ECOPHYSIOLOGICAL IMPLICATIONS OF METABOLIC ALLOMETRY

		WEEKLY CONSUMPTION OF FOOD
ARVICOLA	30 g	175 g (6 × weight)
RHYNOCEROS	1000 Kg fino a 2000 Kg	650 Kg ($\sim \frac{1}{3}$ × weight)

For instance, 3500 mice ($\sim$20 g) are needed to equal a deer's weight ($\sim$70 Kg), but only 440 mice to equal a deer's consumption (they metabolize 8 times as quickly, per unit weight).

1) EFFECT ON POPULATION BIOMASS

which is distributed in dependence of weight

E.g., in 1 Km^2 of SAVANNAH: 95 Kg of warthogs

460 " ZEBRAS

1250 " ELEPHANTS

This is partly explained by metabolic allometry, although it is not the only explanation.

B) EFFECT ON STORAGE AND ELIMINATION OF POLLUTANTS (OR DRUGS)

Small species accumulate more quickly because they respirate, eat and absorb at higher rhythms, but also catabolize and expel more quickly (thus higher doses of drugs are needed to produce a certain effect, for example).

POSSIBLE CALCULATIONS OF AN LSD DOSE FIT TO AN ELEPHANT

CRITERION	DOSE
WEIGHT and EFFECTIVE DOSE in CATS	297 mg
METABOLIC RATE IN CAT and ELEPHANT	80 mg
WEIGHT and EFFECTIVE DOSE IN HUMANS (less resistant to LSD than cats)	8 mg
METABOLIC RATE IN HUMANS and ELEPHANTS	3 mg
CEREBRAL SIZE IN HUMANS and ELEPHANTS	0.4 mg

From: Schmidt-NIELSEN. How animals work
Camb. Univ. Press

MANY FUNCTIONAL and STRUCTURAL VARIABLES HAVE DIMENSIONS THAT DEPEND ON BODY WEIGHT ACCORDING TO RELATIVELY CONSTANT "LAWS" - → b_w

For Mammals:

$$O_2 \text{ CONSUMPTION } (l\,h^{-1}) = 0.676 \times b_w^{0.75}$$

$$\text{SPECIFIC } O_2 \text{ CONSUMPTION } (l\,h^{-1}\,kg^{-1}) = 0.676 \times b_w^{-0.25}$$

$$\text{VENTILATION } (l\,h^{-1}) = 20 \times b_w^{0.75}$$

$$\text{PULMONARY VOL } (l) = 0.063 \times b_w^{1.02}$$

$$\text{TIDAL VOL. } (l) = 0.0062 \times b_w^{1.01}$$

$$\text{BLOOD VOL. } (l) = 0.055 \times b_w^{0.99}$$

$$\text{HEART WEIGHT } (kg) = 0.0058 \times b_w^{0.99}$$

$$\text{RESP. FREQ. } (min^{-1}) = 53.5 \times b_w^{-0.26}$$

$$\text{CARD. FREQ. } (min^{-1}) = 241 \times b_w^{-0.25}$$

Hence, these relations have predictive value.

The variables are proportional to weight (exp $\simeq 1$) or scaled to metabolic rate (exp $\simeq 0.75$).

PHYSIOLOGIC TIME

FREQUENCY : HEART RHYTHM $(min^{-1}) = 241\ b_w^{-0.25}$

DURATION : BEAT DURATION $(min) = \frac{1}{241}\ b_w^{0.25}$

increases with the mass with exp 0.25

SPECIFIC METABOLIC RATE $\propto b_w^{-0.25}$

METABOLIC TIME $\propto b_w^{0.25}$

usually, physiologic time increases with mass

The avg. lifetime in mammals increases with mass, approximately following the above proportions. Thus, small and big animals have approximately the same N of heartbeats during their life.

MOUSE : 600 min^{-1} → 2-3 years of life
($\sim 800 \times 10^6$ heartbeats)

ELEPHANT : 30 min^{-1} → 50-60 years
(same N of heartbeats)

There are exceptions, e.g. humans.

CONFLICT BETWEEN "REAL TIME" AND PHYSIOLOGICAL TIME

The daily, seasonal, etc... cycles have very different physiological meaning for animals of different sizes. E.g., available energy:

$$\text{RESISTANCE TIME} = \frac{\text{AVAILABLE E}}{\text{USAGE VELOCITY}}$$

The relative storage of reserves is similar in different animals, thus the limit is metabolic rate. Therefore:

$$\text{RESISTANCE TIME} \propto BW^{0.25}$$

Small animals resist less and must eat almost continuously (except when ↓BM at sleep). In absence of enough food, they lower their metabolism.

WINTER:
- MIGRATION (BIRDS)
- ACCUMULATION OF RESERVES
- HIBERNATION (FAT + ↓ METAB.)

little necessary for the big.

WHY 0.75?

- TO DISTINGUISH 0.67 from 0.75, it is necessary to have Δ WEIGHT ≃ 10

  To determine differences < 0.75, one needs a range of 4g – 800 ton (10 whales).

- IT MUST BE < 1

  An ox with specific BM like that of a SHREW (Suncus etruscus, ∼1.8 g) would have a surface T ≃ 100°C

  A mouse with a specific BM like that of an ox would need a ∼20 cm thick fur.

- IN AFFINE SPECIES, THE ORGANIC and CELLULAR PHYSIOL. FEATURES ARE IN ALLOMETRIC RELATION WITH m.

MEANING OF THE EXPONENTS FOR THE METABOLIC RATE (why 0.75?)

1. FRACTAL GEOMETRY OF TRANSPORT SYSTEMS LIKE THE CIRCULATORY
2. MULTICAUSALITY OF ALLOMETRIC RELATIONS

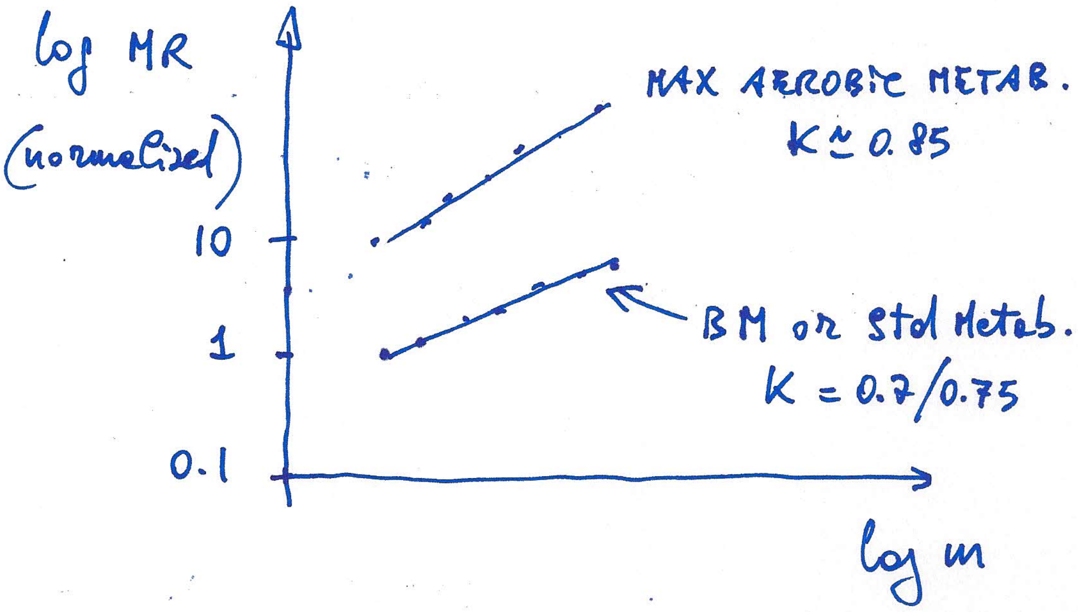
A) <u>BM</u>

	RELATION WITH body mass m	
- PROTEIN SYNTHESIS	$RATE = a_1 m^{b_1}$ →	
- Na^+/K^+ ATPase	" $= a_2 m^{b_2}$ →	$BM = a_5 m^{0.75}$
- Ca^{2+} ATPase	" $= a_3 m^{b_3}$ →	
- UREA SYNTHESIS (etc.)	" $= a_4 m^{b_4}$ →	

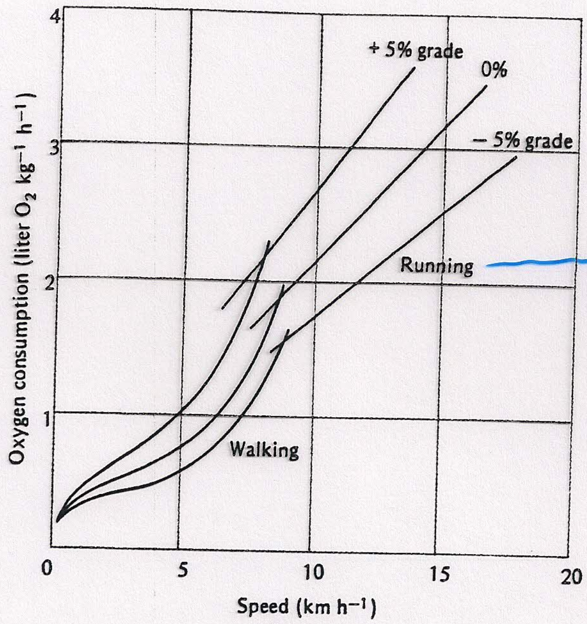
B) MAX. AEROBIC WORK RATE

- SUPPLY O_2 (RESP.)	$RATE = a_6 m^{b_6}$ →	
- " O_2 (CIRCUL.)	" $= a_7 m^{b_7}$ →	$W_{MAX} = a_{10} m^{0.85}$
- CONTRACTION	" $= a_8 m^{b_8}$ →	
- Ca^{2+} ATPase	" $= a_9 m^{b_9}$ →	

Different relations are produced by different component factors. In fact, for BM the exp. is 0.75, whereas for aerobic metabolism it is 0.85.



The ratio of ~10 between max aerobic metabolism and basal metab. holds for Vertebrates and some Invertebrates. It is an approximate value.



generally linear, at least at intermediat v

(but not for flight and swimming, there are ideal velocities)

Figure 5.14 The energy expenditure of a person during walking and running, at three different grades. [Margaria et al. 1963]

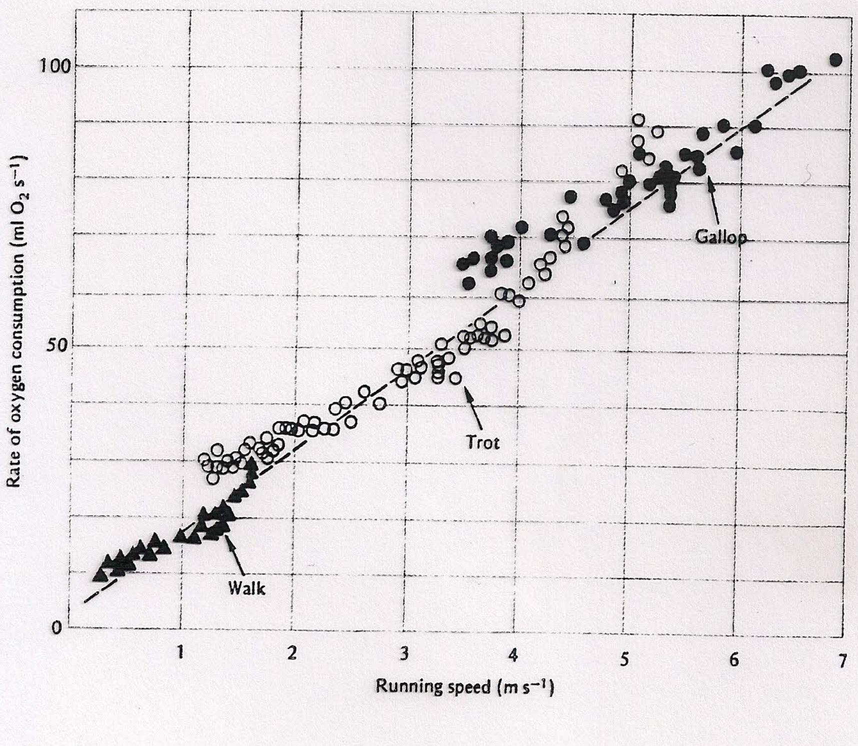


Figure 5.15 The oxygen consumption of a horse increases almost linearly with the running speed. Triangles – walk. Open circles – trot. Filled circles – gallop. This horse had been trained to extend the speed in each gait beyond the normal range. For example. it could trot at speeds where it would normally move in a gallop. [Hoyt and Taylor, 1981]

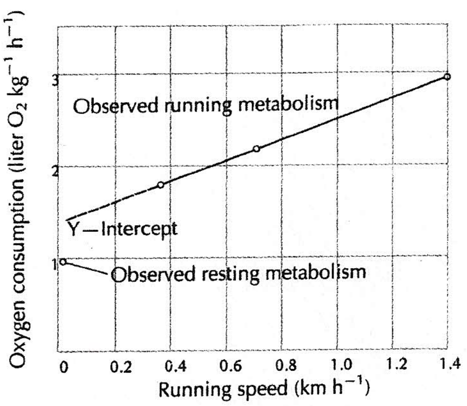


Figure 5.17 The oxygen consumption of running white rats increases linearly with increasing speed. [Taylor et al. 1970]

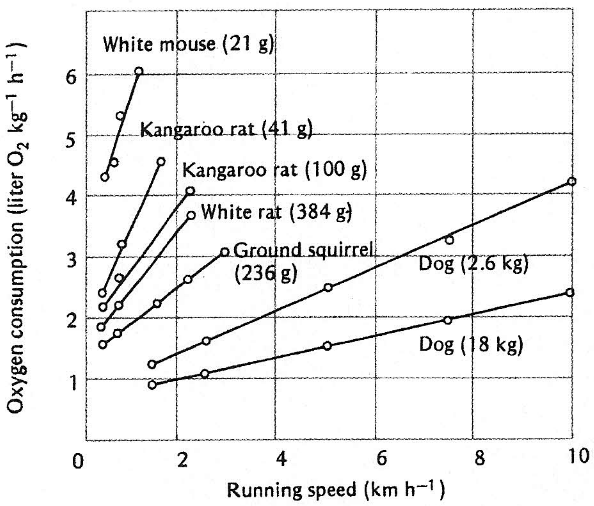


Figure 5.18 The oxygen consumption of a variety of running mammals increases linearly with speed. The increase per unit body weight is smaller the larger the body size of the animal. [Taylor et al. 1970]

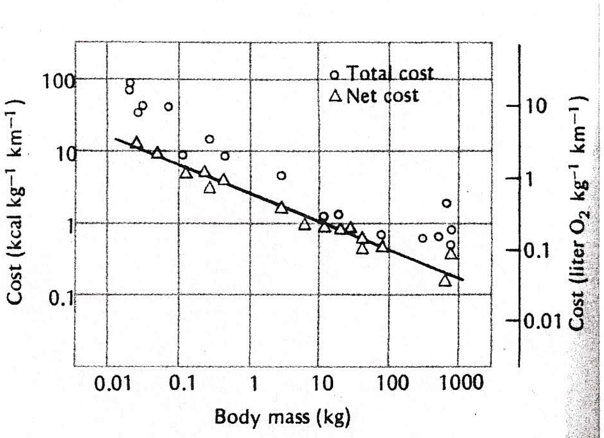


Figure 5.19 The cost of running for mammals of various body sizes. The net cost designates the cost of moving 1 kg body mass over a distance of 1 km, calculated from the increase in metabolism caused by running (and obtained from slopes of regression lines). The total cost includes the total metabolism while running and is therefore somewhat higher. [Schmidt-Nielsen 1972a]

FROM: SCHMIDT-NIELSEN, Animal Physiology

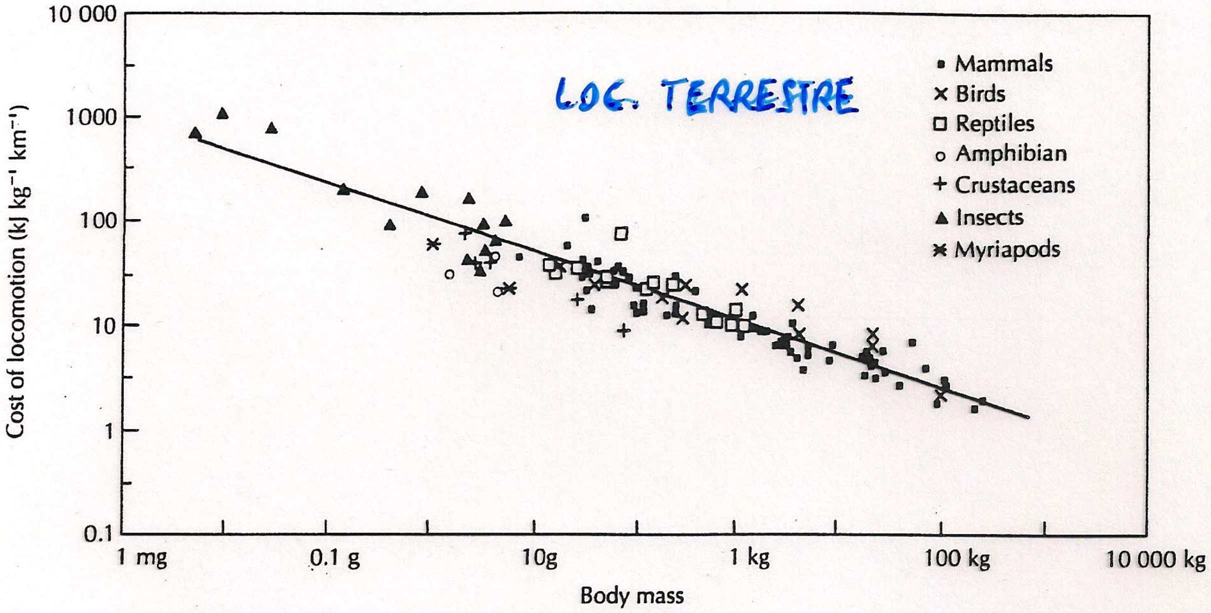


Figure 5.20 The cost of transport for animals of various types. To move a given distance small animals, regardless of type, consume more oxygen per unit mass than larger animals. This relationship holds over a wide range of body sizes and leg numbers, from elephants to centipedes. [Full and Tu 1991]

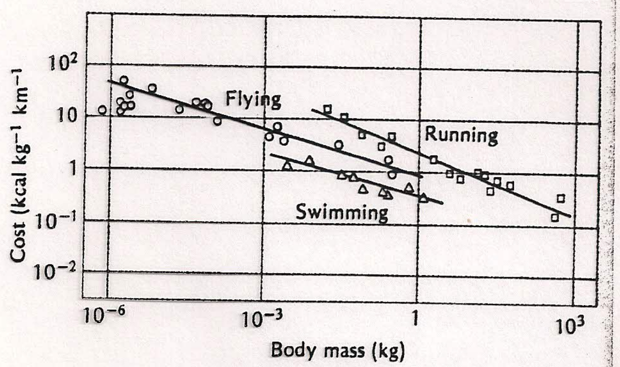


Figure 5.22 Comparison of the energy cost of moving one unit body weight over 1 km for running, flying, and swimming. [Schmidt-Nielsen 1972a]

- SUPPORT
- DENSITY
- VELOCITY

FROM: SCHMIDT-NIELSEN, Animal Physiology

SEASONAL AVOIDANCE

TRIGGER : PHOTOPERIOD, FOOD

LOCAL : - WINTER OR SUMMER REFUGE, DEEP WATER, DEN
- OFTEN CONTROLLED HYPOTHERMIA

WIDE SCALE : MIGRATION

(DISTANCE : depends on locomotion type
" dimensions)

~~MAX.~~ ADVANTAGEOUS for: AQUATIC ECTOTHERMS
(metabolic rate in Pisces ~ 10^{-1} compared to similar sized endotherms).
: LARGE AQUATIC ENDOTHERMS

Flight allows large-scale movement for many animals of different sizes

LONG MIGRATIONS by SWIMMING OR WALKING only for LARGE ENDOTHERMS (min 20 kg for terrestrial mammals).

TERREST. : 500-1000 km (ALCI, CARIBOU, ANTILOPI, non tanti per la T)

VOLO : INTEREMISF. UCCELLI (10 000)
PIPISTRELLI anche 1000
FARF. Monarca 3000 (ma poco con. ectot. terr.)
(riserve lip.)

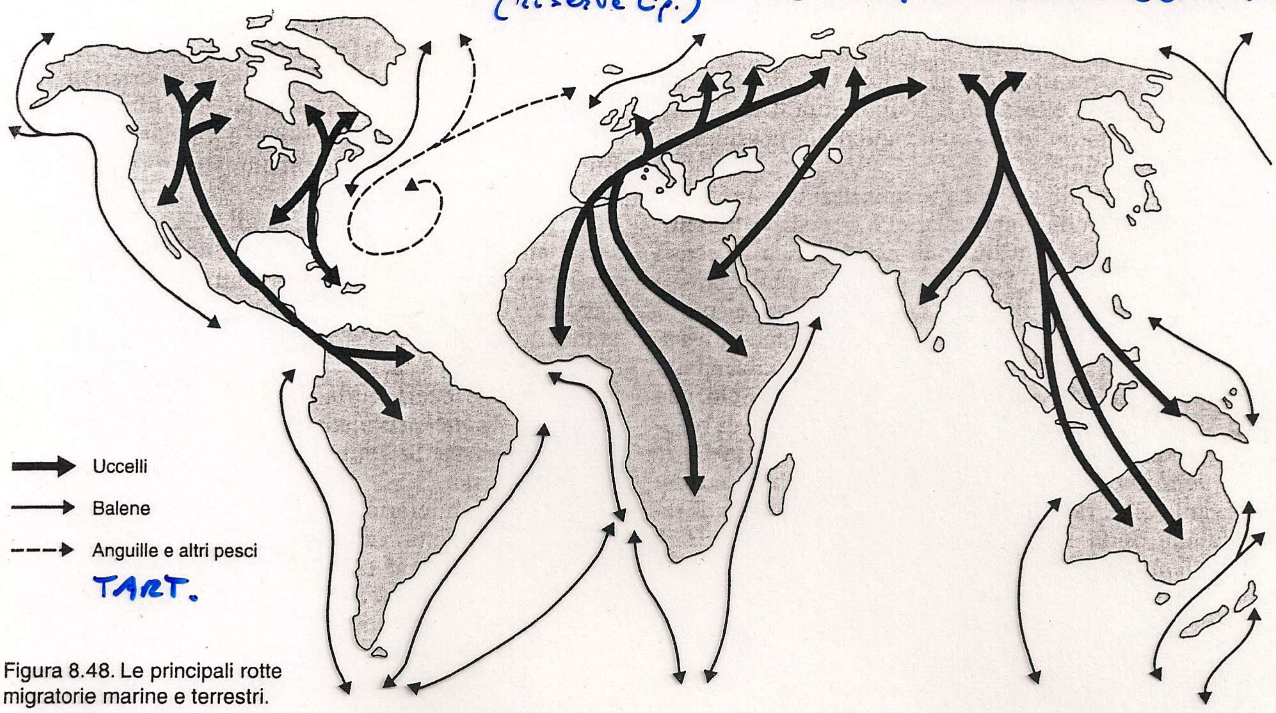


Figura 8.48. Le principali rotte migratorie marine e terrestri.

BECCAFICO : GENET. (Sylvia borin)
OCA SELV. : APPRESO

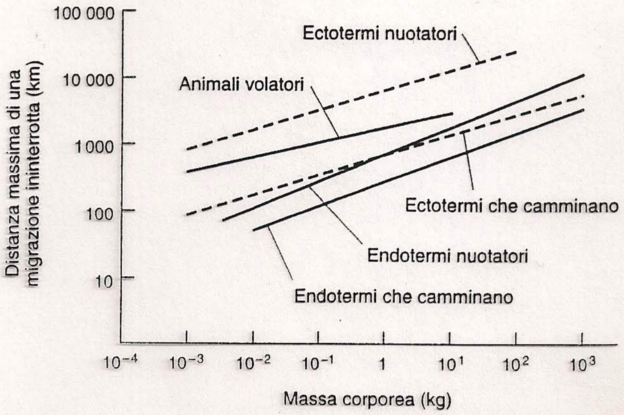


Figura 8.47. La massima distanza di migrazione possibile in relazione alla taglia. I pesci e gli animali volatori percorrono lunghe distanze in maniera relativamente economica e gli animali più grandi percorrono distanze maggiori rispetto a quelli piccoli (confrontare le figure 3.14. e 3.16.). (Da PETERS, 1983; cortesia della Cambridge University Press).

From: Willmer et al. Environmental Physiology of Animals, 2005.