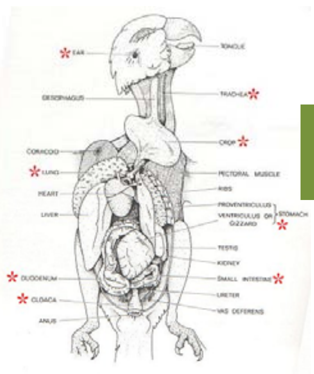


Physiology

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

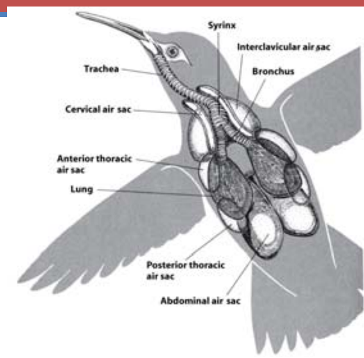
Endurance.

- 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 O_2; waste removal

The Respiratory System.

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

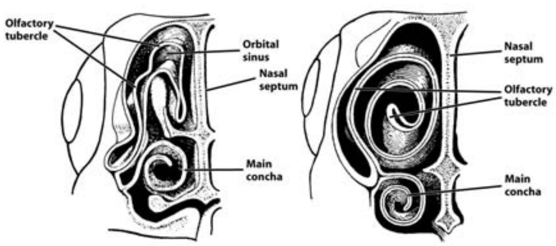
The Respiratory System



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

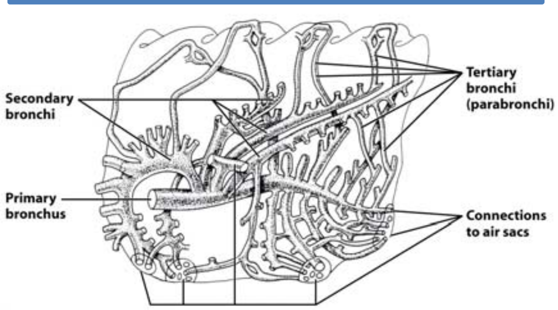


- Control heat exchange; smell; remove H_2O

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

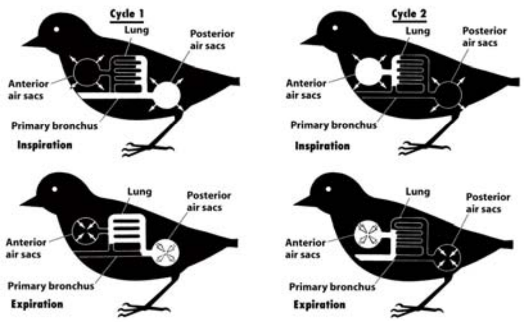
The Respiratory System



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



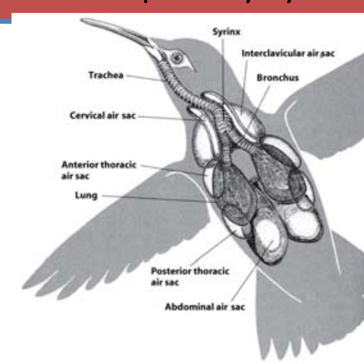
The Respiratory System.

- 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



The Respiratory System.

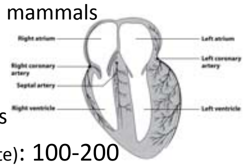
- Wing and furcula movements complement sternum
- Flight actually assists respiration

The Respiratory System.

- Breathing rate decreases with increased body size
- Hummingbird: 143/minute
- Turkey: 7/minute
- Flight: increase respiration rate 2 to 25x
- Hyperventilation:
  - CO_2 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%

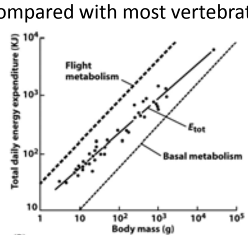


The Circulatory System.

- 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



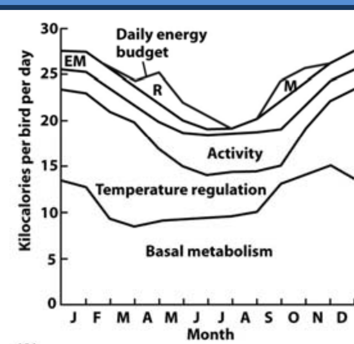
Metabolism.

- 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.

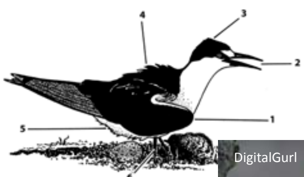
- Metabolism produces heat
- Feathers insulate
  - Feather damage or loss increases metabolism
  - Metabolism and heat loss 2x in "frizzle" chickens
- Down feathers most important

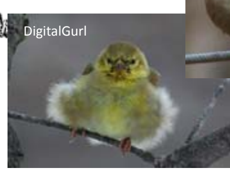
Temperature Regulation.

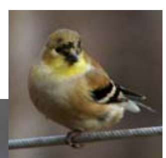
- House Sparrows molt from 0.9 g in August to 1.5 g in September
  - Migration and tropical living reduce this change

Temperature Regulation

- Feather position affects insulation







Temperature Regulation.

- Behavioral Adjustments
  - Seeking shade/shelter
  - Sunning

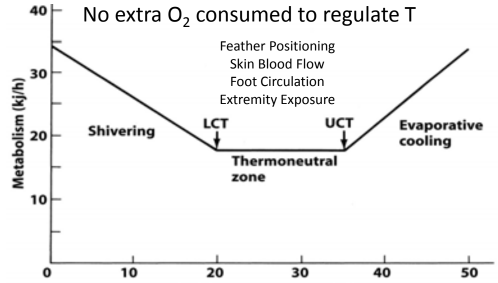
Temperature Regulation.

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

Endothermy.

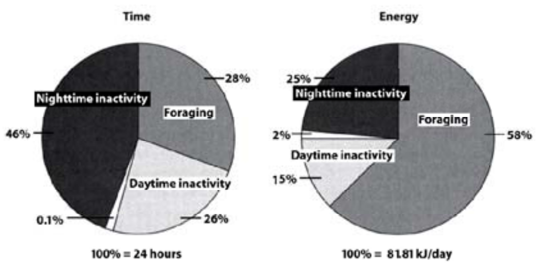
- Thermoneutral Zone

No extra O_2 consumed to regulate T



Endothermy.

- Time and Energy Budgets



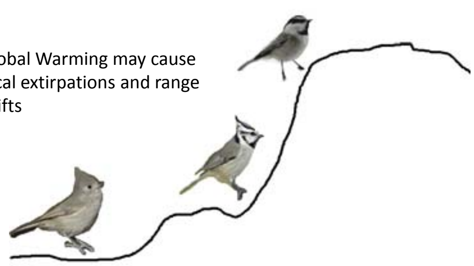
Cold Stress.

- 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.

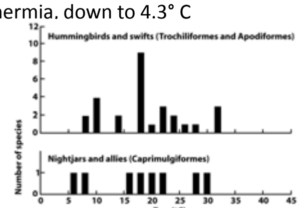
- Birds acclimatize to seasonal temperatures
  - Winter-acclimatized goldfinches can maintain body T at -70° C for 6 to 8 hours
  - Summer-acclimatized cannot do it for more than an hour
  - Modifications made to metabolic pathways

Cold Stress.

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

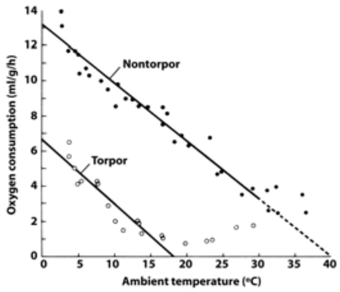
Cold Stress.

- 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

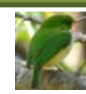
- Torpor
  - Saves energy
    - Conserve energy when limited
    - Store energy for migration
      - Hummingbirds can save 27% of daily energy use
- Cost: warming up is very hard
  - Torpor is only feasible for small birds
  - American Kestrel would take 12 hours to warm up

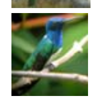
Cold Stress.

- Torpo
  - Sav
    - C
    - S
- Cost:
  - Tor
  - Am warm up

Cold Stress.

- Torpor
  - Found in 6 f
    - Todies
    - Mousebird
    - Hummingb
    - 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 H_2O
  - Large birds can store heat

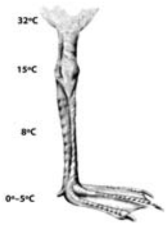
Heat Stress.

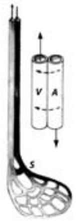
- Evaporative Cooling
  - Panting
    - Uses a lot of water
  - Gular Fluttering

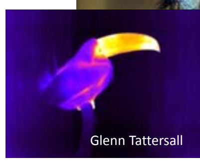
- Birds do not have sweat glands
  - Cutaneous water loss

Heat Stress.

- Countercurrent Exchange







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