# Vertebrate Locomotion: Aquatic

# Swimming

- Nearly all vertebrates can swim
- Sole form of locomotion for fish and larval amphibians
  - **Primary swimmers**
- Terrestrial vertebrates that readapt to aquatic life – still breathe air
  - **Secondary swimmers**

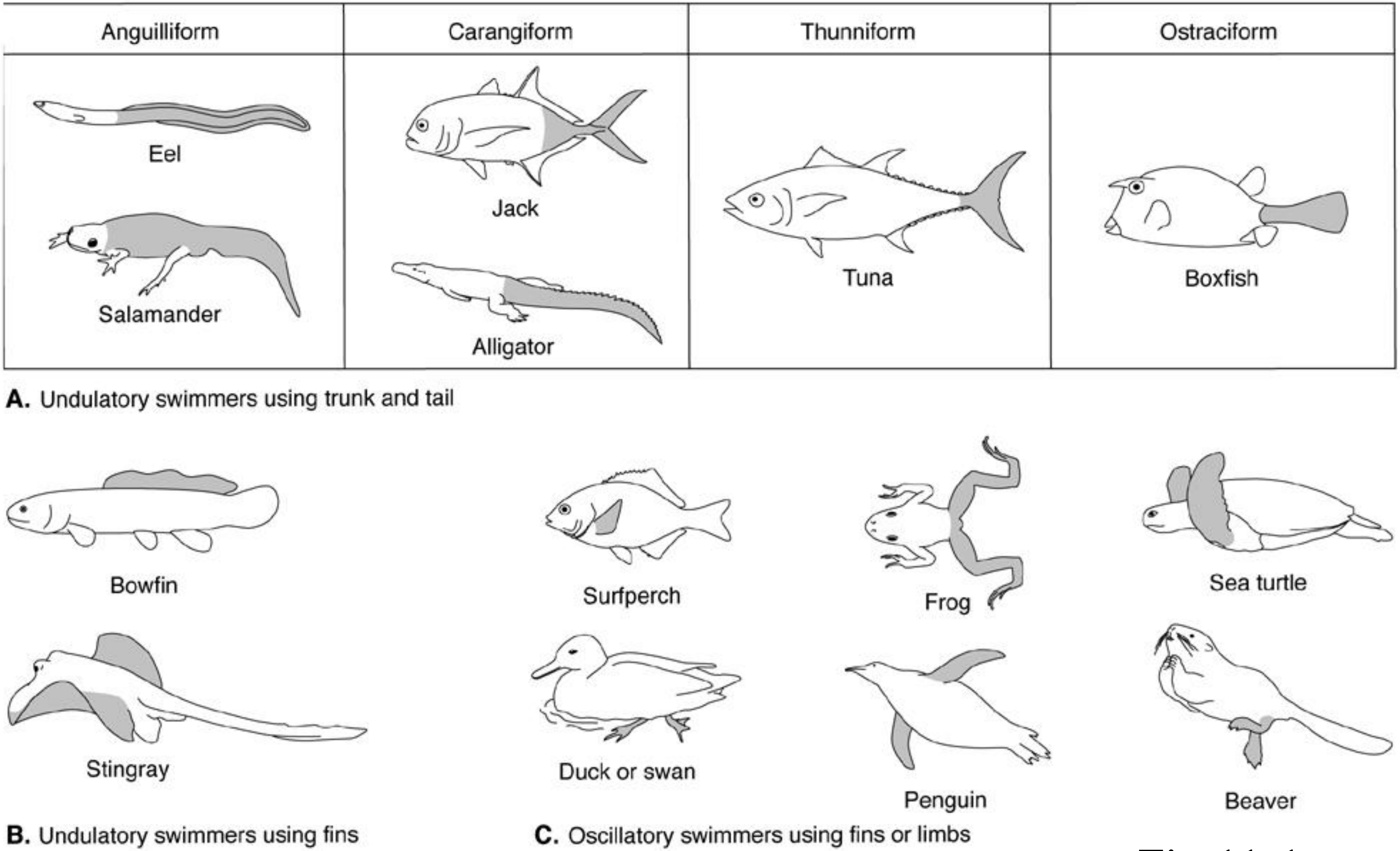
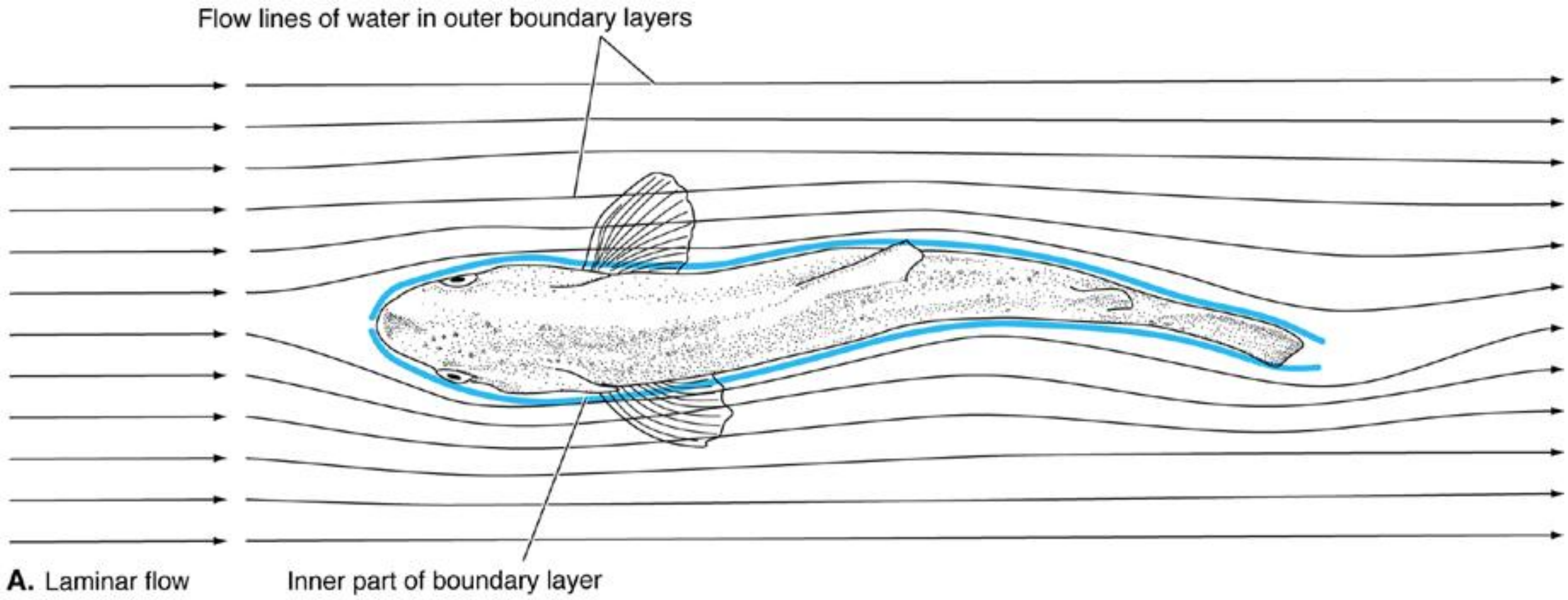



Fig 11-1

**Undulatory swimming** vs. **oscillatory swimming**

# Aquatic Environment

- **Buoyancy** – major supporting force
  - Weight of fish > buoyancy – generate lift to overcome
- **Resistance** -drag
  - Frictional drag
  - Pressure drag




Frictional drag is lowest when the surface area of the fish is minimized relative to mass, the fish is swimming slowly, and the water flows smoothly across its surface (laminar flow)

Fig 11-2

When a fish swims more rapidly, the boundary layer increases in thickness and the increased undulations disrupt the smooth flow of water. The boundary layer separates producing eddies – increases friction drag and causes pressure drag.

High pressure at head, low pressure at tail tends to hold the fish back – long slender bodies reduce pressure drag

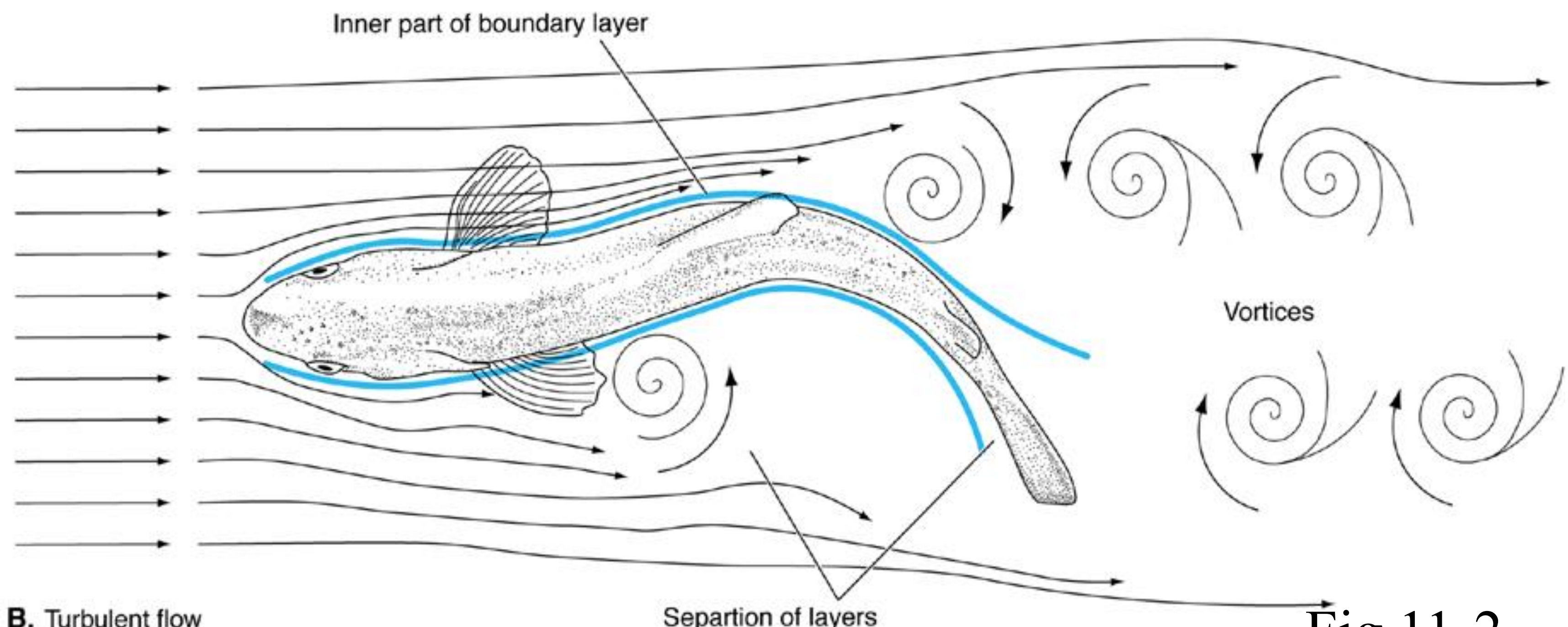



Fig 11-2

# Types of swimming

- **Transient** – lie quietly in water but can accelerate rapidly; e.g. reef fish, bass
- **Periodic** – sudden bursts of speed but mostly slow cruising; e.g. tuna, shark
  - **Anguilliform** – most of trunk and tail move back and forth; e.g. eel
  - **Carangiform** - caudal half of tail; e.g. jacks
  - **Thunniform** – mostly tail; e.g. tuna
  - **Ostraciform** – only tail; e.g. boxfish

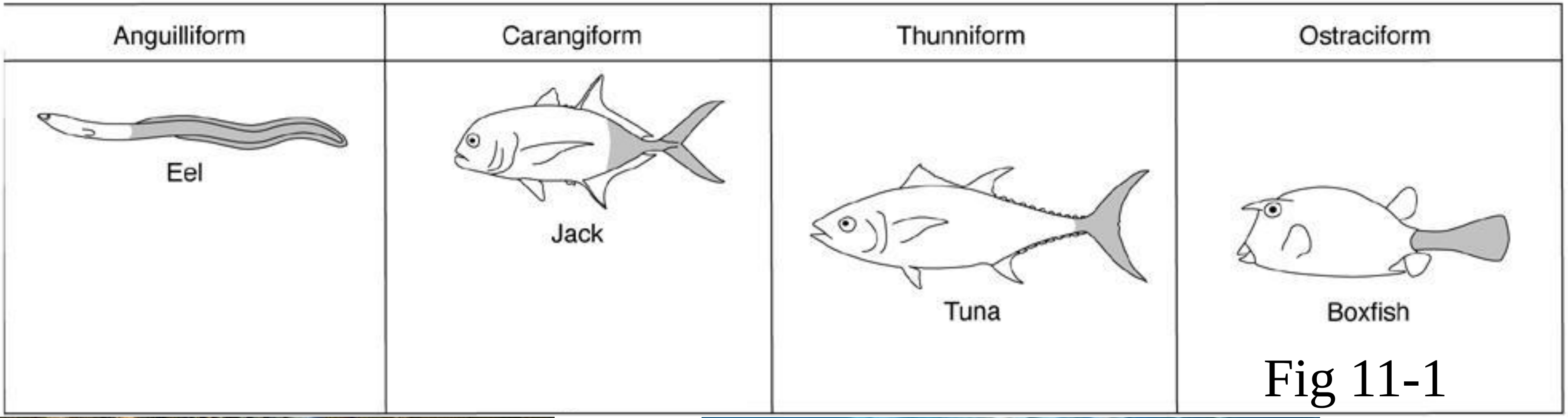
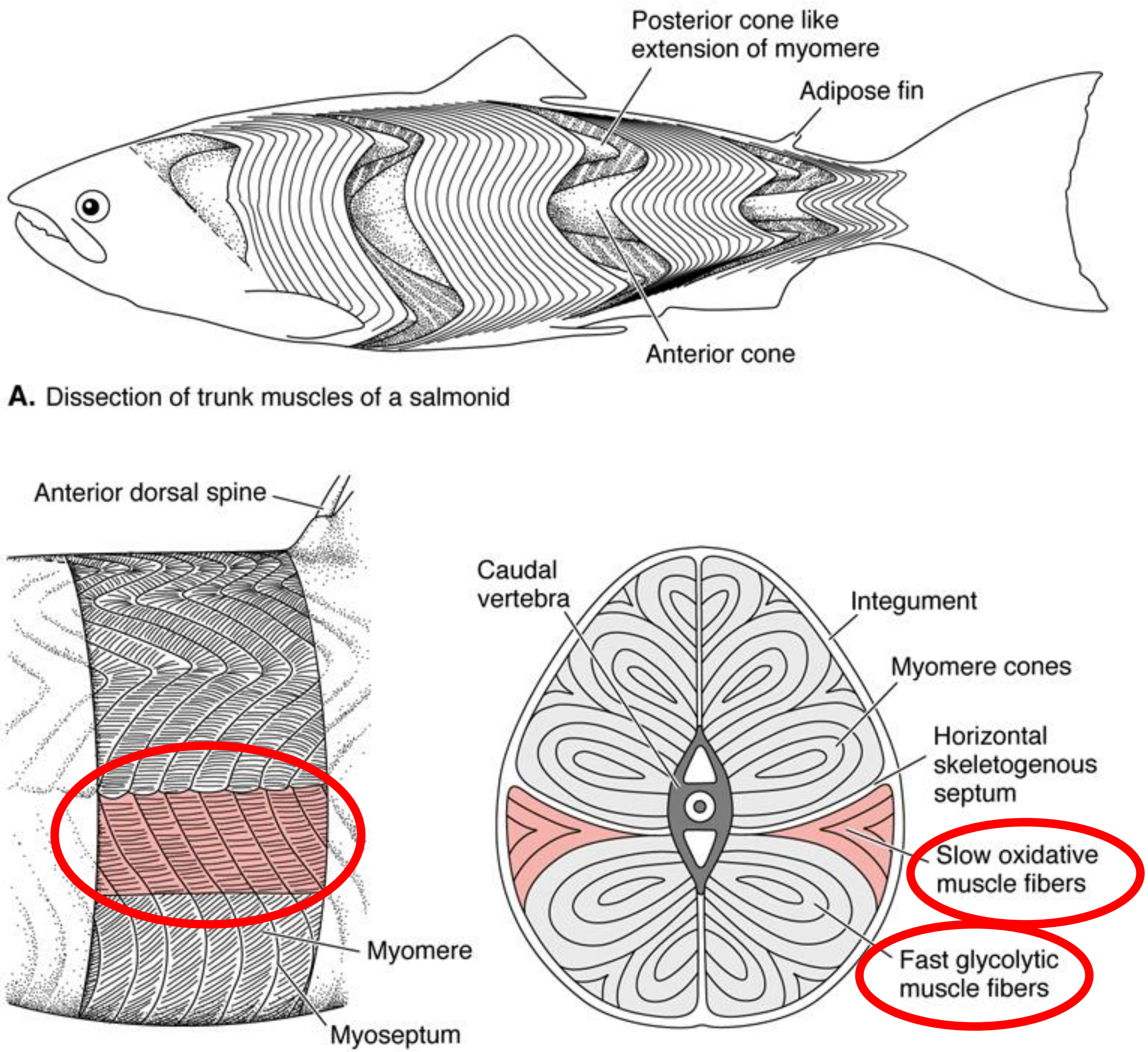

Anguilliform
Carangiform
Thunniform
Ostraciform
Eel
Jack
Tuna
Boxfish

Fig 11-1

# Myomeres

- Vertebral column prevents body from shortening
- Contraction of myomeres on one side pulls myosepta together – curvature
- Myomeres zigzag and overlap
  - One myomere can influence greater body length
  - Ensures smooth force generation and flow of undulations




**A.** Dissection of trunk muscles of a salmonid

**B.** Distribution of muscle fiber types

**C.** Distribution of muscle fiber types in cross section

Fig11-4

# Buoyancy - Sharks

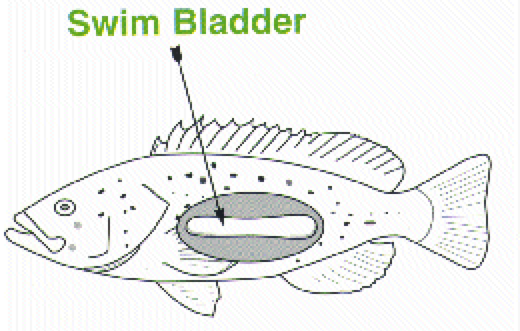
Shark density is reduced by

1. Cartilaginous skeleton
2. Lipid stores
3. Urea in body fluid

Sharks overcome remaining sinking by

– Heterocercal tail

# Swim Bladder




- Sarcopterygians/early actinopterygians
  - Lunglike air sac
  - Evolved into a swim bladder
- **Swim bladder** makes fish less dense
- Telosts can regulate gas in swim bladder and float in any level of water with little effort
  - Increased control of buoyancy
  - Bone replaces cartilage, tail becomes symmetrical, lipids don’t accumulate, fins don’t generate lift

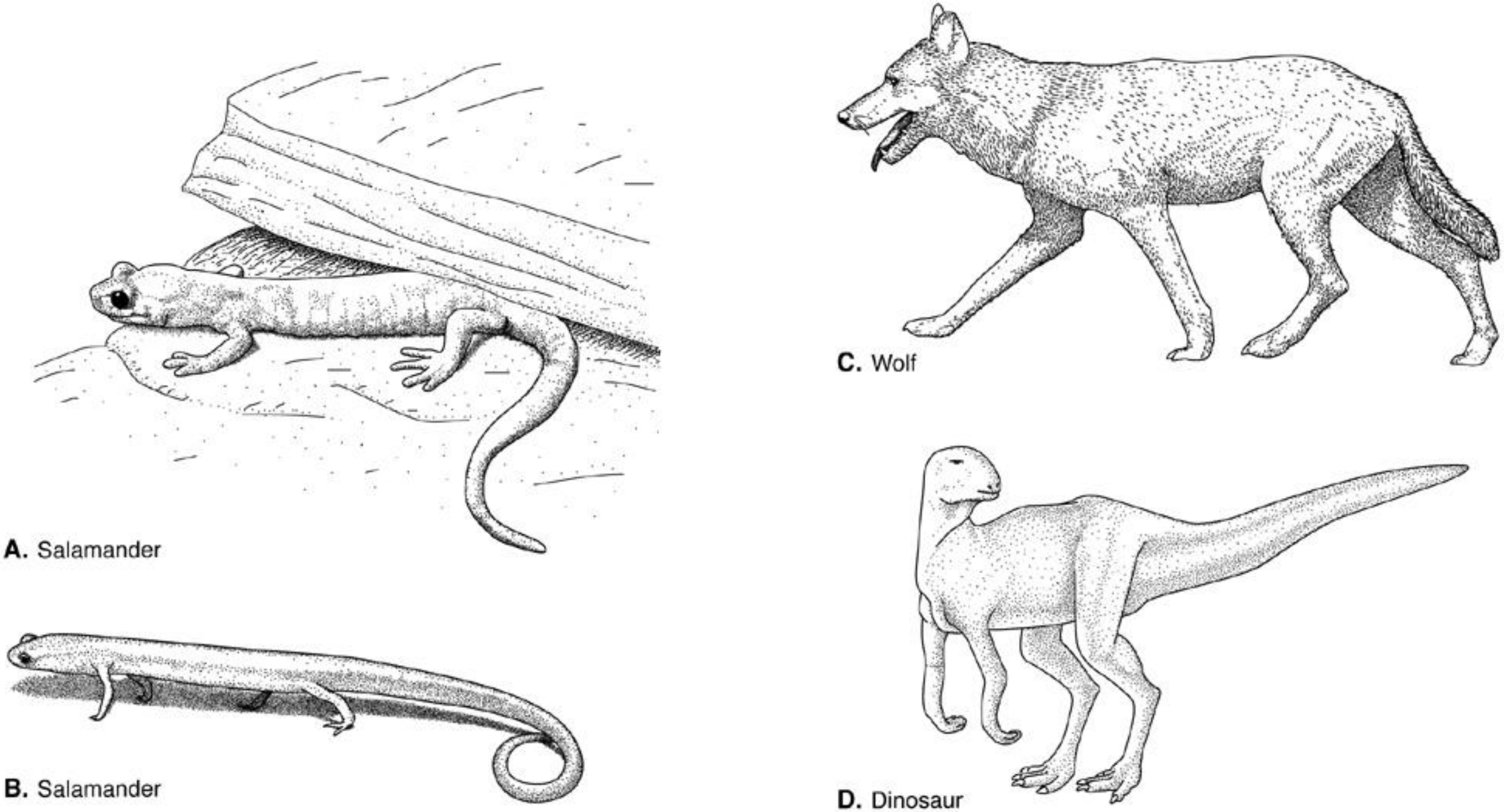
# Stability

- Displacement forces
  - **Yaw** – tail action causes head to move side-to-side
    - Head is heavy so inertia
    - Surface area of median fins reduces lateral body movement
  - **Roll** – rotate on longitudinal axis
    - Median and paired fins
  - **Pitch** – head to move up and down
    - Also countered by median and paired fins

# Vertebrate Locomotion: Terrestrial

# Vertebral Support

- Supporting body weight on land was a major problem
  - Air less dense, little lift
  - Rest lying on ground – but still need to prevent collapse
- Vertebral column – strong, support beam
  - Supports against body
  - Transfers weight to girdles and appendages




Limb positions of tetrapods

Fig 11-7

# Vertebral Support

- Intervertebral discs –
  - Remnant of notochord – nucleus pulposus surrounded by thick layers of connective tissue
  - Allow bending, act as shock absorbers, distribute forces evenly over adjacent centra
- Zygapophyses
  - Neural arches fused to centra
  - Restrict bending in some directions
- Strong ligaments link vertebrae
- Neural spines – levers to transmit force
  - Longer so increases mechanical advantage

# Limb support

- Weight transfer to pelvic girdle by sacral vertebrae or ribs
  - # and degree of fusion correlates with forces – e.g. mammals have more than amphibians/reptiles
- Weight transfer to pectoral girdle by muscular sling between trunk and girdle/appendage
  - Mammals – serratus ventralis is major muscle
- Legs must be drawn under body by muscle action
  - Muscles crossing joints stabilize

# Reducing stabilization energy

- Vertical alignment of limb segments
  – Direct transfer of weight to ground
- Stay mechanisms – ungulates/horses
  – Stand while sleeping

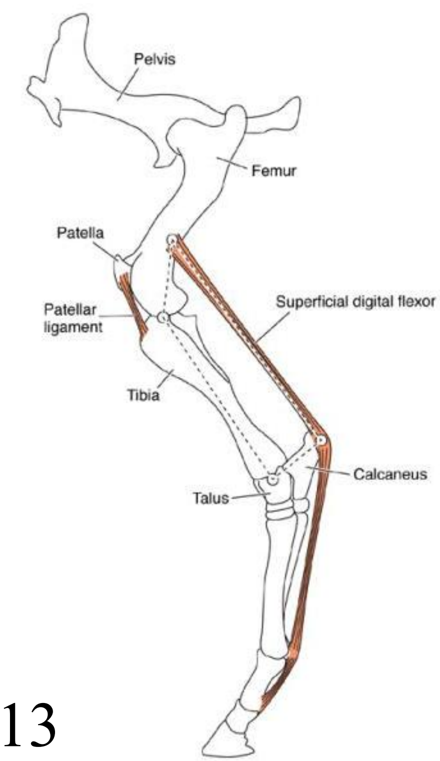



Fig 11-13

# Waling and Running

- Walking probably began in water
  - Ancestral locomotion pattern
- Paired fins evolved into jointed limbs
  - Appendicular musculature developed
- Limbs and girdles strengthened to support entire weight and maintain stability

# Walking terminology

- **Step cycle**
  - Propulsive phase – one foot placed on ground – develops thrust and accelerates body and moves it forward
  - Swing phase – foot is removed from ground and advanced in prep for next foot placement
  - Length of step = distance trunk moves during propulsive phase
  - Stride length = movement from once cycling of all legs e.g. quadruped four step cycles

# Reptiles/Amphibians

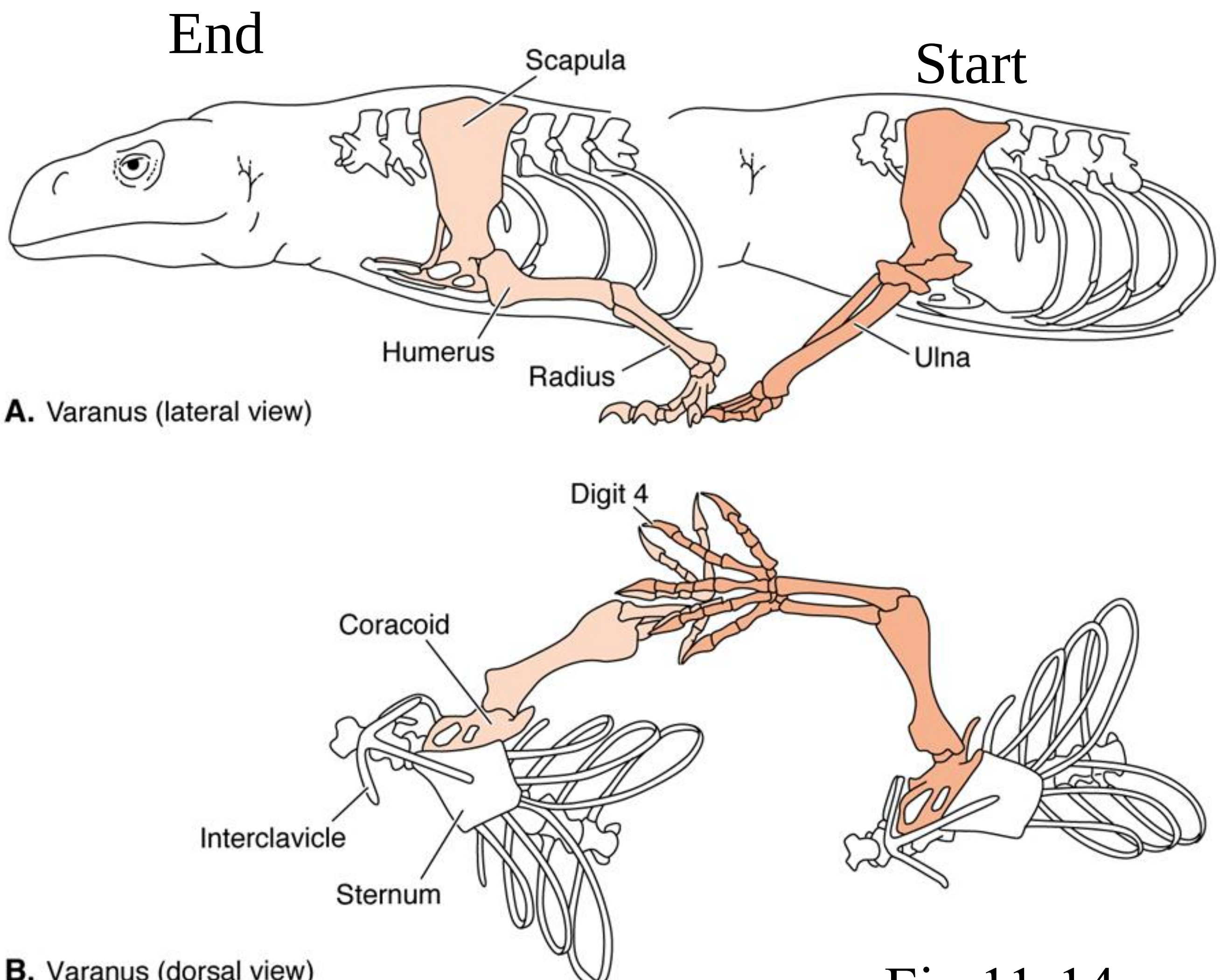


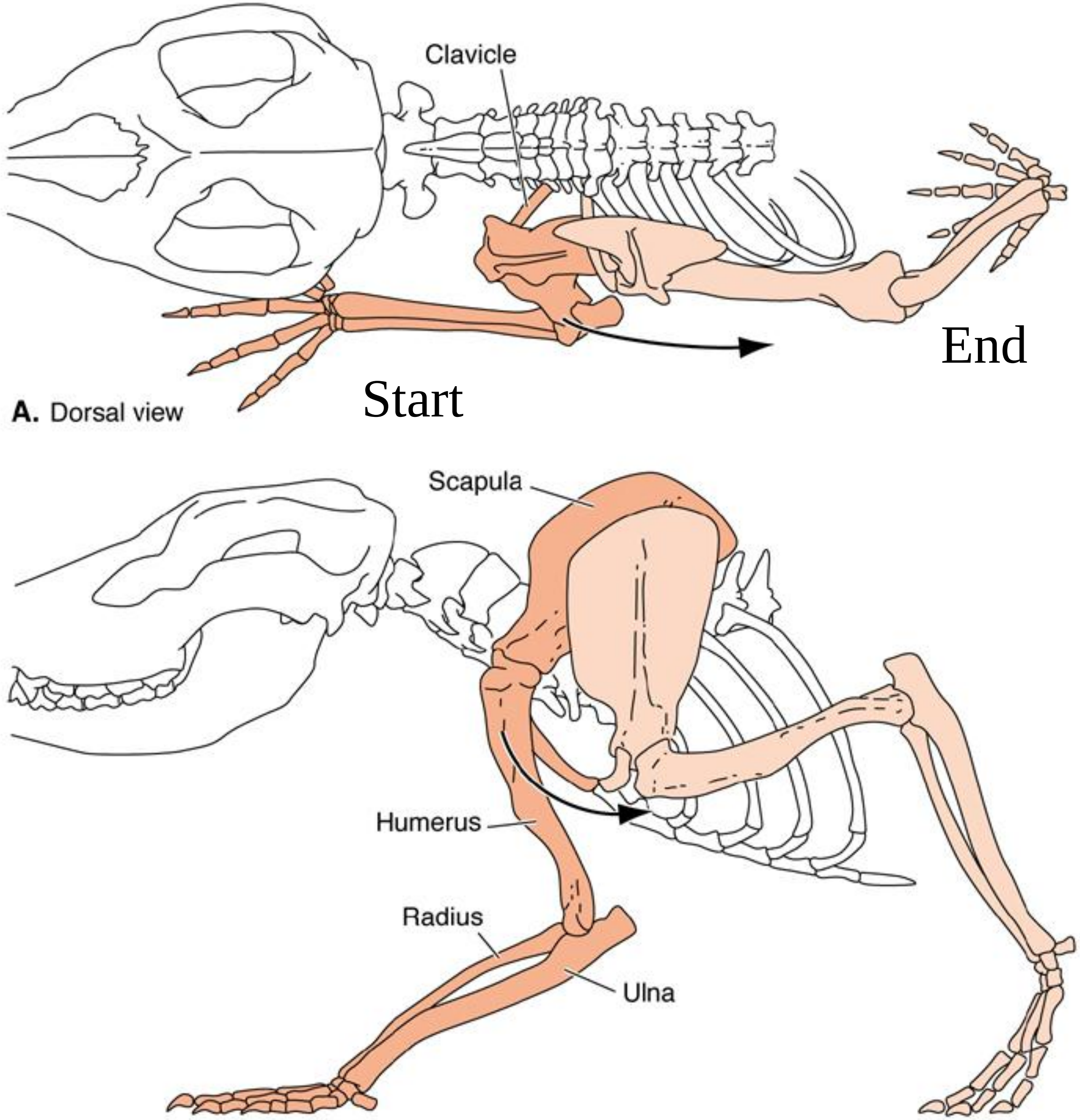

Fig 11-14

# Mammals

- Limbs have rotated under body
  - Humerus/femur move fore and aft
  - Stance (distance between feet) narrower
  - Limbs closer to center of gravity
  - Better support with less muscular effort
  - Swing through longer arcs – longer step/stride lengths
    - No extra energy expenditure
  - Degree to which limbs are beneath the body varies among mammals

Cursorial – limbs well under body

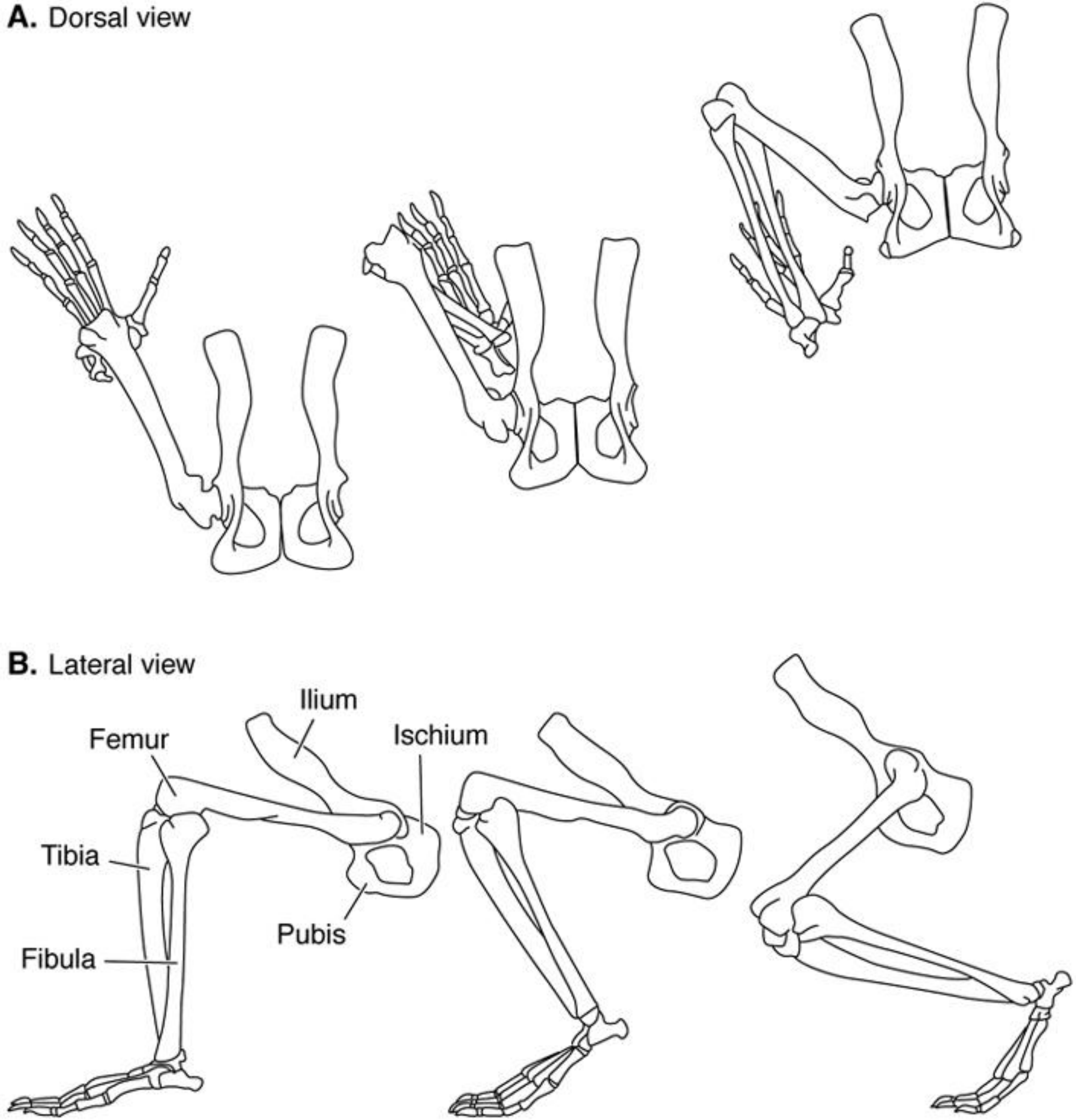
Fig 11-17




A. Dorsal view

B. Lateral view

Fig 11-18


A. Dorsal view
B. Lateral view
Ilium
Femur
Ischium
Tibia
Pubis
Fibula

# Gait

- Combination of feet that are on or off the ground during stride
  - Changes cause different stride length
  - Faster than a walk involve more instability
- Slow moving mammals – diagonal couplet walk
  - Shift gait when begin to run
- **Symmetrical gait** – left and right hind feet or left and right front feet move 0.50 out of phase and evenly spaced
- **Asymmetrical gait** – two hind or two front feet are nearly in phase

- **Plantigrade** – soles of feet flat on ground e.g. primates
- **Digitigrade** – walk on digits with wrist and ankle off ground e.g. carnivores
- **Unguligrade** – walk on tip of digits that reach ground e.g. ungulates

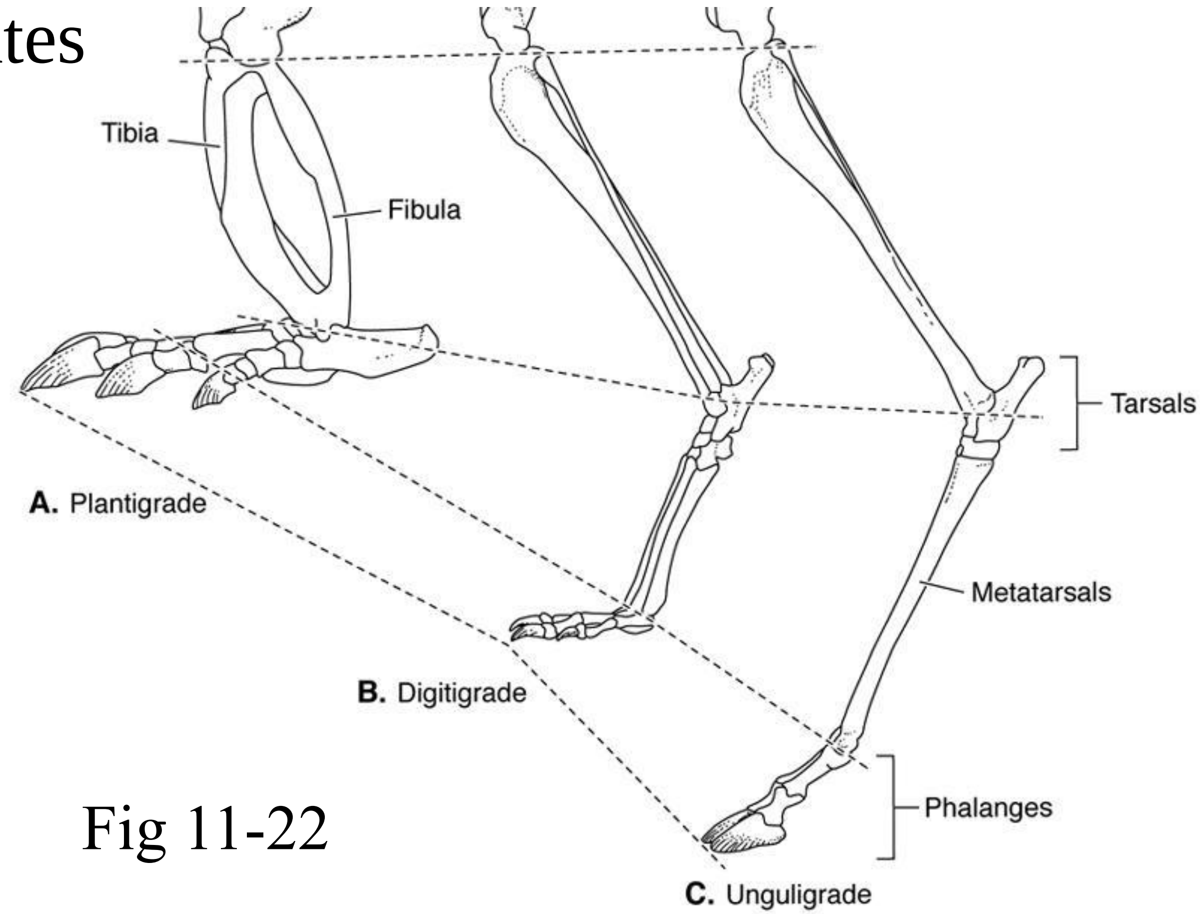
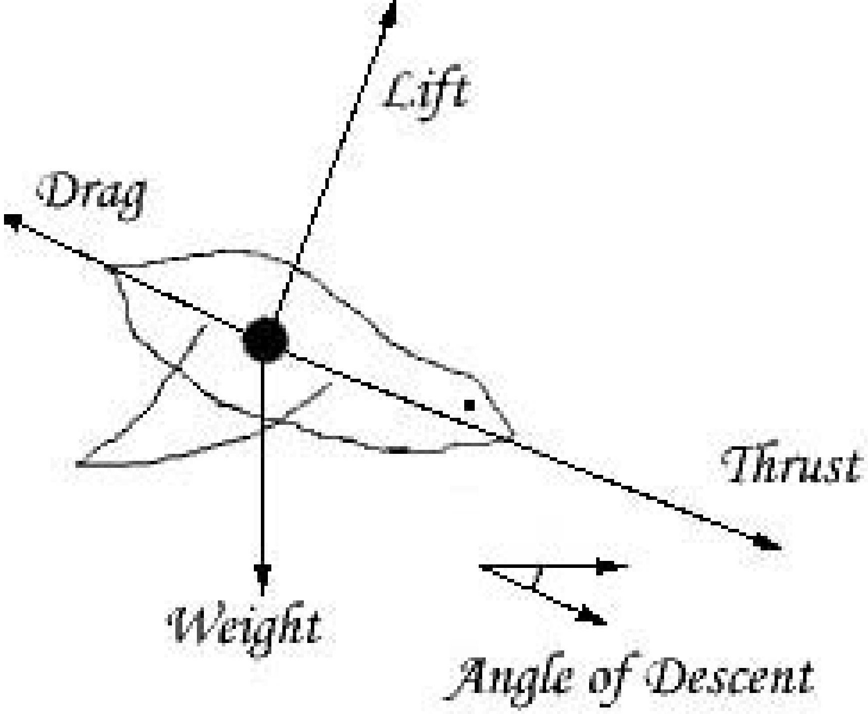



Fig 11-22

# Jumping

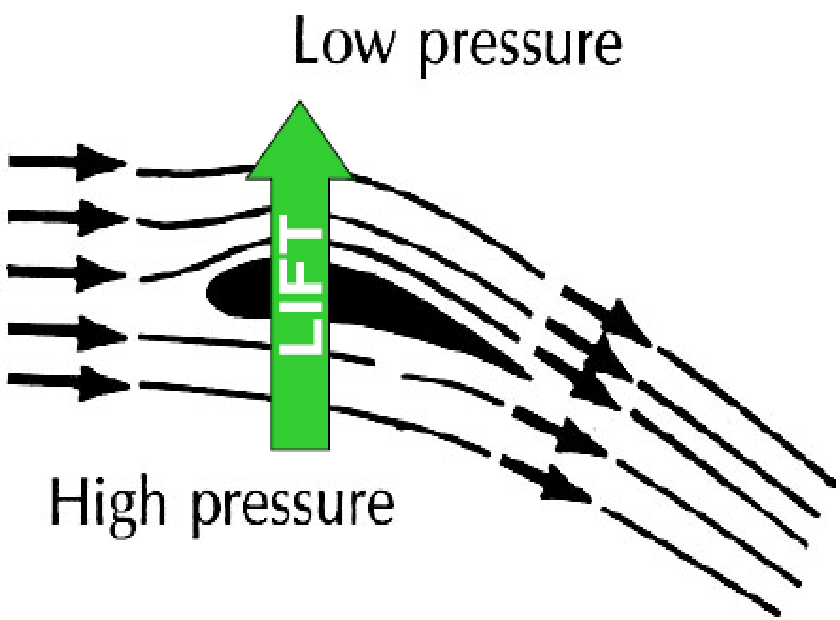
- Most vertebrates can jump
- Specialized for jumping = **saltatorial**
  - e.g. Frogs, toads, kangaroos, tarsier, and some rodents
- Convergent evolution
  - Hind legs elongated, powerful and strong
  - Center of mass shifted backward; strengthened vertebrate – reduce twisting
  - Mammals – long tail stores energy (not in amphibians)

Vertebrate Locomotion: Aerial



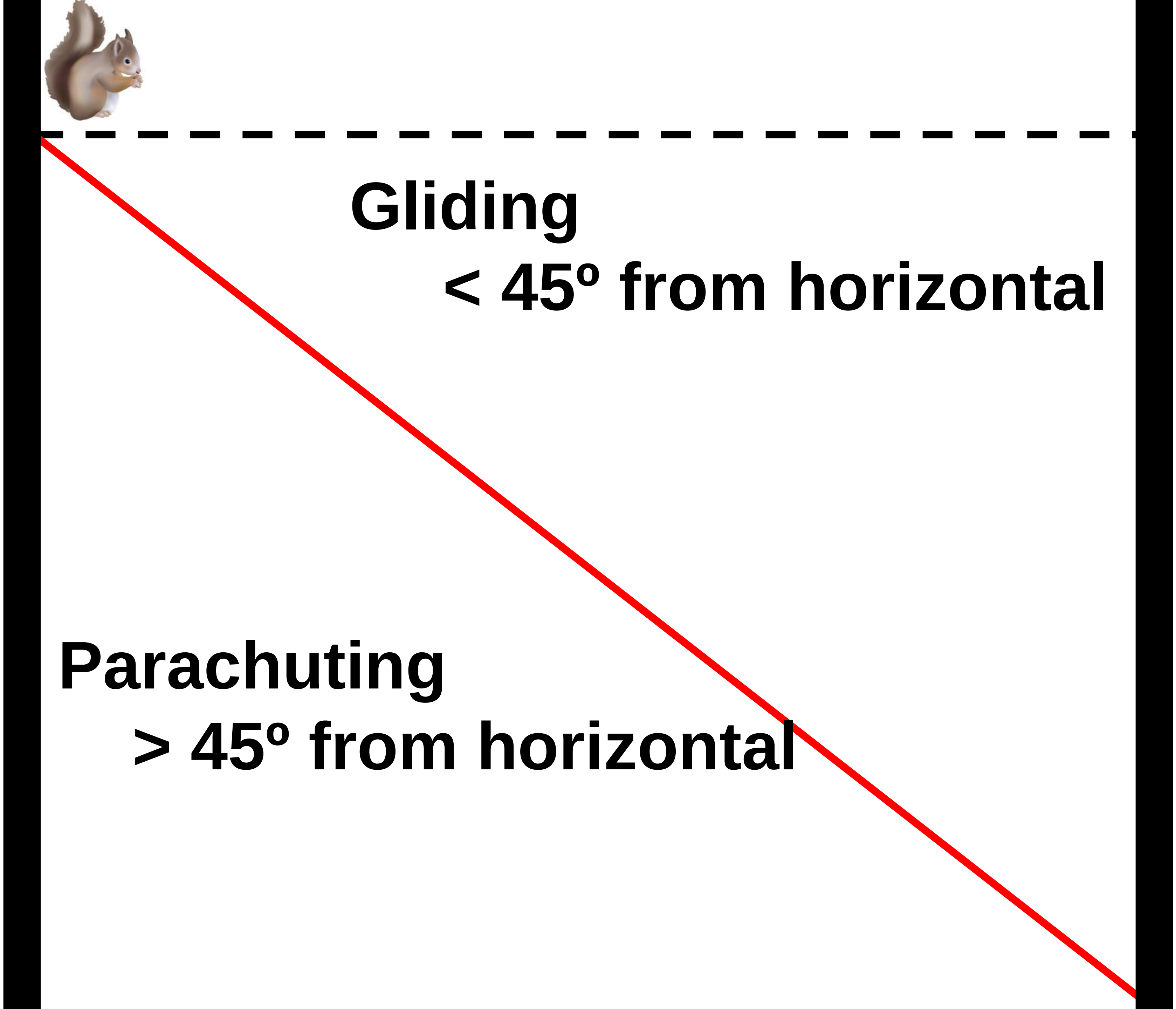

**Upward force of lift counters the downward force of weight**

**Forward force of thrust counters the friction forces or drag**




# Types of Ariel Locomotion

- Parachuting
  - Common in vertebrates
- Gliding – adaptations for lift
- Flying
  - Active flapping to generate horizontal movement
- Soaring
  - Gliding in moving air


Gliding
< 45º from horizontal
Parachuting
> 45º from horizontal

# Gliding - Fish

- Flying fish
  - “Two-winged” and “four-winged”
  - Extend enlarged pectoral fins
  - 50 m



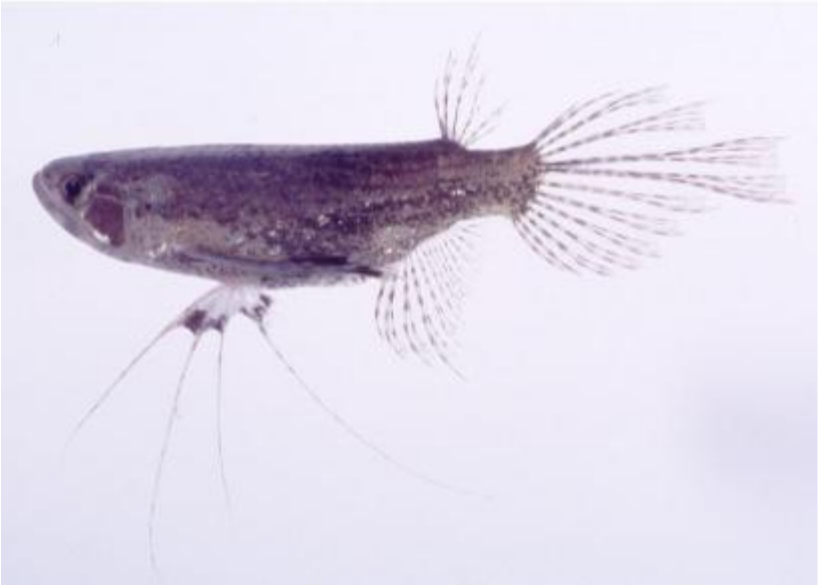
# Gliding - Fish

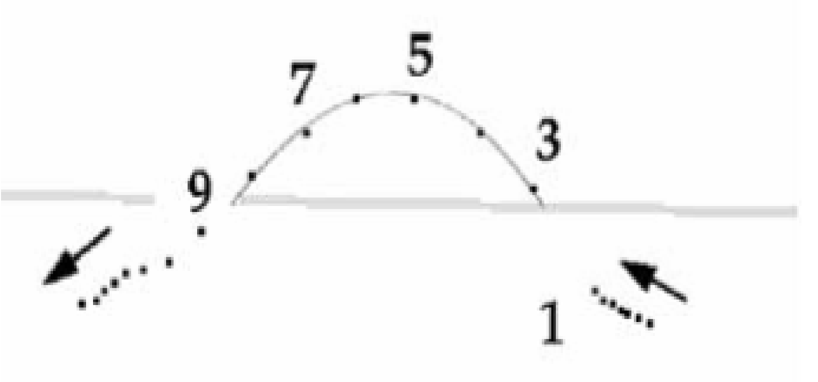
- Flying half-beaks
  - Enlarged pectoral fins

- Freshwater hatchet fish (possibly flying)
  - Large sternal region with large muscles; flaps pectoral fins

# Gliding? - Fish

- African butterfly fish
  - Large pectoral fins
    - May flap while in air
  - Video analysis
    - Parabolic path
    - Fins do not generate lift
    - Jumps for the water, does not glide

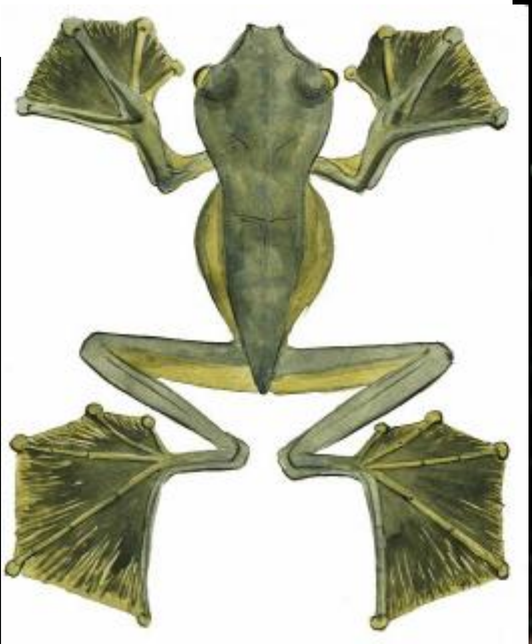





Saidel et al (2004) Env Biol Fishes 71:63-72

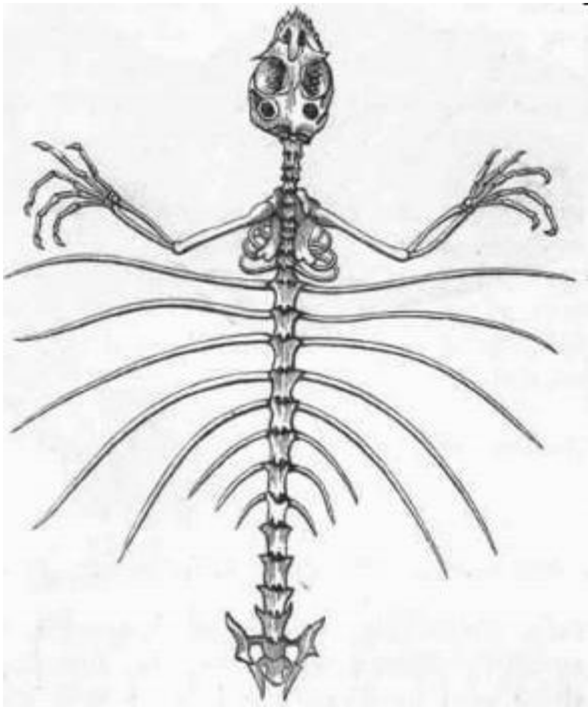
# Gliding - Amphibians

- Flying frogs
  - Enlarged toe membranes – spread when gliding



# Gliding - Reptiles

- *Draco* lizards
  - Extended ribs
  - Patagium



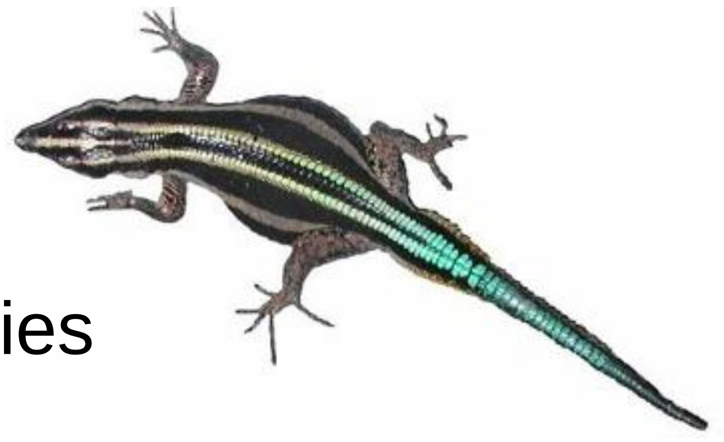
# Gliding - Reptiles

- Gliding geckos
  - Flaps of skin on limbs, torso, tail and head
- Flying snakes
  - Stretches body sideways and opens ribs



# Gliding? – Reptiles

- Neon blue-tailed tree lizard
  - Appeared to glide
  - No obvious adaptations
  - Video analysis – performed better than non-gliding species
  - Very light weight
    - X-ray analysis revealed skeletal air spaces
    - Skull and girdles smaller



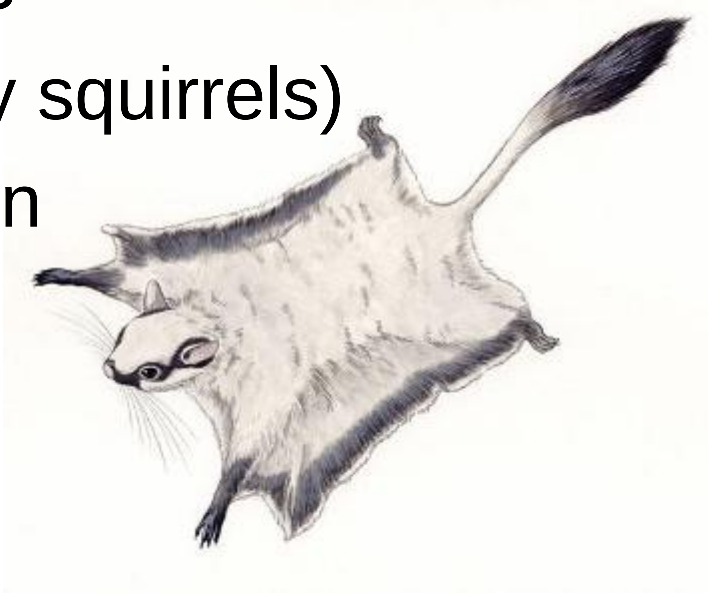
Vanhooydonck et al. (2009) J Exp Biol 212:2475-2482

# Gliding - Mammals

- Wrist-winged gliders
  - Stretches loose folds of skin after jumping
- Greater glider
  - Flying membrane extends to elbow
- Feather-tailed possums
  - Stiff-haired feather like hair

# Gliding - mammals

- Flying squirrels
  - Found nearly worldwide
  - Flap of furry skin from wrist to ankle
- Scaly-tailed flying squirrels
  - African rodents (not actually squirrels)
  - Gliding membranes between front and hind legs



# Gliding - mammals

- Colugos or flying lemurs
  - Not primates but sister taxa
  - Patagium is as large as geometrically possible
  - Spaces between fingers and toes webbed

# Evolution of Flight

- Pterosaurs
  - First vertebrate group to evolve flight
  - Late Triassic – about 225 million years ago
- Birds
  - Late Jurassic – about 150 million years ago
- Bats
  - 60 million years ago

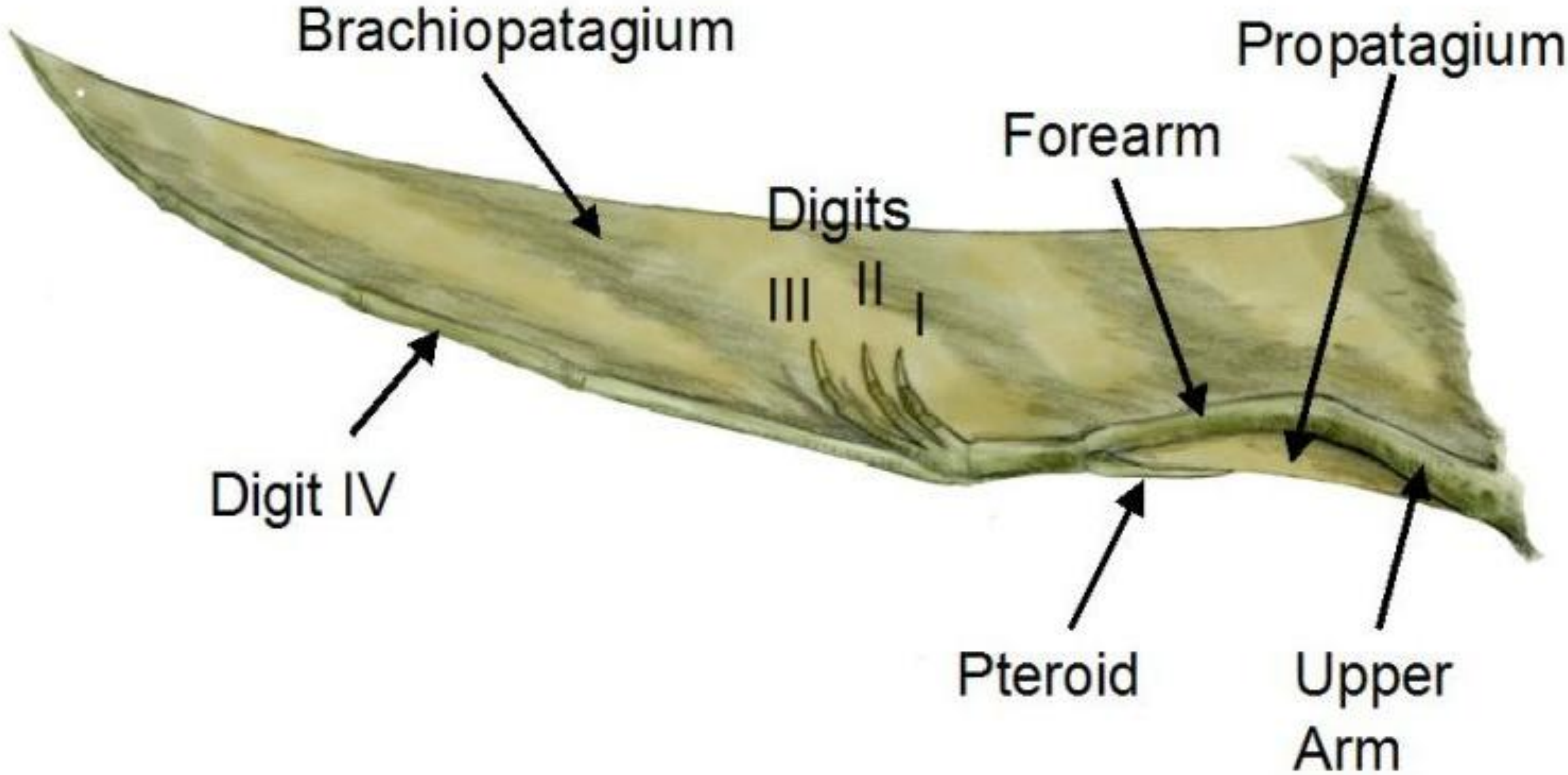
# Advantages of Flight

- Exploit inaccessible food resources
- Escape from non-flying predators
- Cover large expanses rapidly and cheaply
- Dispersal

# Pterosaur Flight

- Successful for 135 million years
  - Likely due to well developed flight
- Largest had 15 m wingspan
- Debate
  - Mode of flight
  - How they take-off

# Pterosaur Wing



# Pterosaur Adaptations

- Uropatagium – between the hind limbs
  - Second lifting surface
  - Support legs during flight
  - Two types:
    - Broad: links across hind limbs
    - Split: triangular membrane along each limb

# Pterosaur Adaptations

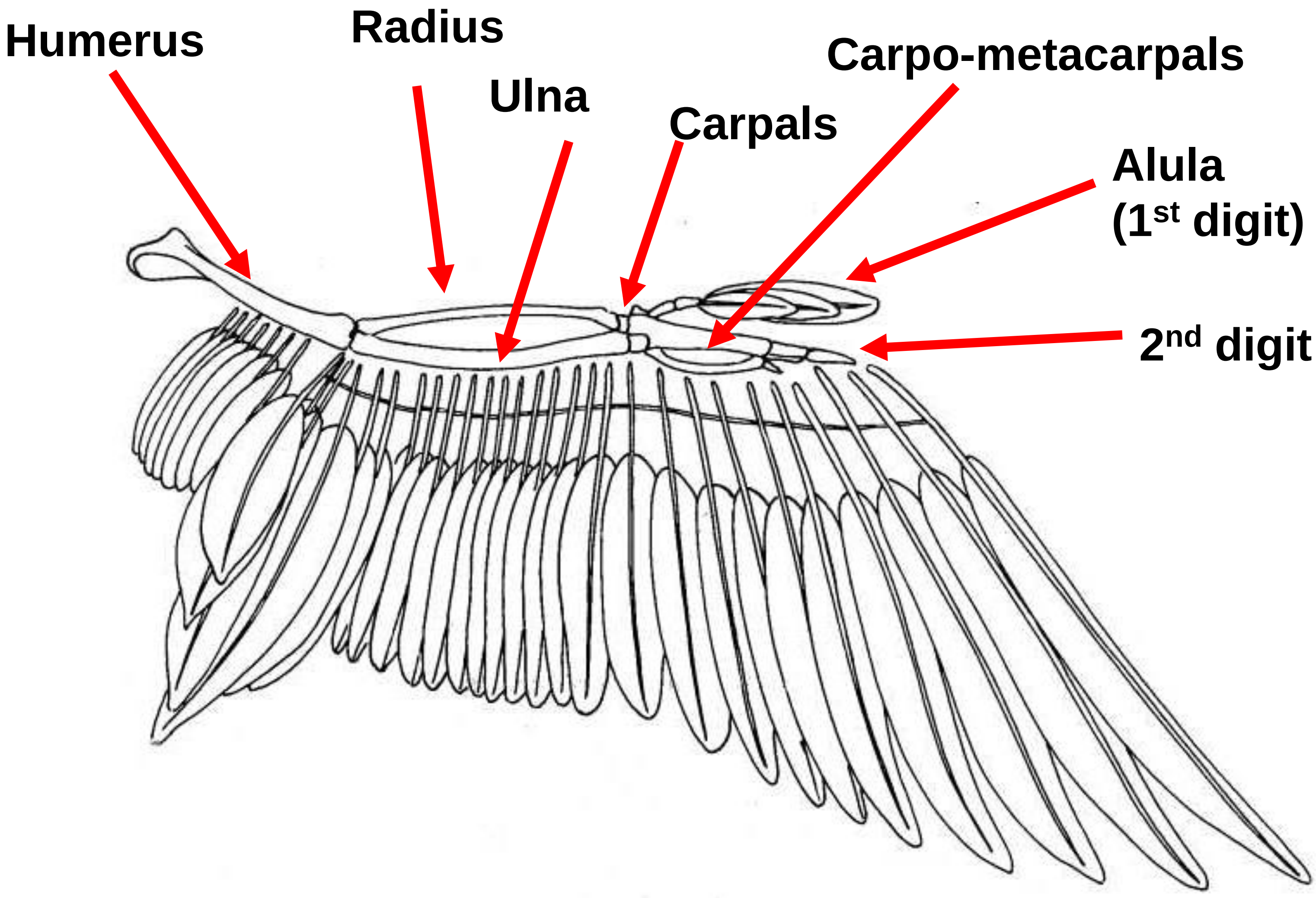
- Light-weight bones
- Stiffened torso
- An efficient respiratory system similar to birds
  - Lung-air sac system and flow-through ventilation
  - Provides the respiratory and metabolic potential for flapping flight

# Avian flight





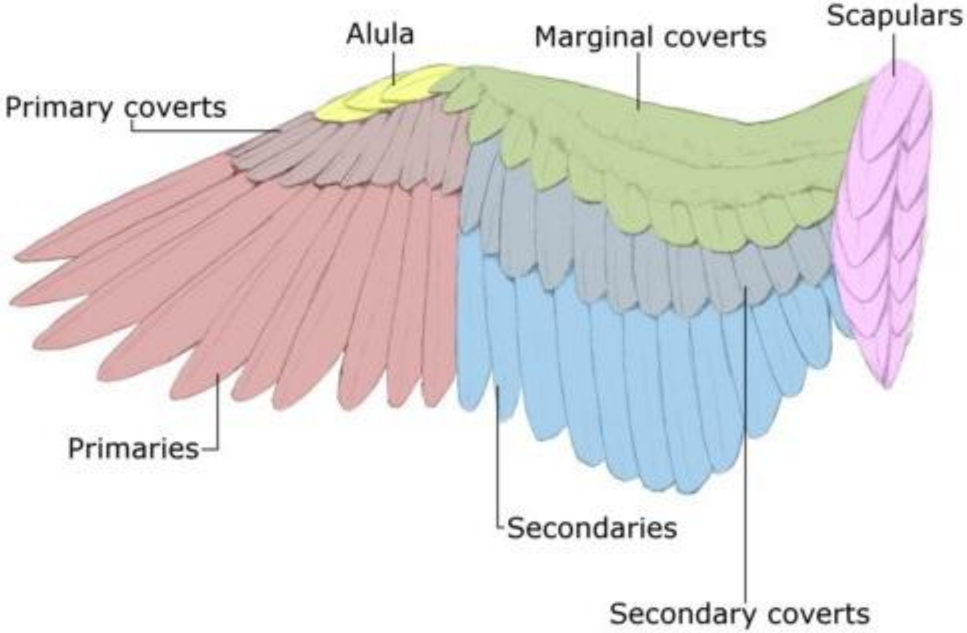

# Avian Wing



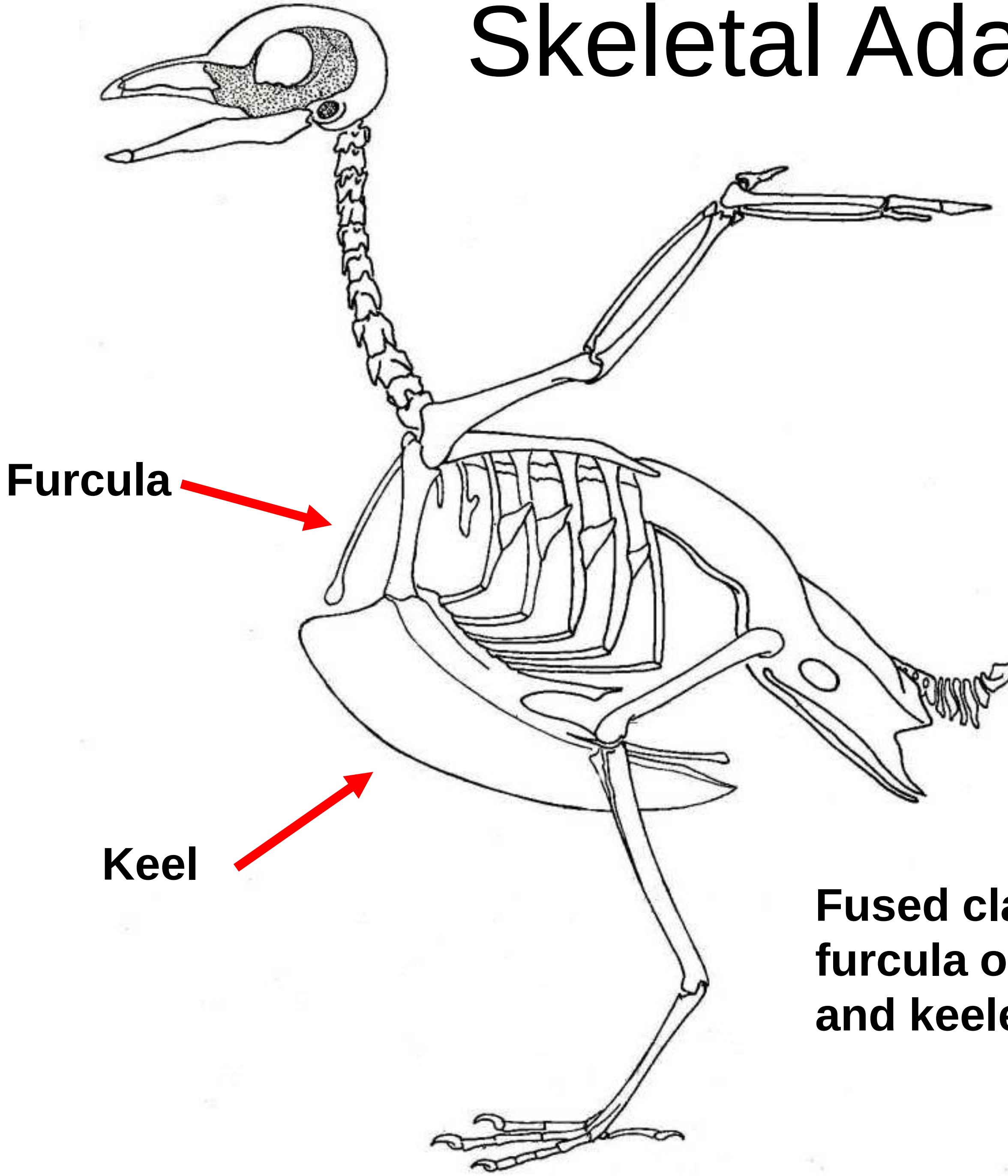
Humerus
Radius
Ulna
Carpals
Carpo-metacarpals
Alula
(1st digit)
2nd digit

# Feathers

- Aid in generation of lift and thrust
- Primaries – thrust
- Secondaries - lift

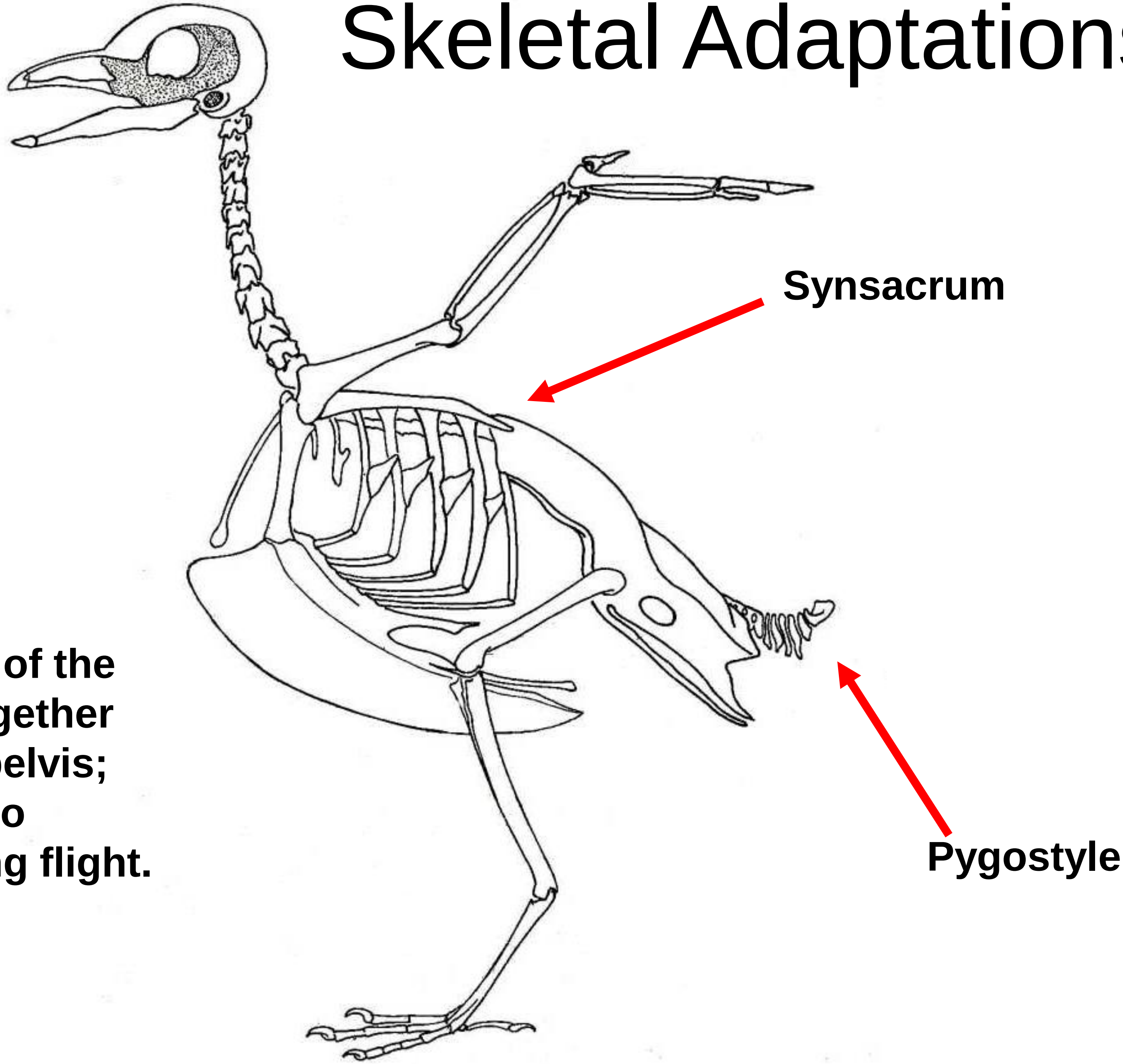



# Skeletal Adaptations



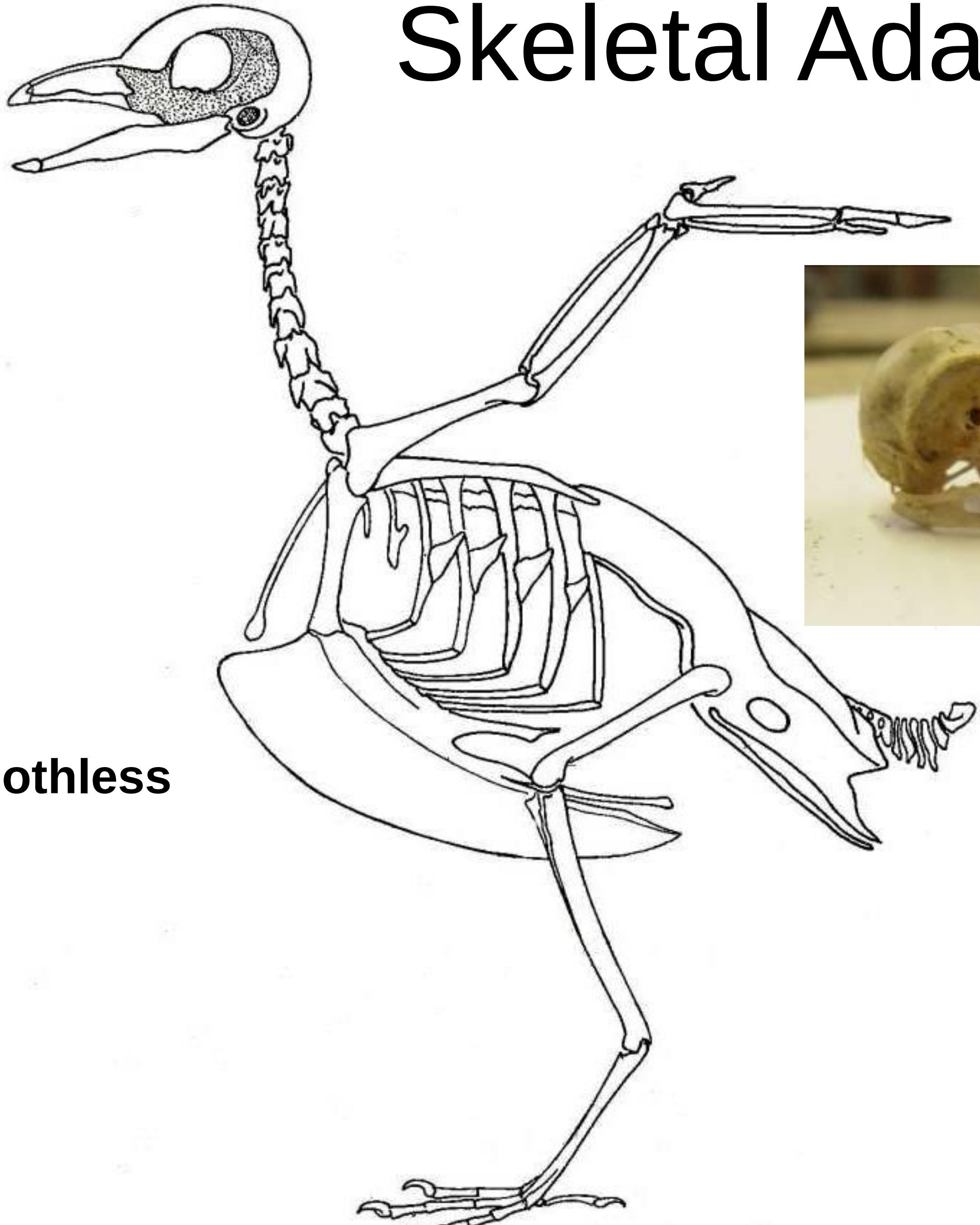

**Fused clavicle called furcula or wishbone and keeled sternum**

# Skeletal Adaptations




**The vertebrae of the back fused together and fused to pelvis; gives rigidity to skeleton during flight. Fused caudal vertebrate.**

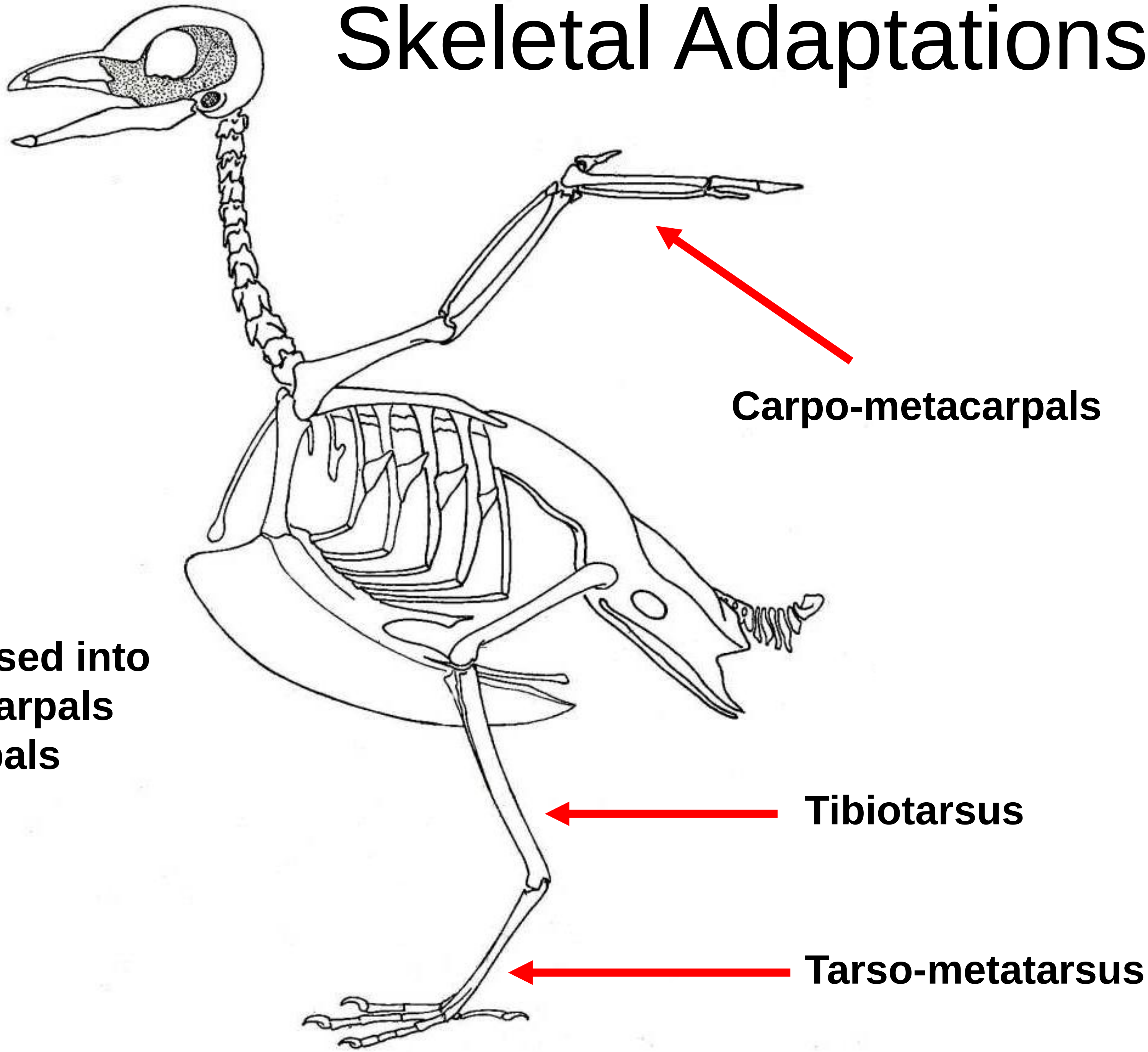
# Skeletal Adaptations



**Bill**

**Lightweight toothless bill.**

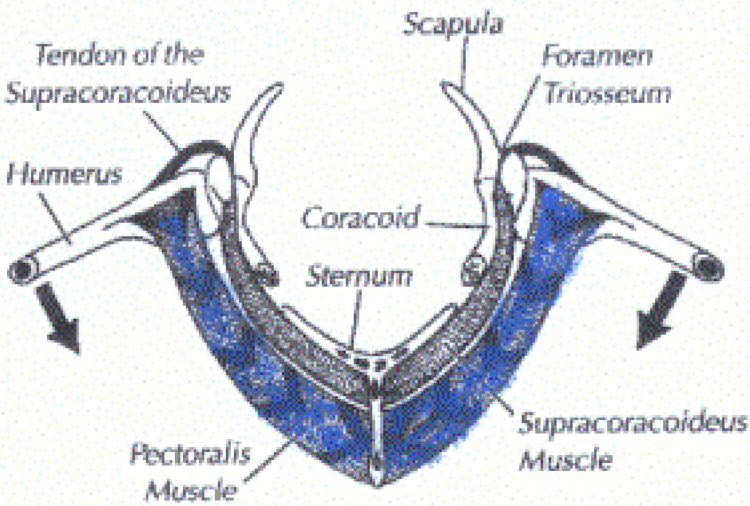
# Skeletal Adaptations

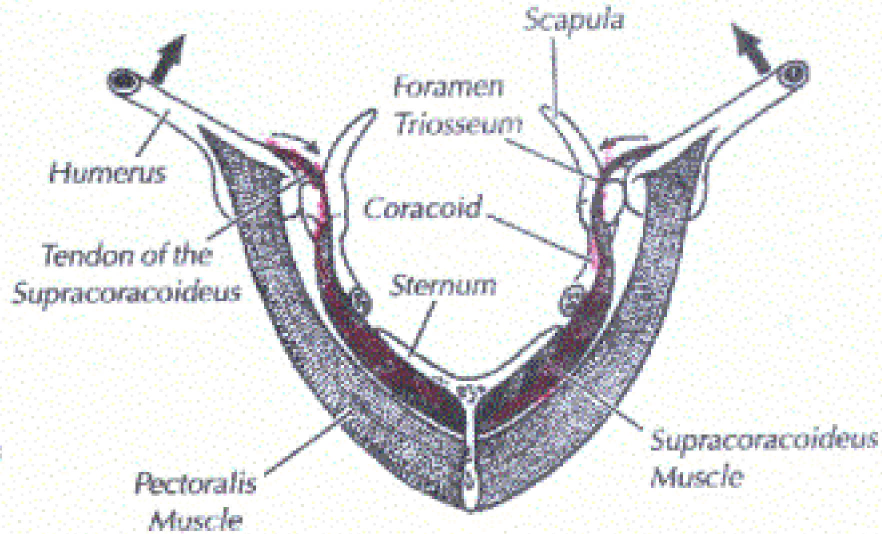


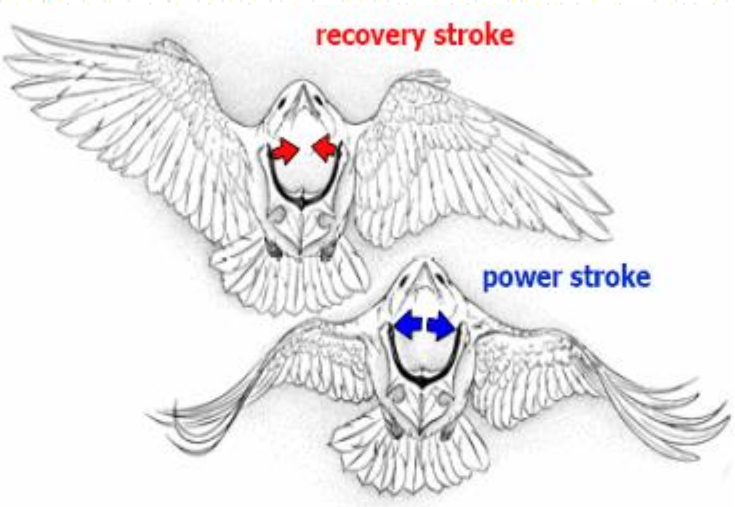

**Foot bones fused into metatarsus. Carpals and meta-carpals fused.**

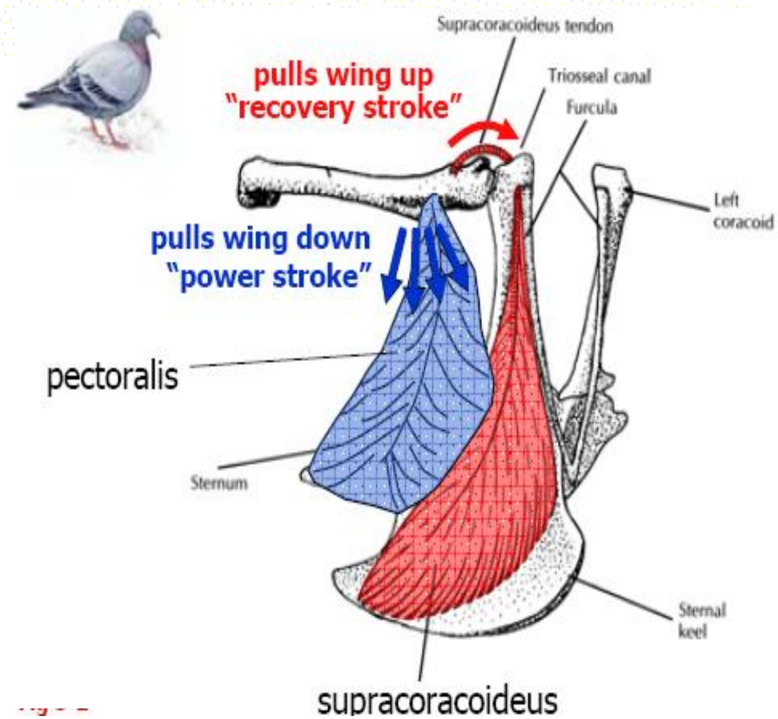
**Downstroke or power stroke**

**Upstroke or recovery stroke**



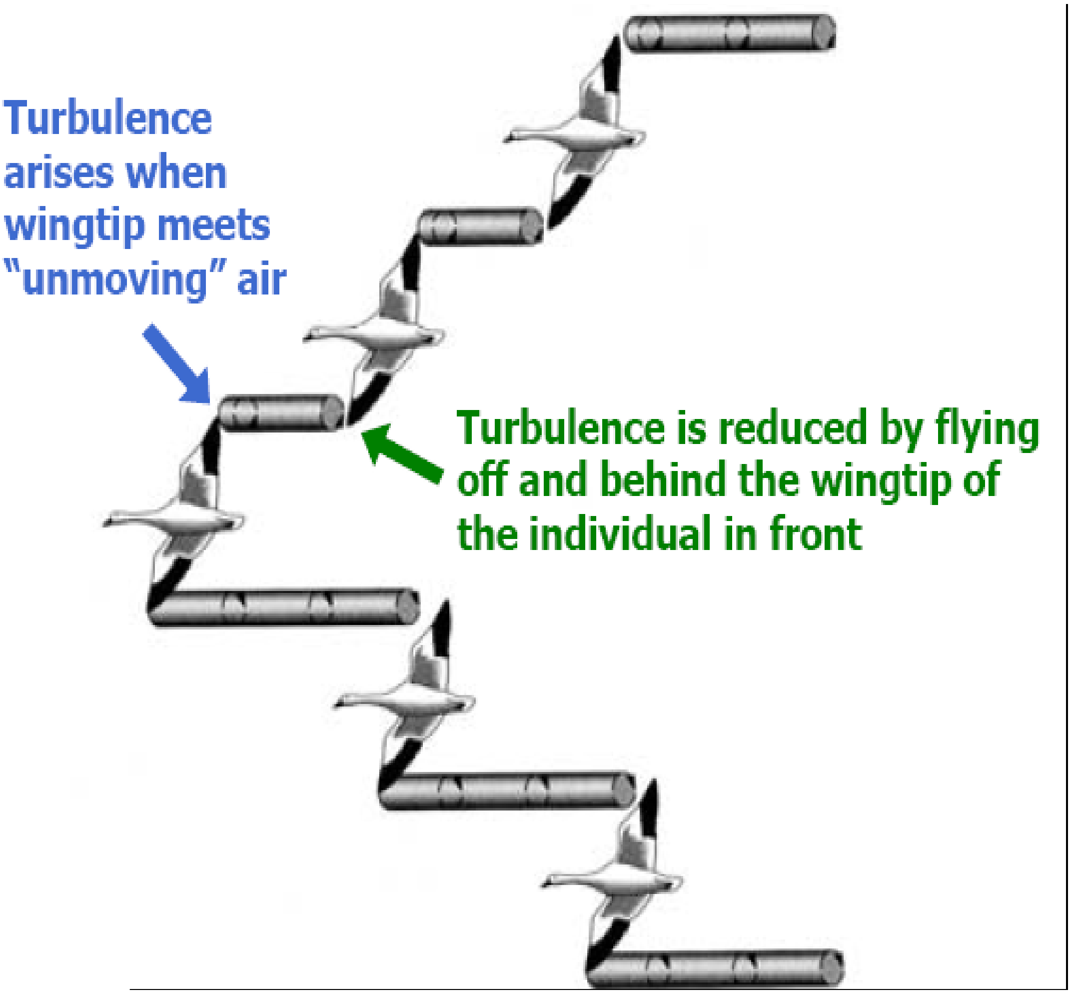



# Bird – Flight Adaptations

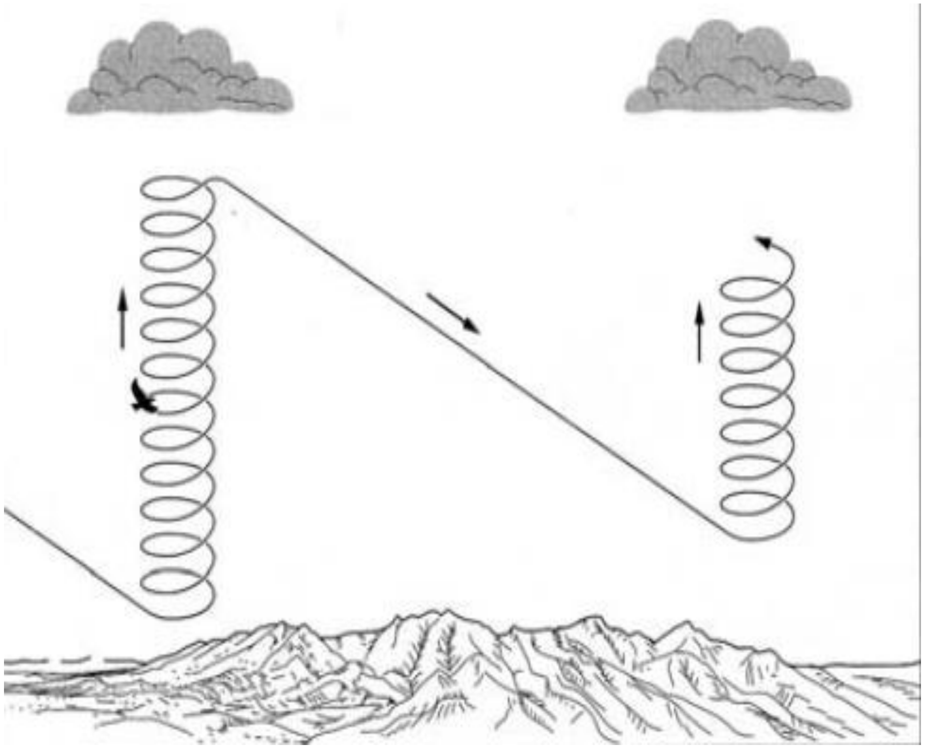
- Regression of reproductive organs during the non-breeding season
- Do not have a bladder
- Efficient respiration
  - One-way flow through system

# Flocking



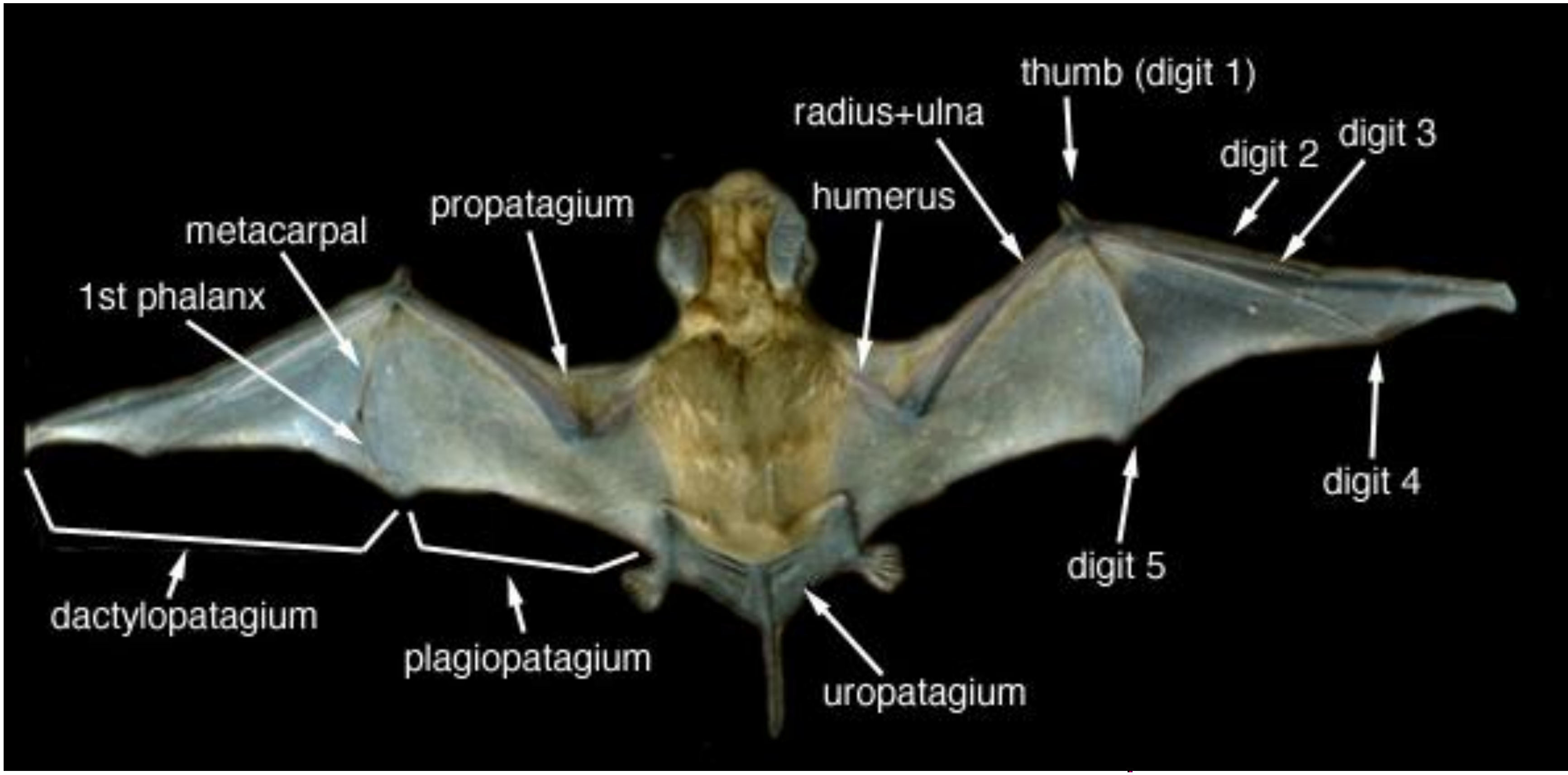
Turbulence arises when wingtip meets "unmoving" air
Turbulence is reduced by flying off and behind the wingtip of the individual in front

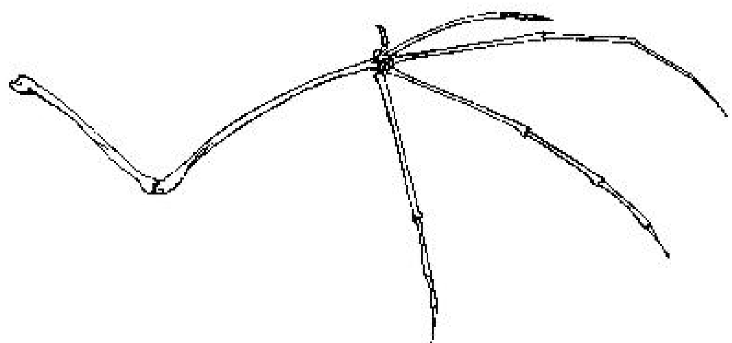
# Soaring

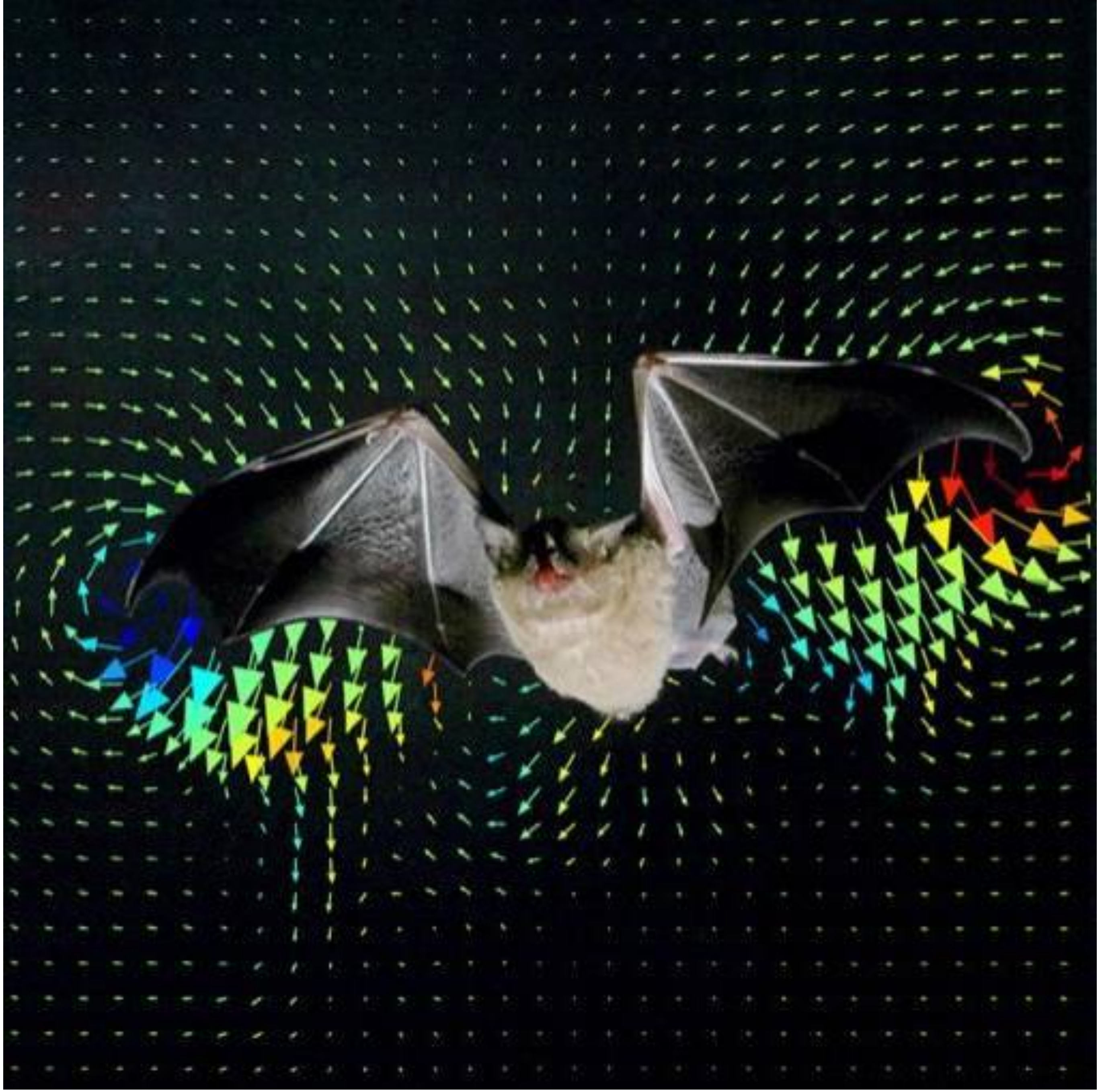


# Bat Flight

# Bat - wing


thumb (digit 1)
radius+ulna
digit 3
digit 2
humerus
propatagium
metacarpal
1st phalanx
digit 4
digit 5
dactylopatagium
plagiopatagium
uropatagium

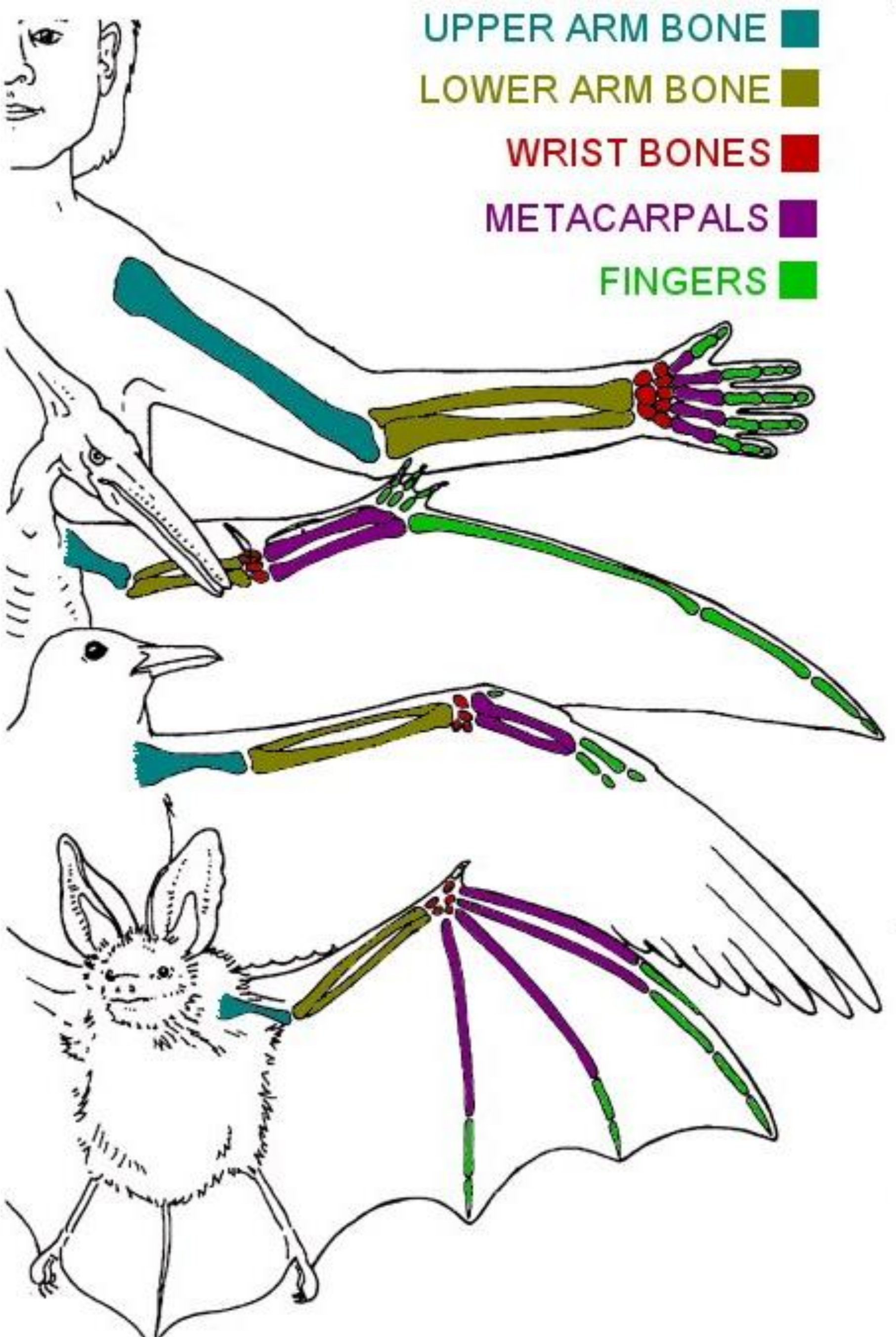




Hedenstrom et al. (2007) Science 316: 894-897

# Bat - Adaptations

- Echolocation
  - Navigate in the dark
- Thinner and lighter bones
- Fused and fewer bones
- Calcar
- Short neck


UPPER ARM BONE
LOWER ARM BONE
WRIST BONES
METACARPALS
FINGERS