Specialising on Change Part 3: Energetics

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Biol 417: Evolutionary Ecology

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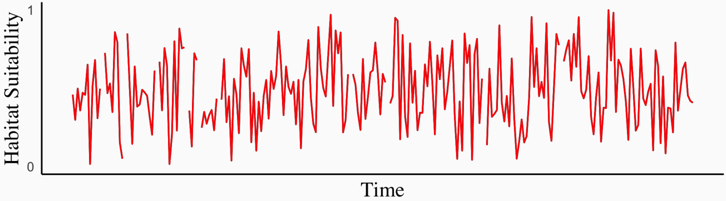
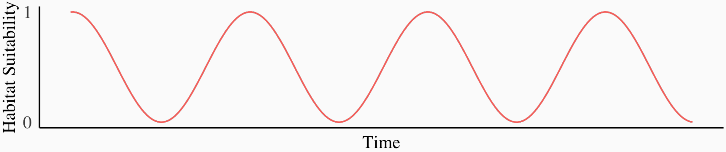
Review

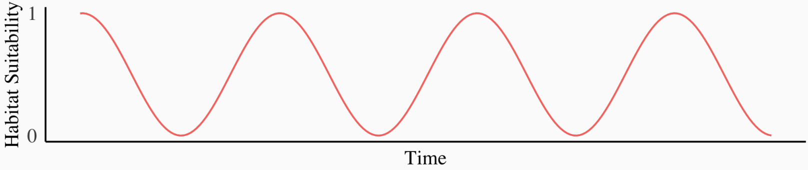
The natural world is stochastic and certain periods in time are more favourable for growth and reproduction than others.



We have been covering mechanisms species have adapted to specialise on **predictable** environmental change.



Review and overview cont.



Last lecture we started covering how entering a state of dormancy (reduced metabolic activity) to conserve energy and 'ride out' unfavourable periods, but dormancy doesn't eliminate energetic expenditures completely, it only **reduces** them.

Organisms need to have something left in the tank at the end of the dormant period... but how long will a 'tank of gas' last?

Mammalian survival time

Allometry is the study of the relationship between form, function and body size.

One important allometric relationship is the scaling of metabolism with body size:

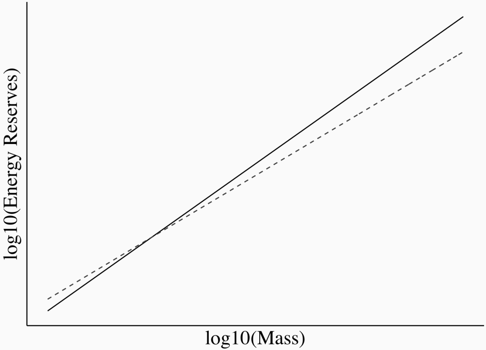
$$\text{Metabolic rate} = 317\frac{\mathrm{kJ}}{\mathrm{day}}M^{0.75}.$$

Brown *et al.* (2004) suggest this metabolic scaling is so important that id underpins every aspect of a species' ecology (termed the '*Metabolic Theory of Ecology*', which we will be covering in detail later on in the course).

... but how does this help us understand the effectiveness of dormancy?

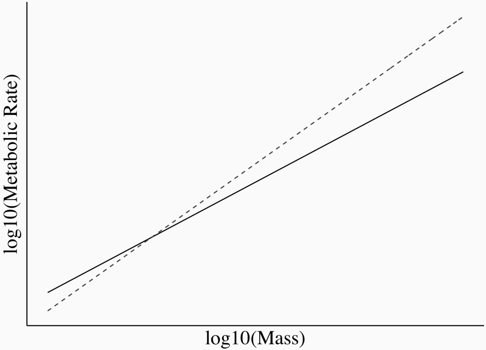
Energy Reserves

Mammals store energy as adipose tissue. Fat reserves increase with body size according to the equation $2948 \frac{\text{kJ}}{\text{g}} M^{1.19}$ (Lindstedt & Boyce, 1985), meaning large mammals can store proportionally more fat than small mammals.



(Dashed line is $2948 \frac{\text{kJ}}{\text{g}} M^1$)

Metabolic rate scales with body size according to $317\ \frac{\mathrm{kJ}}{\mathrm{day}} M^{0.75}$ (Lindstedt & Boyce, 1985), meaning large mammals cost fewer calories per gram to run than small mammals.



(Dashed line is $317 \frac{\mathrm{kJ}}{\mathrm{day}} M^{1}$)

We also know that metabolic rate is temperature dependent, and varies with temperature according to

$$E_{total} = E_{basal} + \frac{E_t + |E_t|}{2},$$

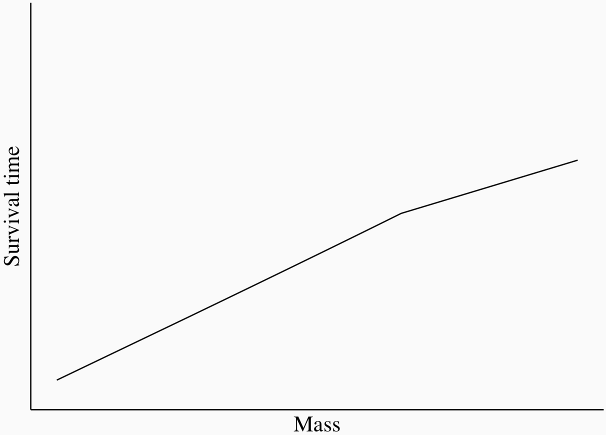
where the energetic cost for thermoregulation (E_t in kJ/day) is

$$E_t = (16M^{0.5}) \times (38 - 22.5M^{0.25} - T),$$

where T is the ambient temperature (Lindstedt & Boyce, 1985).

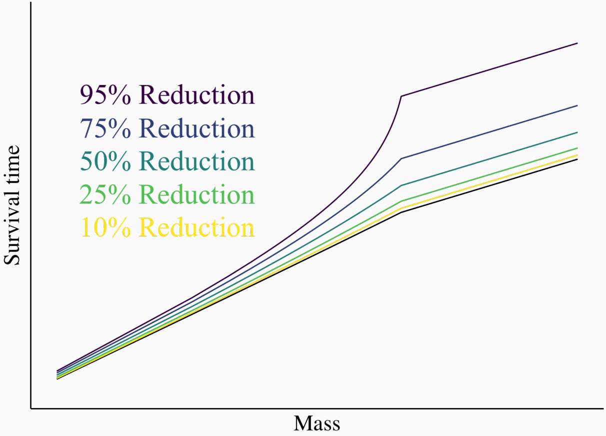
Survival time

From these allometries we can calculate survival time when fasting by dividing usable energy stores by total metabolic rate:



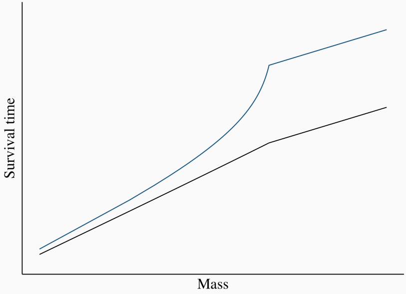
Survival time cont.

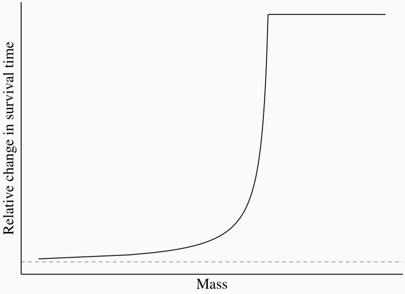
A reduction in basal metabolic via dormancy will result in a non-linear increases survival time.



Survival time cont.

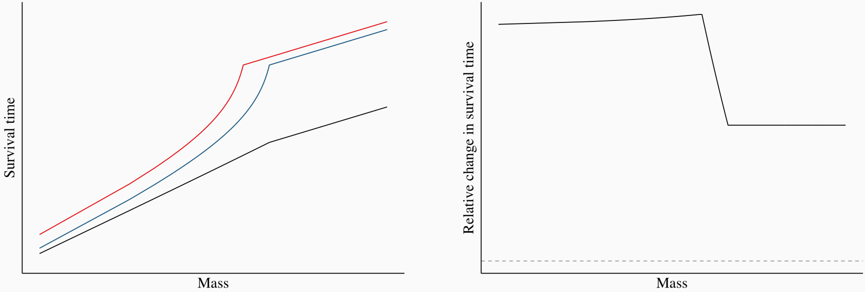
Dormancy will also have disproportionately greater benefits at larger body sizes.

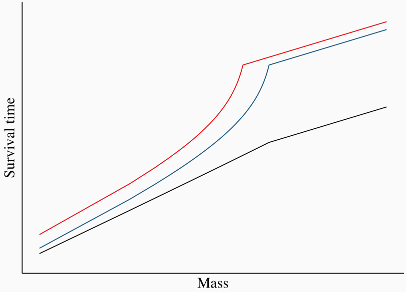




Survival time cont.

Accumulating fat reserves further improves survival time with disproportionately greater benefits at smaller body sizes.





Black = Baseline
Blue = Dormancy
Red = Dormancy + weight gain

All else being equal, large animals can survive longer periods of seasonally imposed fasts due to more effective dormancy.

Increasing body size will have greater benefits for smaller species.

Selection should favour large body size for mammals in seasonal environments.

Size dependent strategies

These scaling rules explain why large mammals build up fat reserves and go dormant in seasonal environments, whereas small mammals tend to build up food caches.

Source: slate.com

Source: www.newyorkupstate.com

Seasonality and Fourier's Law

Seasonal changes in productivity are not the only challenges, and organisms will also need to overcome temperature changes.

Source: wikimedia

Fourier's Law

The physics of energy transfer govern how environmental temperature influences energetics and the capacity to maintain homeostasis (McNab, 2002).

Animals lose heat to the environment according to Fourier's law of thermal conductance:

$$\frac{dE}{dt} = -kA\frac{\Delta T}{L},$$

where: $\frac{dE}{dt}$ is rate of heat transfer, ΔT is the temp. diff. between an animal and the environment, k is the thermal conductance, L and A are the thickness and surface area of any insulative layers.

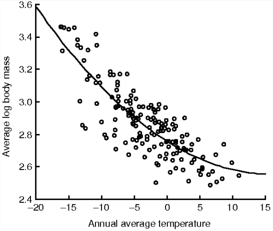
Seasonality Fourier's Law

In seasonal ecosystems that are characterised by dramatic changes in temperature, what options do organisms have to keep the rate of energy loss, $\frac{dE}{dt}$, as low as possible?

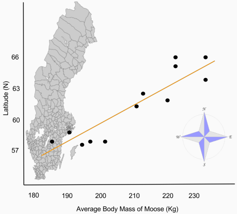
$$\frac{dE}{dt} = kA\frac{\Delta T}{L}$$

- k? as small as possible.
- A? as small as possible.
- L? as large as possible.
- ΔT? as small as possible.

Bergmann's rule

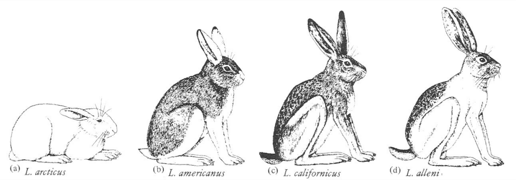


Source: Blackburn & Hawkins (2004)



Source: Sand *et al.* (1995)

Allen's rule



Source: MUN

Insulative layers (L)

Energy transfer is inherently inefficient, and the further energy has to travel the less efficient it will be.

$$\frac{dE}{dt} = kA\frac{\Delta T}{L}$$

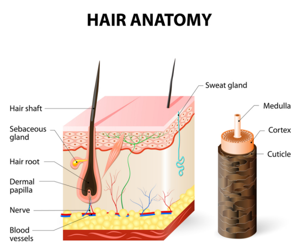
Building thick insulation fat layers increases L, meaning heat from the body's core is not transferred to the environment efficiently.

Lowering conductance k

Thermal conductance k is a material property.

Many species of mammals in seasonal environments have winter coats with larger upper shaft medullas with more air-filled pockets to lower k (Russell & Tumlison, 1996).

Source: discoveryeducation.com



Source: rejuvenatehairtransplant.com

Lowering ΔT

Mammals have body temperature of 38°C on average.

Cold winters e.g., -10°C or -20°C result in very large temperature differentials ΔT meaning heat is lost to the environment at much faster rates (all else being equal).

How can animals lower ΔT?

We'll cover this in detail next lecture.

Take home messages

Entering a state of dormancy (reduced metabolic activity) to conserve energy and 'ride out' unfavourable periods is a common adaptation to predictable changes in habitat suitability that is seen across all taxa.

... but there is upper limit on how long species can stay dormant, which increases with body size, meaning large mammals are more suited to long periods of hibernation and small mammals must rely on other strategies.

Animals are also subject to the physics of energy transfer, and adaptations to cold env. involve minimising $\frac{dE}{dt} = -kA\frac{\Delta T}{L}$.

References

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