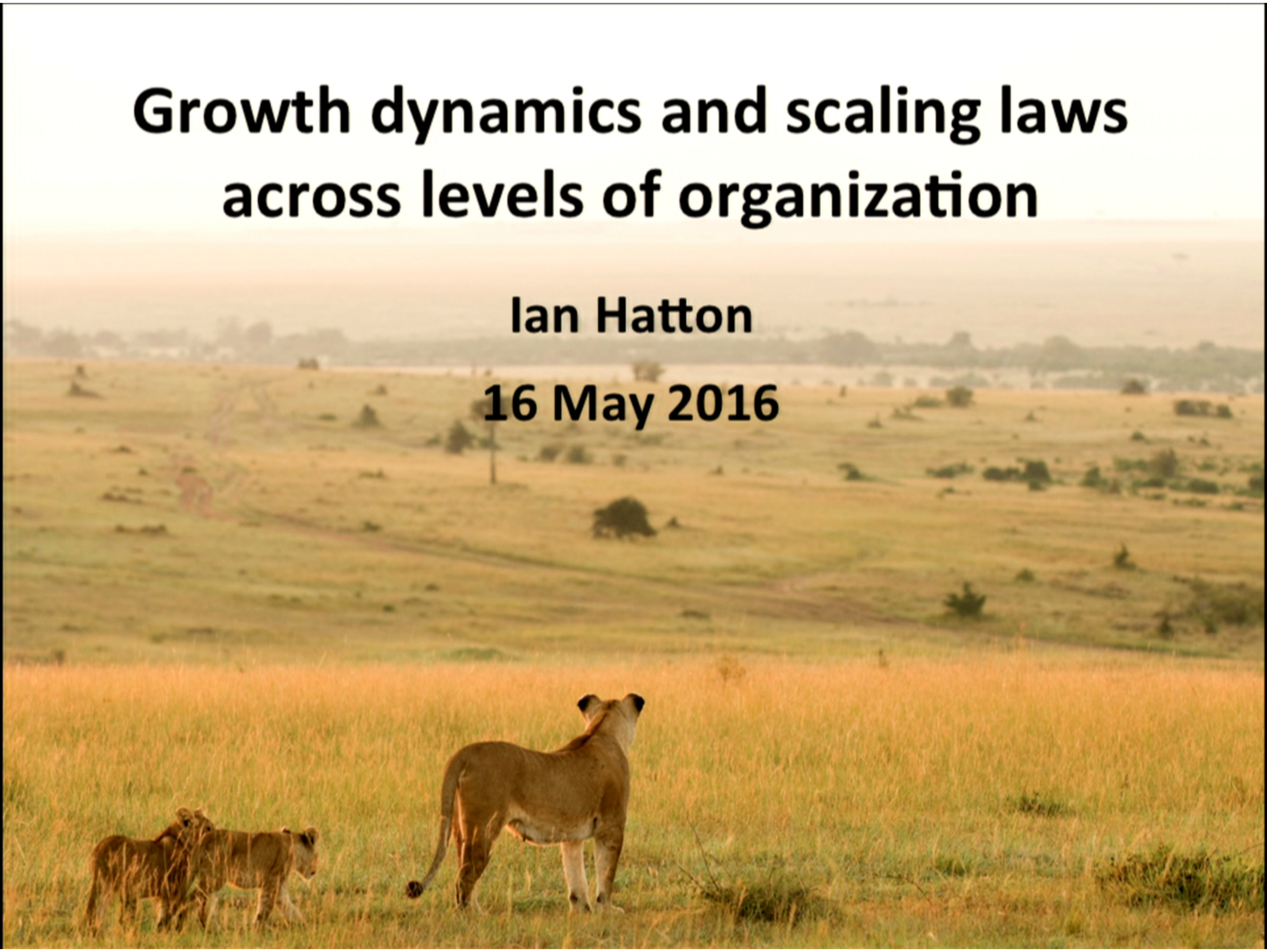
Title: Growth dynamics and scaling laws across levels of biological organization.

Date: May 16, 2016 11:00 AM

URL: http://pirsa.org/16050031

Abstract: <p>Recent findings on quantitative growth patterns have revealed striking generalities across the tree of life, and recurring over distinct levels of organization. Growth-mass relationships in 1) individual growth to maturity, 2) population reproduction, 3) insect colony enlargement and 4) community production across wholeecosystems of very different types, often follow highly robust near Â¾ scaling laws. These patterns represent some of the most general relations in biology, but the reasons they are so strangely similar across levels of organization remains a mystery. The dynamics of these distinct levels are connected, yet their scaling can be shown to arise independently, and free of system-specific properties. Numerous experiments in prebiotic chemistry have shown that minimal self-replicating systems that undergo template-directed synthesis, typically show reaction orders (ie. growth-mass exponents) between Â½ and 1. I will outline how modifications to these simplified reaction schemes can yield growth-mass exponents near Â¾, which may offer insight into dynamical connections across hierarchical systems.</p>



Growth dynamics and scaling laws across levels of organization

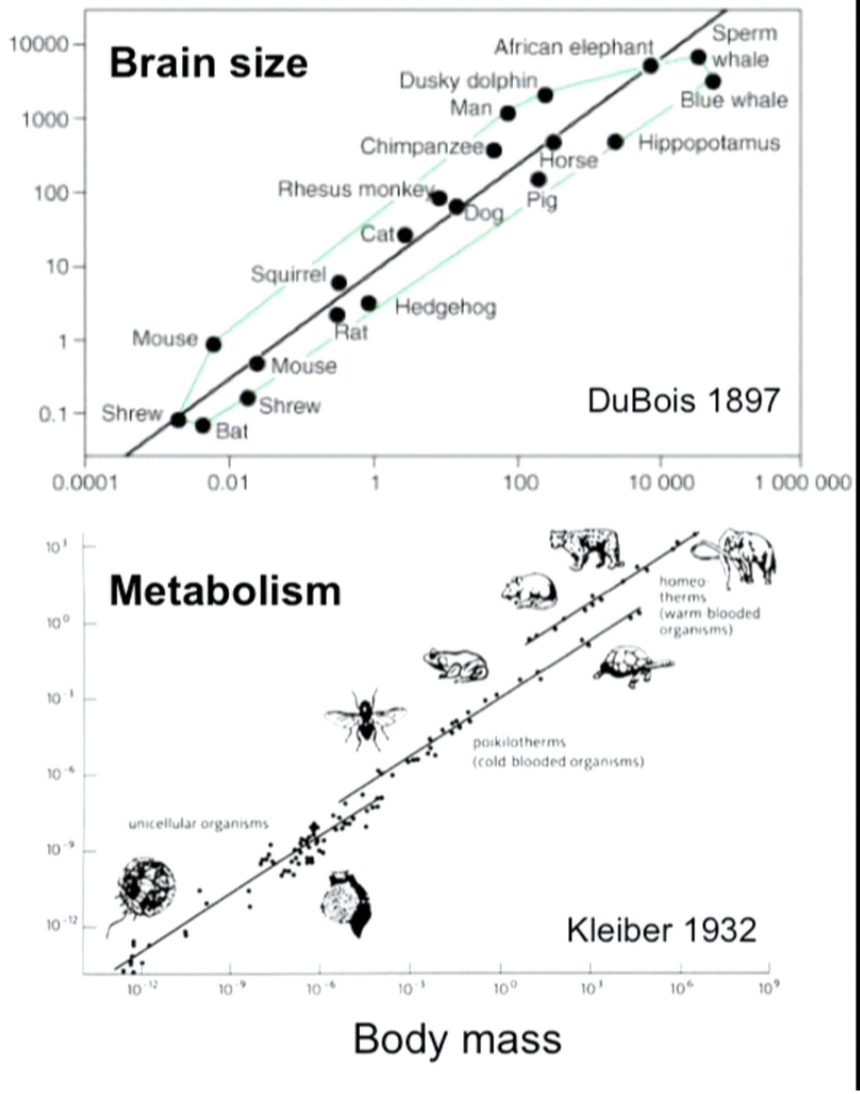
Ian Hatton

16 May 2016

Power laws in biology

$y = c\,x^{k}$

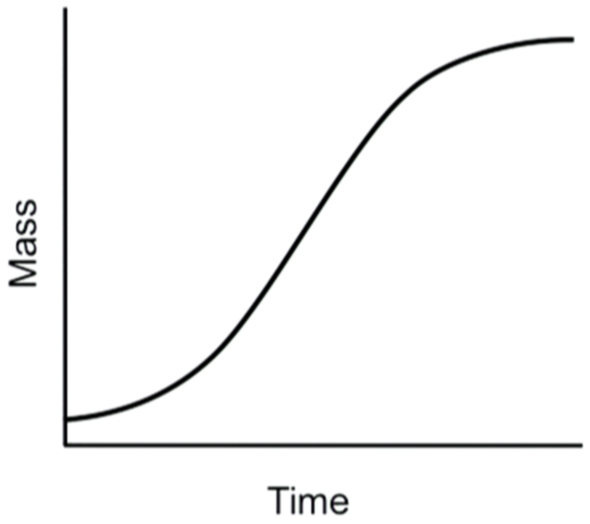
$\log y = \log c + k \log x$



Growth dynamics across levels of organization

Mass may be:

- Bacteria / algae
- Tumor
- Individual body
- Population / colony
- Community



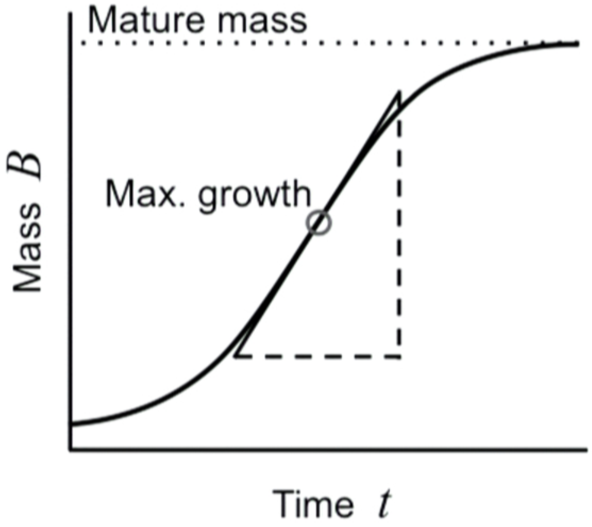
Growth dynamics across levels of organization

Model may be :

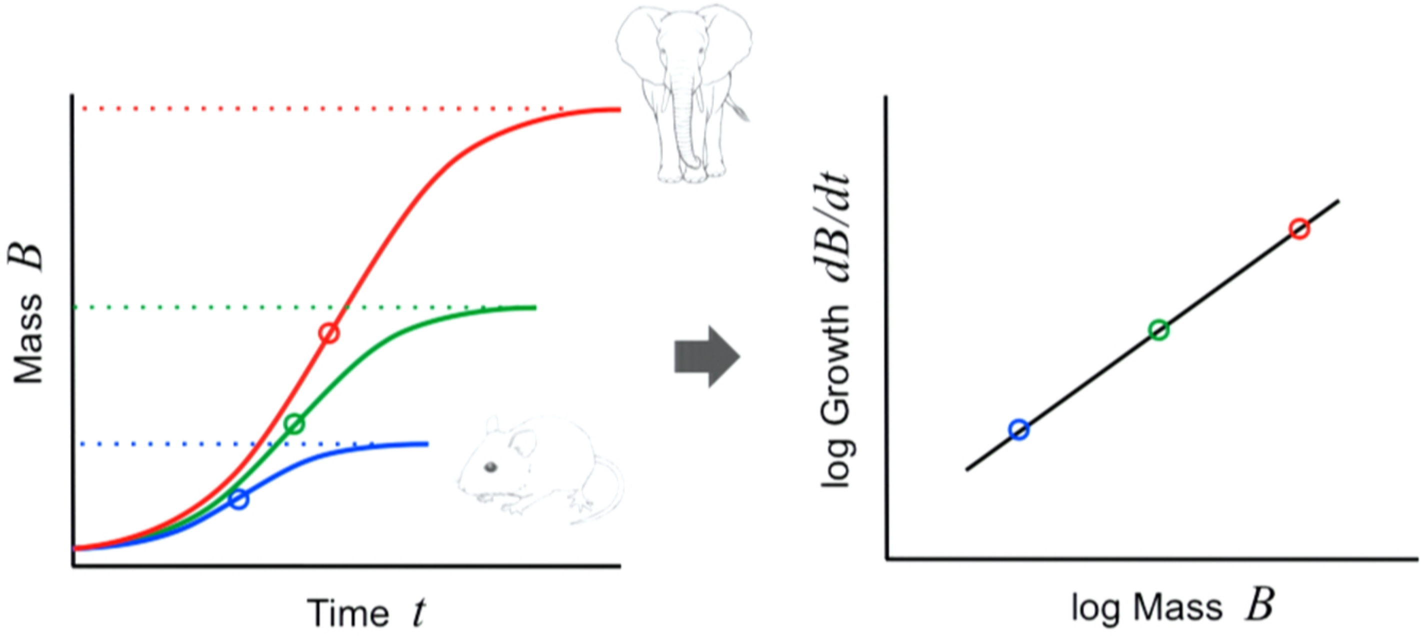
- Logistic $$\frac{dB}{dt} = pB\left(1 - \frac{B}{q}\right)$$

- Gompertz $$\frac{dB}{dt} = pB(\ln q - \ln B)$$

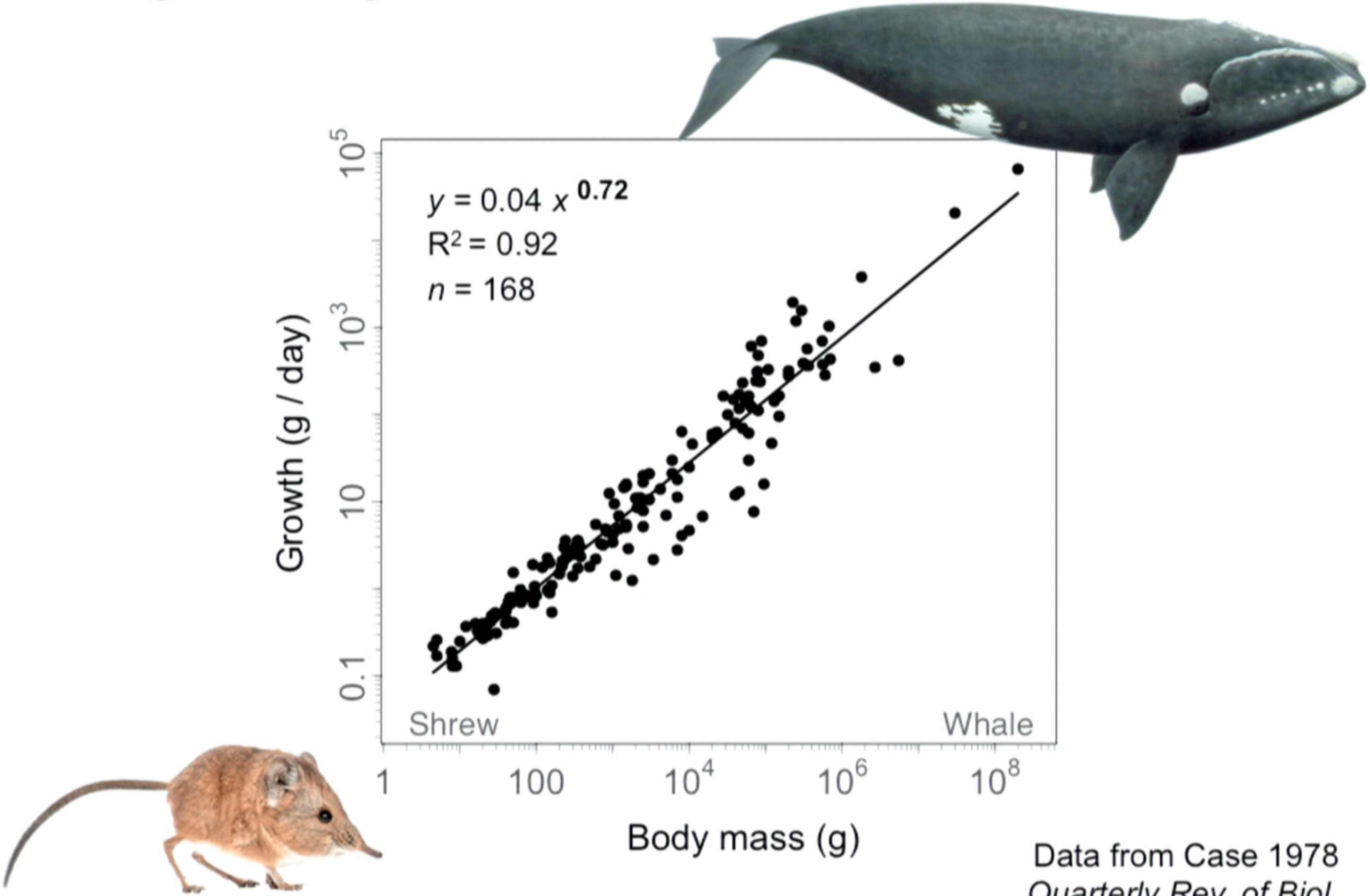
- Bertalanffy $$\frac{dB}{dt} = pB^k - qB$$



Growth vs. mass power law



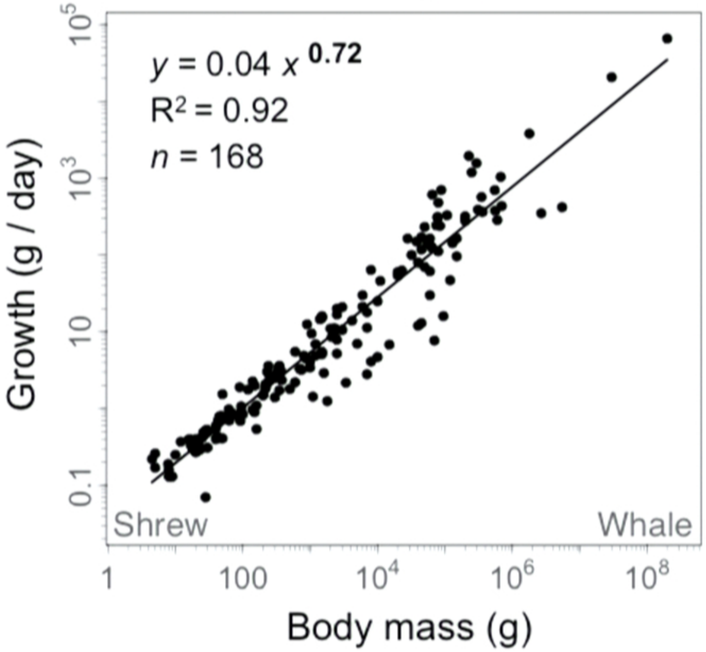
Ontogenetic growth in mammals



Data from Case 1978
Quarterly Rev. of Biol.

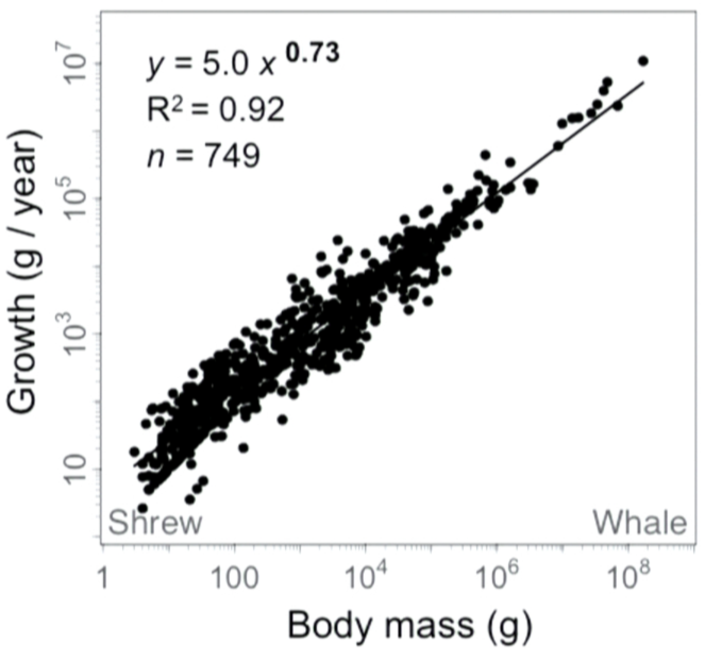
Growth in mammals

Individual ontogeny



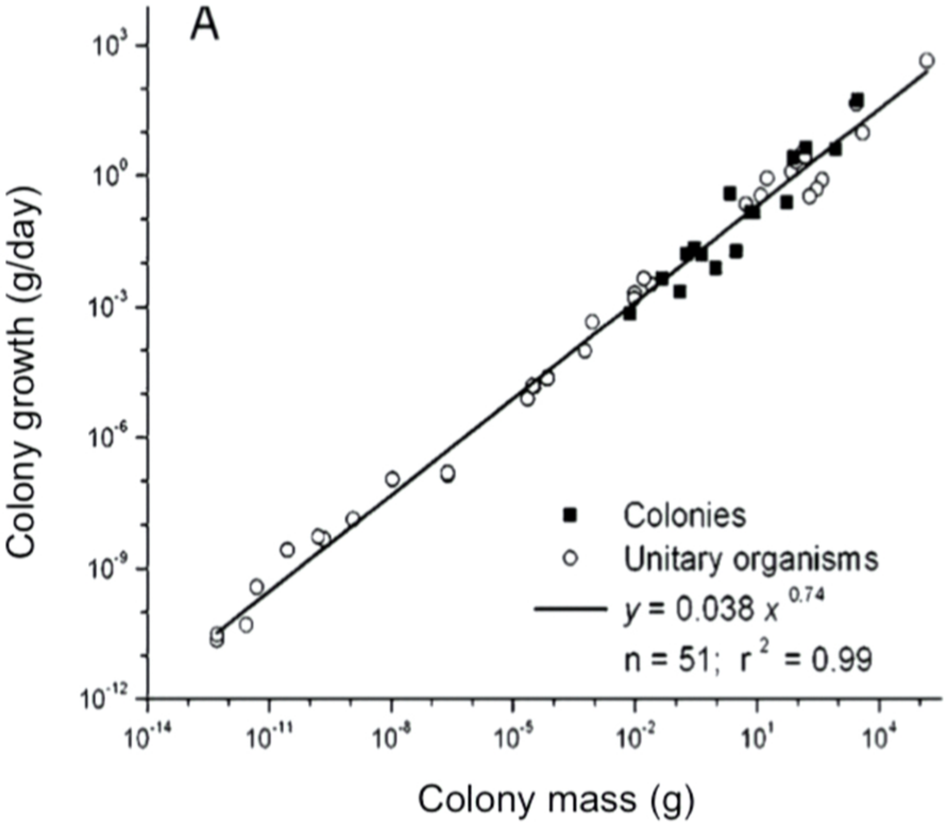
Data from Case 1978
Quarterly Rev. of Biol.

Population reproduction



Data from Hatton et. al. 2015
Science

Social insects colonies



Hou *et. al.* 2010
PNAS

Growth of whole communities

> 1000 peer-reviewed sources from past 50 yrs

> 2000 ecosystems worldwide (mammal, invertebrate, plant and plankton communities)

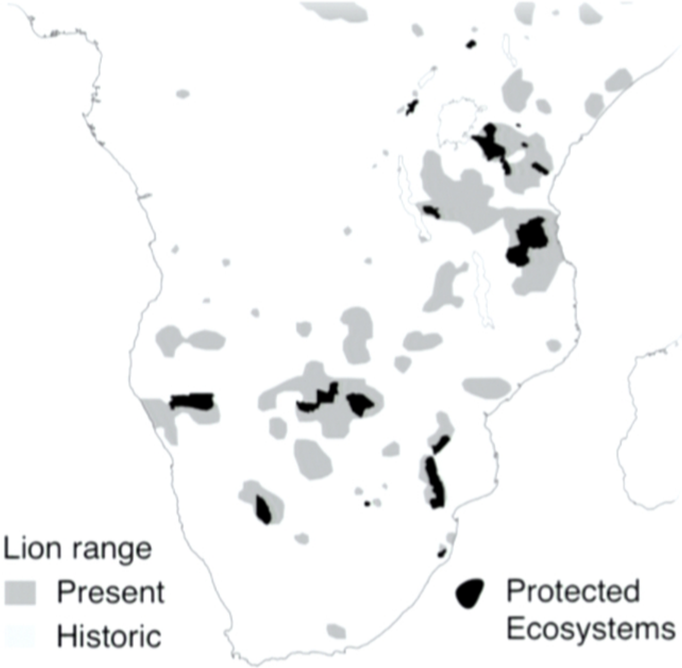
RESEARCH ARTICLE

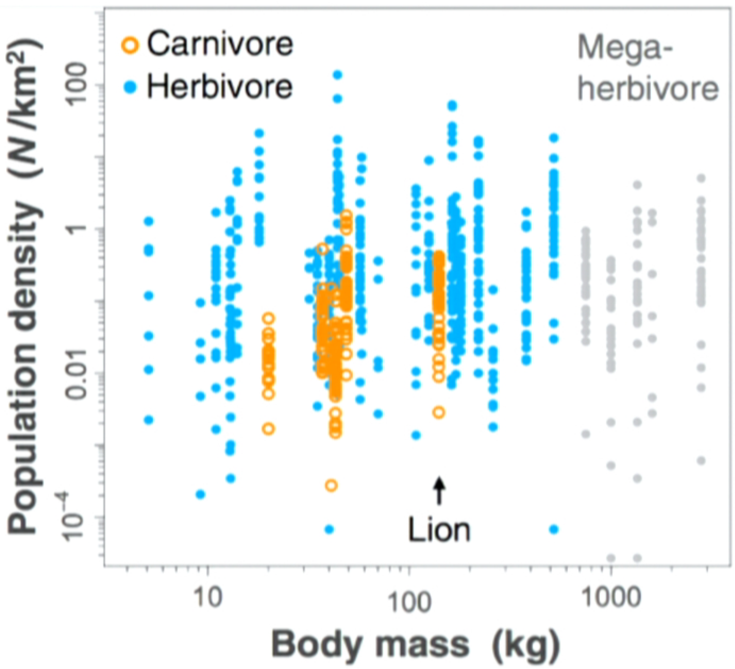
MACROECOLOGY

The predator-prey power law: Biomass scaling across terrestrial and aquatic biomes

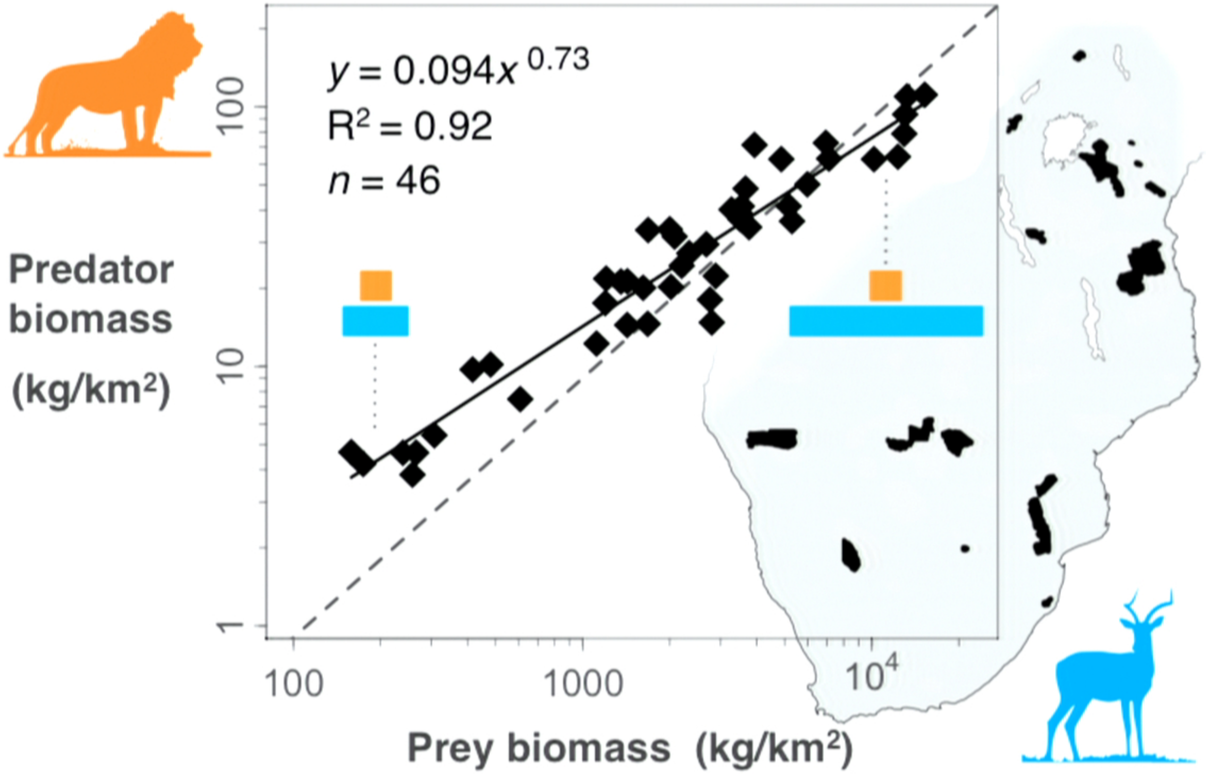
- Collaborators: Kevin McCann, John Fryxell, Jonathan Davies, Matteo Smerlak, Tony Sinclair and Michel Loreau

Animal abundance is variable in African savanna





Ecosystem structure changes systematically



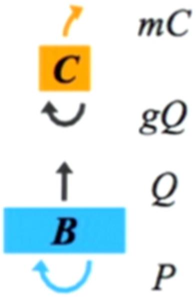
Predator-prey model

Equilibrium Solution: $C^* = cB^{*k}$

Model:

$$\frac{dC}{dt} = gQ - mC$$

$$\frac{dB}{dt} = P - Q$$



Prey production function: $P = rB^k$

Linking structure and function: $c = rg/m$

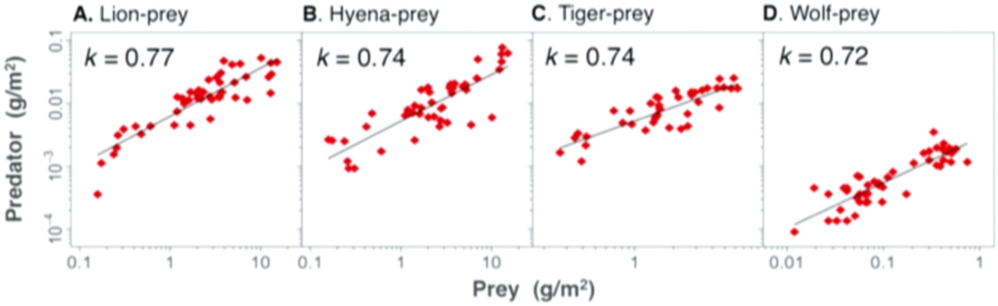
Lion range

Tiger range

Predator-prey scaling

◆ Top-carnivore biomass vs total herbivore prey biomass

k = 0.74 (0.68-0.81), n = 184



$$C^* = cB^{*k}$$

$$k \approx 3/4$$

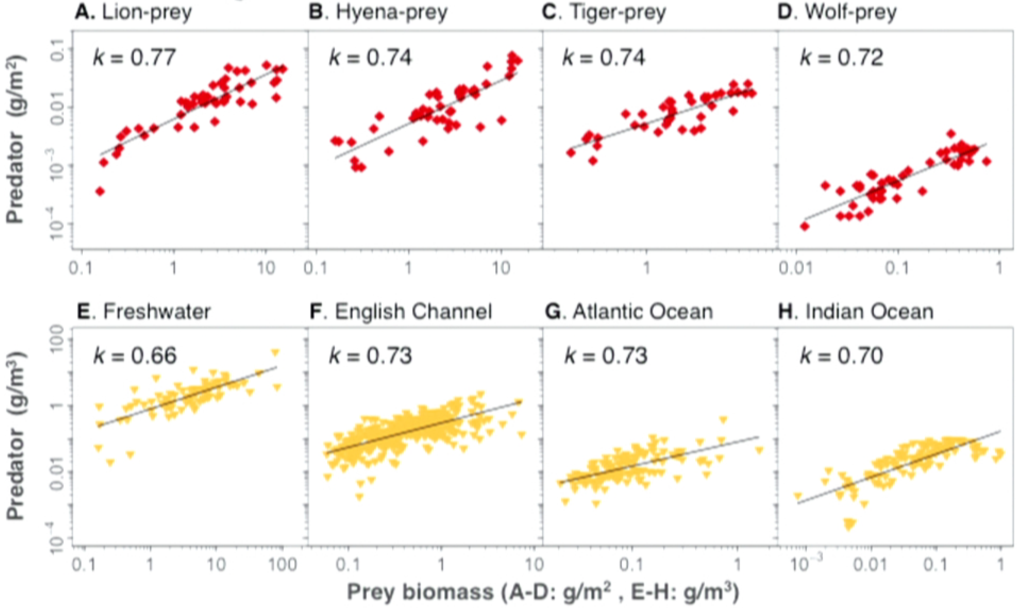
Predator-prey scaling

◆ Top-carnivore biomass vs total herbivore prey biomass

k = 0.74 (0.68, 0.81), n = 184

▼ Zooplankton biomass vs total algal community biomass

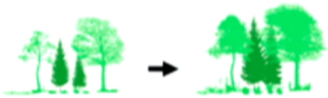
k = 0.71 (0.65, 0.76), n = 667



$$P = rB^k$$

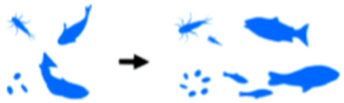
$$k \approx 3/4$$

Production-biomass scaling



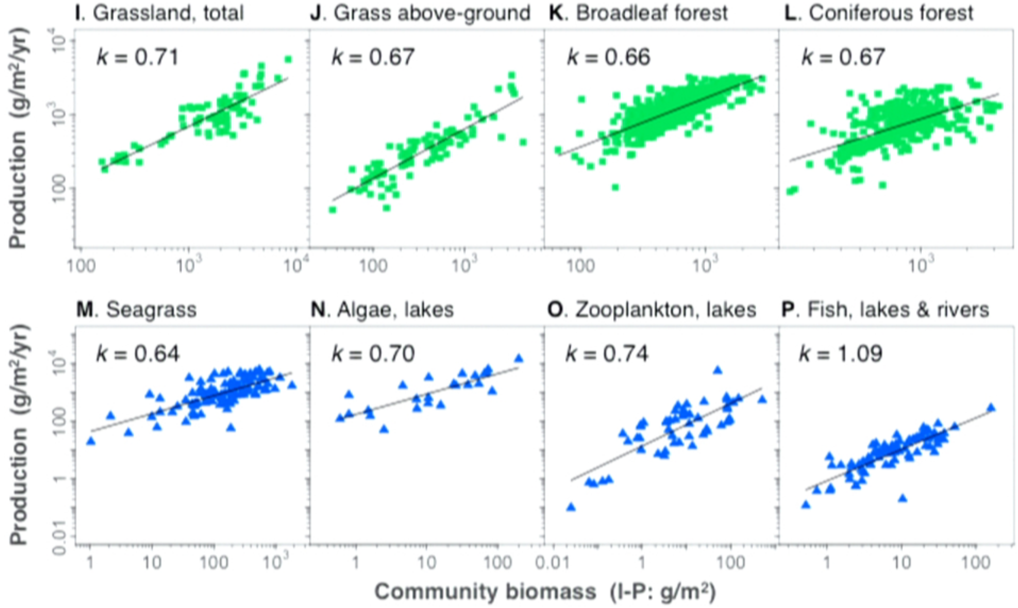
■ Plant community production vs total foliage biomass

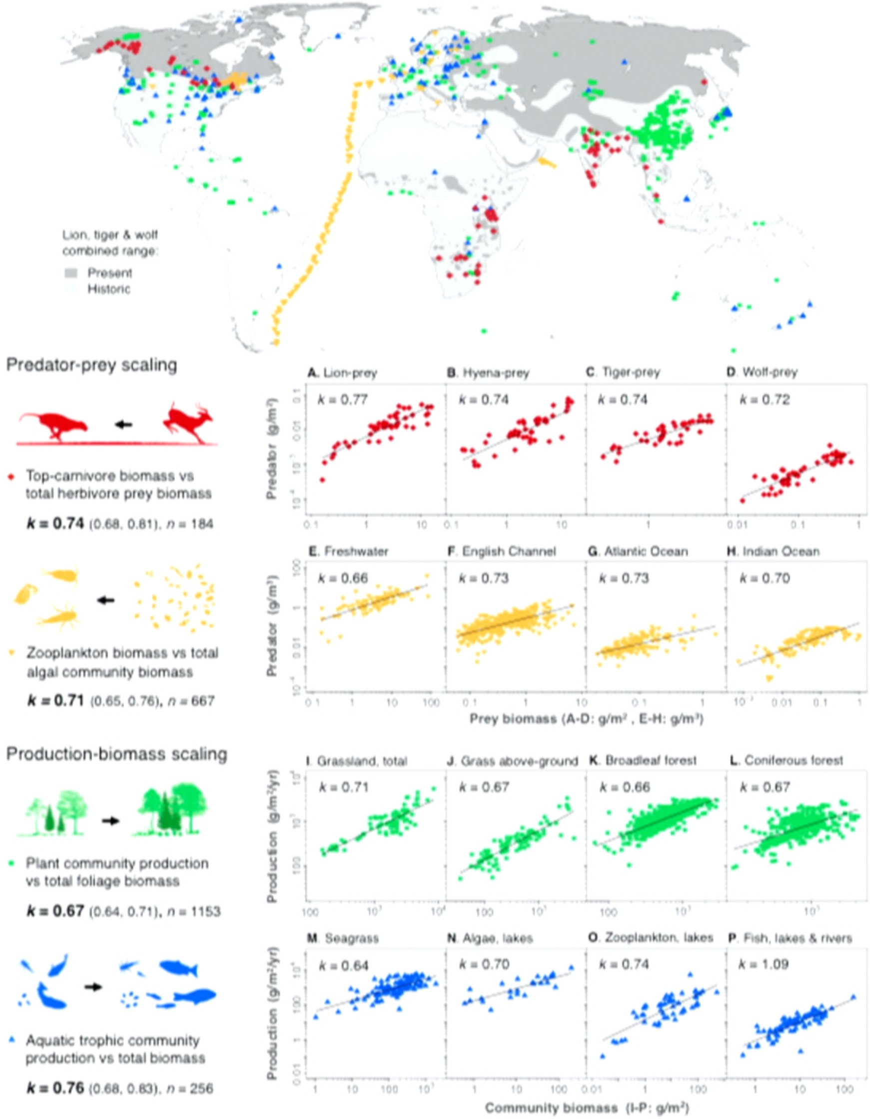
***k* = 0.67** (0.64, 0.71), *n* = 1153



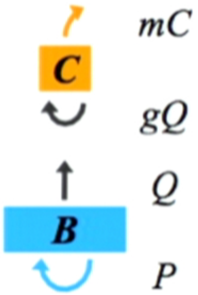
▲ Aquatic trophic community production vs total biomass

***k* = 0.76** (0.68, 0.83), *n* = 256





$$\frac{dC}{dt} = gQ - mC$$



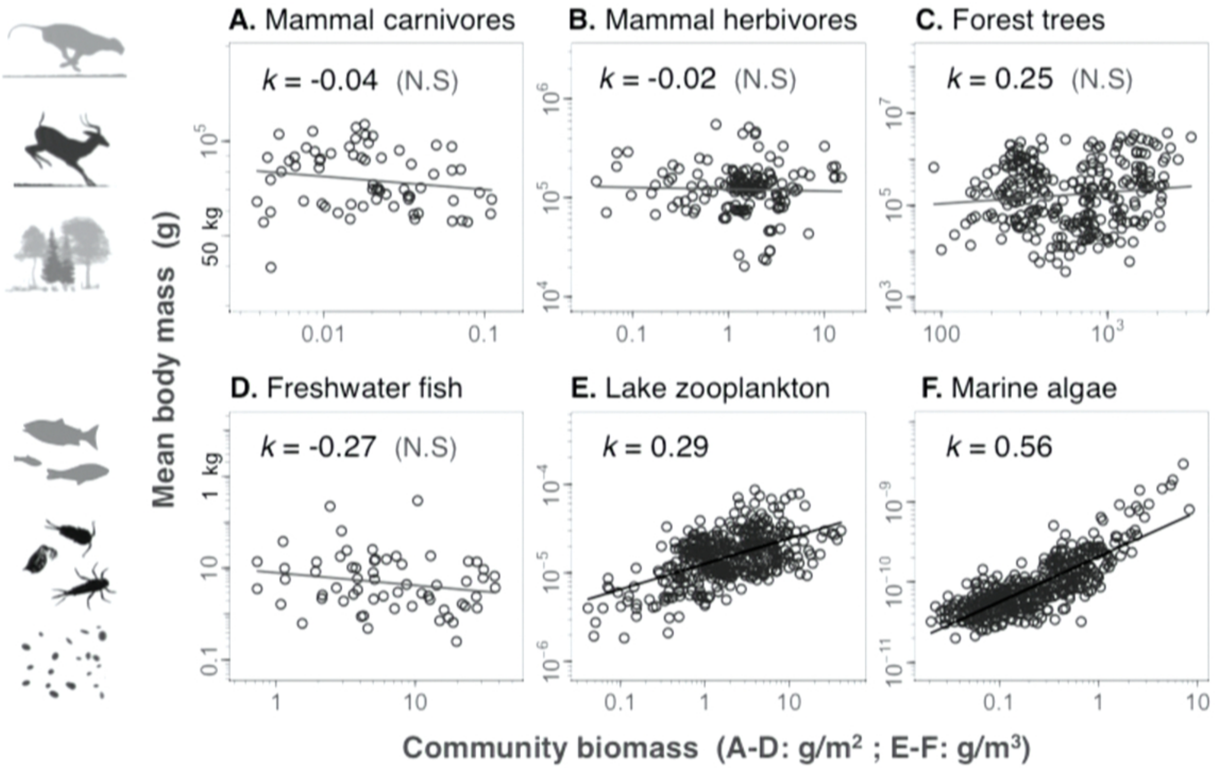
$$\frac{dB}{dt} = P - Q$$

$$C^* = cB^{*k}$$

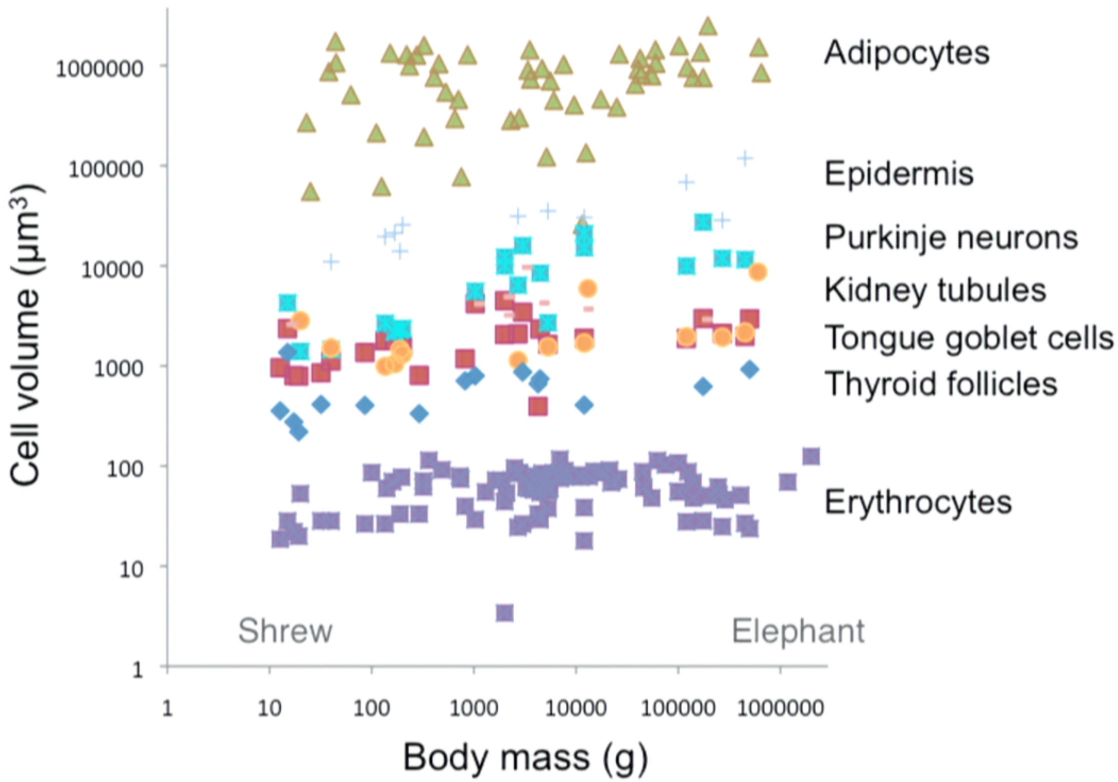
$$c = rg/m$$

$$\frac{dB}{dt} = rB^k$$

These patterns arise independently



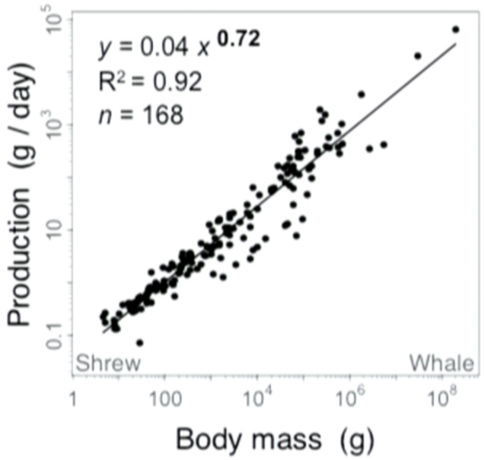
Cells are also size-invariant



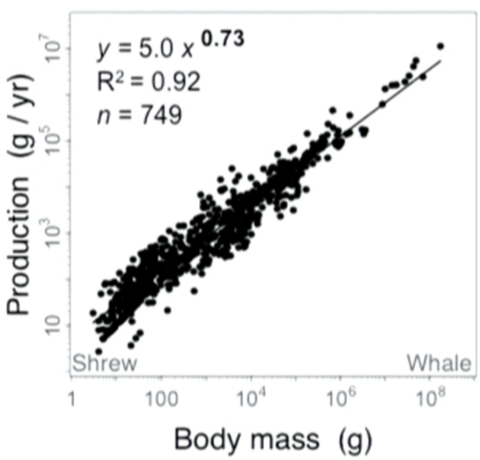
Data from Savage *et. al.* 2007 *PNAS*

Mammal growth across levels of organization

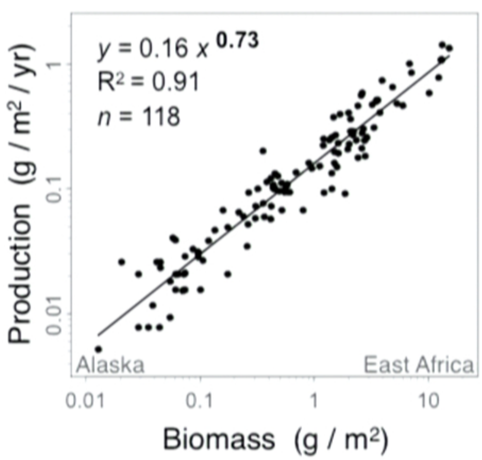
Individual somatic growth



Population reproduction

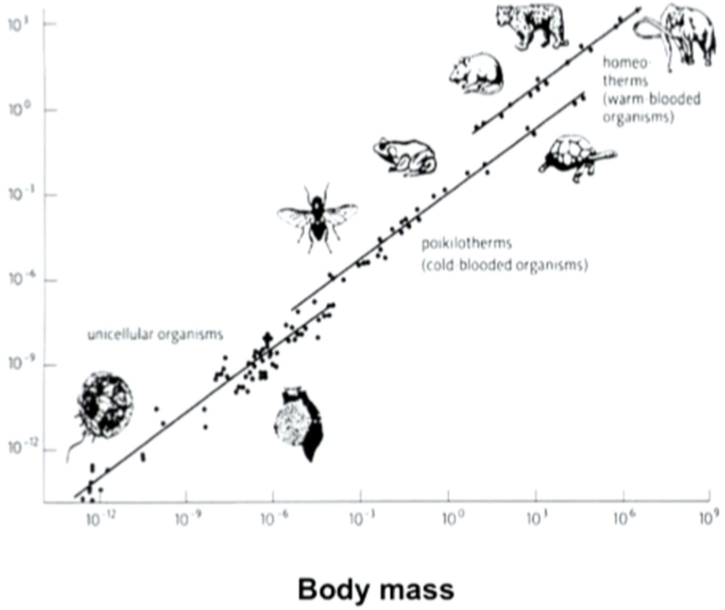


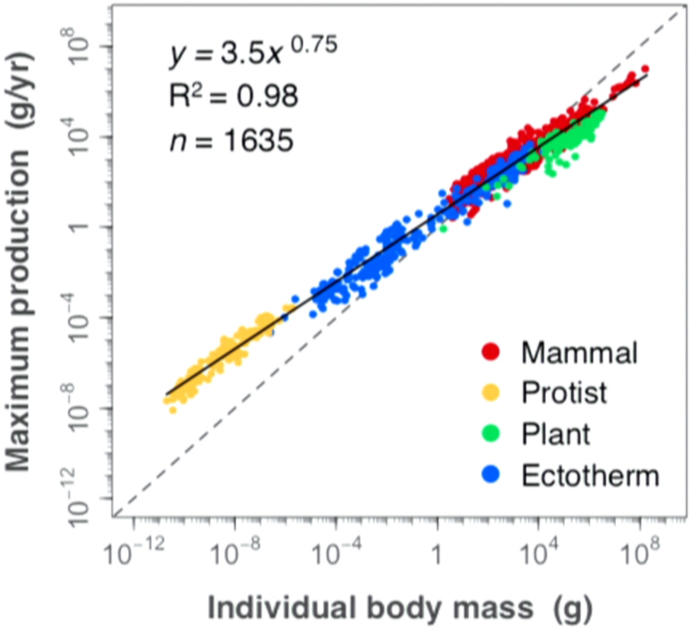
Community production



The cart before the horse?

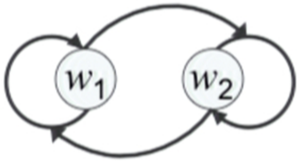
Do energetic constraints limit growth, or did energy supply evolve to fuel growth most efficiently?


Metabolism

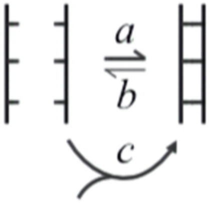

Growth

Classic self-replication

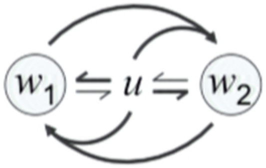
Exponential growth k=1 $$\frac{dB}{dt} = rB$$



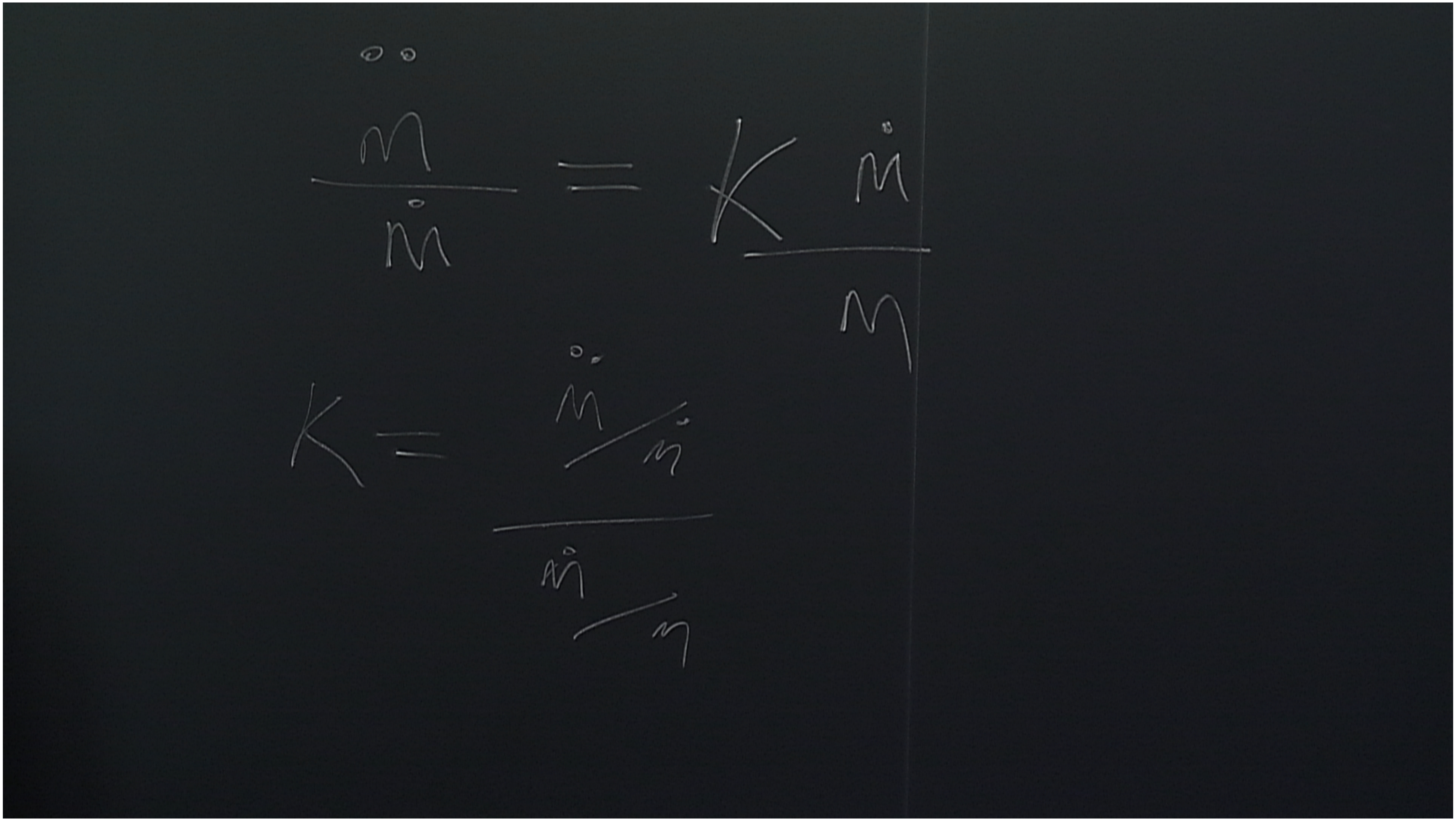
Hypercyclic growth k=2 $$\frac{dB}{dt} = rB^2$$



Template formation k=½ $$\frac{dB}{dt} = rB^{\frac{1}{2}}$$



Other schemes?

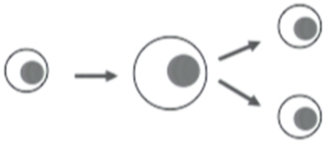


$$\frac{\ddot{m}}{\dot{m}} = K \frac{\dot{m}}{m}$$

$$K = \frac{\ddot{m} / \dot{m}}{\dot{m} / m}$$

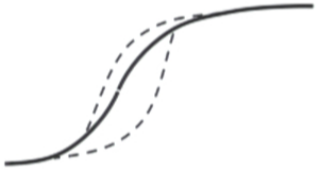
Likely ingredients for theory

Replicators are size invariant



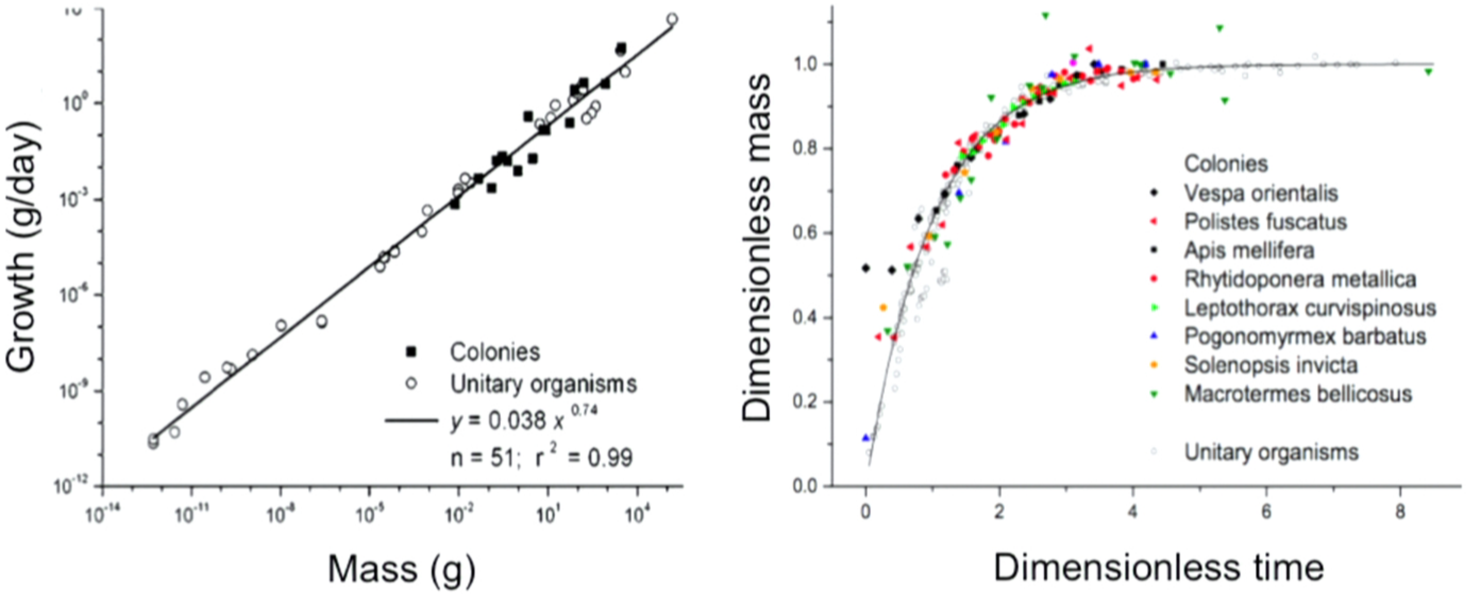
Continuous and discrete dynamics

Promoter and inhibitor signals



Negative feedbacks

Social insects – individuals and whole colonies



Hou *et. al.* 2010
PNAS