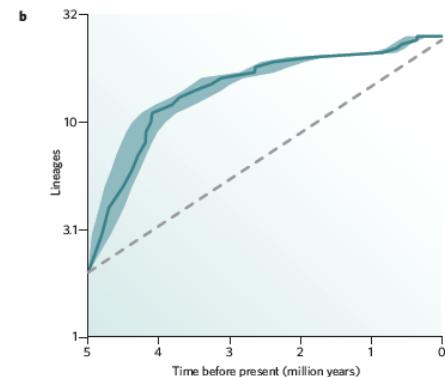
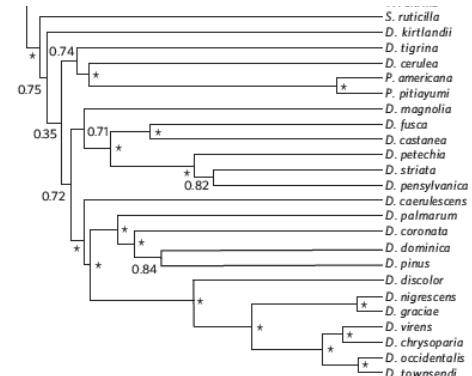
Macroevolution

Macroevolution seeks to understand

1) Changes in biological (taxonomic) diversity through time



Luo (2007)

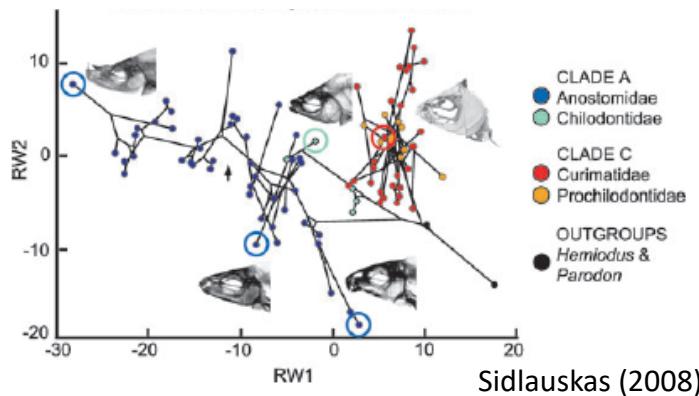


Reznick and Ricklefs 2009

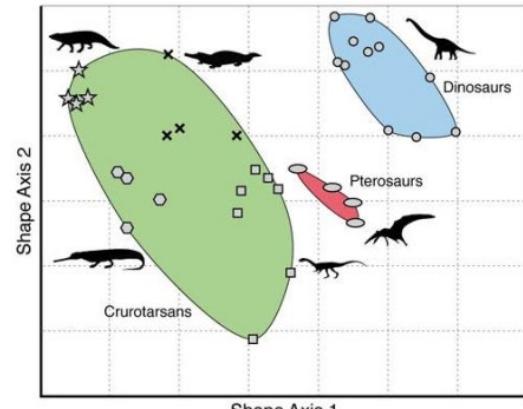
Macroevolution

Macroevolution seeks to understand

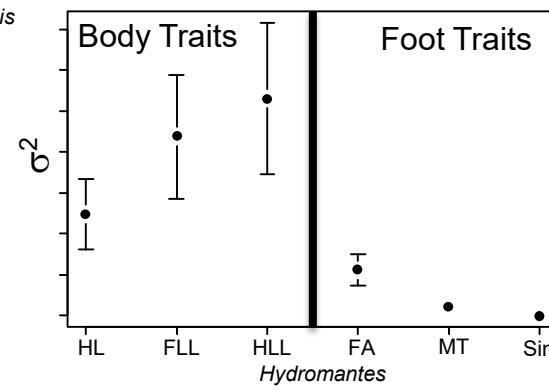
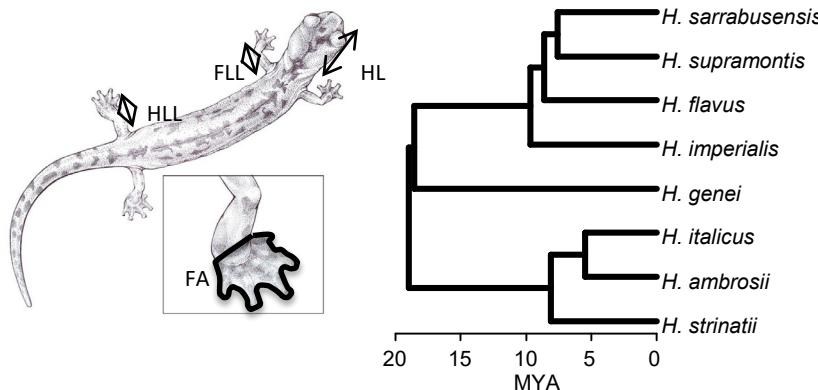
2) Changes in phenotypic diversity through time



Sidlauskas (2008)



Brussatte et al. (2008)



Adams et al. (2017)

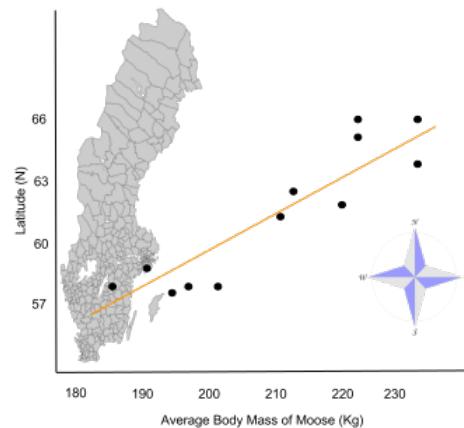
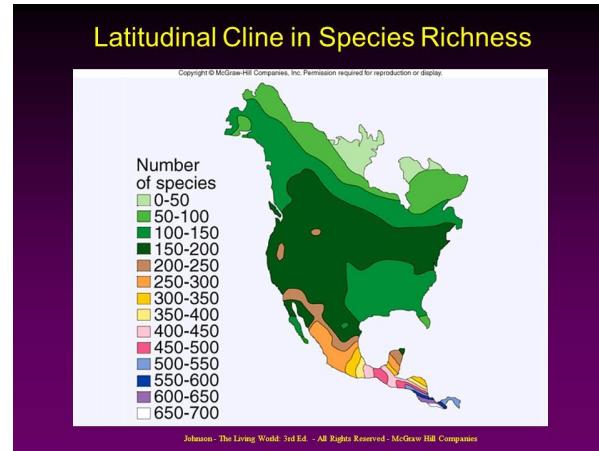
Macroevolution

Macroevolution seeks to understand

3) Changes in biological/phenotypic diversity over space



Great American Biodiversity Interchange
Marshall (1988)



How do we study macroevolution?

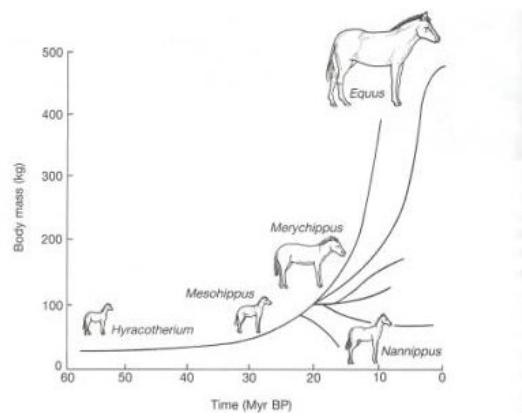
-Paleontological observations + hypotheses



komando.com



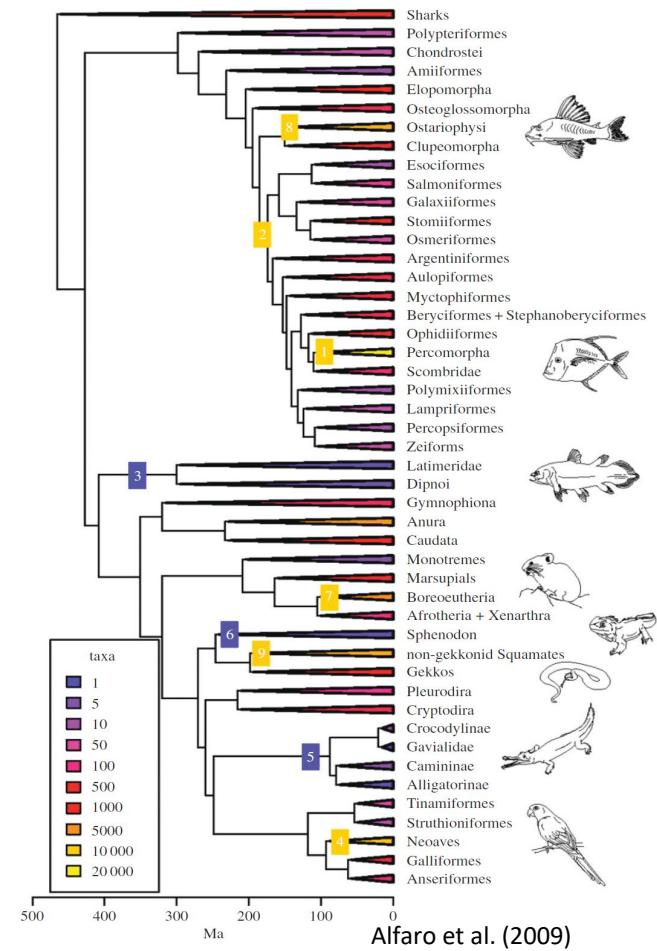
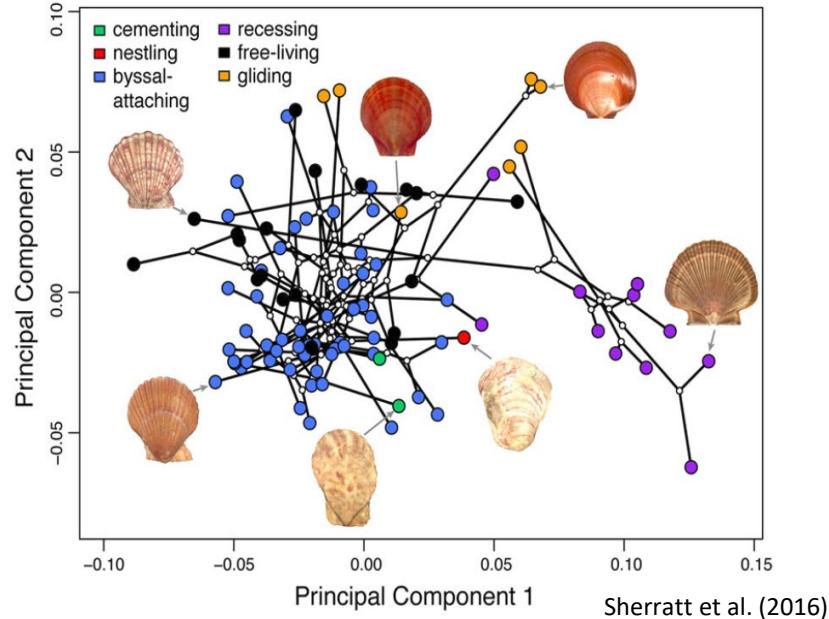
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McFadden (1988b)

How do we study macroevolution?

-Neontological observations + hypotheses

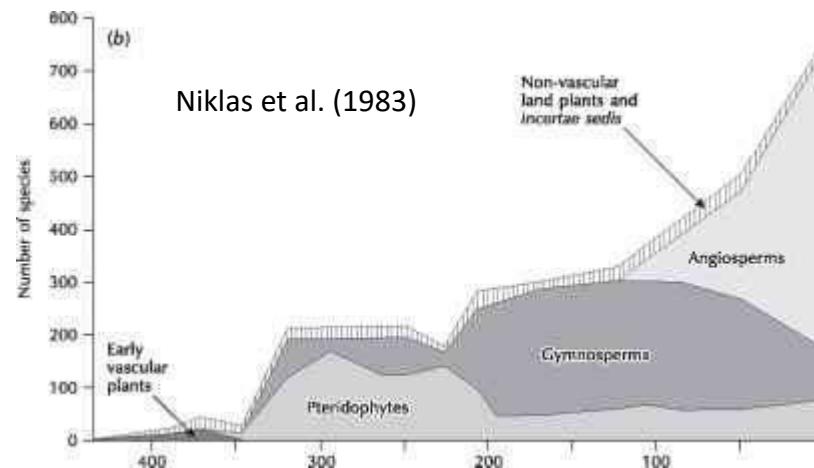
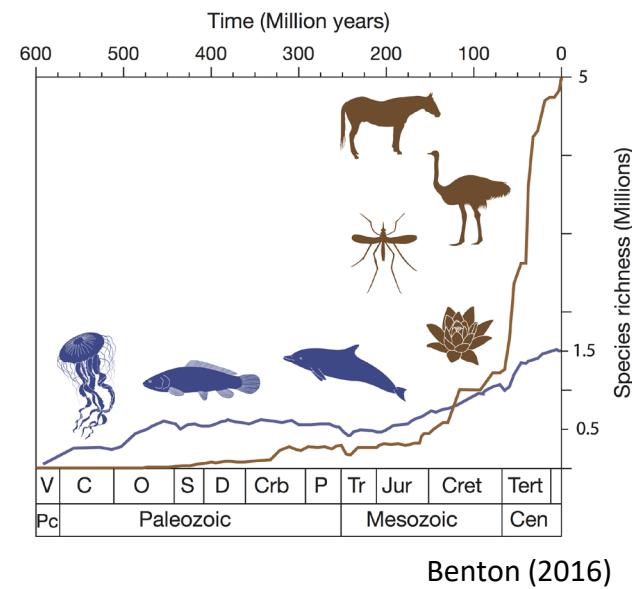
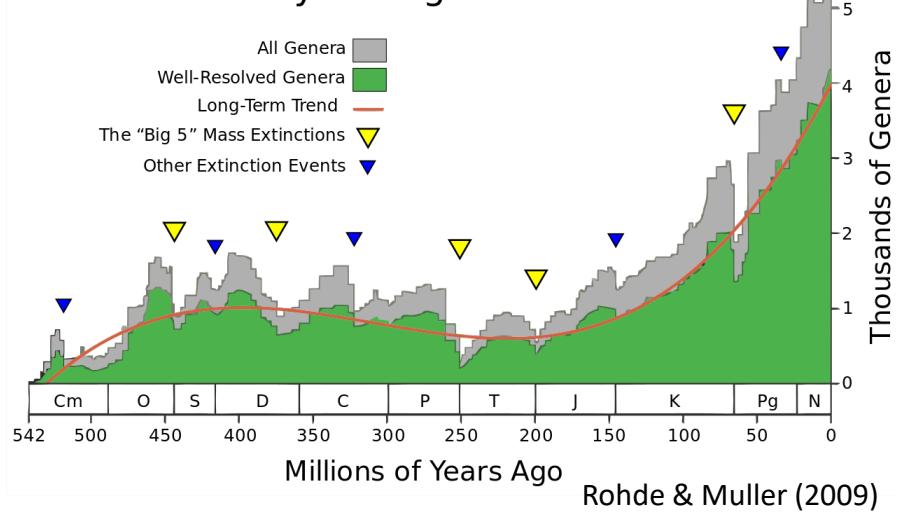


-Modern macroevolution makes extensive use of phylogenies!

Some Macroevolutionary Patterns

Biodiversity accumulation

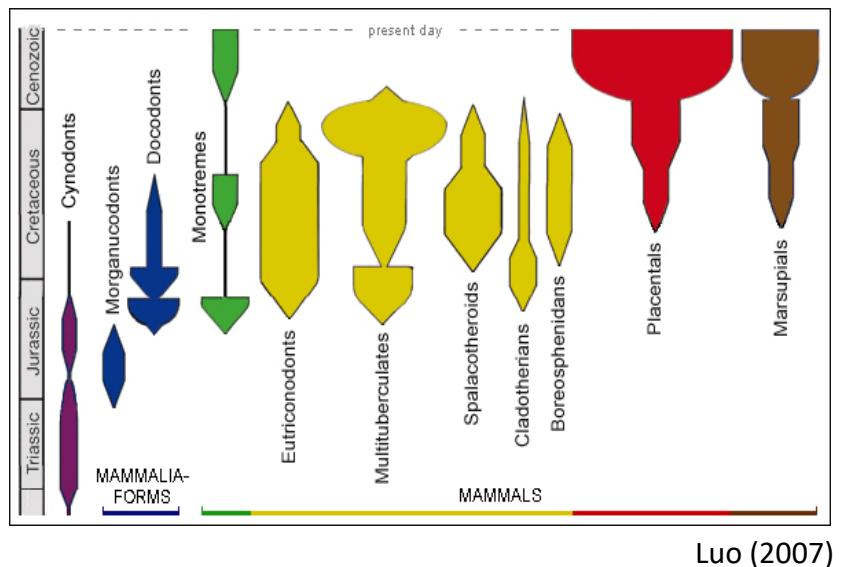
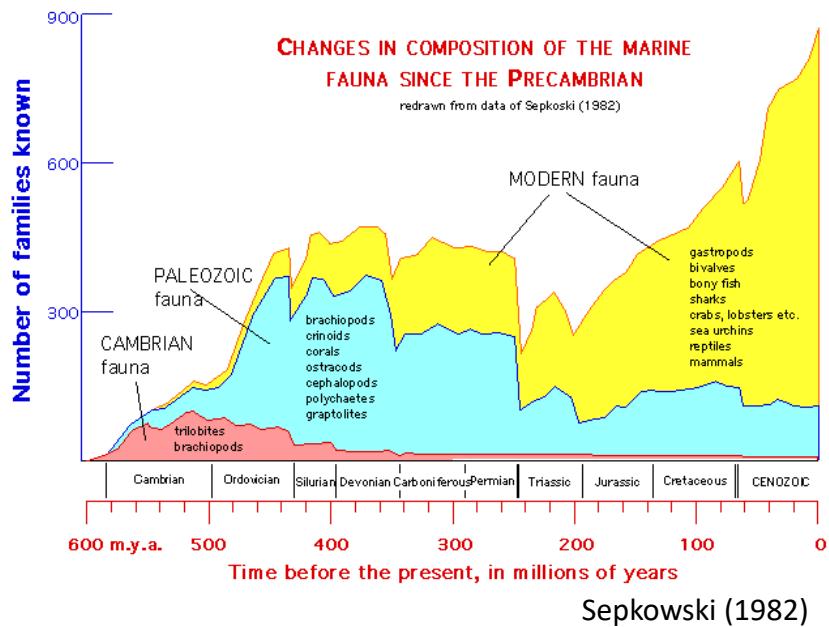
Biodiversity during the Phanerozoic



What processes enhance or limit diversification?

Some Macroevolutionary Patterns

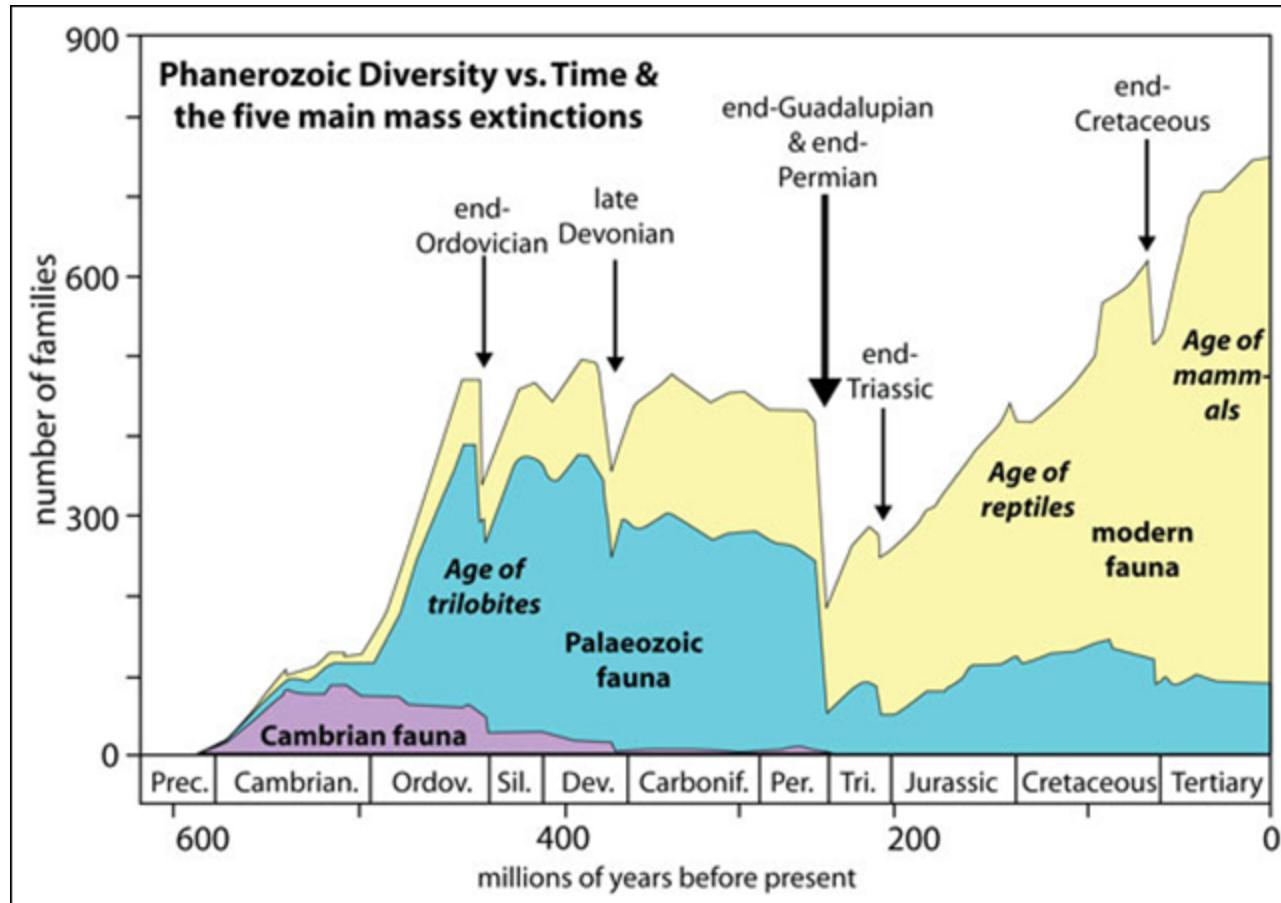
Faunal turnover



Are there distinct biotas at different time periods?

Some Macroevolutionary Patterns

Extinctions and rise of new fauna

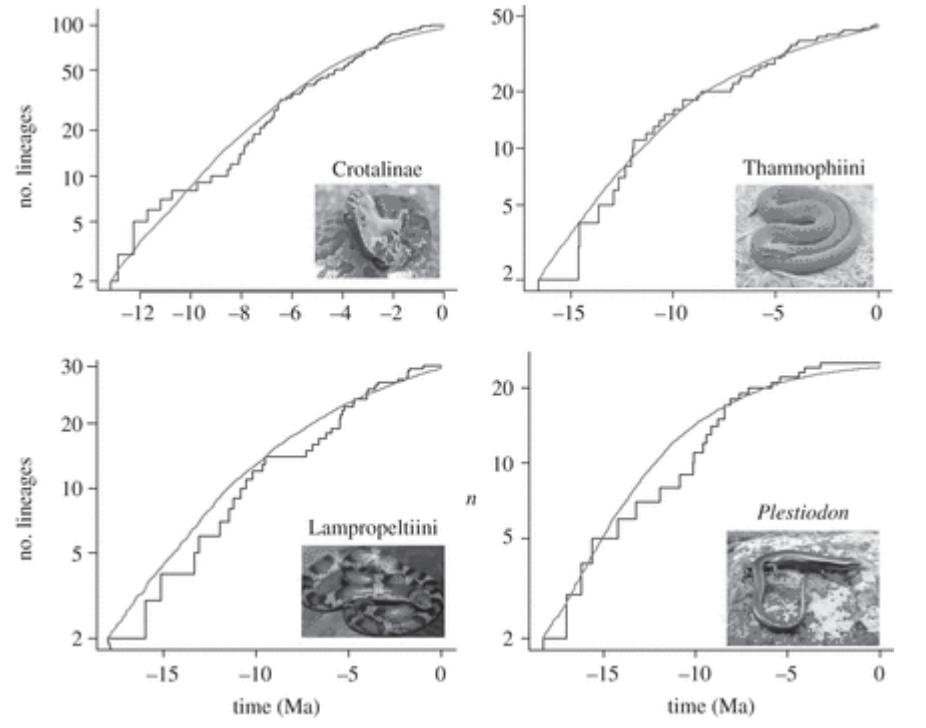
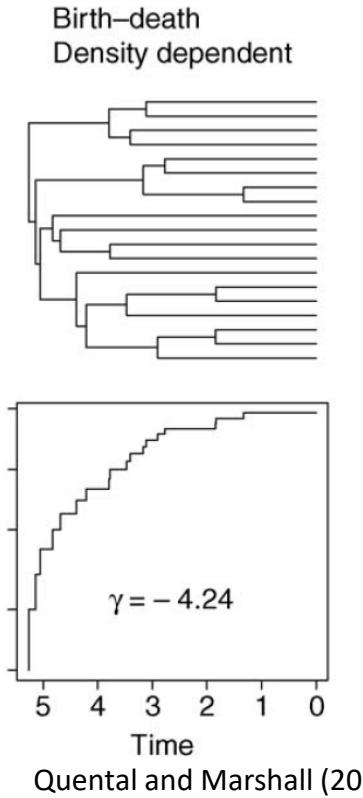


Data from Sepkowski (1982)

What are the causes of mass extinctions?

Some Macroevolutionary Patterns

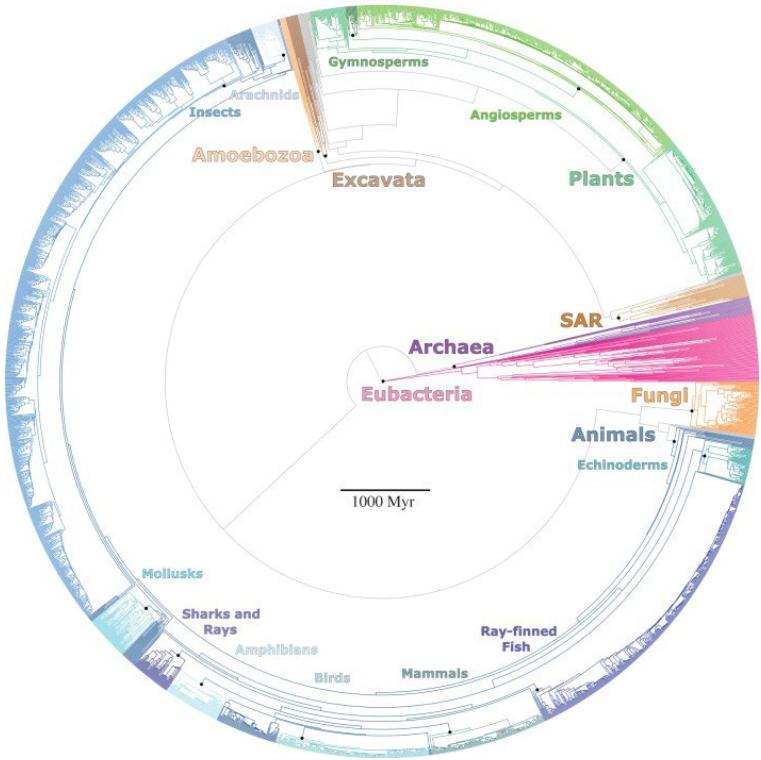
Limits to biodiversity



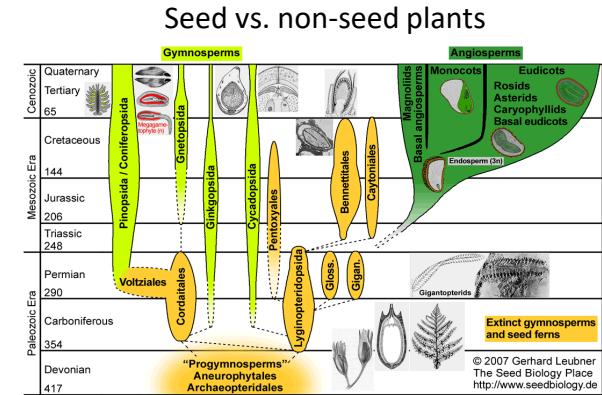
Is diversification density-dependent?

Some Macroevolutionary Patterns

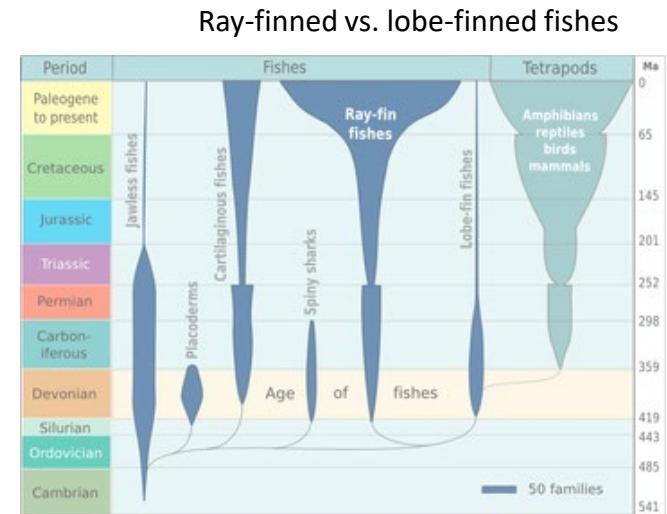
Taxonomic disparity



Scholl and Wiens (2016)



Leubner (2007)

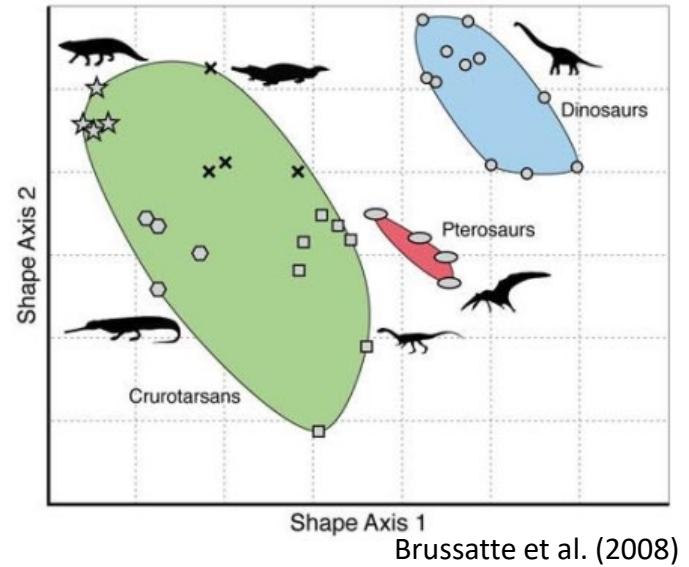
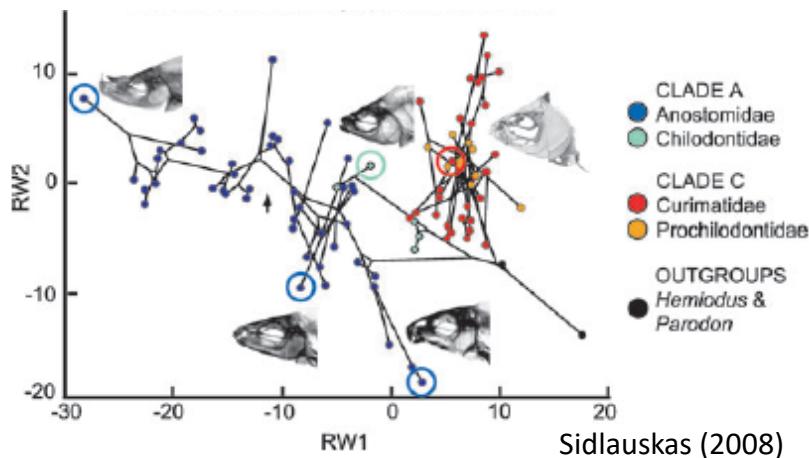


Benton (2005)

Why are some clades taxonomically diverse and others not?

Some Macroevolutionary Patterns

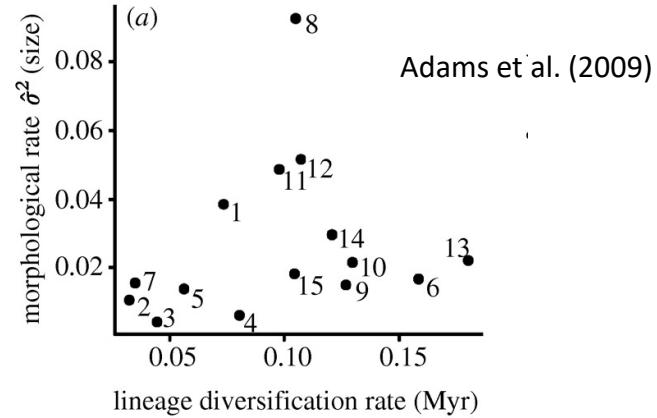
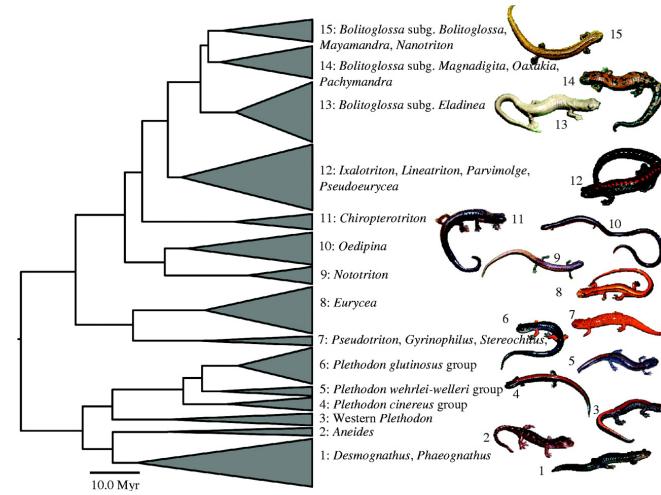
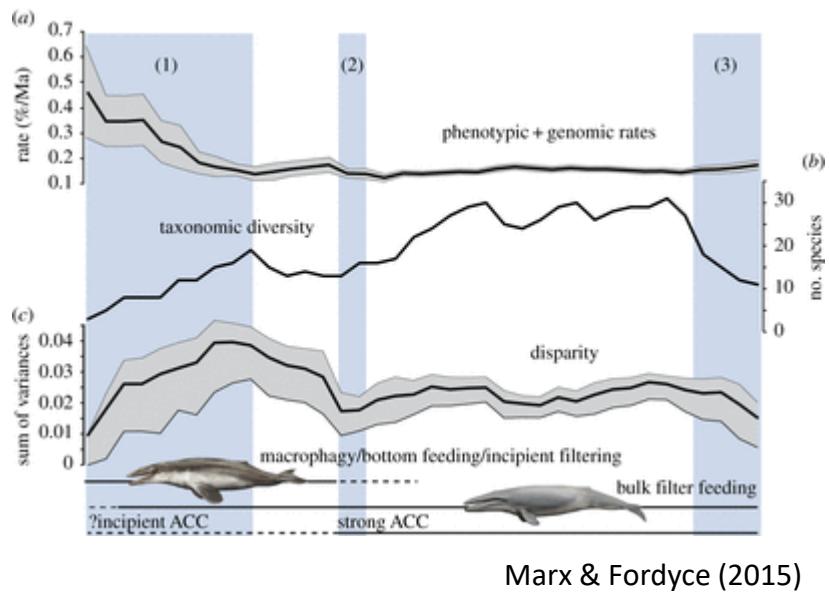
Morphological disparity



Why are some clades more morphologically disparate than others?

Some Macroevolutionary Patterns

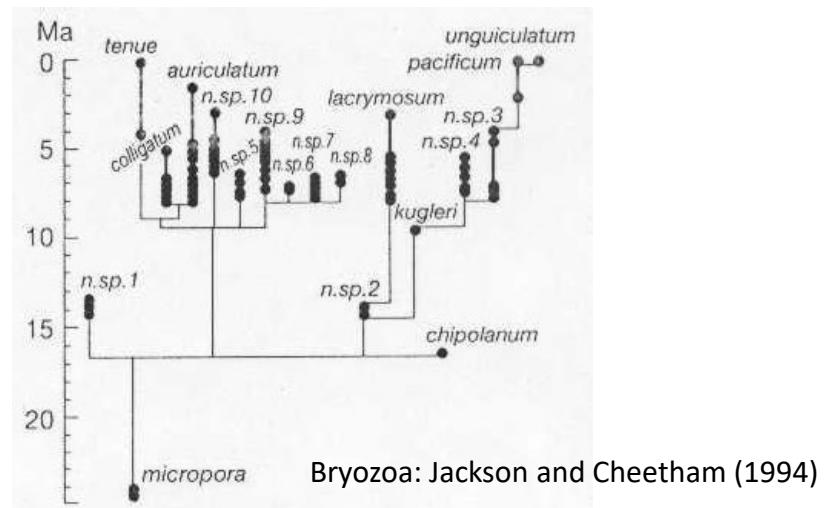
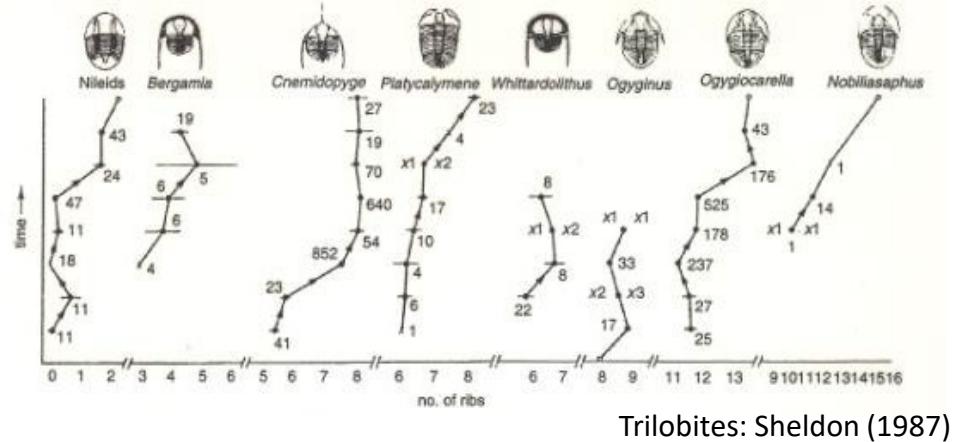
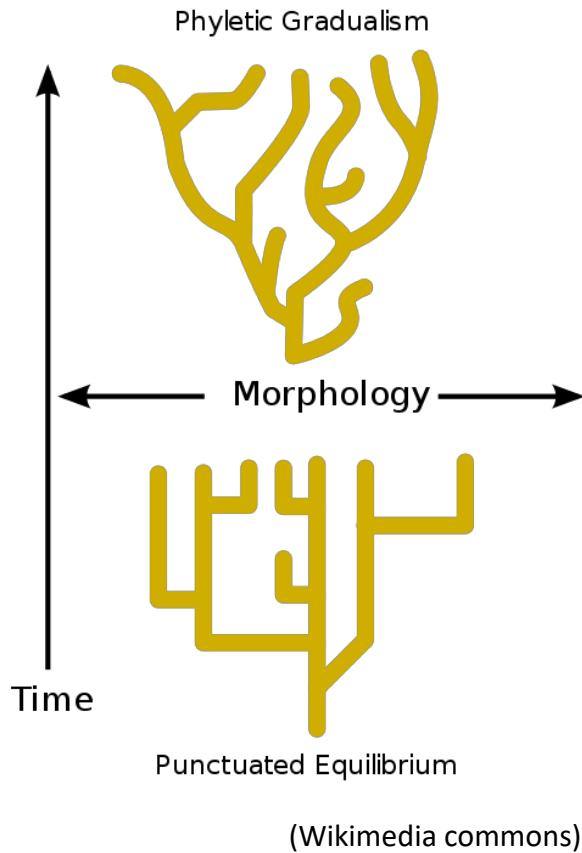
Taxonomic diversity and morphological disparity



Are diversity and disparity coupled or decoupled?

Some Macroevolutionary Patterns

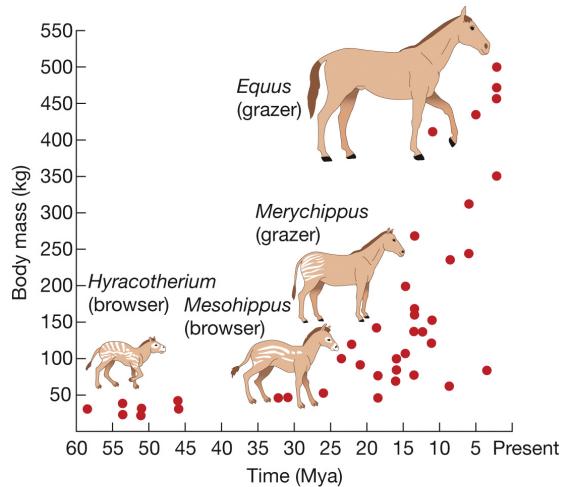
The nature of morphological evolution



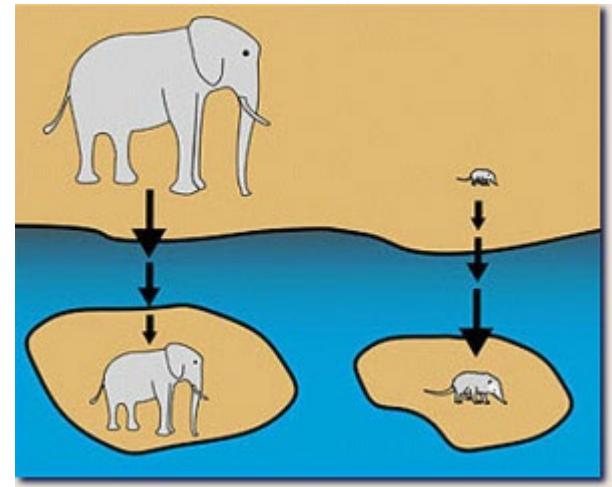
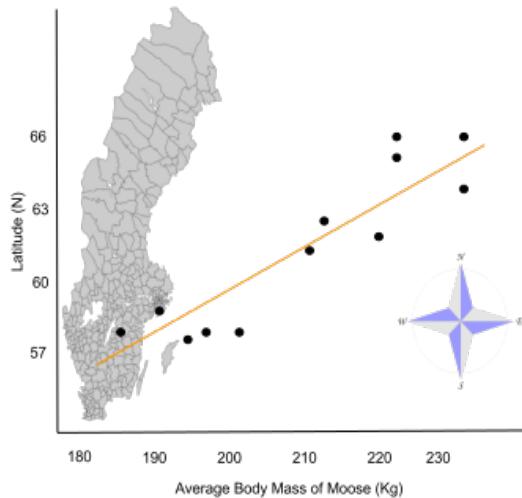
Is morphological evolution gradual or punctuational?

Some Macroevolutionary Patterns

Morphological trends



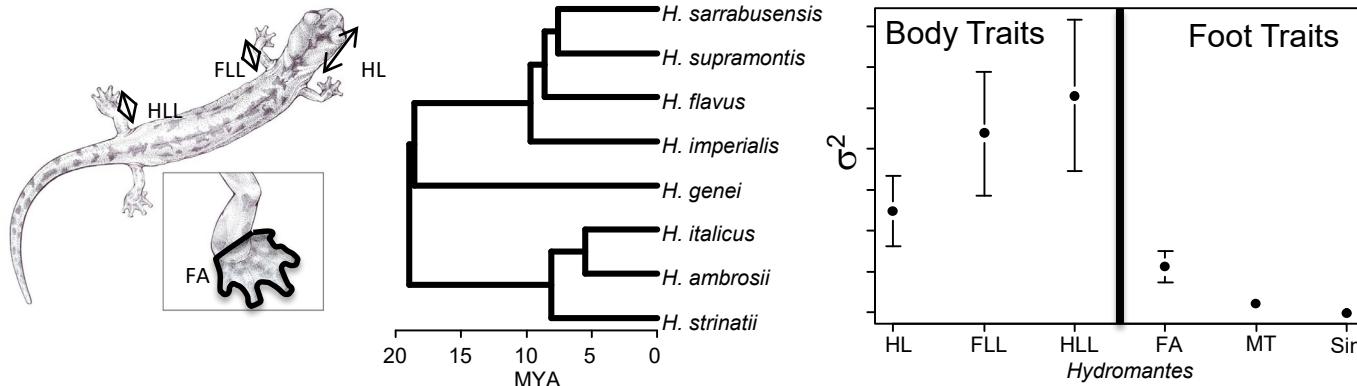
EVOLUTION 4e, Figure 20.13
© 2017 Sinauer Associates, Inc.



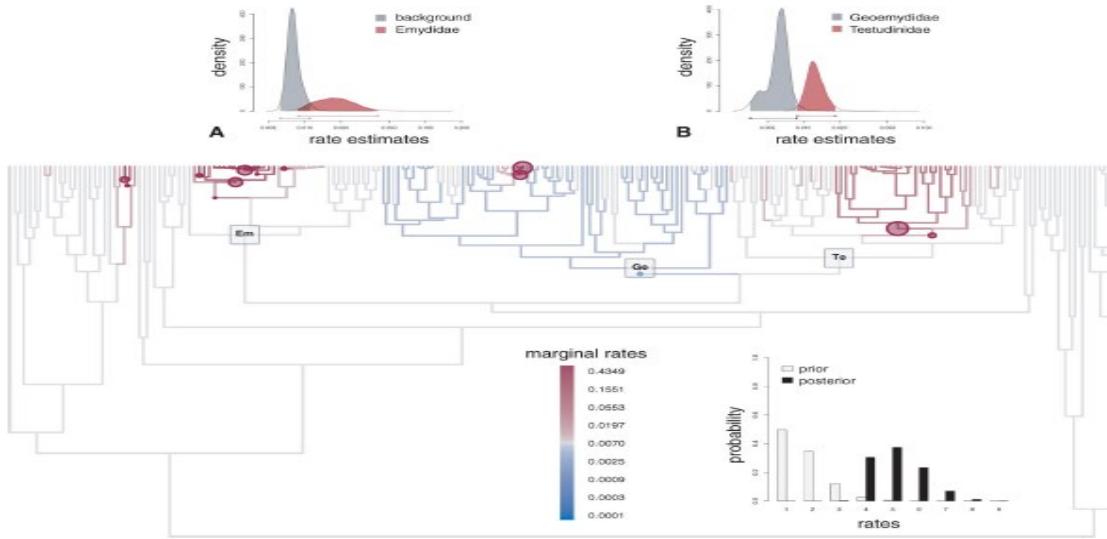
What processes generate phenotypic trends?

Some Macroevolutionary Patterns

The pace of evolution



Adams et al. (2017)

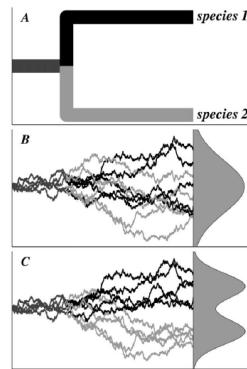
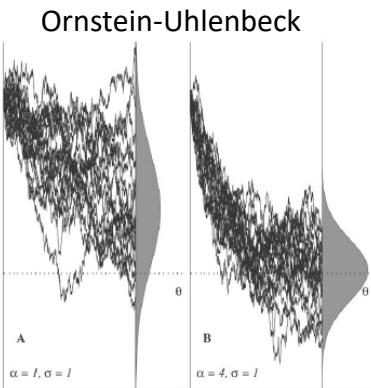
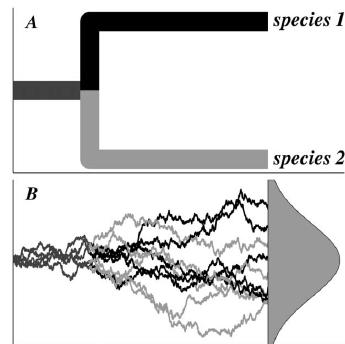
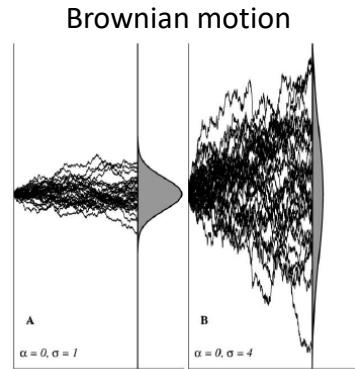


Eastman et al. 2011

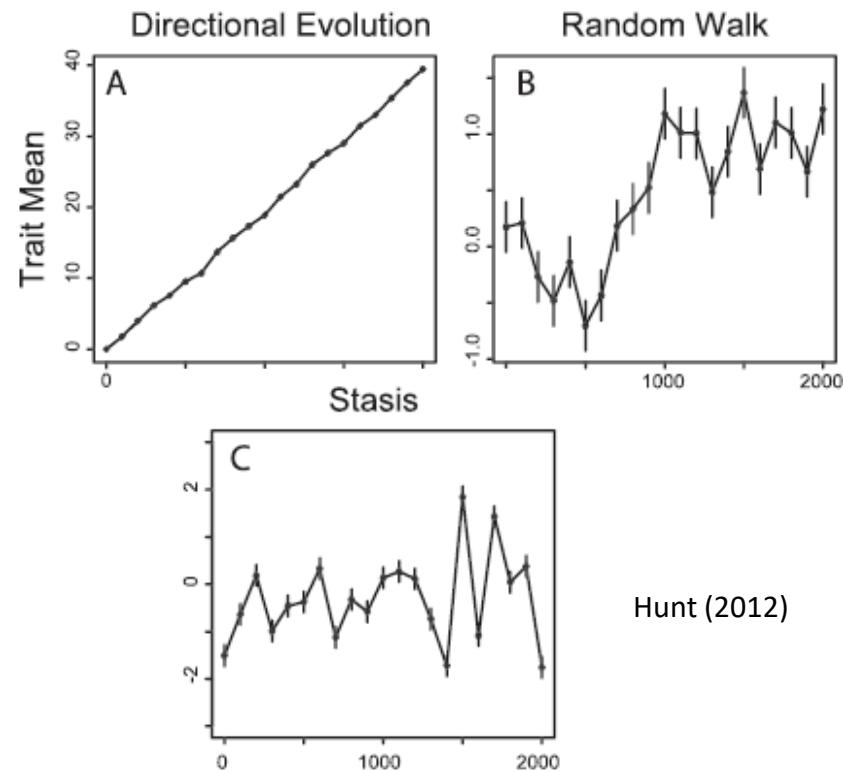
Why is morphological evolution faster in some traits or clades?

Some Macroevolutionary Patterns

The mode of evolution



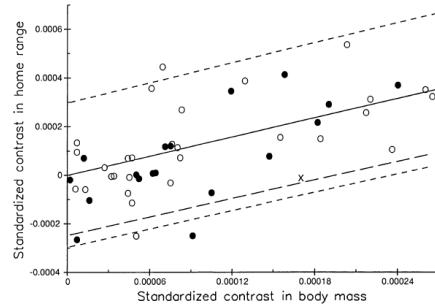
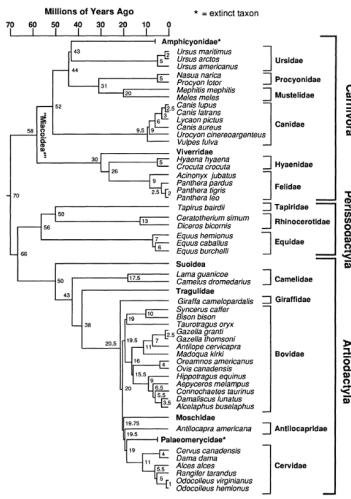
Butler and King (2004)



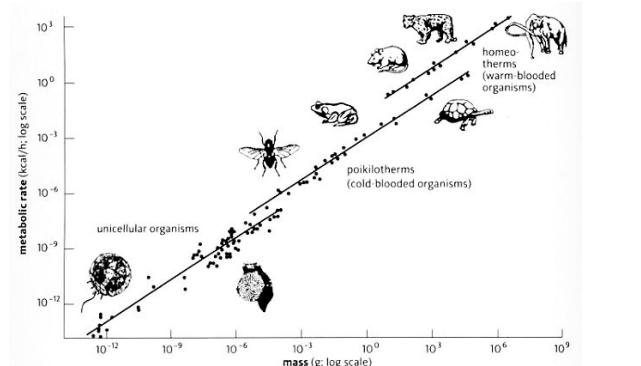
What evolutionary model best describes phenotypic diversification?

Some Macroevolutionary Patterns

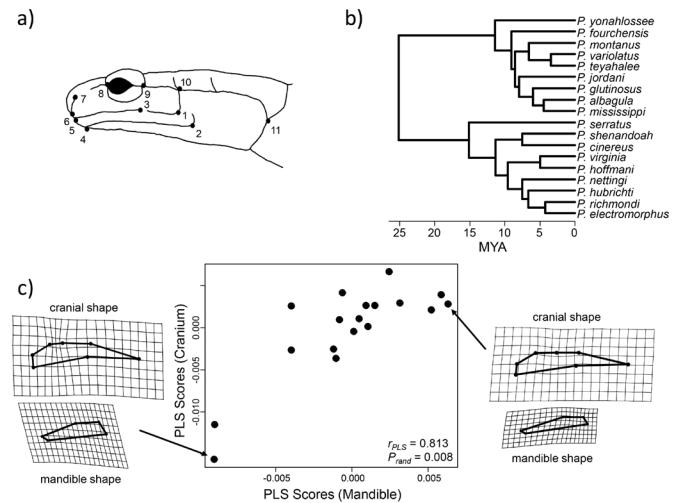
Correlated evolution



Garland et al. (1993)



Hemmingsen, 1960



Adams and Felice (2014)

What processes generate evolutionary covariation among traits?

Key questions in macroevolution

Taxonomic

- How does taxonomic diversity accumulate?
- Is diversification density-dependent?
- What characterizes faunal turnover?
- What are the causes of mass extinctions?
- Why are some clades successful and others not?

Phenotypic

- Why are some clades morphologically more disparate than others?
- Are diversity and disparity coupled over time?
- Is morphological evolution gradual or punctuational?
- What processes generate phenotypic trends?
- Why is morphological evolution faster in some traits and clades?
- What evolutionary model best describes phenotypic diversification?
- What processes generate evolutionary trait covariation?

-Our goal is to learn how to evaluate these questions