Food webs in (deep) time

Paleoecology
Deep time + large space

Are there fundamental constraints that determine ecological interactions?

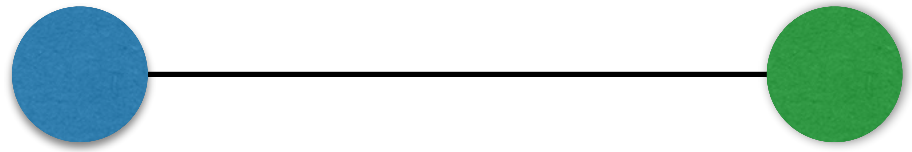
How do animal communities respond to perturbations?

Food web reconstruction

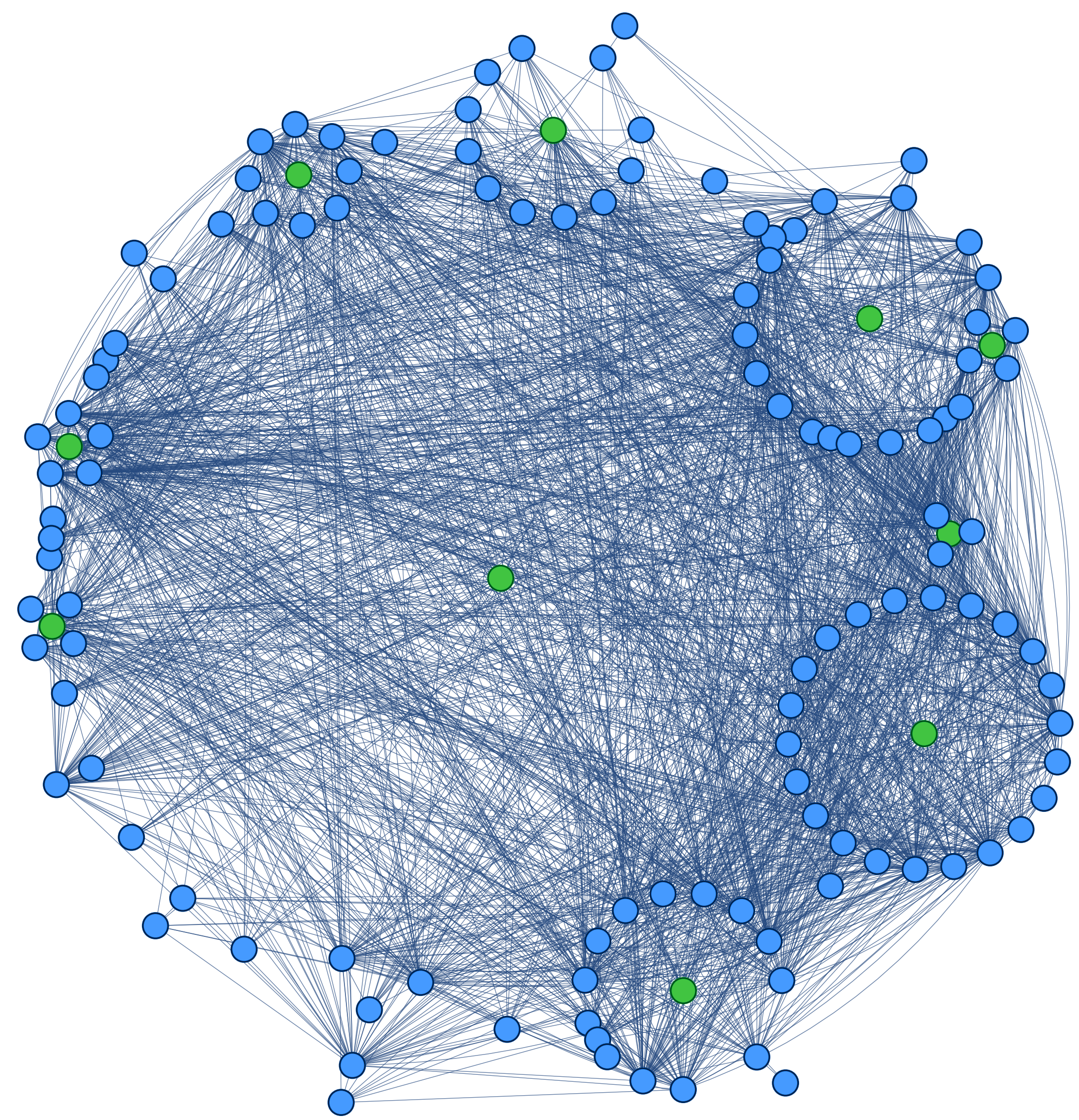
Climatic change and human impact

Dietary, structural, and dynamic consequences

Species interactions in food webs

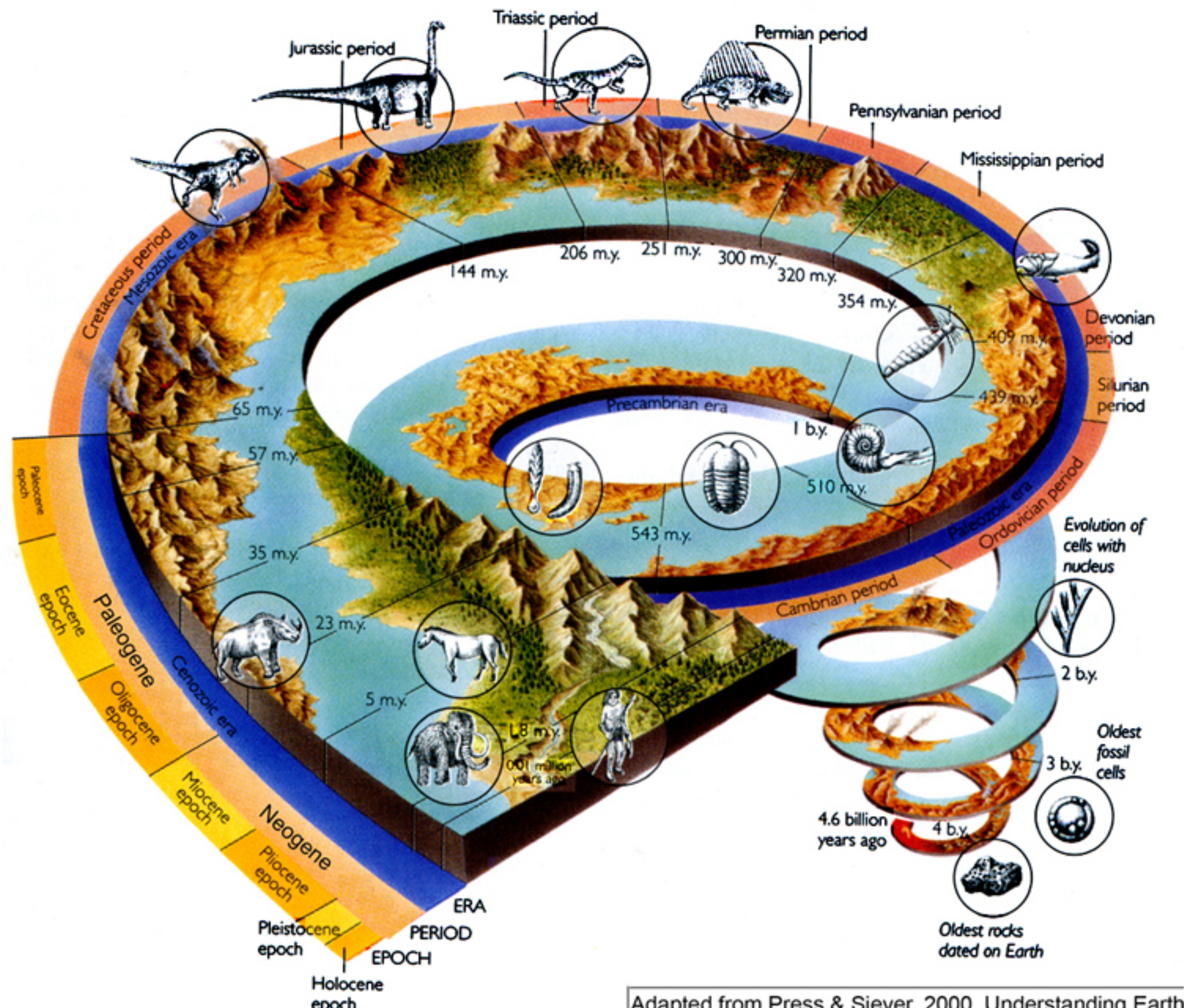


Many ways to measure (all with own biases):
- observation
- gut contents
- stable isotopes
- allometry



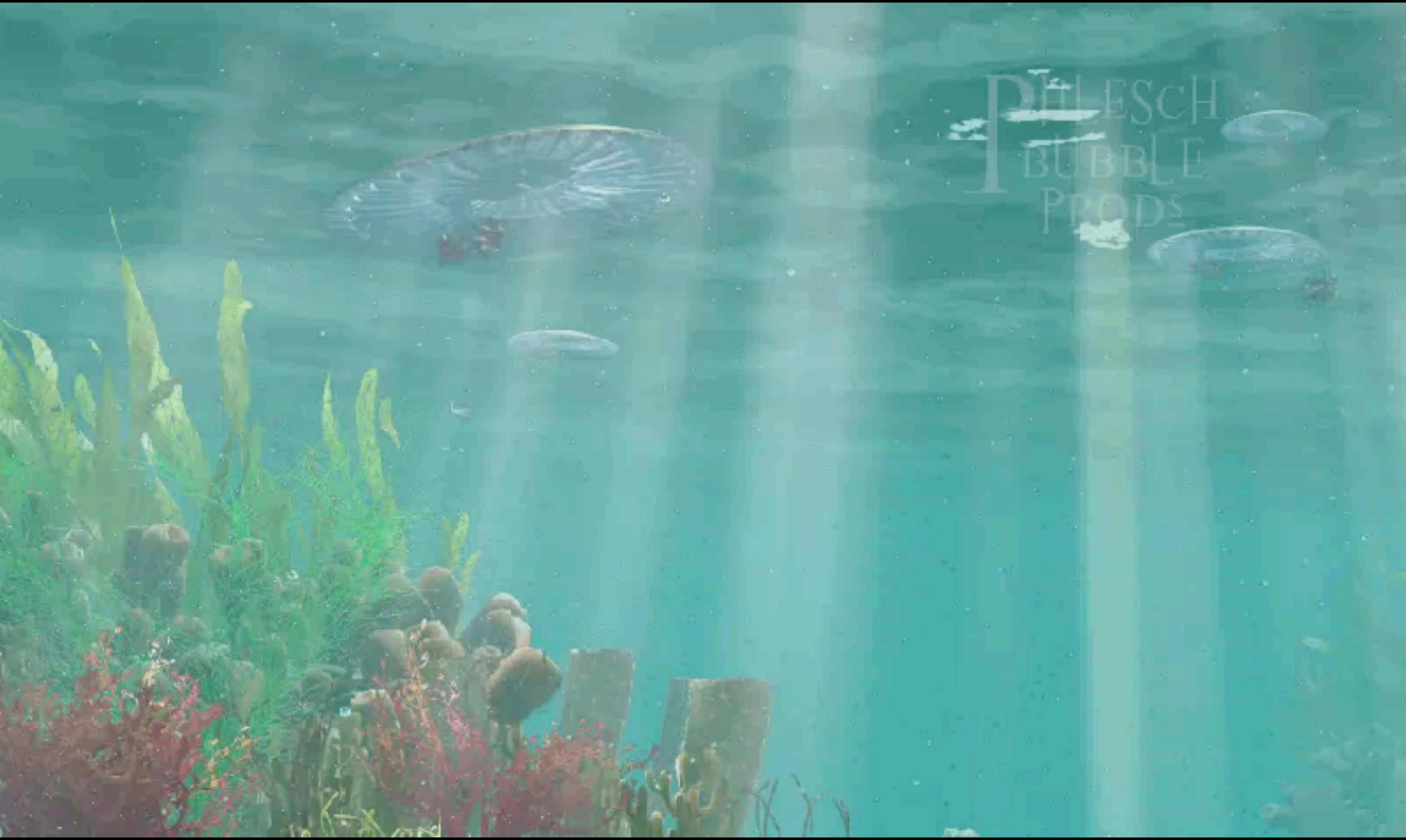
Structure of interactions:
- ecosystem function
- resistance/resilience
- dynamics

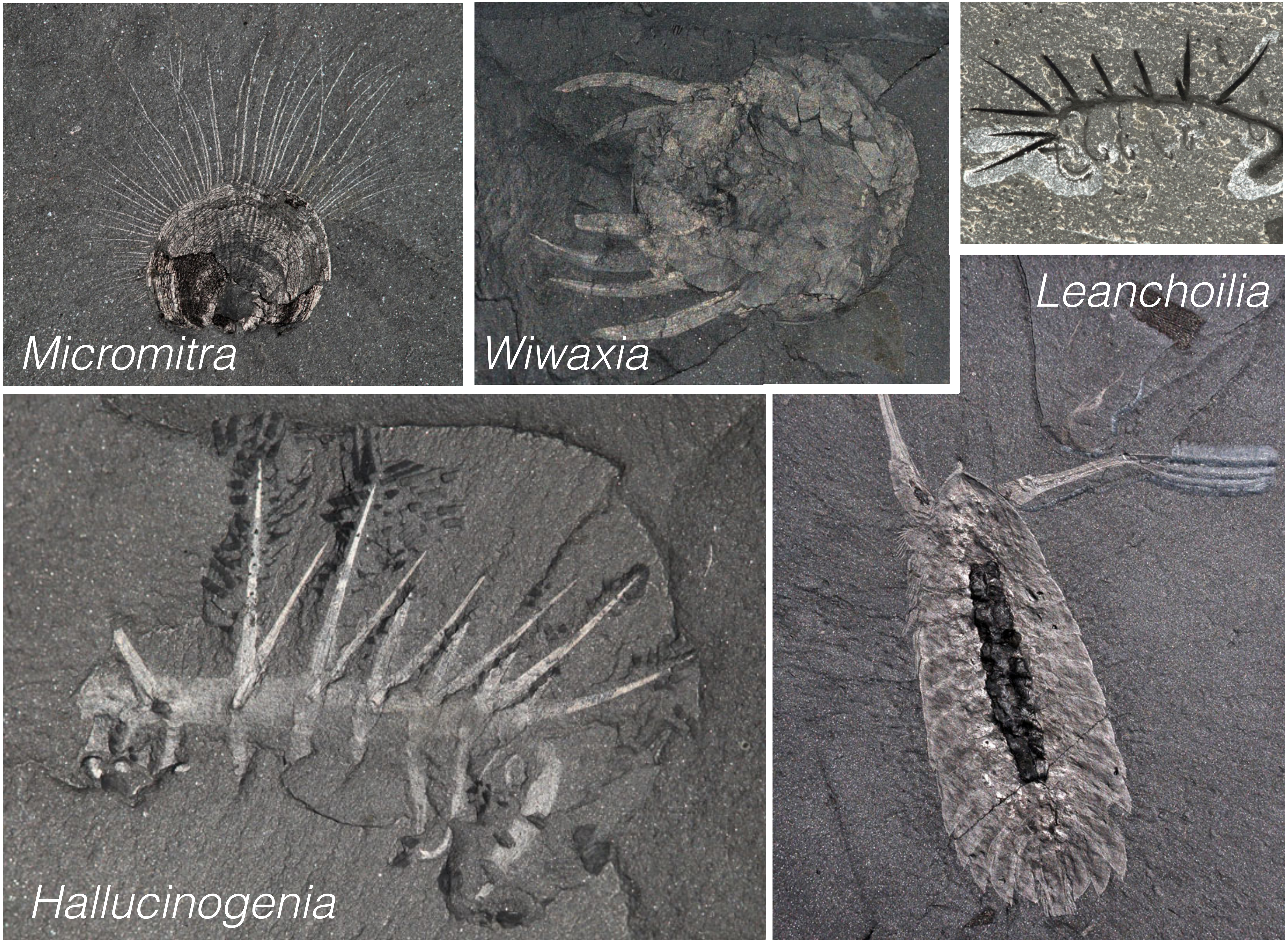
How has the structure of food webs changed over time?



Adapted from Press & Siever, 2000, Understanding Earth

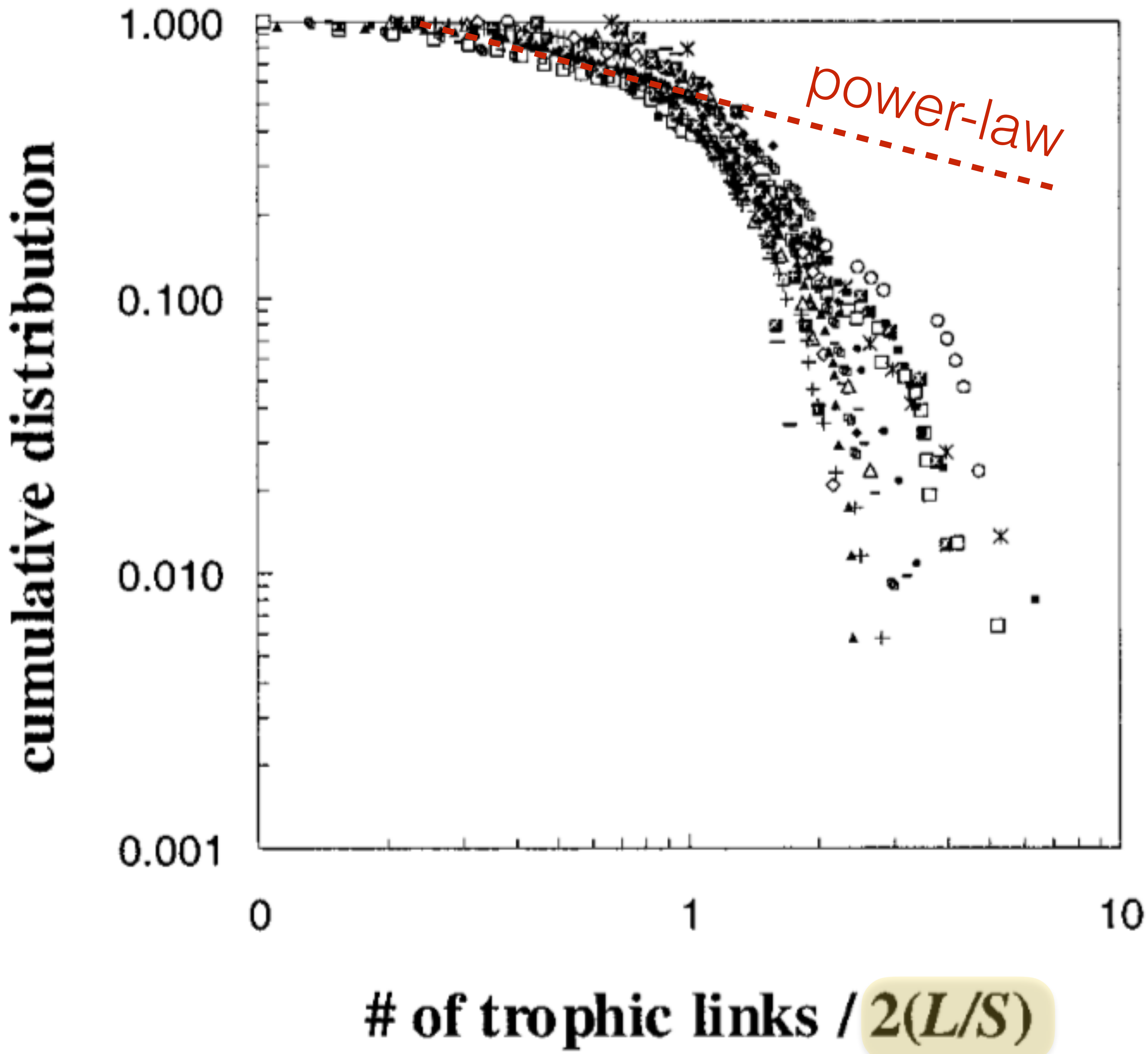
The Cambrian Sea




Micromitra
Wiwaxia
Leanchoilia
Hallucinogenia

The structure of trophic interactions within communities

Scaling the CDFs to 1/2(L/S)…
i.e. controlling for scale dependence

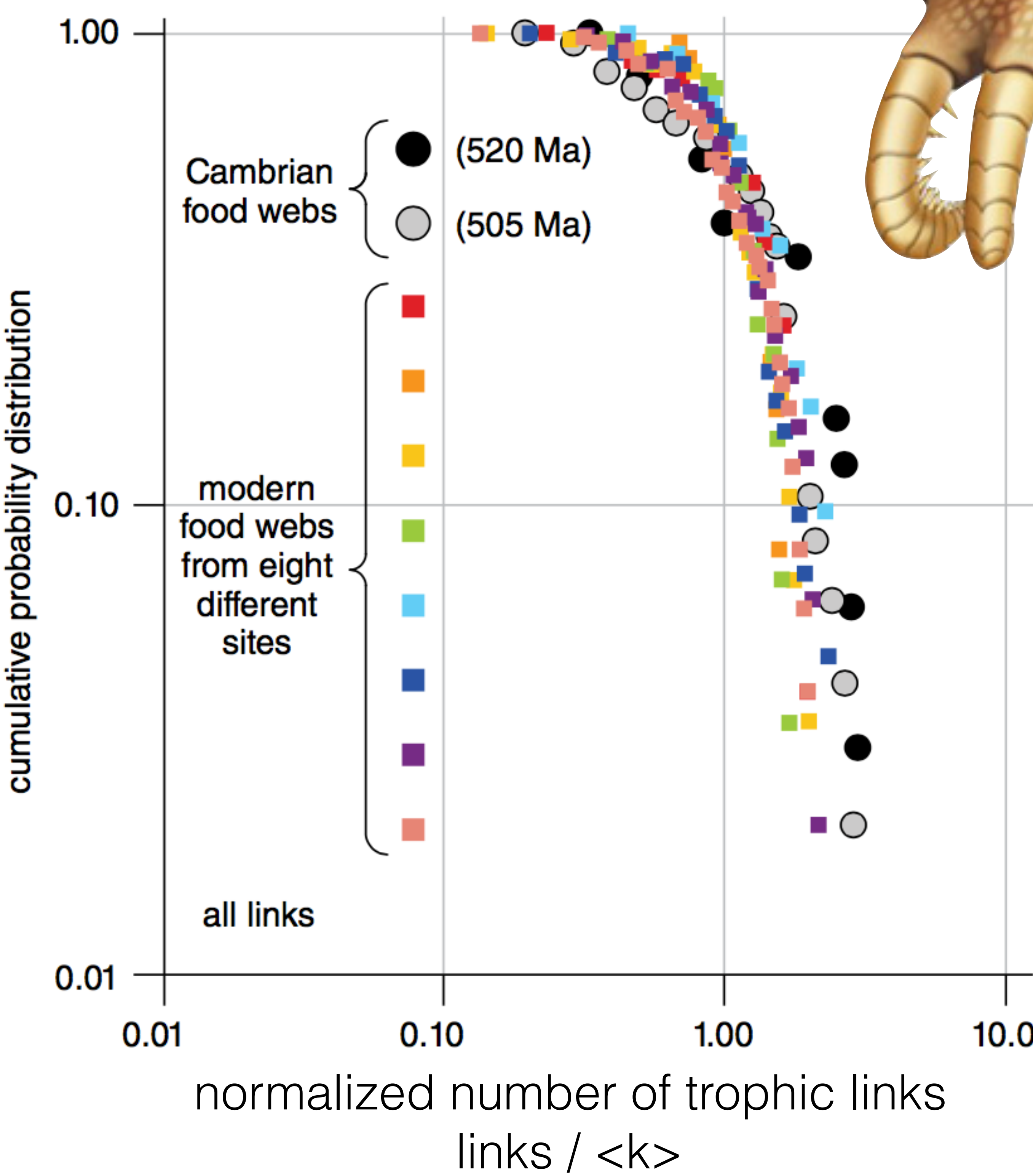


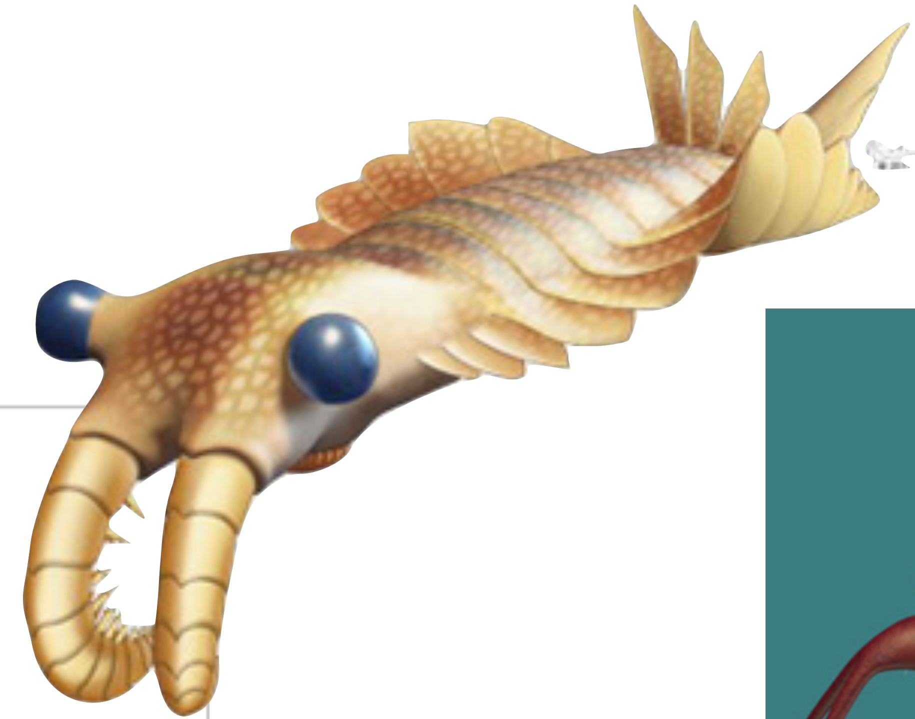
(average degree)

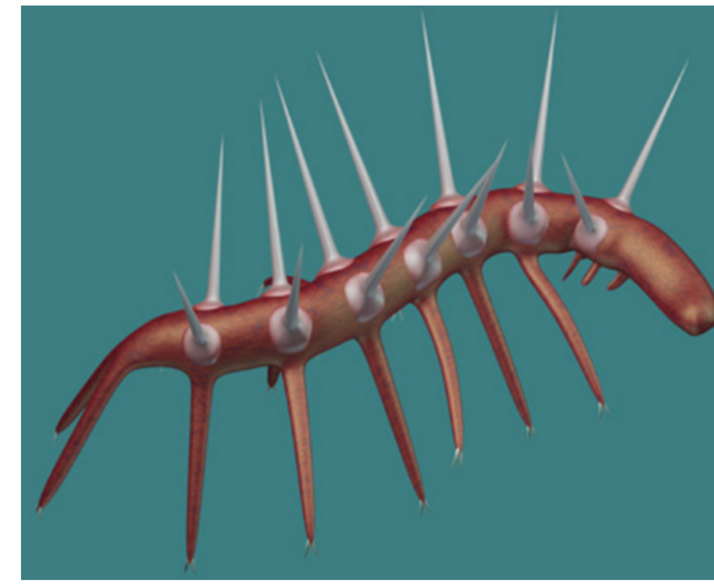
*Distribution tails fall off more quickly than for scale-free nets

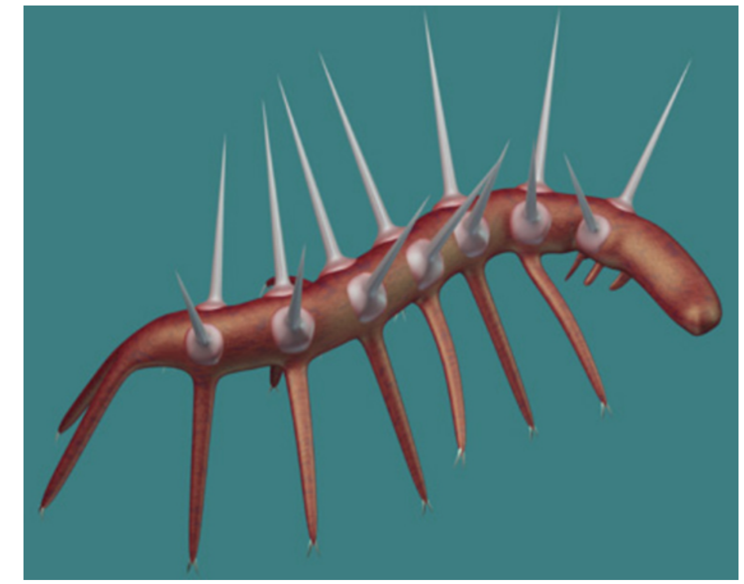
Dunne 2002

Dunne et al. PLoS Biology 2008









<u>There is a fixedness to food webs</u>

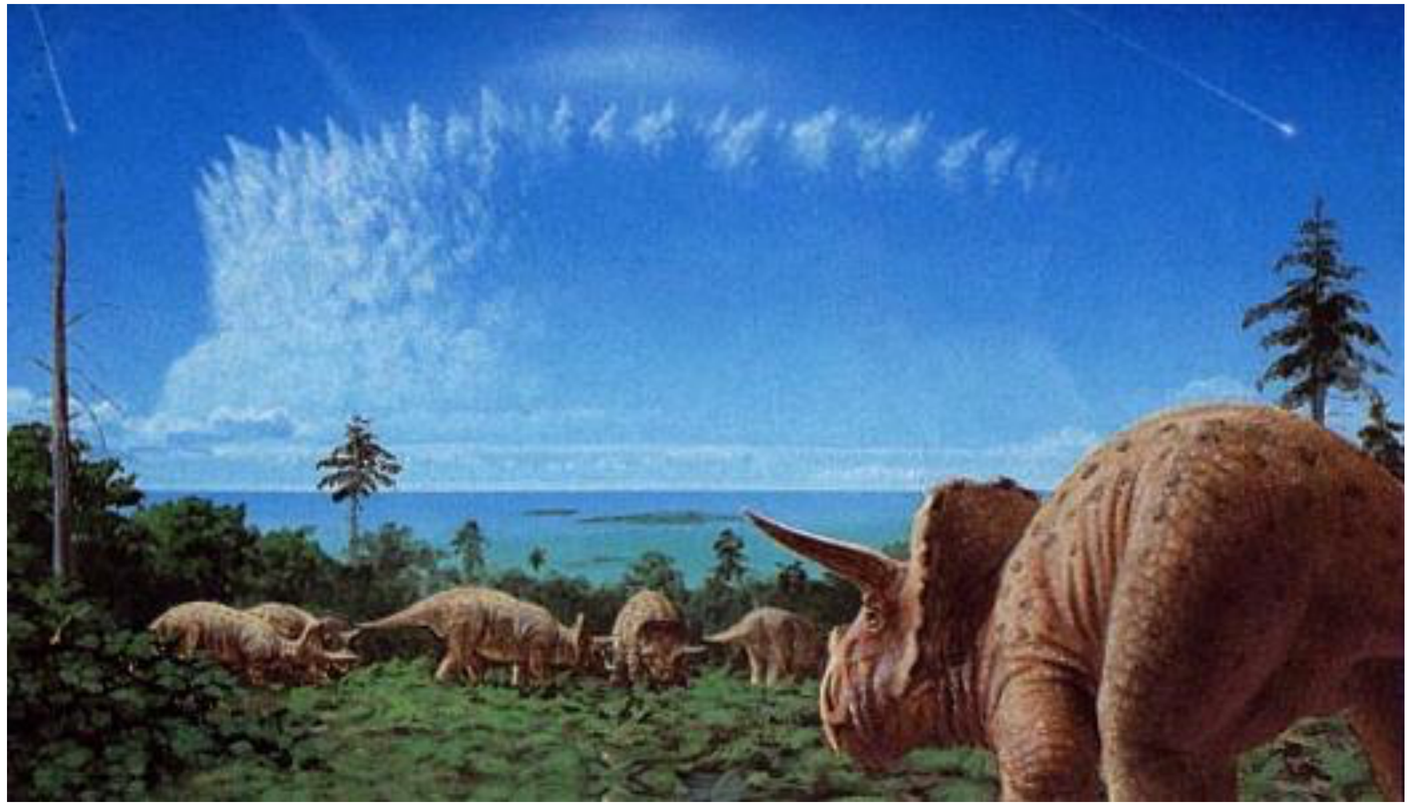
-similar processes constraining interactions

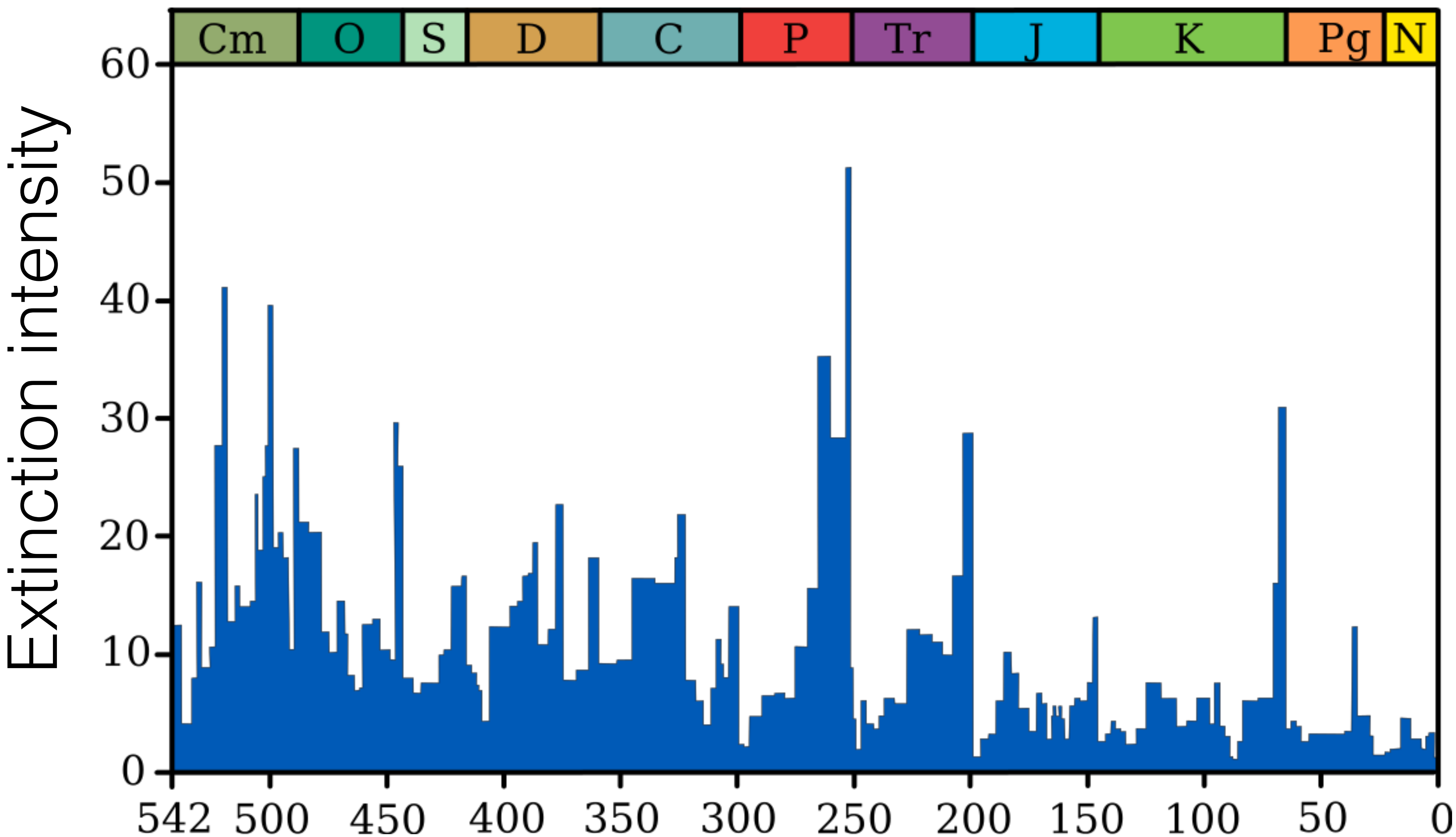
-independent of taxa

-independent of location

-independent of time

-independent of environment




Cm
O
S
D
C
P
Tr
J
K
Pg
N
Extinction intensity
60
50
40
30
20
10
0
542
500
450
400
350
300
250
200
150
100
50
0

Roopnarine et al. ProcRoySoc B, 2007
Mitchell et al. PNAS 2012

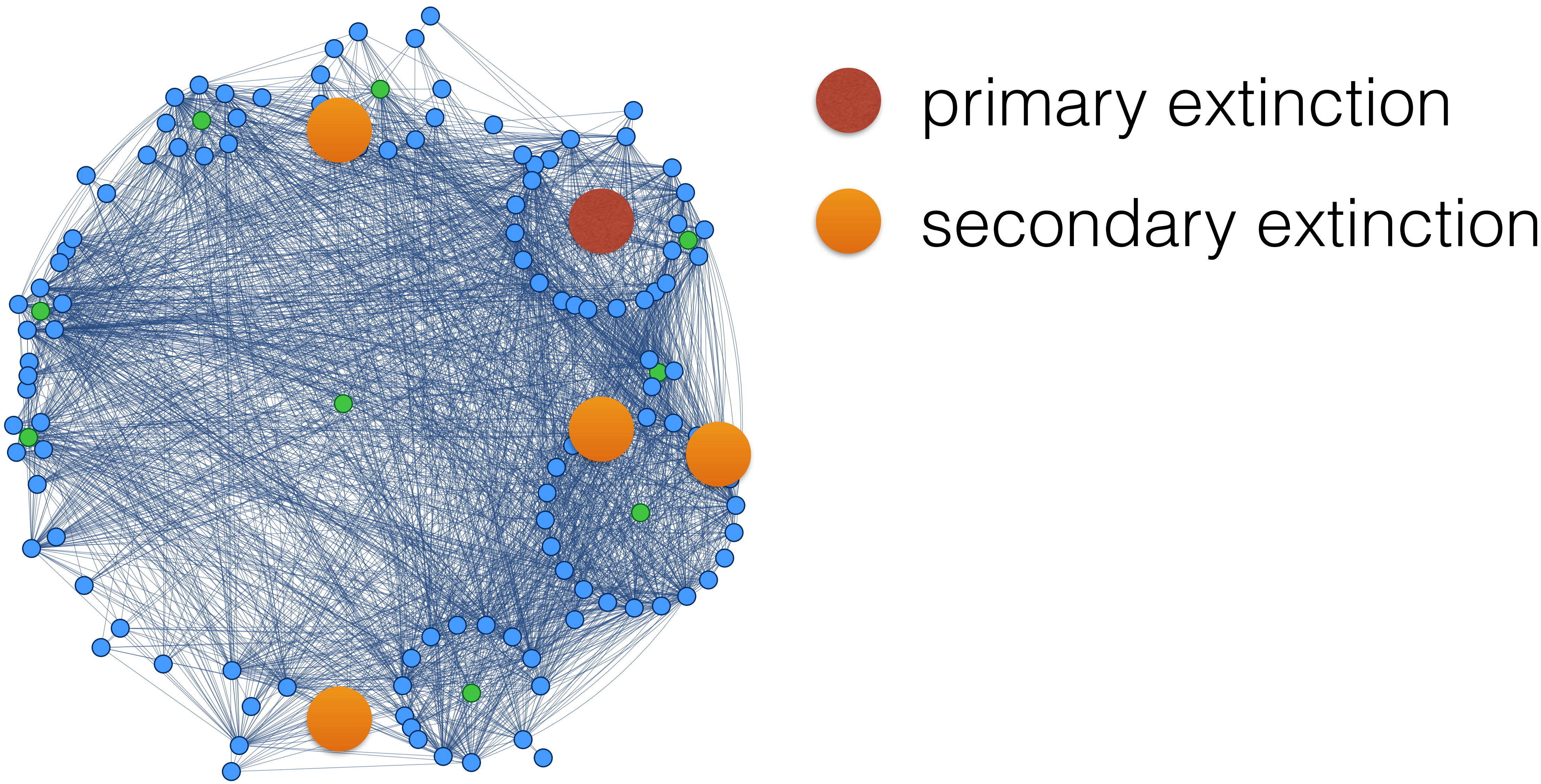
Permian extinction:

251 Million years ago
70% terrestrial vertebrates extinct
96% marine species extinct

end-Cretaceous restructuring:

~72 Million years ago
Decrease in dinosaur richness
Less endemic taxa
Were end-Cretaceous systems less robust? Did this set the stage for the KT extinction event?

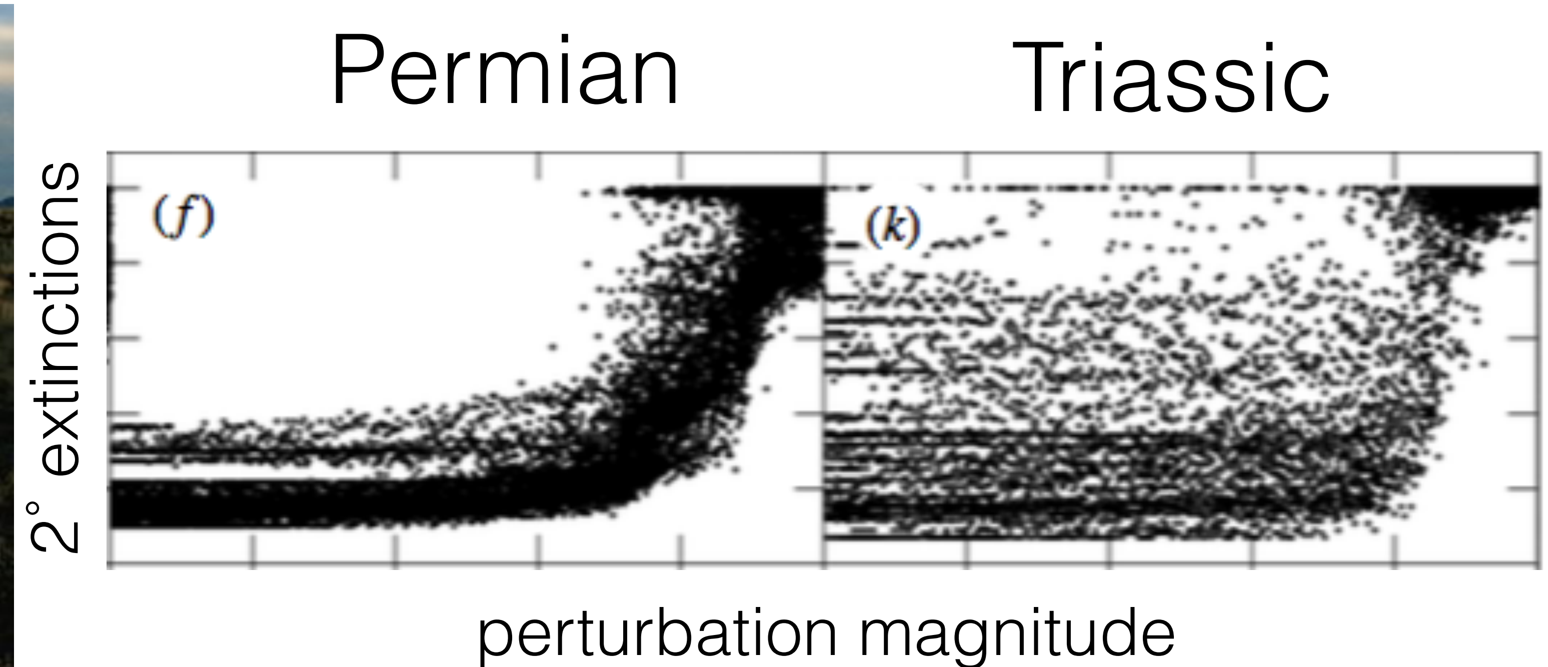
Have large perturbations impacted food web structure or function?



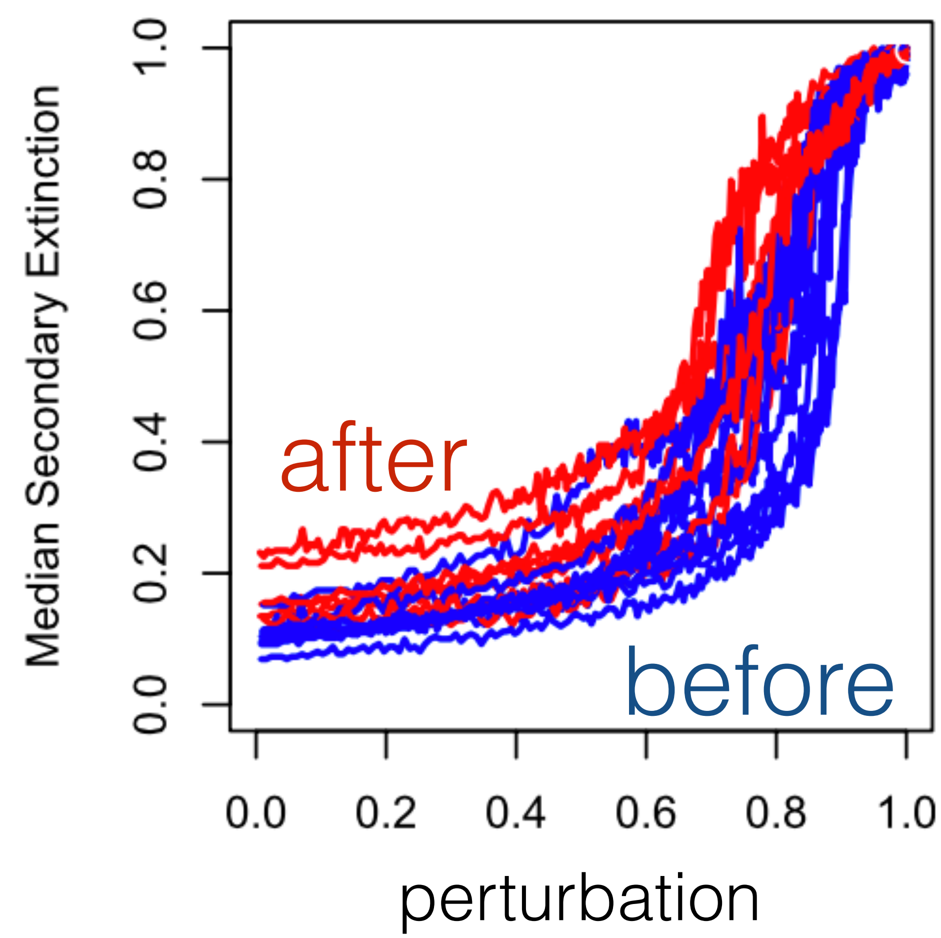
systems with a higher proportion of secondary extinctions are more fragile (less robust)

Roopnarine et al. ProcRoySoc B, 2007
Mitchell et al. PNAS 2012

Permian extinction:



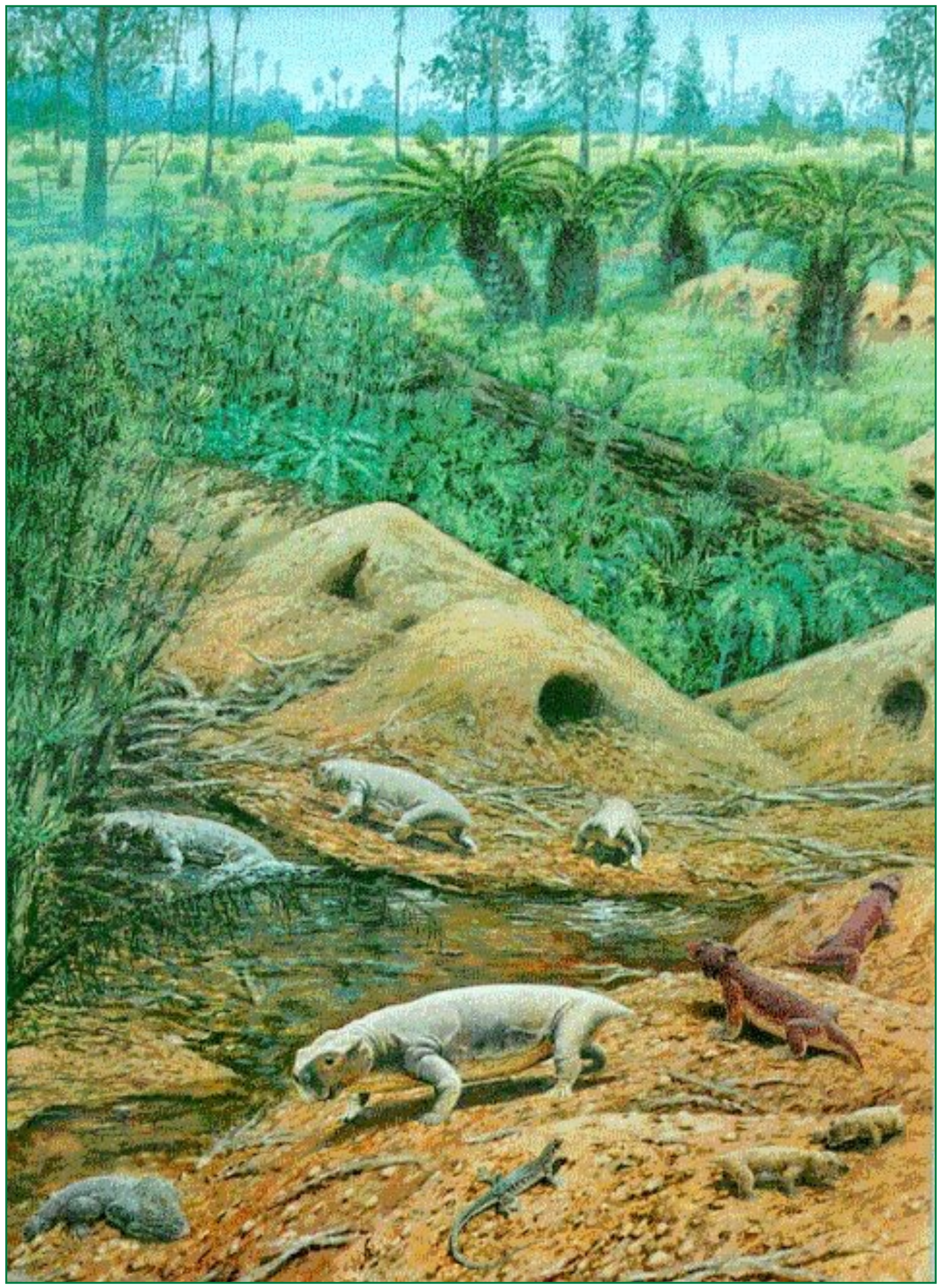
end-Cretaceous restructuring:



Perturbations and food web robustness

-Large perturbations leave less robust communities

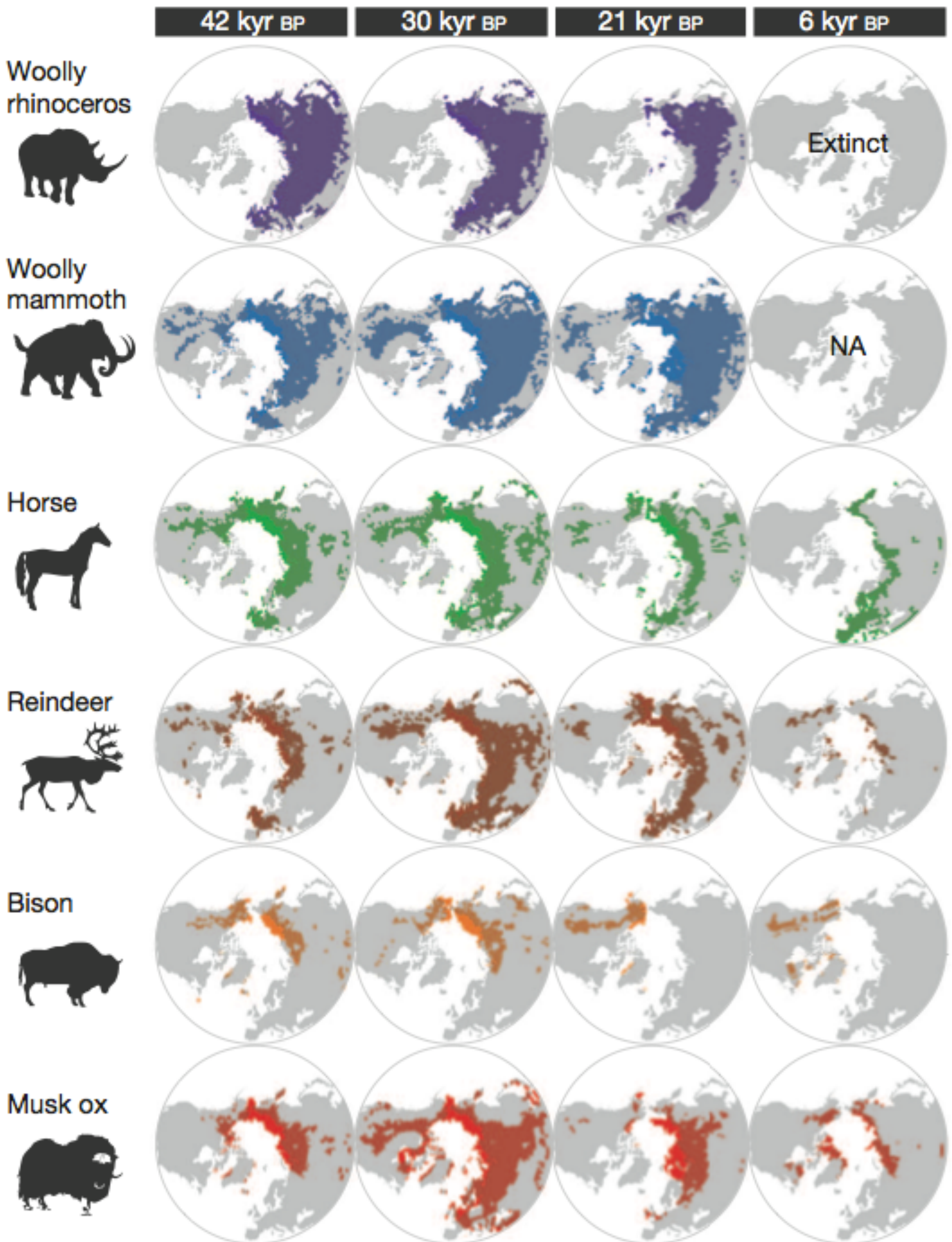
-Declines in robustness may exaggerate extinction events



Climate change?
Humans?

The Mammoth Steppe

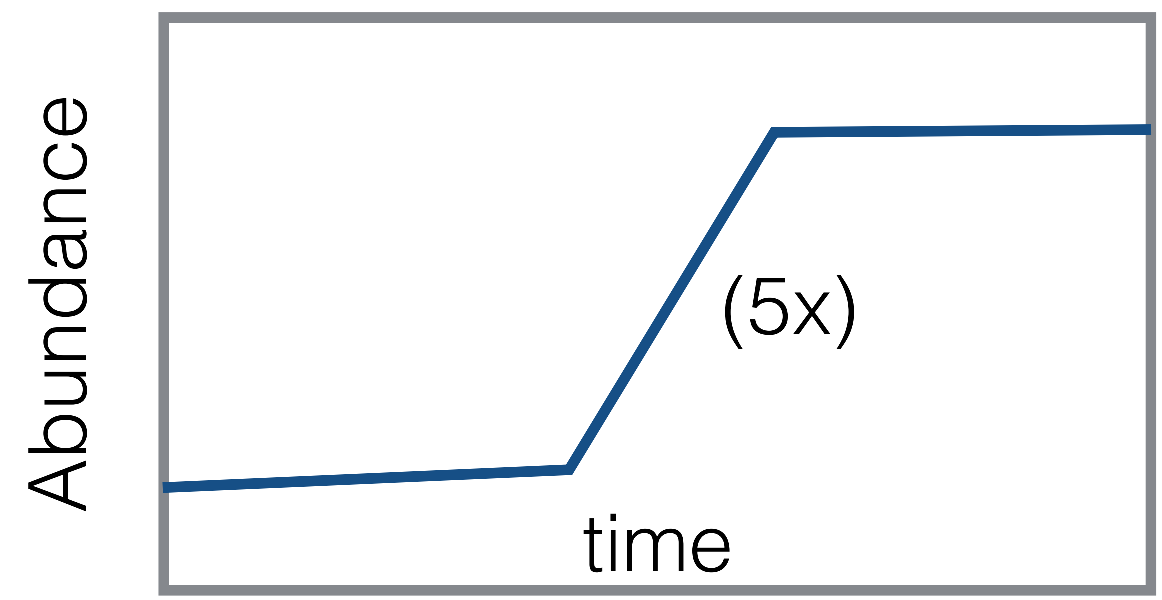
How were species diets impacted by changes in climate?



Lorenzen et al. Nature 2011

Changing herbivore ranges over time

North American Caribou



How were species diets impacted by changes in climate?

Stable isotope ratios trace the flow of biomass through trophic communities and are preserved in animal tissue

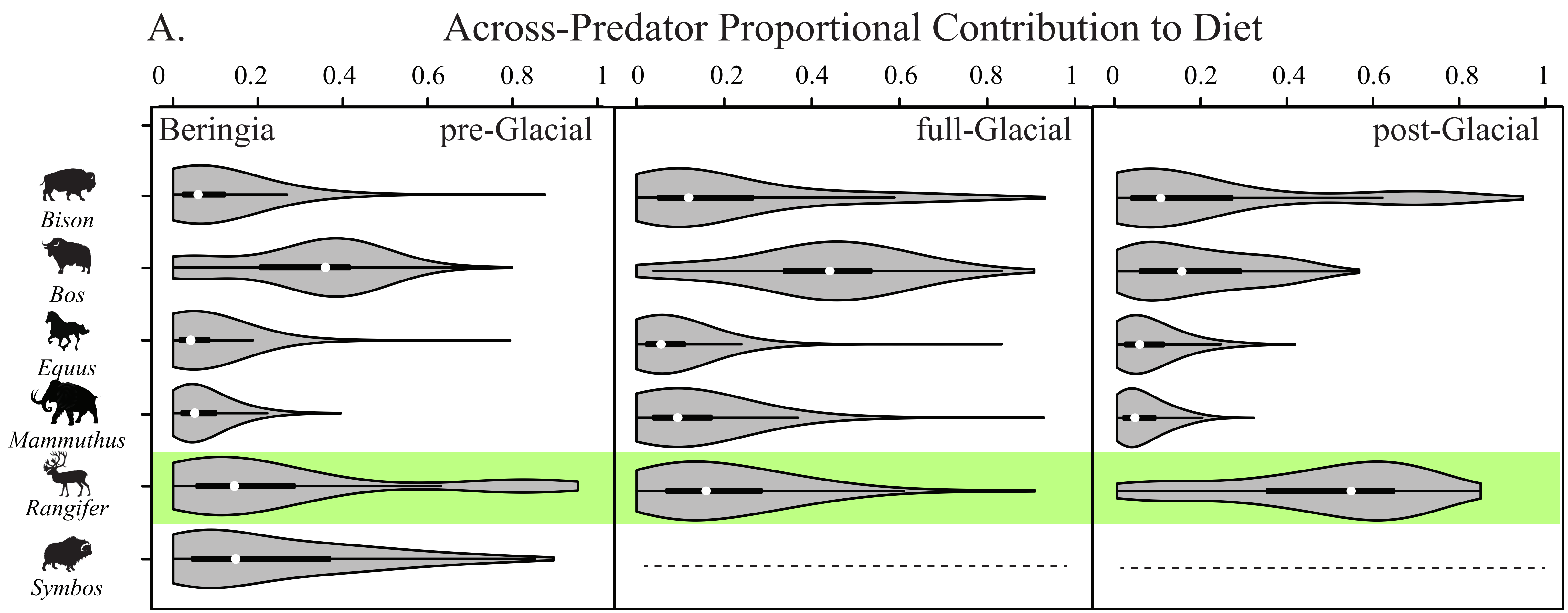
Stable isotope ratios can be used to reconstruct diet - even from fossil remains

Yeakel et al. Proc. Roy. Soc. B, 2013

How were species diets impacted by changes in climate?

Time

Adapting diets across a shifting climate





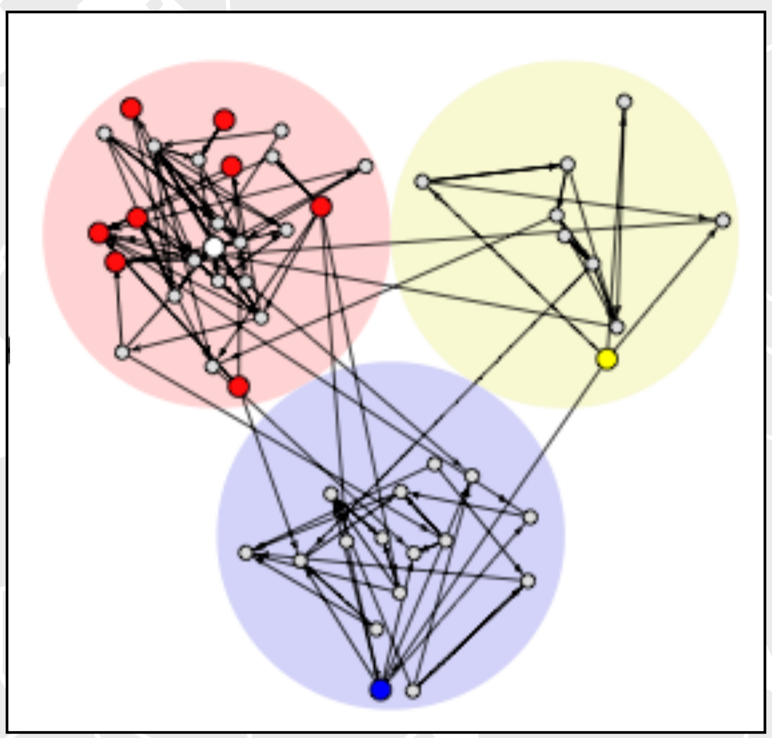



Yeakel et al. Proc. Roy. Soc. B, 2013

How were food webs impacted by changes in climate?

Larger scale patterns of trophic interactions

Structures of interactions in
food webs impact dynamics



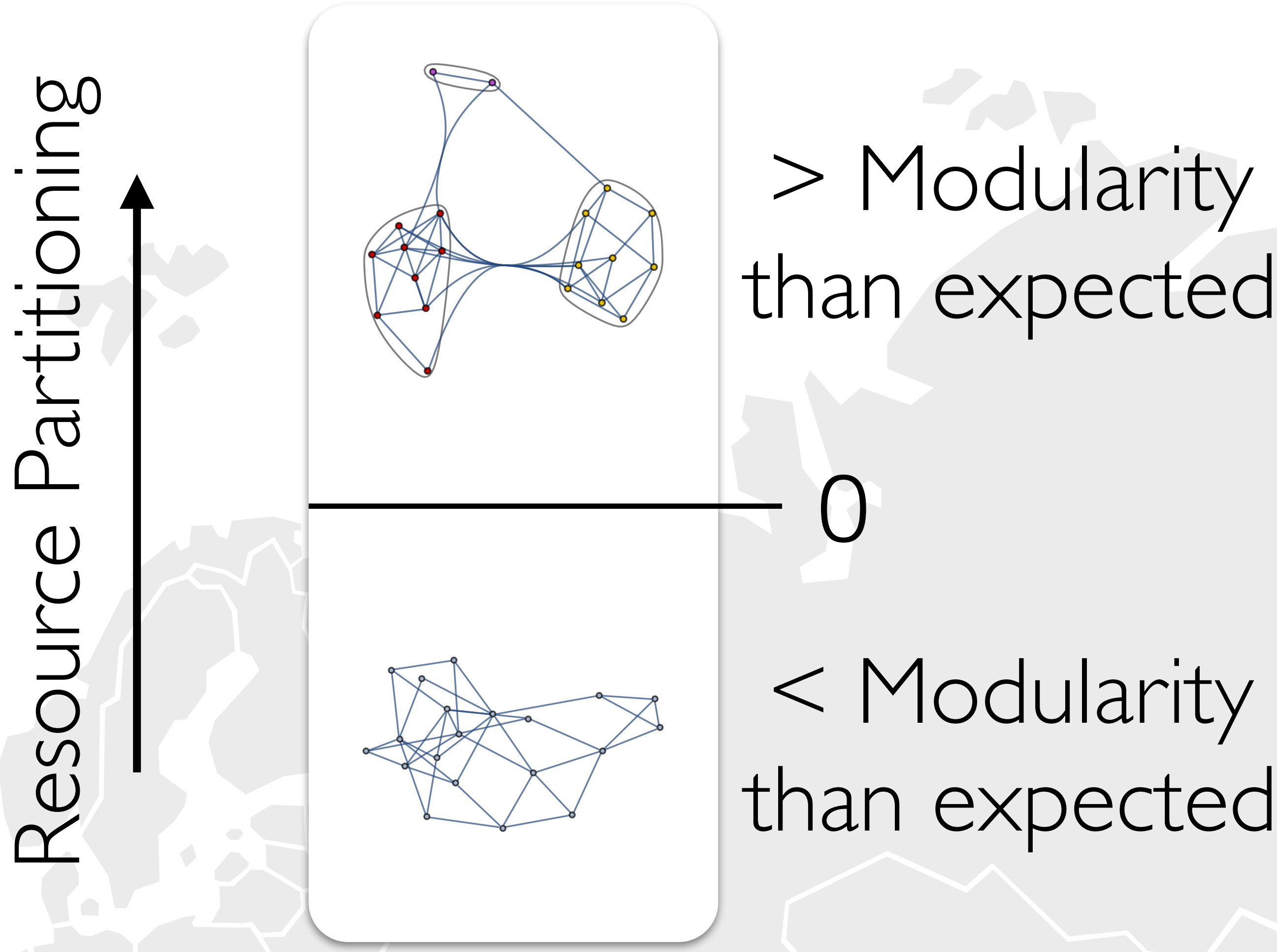
Compartmentalization increases food-web persistence

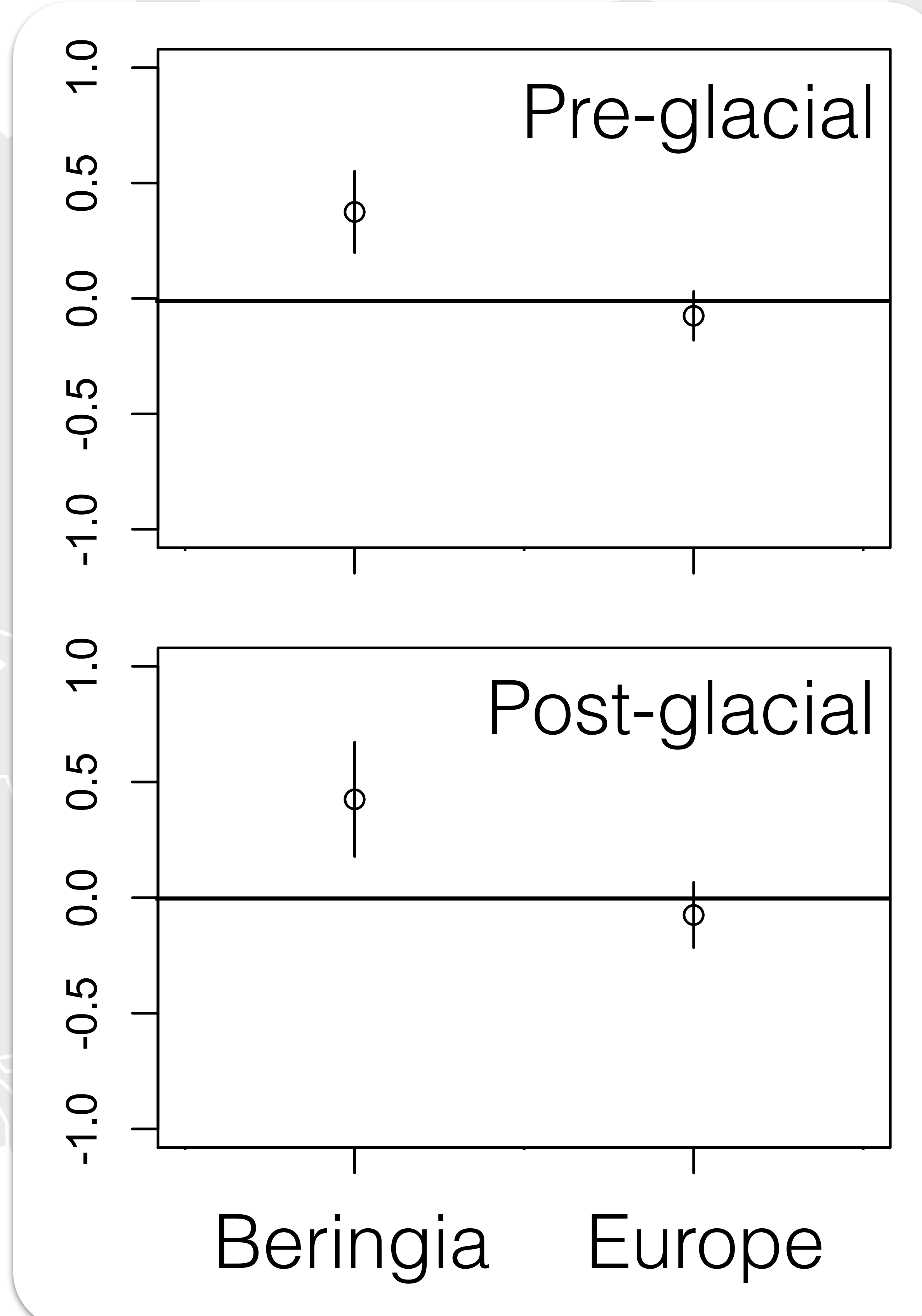
Daniel B. Stouffer[1] and Jordi Bascompte

Integrative Ecology Group, Estación Biológica de Doñana, Consejo Superior de Investigaciones Científicas, 41092 Seville, Spain

Edited* by Robert May, University of Oxford, Oxford, United Kingdom, and approved January 7, 2011 (received for review September 24, 2010)

How were food webs impacted by changes in climate?





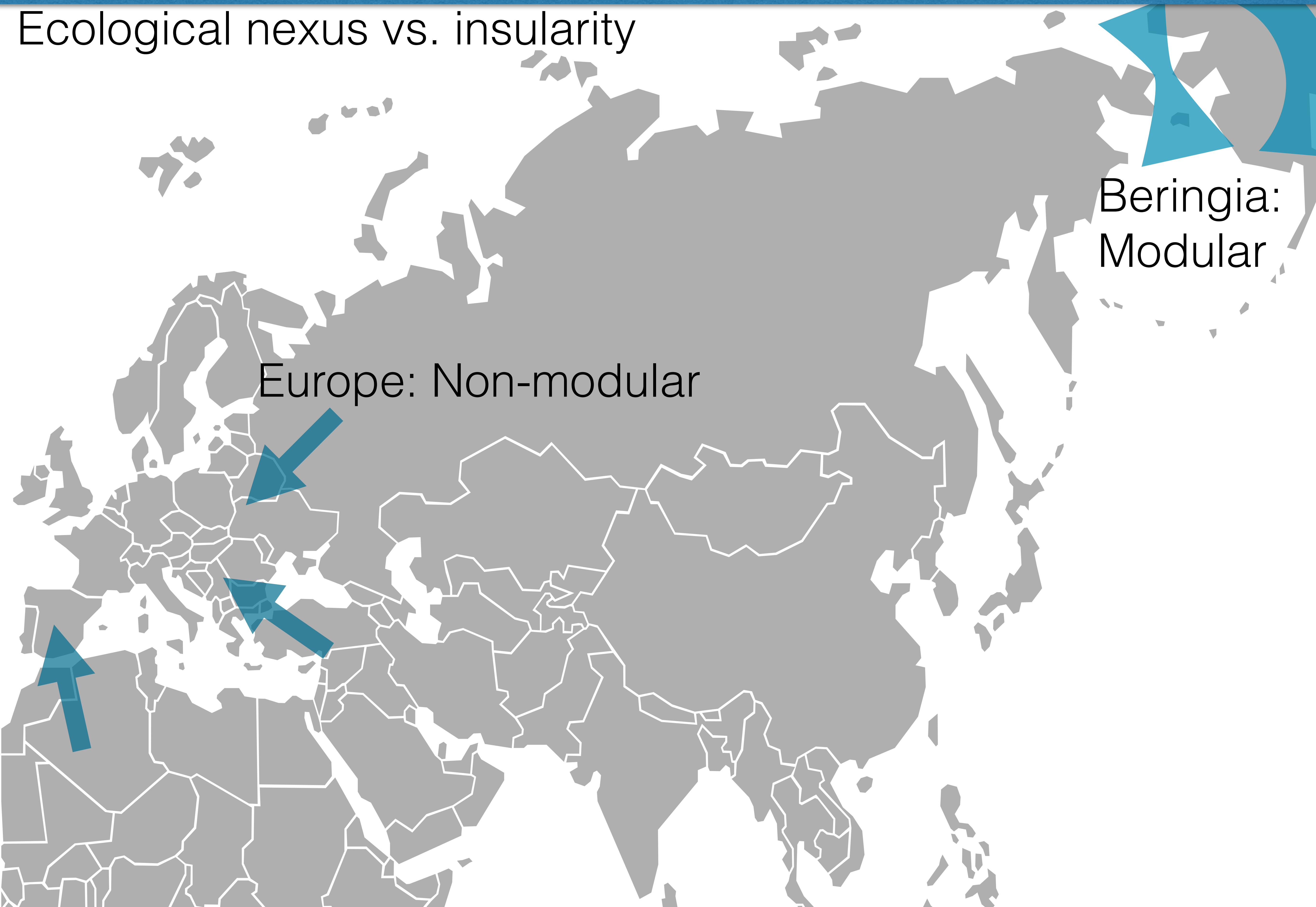
-Spatially distinct

-Temporally consistent

Yeakel et al. Proc. Roy. Soc. B, 2013

How were food webs impacted by changes in climate?

Ecological nexus vs. insularity

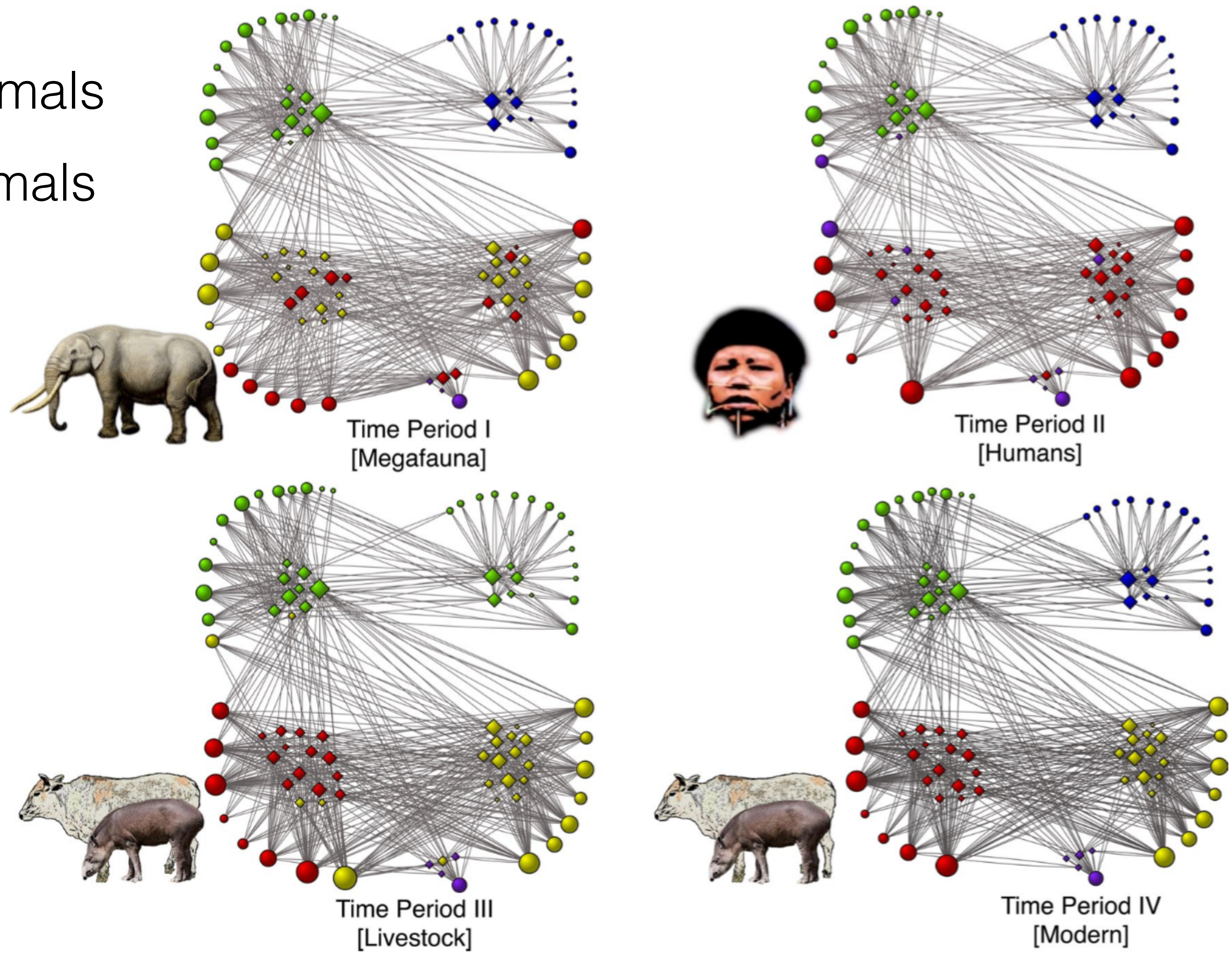


Food webs are one side of the story, but there are many other impacts of extinctions on ecosystems

Pires et al. 2014

- Large birds
- Small birds
- Large mammals
- Small mammals
- Plants

High modularity (seed specialization) | **Low modularity** (human cohesion)



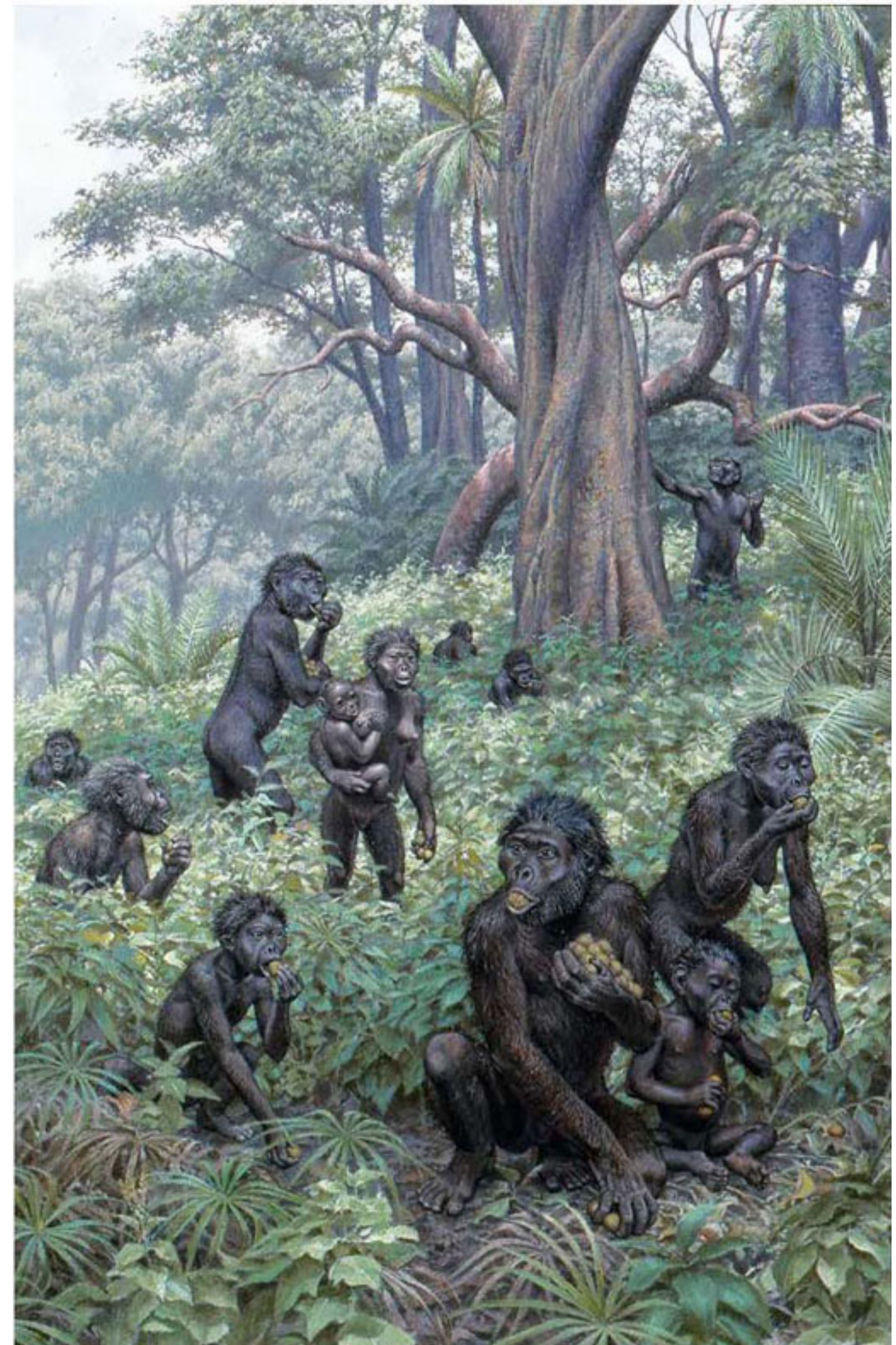
Moderate modularity (restored by livestock) | **High modularity** (less cohesion by humans)

Pires et al. 2014

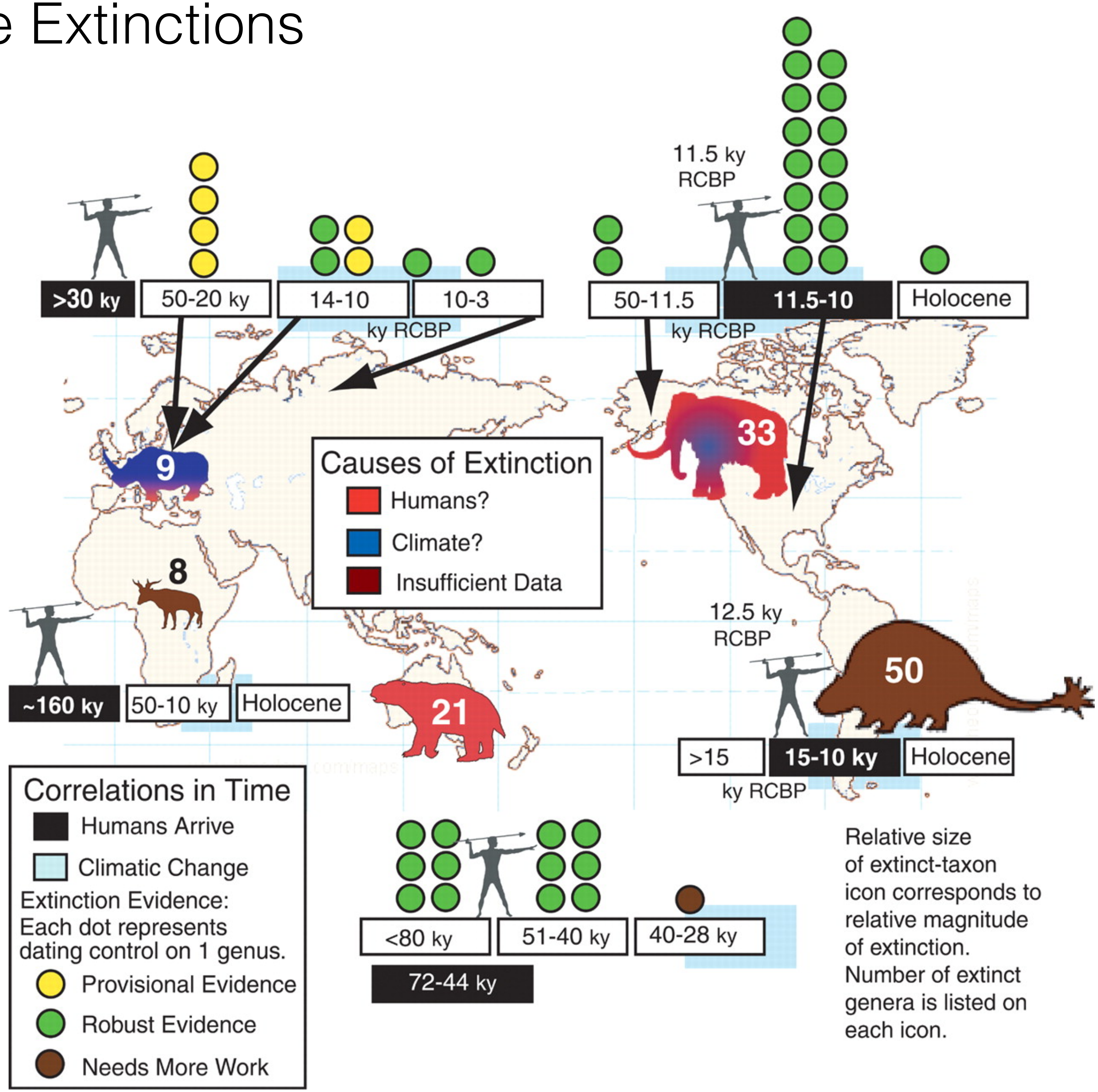
The case for Pleistocene rewilding?

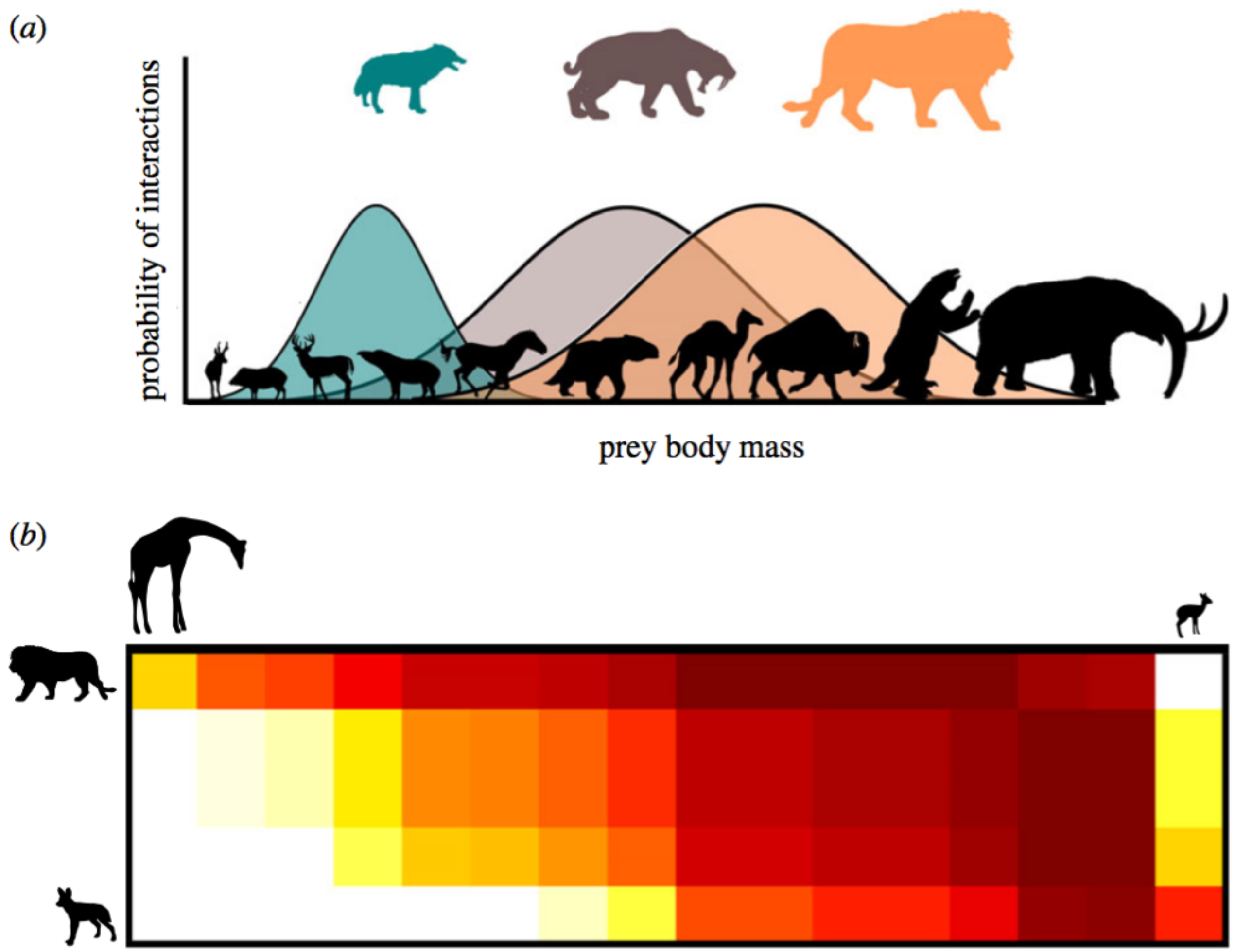
…no analogue communities…

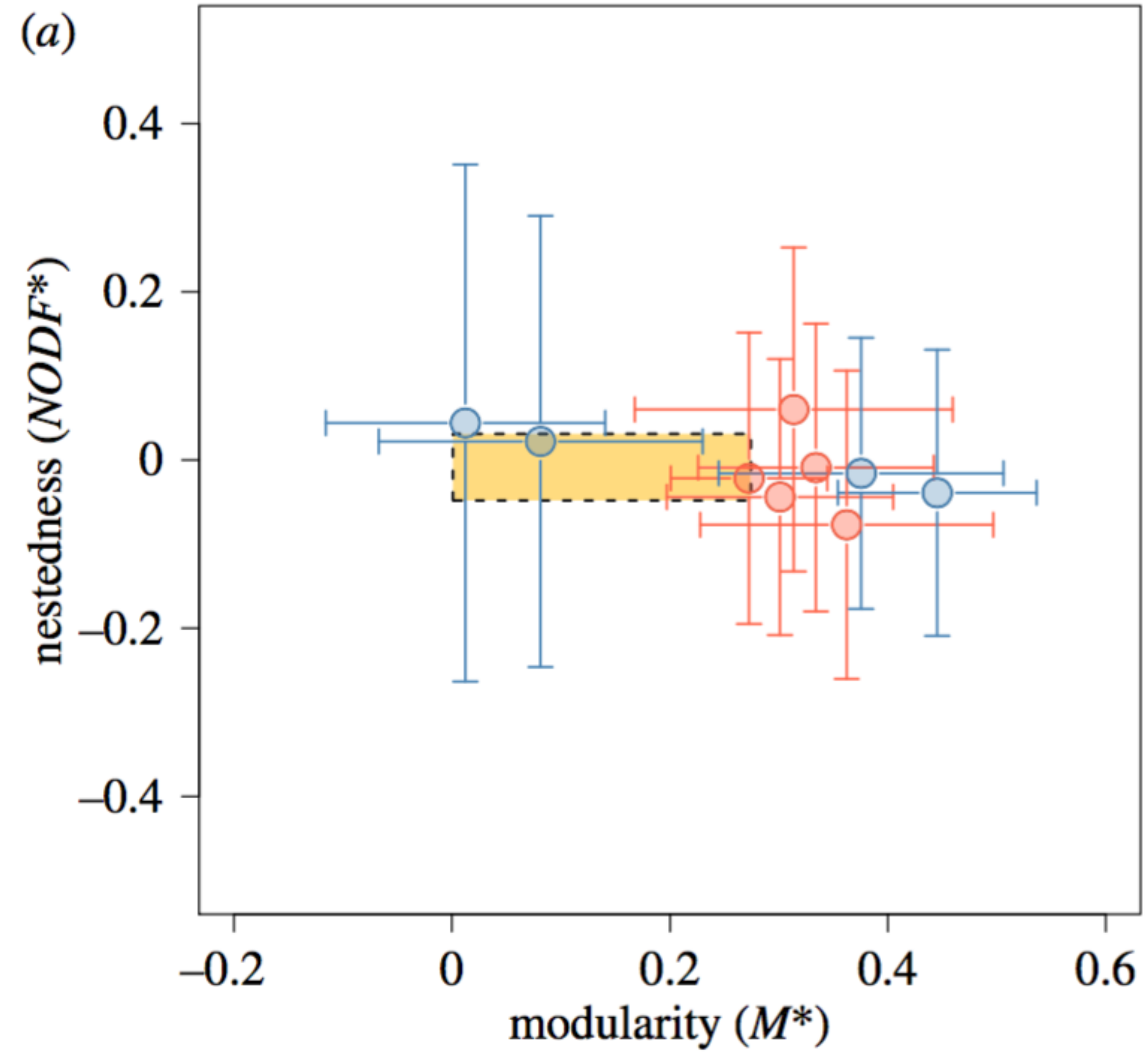
The effects of humans on ecosystems

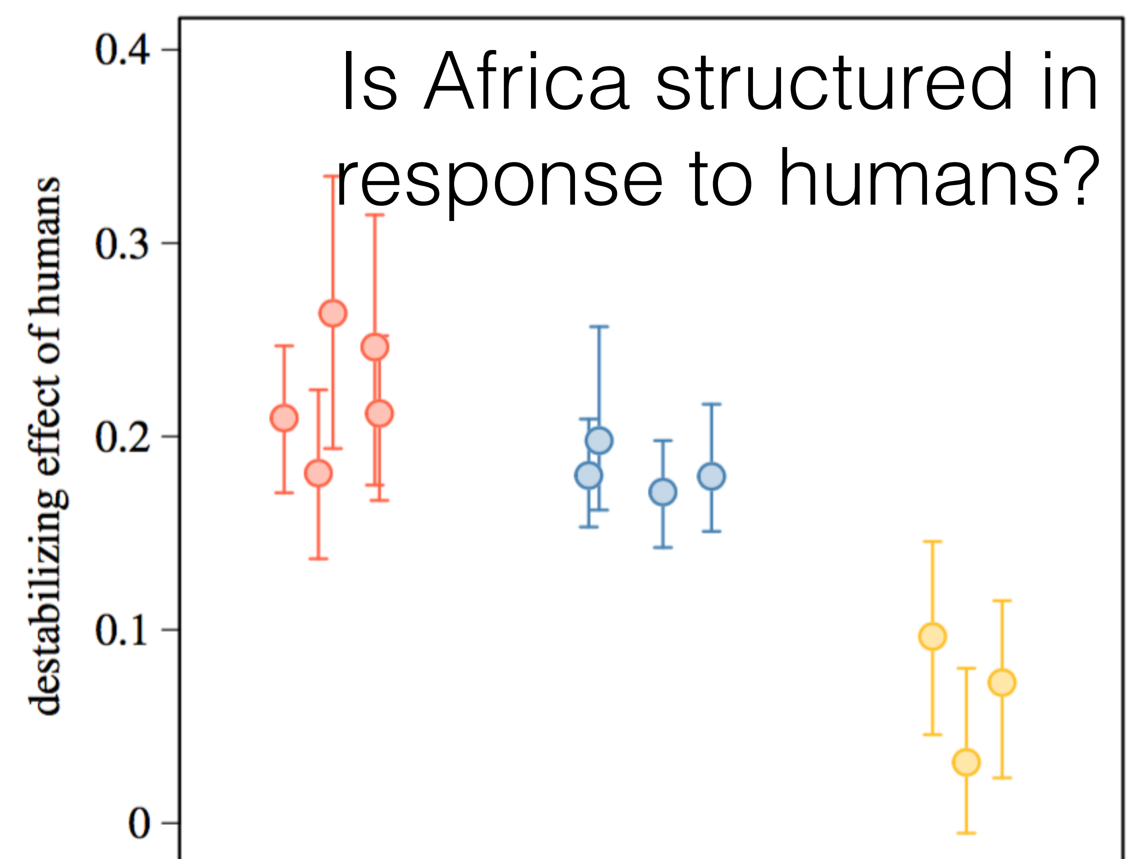


Pleistocene Extinctions



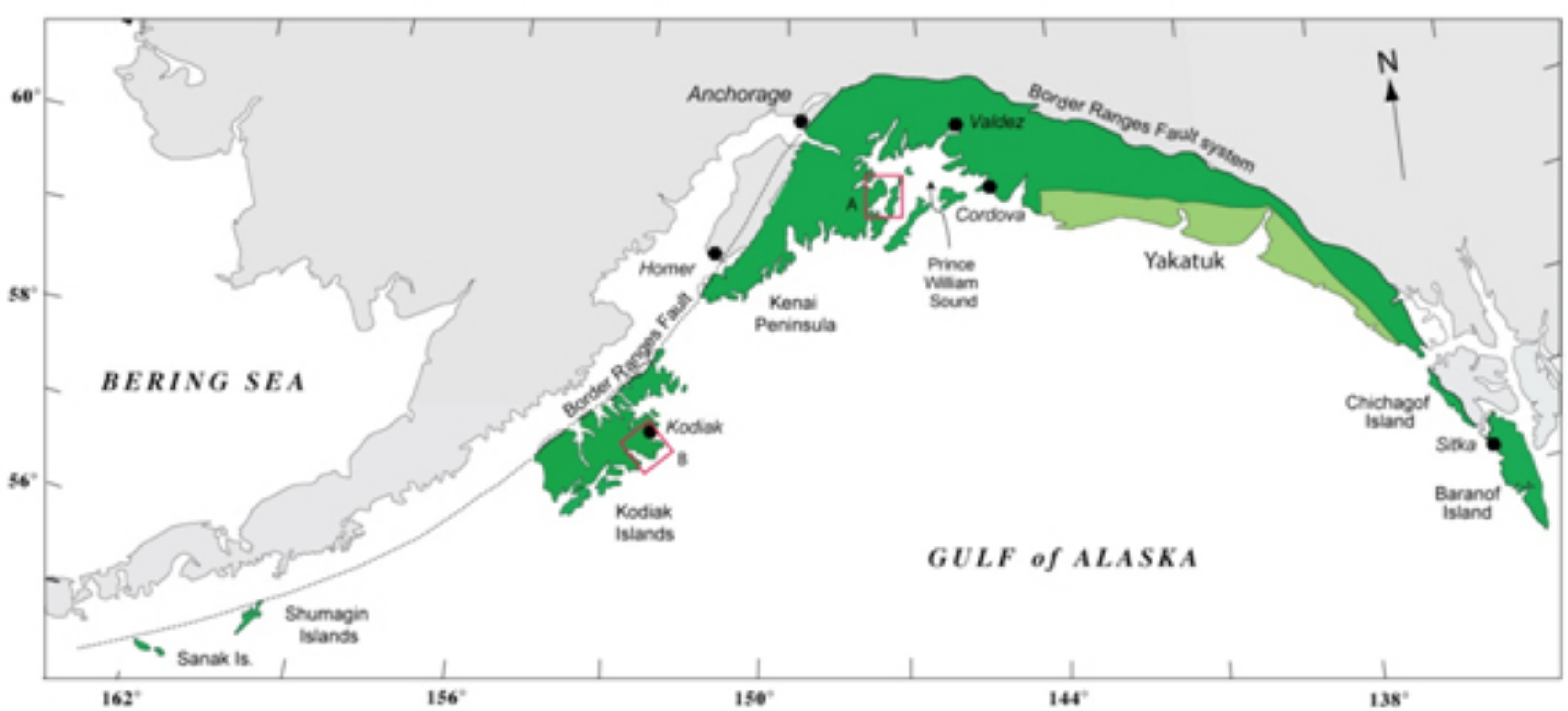






Pires et al. 2015

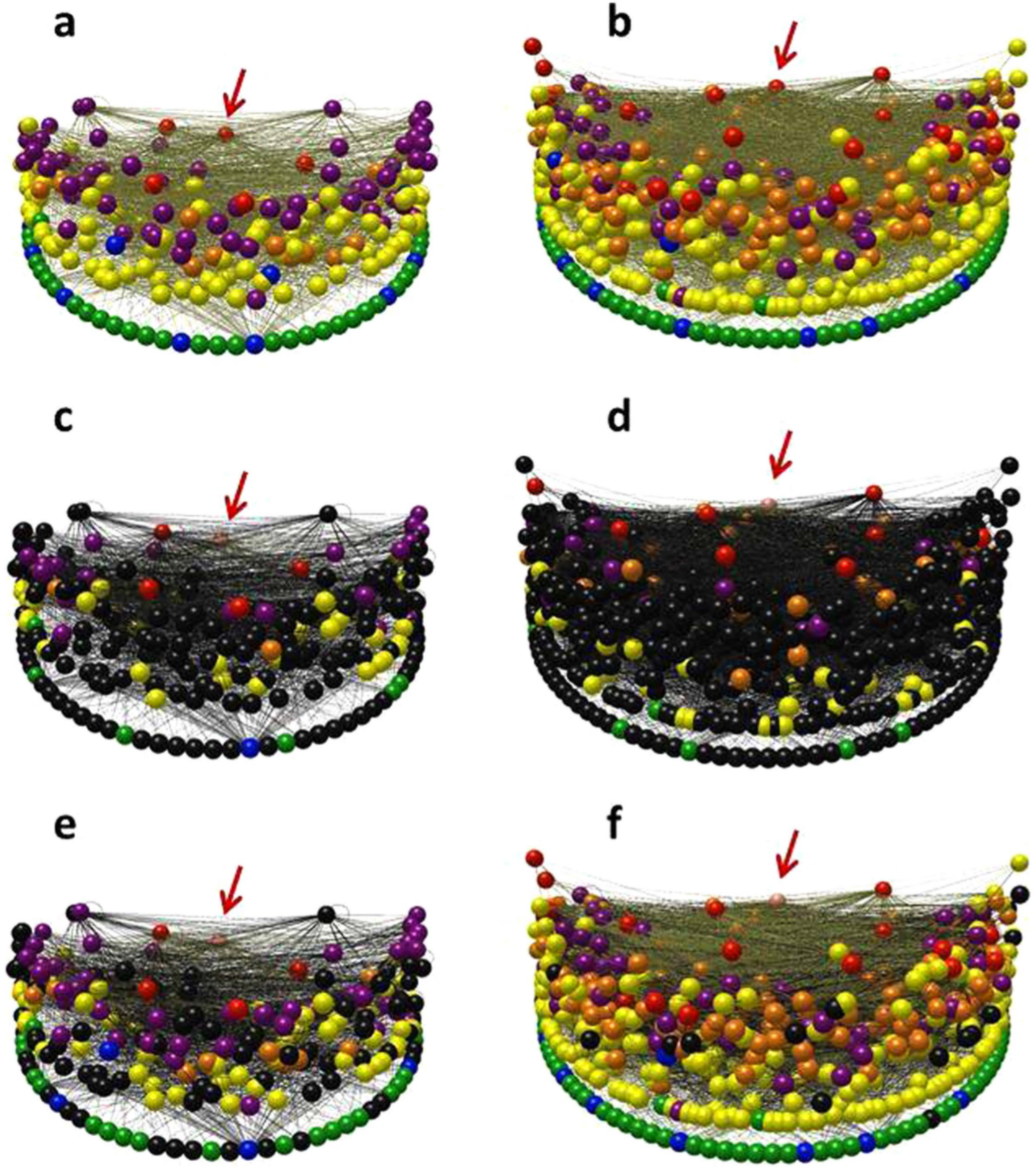
Aleuts on Sanak Island
10000-yr occupation



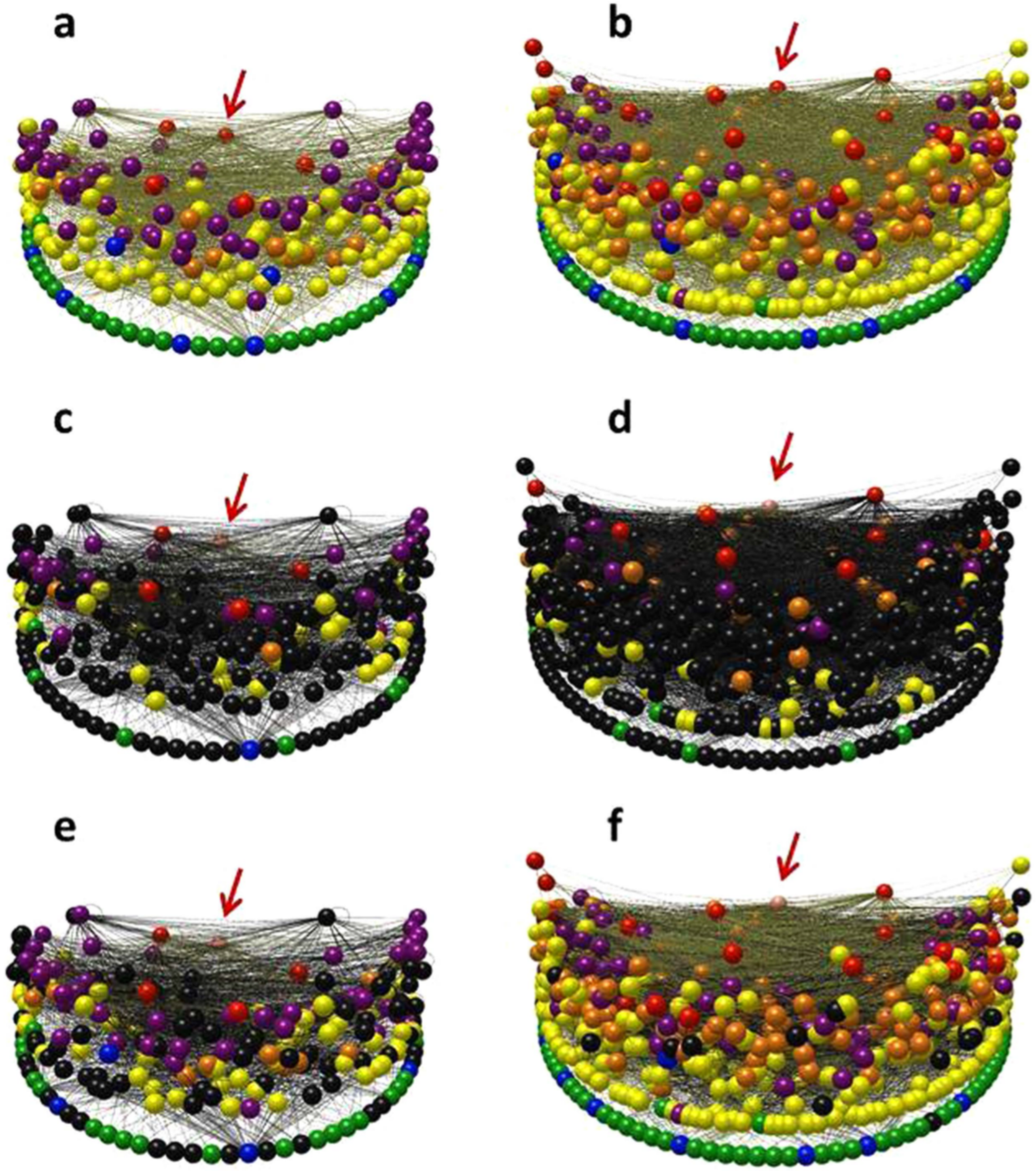
Sanak island
L) Intertidal web
R) Nearshore web

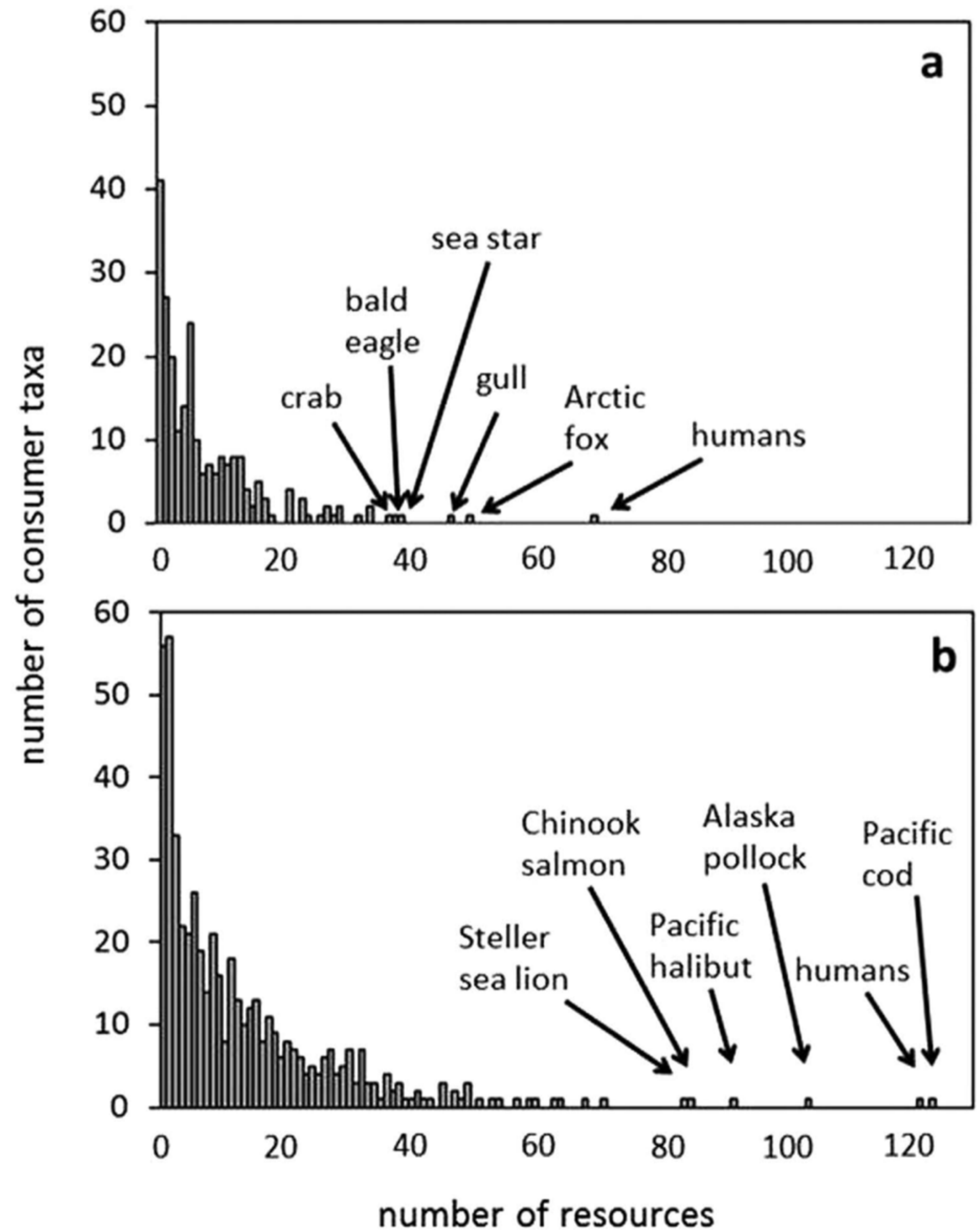
Colored taxa
linked to humans

Colored taxa w/in 2
degrees of humans



Dunne et al. 2016





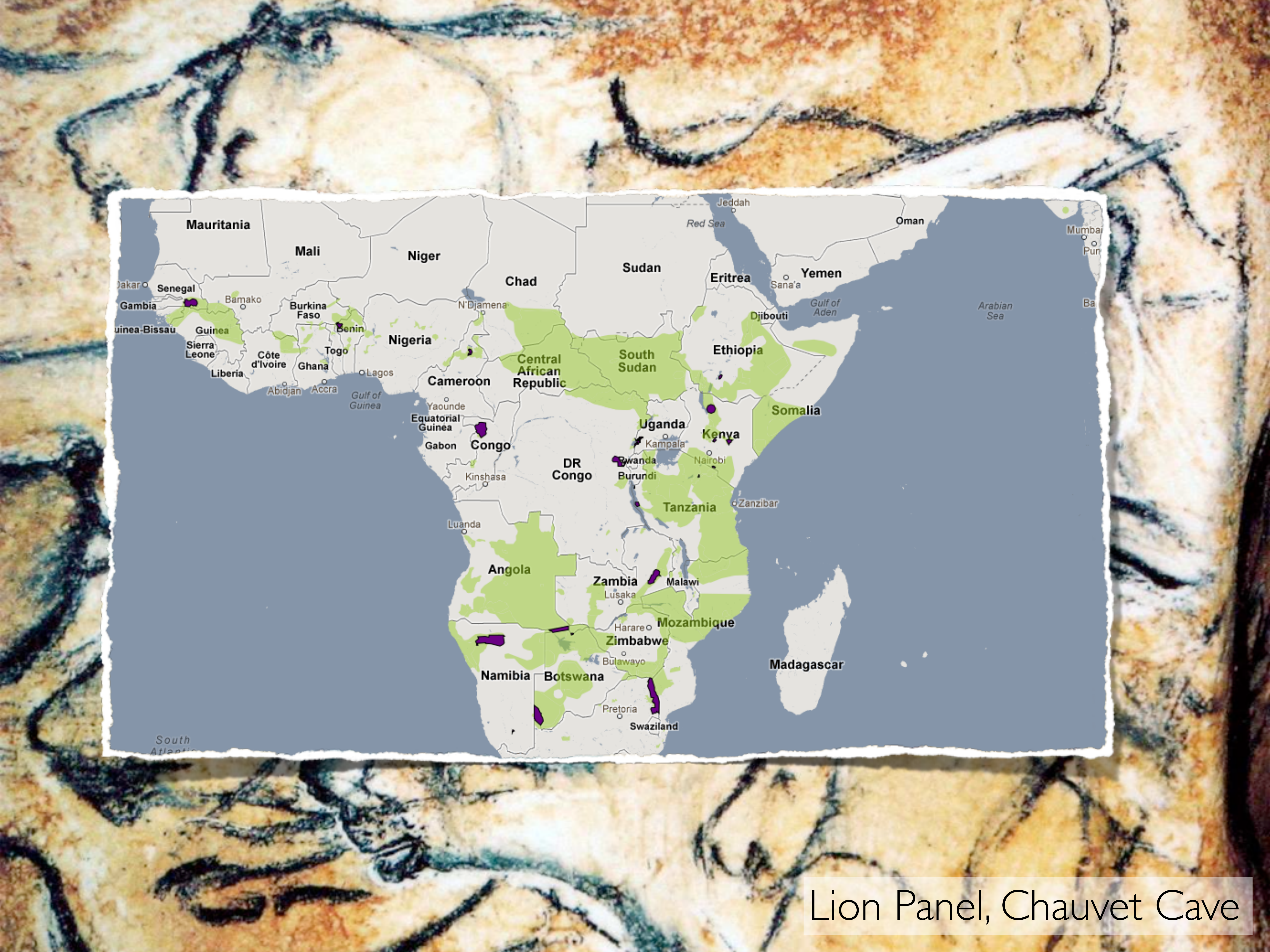
-Not linked to any long-term extinctions on the island
-Possibly via spatial carrying capacity and numerous weak interactions among many species rather than strong interactions among few species.

Dunne et al. 2016

Ashmolean palette
Egypt, Predynastic era

Modern communities are vestiges

Bison, Cave of Altamira



Lion Panel, Chauvet Cave

Use paleontological and historical information to reconstruct the pattern of extinctions in a single community over millennial timescales

Specific

What have been the cumulative dynamic effects of climate, urbanization and industrialization on mammalian communities?

Can this inform our understanding of how modern communities function?

“Desert vegetation can be classified into three basic subdivisions: perennial, ephemeral, and accidental”...

Canis aureus

Hyaena hyaena

Caracal caracal

Felis chaus

Felis sylvestris

Vulpes vulpes

Panthera pardus

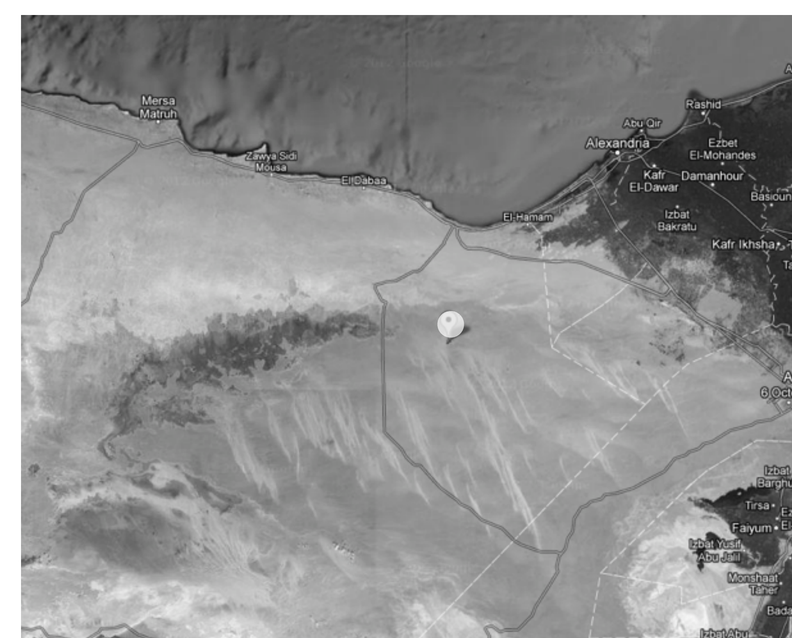
Acinonyx jubatus

Panthera pardus

Guides report leopards in Eastern Desert during mesic periods
Skin observed near El Maghra in 1913

Acinonyx jubatus

Cheetah killed by bedouins in 1974 near El Maghra
Occasionally observed in Sinai in 1930s



Equus asinus

Capra ibex

Gazella gazella

Gazella leptoceros

Gazella dorcus

Ammotragus levia

Alcelaphus buselaphus

Sus scrofa

Addax nasomaculatus

Oryx dammah

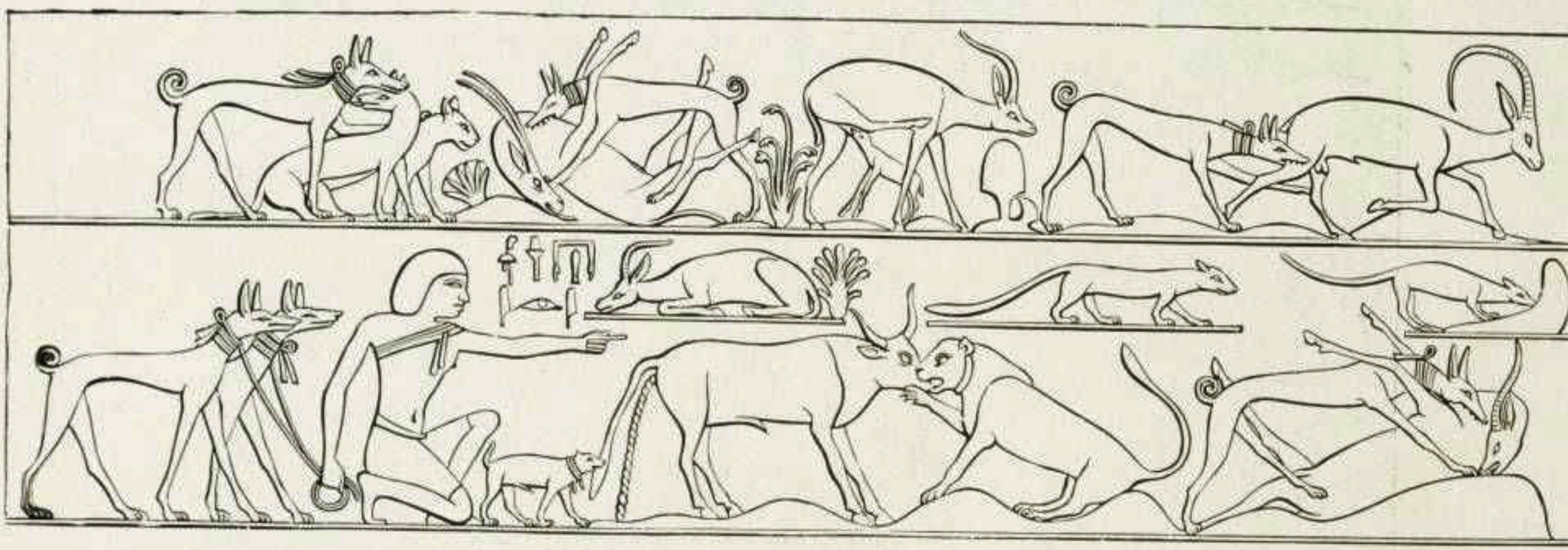
Alcelaphus buselaphus: last observed, 1935
Commonly confused with *Addax*

Sus scrofa:
Last Egyptian boar
British specimen #2450
December 20, 1912

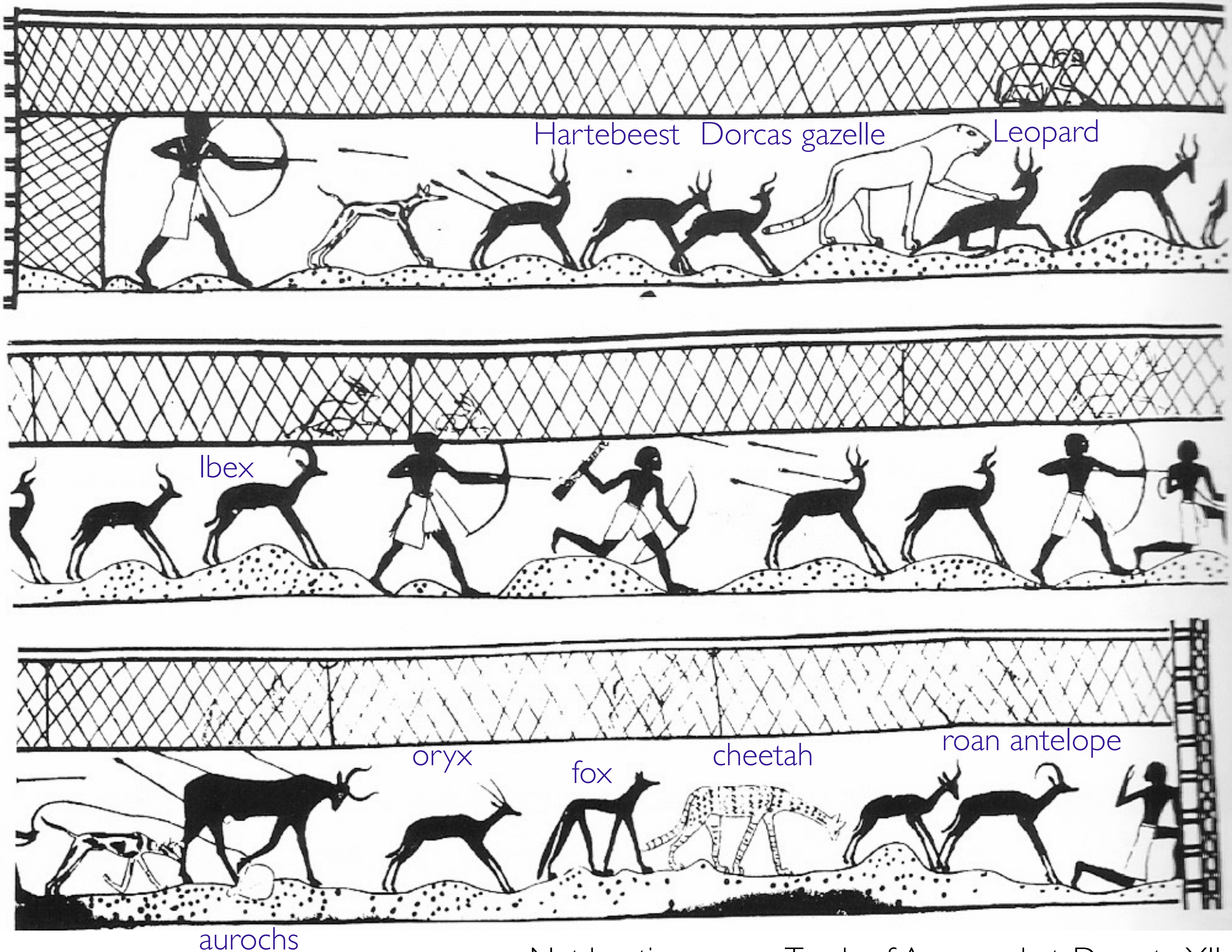
Oryx dammah: W. desert until first half of 19th century

Addax nasomaculatus: Large herds would wander into Egypt from Libya. By 1957, considered one of the rarest mammals in Libya

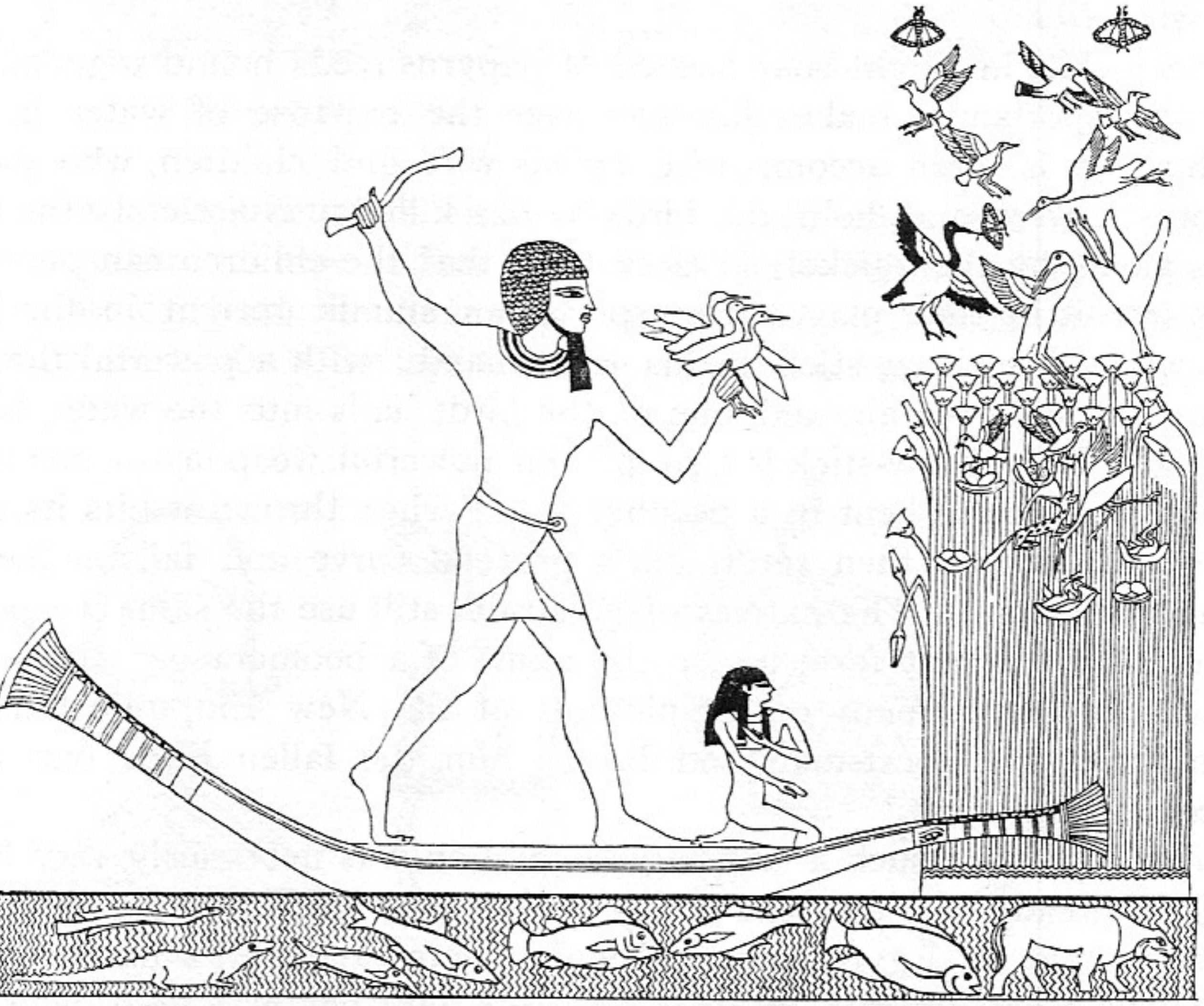
Integrate information of species occurrence over the past 6000 years to reconstruct extinction cascade



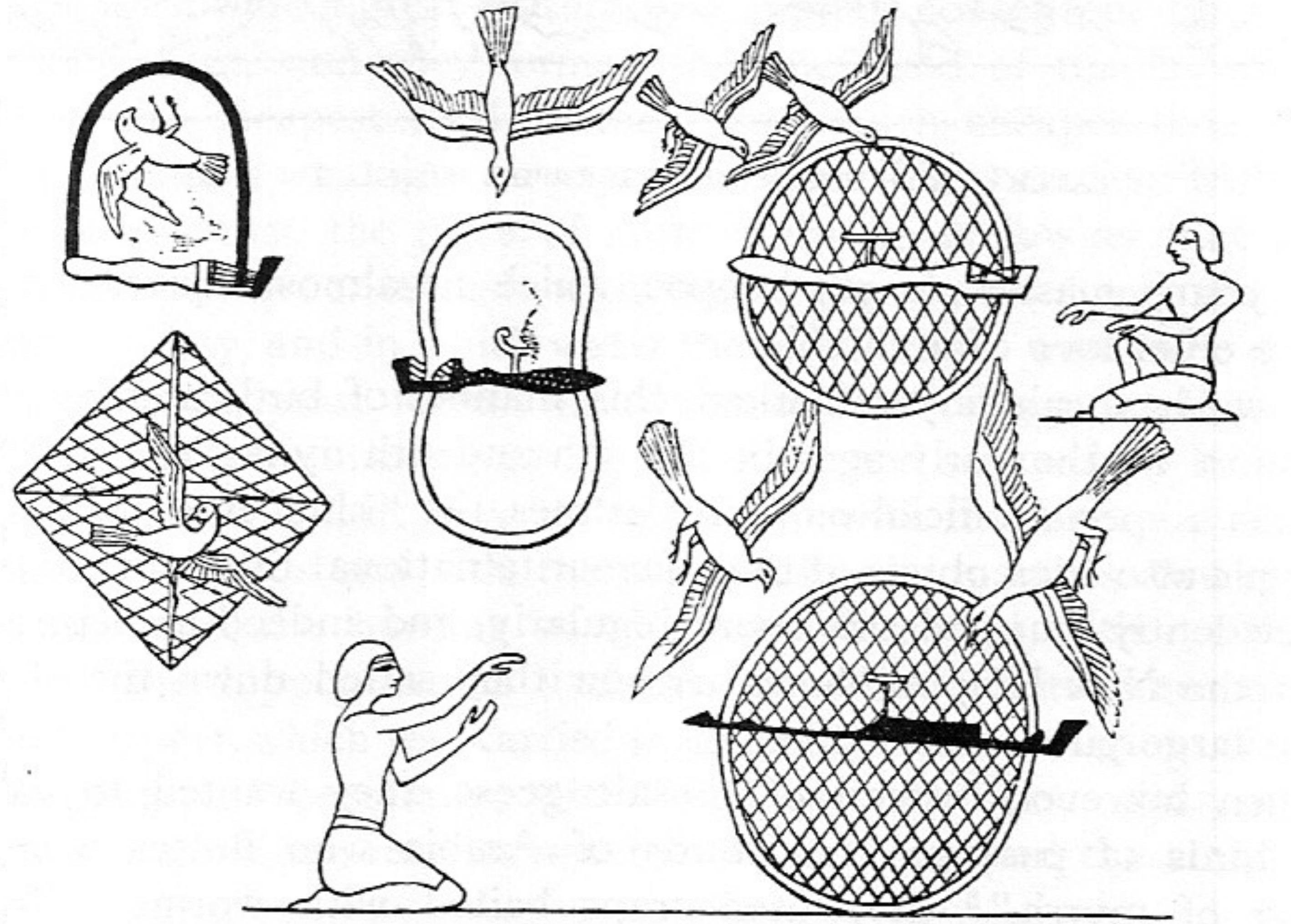
ENJOYMENTS OF HUNTING.



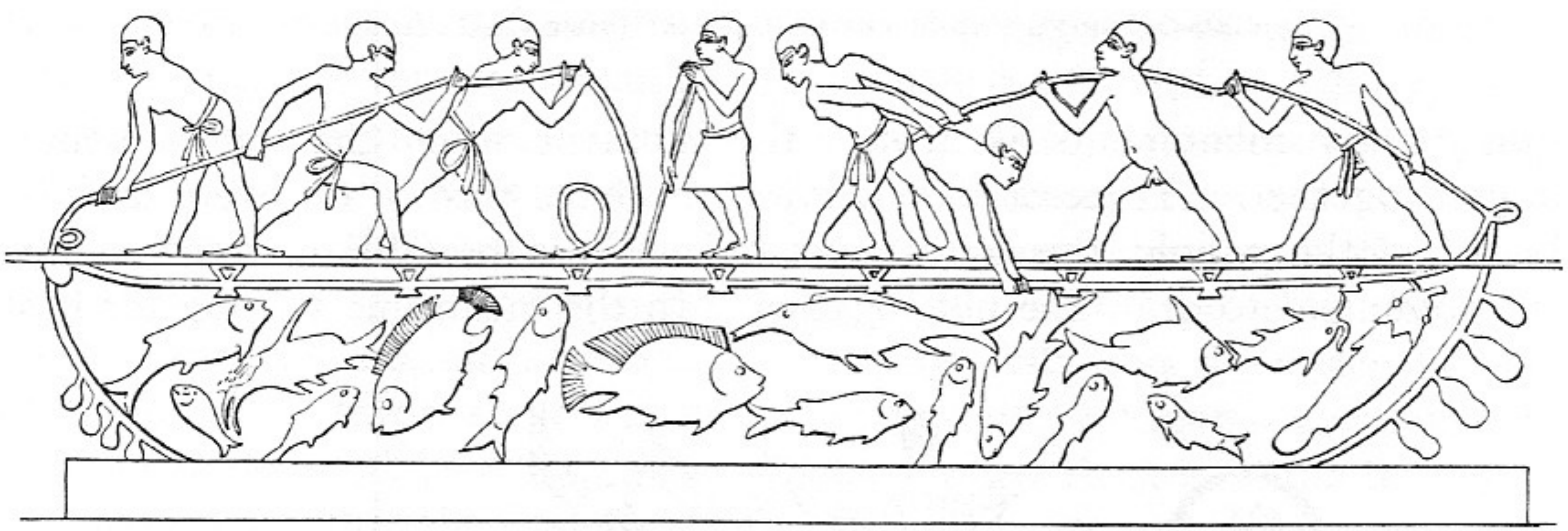
Net hunting   Tomb of Amenemhat, Dynasty XII



After L. D., ii. 130.

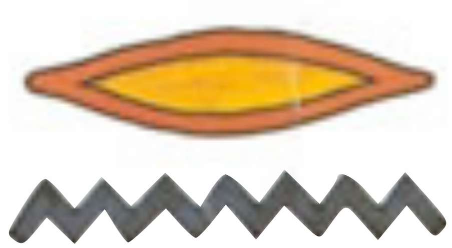


TRAPS, SOME OPEN, SOME CLOSED. From a tomb of the Middle Empire at Beni Ha (after Wilk., ii. 103).



CATCH OF FISH UNDER THE OLD EMPIRE (after L. D., ii. 9).

Domestication & Imports clearly distinguished



rn ~ fattened

3 large aridification events

Late Pleistocene
Archeological deposits

4580 yrs BP
Old Kingdom

3270 yrs BP
New Kingdom

100 yrs BP
Recent history

15 kyrs BP
Oldest known art

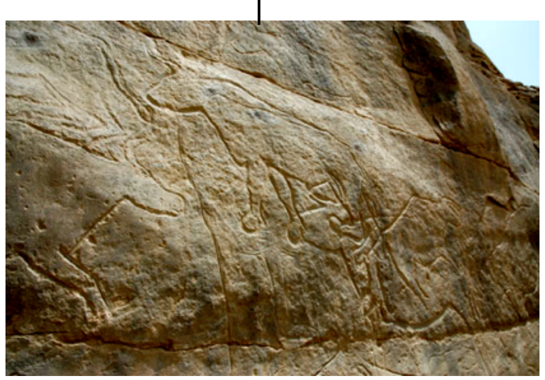
5000 yrs BP

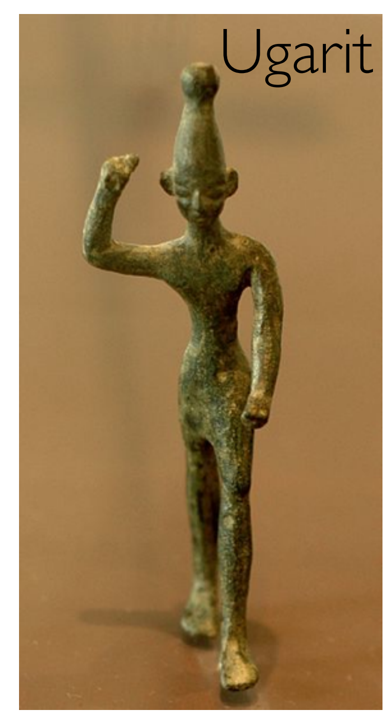
4140 yrs BP
Intermediate Period

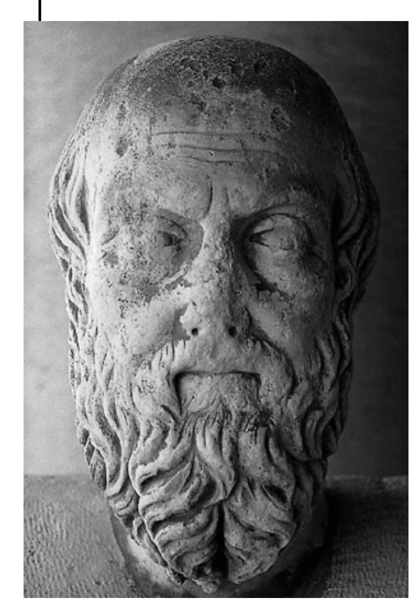
3000 yrs BP

1980 yrs BP
Greco-Roman

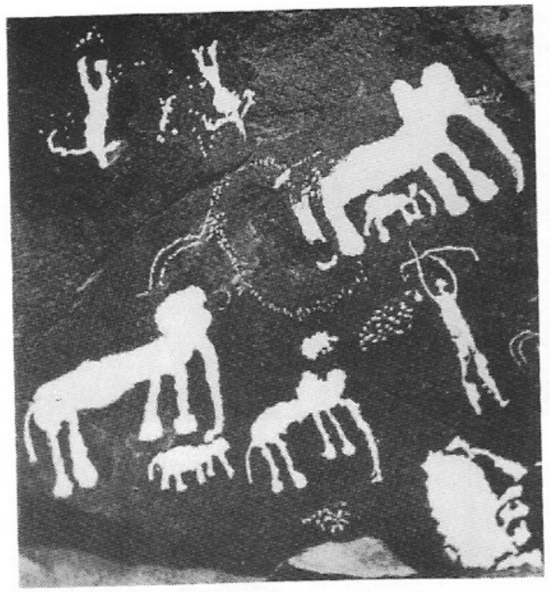
Uruk

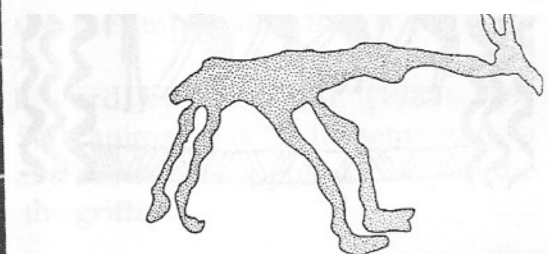




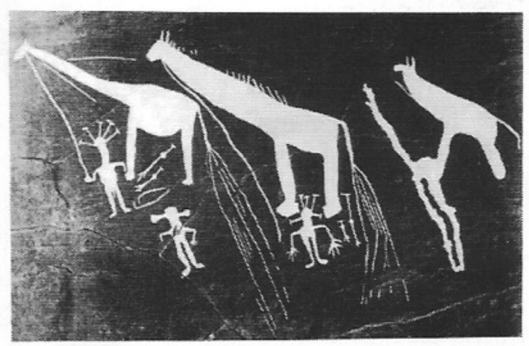


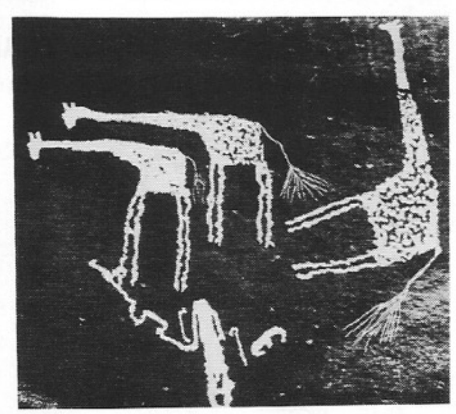
Early Holocene Egypt: Rock Art



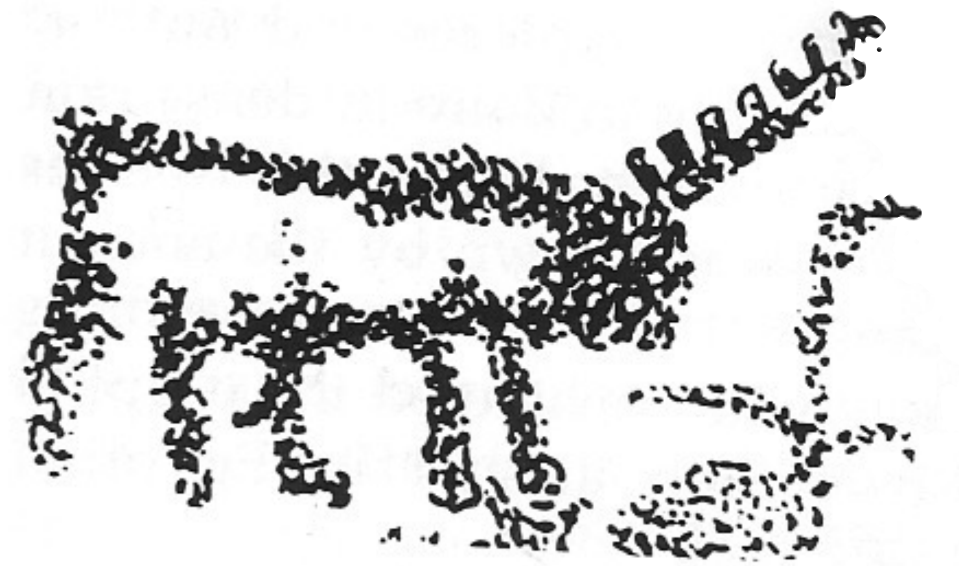


Elephants
Wadi Atwani

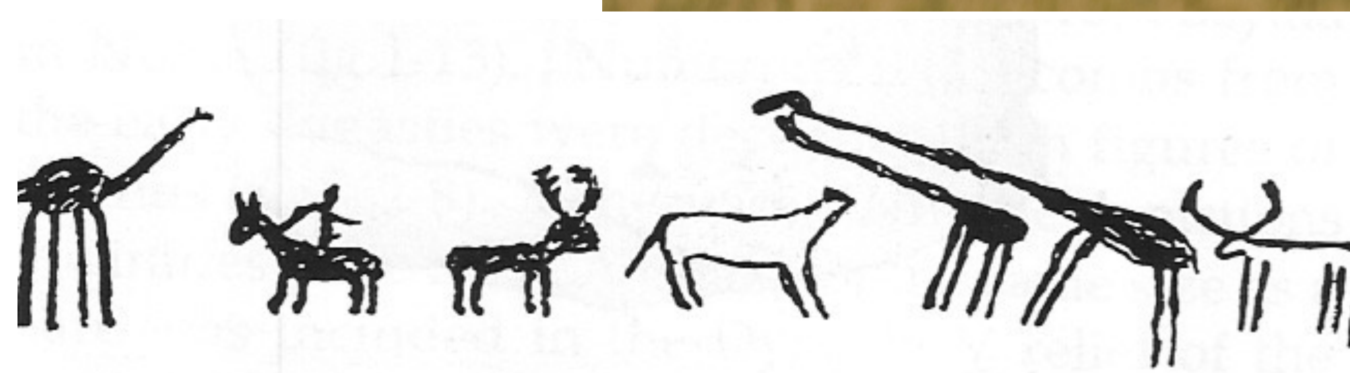


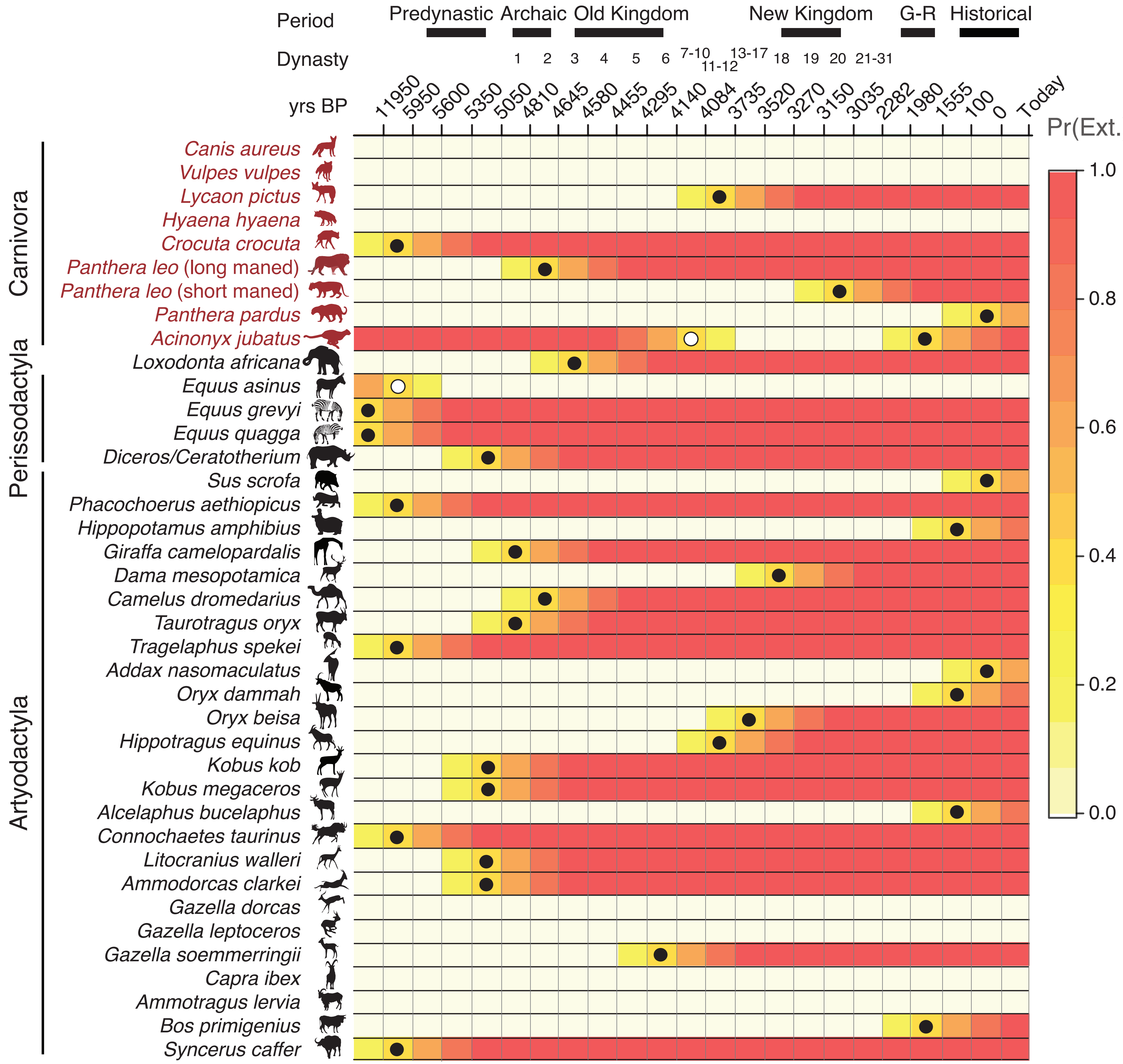


Giraffes
Autochthonous mountain dwellers

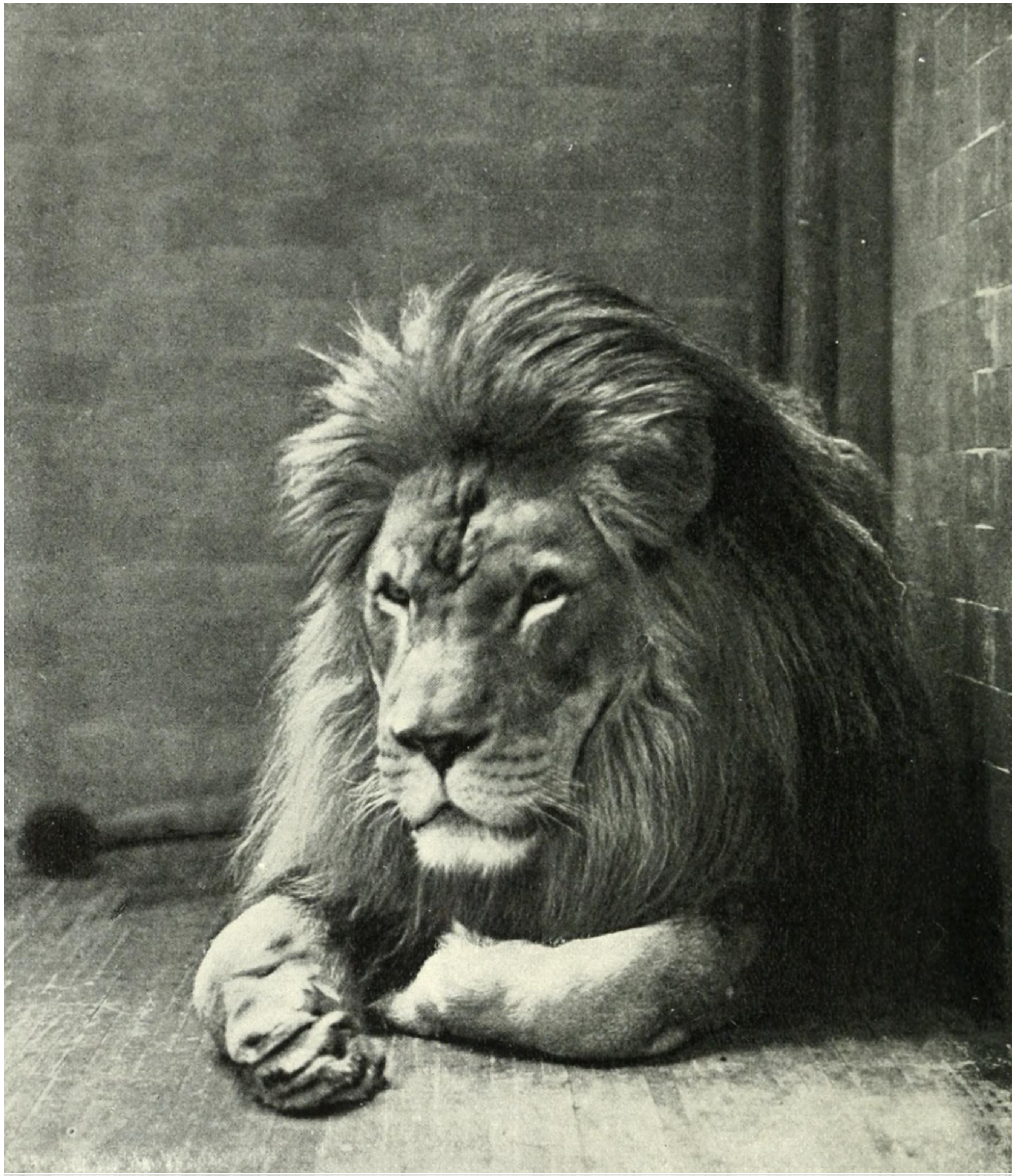


Dama deer ~ migration from mesop. before desertification (Pleistocene remains in Palestine)



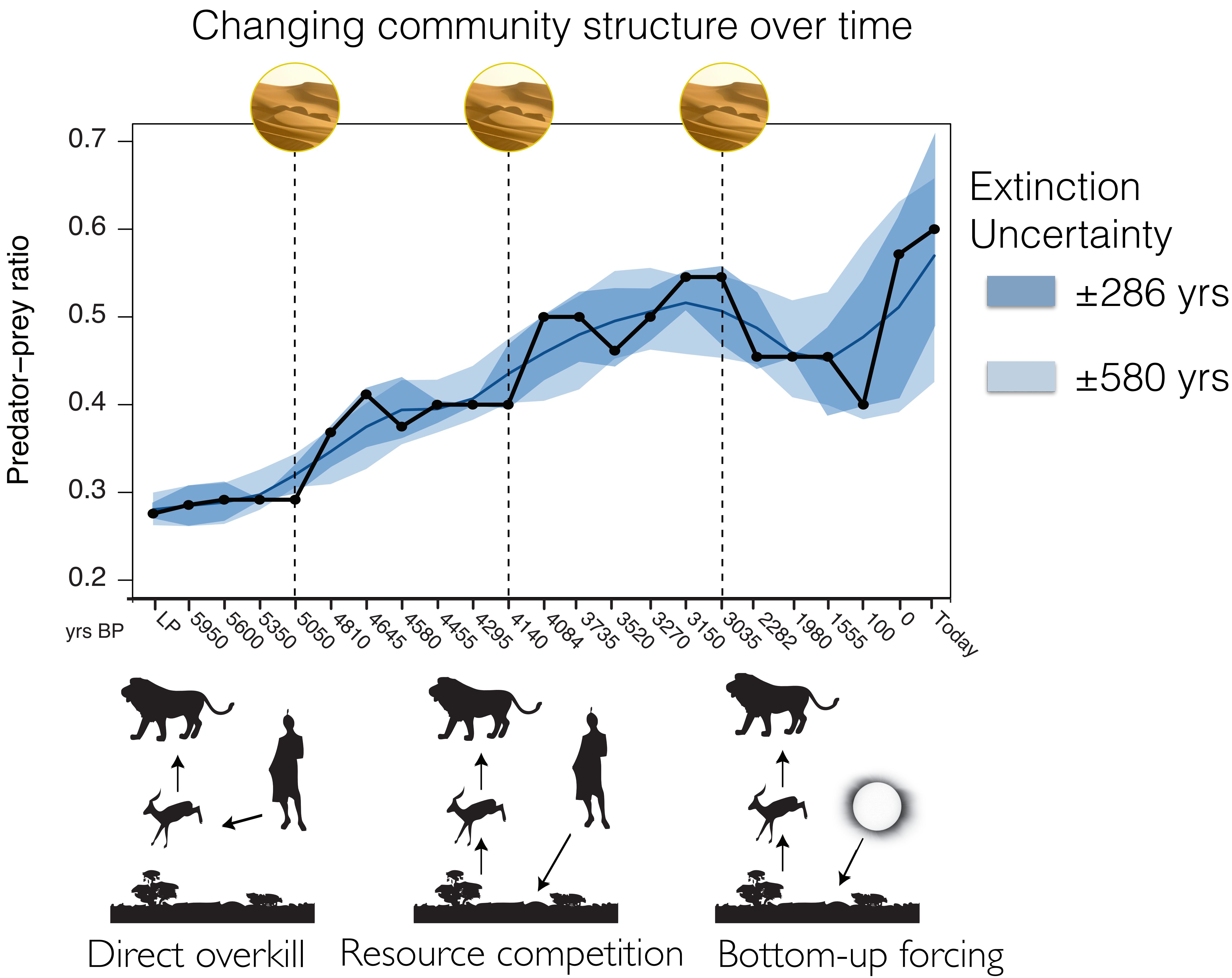


Period
Predynastic
Archaic
Old Kingdom
New Kingdom
G-R
Historical
Dynasty
1 2 3 4 5 6 7-10 11-12 13-17 18 19 20 21-31
yrs BP
11950 5950 5600 5350 5050 4810 4645 4580 4455 4295 4140 4084 3735 3520 3270 3150 3035 2282 1980 1555 100 0 Today
Pr(Ext.)
1.0
0.8
0.6
0.4
0.2
0.0
Carnivora
Perissodactyla
Artyodactyla
Canis aureus
Vulpes vulpes
Lycaon pictus
Hyaena hyaena
Crocuta crocuta
Panthera leo (long maned)
Panthera leo (short maned)
Panthera pardus
Acinonyx jubatus
Loxodonta africana
Equus asinus
Equus grevyi
Equus quagga
Diceros/Ceratotherium
Sus scrofa
Phacochoerus aethiopicus
Hippopotamus amphibius
Giraffa camelopardalis
Dama mesopotamica
Camelus dromedarius
Taurotragus oryx
Tragelaphus spekei
Addax nasomaculatus
Oryx dammah
Oryx beisa
Hippotragus equinus
Kobus kob
Kobus megaceros
Alcelaphus bucelaphus
Connochaetes taurinus
Litocranius walleri
Ammodorcas clarkei
Gazella dorcas
Gazella leptoceros
Gazella soemmerringii
Capra ibex
Ammotragus lervia
Bos primigenius
Syncerus caffer



Long-maned (Barbary?) lion
4645 yrs BP (end of 2nd Dynasty)

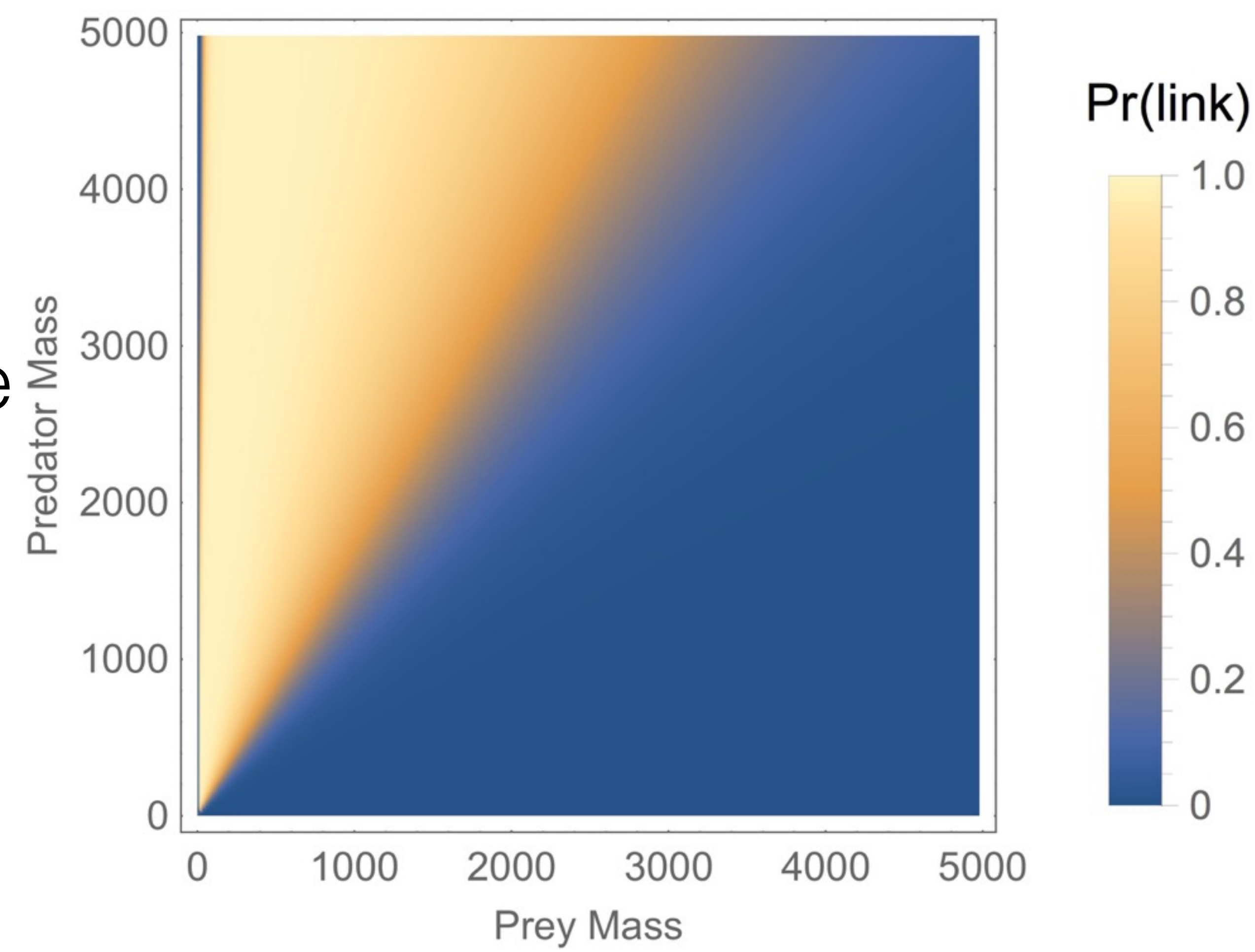
Short-maned lion
3035 yrs BP (end of 20th Dynasty)



Changing community structure over time
Predator–prey ratio
0.7
0.6
0.5
0.4
0.3
0.2
yrs BP
LP
5950
5600
5350
5050
4810
4645
4580
4455
4295
4140
4084
3735
3520
3270
3150
3035
2282
1980
1555
100
0
Today
Extinction Uncertainty
±286 yrs
±580 yrs
Direct overkill
Resource competition
Bottom-up forcing

Fitting models to data…
The Log-Ratio Model (LRM)

Better results, particularly for systems with strong body size constraints (large mammal communities, marine food webs)



m_i = predator mass

m_j = prey mass

$$\log\left[\frac{P(a_{ij}=1)}{P(a_{ij}=0)}\right] = \alpha + \beta \log\left(\frac{m_i}{m_j}\right) + \gamma \log^2\left(\frac{m_i}{m_j}\right),$$

Interaction probabilities modeled as a Logit regression

Quadratic term allows interaction probabilities to have a Gaussian-like shape

What were the dynamic consequences of community change?

Generalization & normalization

$$\dot{X}_i = S_i(X_i) + \eta_i F_i(X_1, \ldots, X_N) - M_i(X_i) - \sum_{n=1}^{N} L_{n,i}(X_1, \ldots, X_N)$$

$$x_i = \frac{X_i}{X_i^*}$$

Response to a perturbation

Jacobian Matrix ~ Functional elasticities

$$J_{ii}|_* = \alpha_i\{\hat{\rho}_i\phi_i + \rho_i(\gamma_i\chi_{ii}\lambda_i + \psi_i) - \hat{\sigma}_i\mu_i - \sigma_i(\sum_{k=1}^{N}\beta_{ki}\lambda_{ki}[(\gamma_k - 1)\chi_{ki} + 1])\}$$

$$J_{ij}|_* = \alpha_i\{\rho_i\gamma_i\chi_{ij}\lambda_{ij} - \sigma(\beta_{ji}\psi_j + \sum_{k=1}^{N}\beta_{ki}\lambda_{kj}(\gamma_k - 1)\chi_{kj})\}$$

Yeakel et al. PNAS, 2014

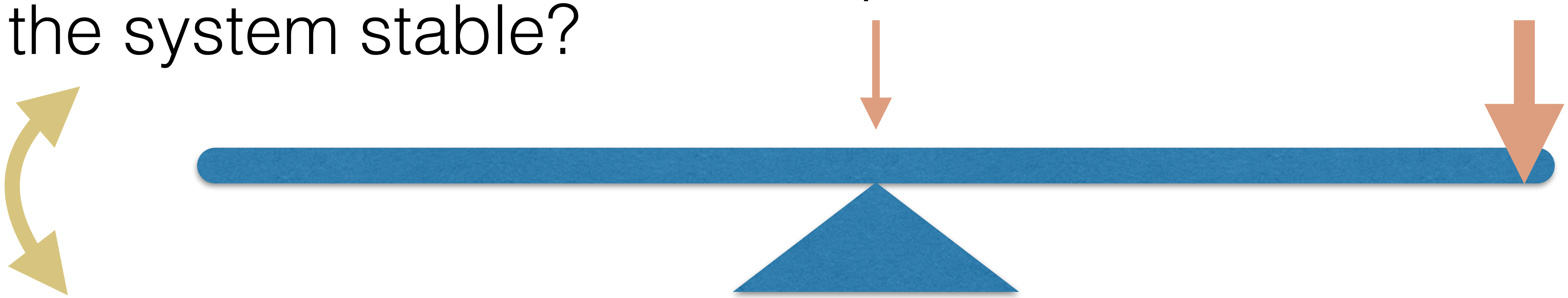
What were the dynamic consequences of community change?

1) **Food web stability**

2) **Species-specific roles & sensitivities to change**

Food web stability:
Is the system stable?

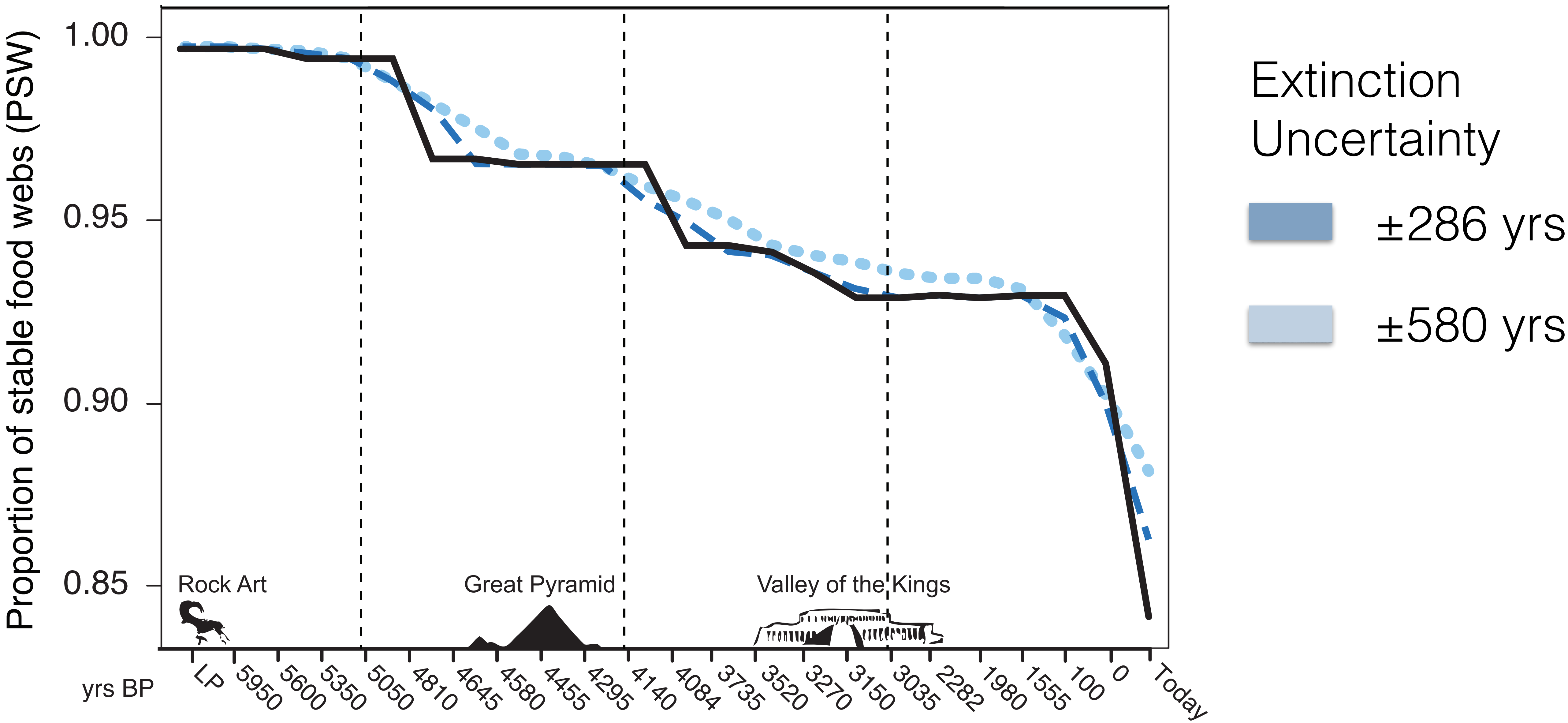
How sensitive is each component to a disturbance?



Yeakel et al. PNAS, 2014

What were the dynamic consequences of community change?

1. **Percent Stable Food webs (PSW):** Declines over time

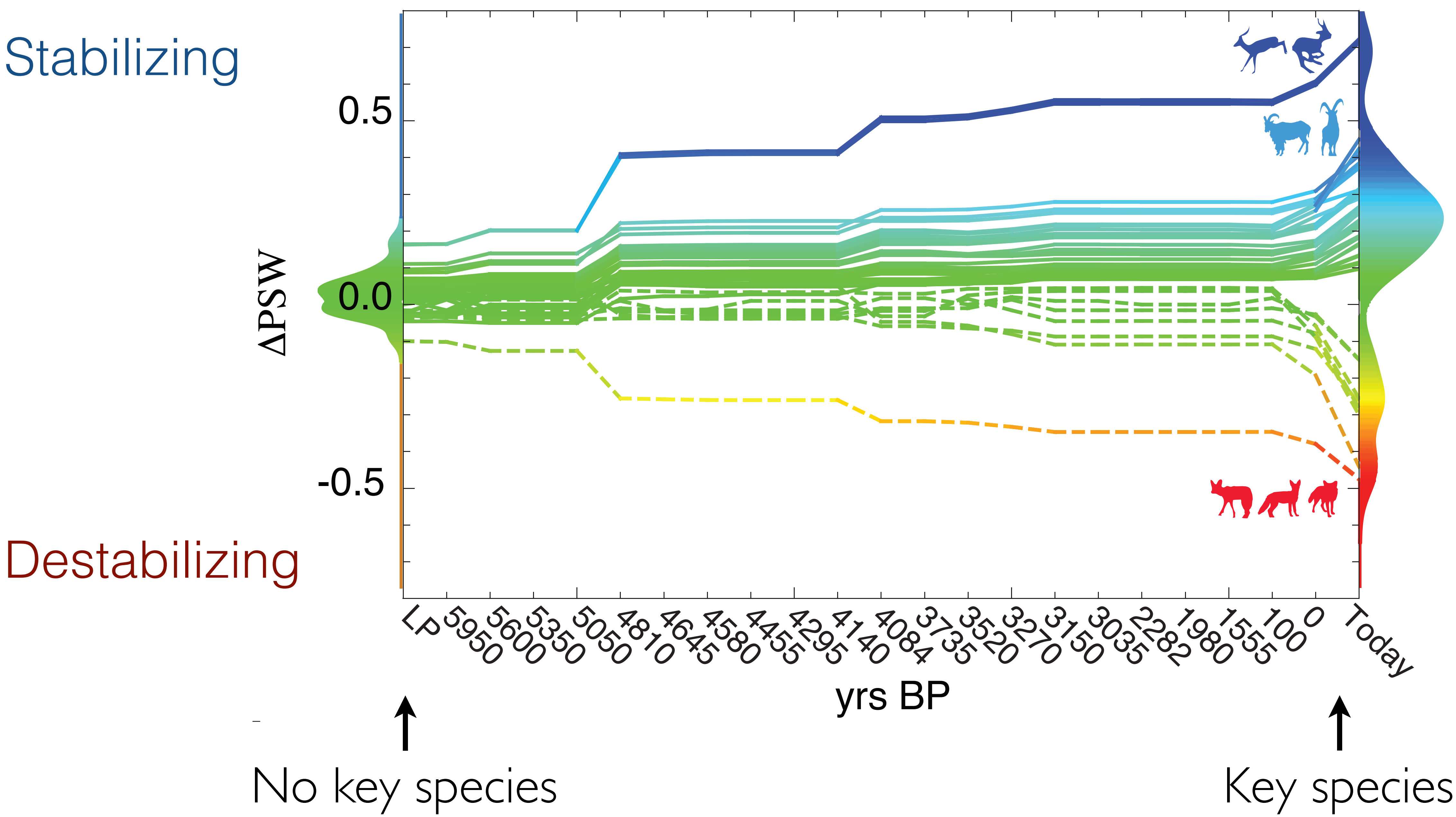


Yeakel et al. PNAS, 2014

What were the dynamic consequences of community change?

1. **Percent Stable Food webs (PSW):** Declines over time

2. **Species' Impact:** Key species emerge as food web unravels



Yeakel et al. PNAS, 2014

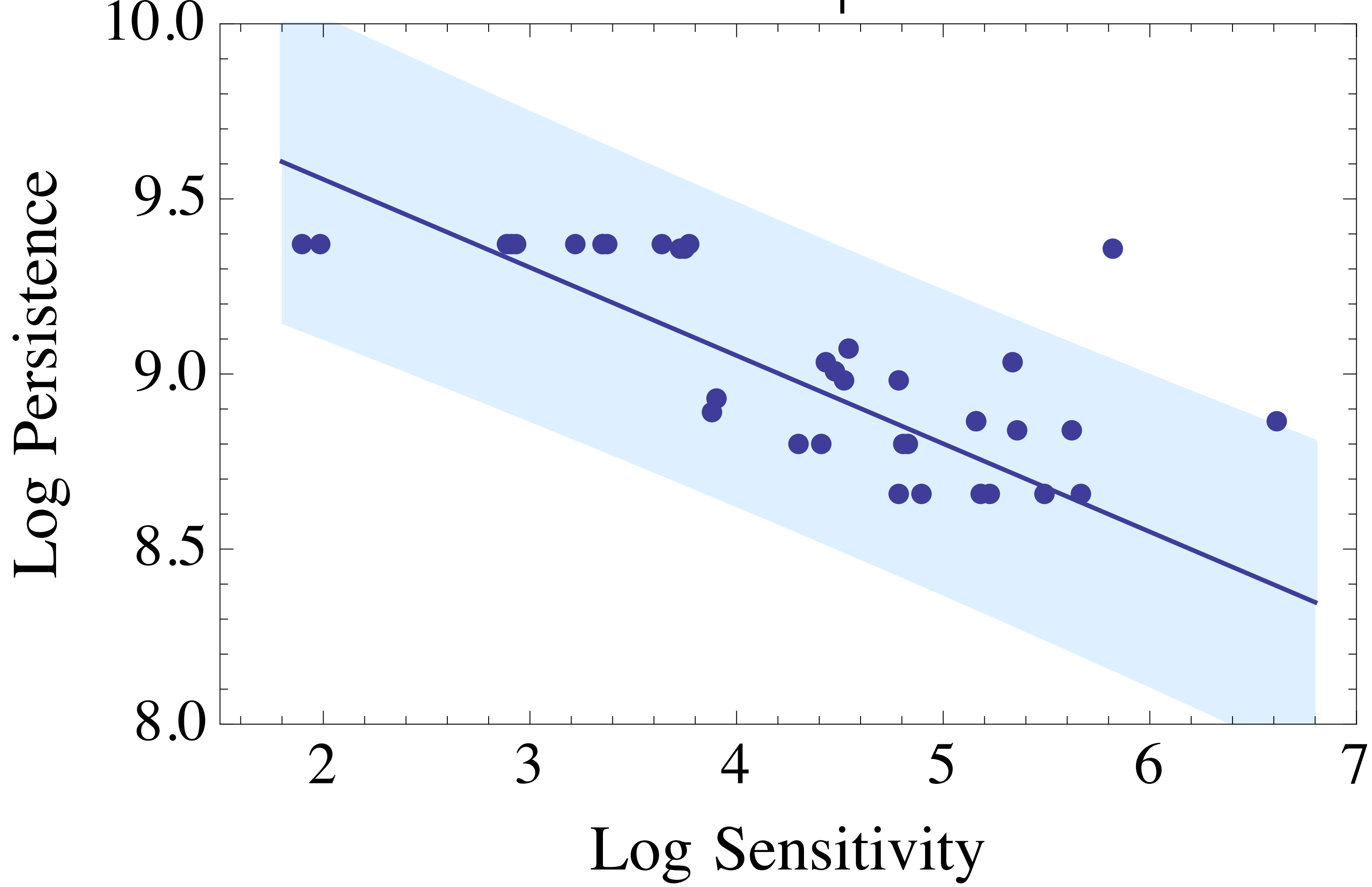
What were the dynamic consequences of community change?

1. **Percent Stable Food webs (PSW):** Declines over time

2. **Species' Impact:** Key species emerge as food web unravels

3. **Species' Sensitivity:** Does sensitivity predict persistence?

Persistence is predictable



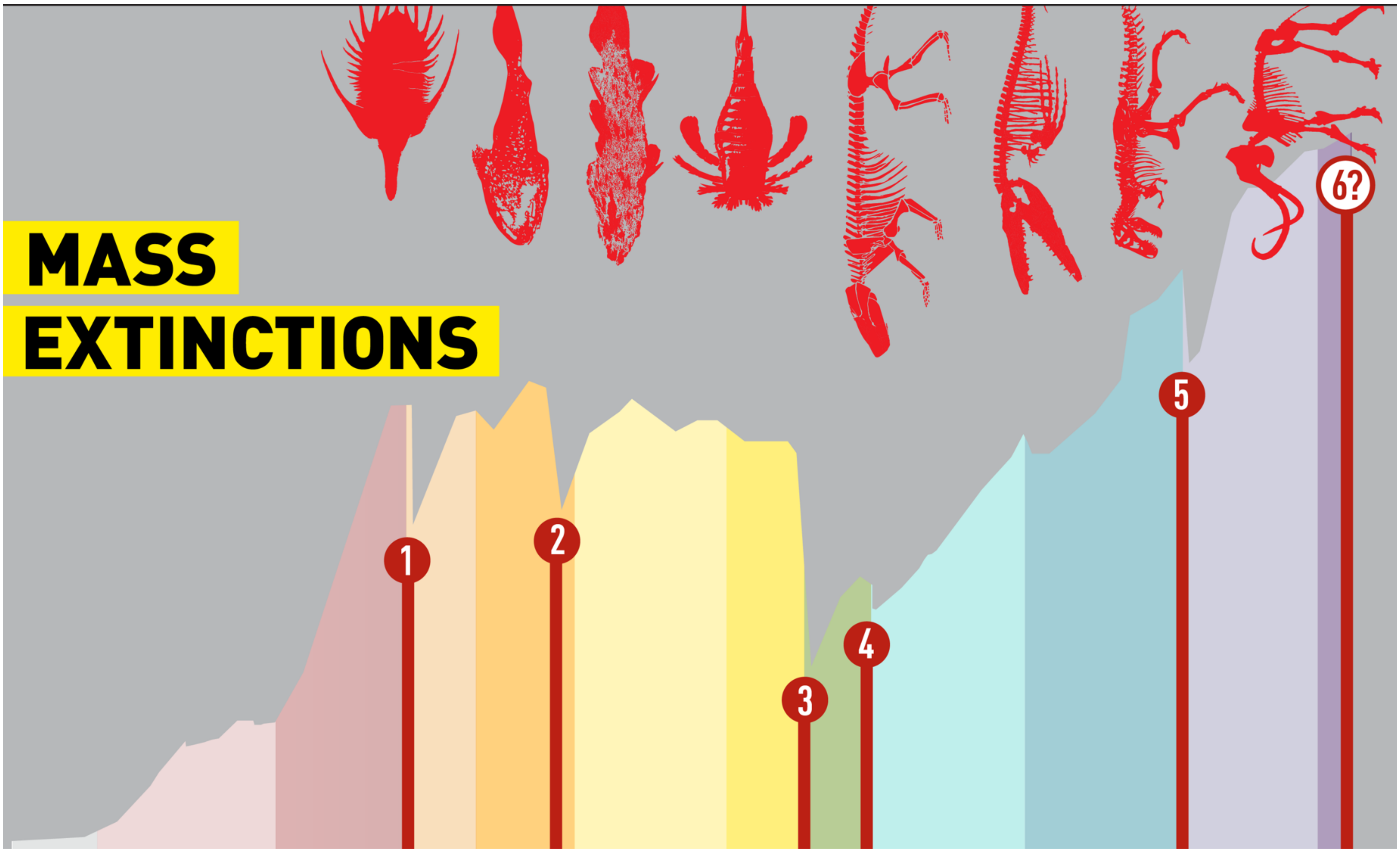
$$\mathrm{Se}_i = \log\left(\sum_k \frac{|v_i^{(k)}|}{|\lambda_k|}\right)$$

Species-specific excitability to an external perturbation

Aufderheidt et al. 2013

Yeakel et al. PNAS, 2014

Food webs and the Future



Community-level frameworks are vital for understanding/predicting/preventing future changes to our ecosystems

Thanks for listening, and enjoy the rest of CSSS!
Questions?