Heat Tolerance

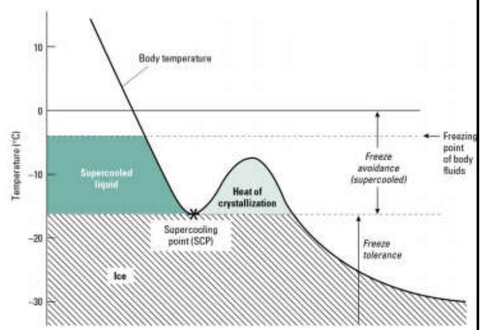
- **Heat death**
  - Protein and enzyme denaturing
  - Lipid breakdown
  - Inadequate O_2 (Hb affinity shifts)
  - Membrane fluidity
  - Runaway reaction rates
  - Ratio of bound to unbound water
- **Tolerance**
  - HSP
  - Acclimation: modify membrane structure, Hb affinity or hematocrit, enzymes to control reaction rates
- **Critical Thermal Maximum** (upper critical temperature)

Cold Tolerance

- **Cold Death**
  - Near freezing - reduction in rates of vital reactions
  - Freezing
    - Desiccation
    - Vitrification
- **Tolerance**
  - Acclimation: enzymes compensate for low reaction rates, modify membrane structure
  - Freeze tolerance – allow ice formation in some areas
  - Freeze avoidance – do not allow ice formation

Cold Tolerance

- **Freeze avoidance/intolerance**
  - Spatial avoidance
  - Supercooling
    - Void gut
    - Antifreeze proteins
- **Freeze tolerance**
  - **Ice nucleating agents** – control where ice forms
  - **Cryoprotectants** – protect cells from ice damage



- **Thermal hysteresis** – separation of the freezing and meting point of fluids.
  - Due to action of antifreeze proteins.
  - Allows for supercooling and prevention of ice formation.

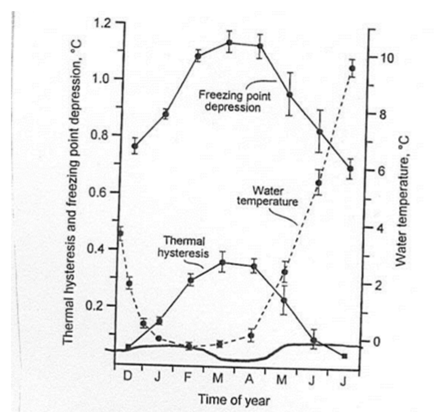


Figure 4.16 Water temperature and the freezing point and thermal hysteresis of the body fluids of Atlantic cod (*Gadus morhua*) as a function of the time of the year. Source: From Fletcher et al. (1987).

Osmolarity and Colligative Properties

- **Marine invertebrates** – isosmotic, ocean thermal inertia prevents complete freezing
- **Marine vertebrates** – generally hyposmotic, will freeze at warmer temperatures than surrounding water
- **Freshwater vertebrates** – generally hyperosmotic, will freeze at colder temperatures than surrounding water, can be surrounded by ice and not freeze themselves

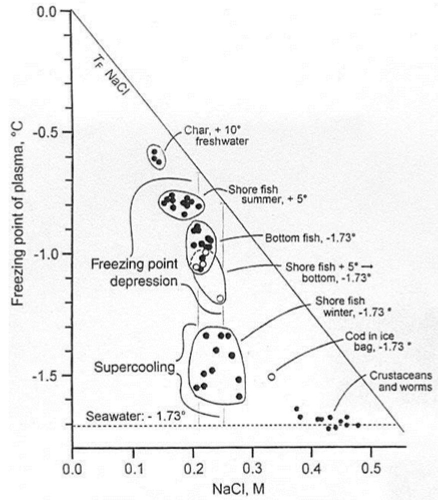
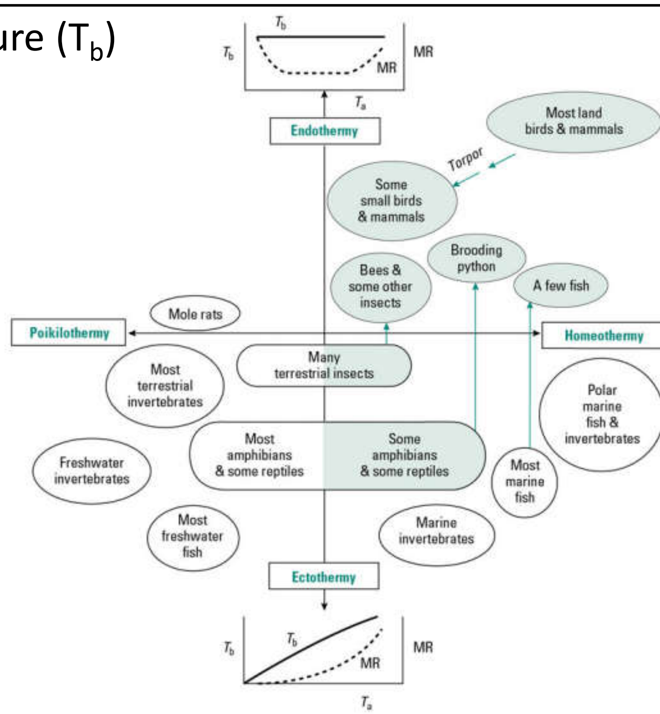


Figure 4.15 Freezing point of plasma as a function of the plasma sodium chloride (NaCl) concentration in fishes and marine invertebrates. A standard freezing point curve for NaCl is included. The difference between the standard curve and the freezing point of plasma is due to either supercooling or the accumulation of organic molecules. Source: Modified from Scholander et al. (1957).

Body Temperature (T_b)



- Thermal regulators vs. conformers
- Behavioral vs. physiological thermal regulation
- Measuring thermal tolerance
  - CT_{Max} CT_{Min}
  - LT_{50} UT_{50}

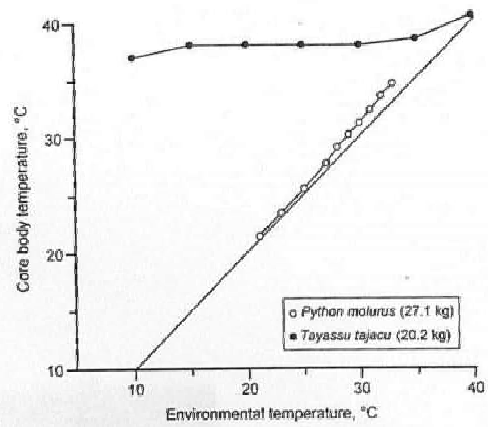
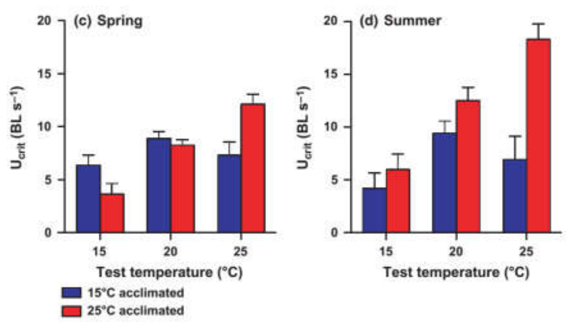


Figure 4.1 Body temperature in poikilotherm (*Python molurus*) and a homeotherm of similar mass (the collared peccary [*Tayassu tajacu*]) as a function of environmental temperature. Sources: Data taken from Zervanos (1975) and Van Mierop and Barnard (1978).

Thermoregulatory Behavior

- Ectotherms expected to select habitats that optimize fitness (performance)



Regulation of thermal acclimation varies between generations of the short-lived mosquitofish that developed in different environmental conditions

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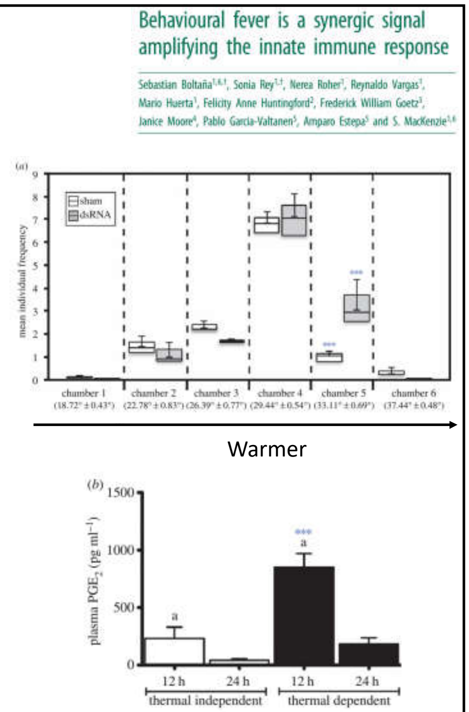
Fig. 2. Burst swimming (a, b) and sustained swimming (U_{crit}; c, d) performance of fish collected in spring and summer. Each panel shows results from cold (15 °C; blues bars)- and warm (25 °C; red bars)-acclimated fish, and acute test temperatures are shown on the x-axis. There were significant interactions between season, acclimation and test temperature.

- Tradeoffs between costs and risk of finding optimal temperatures

Behavioral Fever

- Ectotherms select warmer temperatures (behavioral thermoregulation) as part of immune response
- Zebrafish challenged with virus select warmer temperatures in gradient and upregulate anti-viral genes
- Same hormonal response (PGE, prostaglandin) as in endotherms.



Endothermy

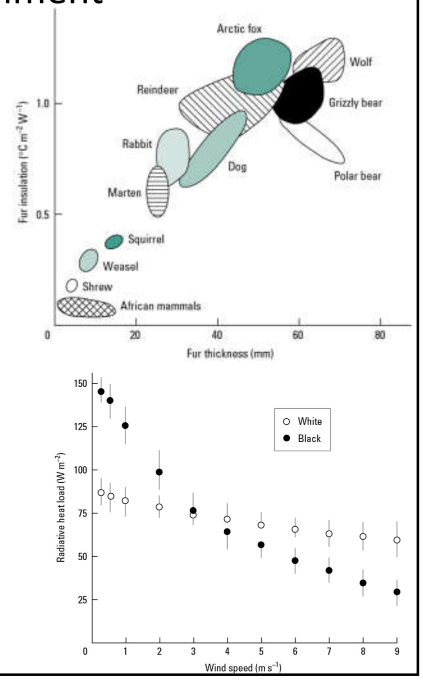
- Facultative endotherm


- Partial endotherm

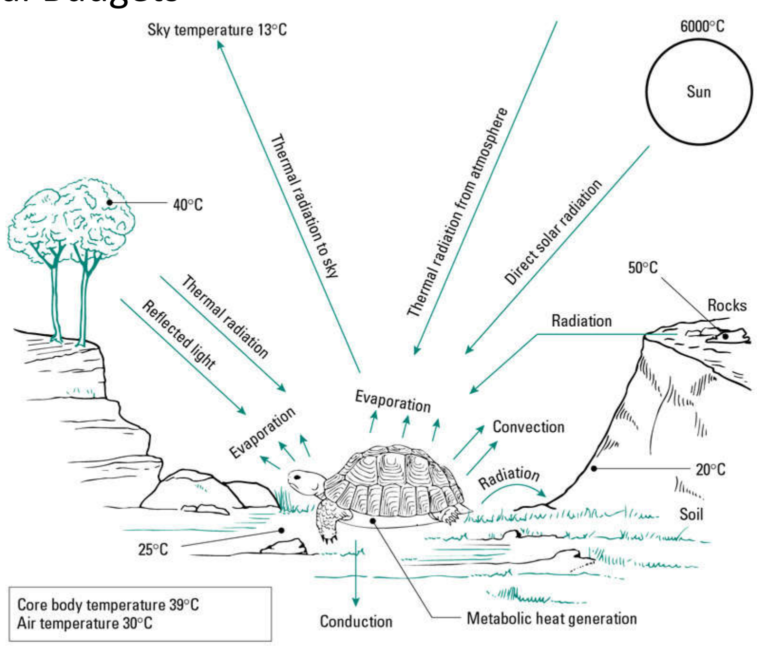

- Regional endotherm

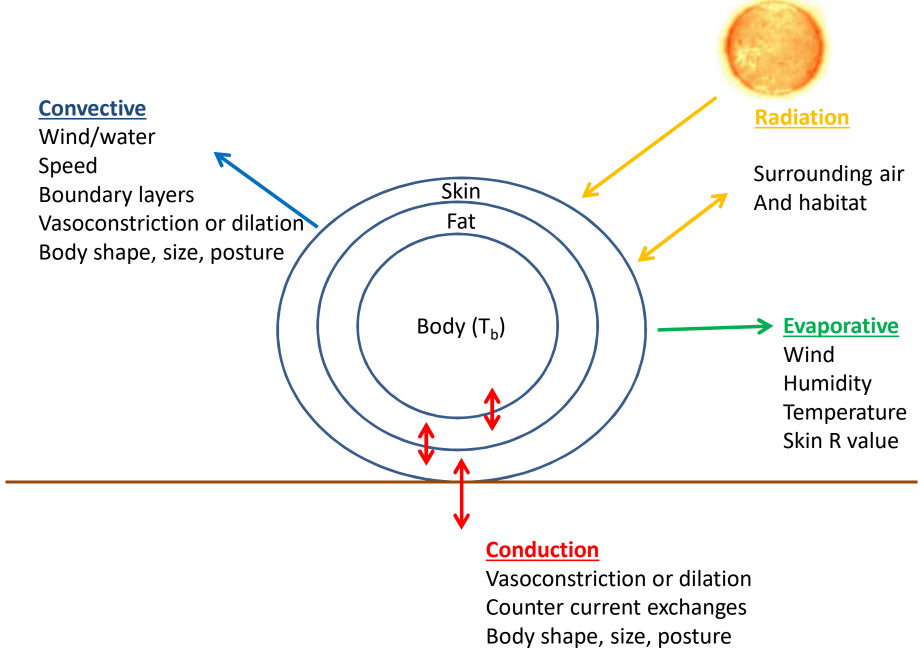

Thermal Exchange with Environment

- **Conduction** – direct transmission of molecular motion
- **Convection** – transfer through a fluid medium (air or water)
- **Radiation** – **emission** or **absorption** of electromagnetic radiation
- **Evaporation** – heat loss through heat of vaporization



Thermal Budgets





Insulation

- Better insulation = less heat loss (cooler surface) and greater difference between T_b and T_s
- Thicker fur generally better insulator.
- Blubber and thermogenic brown fat
- Polar bear outlier:

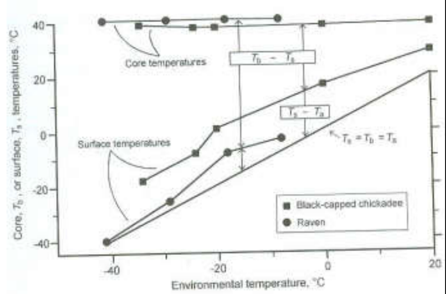
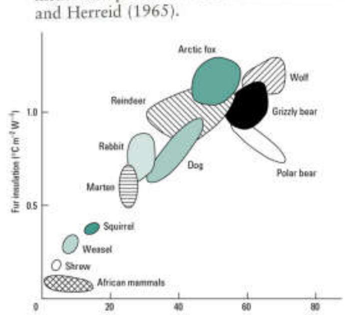


Figure 2.9 Core and surface temperatures of ravens (*Corvus corax*) and black-capped chickadees (*Parus atricapillus*) as a function of environmental temperature. Source: Derived from Veghte and Herreid (1965).



Convection

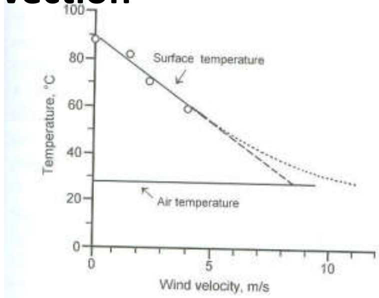


Figure 2.6 Surface temperature of ravens (*Corvus corax*) as a function of wind velocity when exposed to a 300-W tungsten lamp. Source: Modified from Marder (1973).

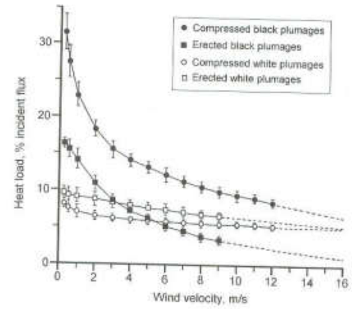
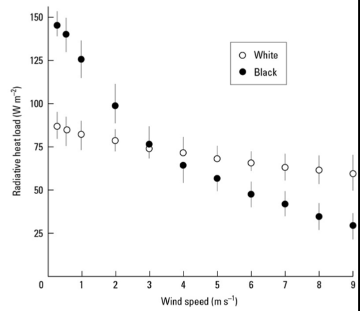


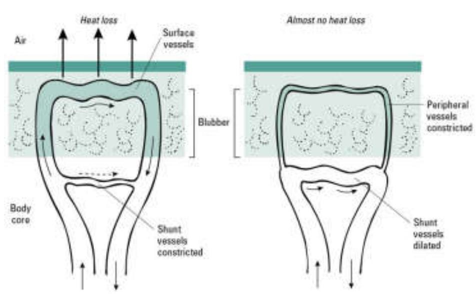
Figure 2.7 Radiative heat load as a function of wind velocity in black and white pigeons (*Columba livia*), depending on whether their plumage is erect or compressed. Source: Modified from Walsberg et al. (1978).

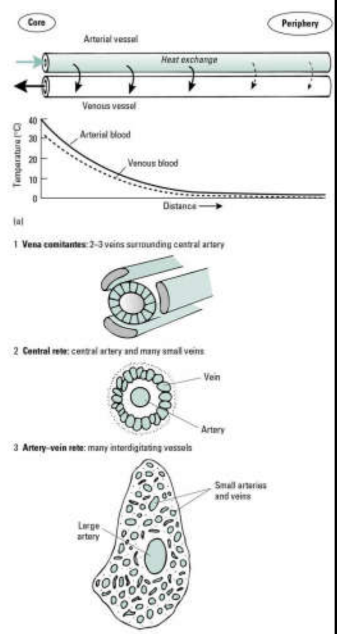
- Wind or water velocity increases heat exchange
- Modifications
  - Skin/plumage color
  - Hair or feather erection
  - Habitat selection
  - Body size, shape and posture



Blood Flow and Convection/Conduction

- Vasodilation or constriction
- Counter current exchange systems





Redistribution of blood within the body is important for thermoregulation in an ectothermic vertebrate (*Crocodylus porosus*)

Frank Seebacher · Craig E. Franklin

Fig. 4 Proportional blood flow to different tissues during thermal equilibrium (*Equilibrium*), immediately after heat was applied (*Heat on*), midway during heating (*Heating*), immediately following removal of heat (*Heat off*), and midway during cooling (*Cooling*). The *upper panel* (**a**) shows distribution of flow by different intensity of color, and a key to the colors is given to the right. The *lower panels* (**b**)