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

* see Syllabus for Outcomes and Objectives

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

*See syllabus for additional details

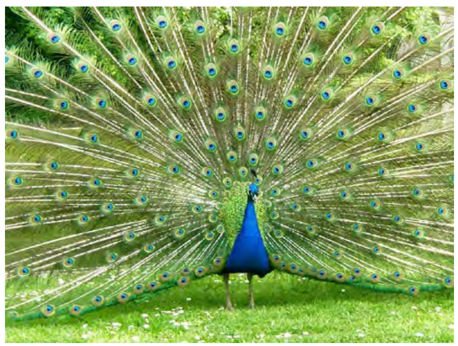
Introduction to Macroevolution

Biologists observe wondrous diversity in taxa and traits

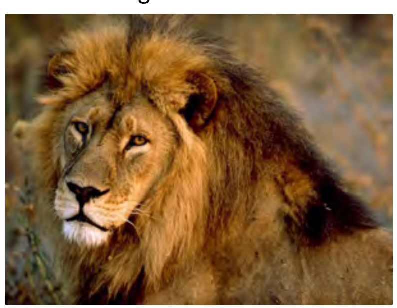

C. Kelly

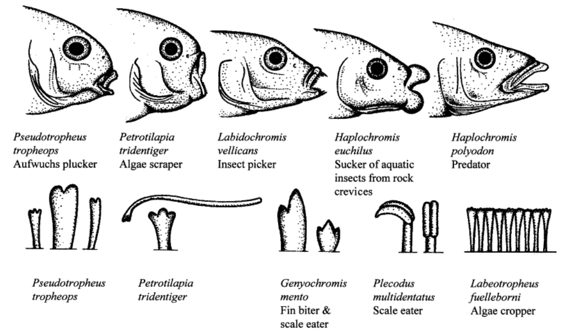

Butterflyworld.com


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 <u>eternal</u>, <u>immutable</u>, and <u>discrete</u>

- '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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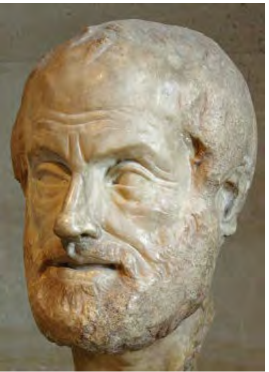

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Radical shift in thinking during 19th century

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

- Species were not eternal (fossils discovered; species went extinct)
- 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


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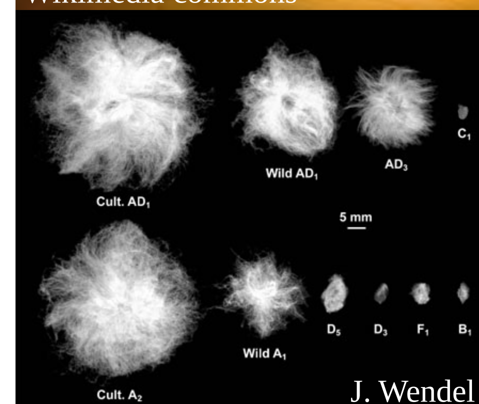
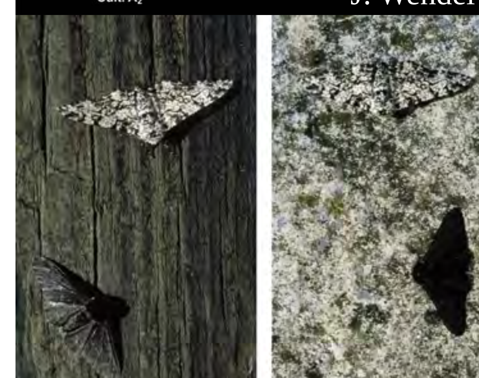


J. Wendel


from Futuyma & Kirkpatrick (2017)

Darwinian Evolution

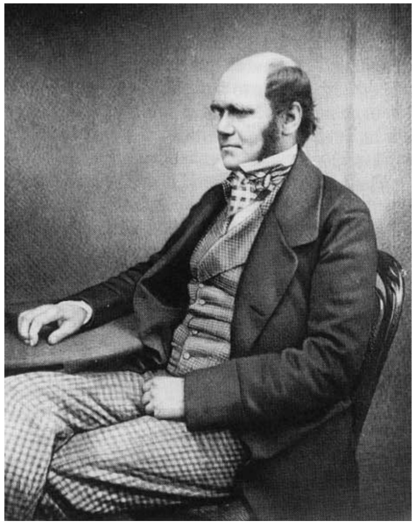
Darwin proposed mechanism that explained these observations: <u>**Evolution by natural selection**</u>

-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)

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



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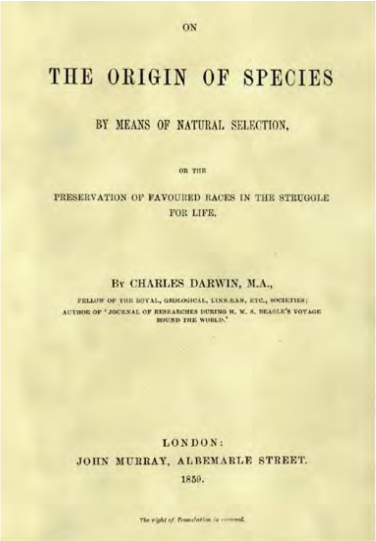


ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

BY CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.

Wikimedia Commons

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

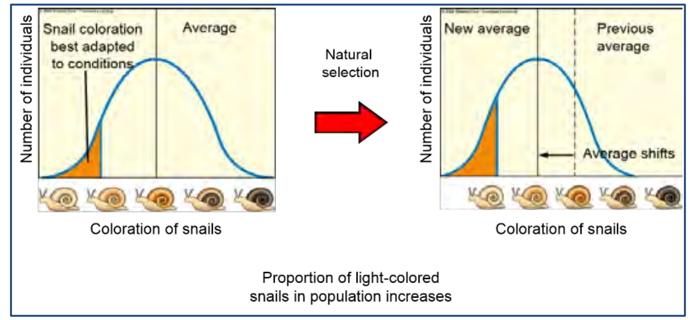
-Individuals with the most favorable trait values have a better chance of surviving and reproducing: they are 'naturally selected'

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

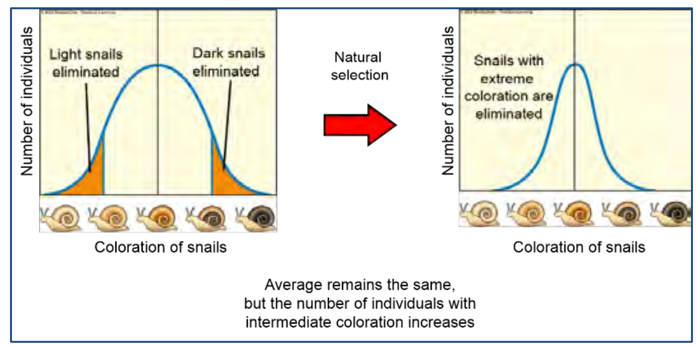
Common Patterns of Natural Selection

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

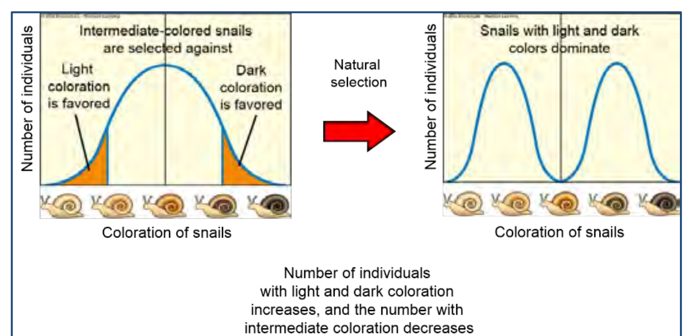
Directional selection: phenotypic shifts in a particular direction



Stabilizing selection: intermediate phenotypes selected



Diversifying selection: extreme phenotypes selected



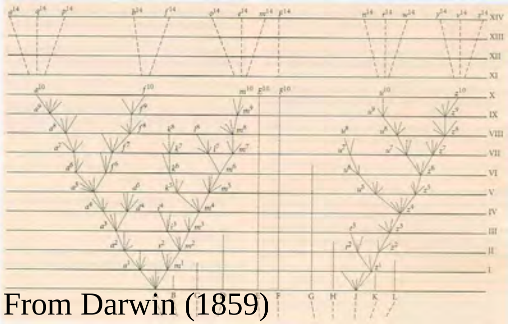
Consequences of Natural Selection

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!

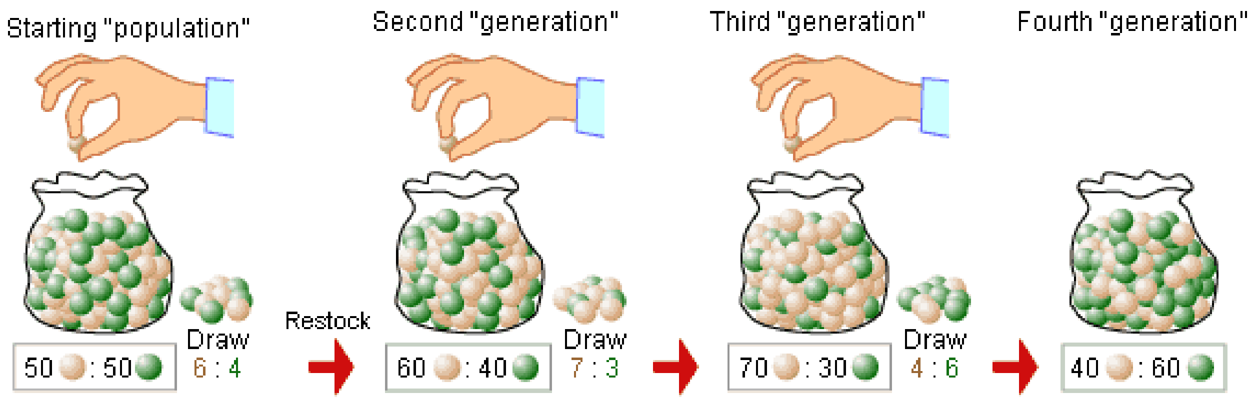


From Darwin (1859)

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

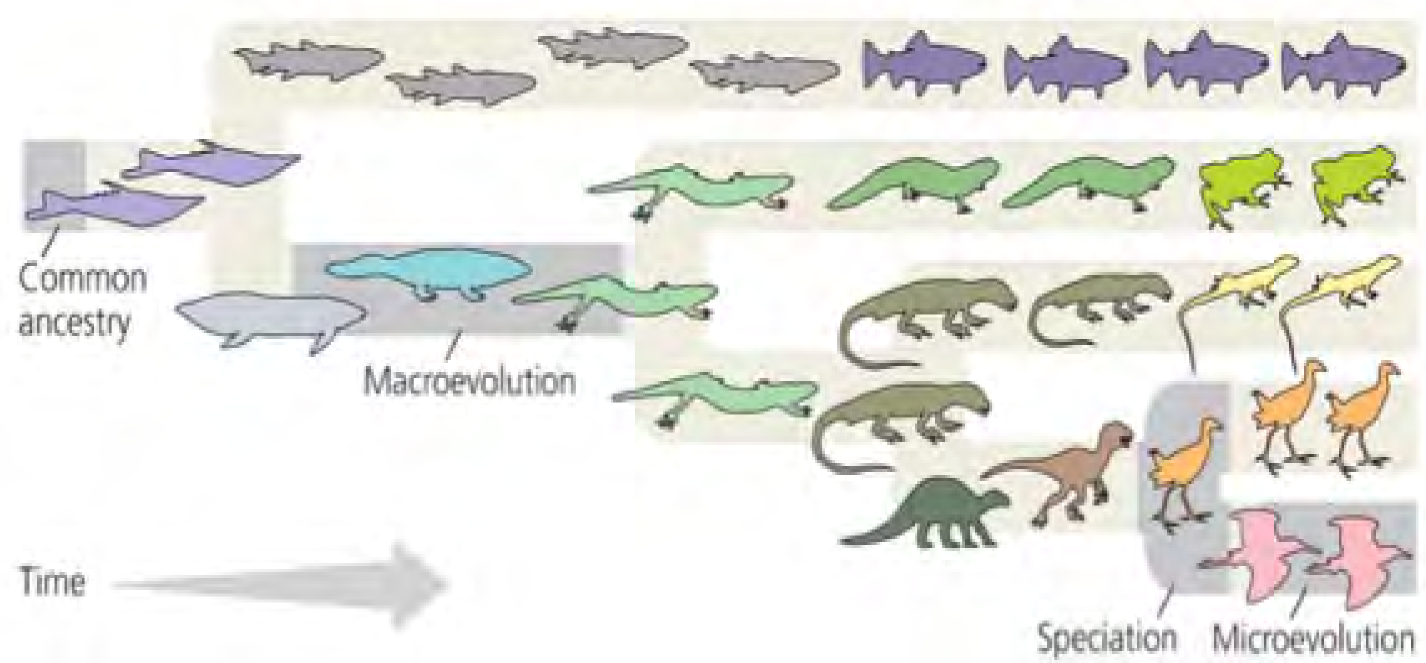
-Genetic drift is differential survival &/or reproduction of genotypes and phenotypes unrelated to selection

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)



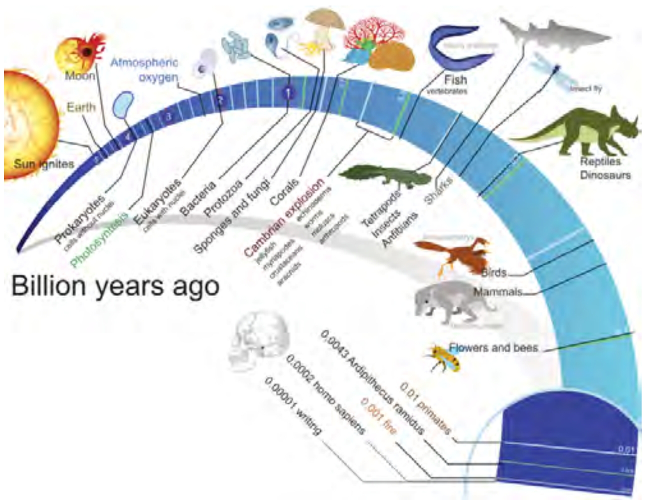
-View espouses that microevolution + time = macroevolution*

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

Image: https://quizlet.com/au/575369299/week-1-macroevolution-flash-cards/

The Importance of Time

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



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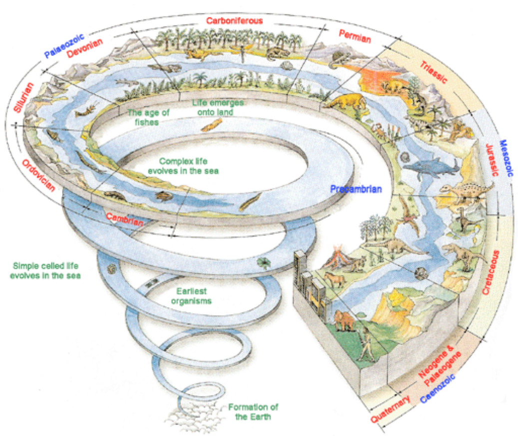

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Macroevolution

What is macroevolution?

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

Macroevolution encompasses the study of:

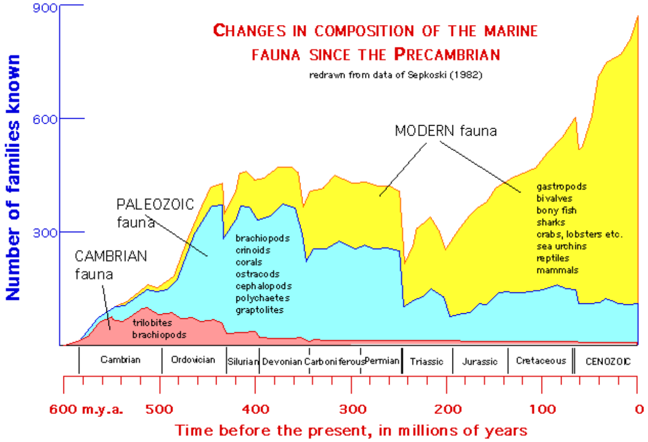
- -Deep time patterns of the origins of diversity
- -The splitting of lineages (speciation / cladogenesis)
- -The changing of lineages (anagenesis)
- -Patterns of biodiversity (diversification rates, mass extinctions, etc.)

- -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.)

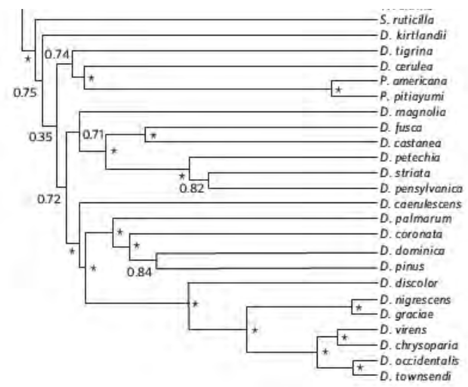
Macroevolution

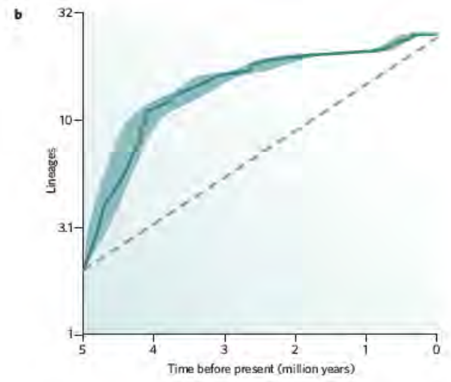
Macroevolution seeks to understand

1) Changes in biological (taxonomic) diversity through time

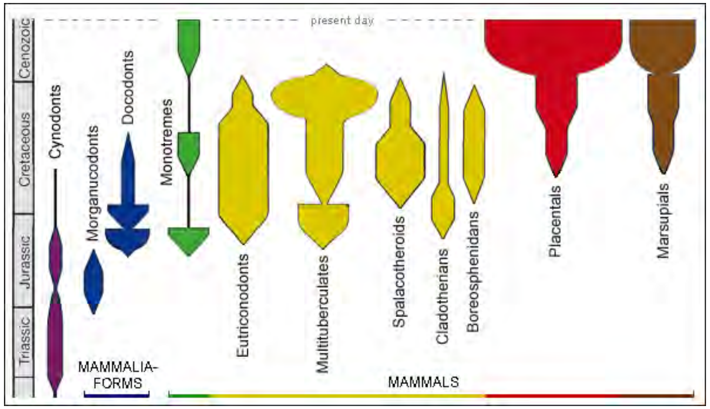


after Sepkowski (1982)





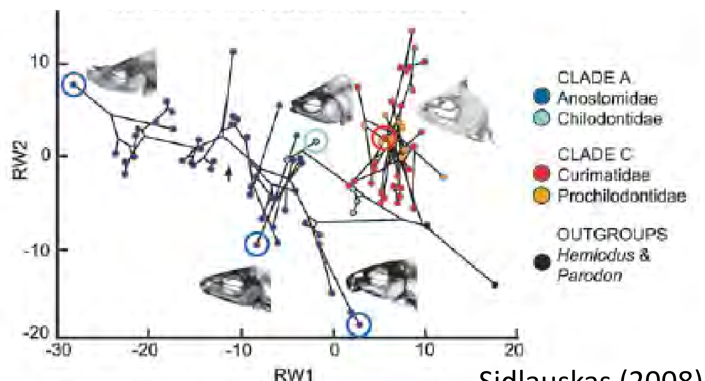
Reznick and Ricklefs 2009



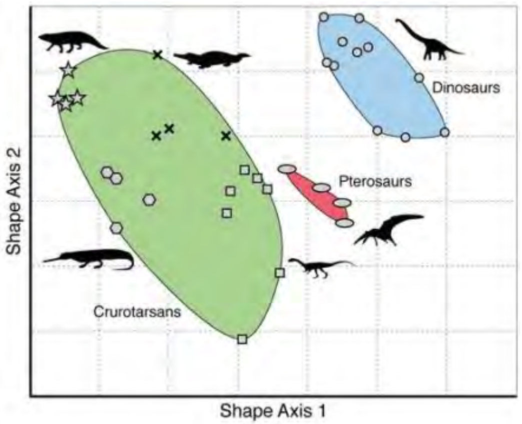
Luo (2007)

Macroevolution seeks to understand

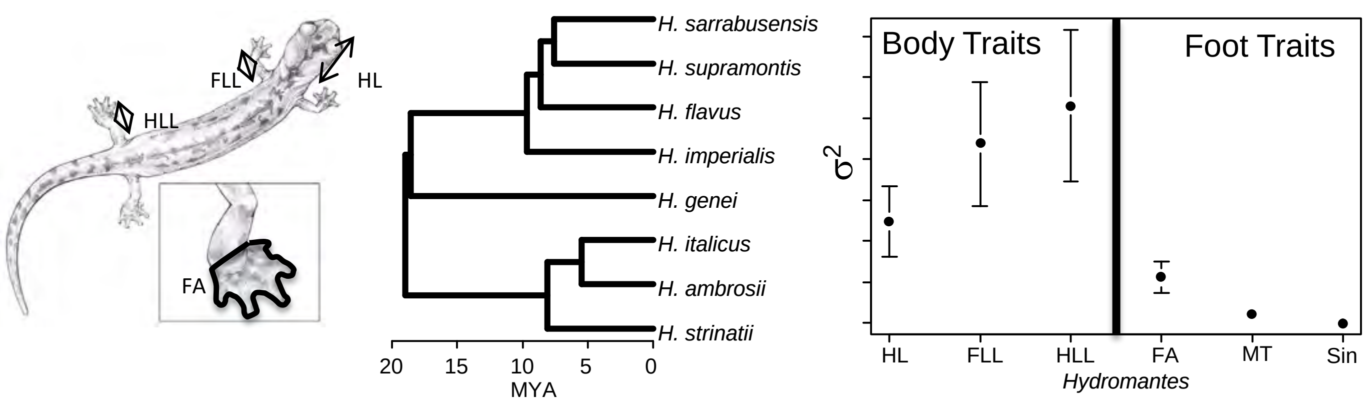
2) Changes in phenotypic diversity through time



Sidlauskas (2008)



Brussatte et al. (2008)

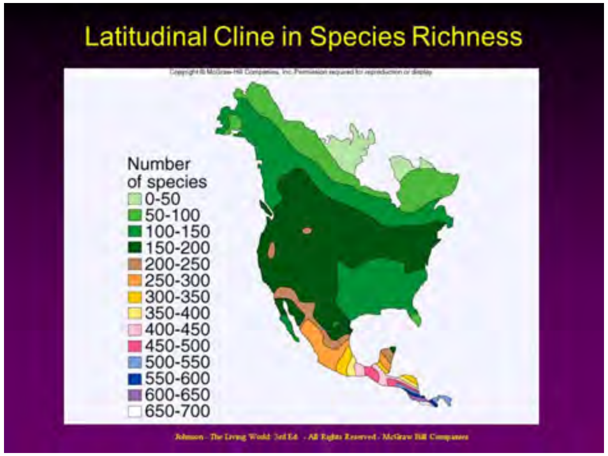


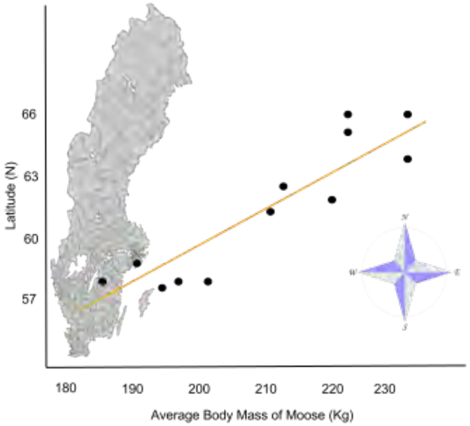
Adams et al. (2017)

Macroevolution seeks to understand

3) Changes in biological/phenotypic diversity over space

Great American Biodiversity Interchange
Marshall (1988)





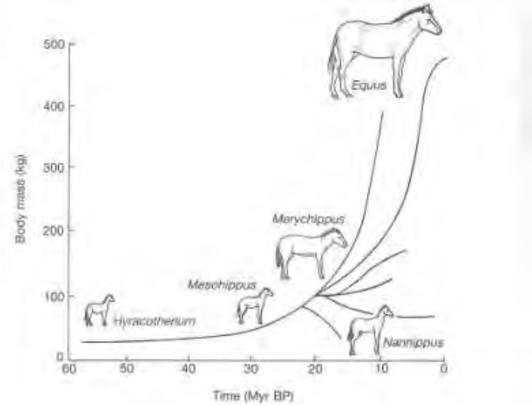
Bergmann's rule:
(from Sand et al. 1995)

How do we study macroevolution?

-Paleontological observations + hypotheses

komando.com

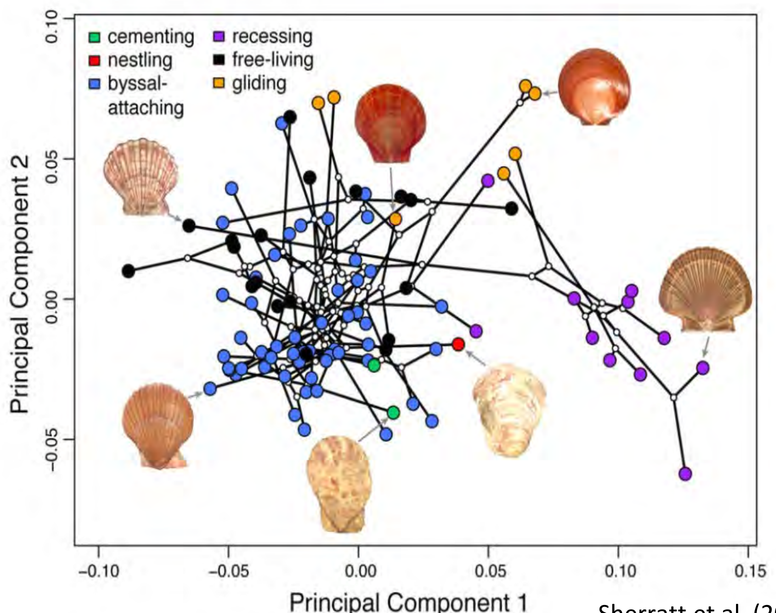
brittanica.com



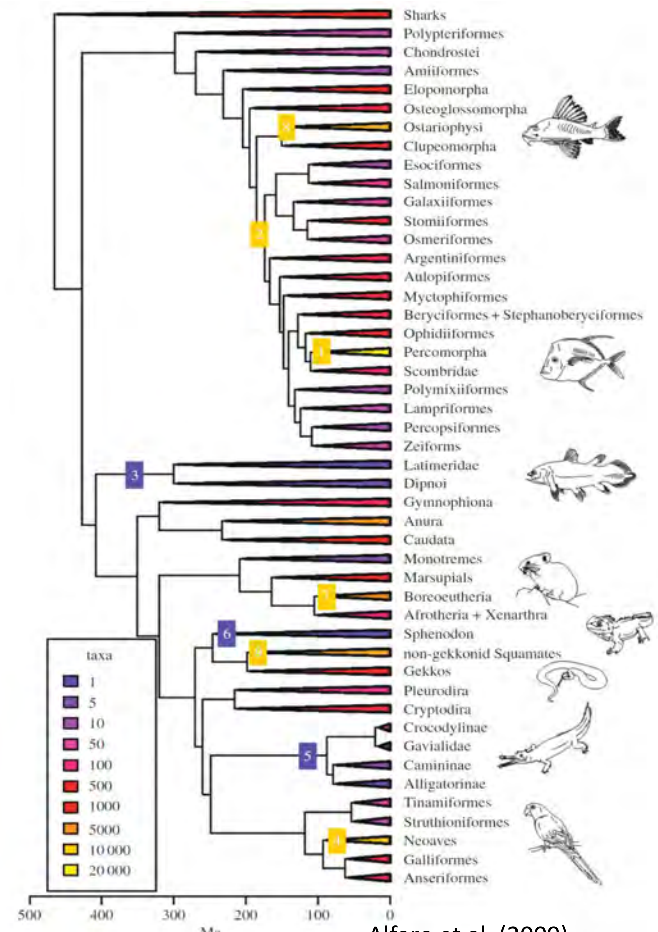
McFadden (1988b)

How do we study macroevolution?

-Neontological observations + hypotheses



Sherratt et al. (2016)

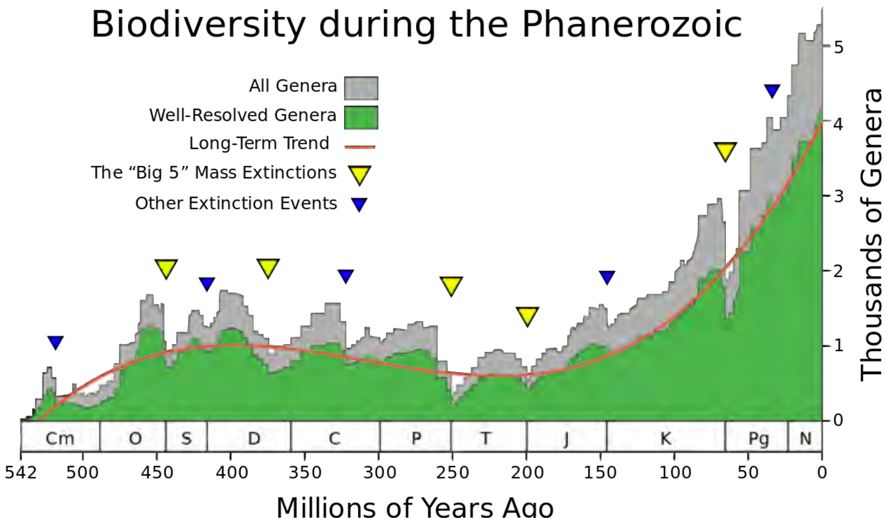


Alfaro et al. (2009)

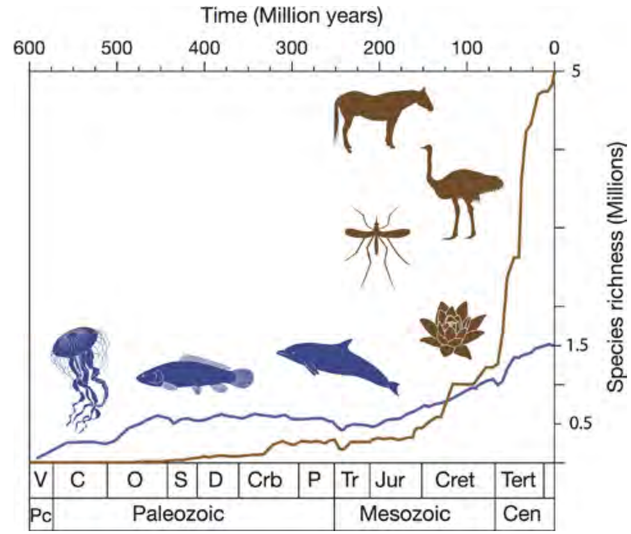
<u>-Modern macroevolution makes extensive use of phylogenies!</u>

Some Macroevolutionary Patterns

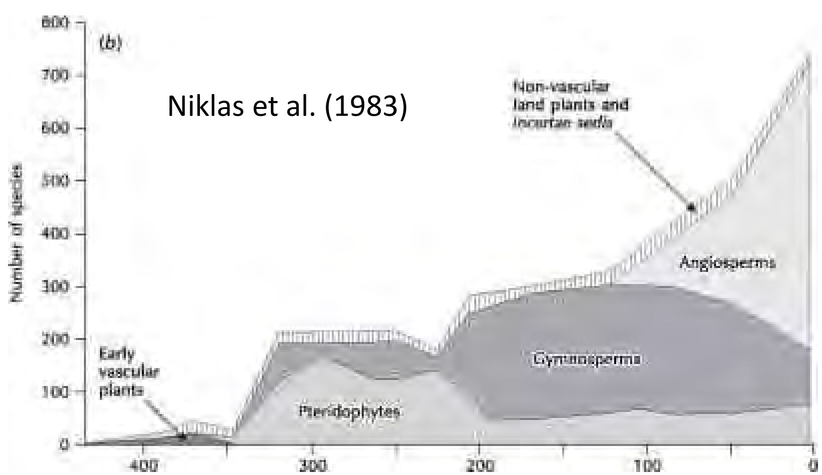
Biodiversity accumulation



Rohde & Muller (2009)



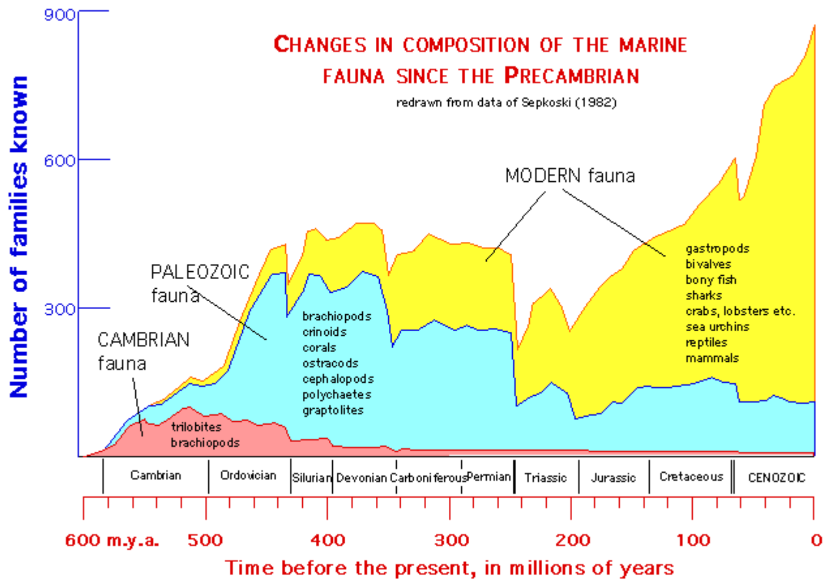
Benton (2016)



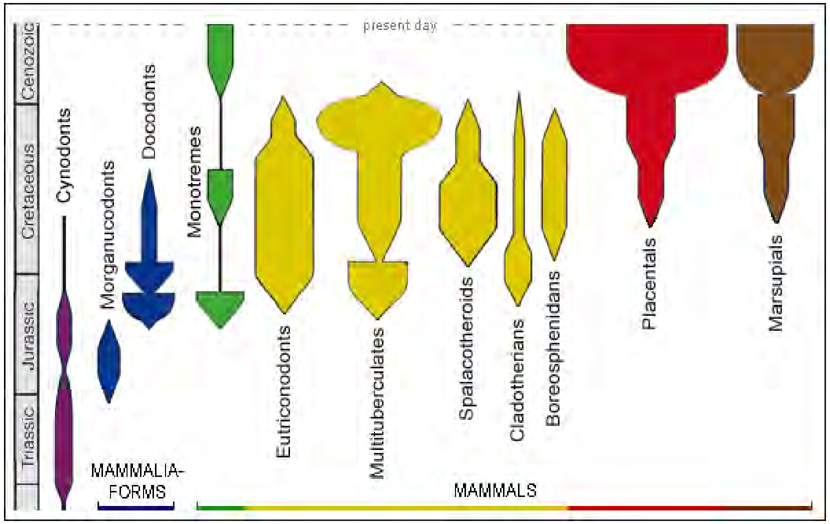
Niklas et al. (1983)

What processes enhance or limit diversification?

Faunal turnover



Sepkowski (1982)

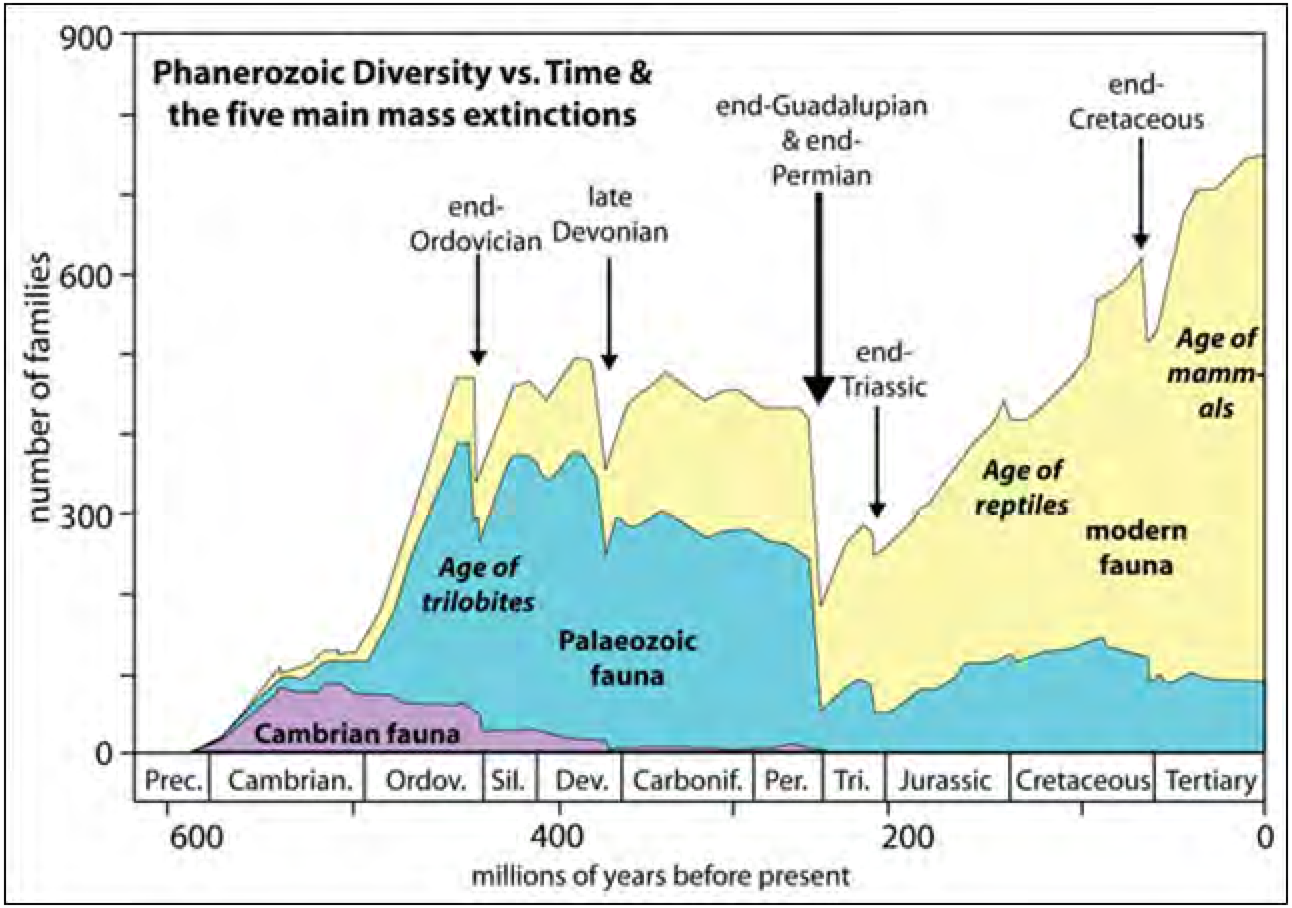


Luo (2007)

Are there distinct biotas at different time periods?

Some Macroevolutionary Patterns

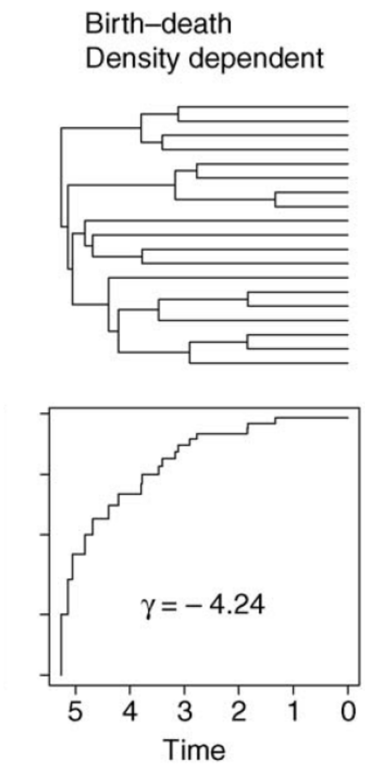
Extinctions and rise of new fauna



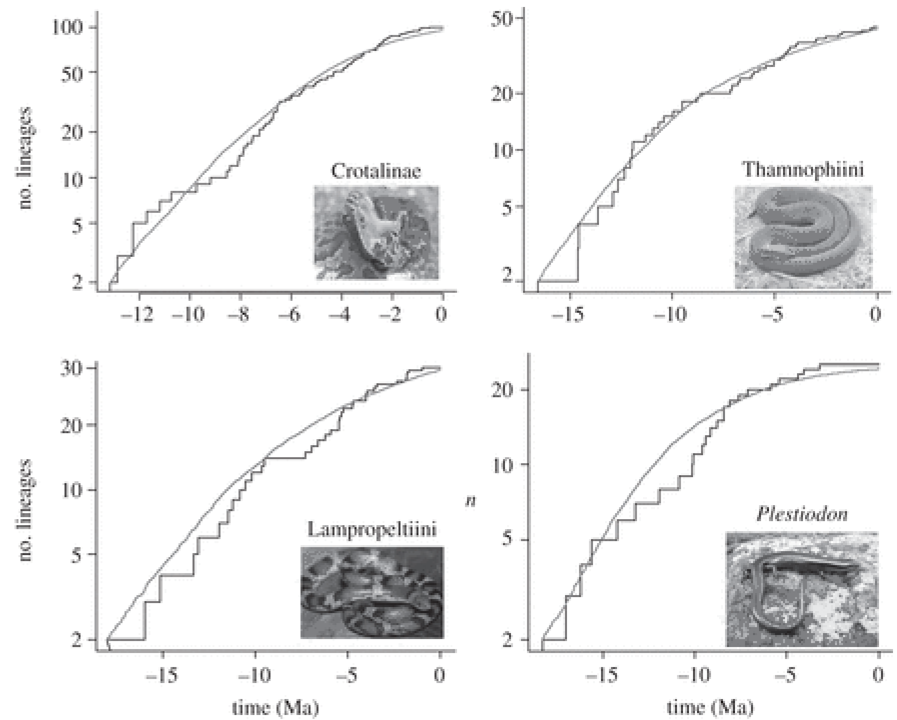
Data from Sepkowski (1982)

What are the causes of mass extinctions?

Limits to biodiversity



Quental and Marshall (2010)

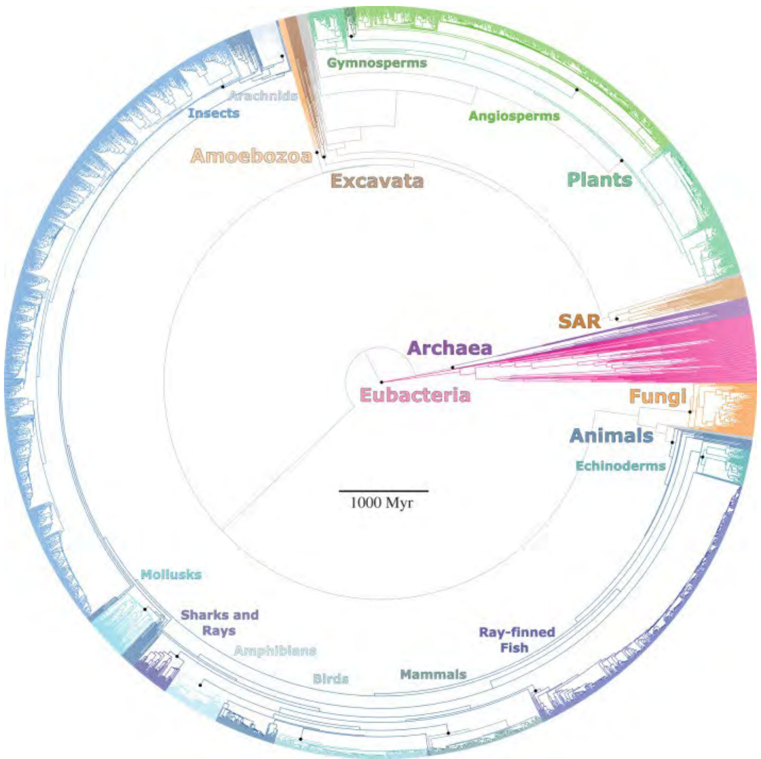


Burbrink et al. (2012)

Is diversification density-dependent?

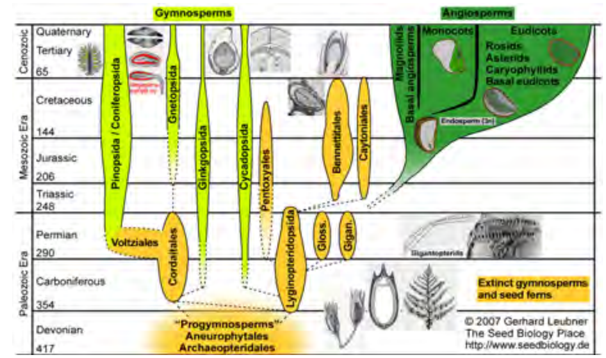
Some Macroevolutionary Patterns

Taxonomic disparity



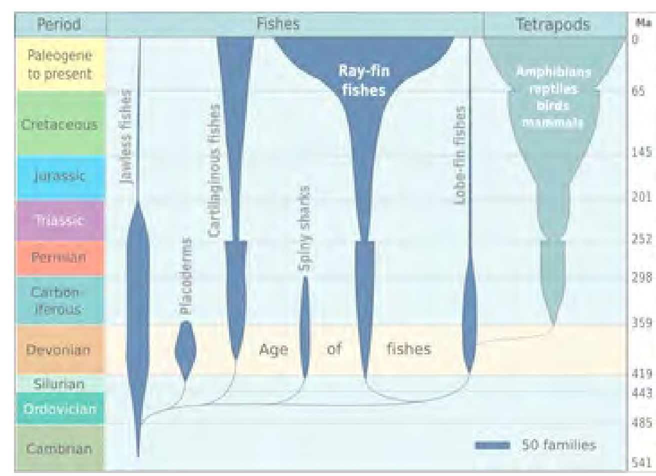
Scholl and Wiens (2016)

Seed vs. non-seed plants



Leubner (2007)

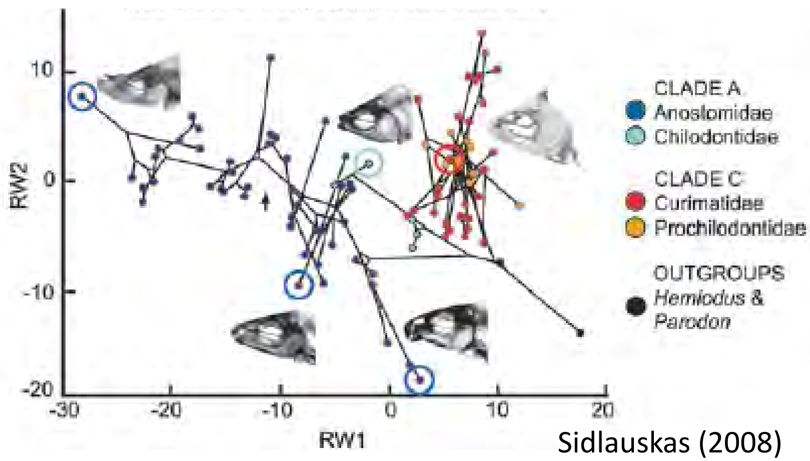
Ray-finned vs. lobe-finned fishes



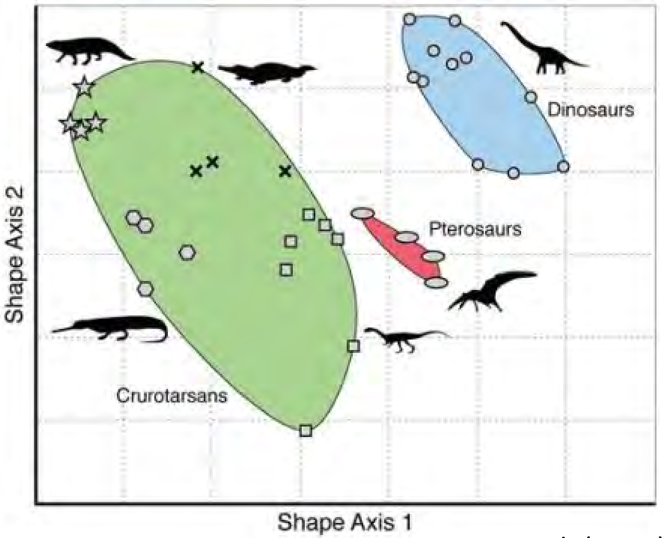
Benton (2005)

Why are some clades taxonomically diverse and others not?

Morphological disparity



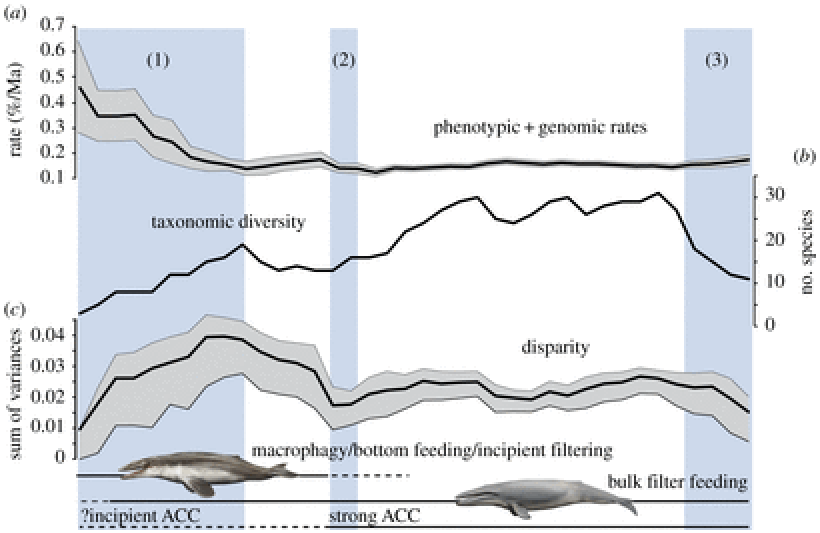
Sidlauskas (2008)



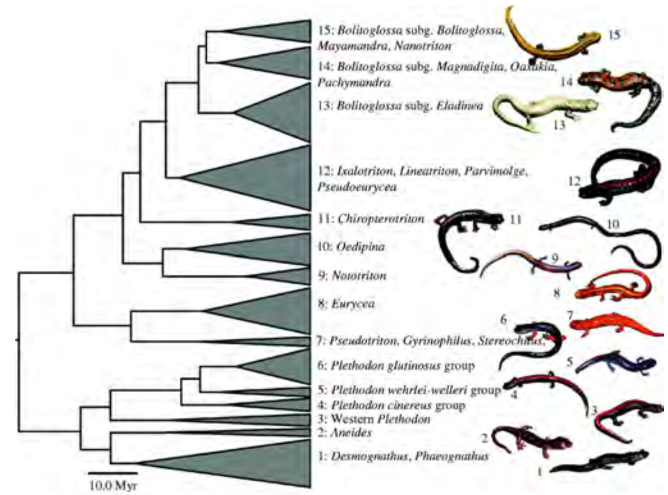
Brussatte et al. (2008)

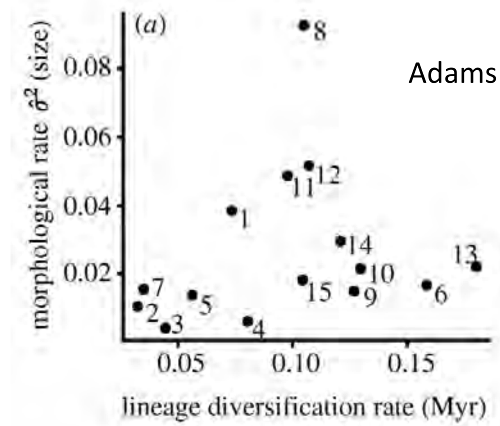
Why are some clades more morphologically disparate than others?

Taxonomic diversity and morphological disparity



Marx & Fordyce (2015)

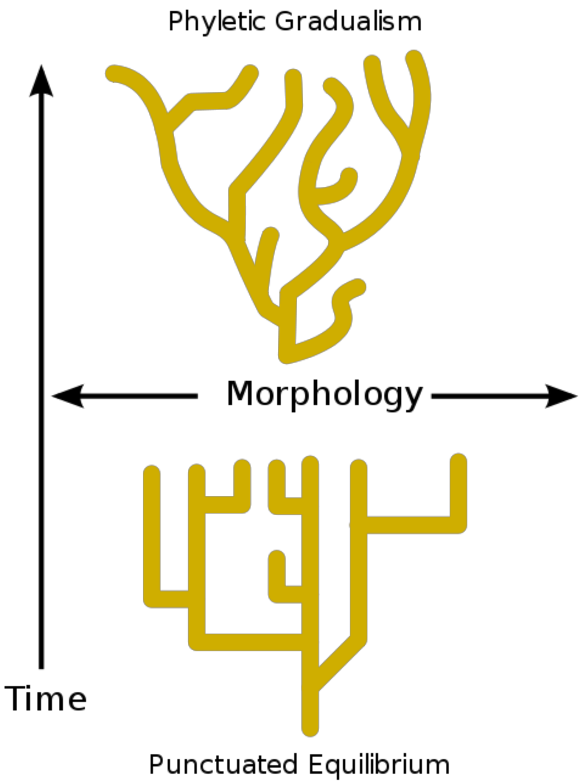




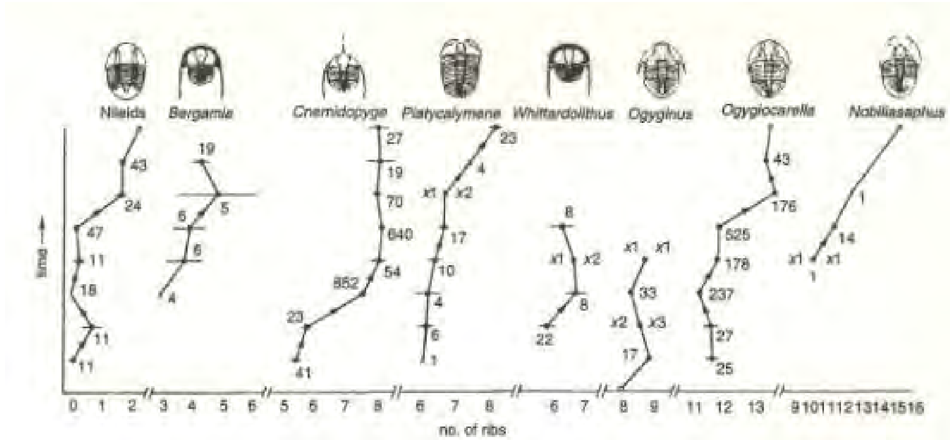
Adams et al. (2009)

Are diversity and disparity coupled or decoupled?

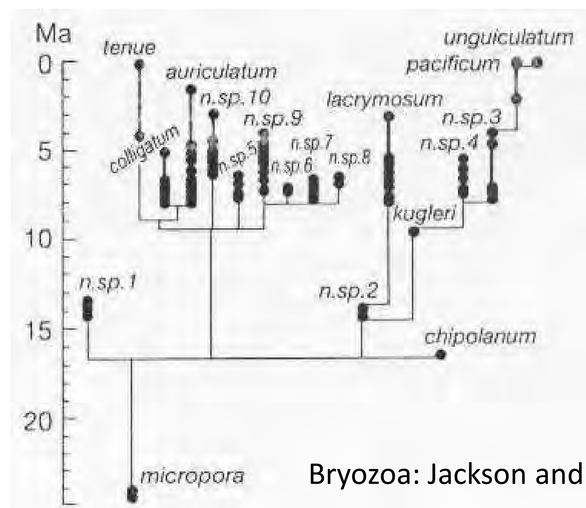
The nature of morphological evolution



(Wikimedia commons)



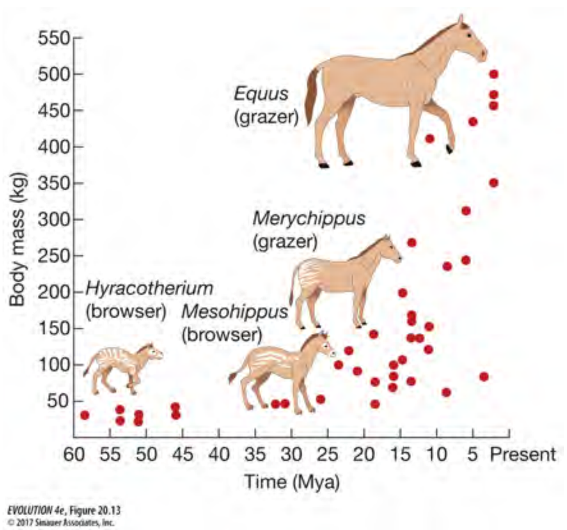
Trilobites: Sheldon (1987)



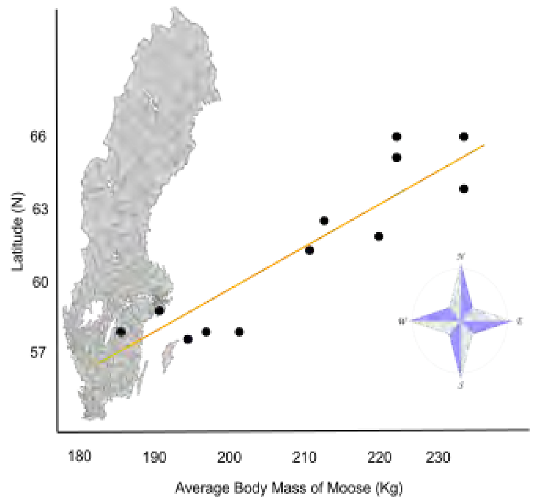
Bryozoa: Jackson and Cheetham (1994)

Is morphological evolution gradual or punctuational?

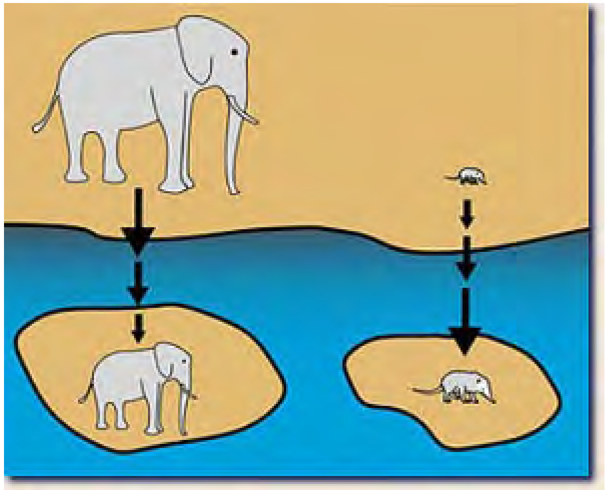
Morphological trends



Cope's rule:
Taxa increase in size over time



Bergmann's rule:
Body size increases in cooler climates
(data from Sand et al. 1995)
Image: Wikimedia



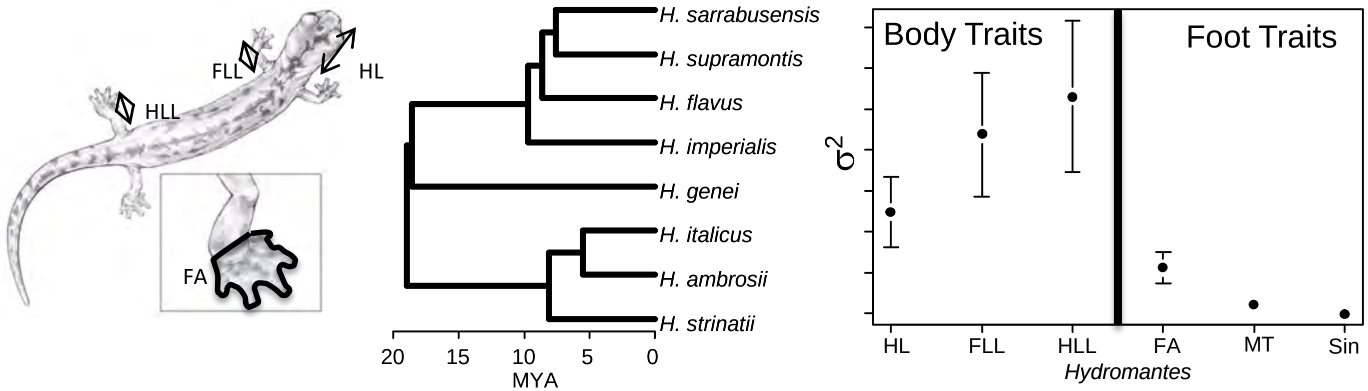
Island (Foster's) rule:
Taxa increase or decrease in size on islands

Image: (c) 2006 MBARI

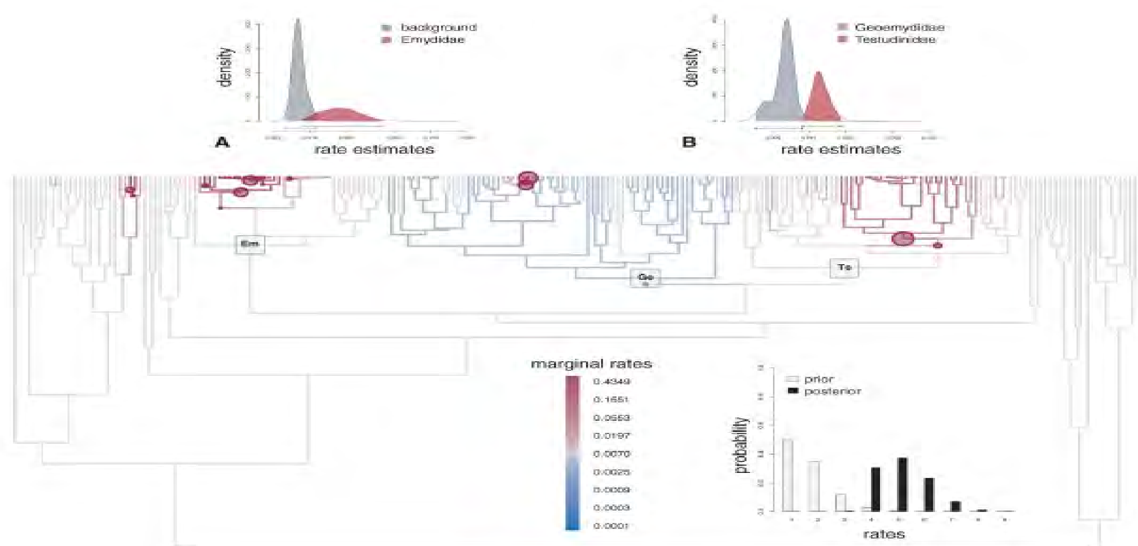
What processes generate phenotypic trends?

Some Macroevolutionary Patterns

The pace of evolution



Adams et al. (2017)

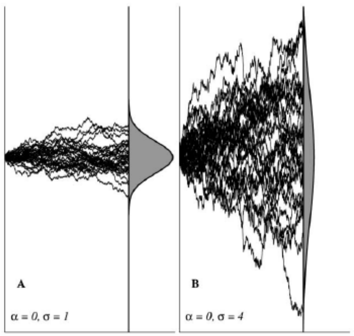


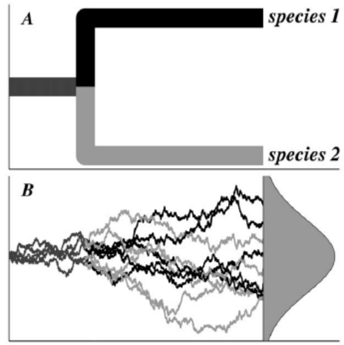
Eastman et al. 2011

Why is morphological evolution faster in some traits or clades?

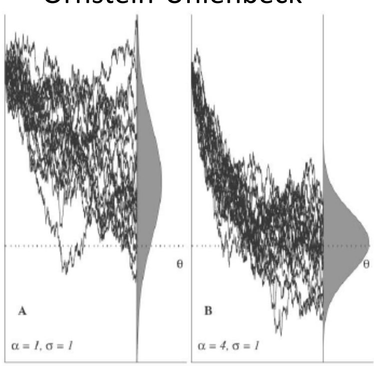
The mode of evolution

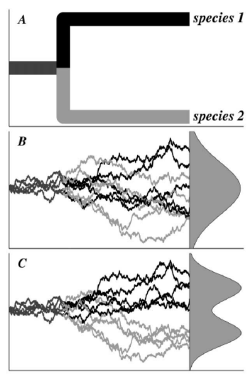
Brownian motion



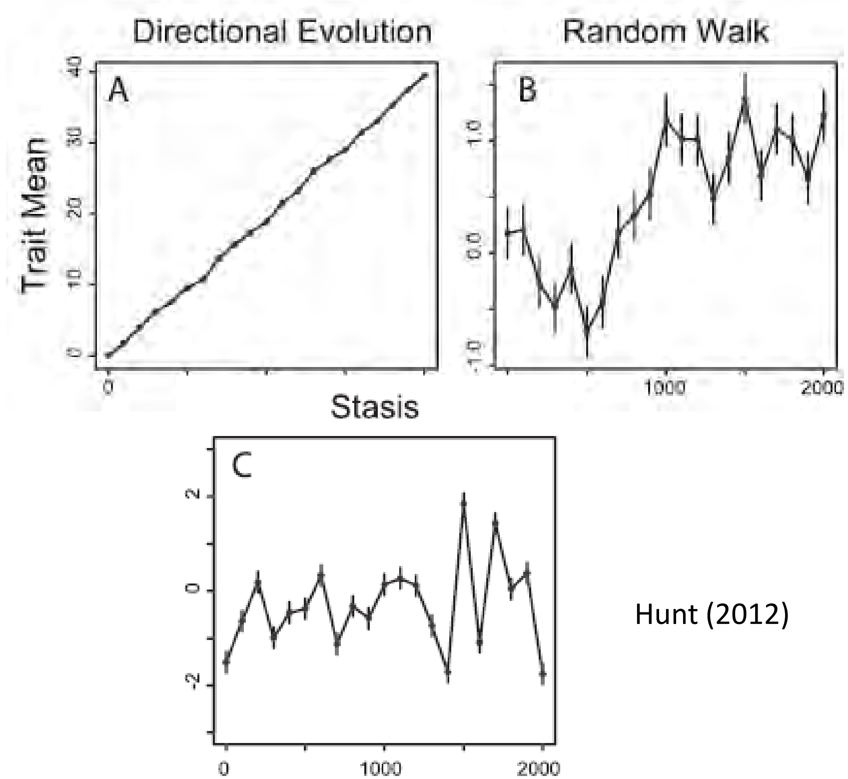


Ornstein-Uhlenbeck





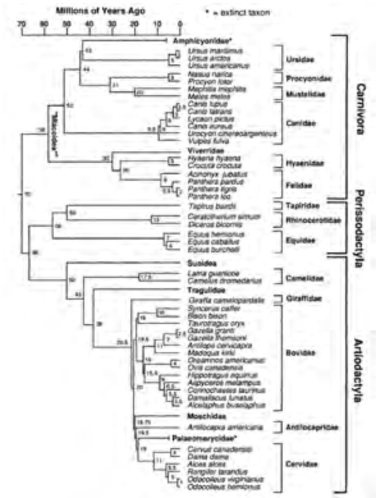
Butler and King (2004)

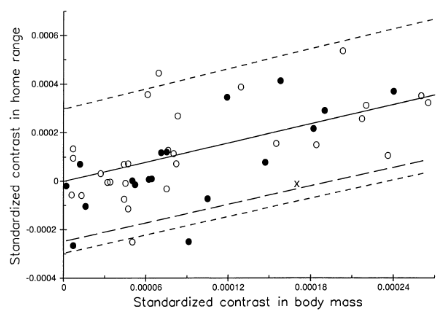


Hunt (2012)

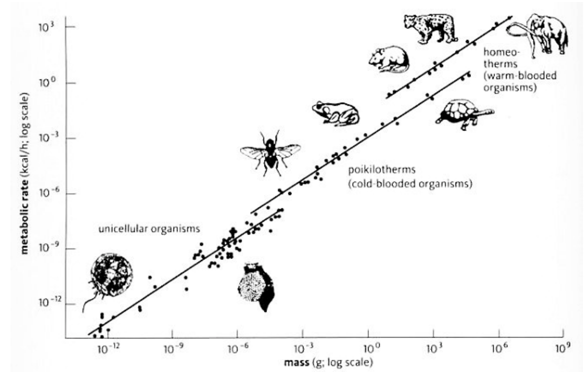
What evolutionary model best describes phenotypic diversification?

Correlated evolution

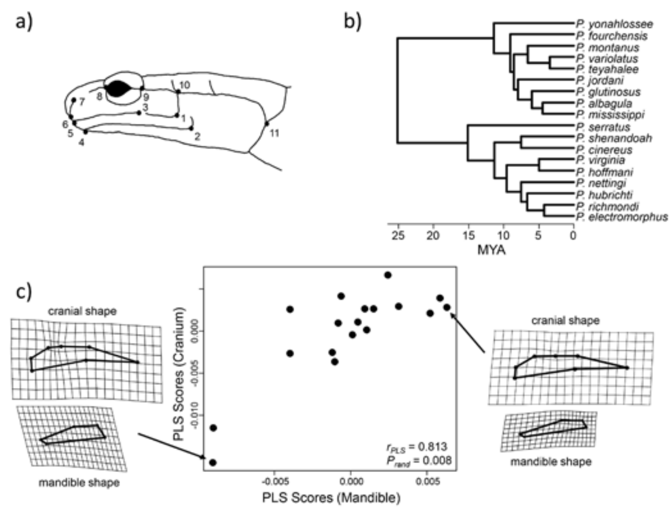




Garland et al. (1993)



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