Part 4: Ancient Food Webs

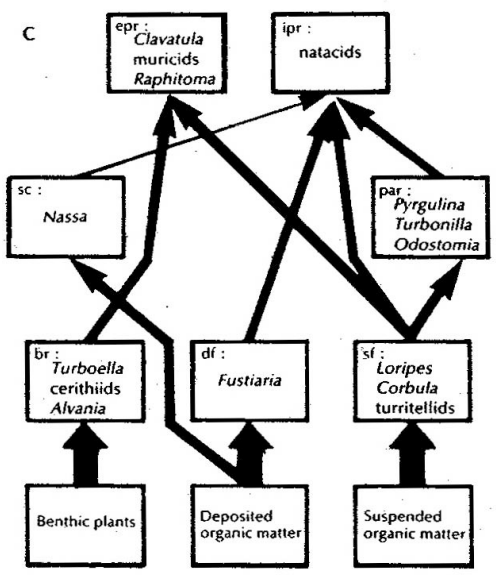
Is it possible to compile detailed paleo food web data?

Are species interactions structured differently
in ancient versus modern ecosystems?

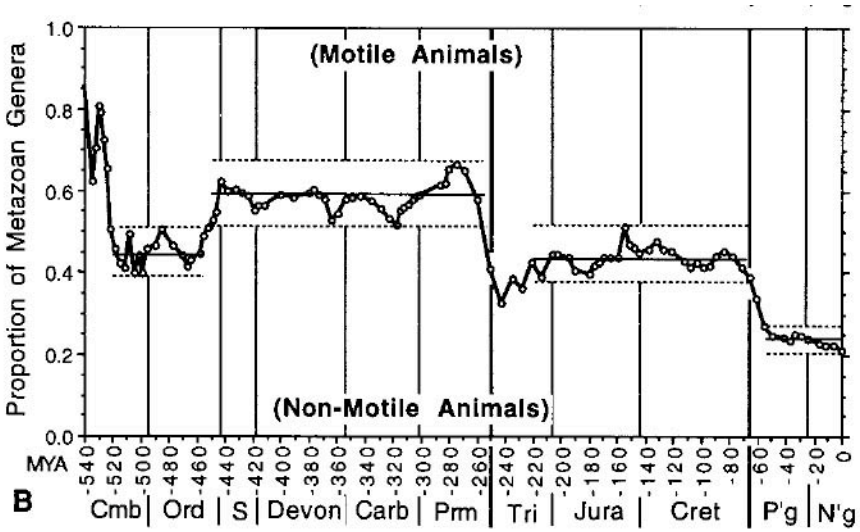
→ Does food-web complexity or structure change across extinction boundaries?
→ Do major evolutionary innovations ramify throughout food webs?
→ Does community structure in a particular basin change through time?
→ How does community structure respond to major environmental perturbations?
→ What do differences/similarities in ecological network structure suggest about fundamental constraints on species interactions?
→ Does invasion of humans into ecosystems alter food webs?

Earlier paleo-community ecology research

Miocene (14 Ma) Seagrass Community



Phanerozoic Marine Animal Diversity

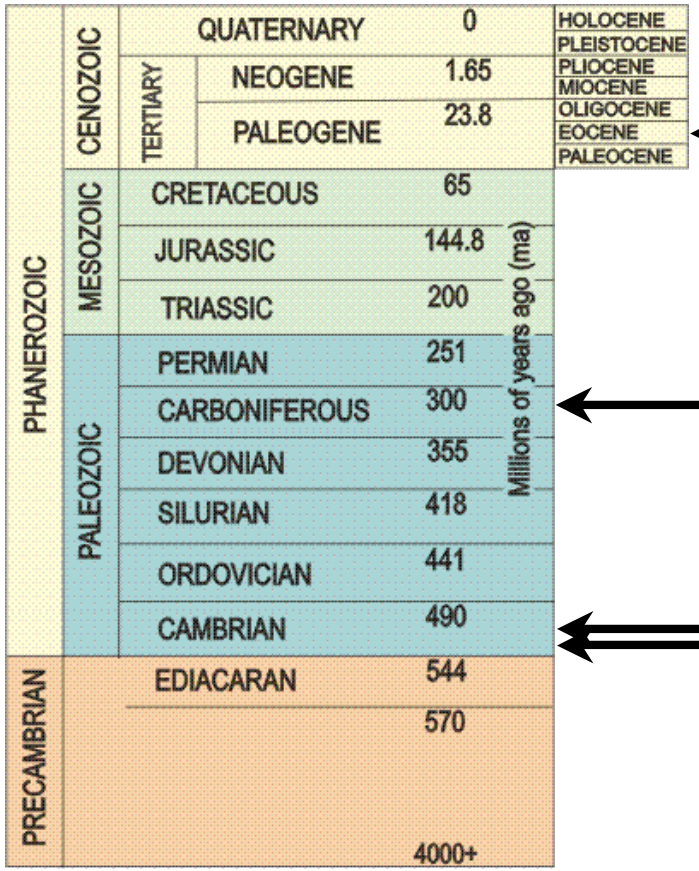


Resolution/Aggregation Issues!

Hoffman A (1979) A consideration upon macrobenthic assemblages of the Korytnica Clays. *Acta Geologica Polonica* 29:345-352.

Bambach RK, et al. (2002) Anatomical & ecological constraints on Phanerozoic animal diversity in the marine realm. *PNAS* 99:6854-6859.

Geologic time scale



Messel Shale (49 Ma)

Ames Limestone/Shale (320 Ma)

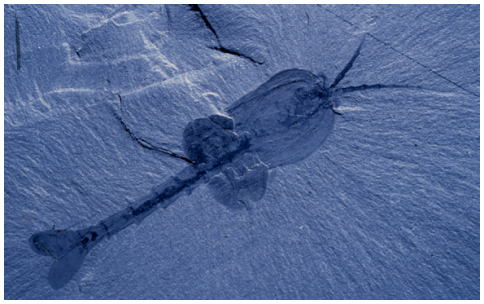
Burgess Shale (505 Ma)

Chengjiang Shale (520 Ma)

Burgess Shale Biota

Wiwaxia

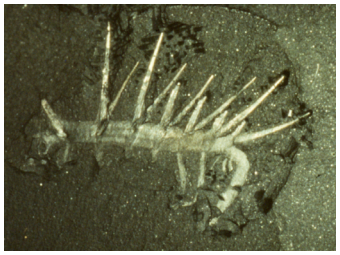
Waptia



Marella

Anomalocaris

Hallucigenia

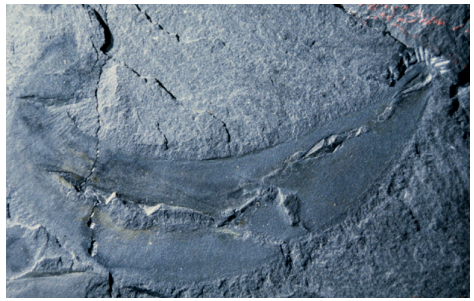


Opabinia

Ollenoides

Pikaia

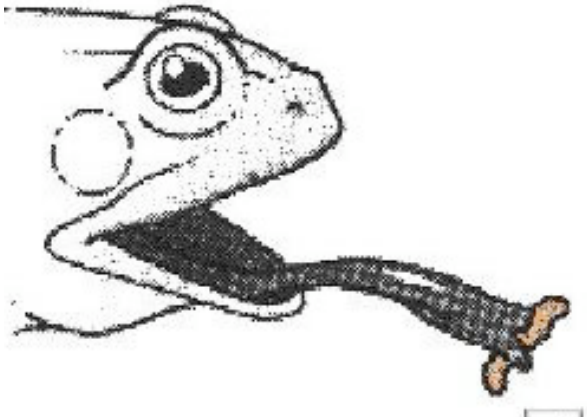
Ottoia



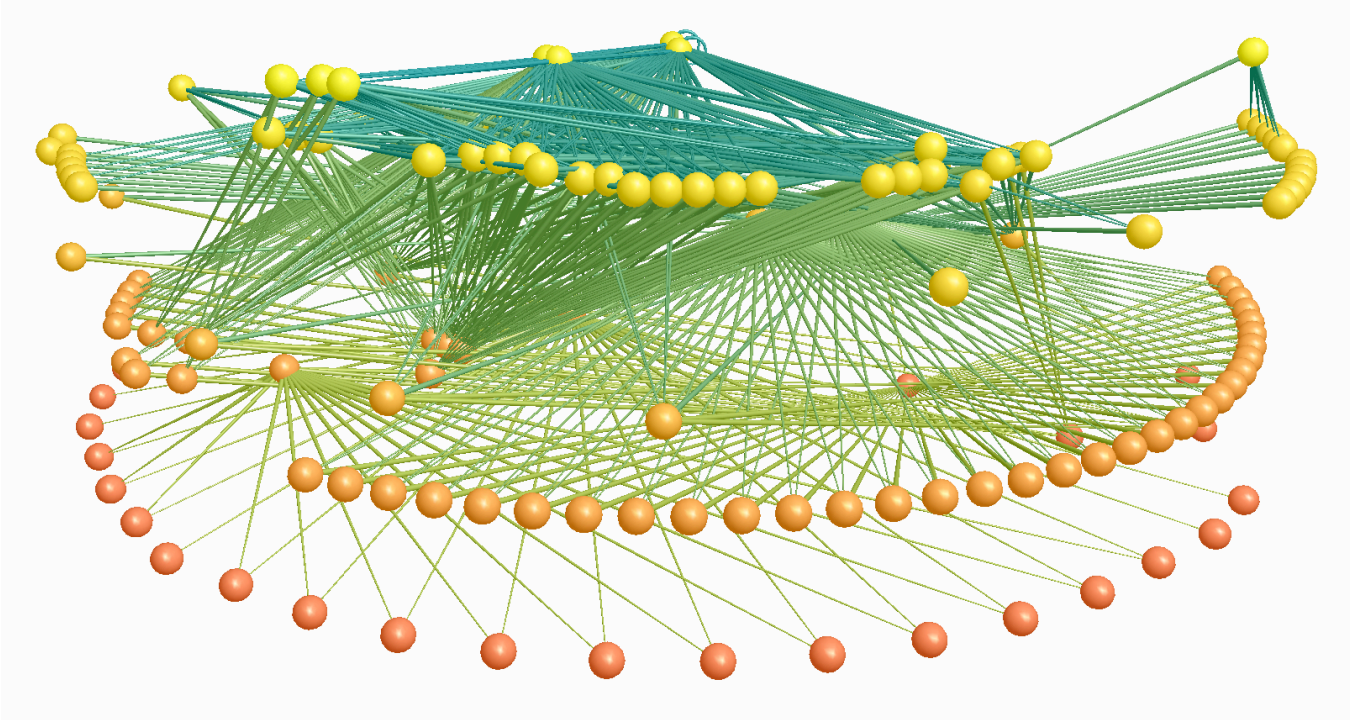
Lines of evidence for feeding links

- Body size
- By analogy with associated taxa
- Damage patterns
- Environmental deposition
- Functional morphology
- Gut contents
- Stable isotopes
- Trace fossils
- Coprolites
- The occasional smoking gun….

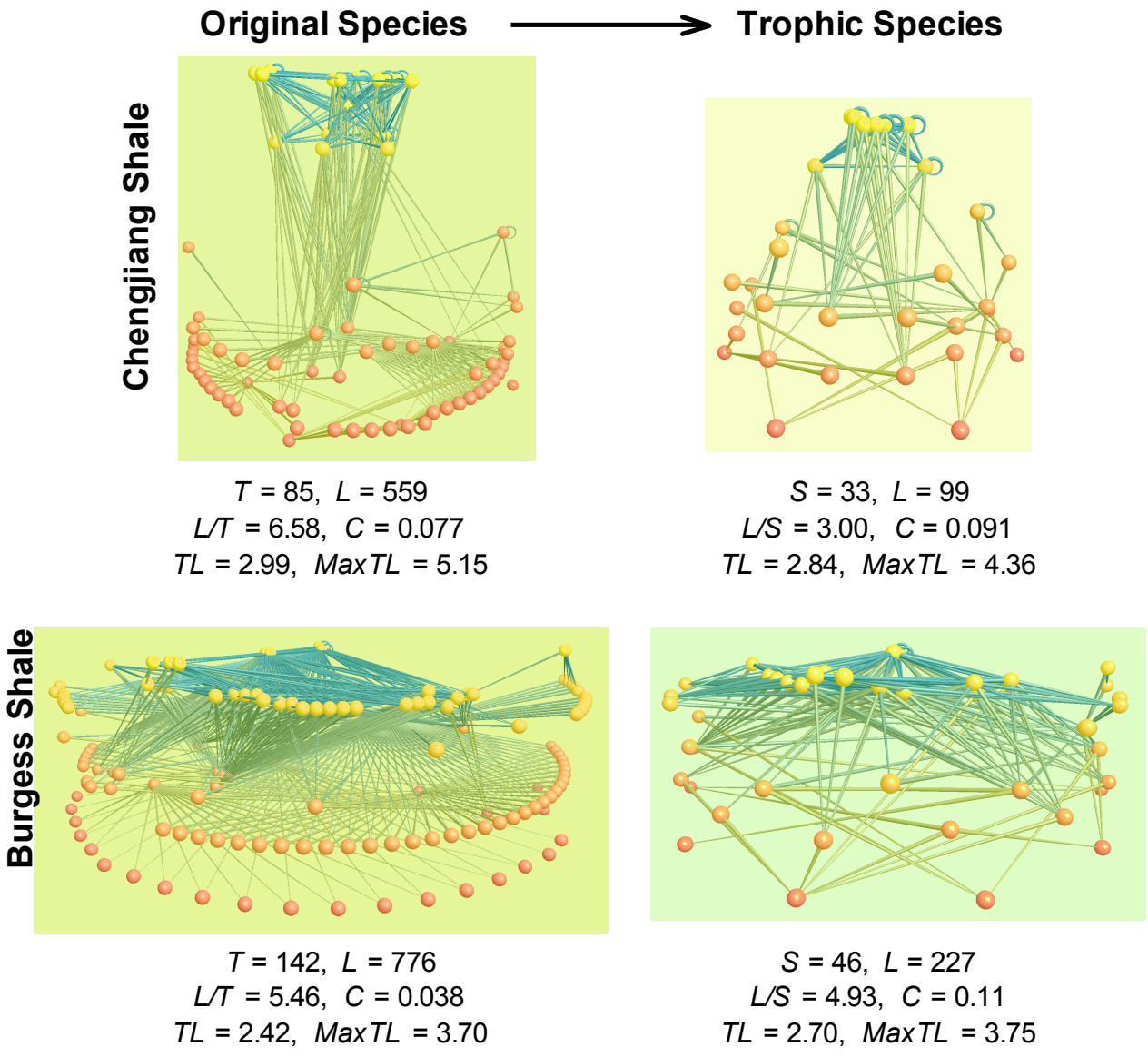
An Exquisitely Preserved Frog Tongue with Last Insect Meal and Other Exceptional Frozen Behavior in Dominican Amber



Burgess Shale Food Web

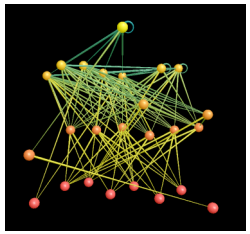


85 Species, 559 Links, 6.6 Links/Species, 0.08 Connectance (L/S^2)
Mean Trophic Level = 2.99, Maximum Trophic Level = 5.15

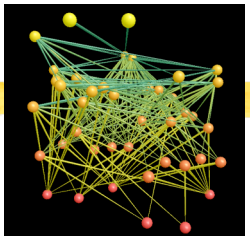

Original Species
Trophic Species
Chengjiang Shale
T = 85, L = 559
L/T = 6.58, C = 0.077
TL = 2.99, MaxTL = 5.15
S = 33, L = 99
L/S = 3.00, C = 0.091
TL = 2.84, MaxTL = 4.36
Burgess Shale
T = 142, L = 776
L/T = 5.46, C = 0.038
TL = 2.42, MaxTL = 3.70
S = 46, L = 227
L/S = 4.93, C = 0.11
TL = 2.70, MaxTL = 3.75

We may perhaps therefore see in the process of evolution an increase in diversity at an increasing rate till the early Paleozoic, by which time the familiar types of community structure were established.

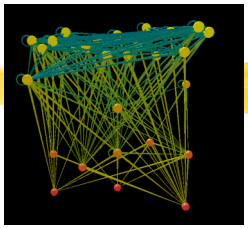
G. Evelyn Hutchinson, 1959, *The American Naturalist*
Homage to Santa Rosalia or Why Are There So many Kinds of Animals?



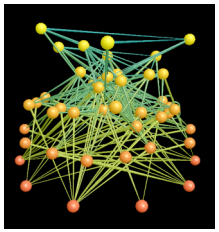
Bridge Brook (lake)



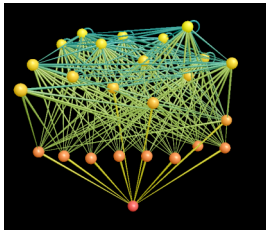
St. Martin (terrestrial)



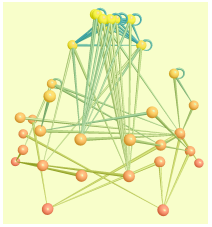
Coachella Valley (terrestrial)



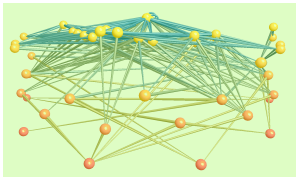
St. Marks (estuary)



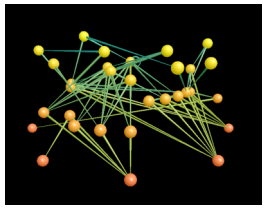
Skipwith (pond)



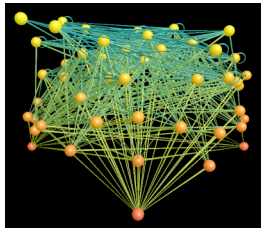
Chengjiang (marine)



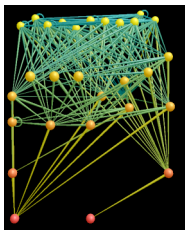
Burgess (marine)



Chesapeake Bay (estuary)



Caribbean Reef (marine)



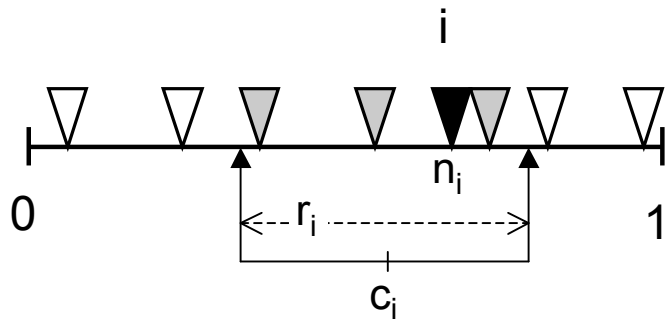
Benguela (marine)

17 food-web properties:

- % Top spp.
- % Intermediate spp.
- % Basal spp.
- % Cannibal spp.
- % Herbivore spp.
- % Omnivore sp.
- % Species in loops
- Mean chain length
- Chain length SD
- Log number of chains
- Mean trophic level
- Mean max. trophic simil.
- SD vulnerability (#pred.)
- SD generality (#prey)
- SD links (total links)
- Mean short path length
- Clustering coefficient

Niche model: Benchmark for comparison

A way to compare ecological networks with different numbers of species and links



For each empirical food web, use its *S* and *L* to generate 1000 niche model webs. For each set of 1000 model webs, calculate a mean value for each of 17 food-web properties and its standard deviation.

normalized error (NE) = (model mean – empirical value)/SD of model values

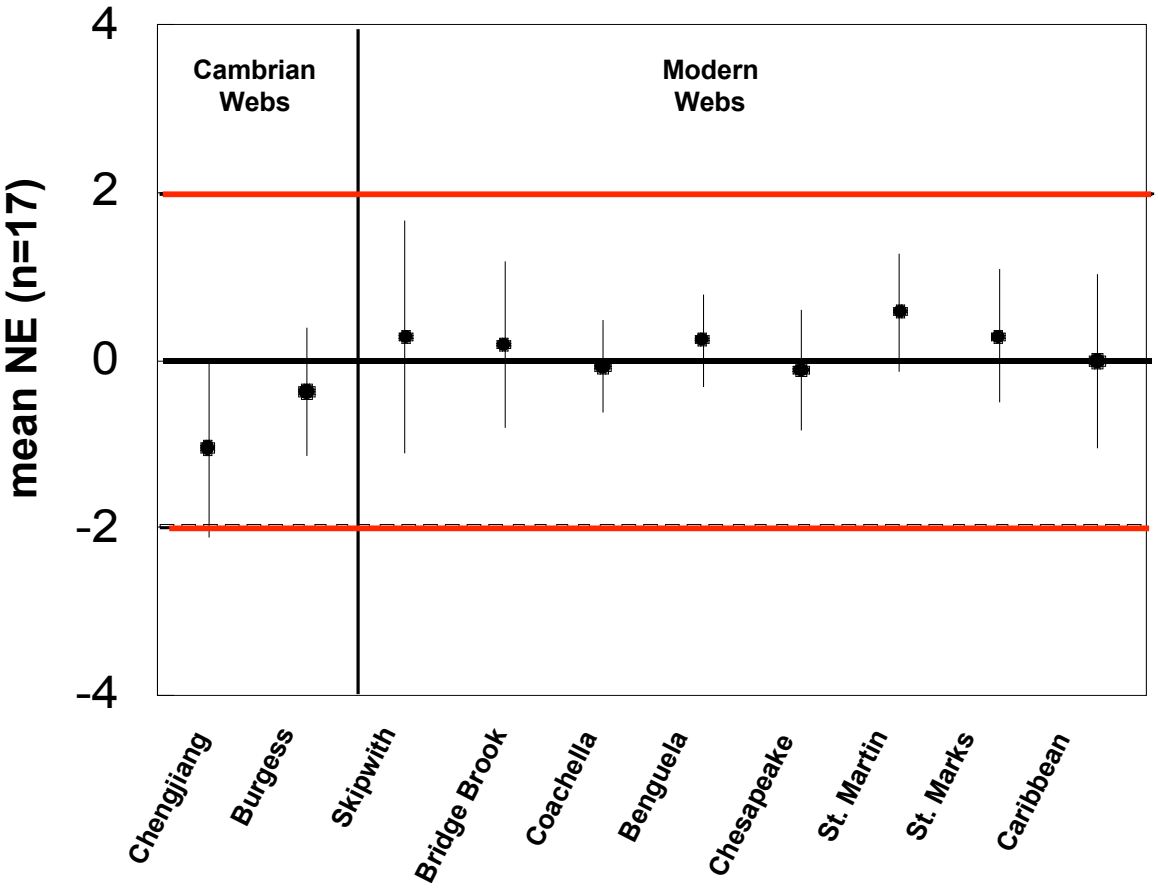
NE shows how closely the niche model estimates the empirical value of a structural property for a particular web

NE = 0 → perfect model estimation of the property
NE > 0 → model overestimated the property
NE < 0 → model underestimated the property

NEs within ±2 indicate a good fit of the model to the data

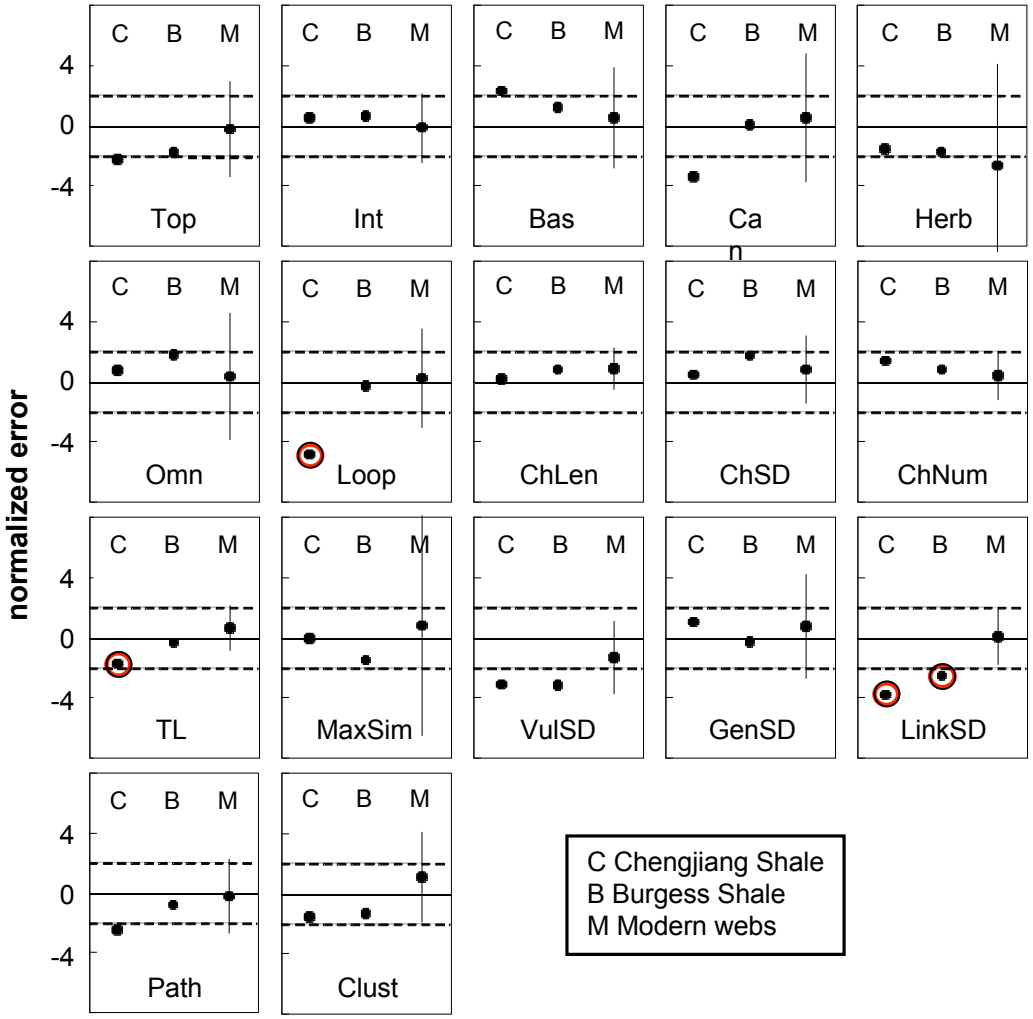
Normalized Error (NE) = how closely the model estimates the network structure

NEs within ±2 indicate a good fit of the model to the data



On average, Cambrian web network structure does not differ significantly from that of modern webs. However, Cambrian food-web property values (esp. Chengjiang) are greater than expected for their *S* & *L* than seen in modern webs

NEs for two Cambrian webs compared to mean NEs across 8 modern webs, for each of 17 food-web network structure properties



show NEs for Cambrian webs that fall outside 95% confidence limits of modern web NE distributions

3 of 17 Chengjiang NEs
- **-SD of # of Predator + Prey**
- **-Mean Trophic Level**
- **-% Species in Loops**

1 of 17 Burgess NEs
- **-SD of # of Predator + Prey**

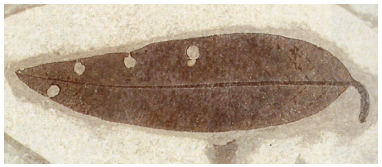
Only 4 of 34 Cambrian network structure property NEs significantly differ from modern web property NEs

Paleo Summary

- For the first time, we have compiled detailed species interaction data for ancient ecosystems, going back to the early Phanerozoic and the radiation of multicellular life on Earth (>500 Ma).
- The structure of Cambrian food webs is remarkably similar to modern food webs (and the niche model predicts the structure of all the webs quite closely).
- Differences in Early Cambrian community structure may result from as-yet unfilled ecological niche space during '*de novo*' ecosystem construction.
- Persistence of ecological network structure through deep time is suggestive of strong constraints on community organization (bioenergetic, network dynamical stability, thermodynamic, ???).
- Novel areas of research are possible that tie together structure, dynamics, function, and constraint at the intersection of ecology and macroevolution.

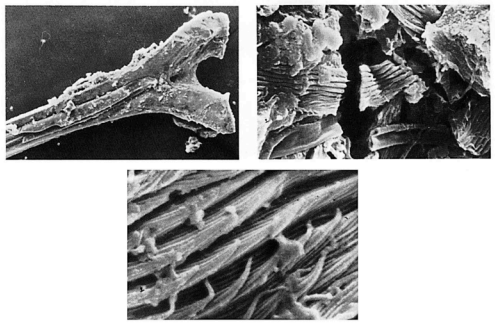
Messel Shale Biota

Laurophyllum
leaf mining



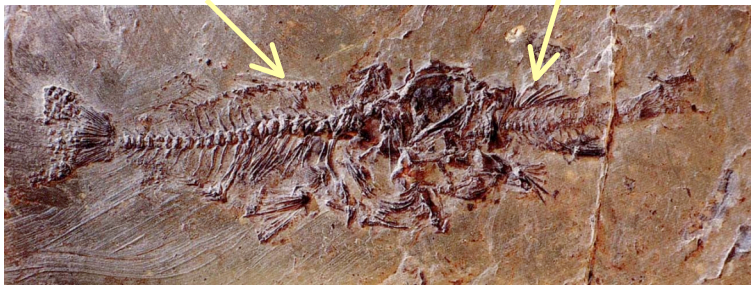
damselfly eggs

Macrocranion
jumping hedgehog
stomach contents



Amphiperca

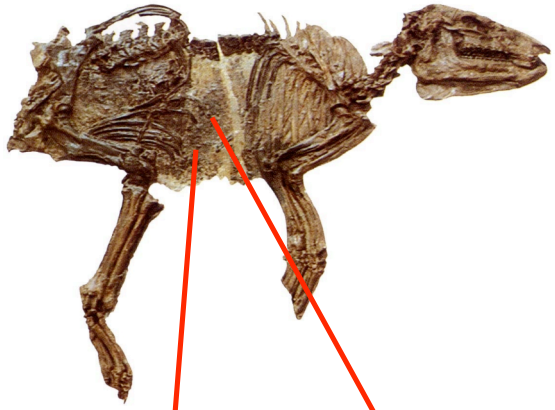
predator prey

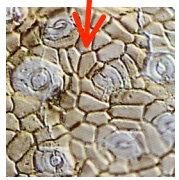


Buprestidae
pollen in gut

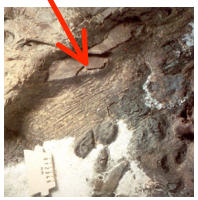
fish and crocodile
coprolites

Propalaeotherium





leaf cuticle



grape seeds

fur

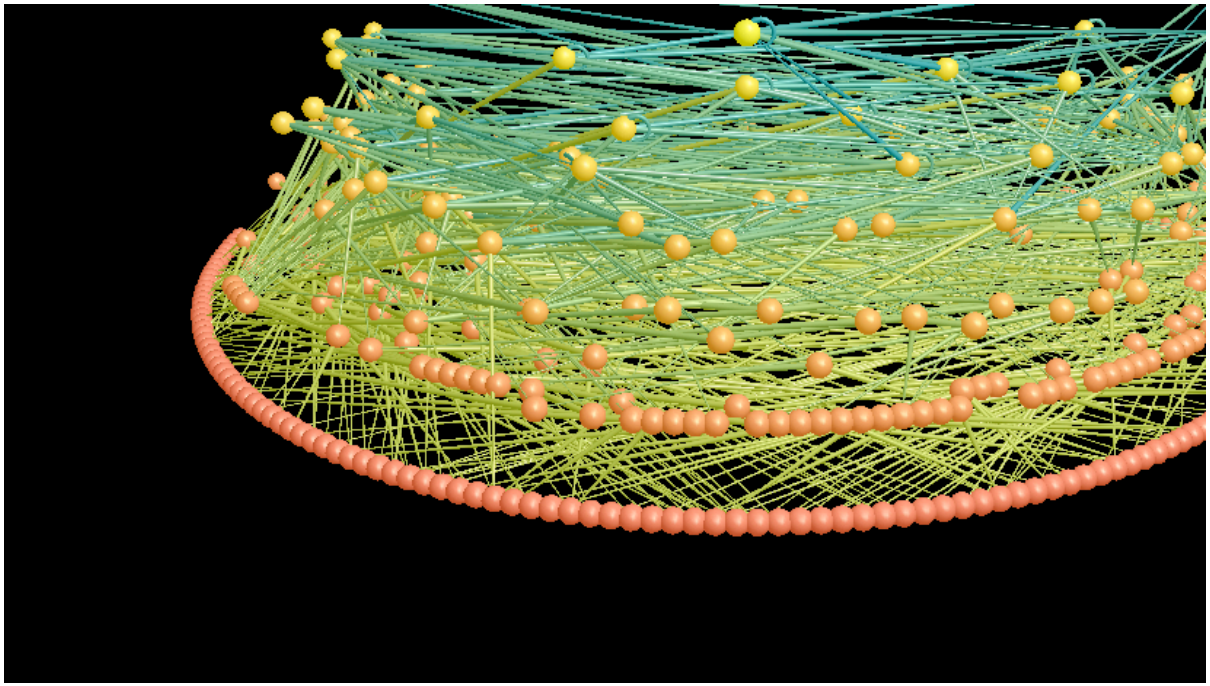
Ailuravus

teeth
(hard seeds)

Schaal, S., and Ziegler, W., (eds.). 1992. *Messel: An Insight into the History of Life and of the Earth*

Messel Shale Food Web

Earliest Middle Eocene Messel Shale in Germany (49 Ma)



Links = 914
C = 1%
L/S = 2.6
Mean TL = 2.1
Max TL = 5.0

35% basal taxa
31% herbivores
7% cannibals
29% omnivores

Original Taxa = 367, Trophic Species = 346

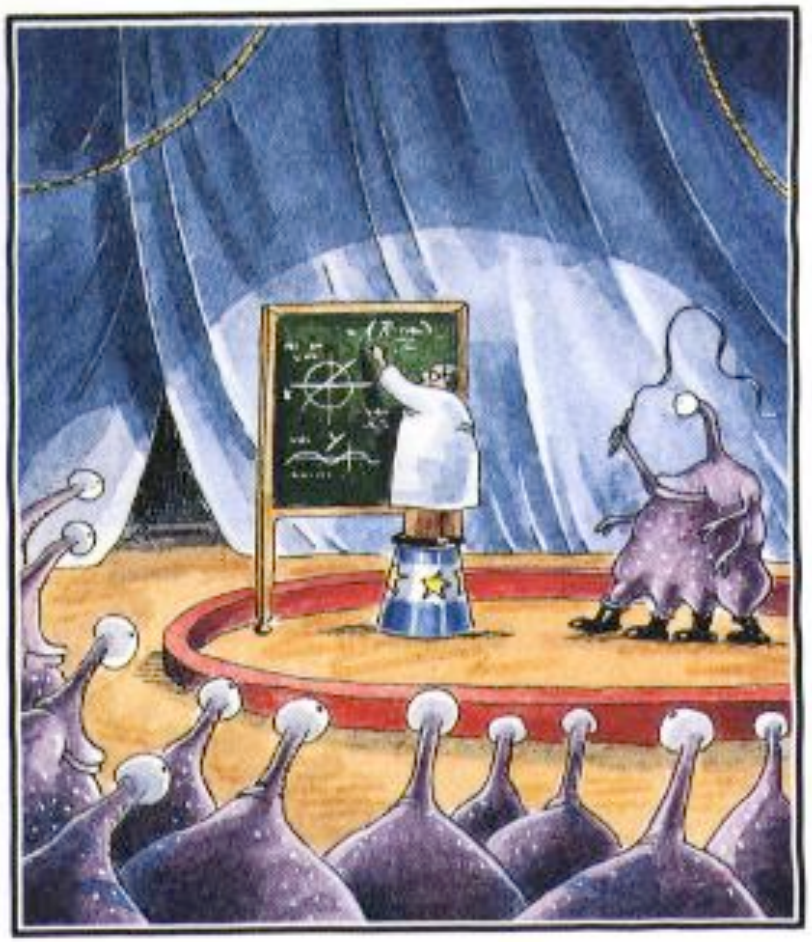
Final Summary

- Food-web structure is similar across ecosystems & through deep time, suggesting strong constraints on how interactions among species can be organized.
- Simple models can generate observed “complex” network structure of food webs.
- Aspects of network structure systematically influence ecosystem robustness to perturbations like biodiversity loss.
- The structure of food-webs appear different in some fundamental ways from the structure of other types of networks.

www.foodwebs.org

PEaCE Lab: Pacific Ecoinformatics And Computational Ecology Lab

Be careful what you learn…



Abducted by an alien circus company, Professor Doyle is forced to write calculus equations in center ring.

For Slides: www.foodwebs.org
(click on people, click on Jennifer Dunne, click on talks, click on summer school lectures)