Patterns of Innovation

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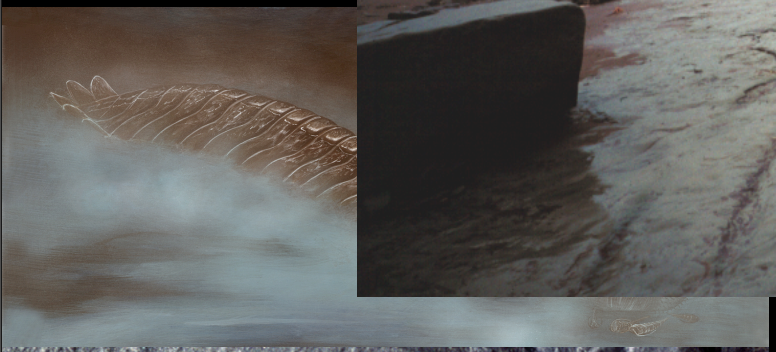
What do we mean by diversity?



Types of diversity:

Taxic (no. of species)

Phylogenetic

Morphologic disparity

Architectural

Ecospace

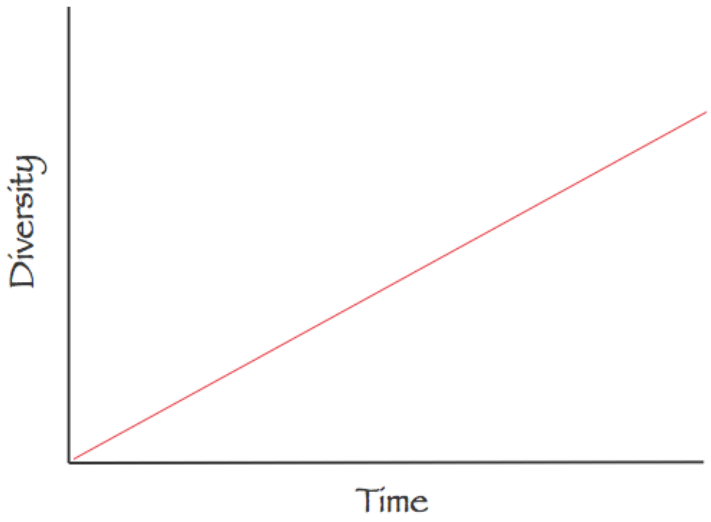
Social/behavioral

Developmental

Erwin, 2008 PNAS

Taxic Diversity

Linear Growth

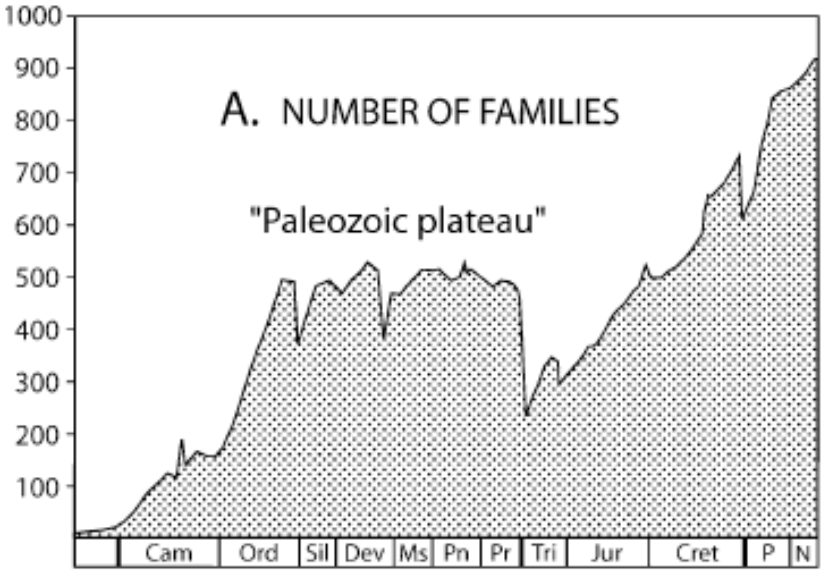


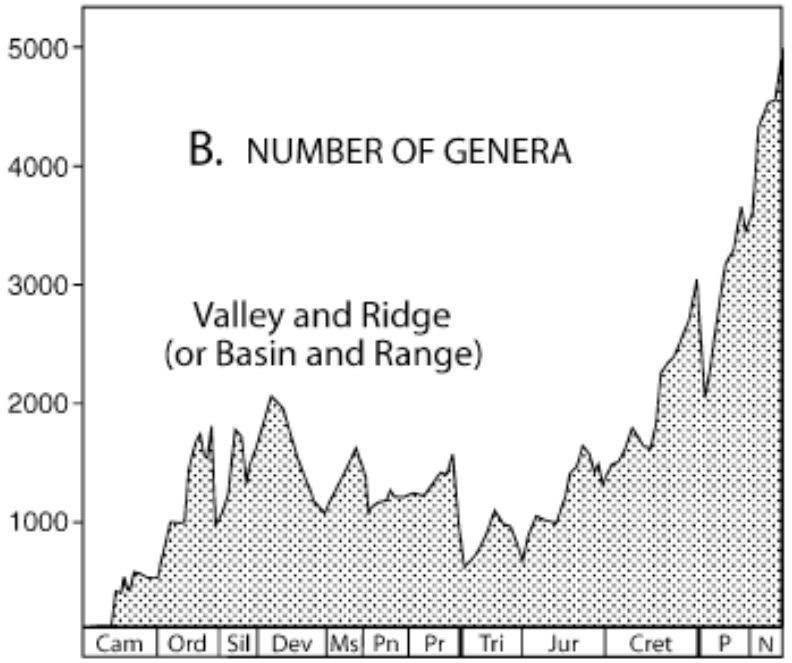
- Accumulation of diversity; diversity unconstrained; can accommodate perturbations
- No feedback, exponential growth (e.g. following mass extinctions)
- Limited role for innovation, ecological facilitation, etc.

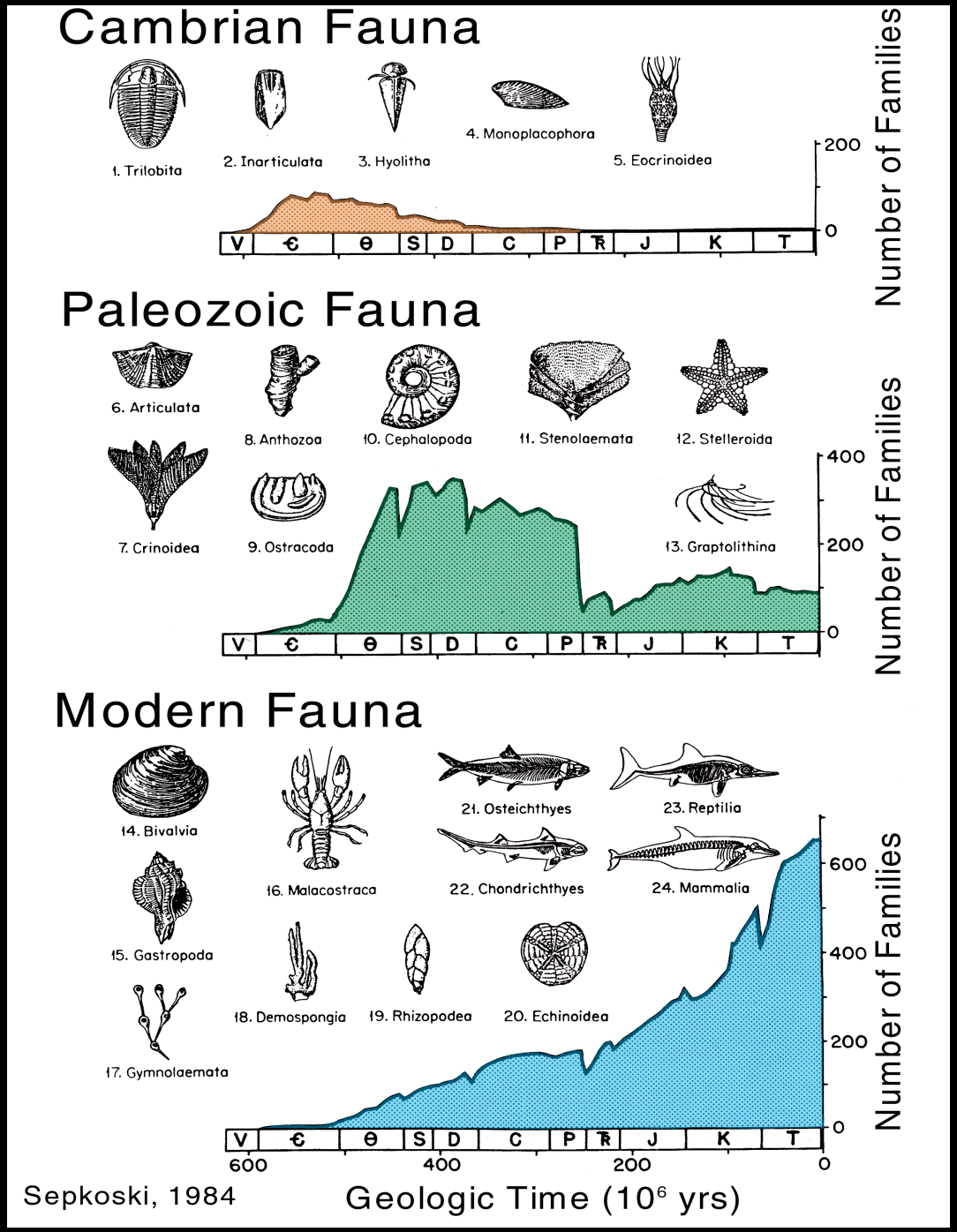
Measures of Taxic Diversity

- Most studies based on Sepkoski's compendium of the first and last occurrences of marine families and genera (NOT species!)
- Recall that species are grouped into genera, genera into families, families into superfamilies and orders, etc.

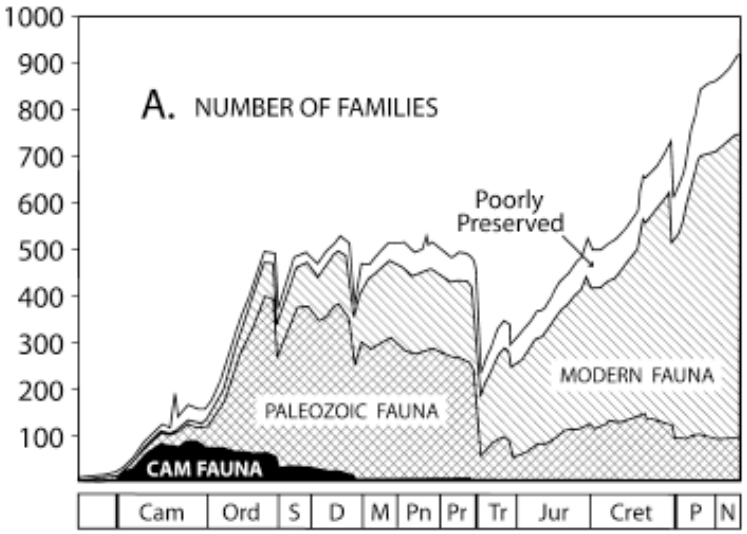
Phanerozoic Marine Diversity

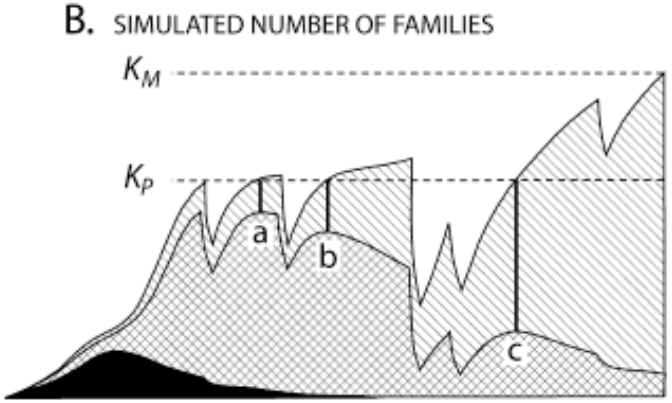





Cambrian Fauna
1. Trilobita
2. Inarticulata
3. Hyolitha
4. Monoplacophora
5. Eocrinoidea
200
0
V
Є
O
S
D
C
P
Ŧ
J
K
T
Number of Families
Paleozoic Fauna
6. Articulata
7. Crinoidea
8. Anthozoa
9. Ostracoda
10. Cephalopoda
11. Stenolaemata
12. Stelleroida
13. Graptolithina
400
200
0
Number of Families
Modern Fauna
14. Bivalvia
15. Gastropoda
16. Malacostraca
17. Gymnolaemata
18. Demospongia
19. Rhizopodea
20. Echinoidea
21. Osteichthyes
22. Chondrichthyes
23. Reptilia
24. Mammalia
600
400
200
0
Number of Families
600
400
200
0
Sepkoski, 1984
Geologic Time (10⁶ yrs)

Coupled Logistic Growth

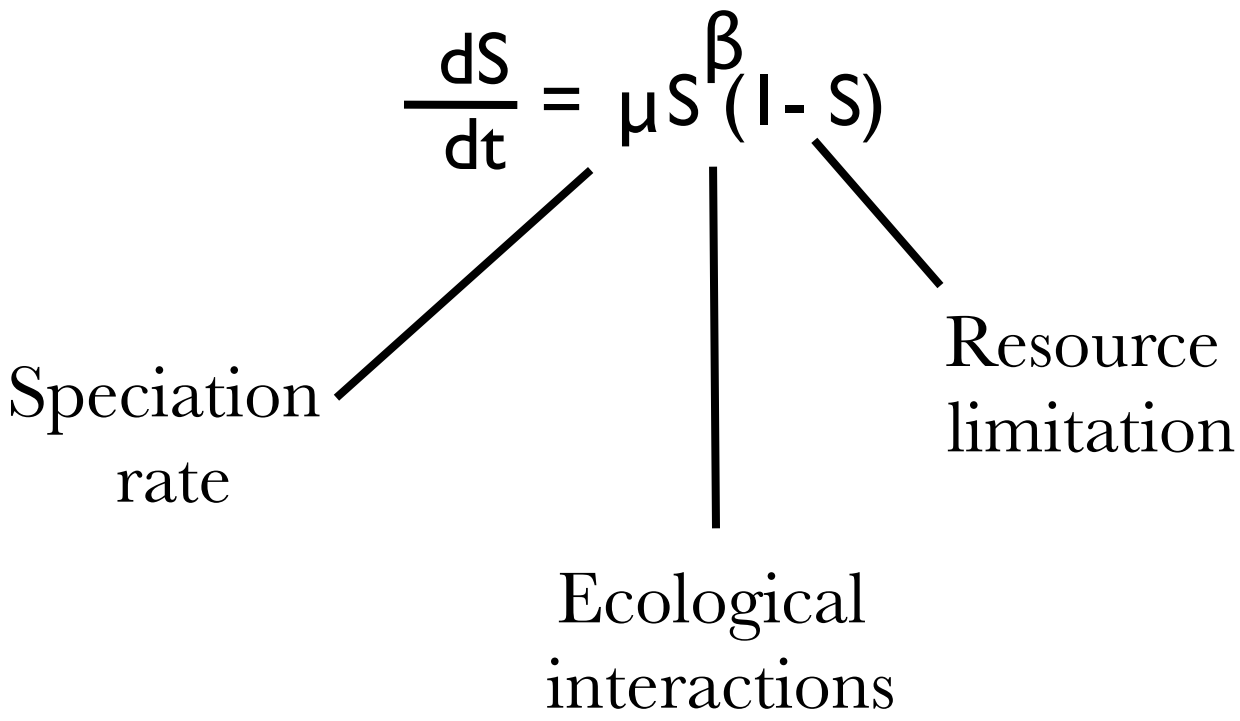




- Each Evolutionary Fauna has an individual carrying capacity that responds to major environmental perturbations (mass extinctions)
- Requires ecological saturation in marine communities and persistent carrying capacities

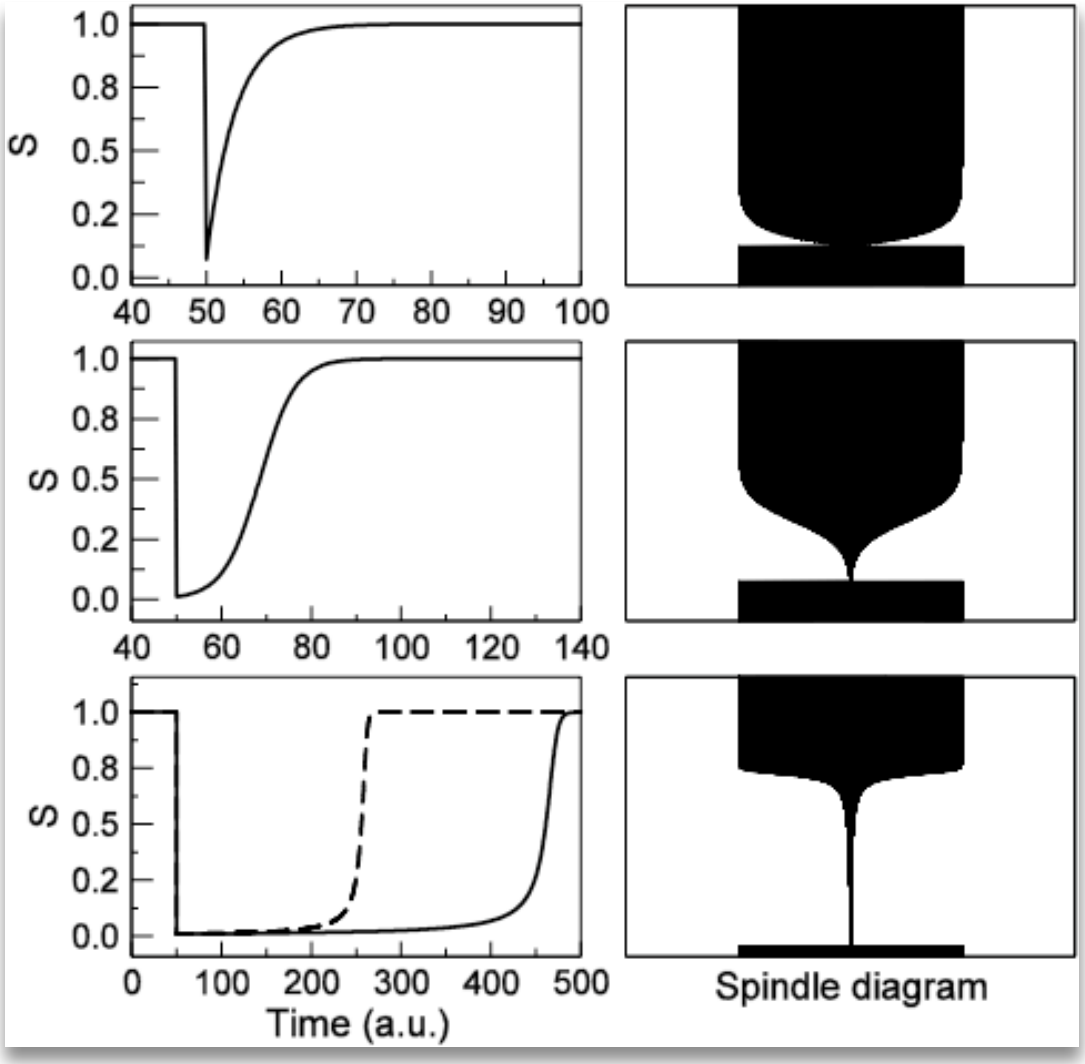
Sepkoski Paleobiology, 1984

Generalized Logistic Growth



Sole et al, in review

Patterns of Growth



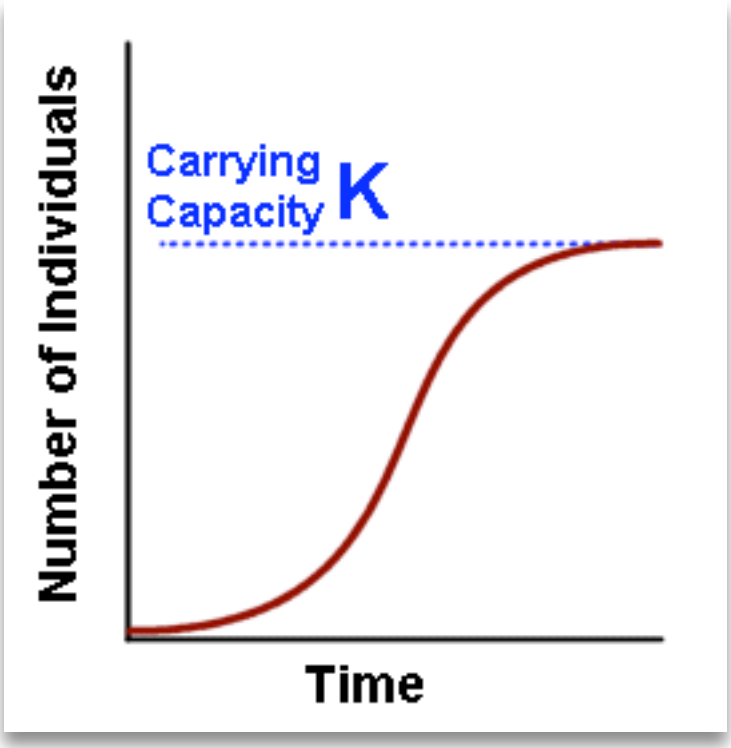
Linear

Logistic

Hyperbolic

Sole et al, in review

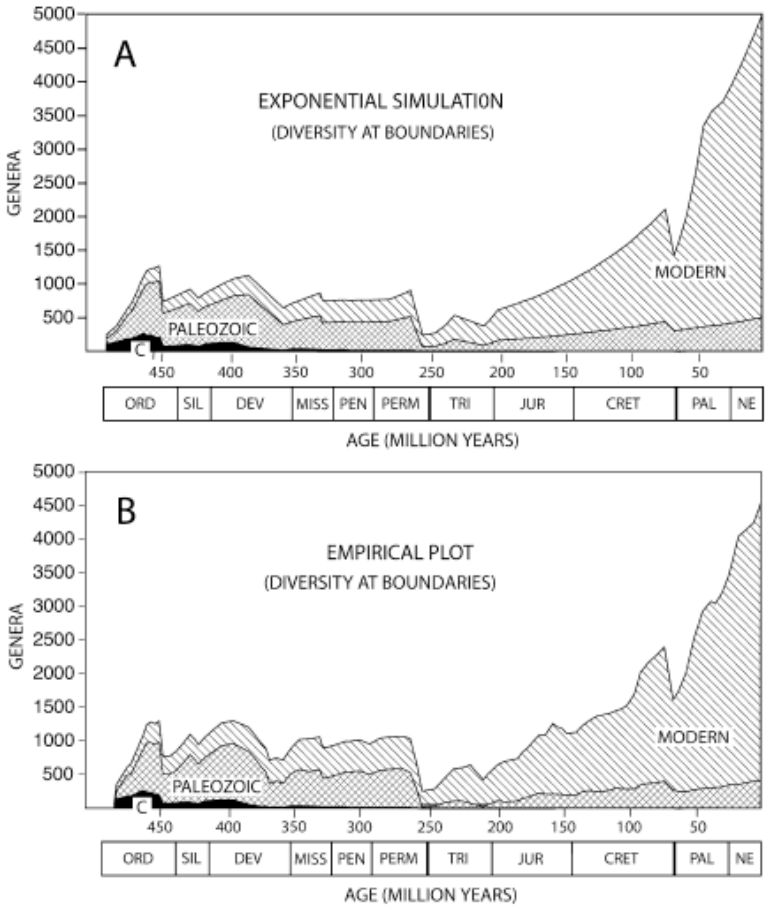
Problems with Logistic Growth



$dN/dT = r N (1-N/K)$

- Logistic growth is a feature of *population* growth
- Requires ecological saturation/density dependent effects
- Yet carrying capacity varies with environment and available adaptations
- Carrying capacity is an exogenous variable
- Is the concept meaningful over evolutionary time?

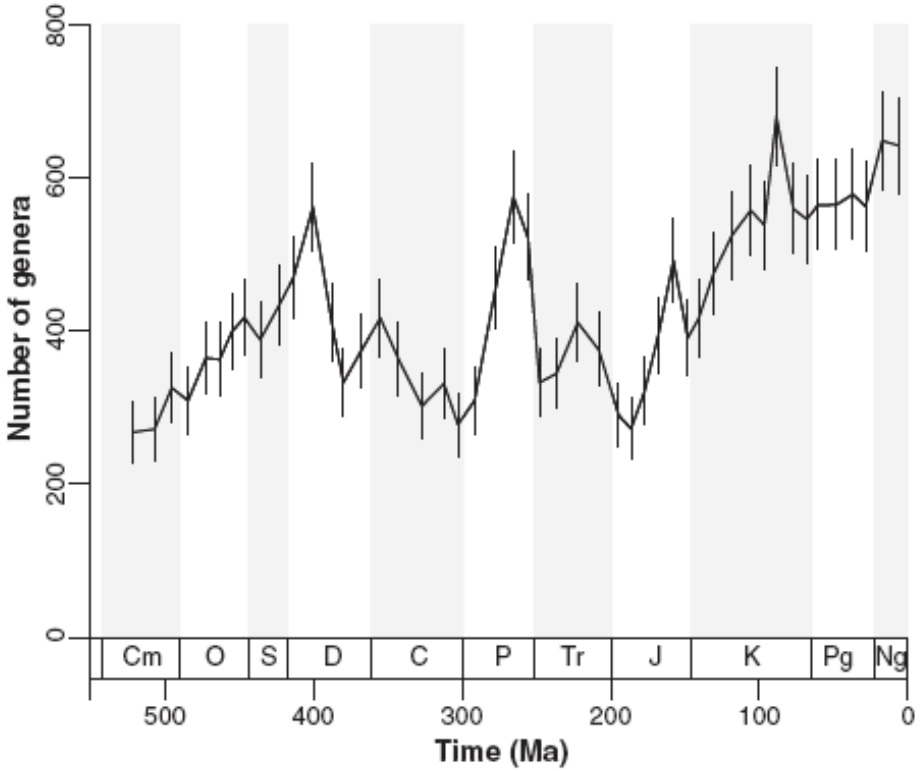
Exponential Diversification



- Diversity unconstrained; reset by environmental perturbations, which lead to rapid diversity increases
- Inconsistent with standardized sampling of PDBD (Alroy et al. 2008).

Stanley 2007 Paleobiology

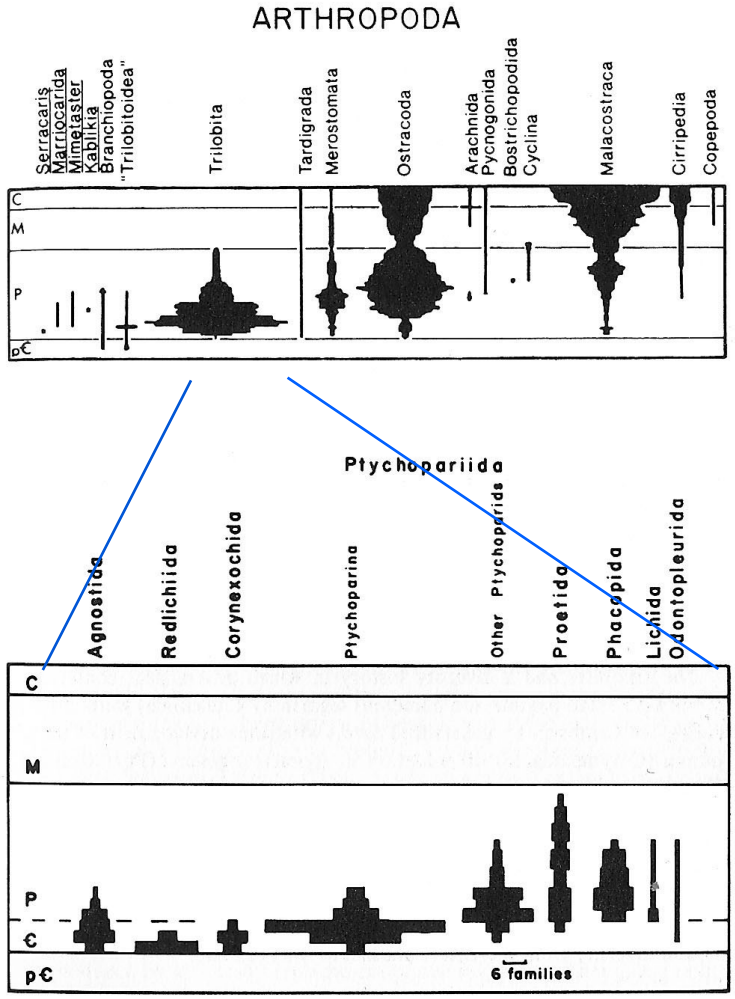
Constrained Diversification



- Apparent high modern diversity is a sampling artifact
- Diversity appears constrained, with Neogene diversity only 1.7x median Paleozoic diversity
- Constraint could be due to carrying capacity, global energy limitation and/or increased metabolic rate

Alroy et al. Science 2008

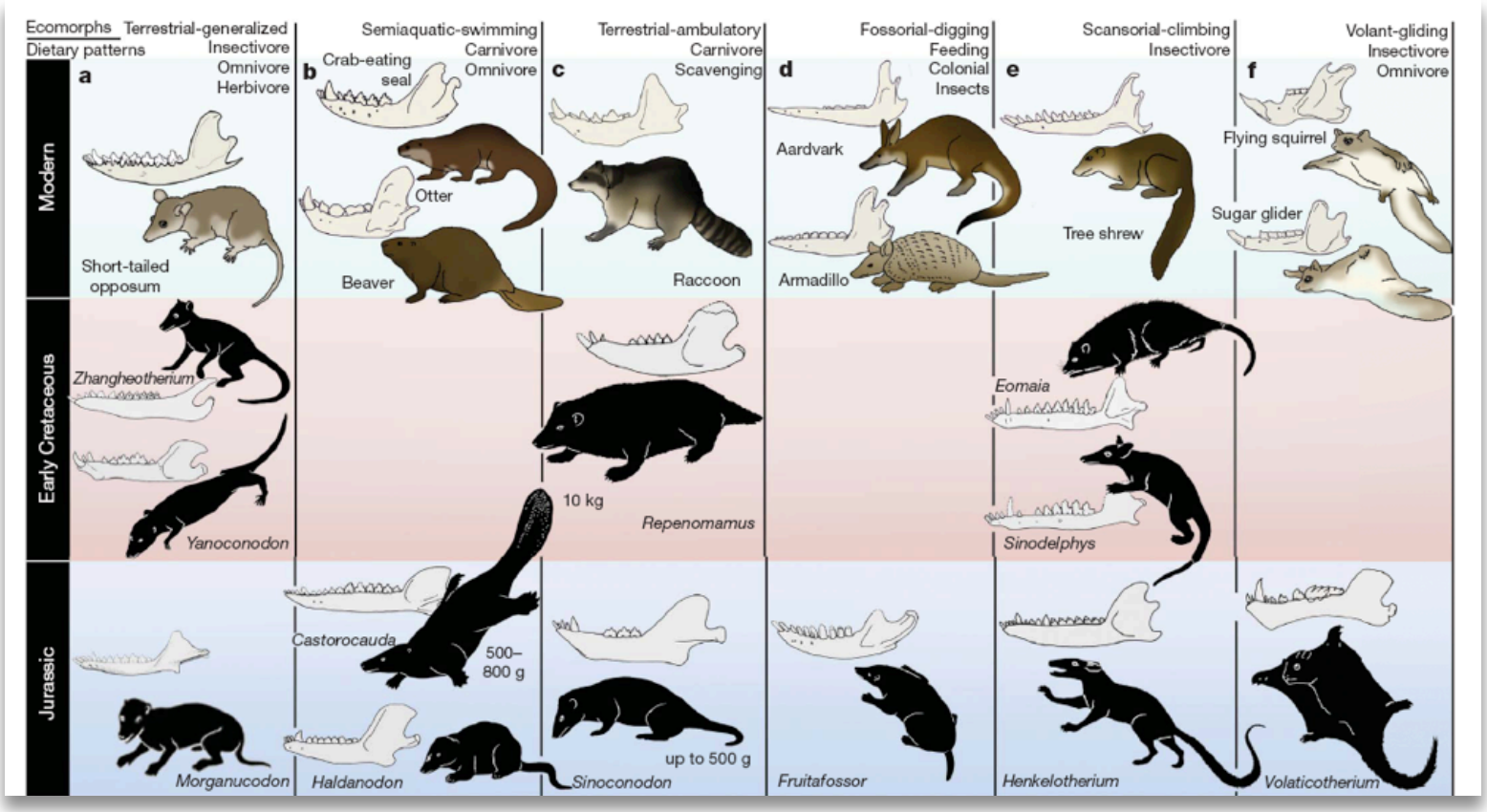
Does competition drive adaptive improvements, specialization and niche subdivision?



Sepkoski 1985

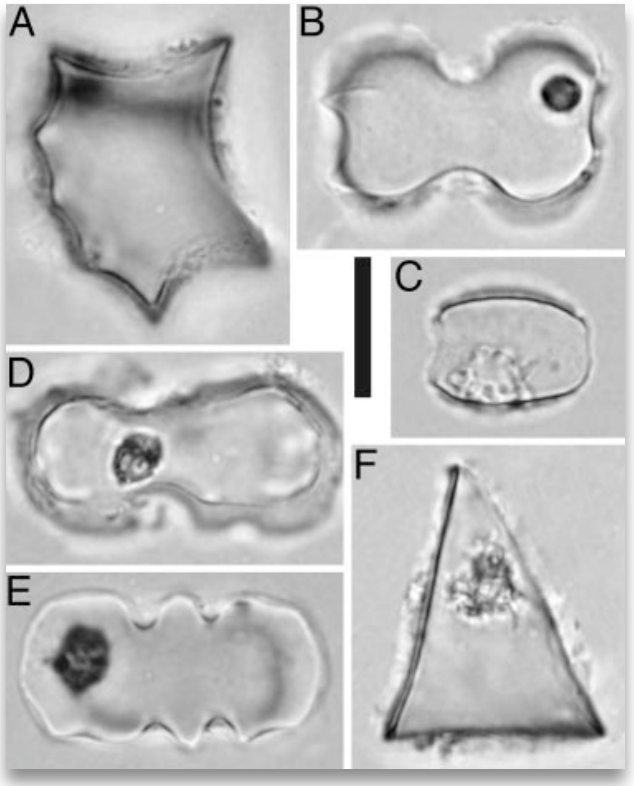
Diversity is Structured:

Convergence between Mesozoic and Modern Mammals



Luo 2007 Nature

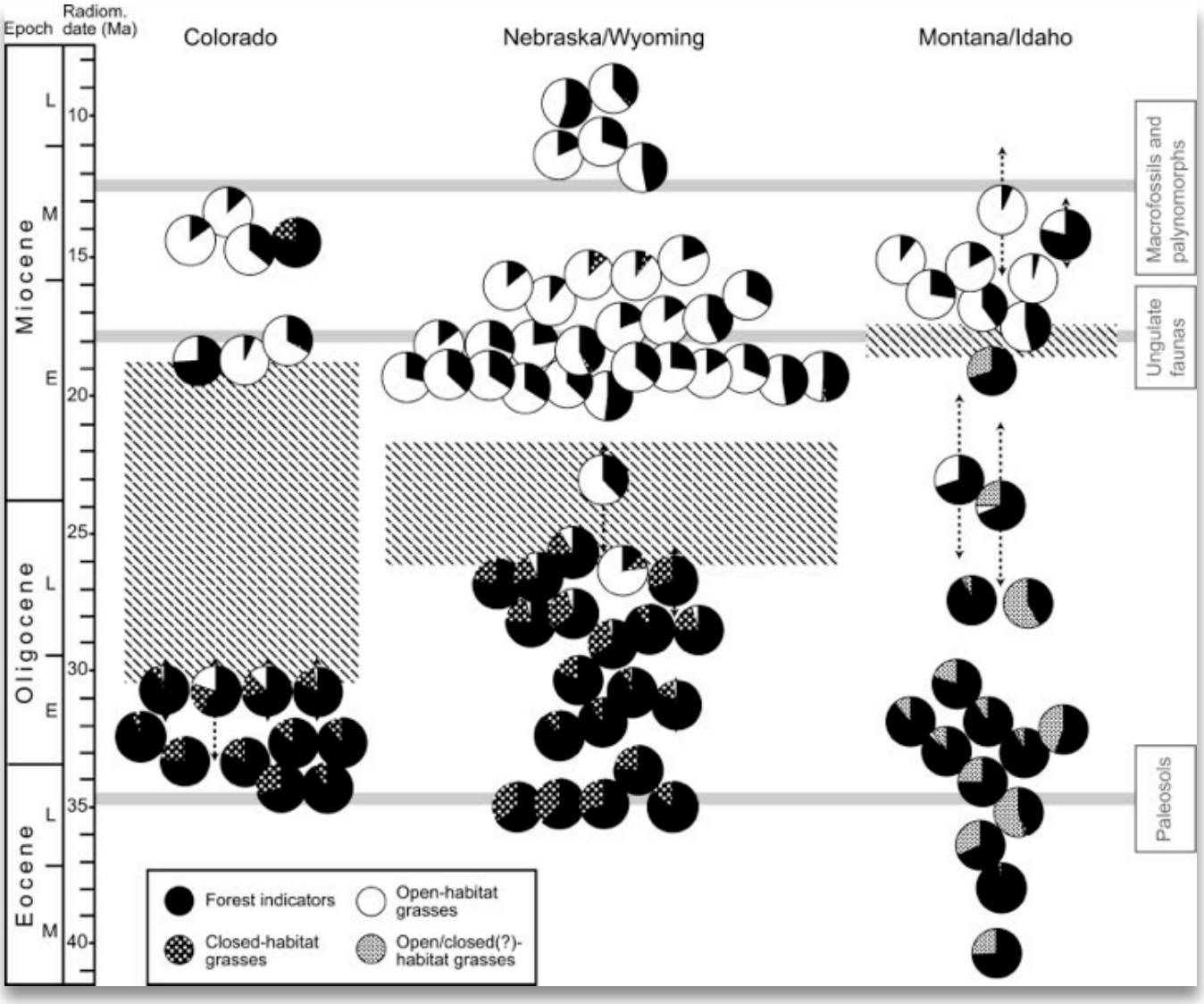
Macroevolutionary lags



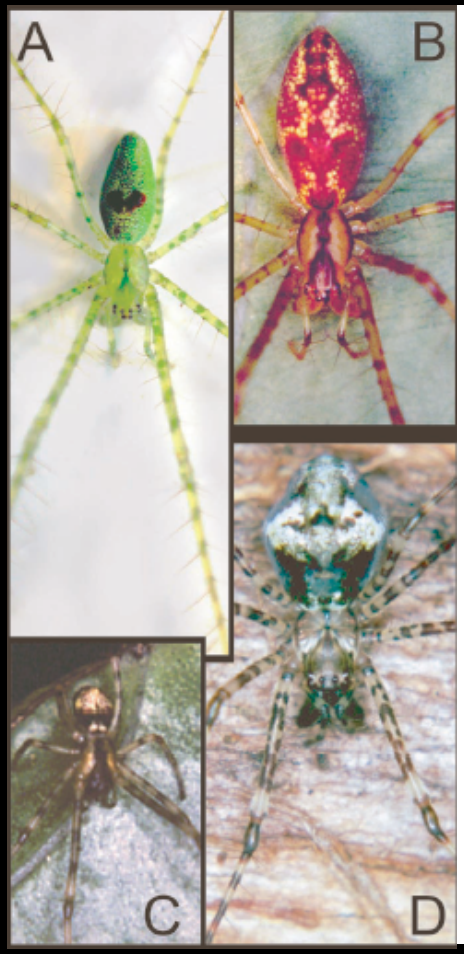
Phytolithes

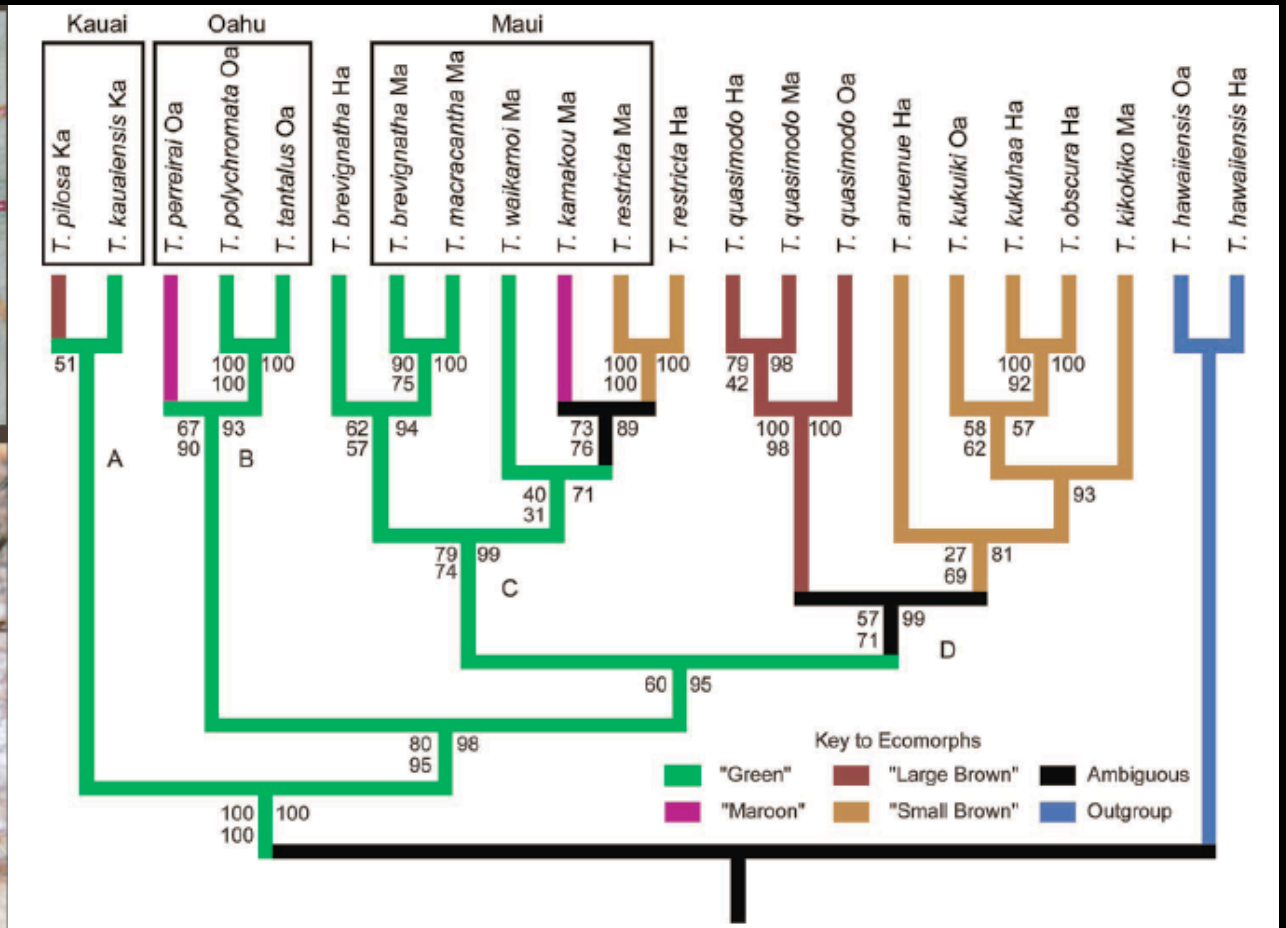
Stromberg 2005

Macroevolutionary Lags



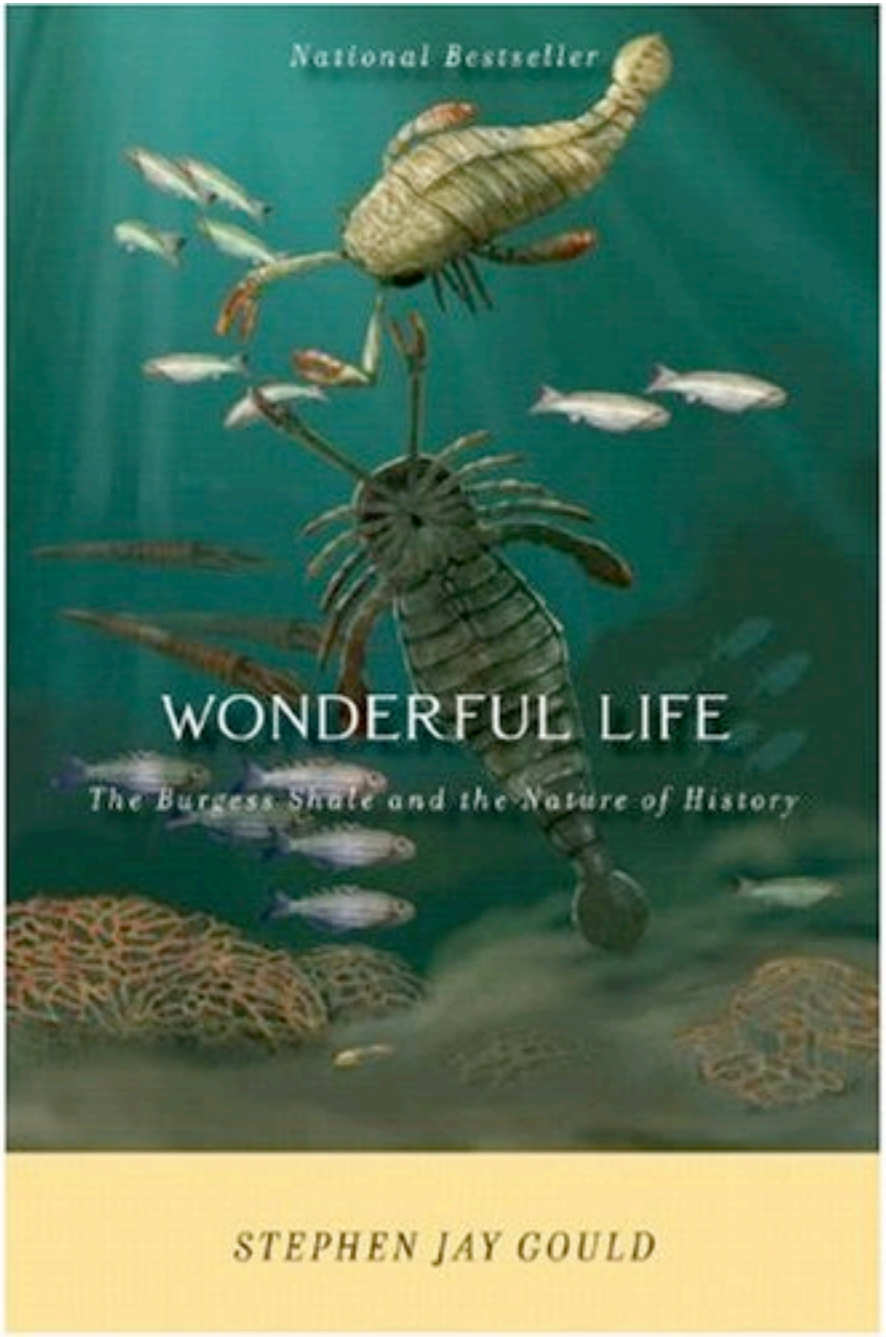
Discovery: Adaptive Radiation of Hawaiian spiders

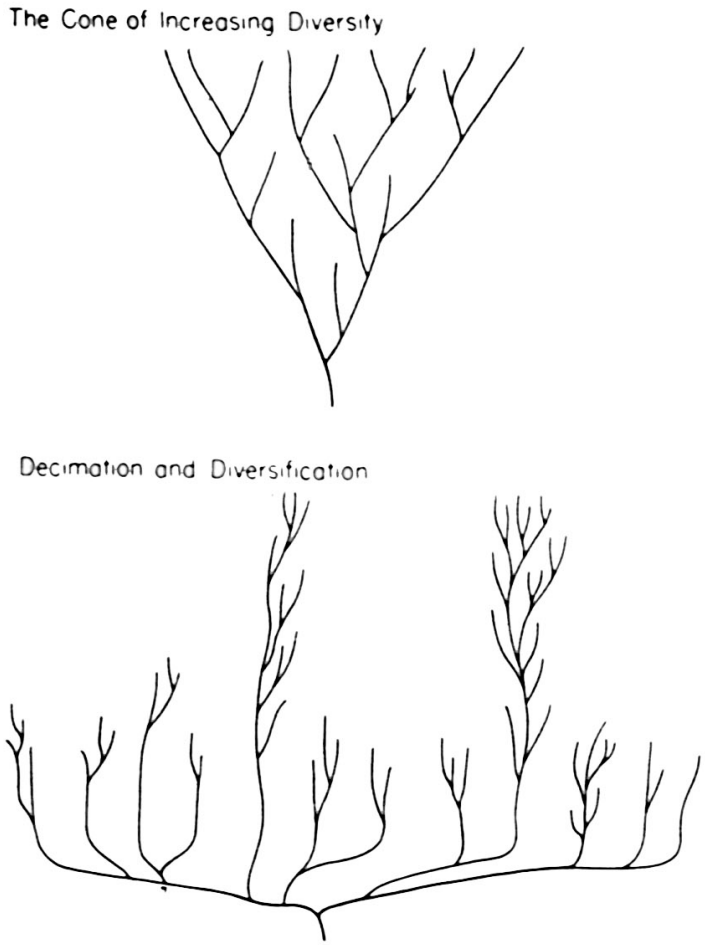




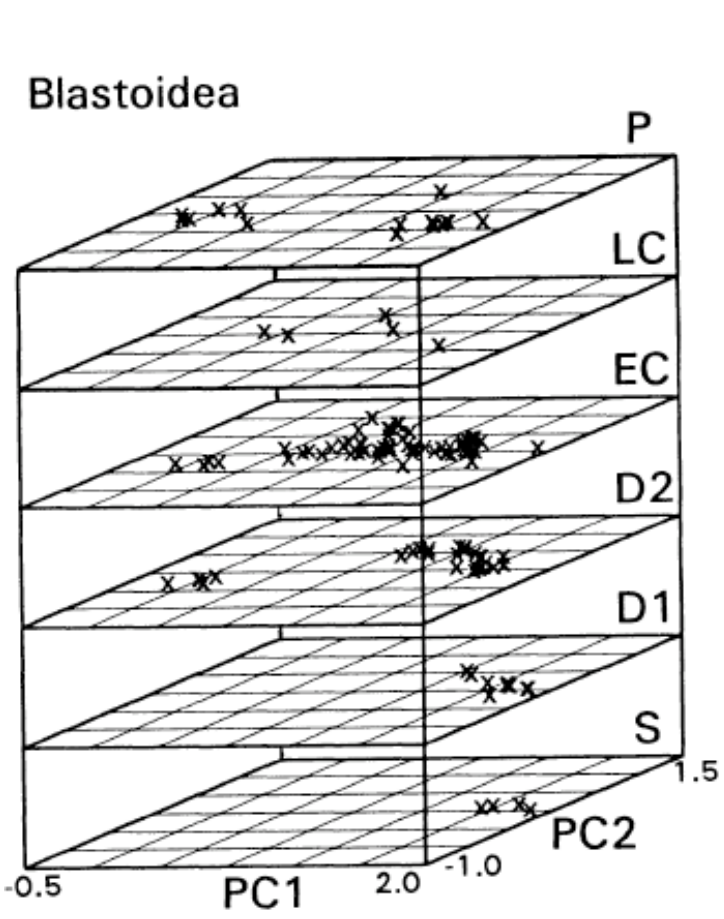
Gillespie, *Science* 2004

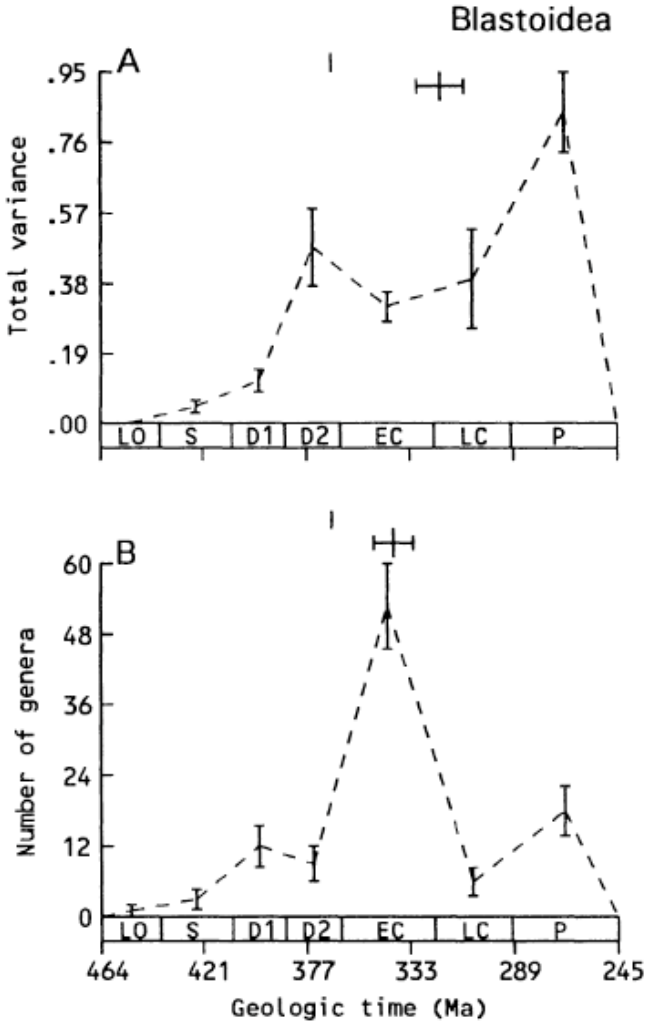
Morphologic Diversity


National Bestseller
WONDERFUL LIFE
The Burgess Shale and the Nature of History
STEPHEN JAY GOULD

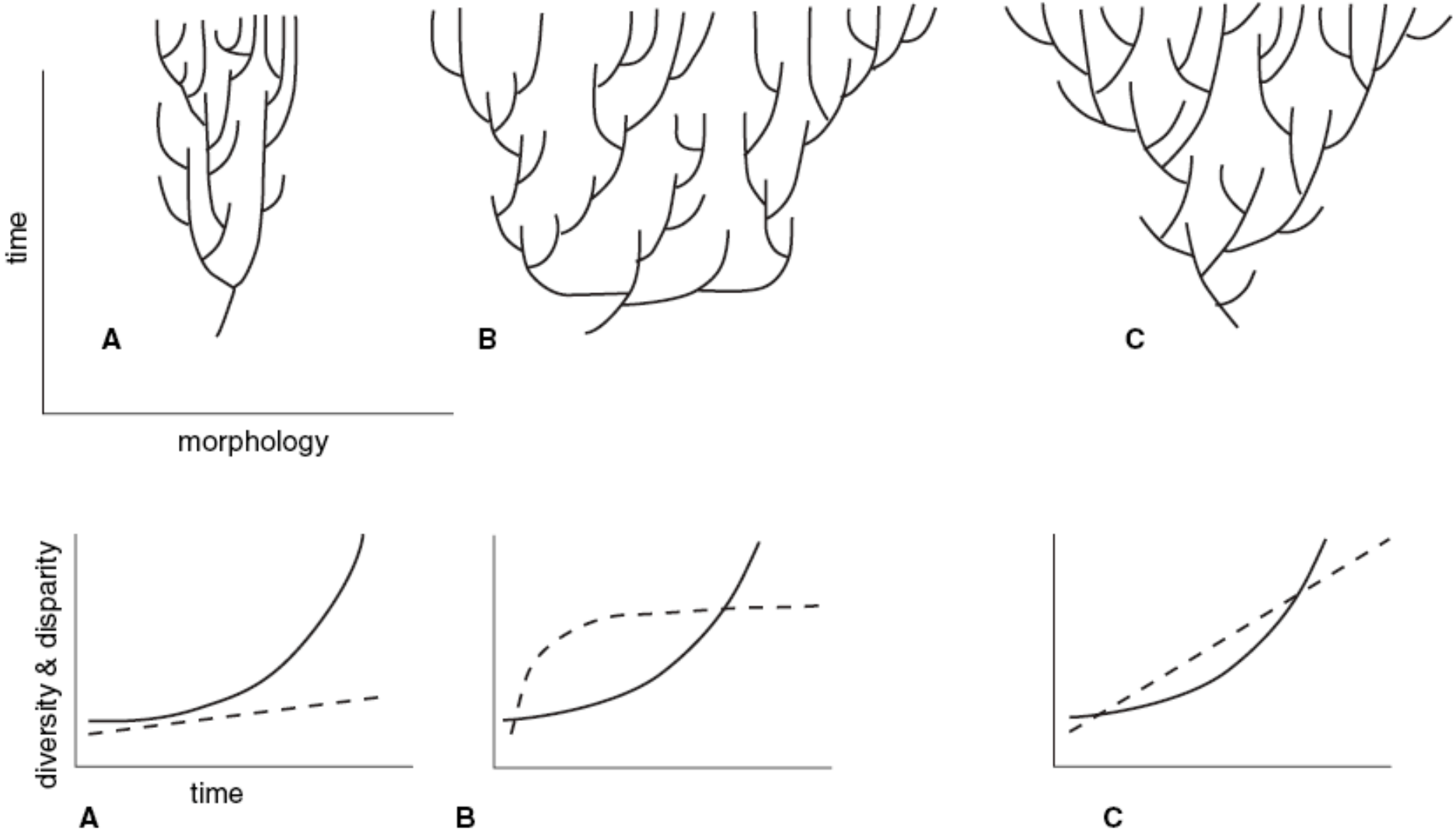


1.17. The false but still conventional iconography of the cone of increasing diversity, and the revised model of diversification and decimation, suggested by the proper reconstruction of the Burgess Shale.


Blastoidea
P
LC
EC
D2
D1
S
-0.5
PC1
2.0
-1.0
PC2
1.5


Blastoidea
A
.95
.76
.57
.38
.19
.00
Total variance
LO
S
D1
D2
EC
LC
P
B
60
48
36
24
12
0
Number of genera
464
421
377
333
289
245
Geologic time (Ma)

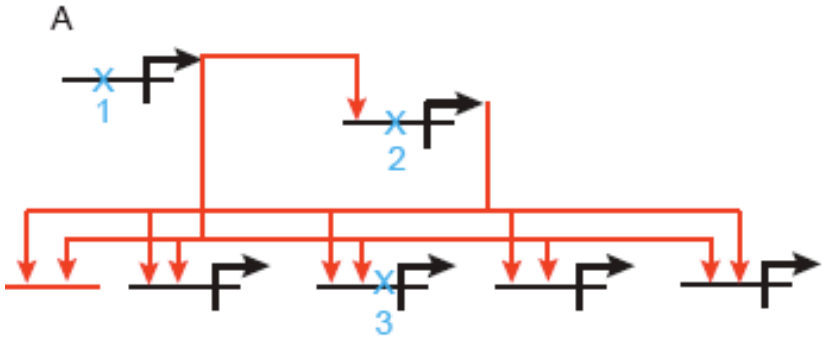
Foote 1993



Wesley-Hunt 2005 after Foote 1993

Developmental Diversity

A



CRM Loss

1 lose expression of whole battery

2 lose expression of whole battery

3 lose expression of differentiation gene

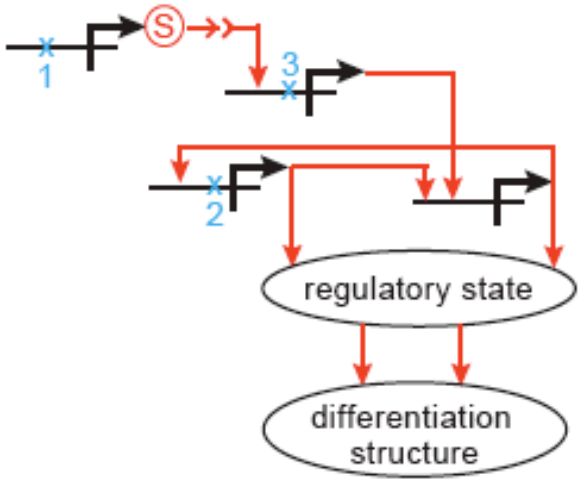
CRM Redeployment

1 battery expressed in a new developmental domain

2 lose expression of whole battery

3 redeploy gene

B



CRM Loss

1 lose development of structure

2 lose stabilization of state; development starts, fades out

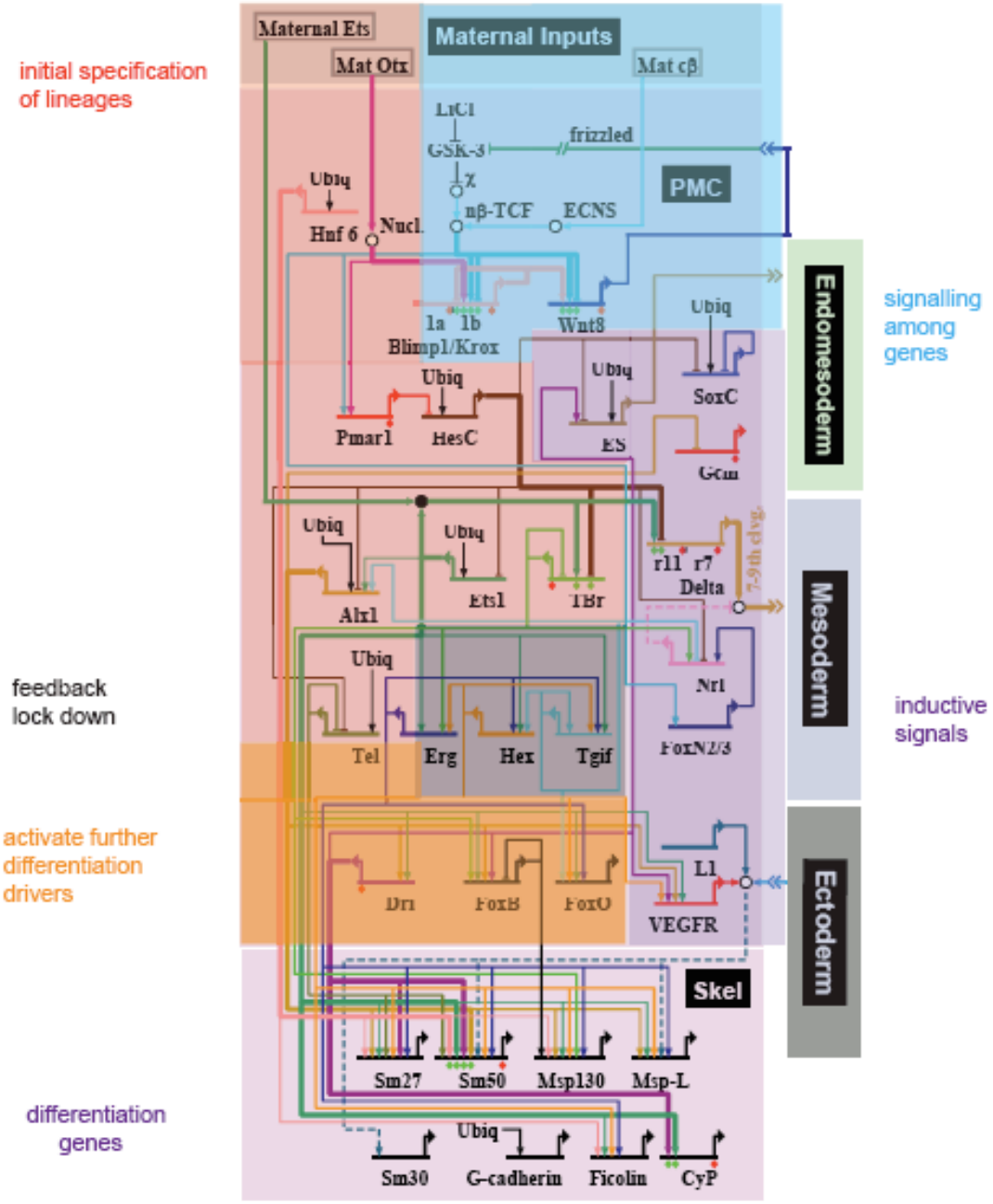
3 lose structure

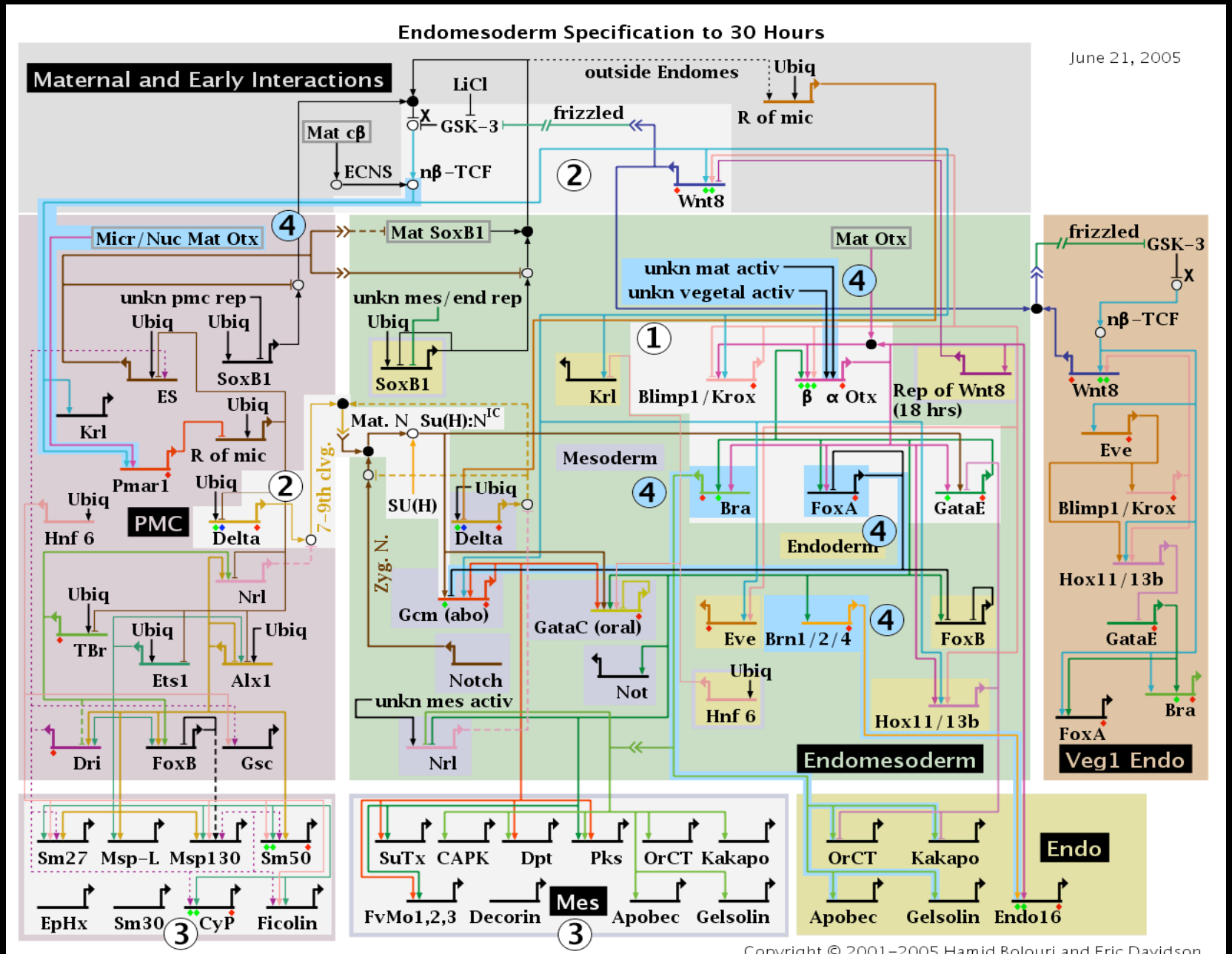
CRM Redeployment

1 can lose subcircuit to be expressed adjacent to new domain and signal expression

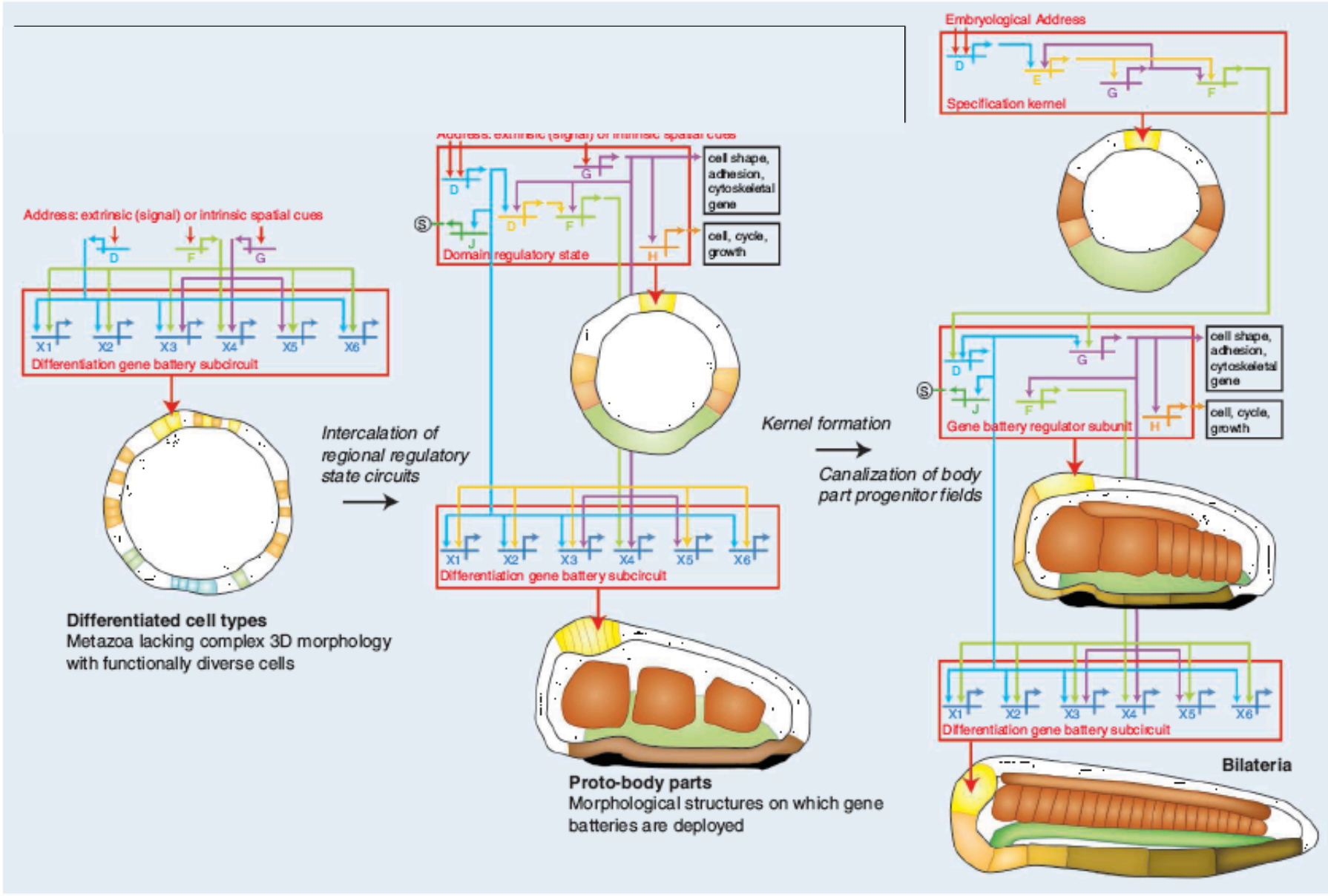
2 lose stabilization of state: development starts, fades out

3 produce structure in another location


initial specification of lineages
Maternal Ets
Mat Otx
Maternal Inputs
Mat cβ
LiCl
GSK-3
frizzled
PMC
Ubiq
χ
nβ-TCF
ECNS
Hnf 6
Nucl
1a
1b
Wnt8
Blimp1/Krox
Ubiq
SoxC
Pmar1
HesC
ES
Gcm
Endomesoderm
signalling among genes
Ubiq
Ubiq
r11
r7
Delta
7-9th elvg.
Alx1
Ets1
TBr
Mesoderm
Ubiq
Nr1
FoxN2/3
Tel
Erg
Hex
Tgif
feedback lock down
inductive signals
activate further differentiation drivers
Dri
FoxB
FoxO
L1
VEGFR
Ectoderm
Skel
Sm27
Sm50
Msp130
Msp-L
differentiation genes
Ubiq
Sm30
G-cadherin
Ficolin
CyP



Sea Urchin endomesoderm GRN



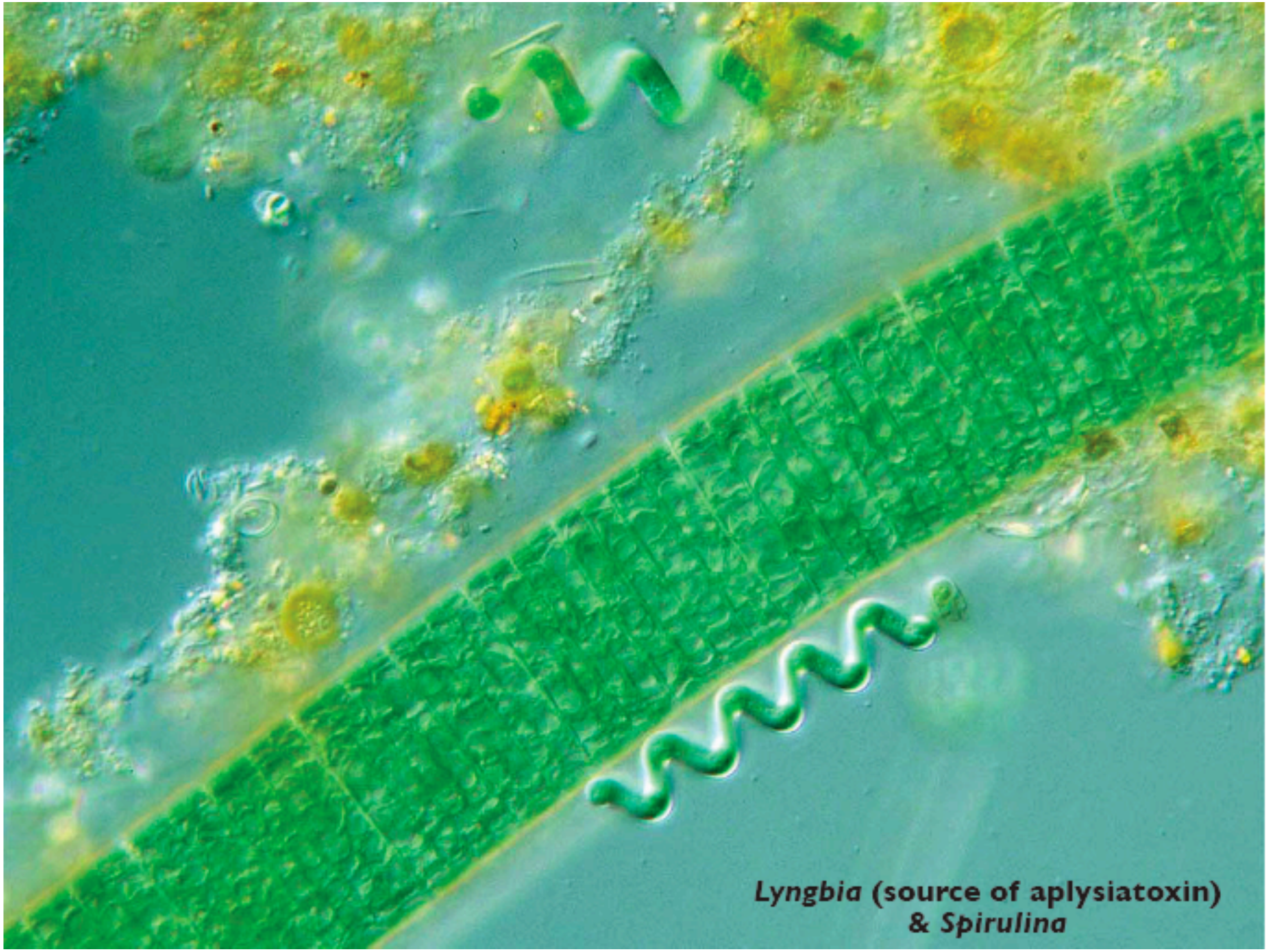
Arendt 2006 after Davidson 2006

Architectural Diversity

How do positive feedback processes influence diversity?

- *Niche Construction*: activities of organisms that influence their environment, often through ecological inheritance and thus affect the fitness of the population

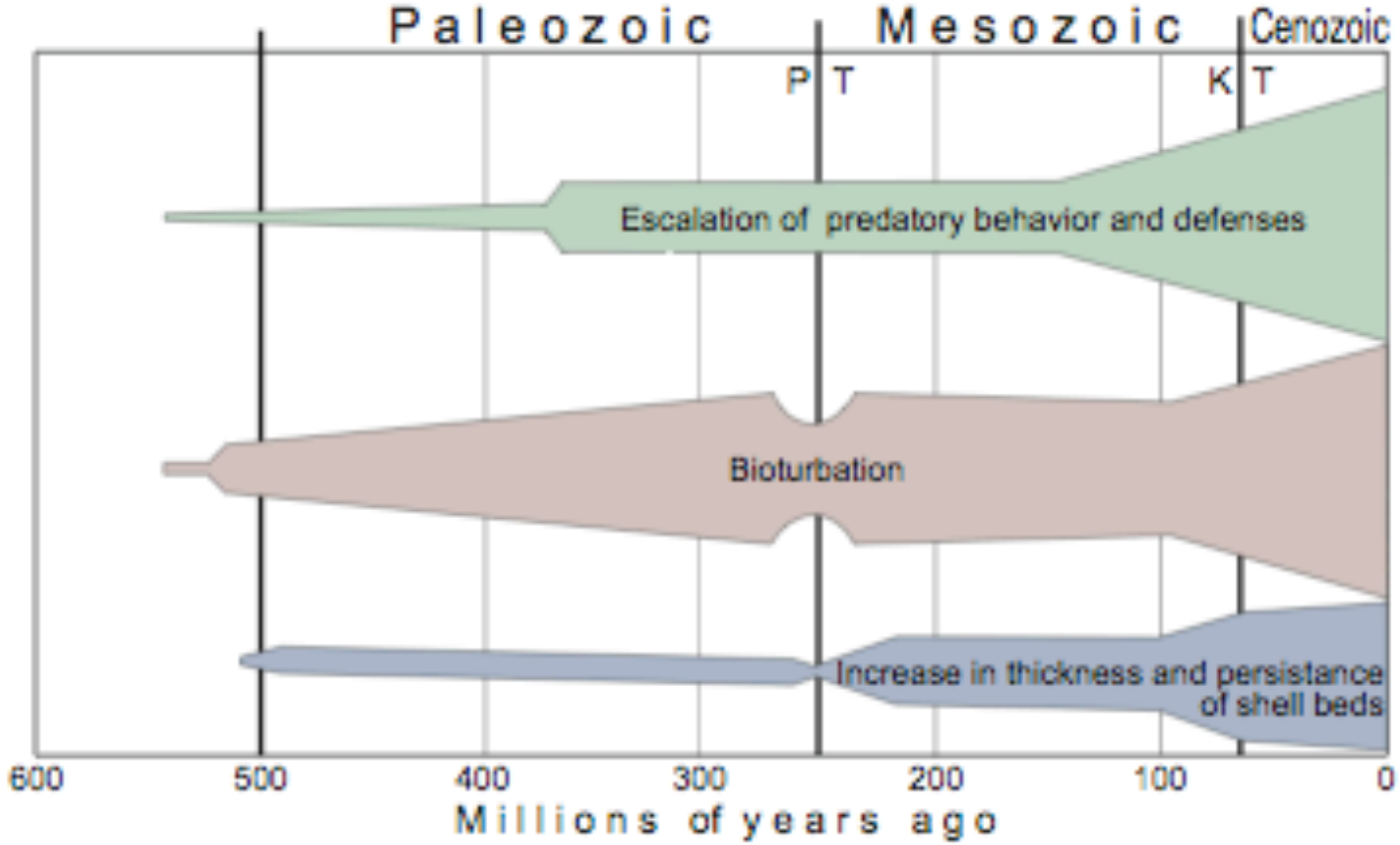
- *Ecosystem Engineering:* modifications to the environment by a species that affects resource availability, either for itself or for other species


Lyngbia (source of aplysiatoxin)
& *Spirulina*

Ecosystem Engineering vs Niche Construction

http://tanzaniaparks.com/cn/tarangire.htm

Ecosystem Engineering & Niche Construction



Erwin, 2008 TREE

Are these different measures of diversity congruent?

- If so, then one (taxa) serves as an easy proxy.
- In fact, we already know that taxic diversity is not a proxy for morphological disparity, and in general it appears that we need independent proxies for each aspect of diversity

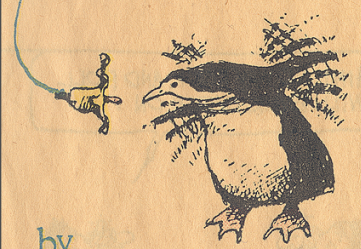
What role does innovation play in the history of diversity?

Each model has different implications for innovation

- ***Coupled logistic***: constrained diversity within each EF; major innovations between faunas
- ***Constrained diversification***: adaptations, occasional innovation but overall constraint

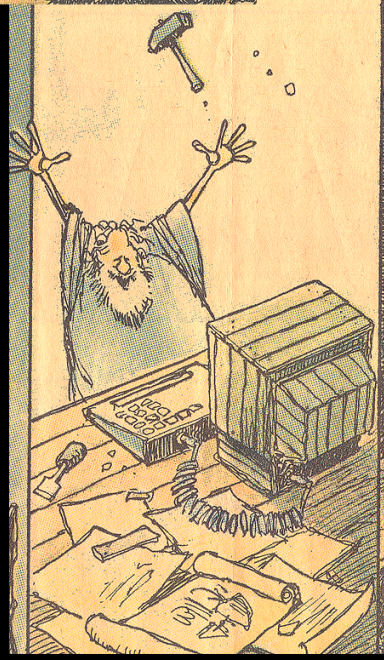
- ***Expanding diversity***: continual expansion
- ***Exponential increase*****:** major innovations fixed following mass extinctions

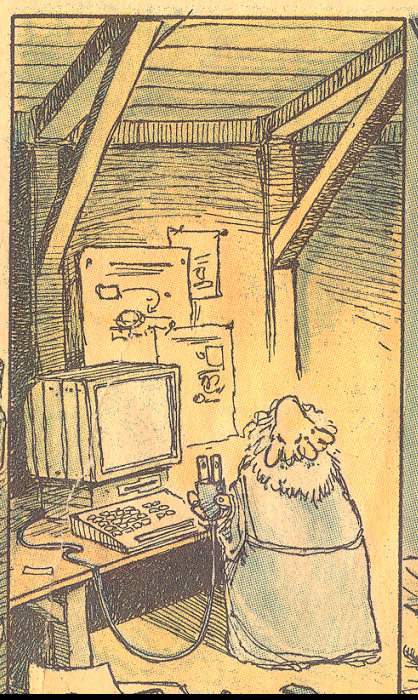
NON SEQUITUR

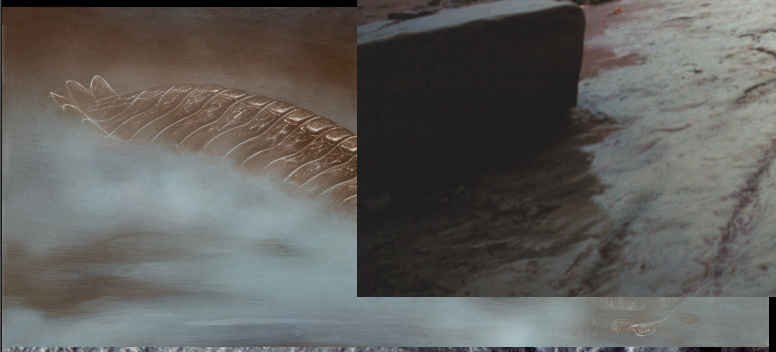


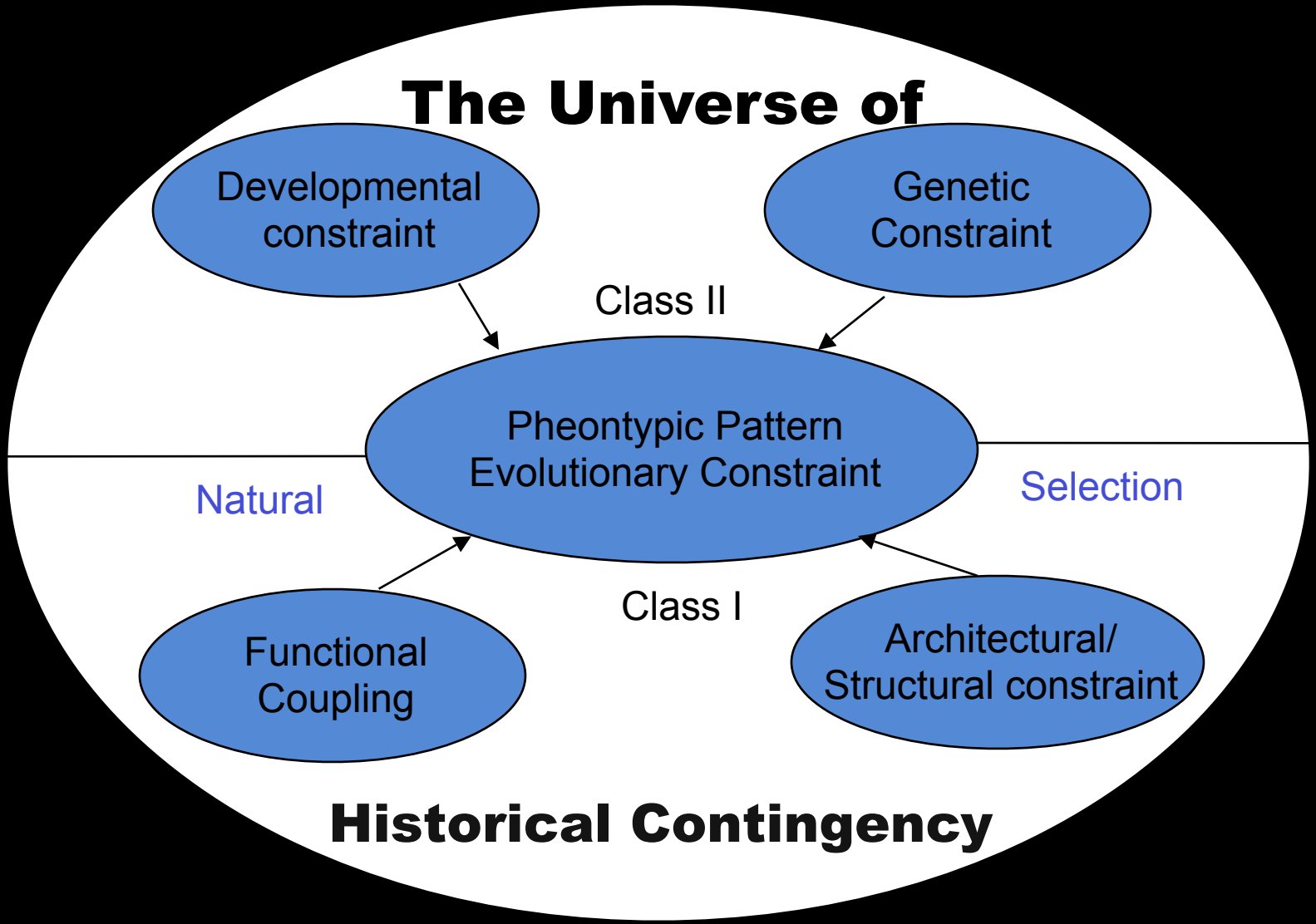
by Wiley

WHY YOU NEVER HEARD ABOUT LEONARDO DA VINCI'S GREATEST INVENTION



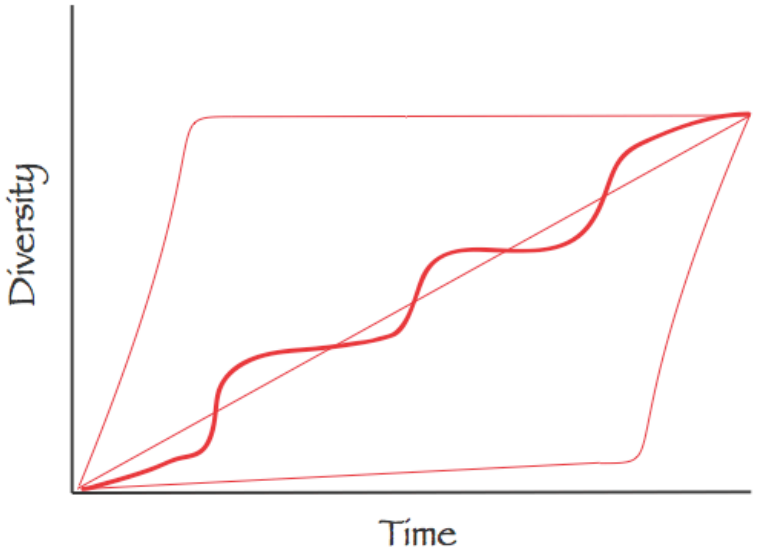






Schwenk 1995

Causes of Increased Diversity



Niche subdivision?

Change in environmental conditions?

Increased nutrient availability?

Adaptations providing access to new resources?