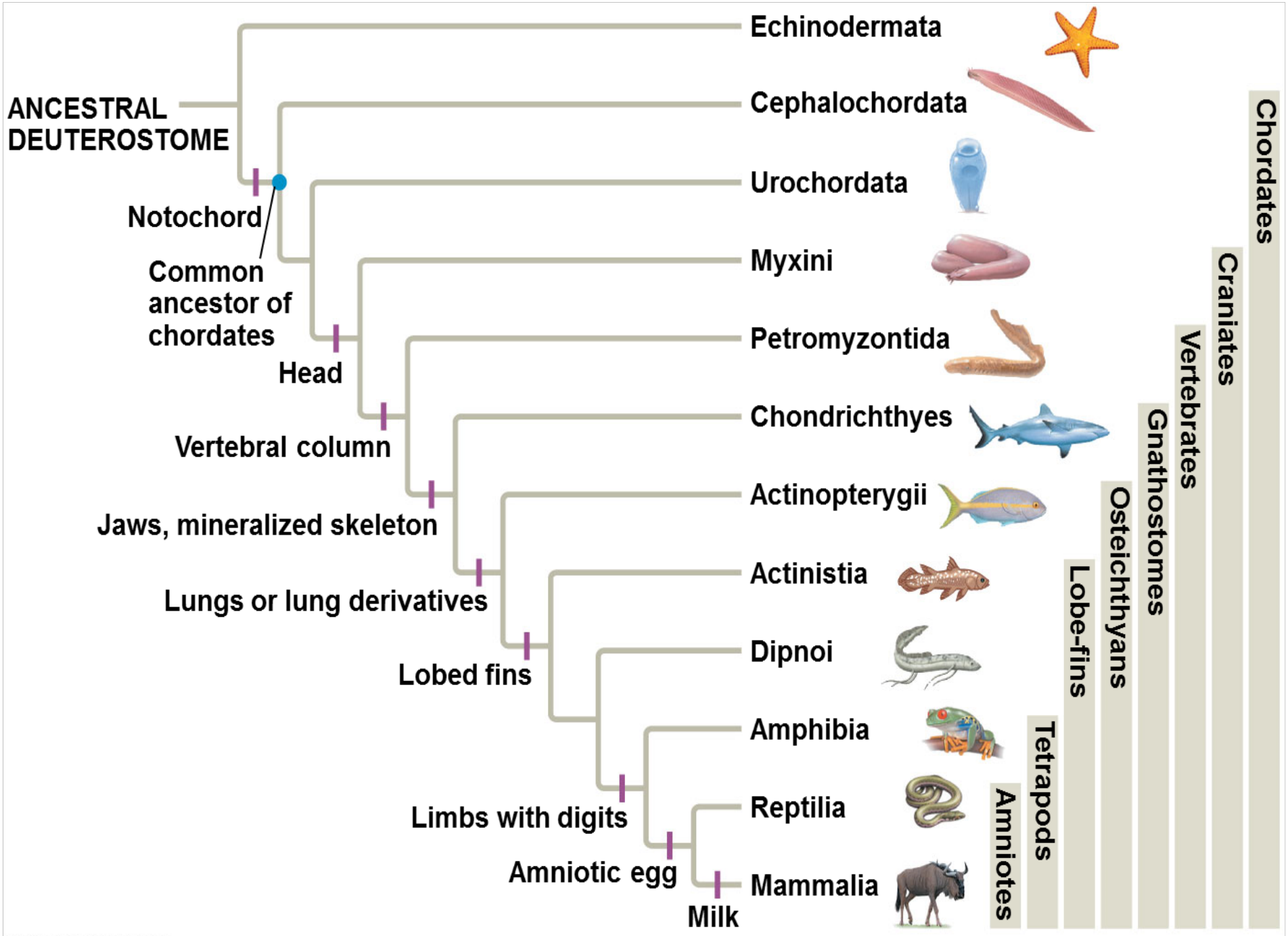
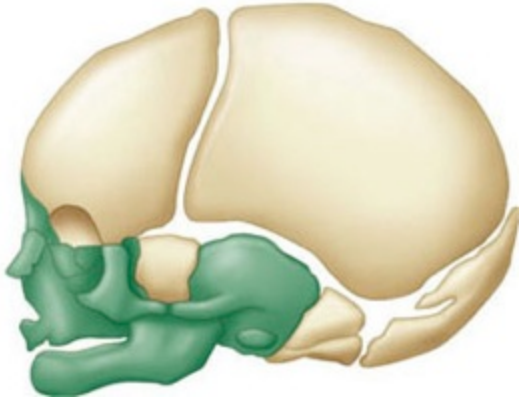
Phylum Chordata!
Part Two, Fish

Reference: Chapter 34.1-34.4



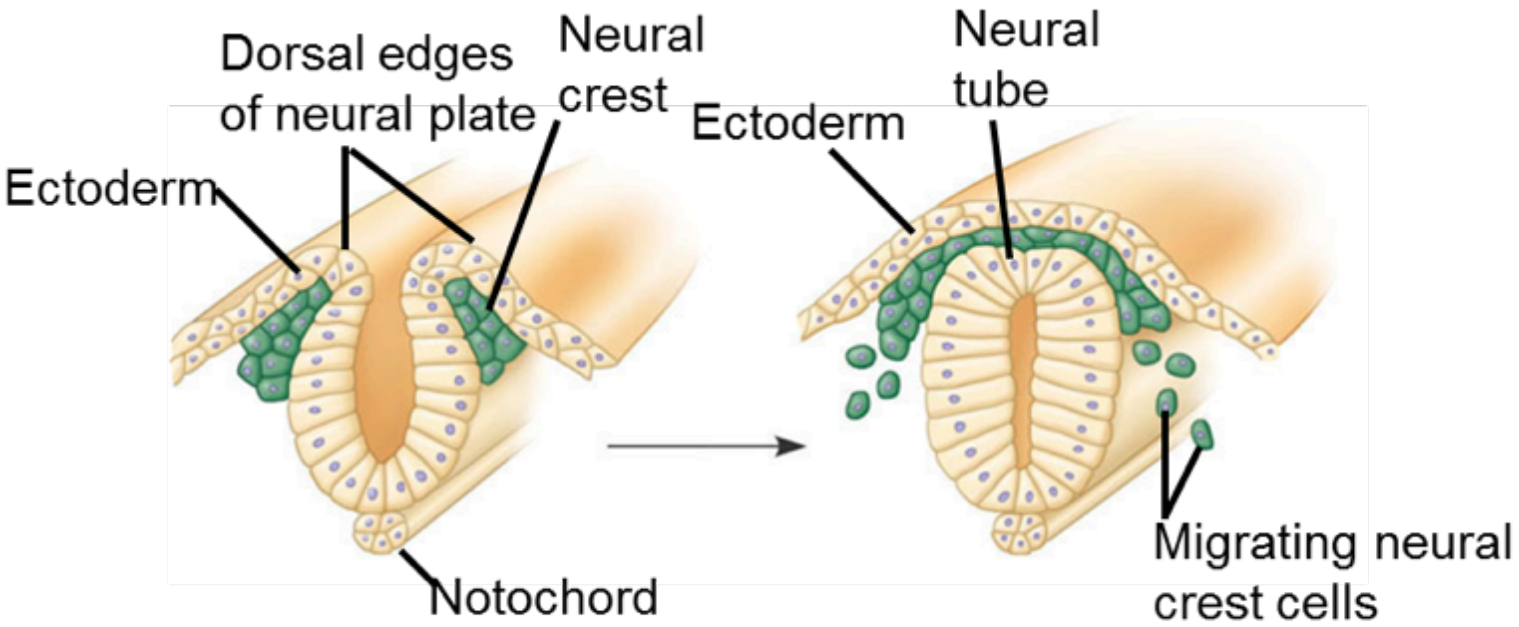
Clade Craniata

- Evolution of a head **(cranium)** opened up a completely new way of feeding (for chordates): **active predation**
- Craniates share the following characteristics:
  - A skull, brain, eyes, and other sensory organs
  - An **endoskeleton** made of cartilage or bone
  - In aquatic craniates, pharyngeal slits evolved into gills
  - Higher metabolism & more muscle than protochordates
  - Heart with at **least two chambers**, red blood cells with hemoglobin, and kidneys
  - Neural crest cells, which give rise to parts of the skull



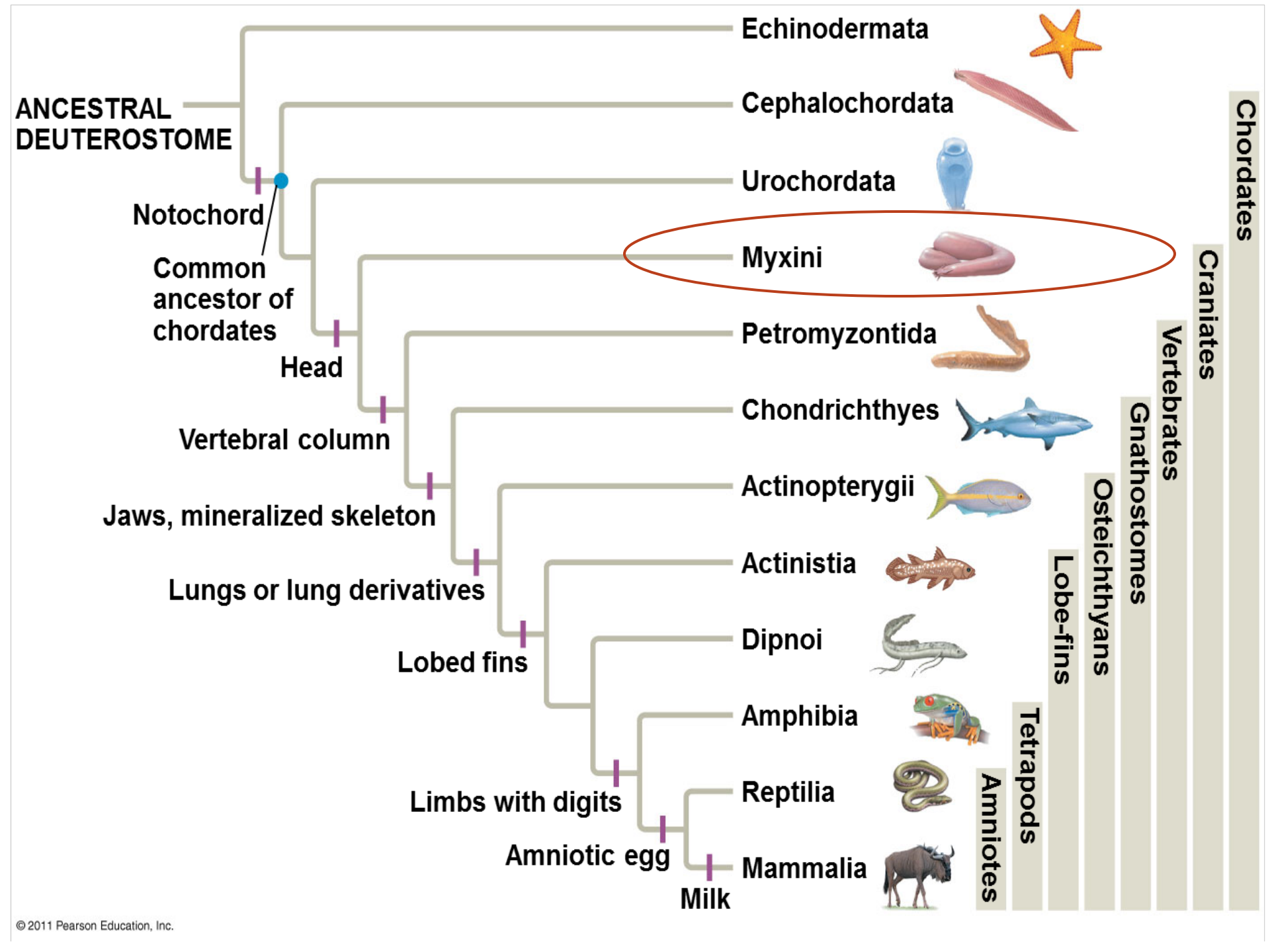
Unique to the Craniata: Neural Crest Cells

- A collection of cells that appear near the dorsal margins of the closing neural tube in an embryo



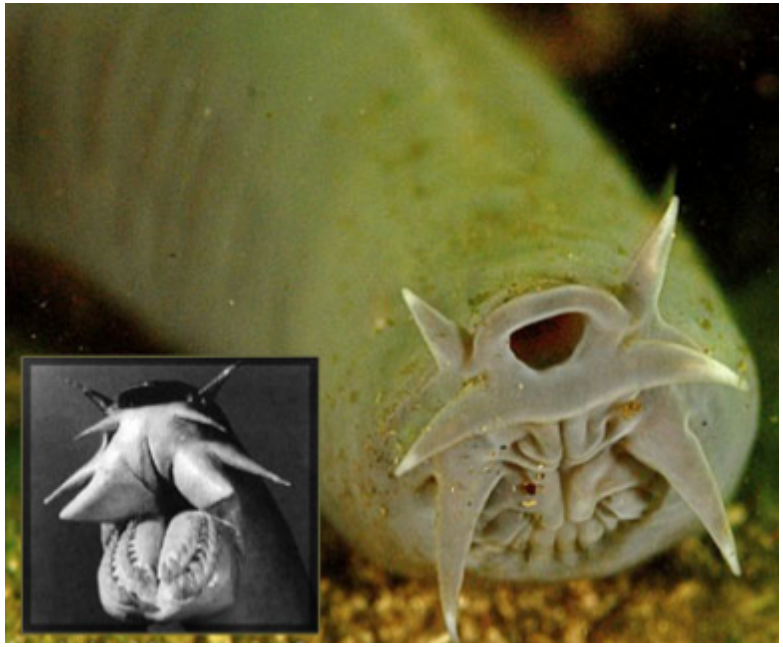
(a) The neural crest consists of bilateral bands of cells near the margins of the embryonic folds that form the neural tube.

(b) Neural crest cells migrate to distant sites in the embryo.



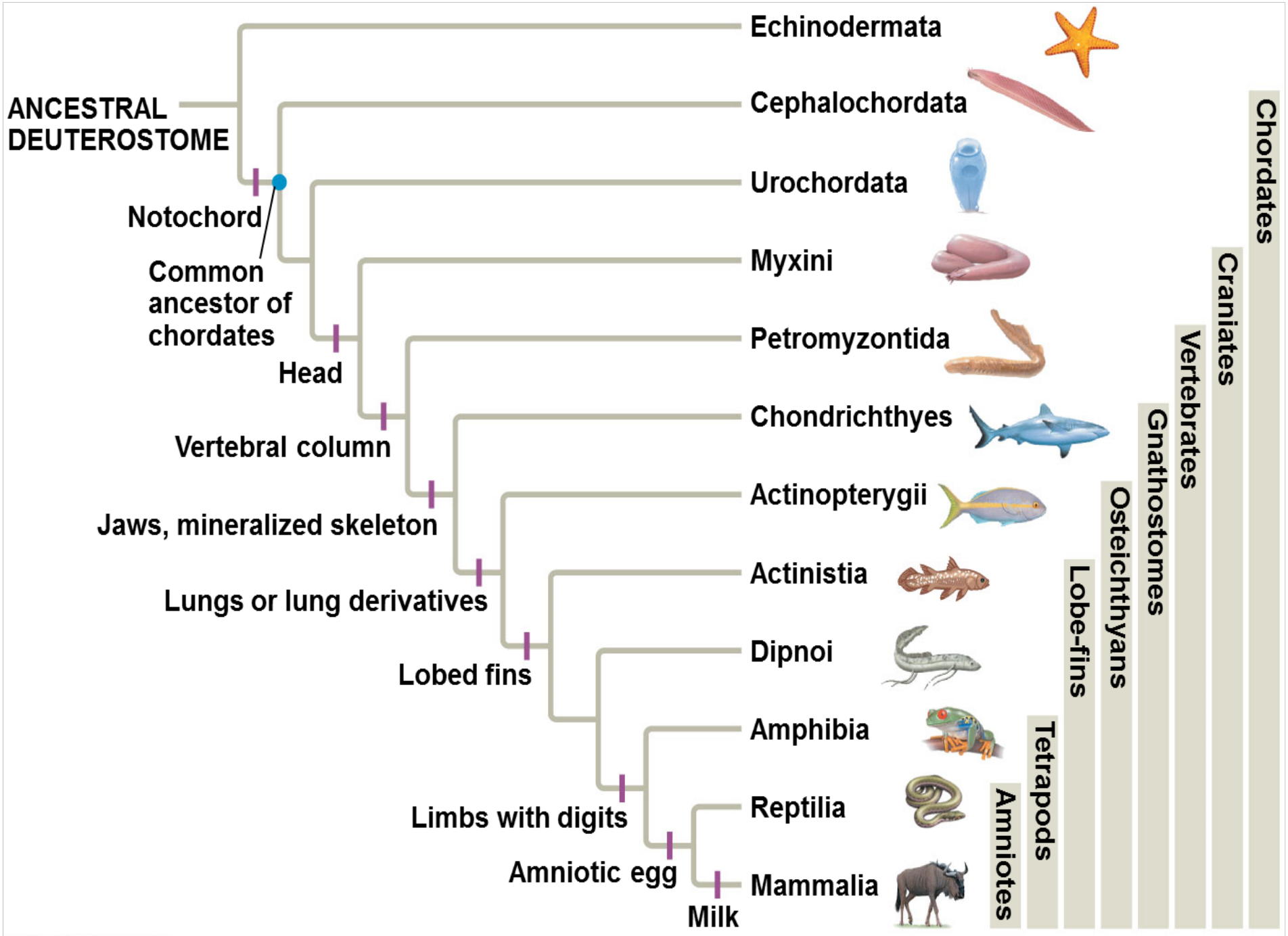
Basal Craniates: Myxini, the Hagfishes

- Basal group of craniates
- Cartilaginous skull derived from notochord
- Lack jaws and vertebrae
- Have small brain, eyes, “ears”, and “teeth”
- Marine; most are bottom-dwelling scavengers
- Produce slime as a defense mechanism
  - Fouls gills of predators
  - Research topic– strong polymer for fibers



Basal Craniates: Myxini, the Hagfishes

Hagfish video,
https://www.youtube.com/watch?v=t5PGZRxhAyU

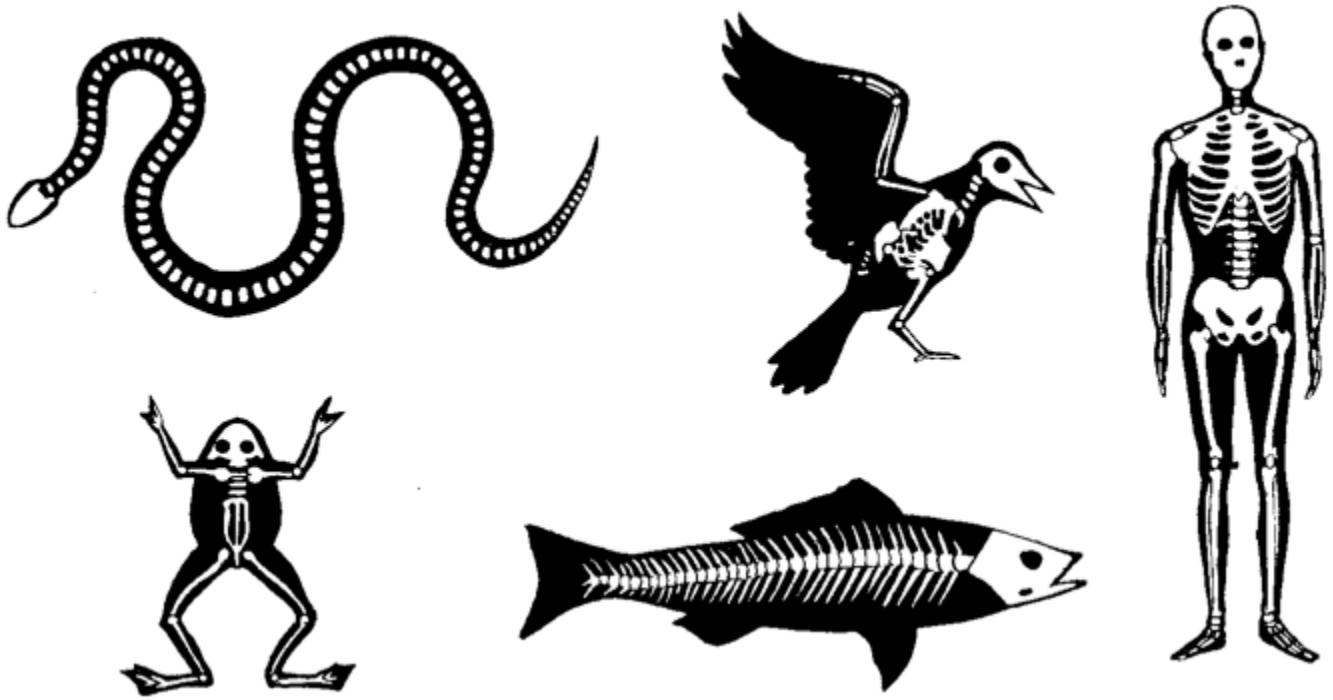


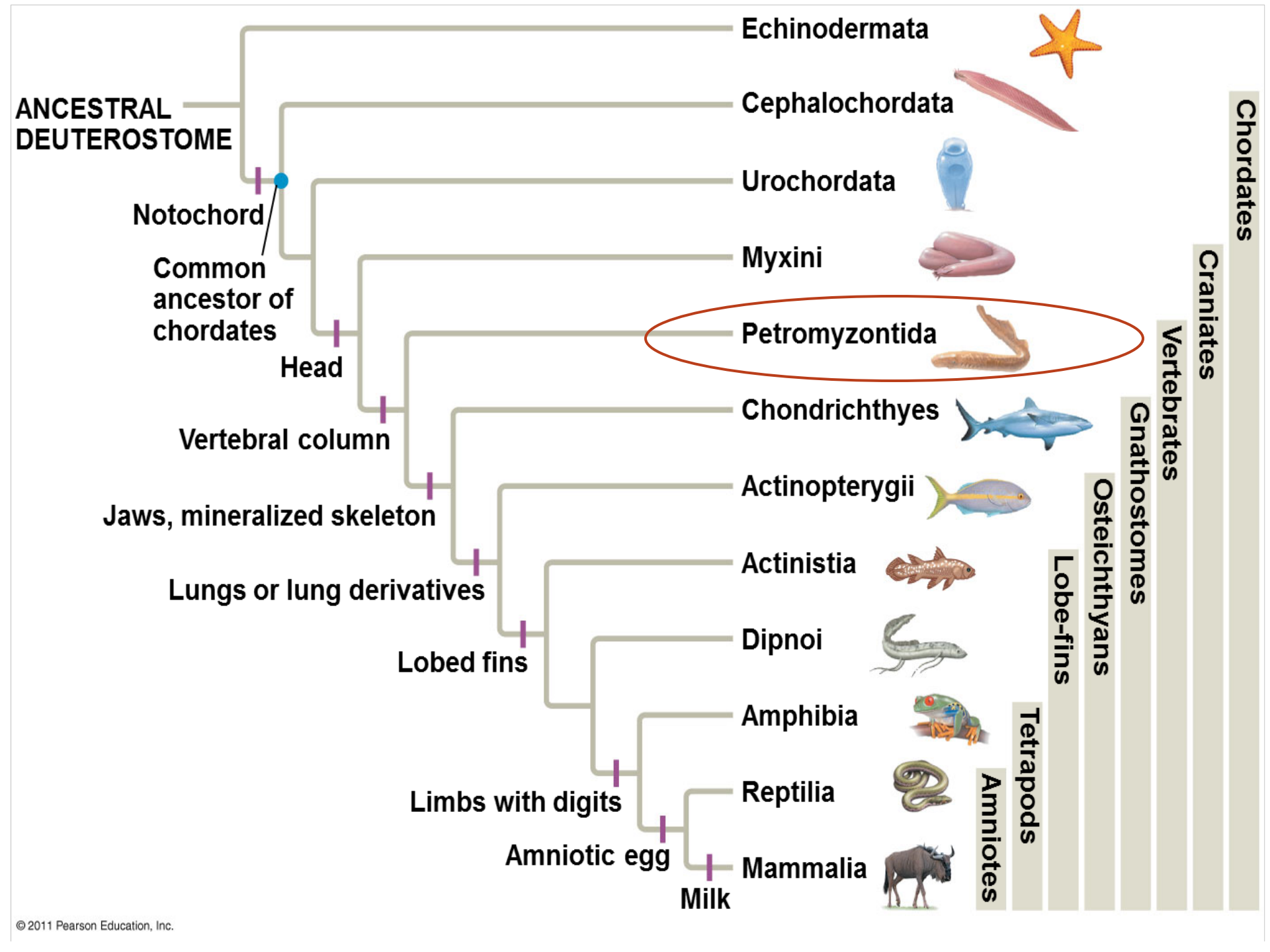
Subphylum Vertebrata

- **Monophyletic** group (includes ALL descendants!)
- Still share the 5 basic chordate characteristics
- Get their name from **vertebrae**, the series of bones that make up the backbone
- The backbone was an innovation that allowed for more efficient movement
- Better at capturing food (and avoiding becoming food)

Subphylum Vertebrata

- Approx. 52,000 species of vertebrates which include the largest organisms ever to live on Earth
  - Fishes (about half of vertebrate species!)
  - Amphibians
  - Reptiles
  - Birds
  - Mammals





Basal Vertebrates: Lampreys (Class Petromyzontida)

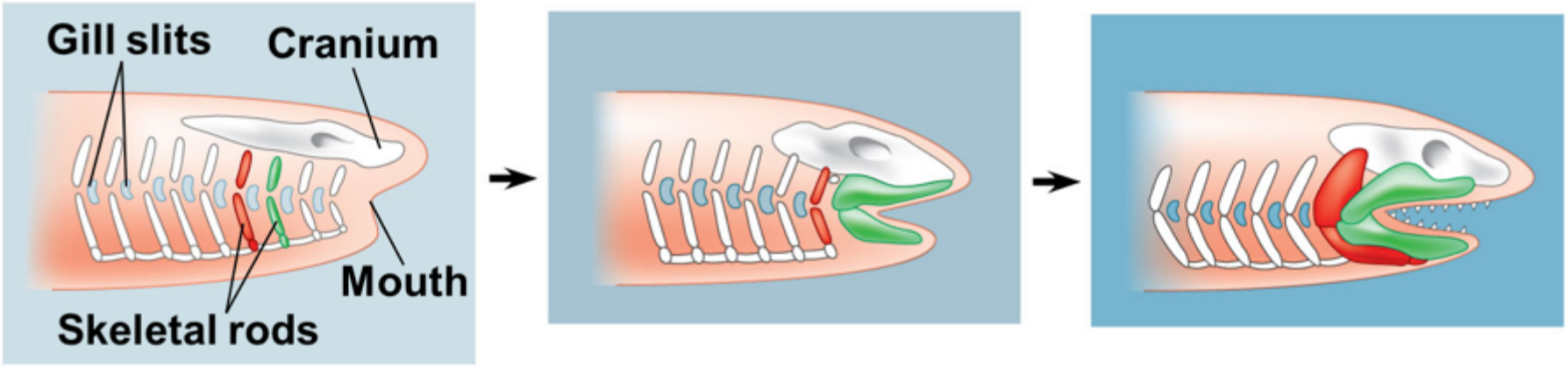
- Member of subphylum Vertebrata, also member of **Superclass Agnatha** (jawless)
- Represent the oldest living lineage of vertebrates
- Lamprey feed by clamping their mouth onto live fish
- Inhabit SW and FW habitats
- Cartilaginous segments surround the notochord and partly over the nerve cord

Gnathostomes are vertebrates that have jaws

- Today **gnathostomes** (jawed) far outnumber jawless vertebrates (agnathans)
- Gnathostomes include sharks and their relatives, ray-finned fishes, lobe-finned fishes, amphibians, reptiles (including birds), and mammals
- Characters common to gnathostomes
  - Genome duplication, including *Hox* genes
  - Enlarged forebrain (enhanced smell and vision)
  - In aquatic gnathostomes, the **lateral line system**, which is sensitive to vibrations

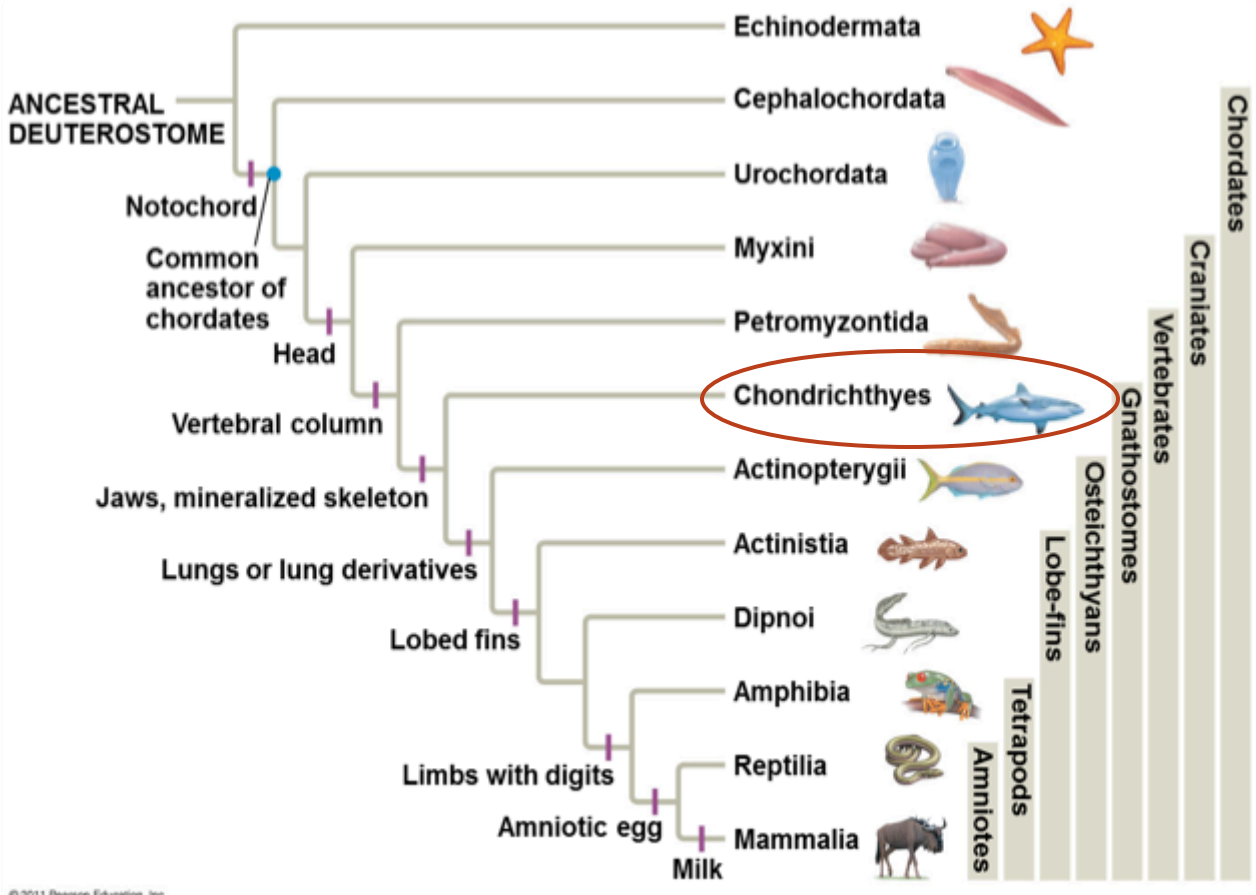
Possible origin of the vertebrate jaw

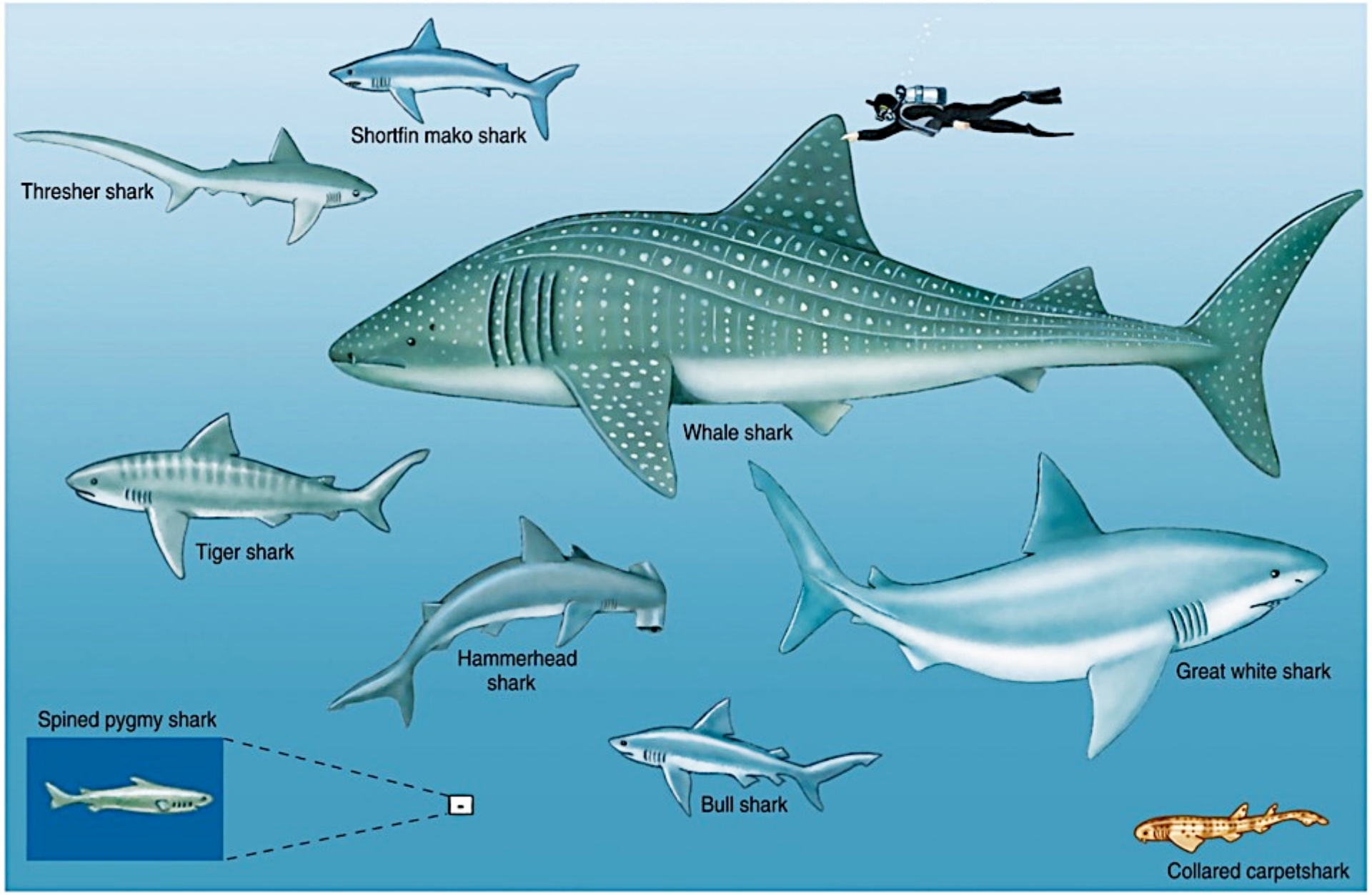
- Gnathostomes have jaws that might have evolved from skeletal supports of the pharyngeal slits
- Extremely successful in capturing prey, defense



Chondrichthyans (Sharks, Rays, and Their Relatives)

- **Class Chondrichthyes** (Chondrichthyans) have a skeleton composed primarily of cartilage
- The largest and most diverse group of chondrichthyans is the subclass **Elasmobranchii**, which includes the sharks, rays, and skates





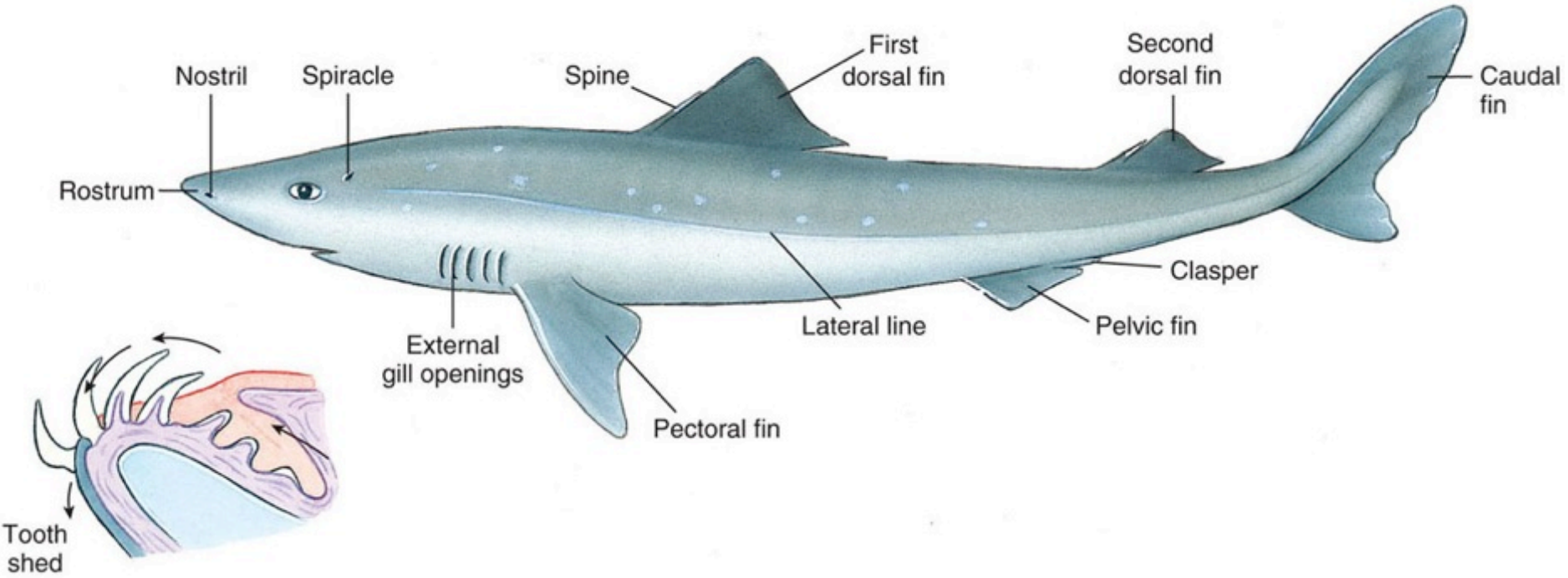
Class Chondrichthyes: Cartilaginous Fishes

Overview

- ~970 living species
- Ancient group, >400 million years old
- Acute senses including sight, smell, and the ability to detect electrical fields from nearby animals
- True bone is completely absent throughout the class
- Phosphatized mineral tissues in teeth, scales, spines
- Nearly all are marine (28 species live primarily in FW)
- After whales, sharks are the largest living vertebrates, reaching 12 m in length

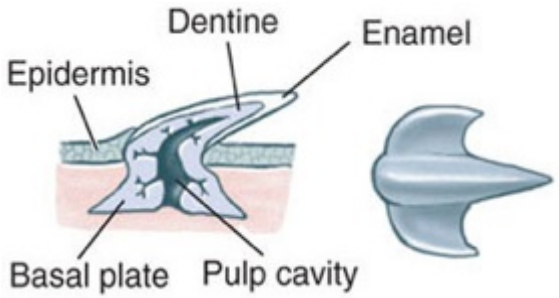
Class Chondrichthyes: Cartilaginous Fishes

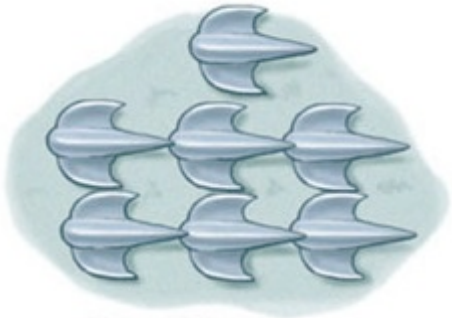
- Body is fusiform
  - Thrust and lift provided by asymmetrical **heterocercal tail**
    - Vertebral column turns upward and extends into dorsal lobe of caudal fin
- **Fins include:**
  - Paired **pectoral** and **pelvic fins**
  - One or two median **dorsal fins**
  - One median **caudal fin**



Class Chondrichthyes: Cartilaginous Fishes

- In males, the medial part of the pelvic fin is modified to form **claspers** used in copulation
- Paired nostrils are associated with olfaction- detect prey at a distance by large olfactory organs sensitive to *one part per 10 billion!*
- Lateral eyes are lidless (but have a nictitating membrane for protection during feeding)
- Tough, leathery skin with **placoid scales**
  - Reduce water turbulence

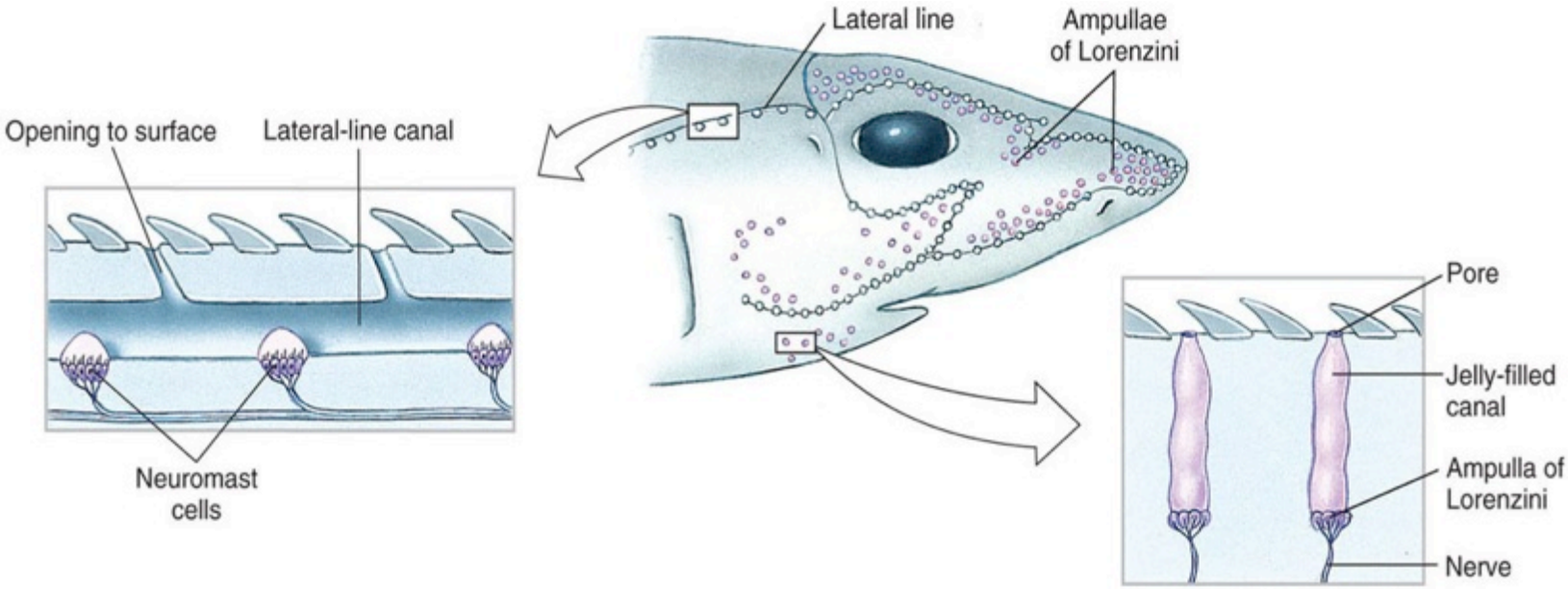




Placoid scales
(cartilaginous fishes)

Class Chondrichthyes: Cartilaginous Fishes

- Prey can also be located from a distance by sensing low frequency vibrations in the **lateral line- neuromasts** in interconnected tubes and pores on side of body
- At close range, switch to vision
  - Most have excellent vision even in dimly lit water
  - Up close, sharks guided by bioelectric fields that surround all animals; **electroreceptors**, the **ampullae of Lorenzini**, are located on the shark's head

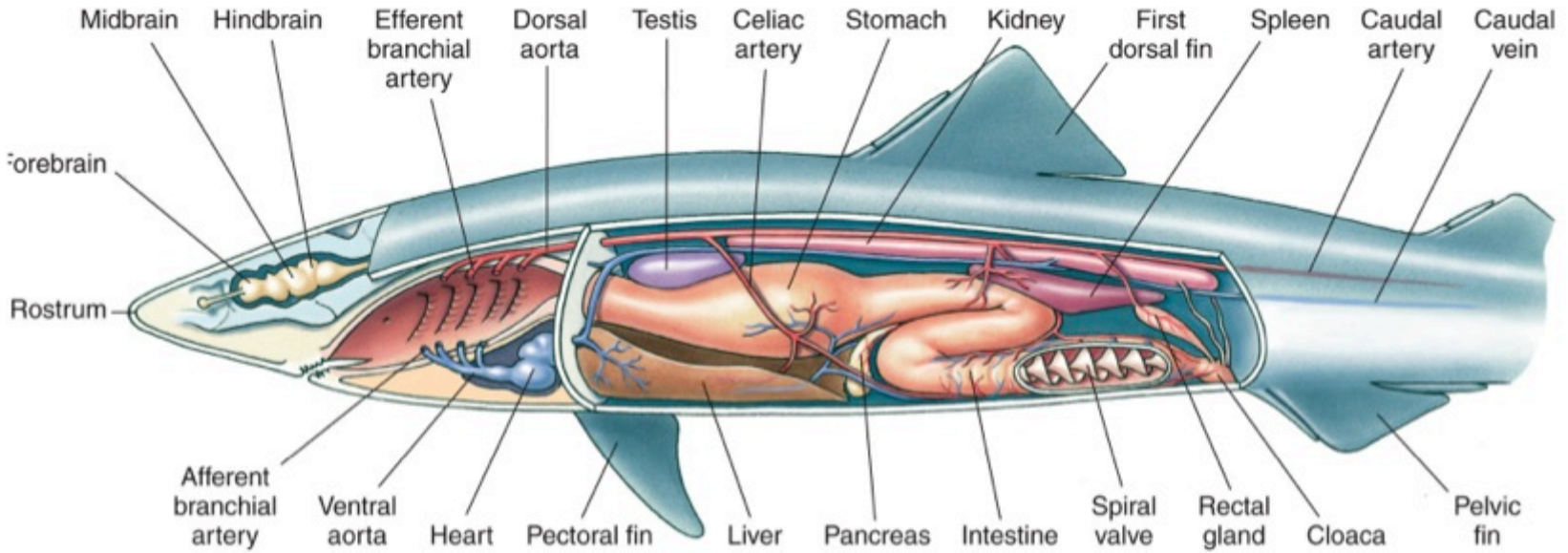


Class Chondrichthyes: Cartilaginous Fishes

- Upper and lower jaws equipped with sharp, triangular teeth that are constantly replaced
  - Scales and teeth essentially the same structure

Class Chondrichthyes: Cartilaginous Fishes

- Mouth opens to pharynx, which opens to gill slits and spiracles
- Short esophagus runs to stomach and small intestine
  - Spiral valve in large intestine slows passage of food and increases absorptive area
- Elasmobranchs retain nitrogenous compounds (urea) in blood
  - Raises blood solute concentrations and eliminates the osmotic inequality between blood and seawater

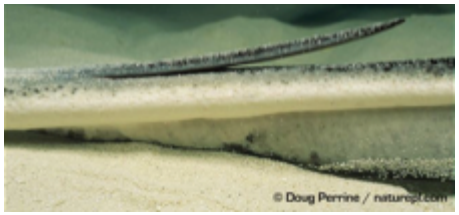


Class Chondrichthyes: Rays

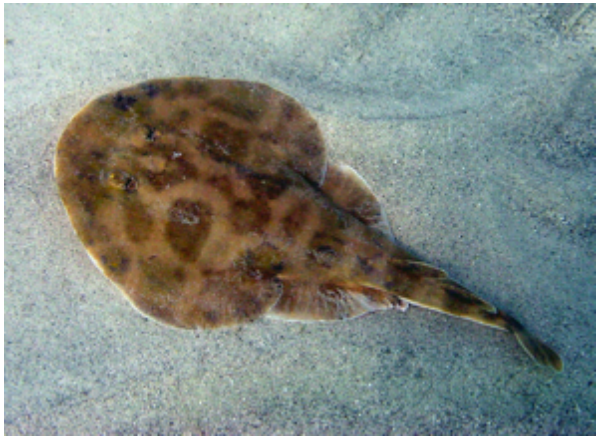
- More than half of elasmobranchs are rays
- Most specialized for benthic life (life on the ocean bottom)
  - Dorso-ventrally flattened body and enlarged pectoral fins used to propel themselves
  - Respiratory water enters through large spiracles on top of the head
- Teeth adapted for crushing prey (molluscs, crustaceans, and sometimes small fish

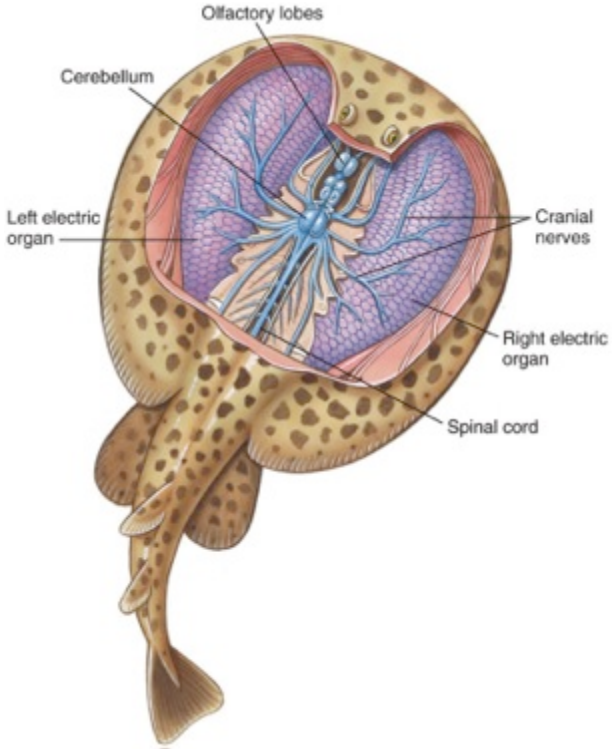
Class Chondrichthyes: Rays

- **Stingrays**
  - Have whiplike tail with spines and venom glands



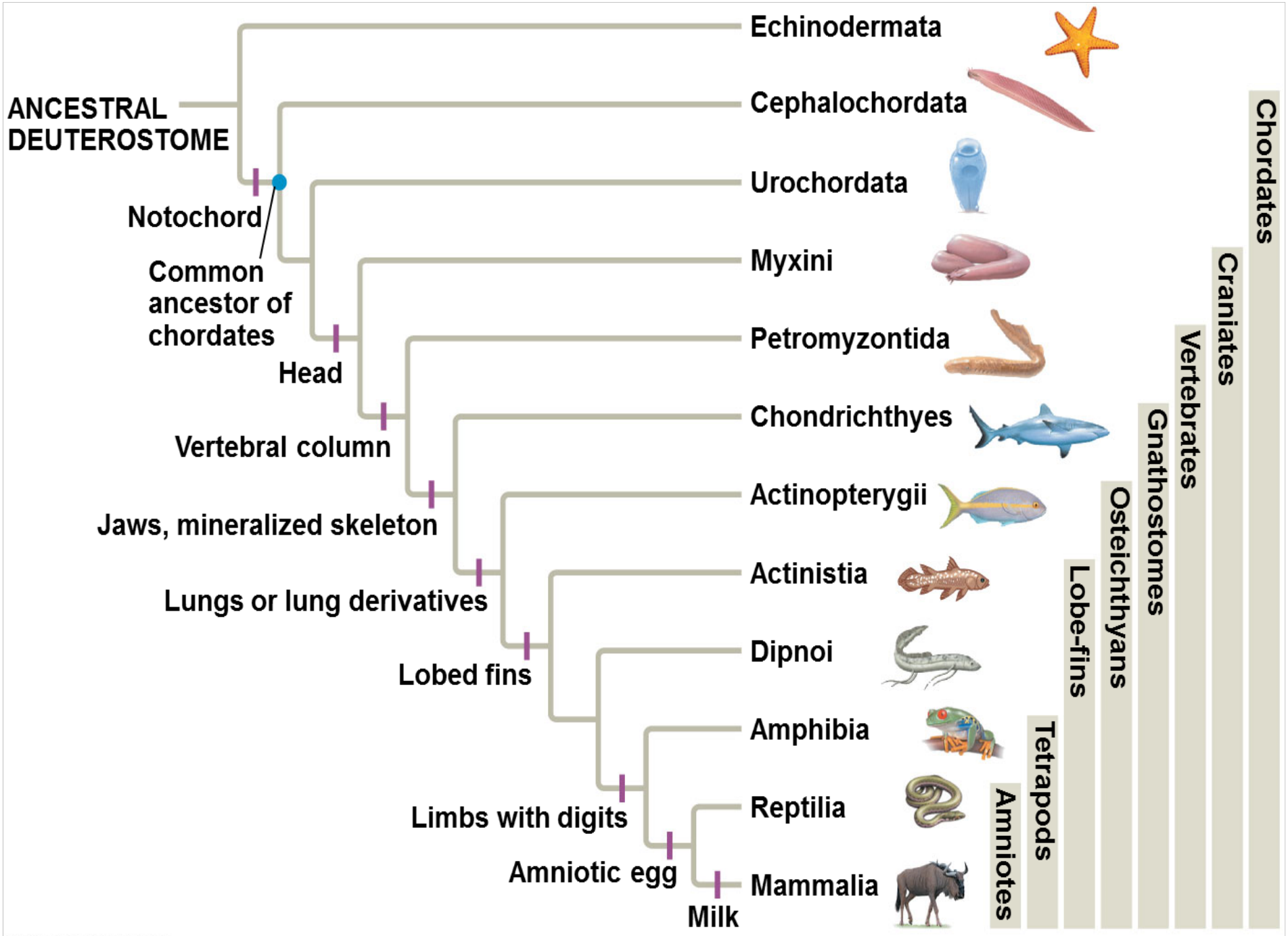
- **Electric rays**
  - Have large electric organs on each side of head





Class Chondrichthyes: Reproduction

- Shark eggs fertilized internally but embryos develop in different ways
  - **Oviparous**: Eggs hatch outside
  - **Ovoviviparous**: Eggs develop within uterus, nourished by yolk, and hatch before release
  - **Viviparous**: Embryo develops within uterus, nourished by yolk sac and **placenta** (nutrients from mother)
- Sharks have a **cloaca**
  - "General purpose" opening to the outside of the body
    - Functions in excretion, reproduction



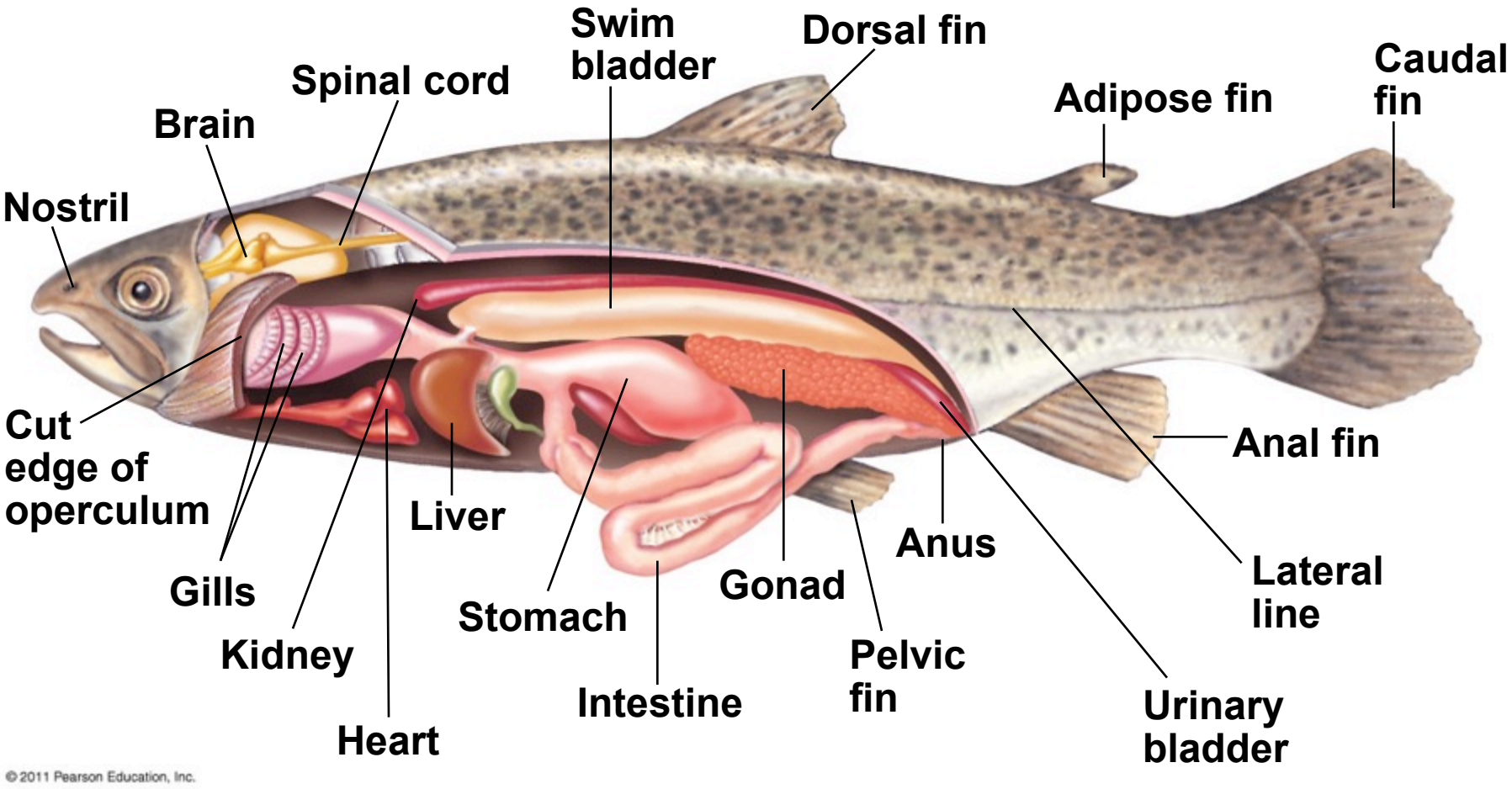
Clade (Superclass?) Osteichthyes

- The vast majority of vertebrates belong to a clade of gnathostomes called **Osteichthyes**
- Nearly all living **osteichthyans** have a **bony endoskeleton**
- Osteichthyans includes bony fish and tetrapods
- Aquatic osteichthyans are the bony fishes
  - **Ray-finned** fishes (**Class Actinopterygii**)
  - **Lobe-finned** fishes (**Class Sarcopterygii**)
    - **Actinistia** (**Coelocanth**; mostly fossil)
    - **Dipnoi** (**lungfishes**)
    - **Tetrapodomorpha** (**tetrapods** → us!)

Characteristics of Bony Fishes

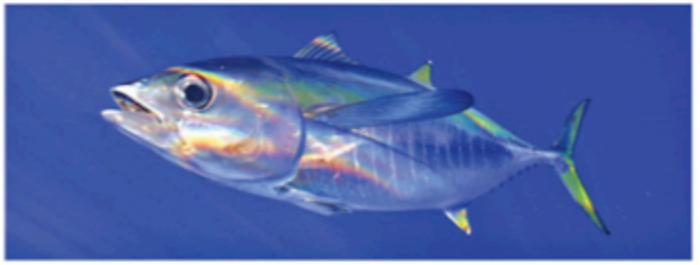
- Most breathe by drawing water over gills protected by a bony **operculum**
- Fishes control buoyancy with an air sac known as a **swim bladder-** derived from primitive lung in now-extinct line of fishes
- Bony fishes have a lateral line system, similar to sharks
- Most species are oviparous, but some have internal fertilization and birthing

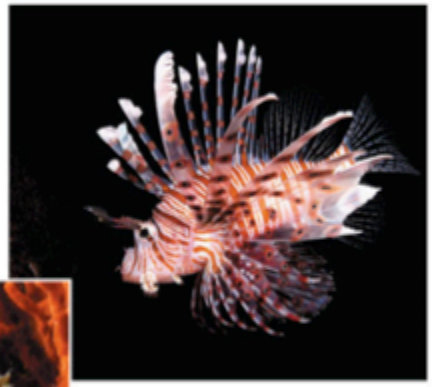
Figure 34.16



Ray-Finned Fishes, Actinopterygii

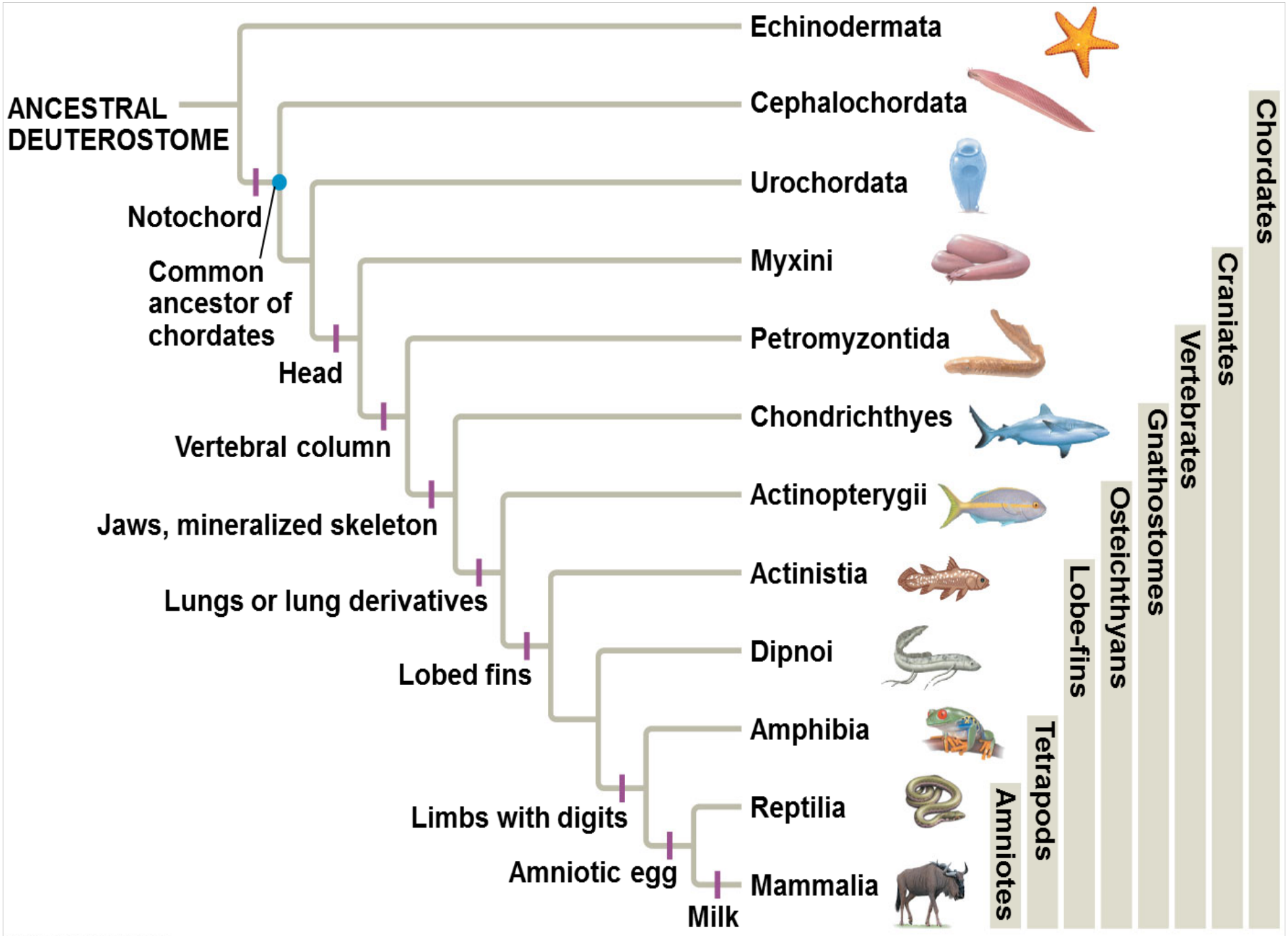
- **Actinopterygii**, the **ray-finned fishes**, includes nearly all familiar aquatic osteichthyans
- Ray-finned fishes originated during the Silurian period (444-416 million years ago)
- Fins, supported by long, flexible rays, are modified for maneuvering, defense, and other functions





Lobe-Fins, Sarcopterygii

- **Lobe-fins** (**Sarcopterygii**) have muscular pelvic and pectoral fins
- Three lineages survive and include **coelacanths (Actinistia)**, **lungfishes (Dipnoi)**, and **tetrapods**



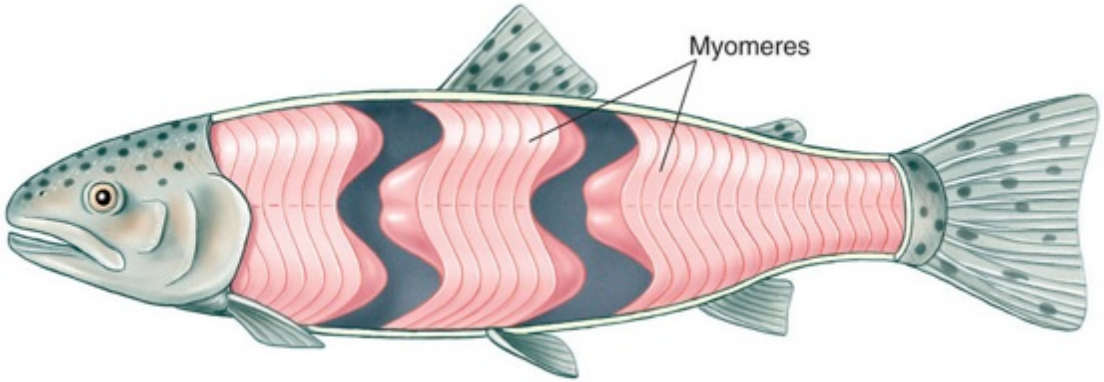
More about those lobe-fins

- Coelacanths were thought to have become extinct 75 million years ago, but a living coelacanth was caught off the coast of South Africa in 1938

Structural and Functional Adaptations of Fishes

Locomotion in Water

- Speed
  - Most fishes swim at most ten body lengths per second
    - Larger fish therefore swims faster
    - Short bursts of speed are possible for a few seconds
- Mechanism
  - Trunk and tail musculature propels a fish
  - Muscles are arranged in zigzag bands called myomeres
    - Have the shape of a W on the side of fish
    - Internally the bands are folded and nested
    - Each myomere pulls on several vertebrae

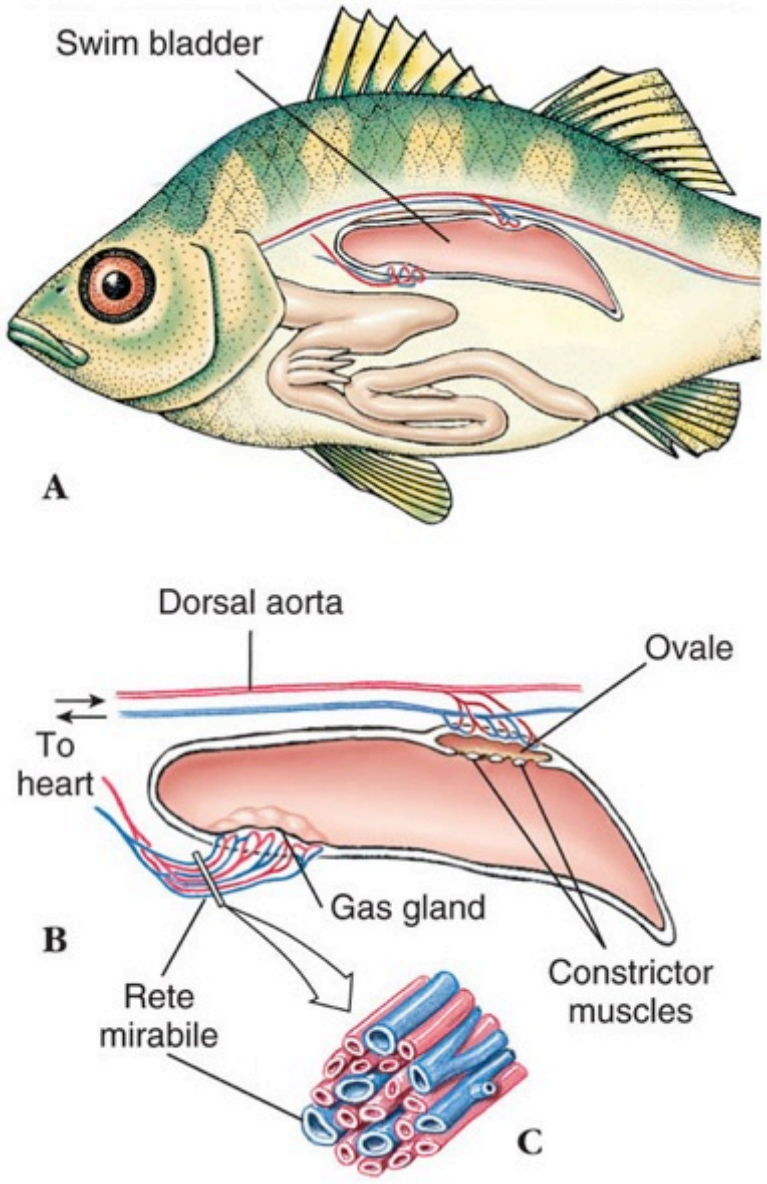


Structural and Functional Adaptations of Fishes

- **Economy**
  - Swimming is the most economical form of motion because water buoys the animal
  - Energy cost per kilogram of body weight for traveling one kilometer is 0.39 Kcal for swimming, 1.45 Kcal for flying, and 5.43 for walking
- **Neutral Buoyancy and the Swim Bladder**
  - Fish are slightly heavier than water
  - Sharks have no swim bladder - to keep from sinking, a shark must continually move forward
    - Shark **liver** has a special lipid called squalene, that acts to keep the shark more buoyant
  - Swim bladder, as a gas-filled space, is the most efficient flotation device

Structural and Functional Adaptations of Fishes

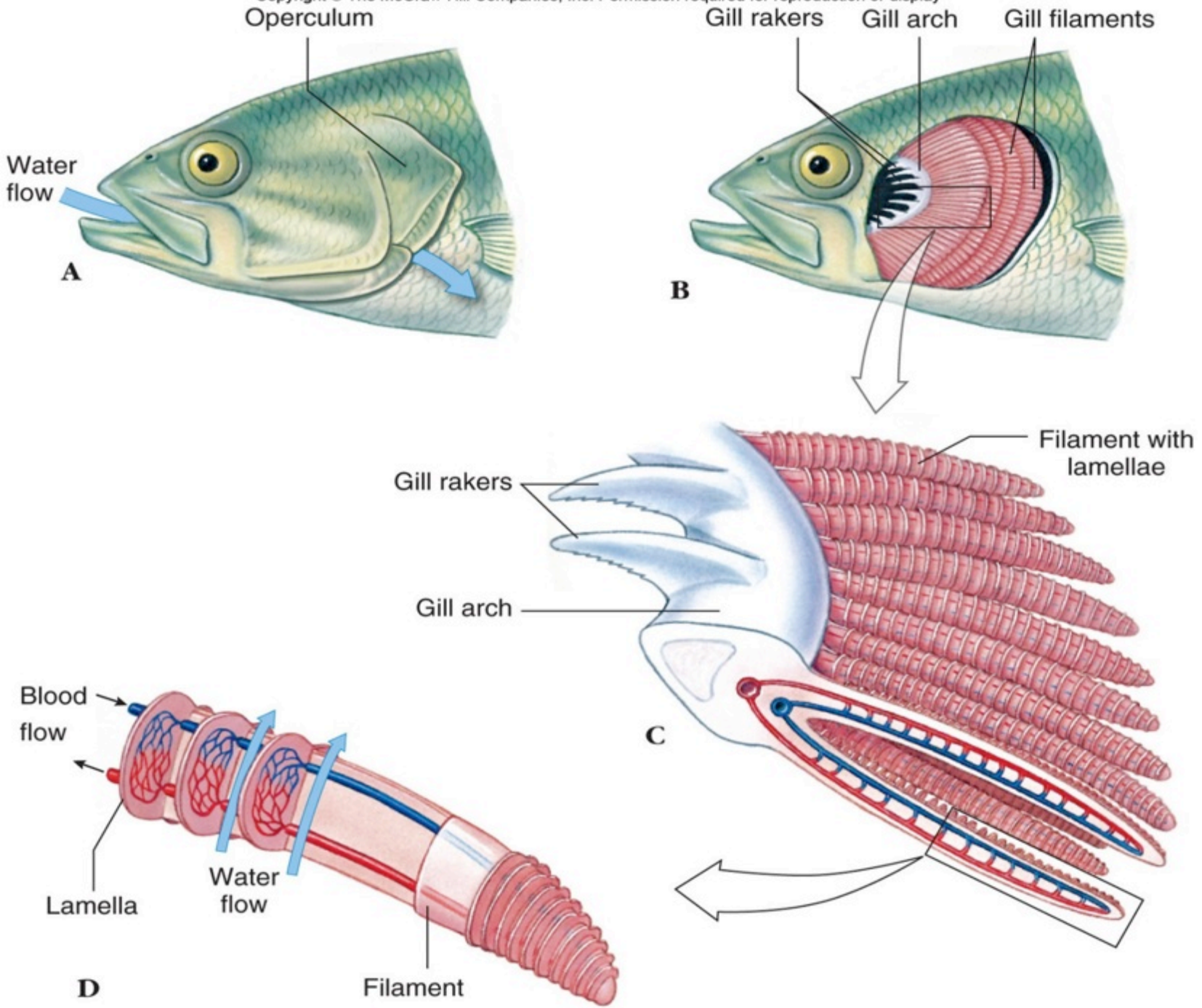
- Swim bladder arose from lungs of primitive bony fishes
  - Absent in tunas, some abyssal fishes, most bottom dwellers
  - Fish controls depth by adjusting volume of gas
  - Due to pressure, as a fish descends, bladder is compressed making total density of the fish greater
  - As a fish ascends, the bladder expands making fish lighter and it will rise ever faster



Structural and Functional Adaptations of Fishes

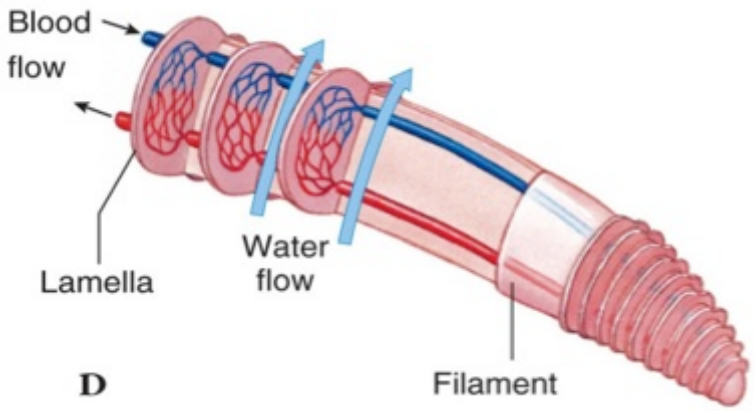
Respiration

- Fish gills are filaments with thin epidermal membranes folded into plate-like **lamellae**
- Gills are inside the pharyngeal cavity and covered with a movable flap, the **operculum**
  - Operculum protects gill filaments and streamlines body
  - Pumping action by operculum helps move water thru gills
- Water flow over gills is continuous



Structural and Functional Adaptations of Fishes

- Water flow is opposite to the blood flow
  - **Countercurrent exchange** maximizes exchange of gases



- Some bony fishes remove 85% of the oxygen from water passing over gills
- Some active fishes use ram ventilation
  - Forward movement forces water across gills
  - Such fishes are asphyxiated in a restrictive aquarium even if the water is saturated with oxygen

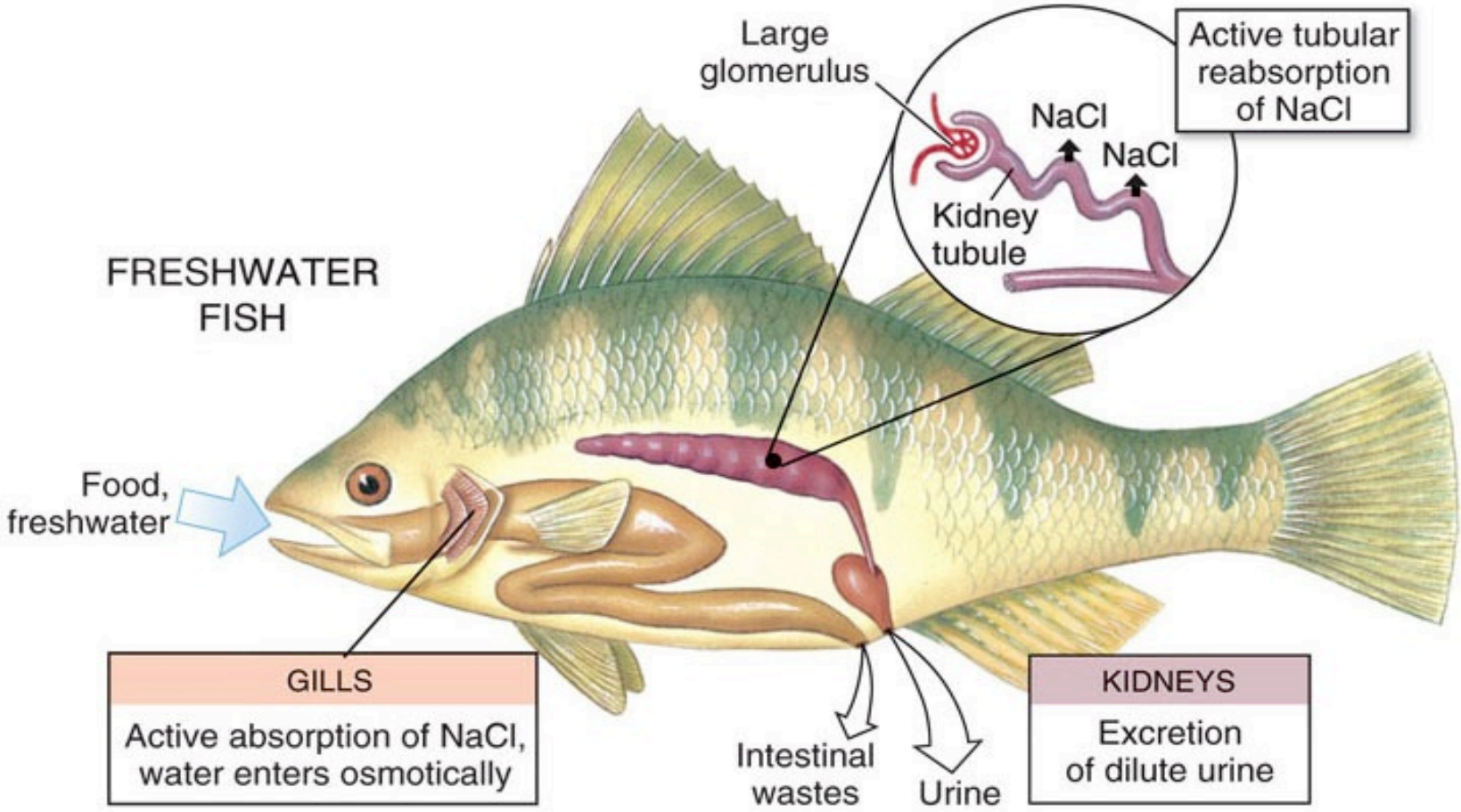
Structural and Functional Adaptations of Fishes

- Fishes Out of Water
  - Lungs of lungfishes allow them to respire in air
  - Eels can wriggle over land during rainy weather (use skin for respiration)
  - Bowfins use gills at cooler temperatures and lung-like swim bladder at higher temperatures
  - Electric eel has degenerate gills and gulps air through vascular mouth cavity
  - Mudskippers spend time on land when tidepool conditions are unfavorable, diffusing oxygen through mouth cavity and skin

Structural and Functional Adaptations of Fishes

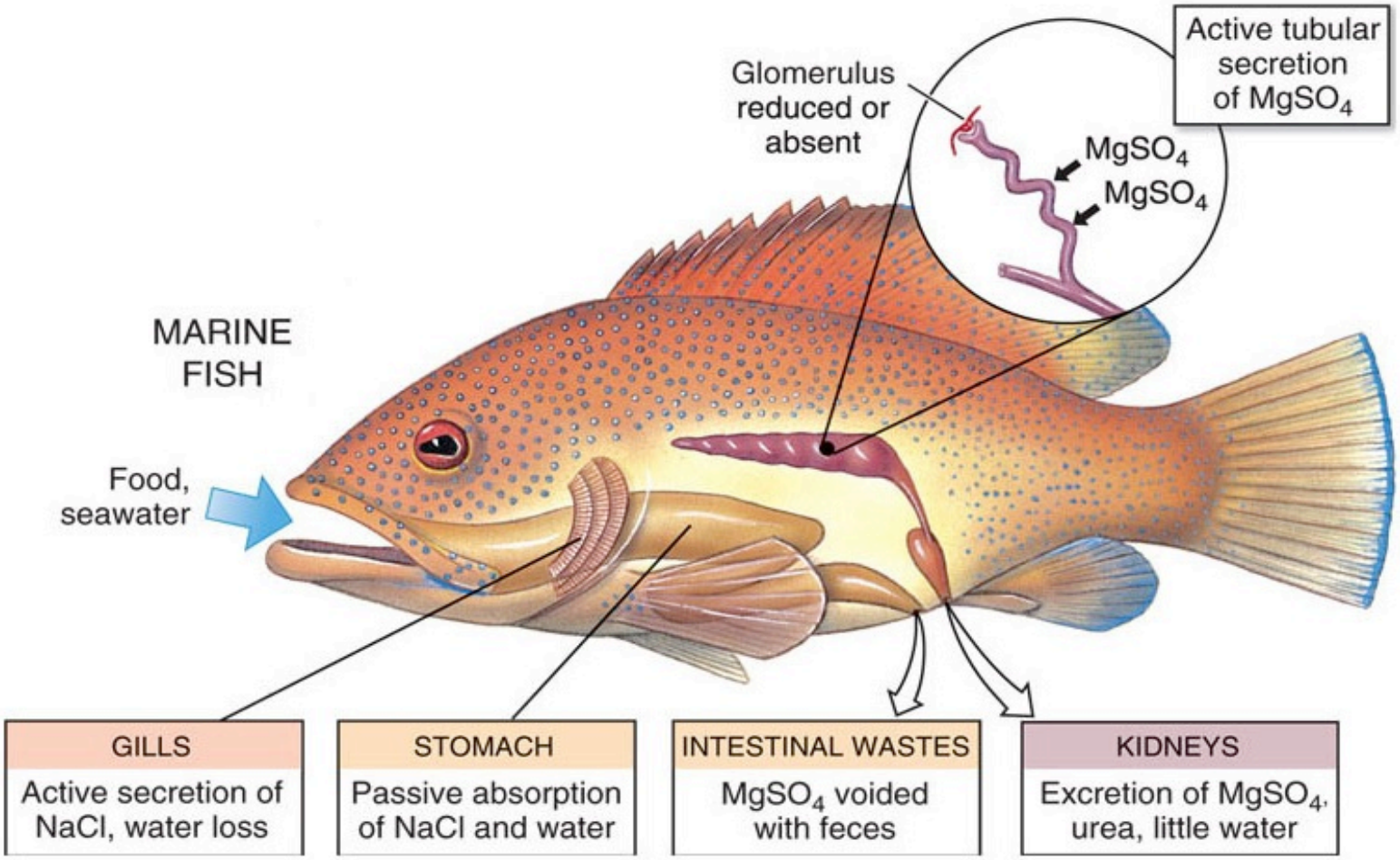
Osmotic Regulation

- Freshwater is **hypotonic** to fish blood
  - Water enters body and salt is lost by diffusion
  - Scaled and mucous-covered body is mostly impermeable, but gills allow water and salt fluxes
- Freshwater fishes are **hyperosmotic regulators**
  - Kidneys pump excess water out (urine)
  - Salt-absorbing cells in gills actively move salt ions from water into fishes' blood
  - Systems are efficient; freshwater fish typically spend little energy maintaining osmotic balance


Large glomerulus
Active tubular reabsorption of NaCl
NaCl
NaCl
Kidney tubule
FRESHWATER FISH
Food, freshwater
GILLS
Active absorption of NaCl, water enters osmotically
Intestinal wastes
Urine
KIDNEYS
Excretion of dilute urine

Structural and Functional Adaptations of Fishes

- Marine bony fishes are **hypo-osmotic regulators**
  - Blood is hypotonic to seawater
  - Tend to lose water and gain salt (dehydration)
  - To compensate for water loss, marine fishes drink SW!
    - Brings in water, but also excess salt
    - Carried by blood to gills and secreted by special salt-secretory cells
    - Divalent ions of magnesium, sulfate and calcium are left in intestine and leave body with the feces
- About 90% of bony fishes are restricted to either FW or SW
  - **Euryhaline fishes** live in estuaries or tidal areas where salinity fluctuates throughout day


Active tubular secretion of $MgSO_4$
Glomerulus reduced or absent
$MgSO_4$
$MgSO_4$
MARINE FISH
Food, seawater
GILLS
Active secretion of NaCl, water loss
STOMACH
Passive absorption of NaCl and water
INTESTINAL WASTES
$MgSO_4$ voided with feces
KIDNEYS
Excretion of $MgSO_4$, urea, little water

Structural and Functional Adaptations of Fishes

Feeding Behavior

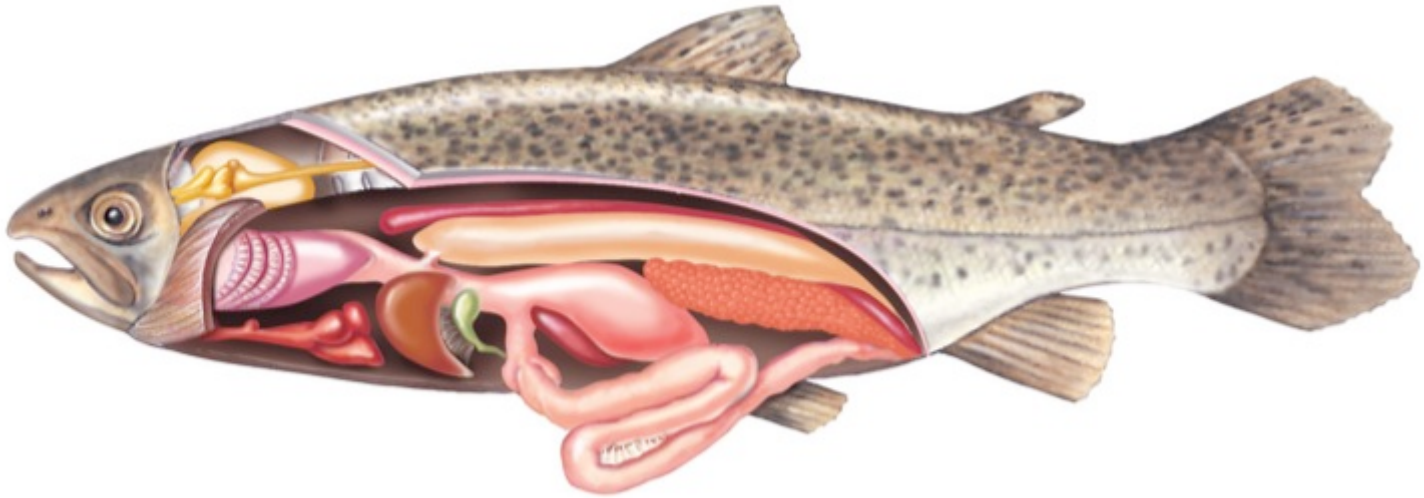
- Fish devote most of their time to food searching and eating
- With the evolution of jaws, fish left a passive filter-feeding life and entered a predator-prey battle
- Most fish are carnivores, feeding on zooplankton, insect larvae, and other aquatic animals
- Most fish do not chew food
  - Would block water flow across the gills
  - A few can briefly crack prey items with teeth, or have molar-like teeth in throat
  - Most swallow food whole- easy with water pressure that sweeps food in when the mouth opens

Structural and Functional Adaptations of Fishes

- Many plankton feeders swim in large schools and using gill rakers to strain food
- **Omnivores** feed on both plants and animals
- **Scavengers** feed on organic debris
- **Detritovores** consume fine particulate organic matter
- **Parasitic** fishes suck body fluids of other fishes

Structural and Functional Adaptations of Fishes

- Digestion follows the vertebrate plan
  - A few lack stomachs
  - Intestine tends to be shorter in carnivores and long and coiled in herbivores
  - Stomach primarily stores food
  - Intestine digests and absorbs nutrients
  - Bony fishes have pyloric ceca (add surface area to small intestine)- apparently for fat absorption



Structural and Functional Adaptations of Fishes

Reproduction and Growth

- Most fishes are **dioecious** (separate sexes) with **external fertilization and external development**
- Guppies and mollies represent ovoviviparous fish that develop in ovarian cavity
- Most oviparous pelagic fish lay huge numbers of eggs
  - Female cod may release 4–6 million eggs
  - Near-shore and bottom-dwelling species lay larger, typically yolky, nonbuoyant and adhesive eggs
  - Some bury eggs
  - Many attach eggs to vegetation
  - Some incubate eggs in their mouth

Fish Development

- Many fish hatch as larval form, with yolk attached
- Transformation from larval form to adult may be accompanied by dramatic change in form, color, gender, etc.
- Most fish continue to grow throughout their lifetime