Optima and Thermal Preference

- **Preferred temperature**
- **Selected temperature**
- Eccritic or **Field Temperature**

- Thermal preferences as a measure of optima

- Dynamics and ecology of preference/optima
  - Energetics and thermal shuttling
  - Behavioral fever
  - Ecdysis
  - SDA/**Postprandial thermophile**
  - Torpor

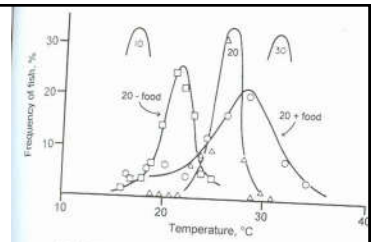


Figure 4.17 The distribution of carp (*Cyprinus carpio*) in a temperature gradient as a function of temperature, thermal acclimation, and the presence or absence of food. The numbers associated with the distributions indicate acclimation temperatures. Source: Modified from Elliott (1981).

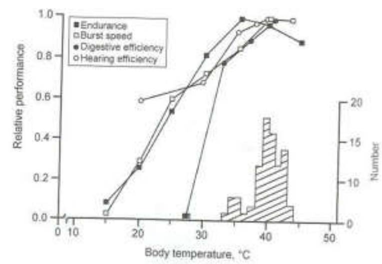


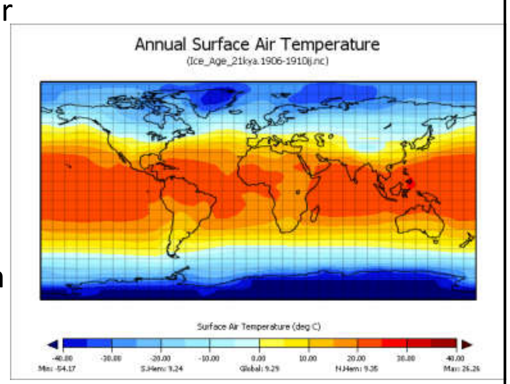
Figure 4.26 The relative performance of endurance, burst velocity, digestive efficiency, and hearing efficiency in the desert iguana (*Dipsosaurus dorsalis*) as a function of body temperature, and the frequency distribution of body temperature of *Dipsosaurus* in the field. Source: From Huey and Kingsolver (1989).

Countergradient selection (temperature compensation)

- Higher latitudes feature lower temperatures and shorter growing seasons.

- Animals with annual life cycles have less time and cooler temperatures in which to complete life cycle.

- Selection for compensatory response – higher metabolic rates and thermal optima along latitudinal gradients.



Temperature as a resource

- For ectotherms, temperature largely determines metabolic rate and the length of the growing season.
- Temperature Sex Determination – female bias at cold temperatures for some species
- Female fitness is more directly linked to body size. Thus, females have longer growing season to get larger and invest more in reproduction.

Environmental Sex Determination: Interaction of Temperature and Genotype in a Fish

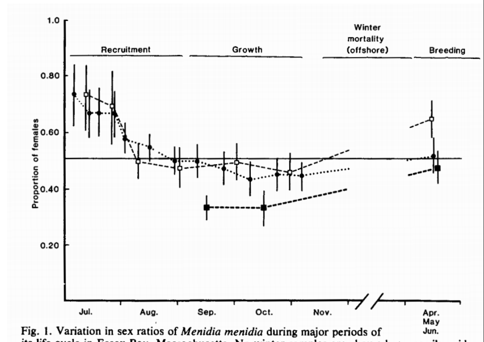
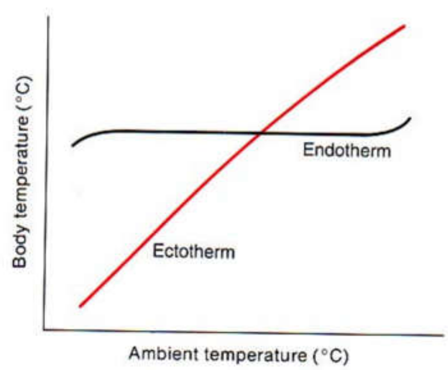


Fig. 1. Variation in sex ratios of *Menidia menidia* during major periods of its life cycle in Essex Bay, Massachusetts. No winter samples are shown because silversides winter offshore and are unavailable for capture in near-shore areas. Samples obtained in the spring are pooled because silversides suffer high winter mortality and are much less abundant afterward. Since a life cycle is completed in 1 year, each year class represents a distinct generation: (■) 1976; (●) 1977; (□) 1978. Vertical lines indicate 95 percent confidence limits based on exact probabilities (*9*). Sample sizes range from 55 to 442 (mean, 255). The horizontal solid line represents a 1:1 sex ratio.

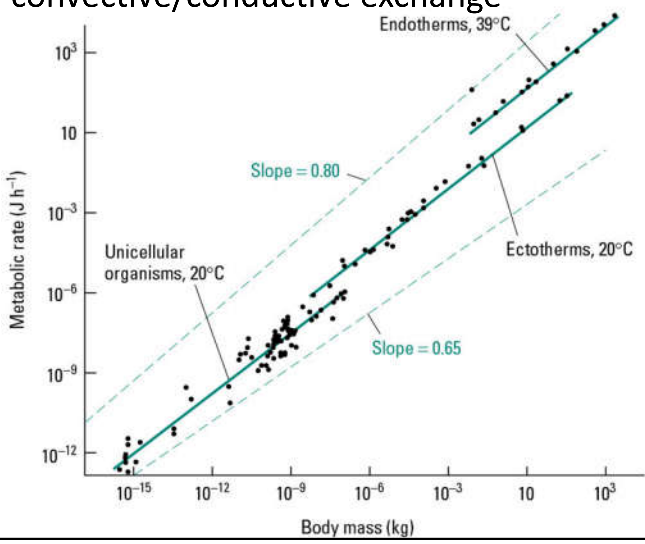
Evolution of Endothermy

- Endotherm (homeotherm)
  - T_b generally regulated by generating heat, $T_b > T_a$
  - Behavioral, physiological and biochemical thermoregulation
  - Mammals and birds (most thermoregulation not behavioral or shivering)
- Ectotherm (poikilotherm)
  - T_b generally regulated by exchange with environment, some shivering
  - Behavioral regulation



Endotherms

- Metabolic rates 4-10 times higher
- Fur, feathers, blubber, body size and shape minimize convective/conductive exchange



Endotherm-Ecotherm differences

Amphibolurus vitticeps

Rattus norvegicus

- 70% of mammal heat generated internally
- Metabolically active organs significantly larger in mammal
  – Brain, liver, kidney, heart and skeletal muscle
- Less active tissues not different (skin, lungs, reproductive organs) or larger in endotherm (stomach)

Hulbert and Else 1989. Evolution of mammalian endothermic metabolism: mitochondrial activity and cell composition. American Journal of Physiology. 256: 63-69.

Endotherm-Ecotherm differences

Amphibolurus vitticeps

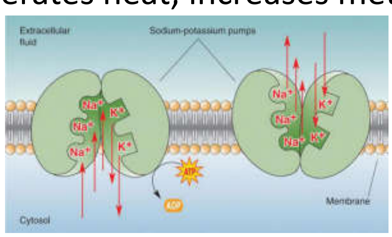
Rattus norvegicus

- Mammals
  - More protein and phospholipids (~50%)
  - Greater mitochondrial surface area
  - Greater cell membrane Na^+ and K^+ leakiness
  - Brown fat
  - All linked to **non-shivering thermogenesis**

Hulbert and Else 1989. Evolution of mammalian endothermic metabolism: mitochondrial activity and cell composition. American Journal of Physiology. 256: 63-69.

Non shivering thermogenesis

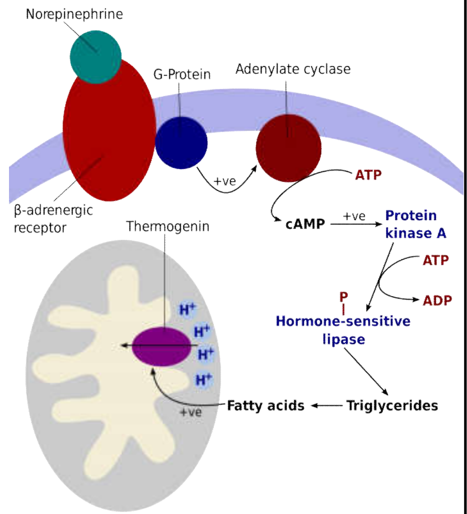
- **Na^+ and K^+ pump activity** to maintain concentration gradient generates heat, increases metabolic rate



- **Futile cycle** – two simultaneous metabolic pathways running in opposite directions. Net result is generating heat while consuming ATP.
  - Glycolysis ↔ Gluconeogenesis
  - Fructose-6-phosphate ↔ fructose-1,6-biphophate

Non shivering thermogenesis

- **Brown Fat**
  - Numerous lipid droplets
  - High concentration of mitochondria with thermogenin
- **Thermogenin** (uncoupling proteins) facilitate mitochondrial heat generation over ATP production.



- More brown fat in hibernating mammals, ~25% of body mass in human infants

Evolution and Endothermy Costs

- Endothermy is expensive, $T_b > T_a$ costs include:
  - Heat
  - Neurological, hormonal or other homeostasis systems
  - Anatomical structures (hair, feathers, blubber)
- Thermal components of niche – temperature is often a prominent component
- Recall basics of energetics and evolution – energy spent thermoregulating can't be allocated to reproduction

Evolution and Endothermy Costs

- Minimizing endothermy costs
  - Insulation
  - Large body size (Bergman's rule)
  - Small appendages, round body (Allen's rule)
  - Heat exchangers (penguin feet)
  - Torpor (bats) or hibernation (bears)
  - Avoidance (migration, torpor, habitat selection)

Advantages to Ectothermy

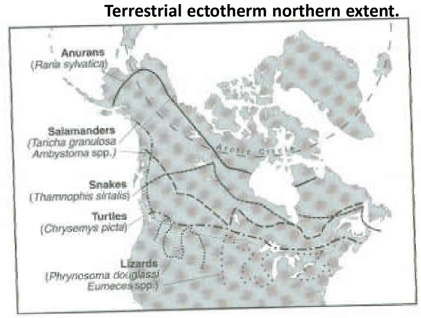
- Wider range of body sizes and shapes
- Modest energy requirements, advantageous in low energy environments

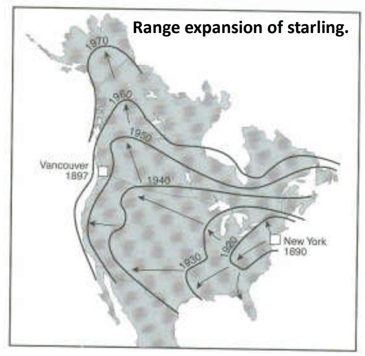
- Better suited to extended periods of low food or low oxygen
- High assimilation efficiency (greater proportion of ingested calories can be allocated to growth and reproduction)

Advantages of Endothermy

- More stable T_b facilitates efficient temperature sensitive physiological processes
- Greater aerobic capacity, less reliance on anaerobic pathways
- Greater aerobic capacity supports elevated sustained activity
  - Ectotherms limited in scope (aerobic and anaerobic)
- Niche expansion into colder habitats
  - Ectotherm activity tightly linked to temperature
  - Ectotherms limited in geographic range

Terrestrial ectotherm northern extent.





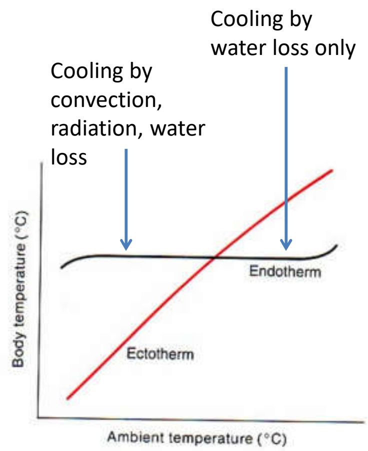
Range expansion of starling.

Endotherm vs. Ectotherm

- Ectotherms more reliant on anaerobic metabolism
  - Low performance at low temperatures often encountered in nature.
  - Aerobic and anaerobic capacity limited by temperatures.
- Endotherms have a broader range of activity.
  - Increased aerobic capacity for sustained activity supplemented by anaerobic sources.
  - Stable body temperature and greater aerobic scope results in sustained performance up to 10x seen in ectotherms.
  - Higher energy demands.

Offsetting costs of endothermy

- Enzymes can be tailed for one temperature.
  - Avoid the need for multiple enzymes with a different operational temperatures.
- Body temperatures usually above ambient so heat can be lost by convection and conduction & not evaporative water loss. If $T_b < T_a$ water loss is the only means of venting heat (limited by humidity).
  - Endotherm T_b a compromise between:
    - disadvantages of cost to heat body
    - Ease of regulating T_b without water loss
- Endotherm Tb generally ranges from 30-45°C
  - Tradeoff between heating costs in cold environments and water loss in hot environments



Other endothermy factors

- Endothermy generally thought to evolve with erect posture
  - Lower heat exchange with ground, insulation limits exchange with air
  - ~30% of mammal SMR is tonic postural muscular activity.
  - Nervous control for erect posture & tonic contraction similar to shivering mechanisms.
- Endothermy not restricted to animals