ESRM 350

Temperature Regulation

Autumn 2014

"**When it is seventy five below zero, a man must not fail in his first attempt to build a fire – that is, if his feet are wet.**"

- Jack London, *To Build a Fire*

The Thermal Environment

- Fluctuations in temperature of the physical environment are a challenge for all animals
- Hot temperatures
  - denature proteins
  - accelerate chemical processes
  - affect properties of lipids
  - typical upper limit for most animals: 45° C
- Cold temperatures
  - disrupt life processes (slow chemical reactions)
  - ice crystals damage cell structures

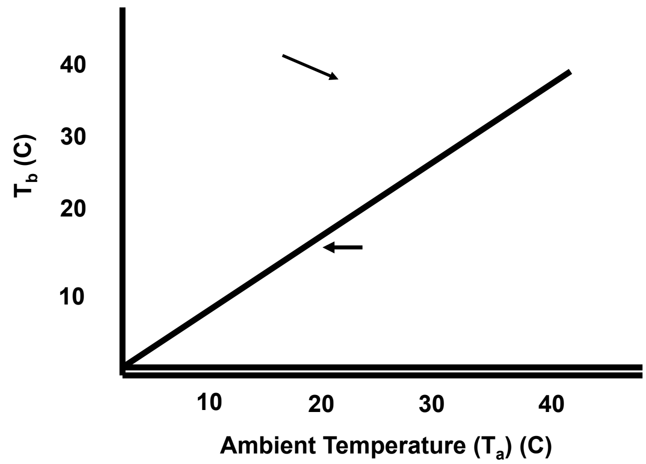
The Thermal Environment

- Fluctuations in temperature of the physical environment are a challenge for all animals
- Hot temperatures
  - denature proteins
  - accelerate chemical processes
  - affect properties of lipids
  - typical upper limit for most animals: 45° C
- Cold temperatures
  - disrupt life processes (slow chemical reactions)
  - ice crystals damage cell structures

- How do animals cope with this challenge?

Poikilothermy

- **Poikilotherms:** Internal body temperature (T_b) fluctuates with that of the ambient environment (T_a)



Advantages of Poikilothermy

- Reptiles and amphibians (also fish)
- Low energy expenditure
  - can live without food for long time
- Can be very small
  - heat loss not an issue

Oregon spotted frog
(Rana pretiosa)

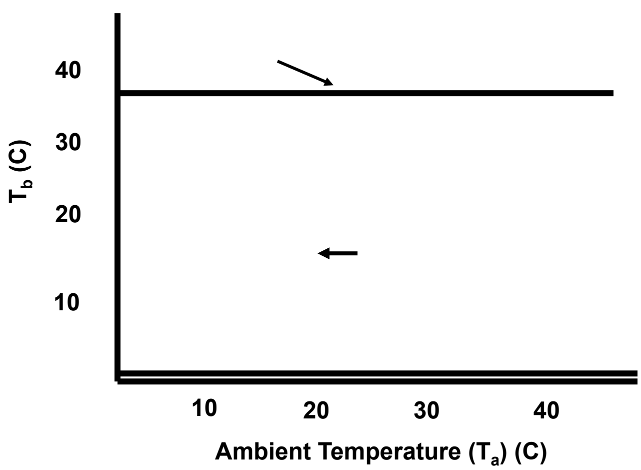
Costs of Poikilothermy

- Inability to exploit cold environs
- Impaired performance prior to warming up; reduced stamina
  - depleted energy stores recovered slowly

Komodo dragon
(Varanus komodoensis)

Homeothermy

- **Homeotherms:** maintain a constant internal body temperature (T_b)



Homeotherms

- Primarily **endothermic** birds and mammals
  - endotherms produce body heat internally (from metabolism)
  - known colloquially as “warm-blooded”
  - typical T_b is 35-42° C
- Are all homeotherms also endothermic?

Homeotherms

- Primarily **endothermic** birds and mammals
  - endotherms produce body heat internally (from metabolism)
  - known colloquially as “warm-blooded”
  - typical T_b is 35-42° C
- Are all homeotherms also endothermic?

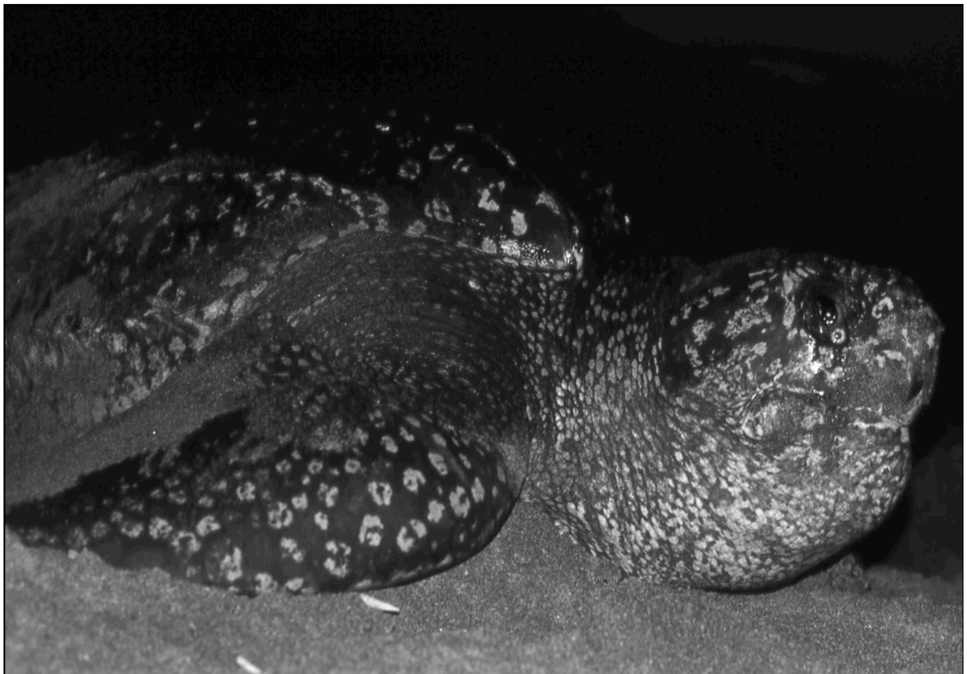
  - no
  - some are **ectothermic** (derive warmth from the ambient environment)
  - i.e., some homeotherms are actually species we would call “cold-blooded”!
  - ectotherms can maintain stable T_b via behavioral regulation (described shortly)

Natural History Aside

- Are any animals other than birds and mammals endothermic?

Natural History Aside

- Are any animals other than birds and mammals endothermic?
  - yes
  - some fishes (tuna)
  - also, at least one reptile…



Leatherback turtle (*Dermochelys coriacea*)

- Can live in very cold waters at high latitudes, also found in warm waters near the equator
- Huge – up to 900 kg
- Deep divers – 1280 meters (4200 ft)
- Travel avg of 6000 km between nesting beaches and foraging grounds
- Produce heat internally (metabolically)
  - heat conserved because of large body size
  - allows for swift movement, even in cold water
    - up to 36 km/h (22 mph)
  - reduce activity to dissipate heat when in warm water
  - internal body temperature relatively stable despite extreme variation in external environment
    - ~ 25° C

Bostrom et al. (2010) *PLoS ONE*

Advantages of Homeothermy

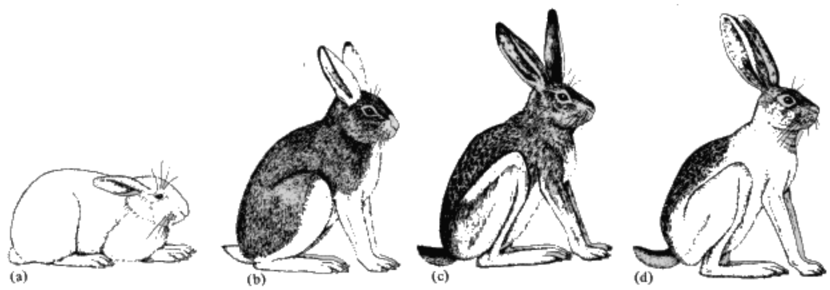
- Can live and function optimally in a wide variety of environments
  - homeotherms found from deserts and the tropics to the arctic
- Greater stamina
  - depleted energy supplies recovered more rapidly
- Can respond rapidly to environmental stimuli
  - don't need to warm up

Costs of Homeothermy

- Homeotherms use enzymes that are specialized for a narrow range of body temperature
  - over-cooling and over-heating can lead rapidly to reduced performance, death
- Great deal of energy required to maintain T_b outside of thermo-neutral zone (TNZ)
  - homeotherms must eat lots of food
  - especially true for small homeotherms
    - high surface-to-volume ratio
    - rapidly lose heat to the ambient environment
  - energetic cost of homeothermy has led to two trends

Allen's Rule

- Homeothermic species (and populations within polytypic species) living in cold climates tend to have smaller extremities (limbs, tails, ears)
  - e.g., the Genus *Lepus* (hares) in North America



Lepus arcticus *L. americanus* *L. californicus* *L. alleni*

Bergmann's Rule

- Homeothermic species (and populations within polytypic species) living in cold climates tend to be larger
  - lots of small critters in the tropics
  - e.g., North American bears

Black bear (*Ursus americanus*)

90-270 kg

Brown bear (*Ursus arctos*)

95-390 kg

Polar bear (*Ursus maritimus*)

410-720 kg

Adaptations for Homeothermy

- Three kinds
  - Structural
  - Physiological
  - Behavioral
- Adaptations can either prevent
  - over-cooling (**hypothermia**), or
  - over-heating (**hyperthermia**)

Structural Adaptations for Avoiding Hypothermia

- Hypothermia – the condition of having a body temperature (T_b) below the normal range
  - impedes proper enzyme function, leads to impaired performance, death
- **Fur**
  - Guard hairs and underfur reduce heat loss by trapping a layer of air, which is then warmed

Musk ox (*Ovibos moschatus*)

Structural Adaptations for Avoiding Hypothermia

- **Feathers**
  - "fluffing" traps air, which is then warmed
  - oil matting leads to hypothermia
- **Blubber**
  - thick, insulative layer of adipose (fat) tissue found under skin
  - marine mammals (cetaceans, pinnipeds)

Weddell seal (*Leptonychotes weddellii*)

Physiological Adaptations for Avoiding Hypothermia

- **Increase heat production**
  - activity (elevated metabolism)
  - shivering
- **Vasoconstriction**
  - narrowing of superficial blood vessels
  - diverts flow of heated blood to the body core

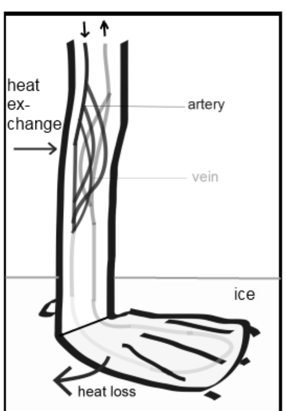
Physiological Adaptations for Avoiding Hypothermia

- **Countercurrent heat exchange**
  - alignment of blood vessels such that arterial blood from core warms up colder venous blood from extremities
  - heat diverted to the core; extremities (e.g., legs or flippers) stay cool, minimizing heat loss
    - weak temperature gradient at interface with ambient environment

Heat exchangers

Physiological Adaptations for Avoiding Hypothermia

- **Countercurrent heat exchange**

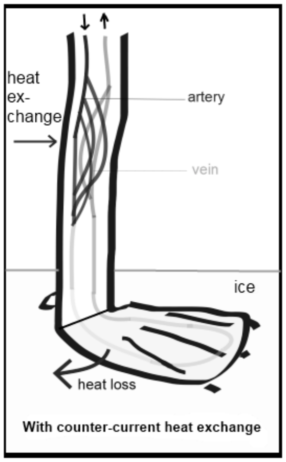


With counter-current heat exchange

- e.g., bare legs of many wading birds
- Why not just feathers?

Physiological Adaptations for Avoiding Hypothermia

- **Countercurrent heat exchange**



- e.g., bare legs of many wading birds
- Why not just feathers?

- Expensive care for feathers (mud, matting, etc.)
- Also good for heat dissipation (heat in venous blood stays in the legs)

Behavioral Adaptations for Avoiding Hypothermia

- **Migration**
  - avoid cold weather
  - elevational
    - e.g., deer
  - latitudinal (N-S)
    - birds, bats, whales
- **Burrowing**
  - in snow or ground
  - e.g., grouse (in snow)


Mule deer (*Odocoileus hemionus*)

Ruffed grouse (*Bonasa umbellus*)

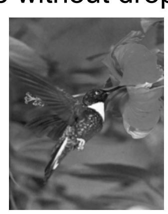
Behavioral Adaptations for Avoiding Hypothermia

- **Change posture**
  - e.g., curl up
- **Form tightly packed groups**
  - e.g., quail, bison

Bison (*Bison bison*)

Behavioral Adaptations for Avoiding Hypothermia

- **Hibernation**
  - state of torpor characterized by depressed metabolism and temperature (reduced heating costs)
  - can last days to weeks
  - typically, basal metabolic rate is reduced to 2-4% of normal rates and T_b is maintained within a few degrees above ambient temperatures
  - common in ground squirrels, bats
  - Interestingly, some species hibernate without dropping temperature
    - bears, hummingbirds (at night)
    - more to save energy



Structural Adaptations for Avoiding Hyperthermia

- Hyperthermia – the condition of having a body temperature (T_b) above the normal range
  - leads to organ failure, death if persistent
- **Small size**
  - Remember Bergmann's rule
- **Thermal windows**
  - Birds: gular pouch, feet, legs, face
  - Mammals: face, feet, arm pits, belly
    - remember Allen's rule
    - hairlessness in humans: signature of evolution as runners?

Physiological Adaptations for Avoiding Hyperthermia

- **Evaporative cooling**
  - Mammals: sweating, panting
  - Birds: no sweat glands, so evaporation via lungs, air sacs, gular pouch
    - accomplished by panting, gular fluttering

Gular pouch of the male frigate bird (*Fregata magnificens*)

Inflated to attract females

Physiological Adaptations for Avoiding Hyperthermia

- **Vasodilation**
  - expansion of peripheral blood vessels to dissipate heat
- **Countercurrent heat exchange**
- **Heat storage**
  - effective for large mammals, birds
  - body volume absorbs heat during day, lost passively at night
  - e.g., camels

Behavioral Adaptations for Avoiding Hyperthermia

- **Reduce activity**
  - Lower metabolism, minimize heat production
- **Increase water intake**
- **Seek cooler activity times and space, heat dissipating opportunities**
  - become crepuscular, nocturnal
  - shade, vegetation to reduce heat gain
  - shift activity space toward water
  - shift activity space underground (become **fossorial**)

Another Natural History Aside

- Behavioral homeothermy in an ectotherm…

Behavioral Homeothermy in an Ectothermic Lizard

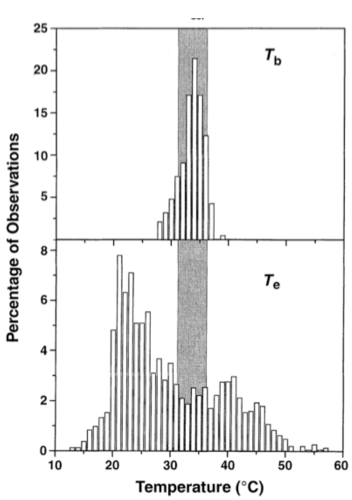


FIG. 1. Distributions of body temperature (T_b) in a population of *Podarcis hispanica atrata* and available operative temperature (T_e) during early autumn. The shaded area identifies the selected temperature range (T_{sel}).

- Lacertid lizard (*Podarcis hispanica atrata*)
- Columbretes Archipelago, Mediterranean Sea (province of Spain)
- Maintain relatively stable T_b by selecting for narrow range of ambient thermal conditions
  - Using sunny microsites
  - adopting basking posture

Bauwens et al. (1996) *Ecology*