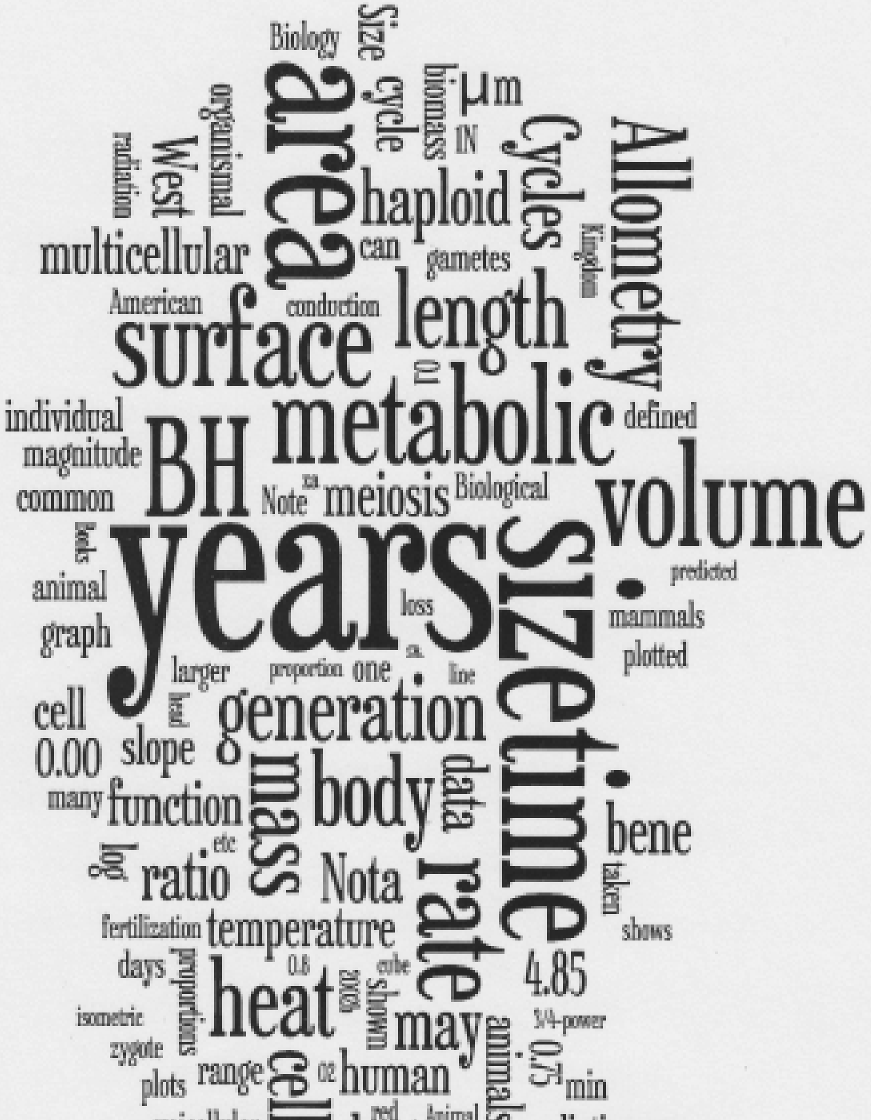
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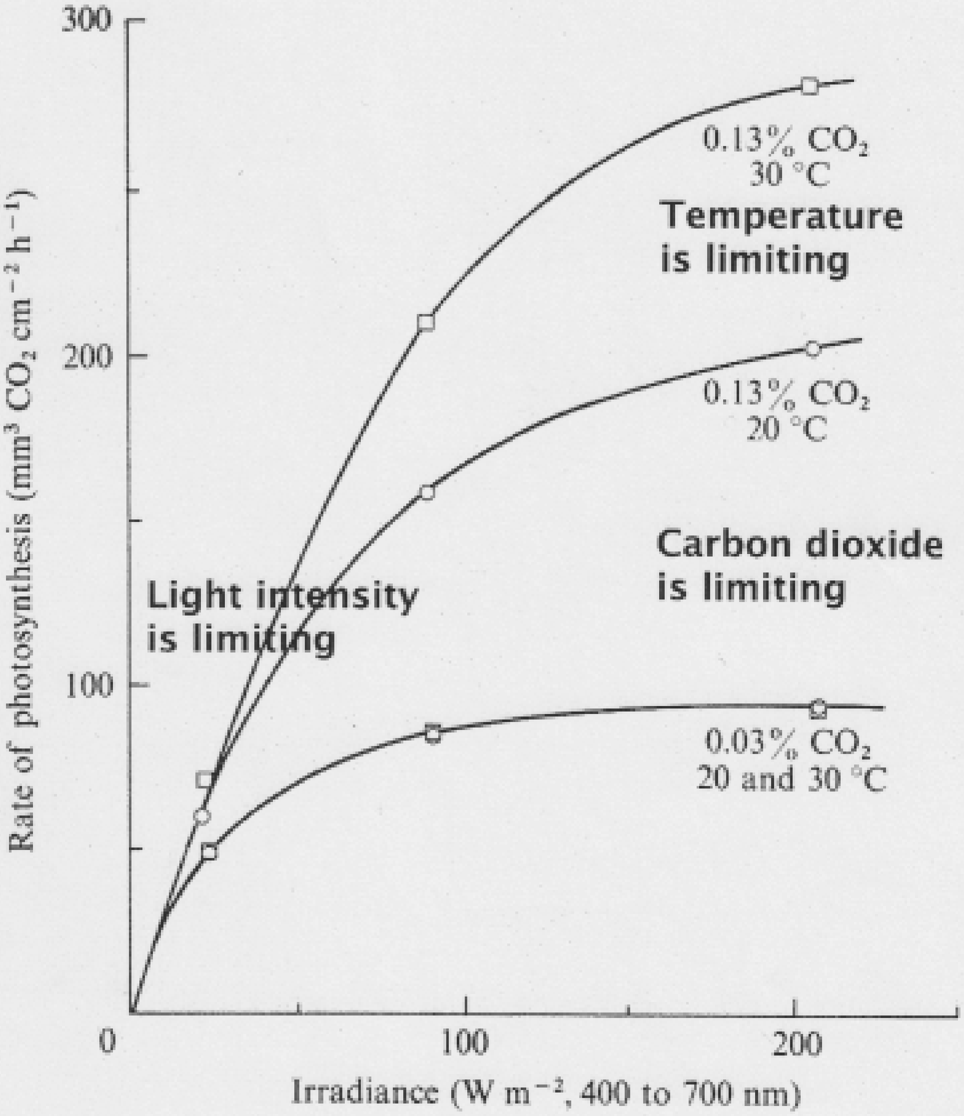
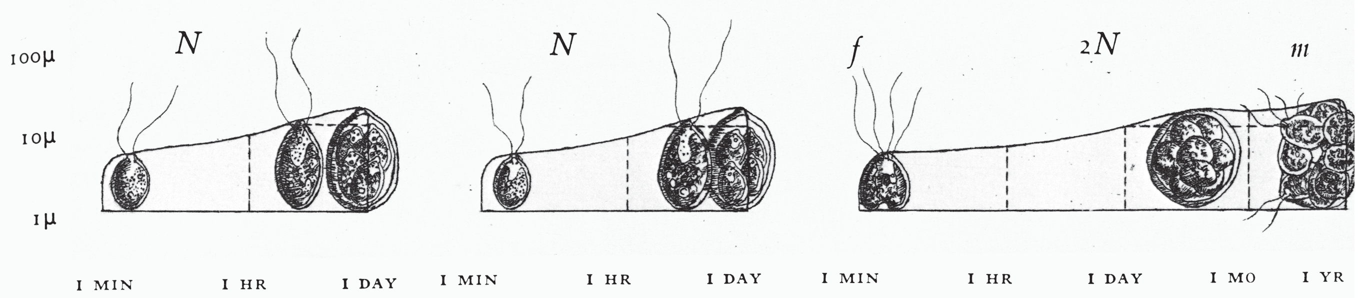


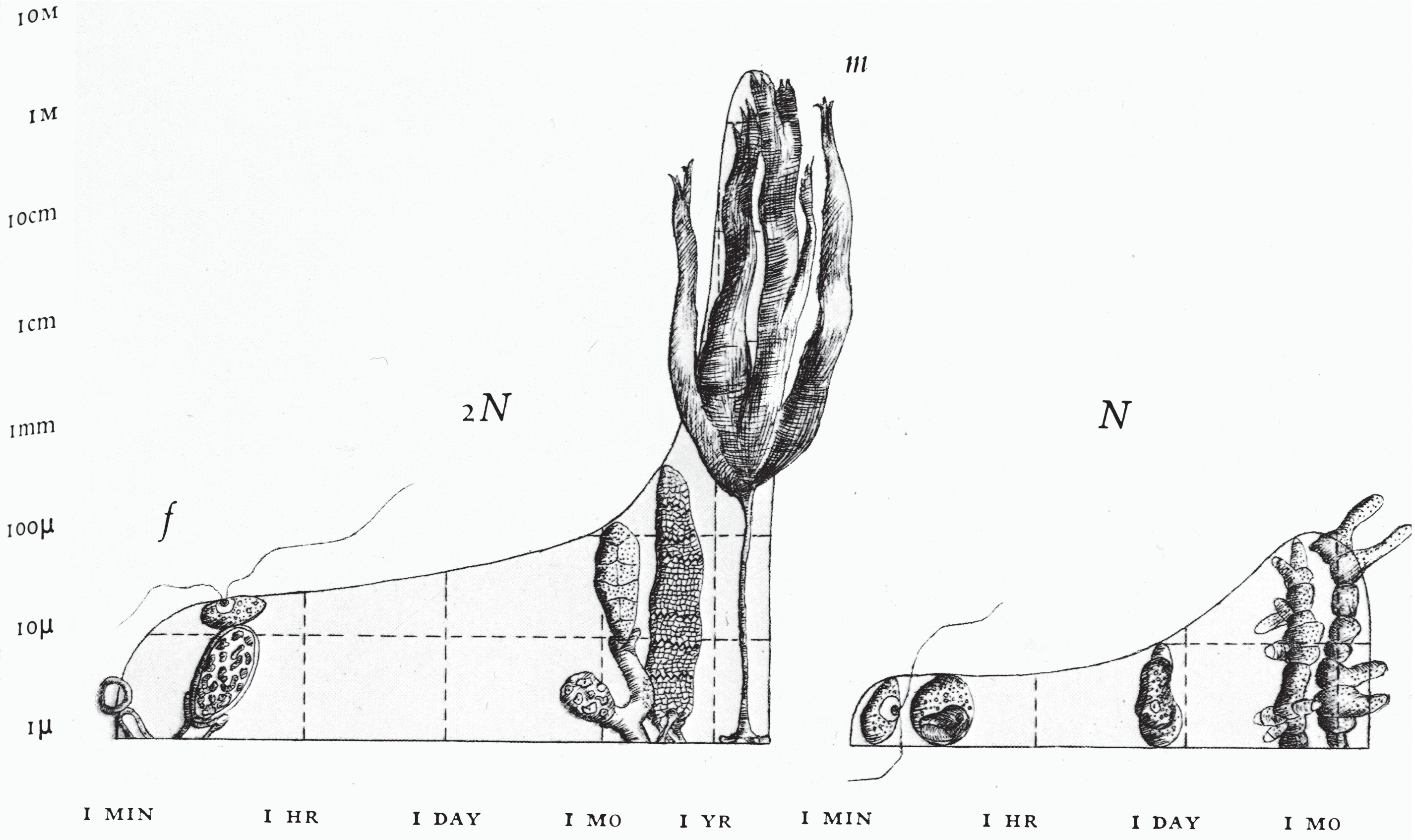
The effect of irradiance, temperature and CO_2 concentration on the rate of photosynthesis

(Source: Milthorpe and Moorby (1974) An Introduction to Crop Physiology. Cambridge University Press. pp. 72.



Chlamydomonas Reinhardi
The first two cycles show the asexual reproduction of the haploid individual. The last cycle shows the sexual cycle with fertilization, encystment of the zygote, and meiosis, which is followed by liberation of the new haploid individuals

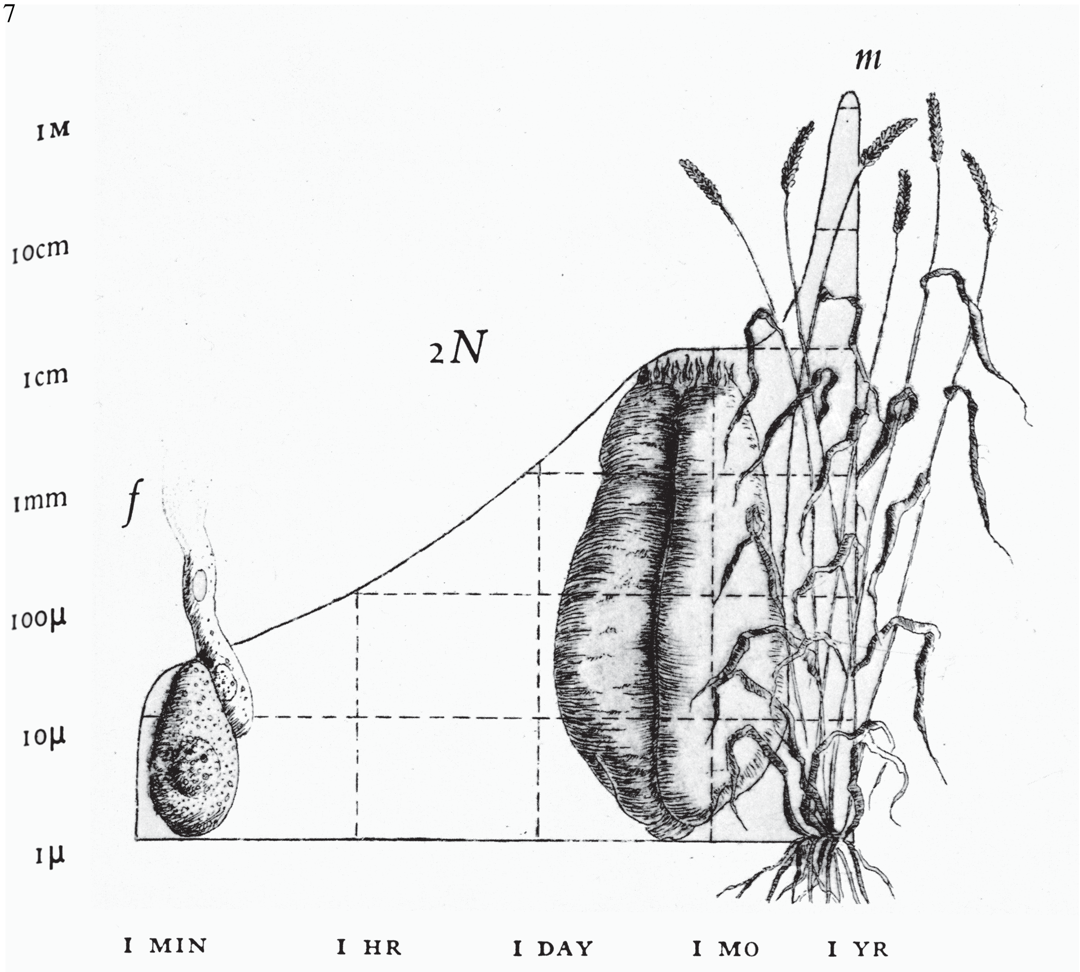
Source:
John Tyler Bonner (1965) Size and Cycle.
An Essay on the Structure of Biology.
Princeton University Press



Laminaria flexicaulis

This large brown alga or kelp has an alternation of generations. The haploid generation is small and inconspicuous (second cycle) especially in comparison with the huge diplod generation (first cycle). In the big frond, there is a distinct growth zone at the junction of the blades and the stipe, and considerable cell differentiation, especially in the stipe, where there are cells specialized for conduction.

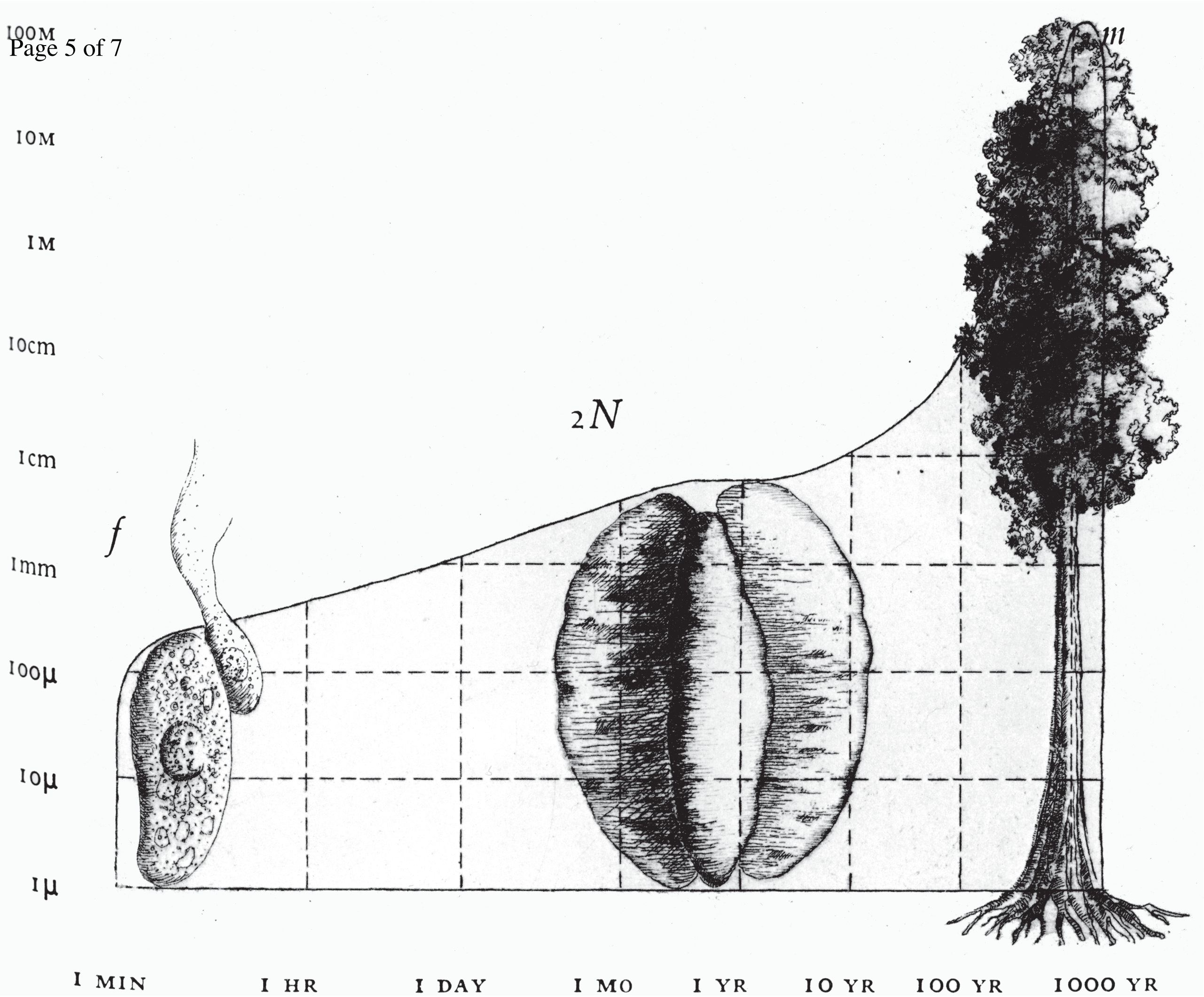
Source:
John Tyler Bonner (1965) Size and Cycle.
An Essay on the Structure of Biology.
Princeton University Press



Triticum aestivum

Wheat, like all higher plants, is characterized by having seeds. This is the resistant stopping place which interrupts the period of size increase. There is growth between fertilization and seed formation, a period of equilibrium, and subsequent growth upon seed germination. Wheat is an annual plant and therefore there is no cambium or secondary thickening. After the single spurt of growth in one season, the main body of the plant turns yellow and dies.

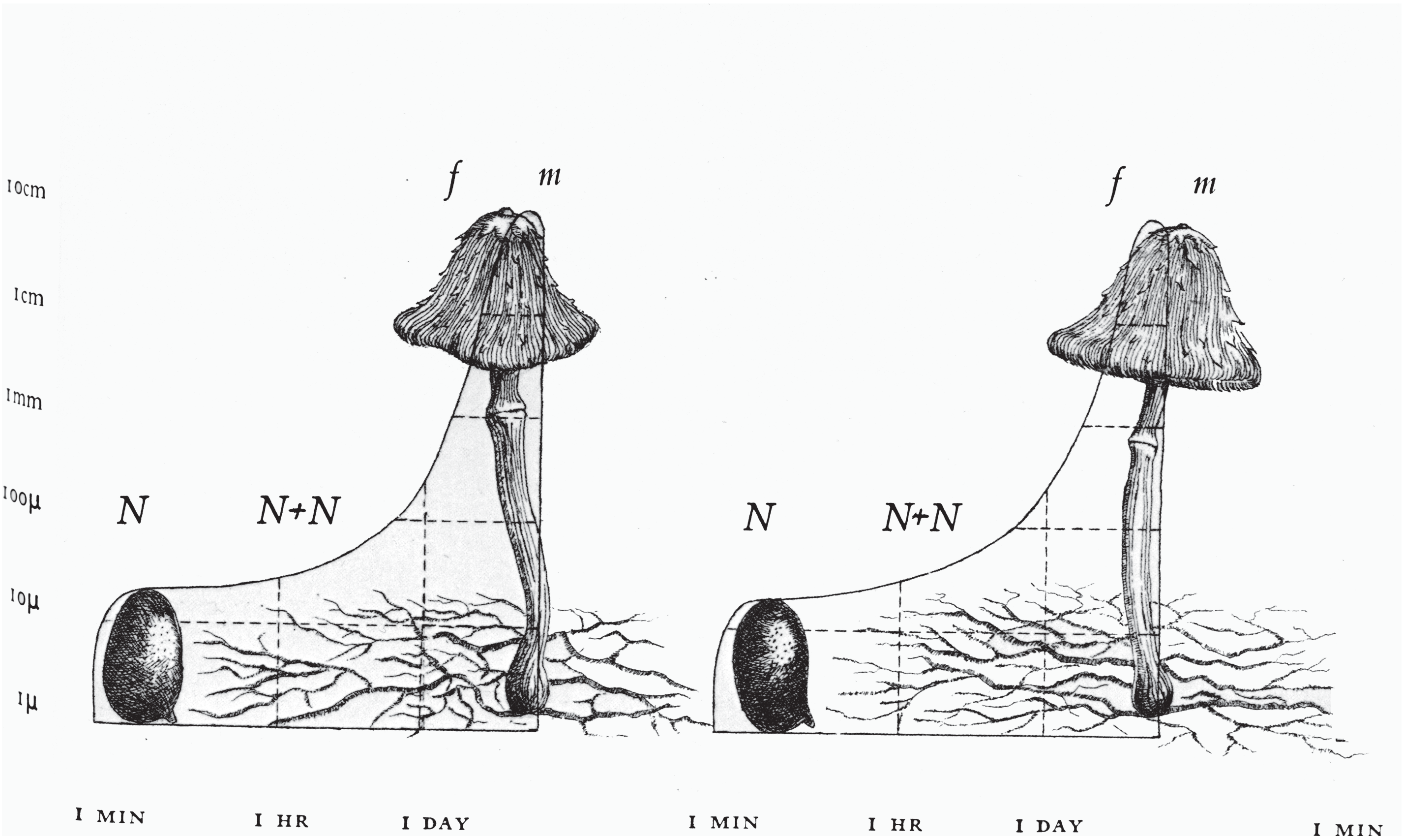
Source:
John Tyler Bonner (1965) Size and Cycle.
An Essay on the Structure of Biology.
Princeton University Press



Sequoia gigantea

Sequoia is the largest tree. Fertilization and the early growth of the seed are essentially the same as annual plants, such as wheat. Because of the cambium and secondary thickening, the size of the tree can increase enormously. Sequoia does not begin to set seed until it is 60 years old and 80 meters high.

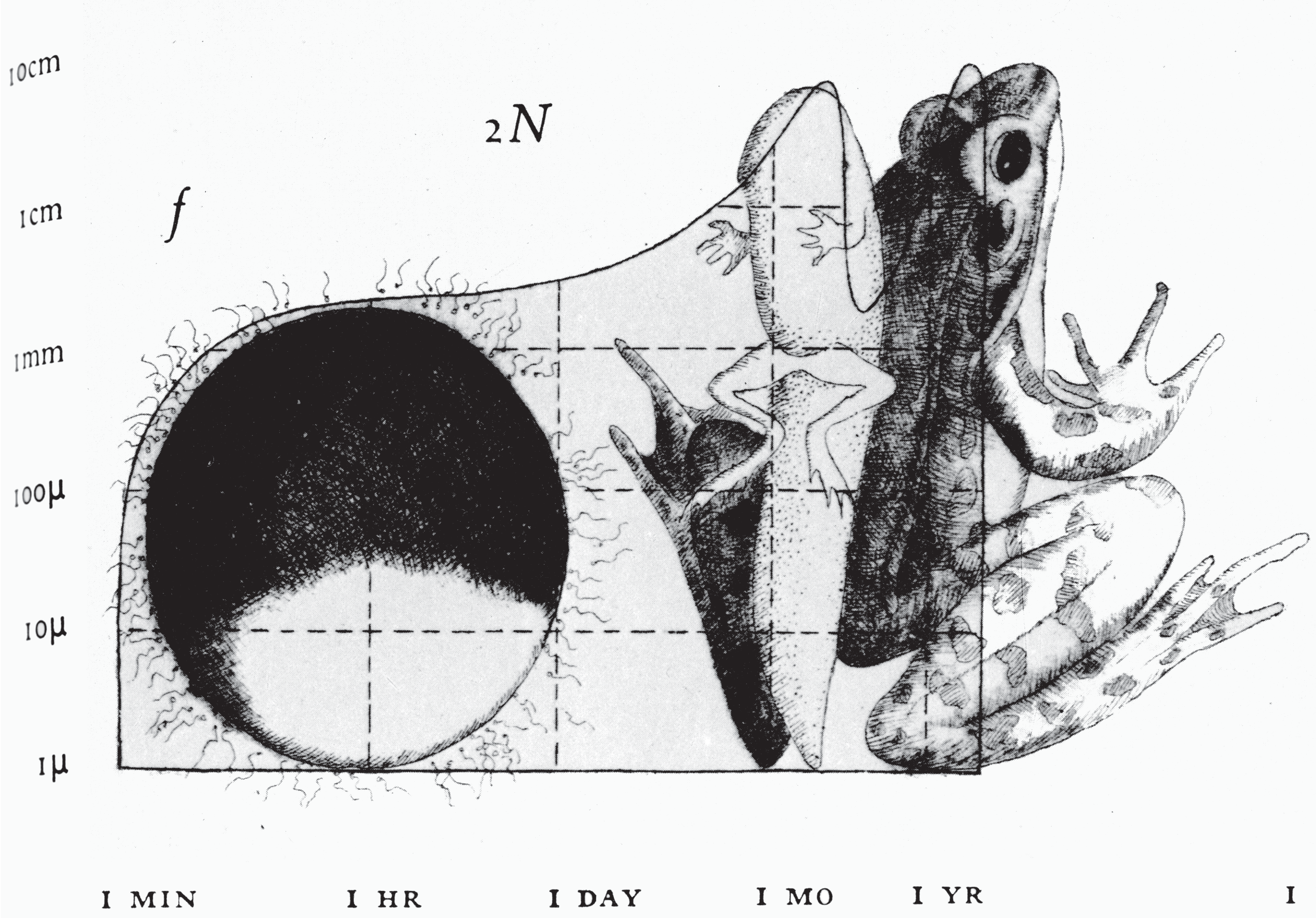
Source:
John Tyler Bonner (1965) Size and Cycle.
An Essay on the Structure of Biology.
Princeton University Press



Coprinus sterquilinus

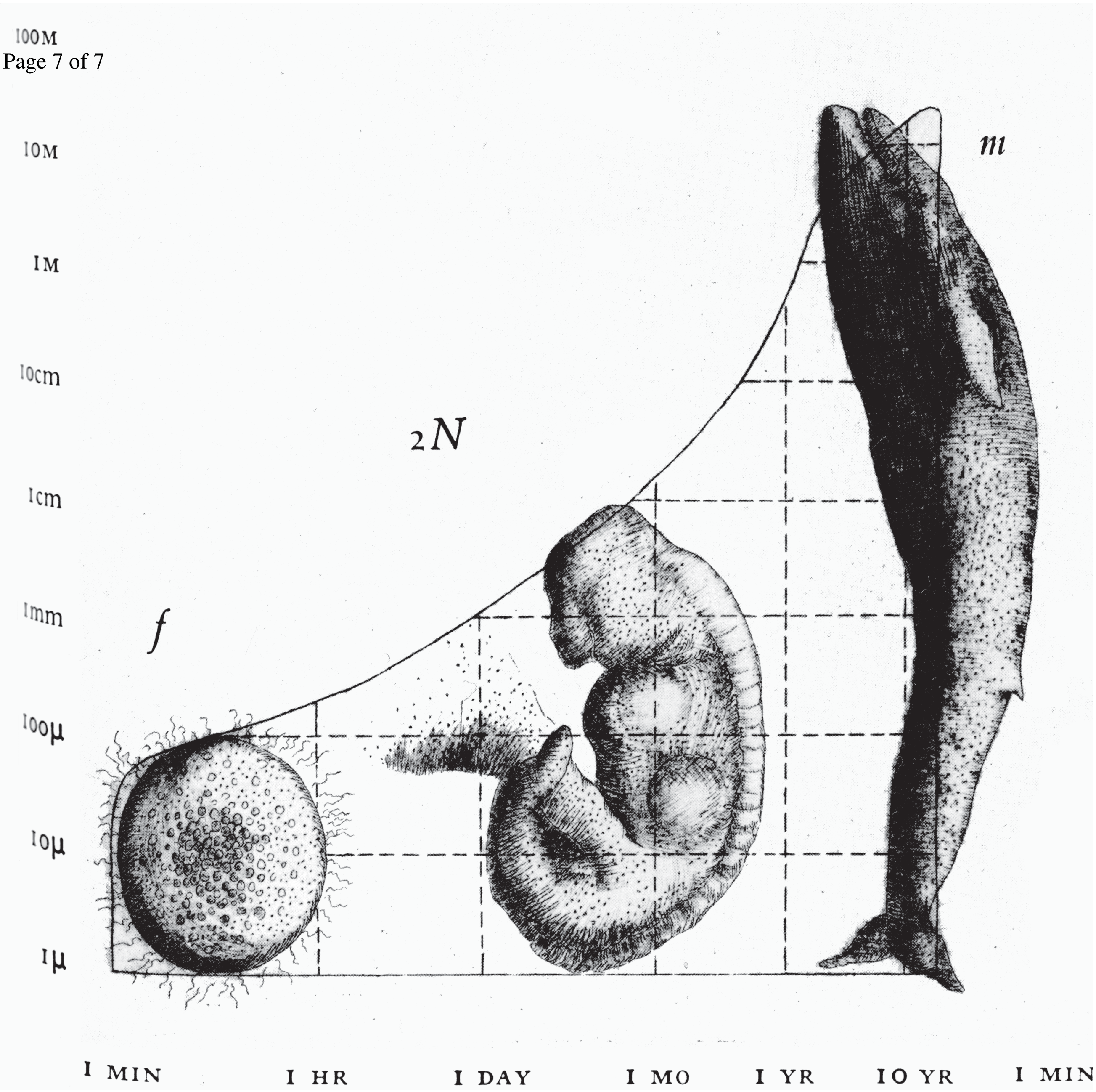
In mushrooms the hypha that emerges from the germinating spore is haploid and gives rise to the primary mycelium. Primary mycelia of compatible mating types will fuse and the nuclei of both will come together in pairs and remain in close association. This is the dikaryon condition found in the secondary mycelium and indicated as N + N in the illustration. Final nuclear fusion or karyogamy only occurs in the subterranean mycelium, and the protoplasm from this mycelium flows into the fruiting body in a matter of hours.

Source:
John Tyler Bonner (1965) Size and Cycle.
An Essay on the Structure of Biology.
Princeton University Press



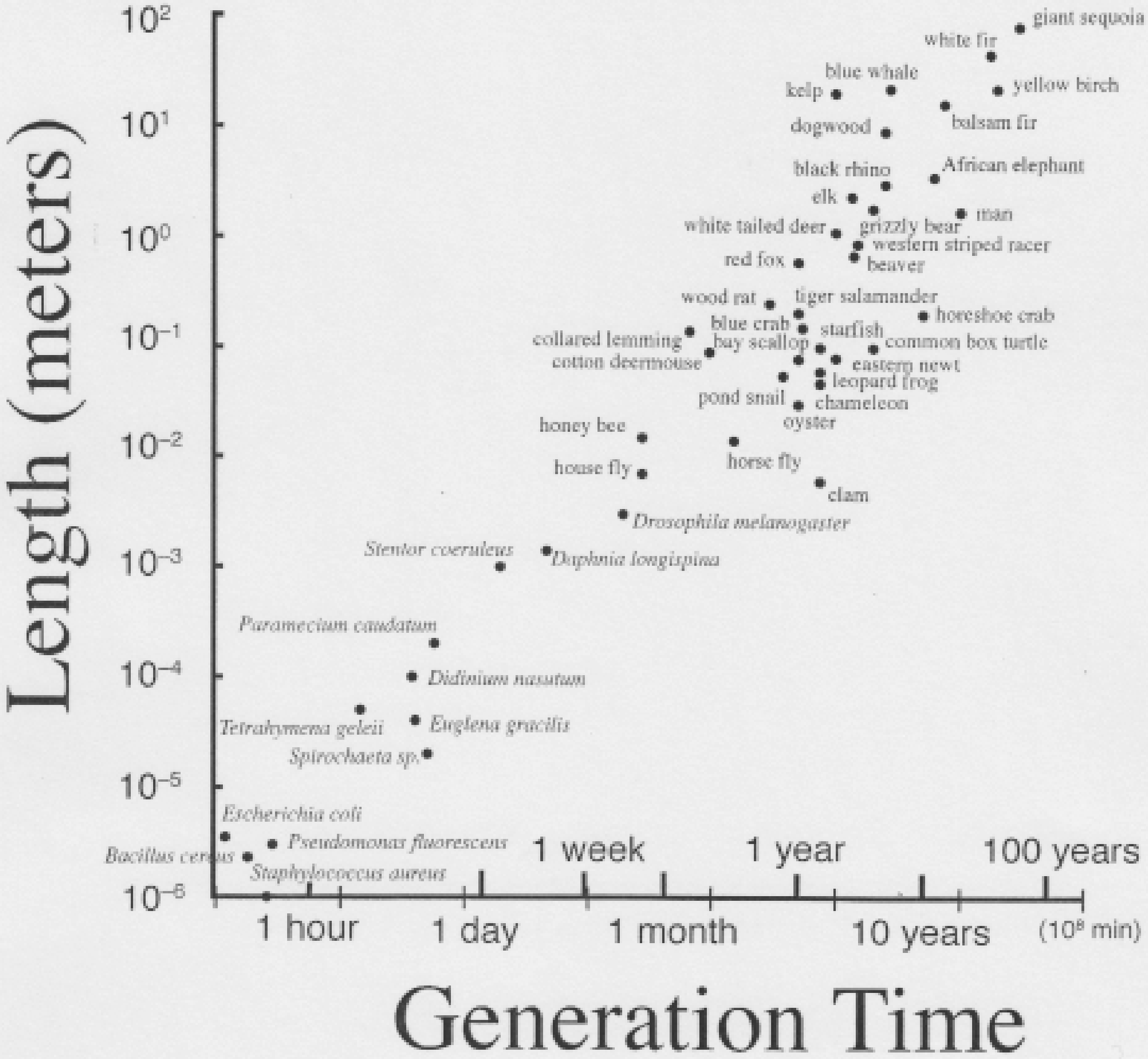
Rana pipens
Metamorphosis in the frog involves the loss of the tail and therefore a minor size reduction.

Source:
John Tyler Bonner (1965) Size and Cycle.
An Essay on the Structure of Biology.
Princeton University Press



Balaenoptera musculus
The blue whale is the largest animal. It is first capable of reproduction when it is 6 years of age and 22 meters long.

Source:
John Tyler Bonner (1965) Size and Cycle.
An Essay on the Structure of Biology.
Princeton University Press



Length (meters)
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
giant sequoia
white fir
blue whale
kelp
yellow birch
balsam fir
dogwood
black rhino
African elephant
elk
man
white tailed deer
grizzly bear
western striped racer
red fox
beaver
wood rat
tiger salamander
horseshoe crab
blue crab
starfish
collared lemming
bay scallop
common box turtle
cotton deermouse
eastern newt
leopard frog
pond snail
chameleon
oyster
honey bee
horse fly
house fly
clam
Drosophila melanogaster
Stentor coeruleus
Daphnia longispina
Paramecium caudatum
Didinium nasutum
Tetrahymena geleii
Euglena gracilis
Spirochaeta sp.
Escherichia coli
Pseudomonas fluorescens
Bacillus cereus
Staphylococcus aureus
1 week
1 year
100 years
1 hour
1 day
1 month
10 years
(10^8 min)
Generation Time

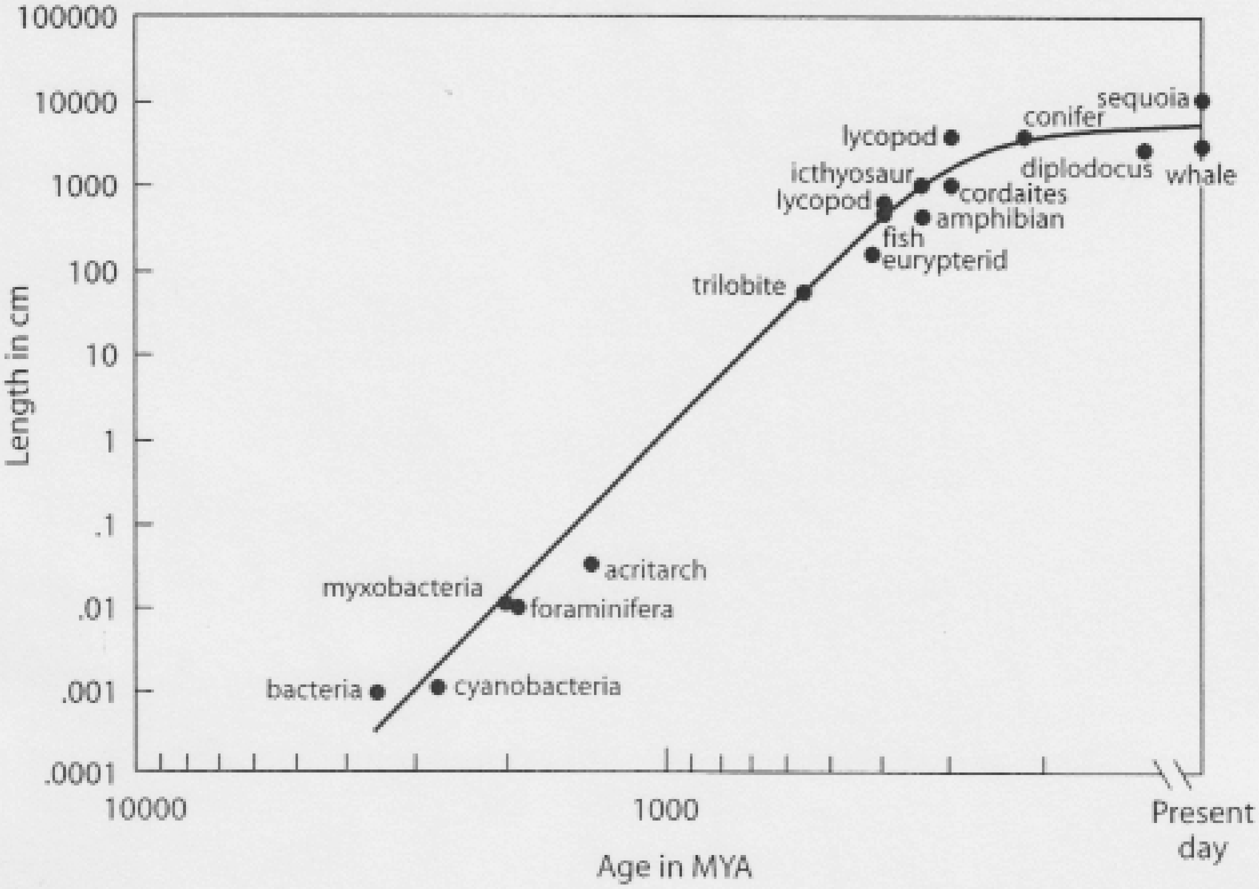


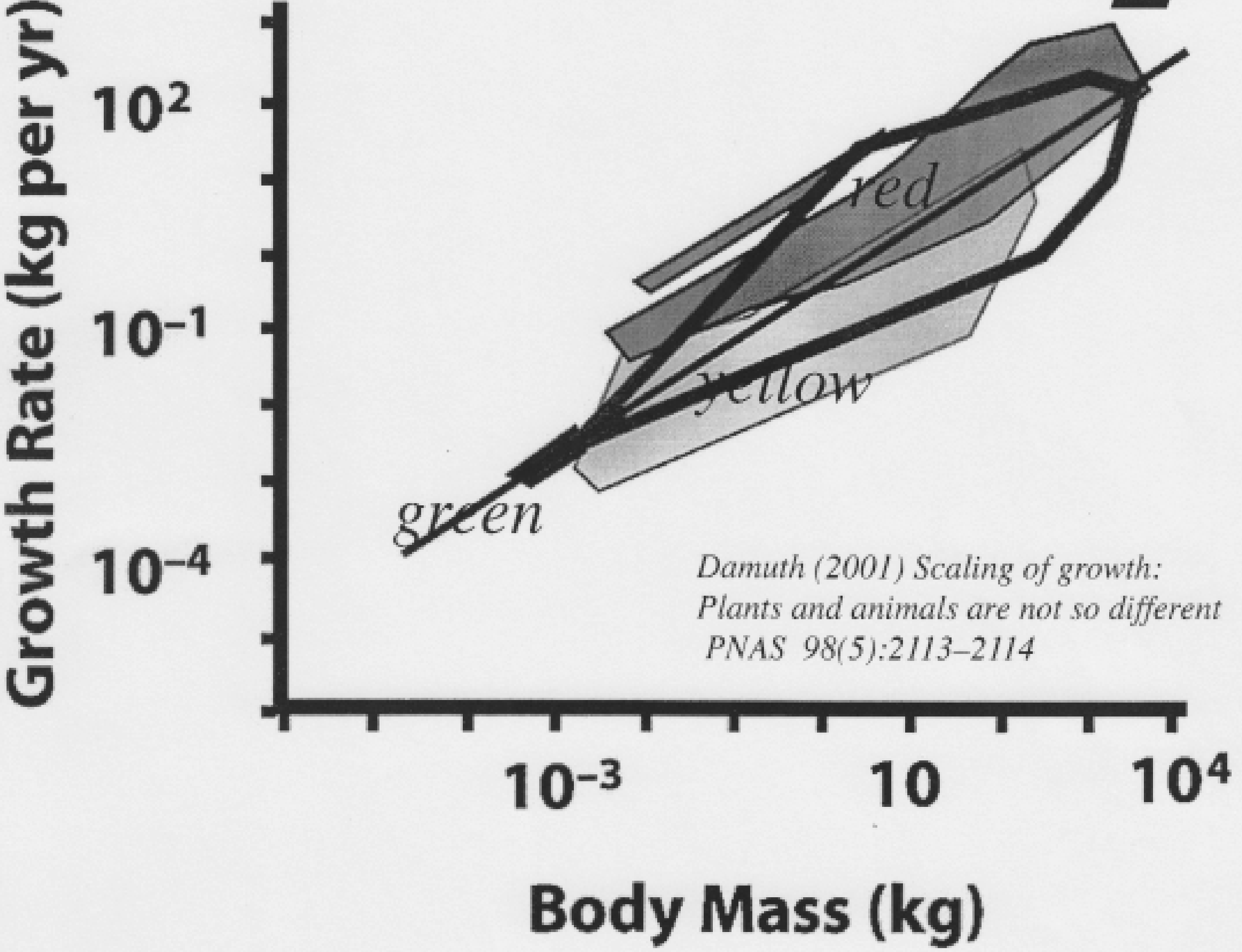
Figure 17. A log-log graph showing a rough estimate of the maximum sizes of organisms at different periods of life on Earth. (Data for the larger forms comes from Bonner, *Size and Cycle*, 1965; for data on the five smaller forms I am indebted to Shuhai Xiao)

WHY
SIZE
MATTERS

John Tyler Bonner

Princeton University Press
Princeton & Oxford

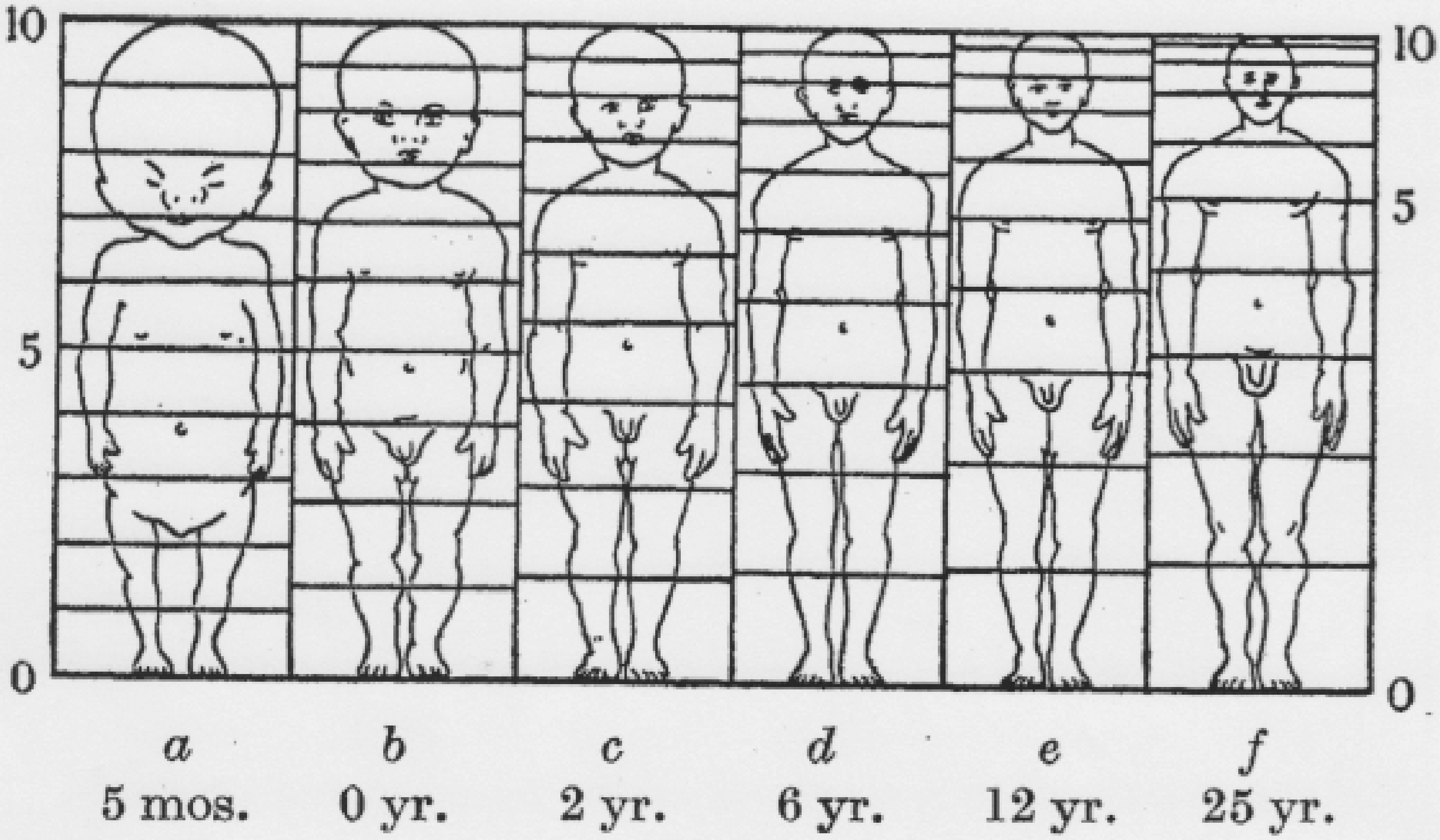
Allometry



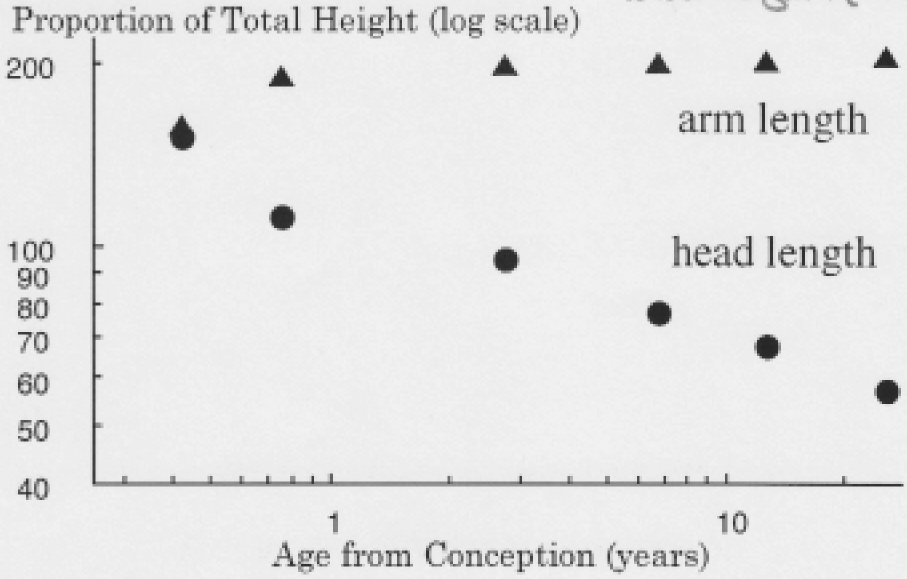
Damuth (2001) Scaling of growth: Plants and animals are not so different PNAS 98(5):2113–2114

Comparison of growth rates of trees and vertebrates, plotted on a common scale. Polygons represent the regions occupied by the data points. The dark green unfilled polygon encloses tree data. The endothermic vertebrates—mammals (large polygon) and birds (small polygon)—are in red, ectothermic vertebrates in yellow. Ectotherms and endotherms overlap in a narrow region.

An example of changing proportions in a biological context. The figure shows the differences in proportion as a prenatal baby develops into a mature adult human[1].



normalized to total height of 440



Head proportion declines with a slope of –0.22 for all ages, while arm length proportion increases (for 0–1 years, the slope is 0.33, declining to 0.02 for 2–26 years).

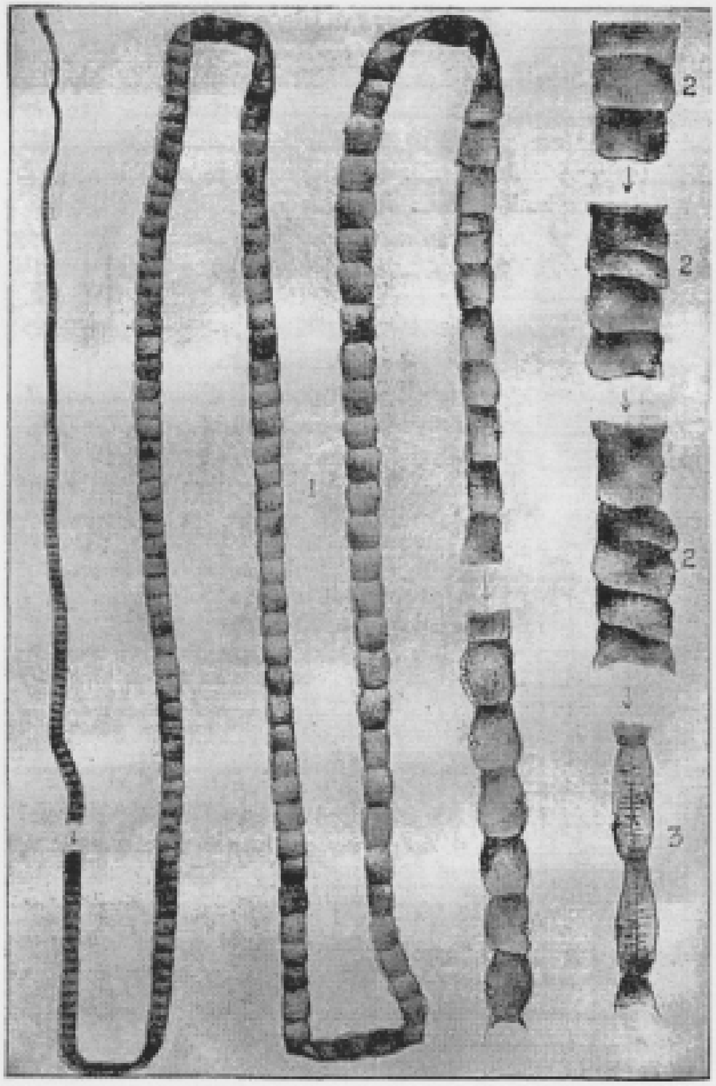
---

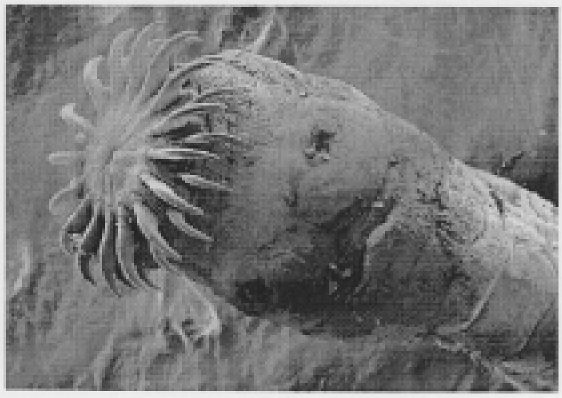
[1] Medawar PB (1944) The shape of a human being as a function of time. Proceedings of the Royal Society of London. Series B, Biological Sciences 132:133–141.

Proportionality of organismal form is closely related to the allometric/isometric foundations of biological scaling. The following example was presented by McMahon and Bonner in the classic book *On Size and Life*:

“[...] songs in animals, In some groups of mammals, the length of the vocal cords or other sound-producing structures is roughly proportional to the length of the animal. [...] the longer the animal, the deeper the voice [... for whales] the songs are both deep and slow [...] a mouse repelling device [...] emits a high-pitched noise [...it] cannot be heard by humans, but apparently it sounds like the end of the world to mice. [...] For this reason, the minature lion in Mandrake’s crater world [shown below] should have squeaked; a growl would really have been below its vocal range.”

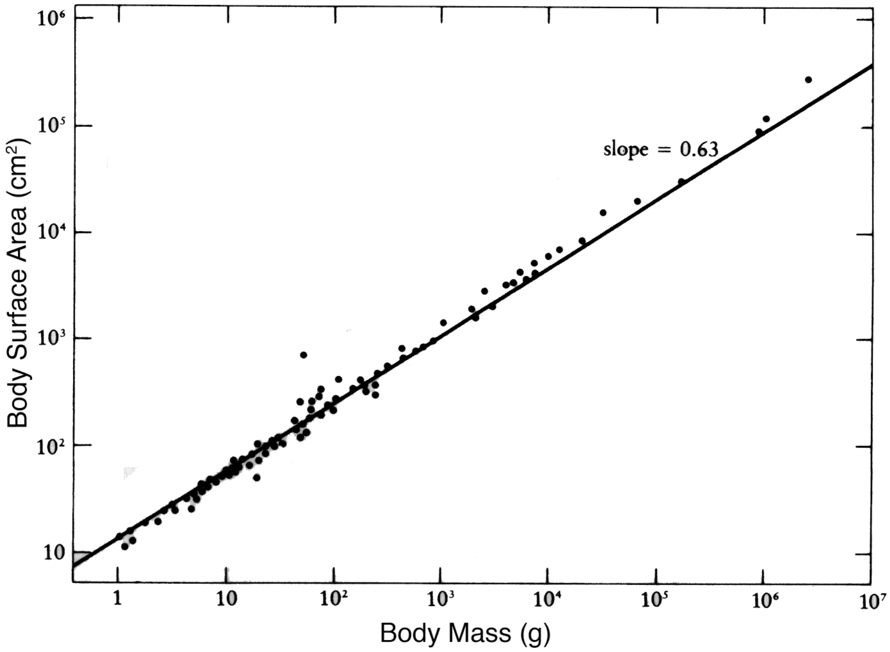
McMahon, Thomas A. and John Tyler Bonner 1983. On Size and Life. Scientific American Books, New York.





Some images of tapeworms. The head (above) often has barbs which anchor the worm in the intestine of the host. The body of the tapeworm can be very long. Note its thin rectangular shape (left), optimized for nutrient uptake from the intestine of the host.

SURFACE AREA *VERSUS* MASS (MAMMALIAN CLADE)[1]



The surface area *versus* mass relation for mammals scales as $M^{0.63}$. This is very similar to the expected scaling for a geometric solid. If we consider one example of a geometric solid, a sphere:

	AREA	VOLUME
	$A_1 = 4 \bullet \pi \bullet r^2$	$V_1 = \pi \bullet r^3$
Scaling by a factor k:	$A_k = 4 \bullet \pi \bullet (k \bullet r)^2$	$V_k = \pi \bullet (k \bullet r)^3$
or	$A_k = 4 \bullet \pi \bullet k^2 \bullet r^2$	$V_k = \pi \bullet k^3 \bullet r^3$
then	$A_k = k^2 \bullet A_1$	$V_k = k^3 \bullet V_1$

Setting A_1 and V_1 equal to 1:

$$A_k \propto k^2 \qquad\qquad V_k \propto k^3$$

Since $(V_k)^{2/3} \propto (k^3)^{2/3}$ or $(V_k)^{2/3} \propto k^2$

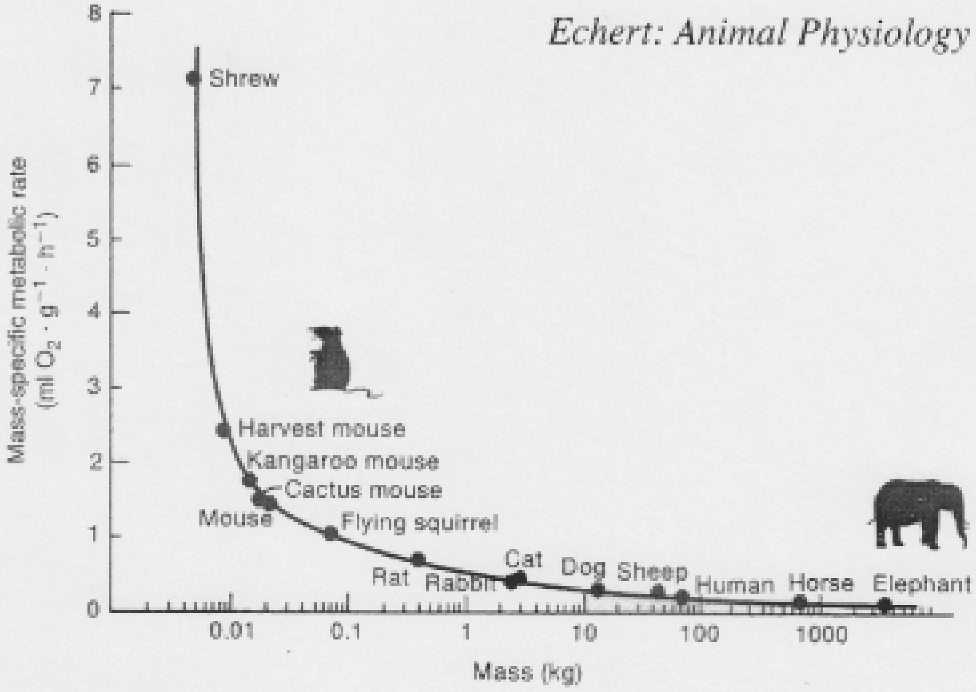
then $(V_k)^{2/3} \propto A_k$

Thus the scaling factor is expected to be $M^{0.66}$.

---

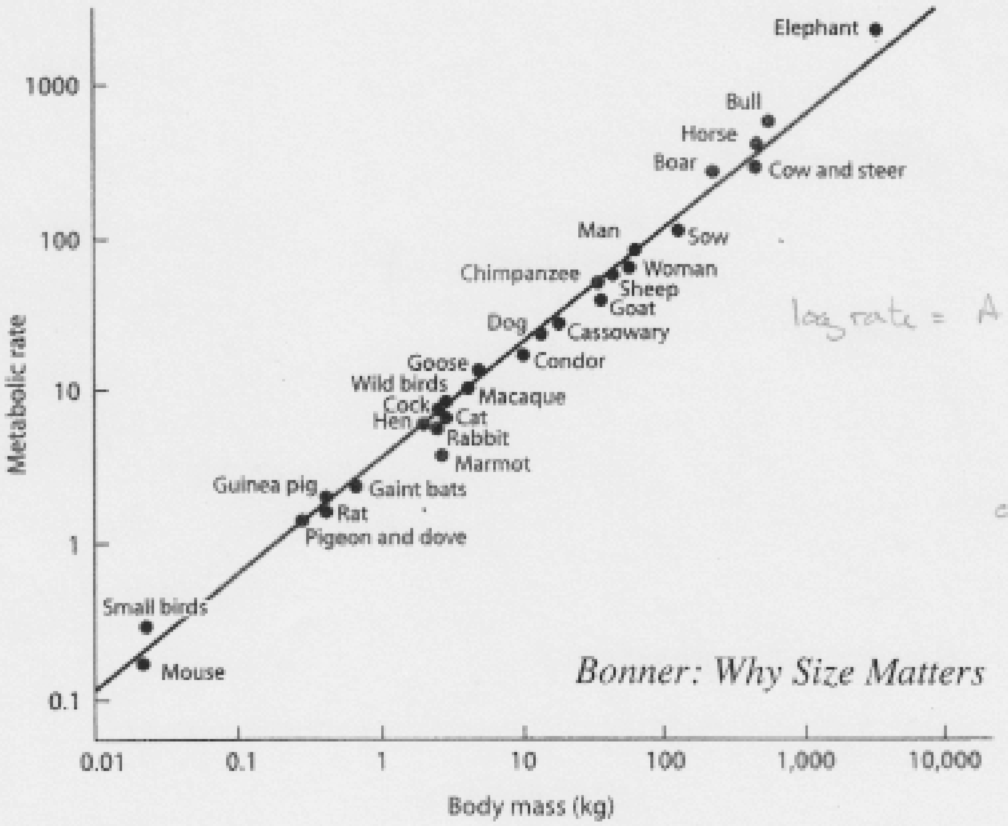
[1] Source: McMahon TA and Bonner JT (1983) On Size and Life. Scientific American Inc. pp. 130.

Metabolic intensity (mass-specific metabolic rate) as O_2 consumption per unit mass, plotted against body mass (on a semi-log plot) for various mammals.



Echert: Animal Physiology

Metabolic rate (O_2 consumption) plotted against body mass (on a log-log scale) for various mammals (and birds).



Bonner: Why Size Matters

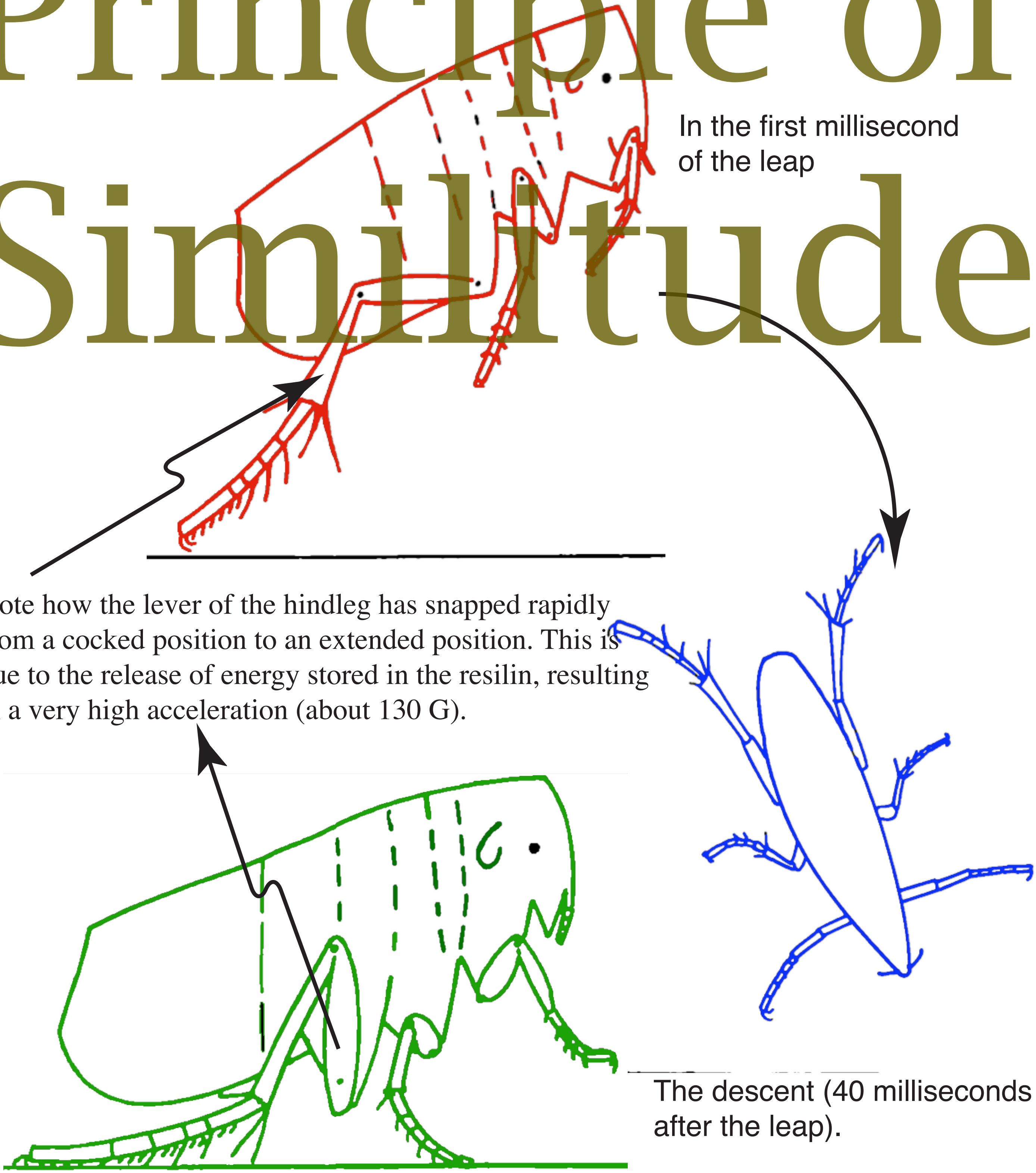
$\log \text{rate} = A + B \log(\text{mass})$

$\simeq$

$3/4$

or $M^{3/4}$

Principle of Similitude



In the first millisecond of the leap

Note how the lever of the hindleg has snapped rapidly from a cocked position to an extended position. This is due to the release of energy stored in the resilin, resulting in a very high acceleration (about 130 G).

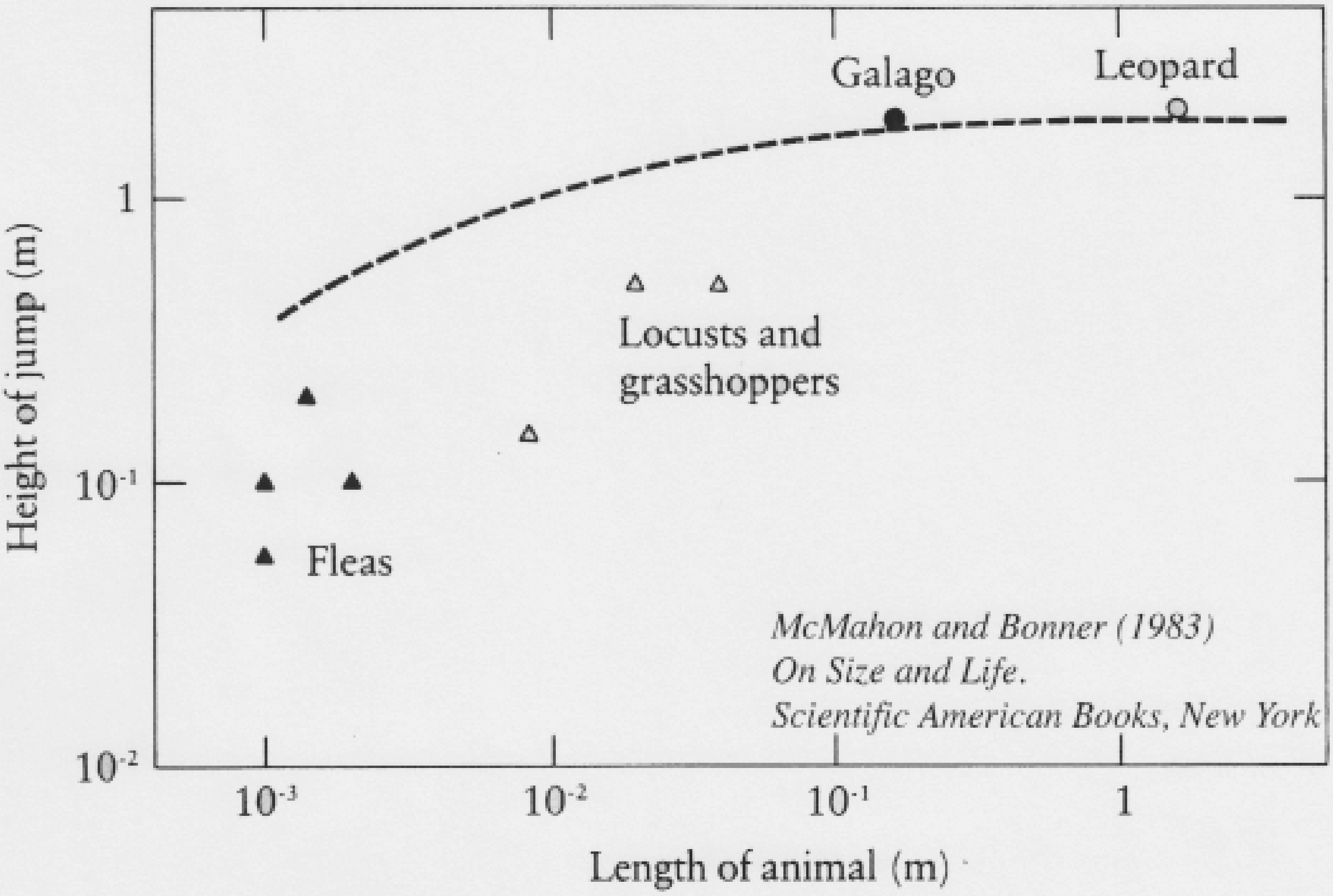
The descent (40 milliseconds after the leap).

1 millisecond before the leap

Current Topics in Biophysics
(SC/BPHS 2090 2.0)

Biophysical Currents

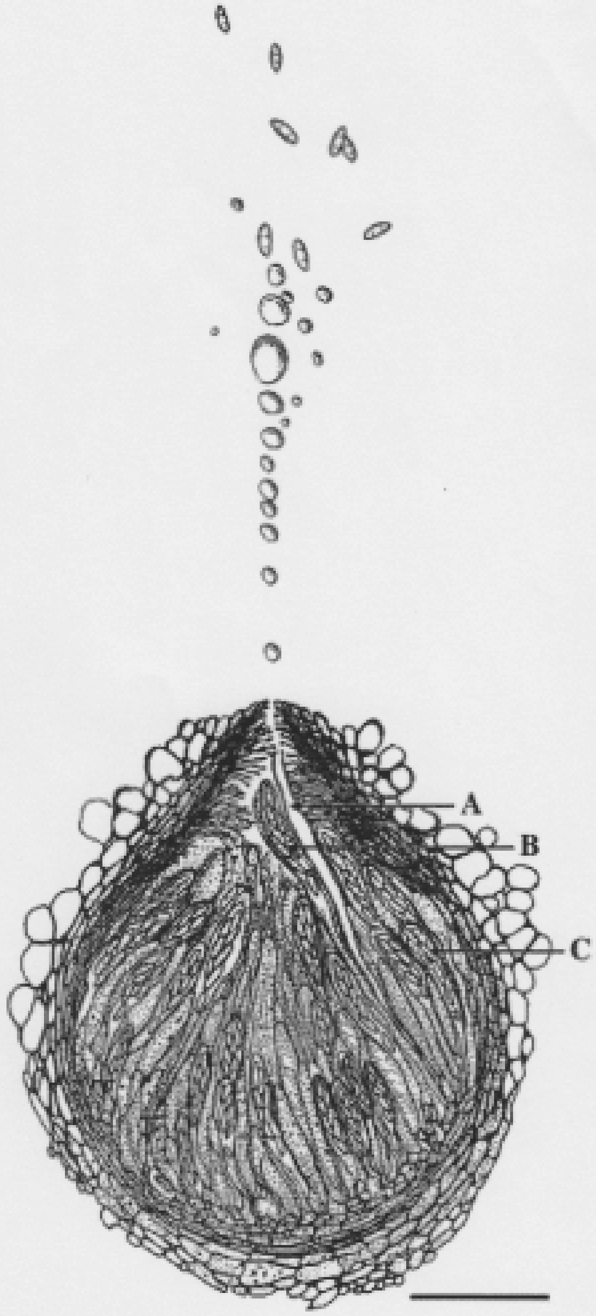
Jumping Animals



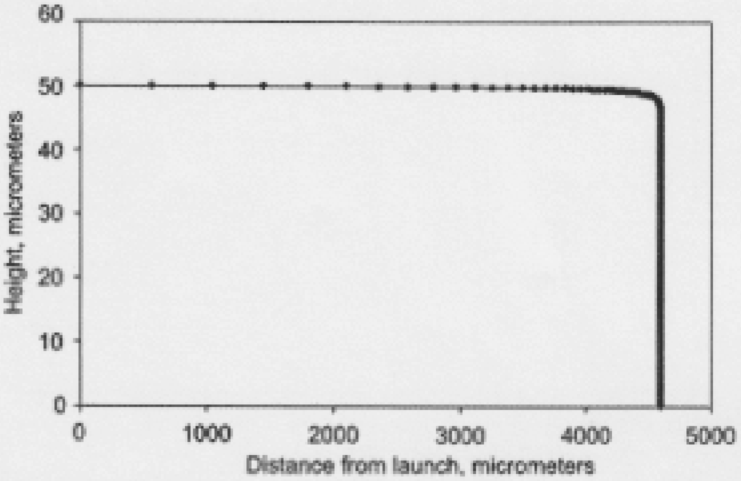
McMahon and Bonner (1983)
On Size and Life.
Scientific American Books, New York

Jumping heights for various animals. The broken line indicates the theoretical height attainable assuming a specific energy of 20 joules per kilogram available for jumping, taking into account air resistance.

BioBallistics



Longitudinal section through a mature perithecium of G. zeae. An ascus retracting following ejection of spores and fluid (A); a mature ascus, extending upward to the end of the ostiolar canal to discharge (B); and a mature, unextended ascus (C). Bar = 50 μm.



Spore trajectory. 20 μs intervals between points, 34.5 m s^{-1} initial speed, 2.58 mm s^{-1} impact speed. (based on an iterative computer program - too fast & too small to image with a camera)

Trail, F., Gaffoor, I., and S. Vogel (2005) Ejection mechanics and trajectory of the ascospores of *Gibberella zeae* (anamorph *Fusarium graminearum*). Fungal Genetics and Biology 42(6):528–533.

They report a launch speed of 34.5 m sec^{-1} (An acceleration of 870,000 g. Ejection is "driven" by a pressure of 1.54 MPa.