

High Body Temperature.

- Active in early morning, winter, high mountains
- Requires a lot of energy and water
- Adaptations for thermoregulation and water conservation

Adaptations.

- Highly efficient respiratory system
- Powerful heart, circulation
- Specialized feeding apparatus
- Water reserves (metabolic)

High Body Temperature.

- Endothermy
 - Maintained by metabolic heat
- Most birds = 40° C
- Physiological processes faster at higher T
 - (nerve impulses 1.8x faster and muscles 3x/10° C)
- Costs: birds need 20 to 30x the energy of reptiles
 - : close to dangerously high T

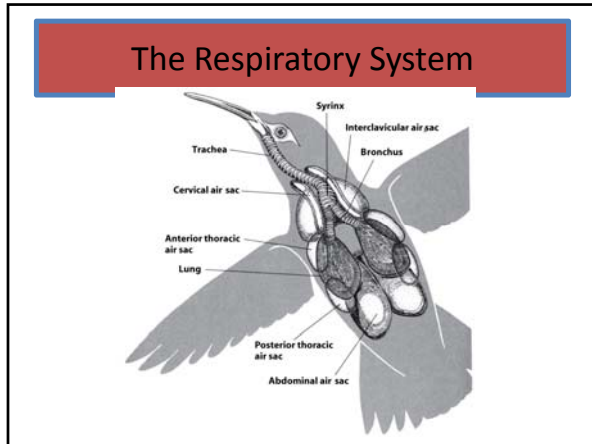
Endurance.

- Increased aerobic metabolism and insulation
- Constant body T and dependable muscles
- Allow sustained activity
 - Bar-tailed Godwit can fly 7,200 miles (9 days)
- Enable ecological breadth of birds
- Need a lot of E and O₂; waste removal



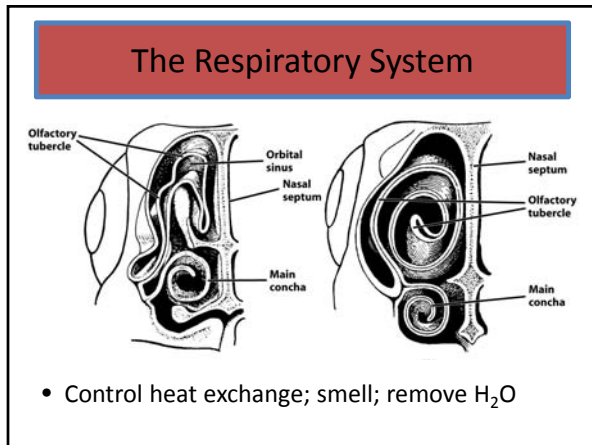
The Respiratory System.

- Lungs small and compact
 - Same weight but ½ volume of mammals
- Supplemented by air sacs



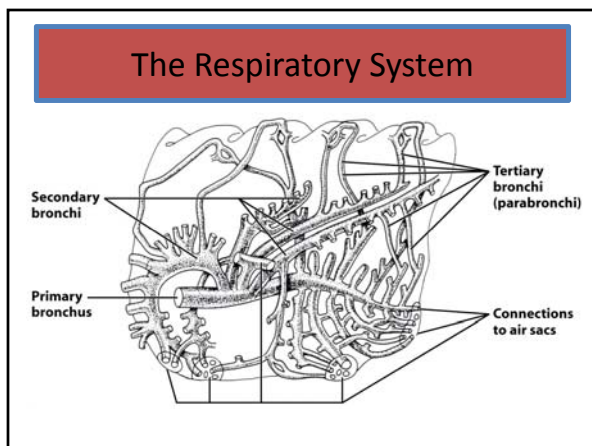
The Respiratory System.

- Breathing accomplished by moving sternum and ribs (mammals have diaphragm)
- Air enters through nostrils (some with flaps)
 - Passes over conchae



The Respiratory System.

- After conchae, into trachea then bifurcates at bronchi
- Secondary bronchi
- Most lung tissue is tertiary bronchi and capillaries
 - Gas exchange occurs in capillaries



The Respiratory System.

- Inhaled air doesn't enter lungs directly
 - Inhalation: Posterior Air Sacs
 - Exhalation: Lungs
 - Inhalation: Anterior Air Sacs
 - Exhalation: Expelled from the body
- Almost all air in lungs replaced with each breath
 - More efficient than mammals

The Respiratory System.

- Number of Air Sacs varies (6 – 12)
- Cervical Air Sacs Can Be Visible



The Respiratory System.

- Air sacs inside bones
 - Theropod dinosaurs also
- Help dissipate heat
- “Air Bags” to cushion internal organs
- Interclavicular sac pressure essential for voice

The Respiratory System.

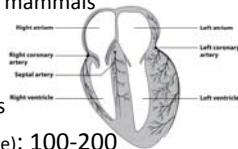
- Wing and furcula movements complement sternum
- Flight actually assists respiration

The Respiratory System.

- Breathing rate decreases with increased body size
- Hummingbird: 143/minute
- Turkey: 7/minute
- Flight: increase respiration rate 2 to 25x
- Hyperventilation:
 - CO₂ decrease increases pH, causing blood vessels to constrict; in birds, blood flows fine at pH 8

The Circulatory System.

- Double circulatory system
- 4 chambered Heart
 - Average of 41% larger than mammals
- Heart rate
 - Average 220 bpm
 - 1200 bpm in hummingbirds
- Cardiac Output (mL/kg/minute): 100-200
 - Major Organs: 8-10% each
 - Brain and Eyes: 3 and 4%

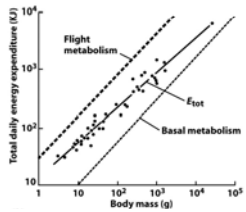


The Circulatory System.

- Slower heart rate than mammals
 - Larger stroke volume means comparable cardiac output
 - Bird heart vs. Mammal heart
 - Larger
 - Ventricles empty more completely
 - Ventricles fill more completely (at high bpm)
 - More muscle fibers
 - Thinner fibers w/ more mitochondria
 - Costs: high blood pressure


Metabolism.

- Basal Metabolism:
 - Minimum energy usage
 - Birds have high BMR compared with most vertebrates
- Scales with body mass
- Lower surface area to volume ratio means large birds cannot produce as much heat per unit volume



Metabolism.

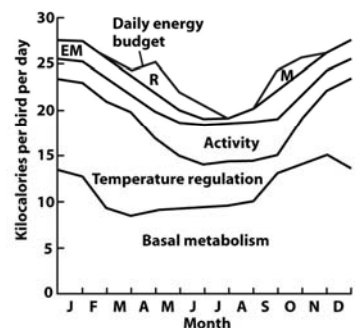
- Activity increases metabolic rate
- Awake means rate increases 25 to 80%
- Swimming Mallards at 3.2 to 5.7x BMR
- Greater Rheas on treadmills wearing hoods
 - Aerobic metabolism peaked at 36x minimum resting rate
 - 2x aerobic scope of mammals



Metabolism.


- Small birds flying = 25x BMR for hours
 - Mammals: max 6x BMR
- Range from 2.7 to 23x
 - Due to wing shape, flight style, wind, etc.

Metabolism



Temperature Regulation.

- Metabolism produces heat
- Feathers insulate
 - Feather damage or loss increases metabolism
 - Metabolism and heat loss 2x in “frizzle” chickens
- Down feathers most important



Temperature Regulation.

- House Sparrows molt from 0.9 g in August to 1.5 g in September
 - Migration and tropical living reduce this change

Temperature Regulation

- Feather position affects insulation

The diagram shows a blackbird with labels 1-6 pointing to different feather areas: 1 (wing), 2 (beak), 3 (neck), 4 (back), 5 (tail), and 6 (feet). Below the diagram are two photos: one of a blackbird and one of a yellow bird.

Temperature Regulation.

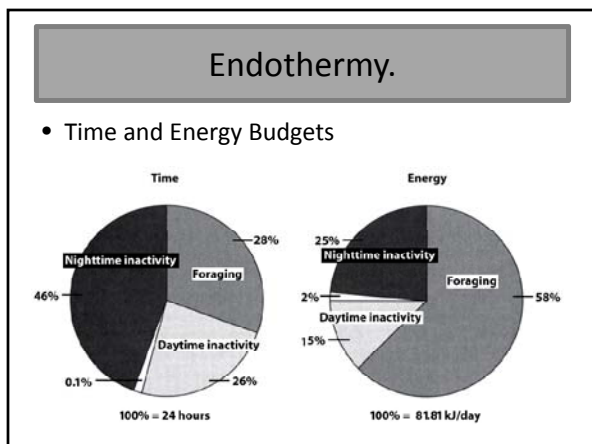
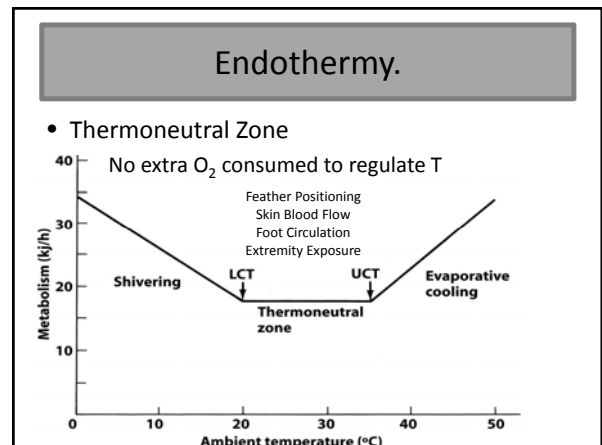
- Behavioral Adjustments
 - Seeking shade/shelter
 - Sunning

A photograph of a bird perched on a branch, sunning itself.

Temperature Regulation.

- Black Plumage concentrates heat at the surface
 - Wind rapidly removes heat

A photograph of a black bird perched on a rock.



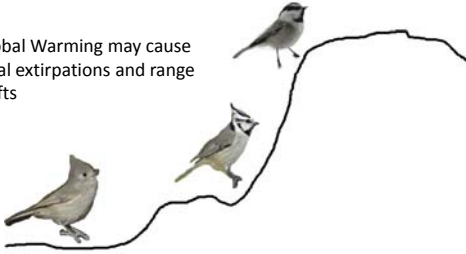
Cold Stress.

- Shivering (below LCT)
 - Pectoralis, legs
- Mammals have non-shivering thermogenesis
 - Brown adipose
- Birds are adapted to ambient temperatures
 - Snow Buntings shiver at 10° C, cardinals at 18° C
- Large birds are able to withstand lower T before shivering

Cold Stress.

- Temperature Adaptation determines range

Global Warming may cause local extirpations and range shifts




Cold Stress.

- Birds acclimatize to seasonal temperatures
 - Winter-acclimatized goldfinches can maintain body T at -70° C for 6 to 8 hours
 - Summer-acclimatized cannot do it for more than an hour
 - Modifications made to metabolic pathways

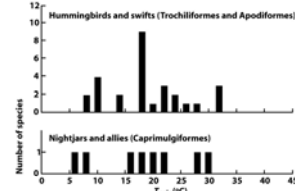
Cold Stress.

- Microclimate
 - Burrows (soil or snow), sheltered nest sites, evergreen trees
 - Huddling together



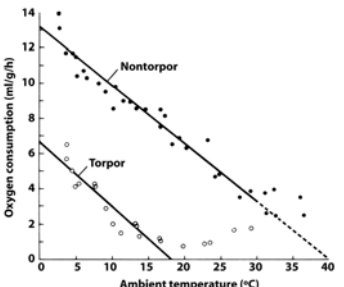
Cold Stress.

- Facultative Hypothermia and Torpor
 - Lower body T by 6° C or more at night
- Torpor
 - Extreme hypothermia. down to 4.3° C
 - Unresponsive



Cold Stress

- Torpor

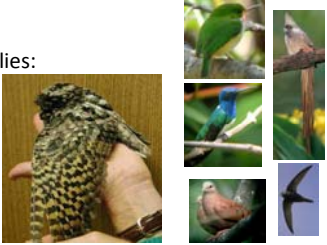


Cold Stress

- Torpor
 - Saves energy
 - Conserve energy when limited
 - Store energy for migration
 - Hummingbirds can save 27% of daily energy use
- Cost: warming up is very hard
 - Torpor is only feasible for small birds
 - American Kestrel would take 12 hours to warm up

Cold Stress.

- Torpor
 - Found in 6 families:
 - Todies
 - Mousebirds
 - Hummingbirds
 - Swifts
 - Pigeons
 - Nightjars
 - One species actually “hibernates”, entering torpor for months




Heat Stress.

- Avoidance
 - Shade, bathing, soaring
- Controlled Hyperthermia
 - Allowing body T to rise closer to lethal levels
 - Saves H₂O
 - Large birds can store heat

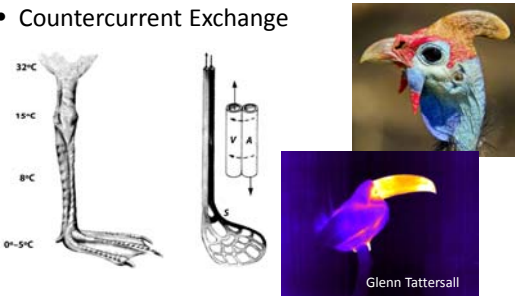
Heat Stress.

- Evaporative Cooling
 - Panting
 - Uses a lot of water
 - Gular Fluttering
- Birds do not have sweat glands
 - Cutaneous water loss



Heat Stress.


- Countercurrent Exchange
 - Diagram showing temperature gradients (32°C, 15°C, 8°C, 0-5°C) and blood flow directions (V, A, S) in a leg.



Glenn Tattersall

Heat Stress.

- Body size adaptations
 - Smaller can dissipate heat more easily



Heat Stress.

- Flight increases heat production, but also increases dissipation rate
 - At high enough T, some birds will not fly