Systematics, Genetics and Speciation

Fundamentals of Fish Biology

27 January 2014

Why should I listen today?

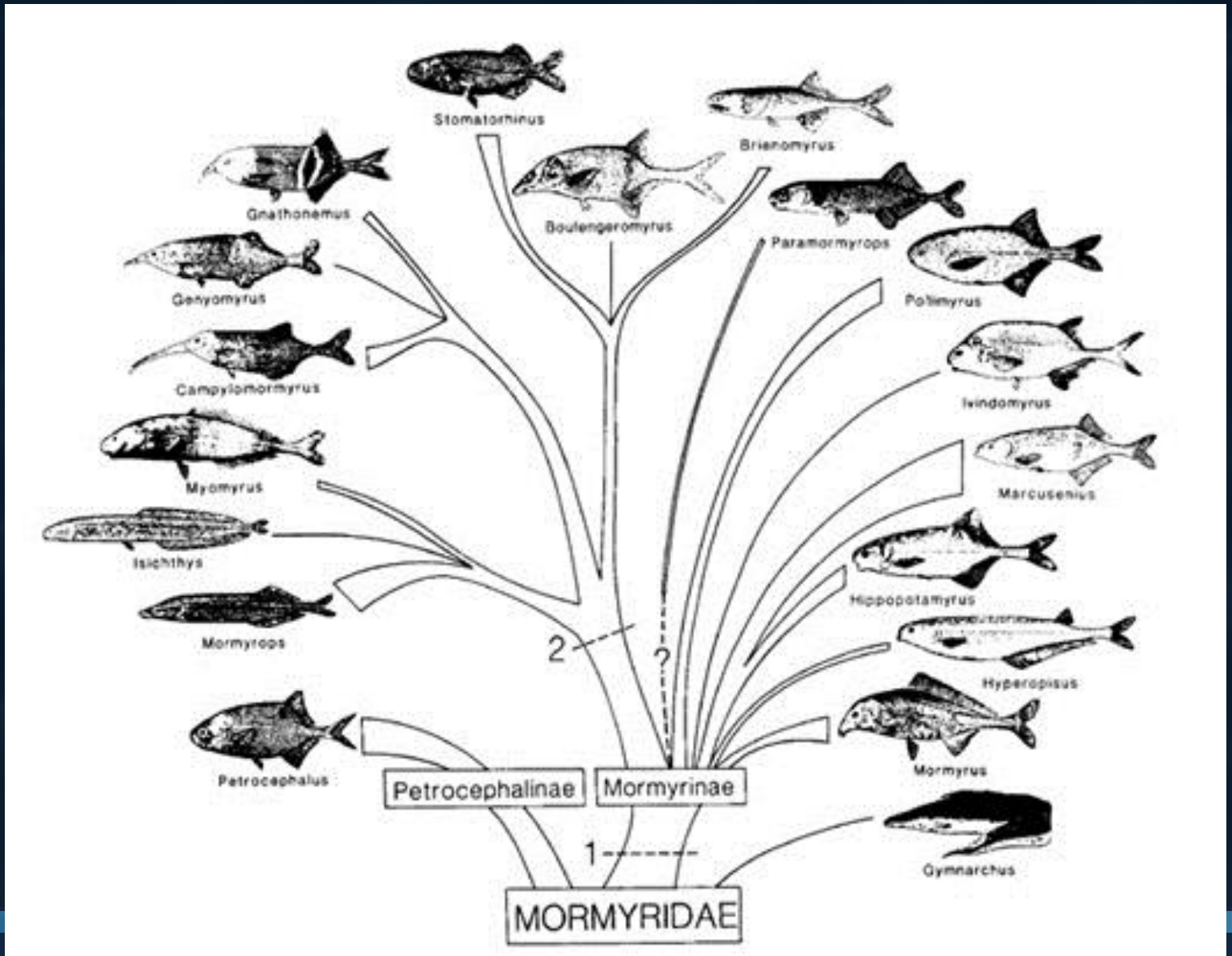
Class objectives

1. understand general terms about Systematics of fish
2. be able to list the five methods of categorizing fish groups
3. understand how species evolve via allopatric and sympatric speciation
4. understand the taxonomy and binomial nomenclature behind the system of naming fish

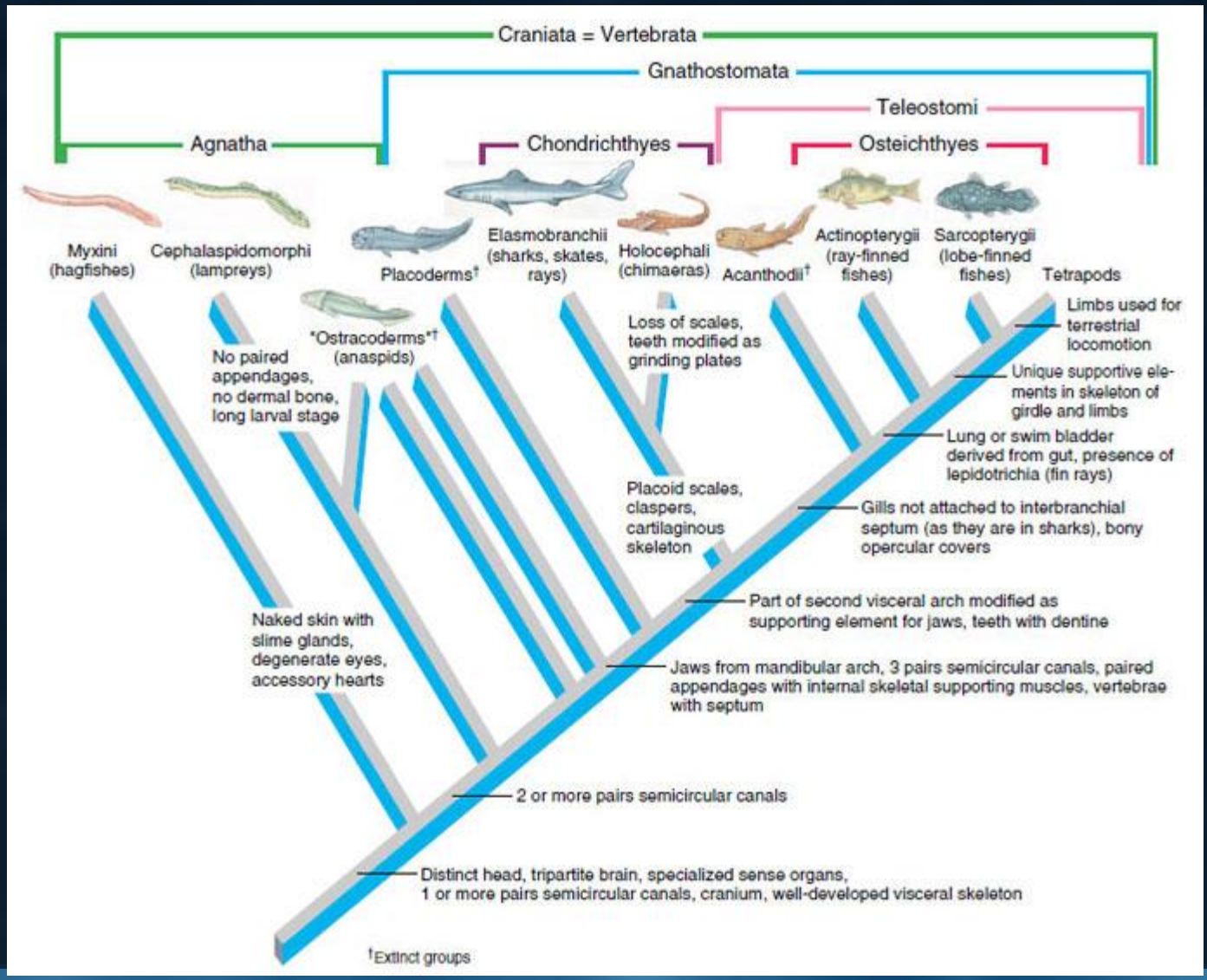
Some definitions

- Systematics – the study of the evolutionary relationship among organisms
- Taxonomy – the science of describing and classifying organisms
- Evolutionary Trees – early diagrams used to show relationships among higher levels
- Phylogenetic systematics –uses branching diagrams called cladograms – each branch represents a monophyletic group of organisms (e.g. species, families, order…) – uses characteristics that can be quantified and therefore reduces subjective classification

Evolutionary Trees



Cladograms


Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms†
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
Ostracoderms† (anaspids)
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, paired appendages with internal skeletal supporting muscles, vertebrae with septum
2 or more pairs semicircular canals
Distinct head, tripartite brain, specialized sense organs, 1 or more pairs semicircular canals, cranium, well-developed visceral skeleton
†Extinct groups

More definitions

- Monophyletic group is a group including an ancestor and all descendants (e.g. vertebrates)
- Paraphyletic group is a group containing some but not all descendants of an ancestor (e.g. dinosaurs)
- Polyphyly is a group containing descendants of different ancestors (e.g. invertebrates)

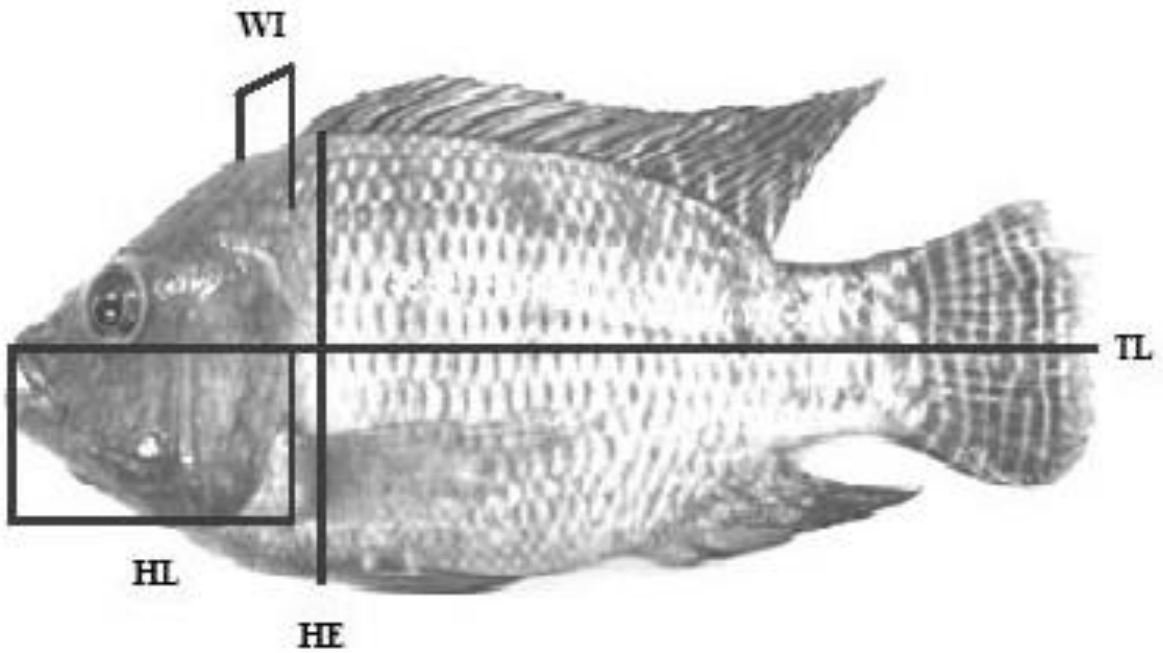
Other ways of classifying fish

- Warm vs cold water fishes (bass and trout)
- Saltwater vs freshwater
- Pelagic or benthic
- Reproductive styles
- Trophic level
- Freshwater fish based on evolutionary history (primary, secondary, diadromy)

Five categories of taxonomic methods

- Morphometric measurements
- Meristic traits – considered most reliable
- Anatomical characteristics
- Color patterns
- Karyotypes – describe number and morphology of chromosomes

1. Morphometric traits



TL - total length; HL - head length; HE - height; WI - width.

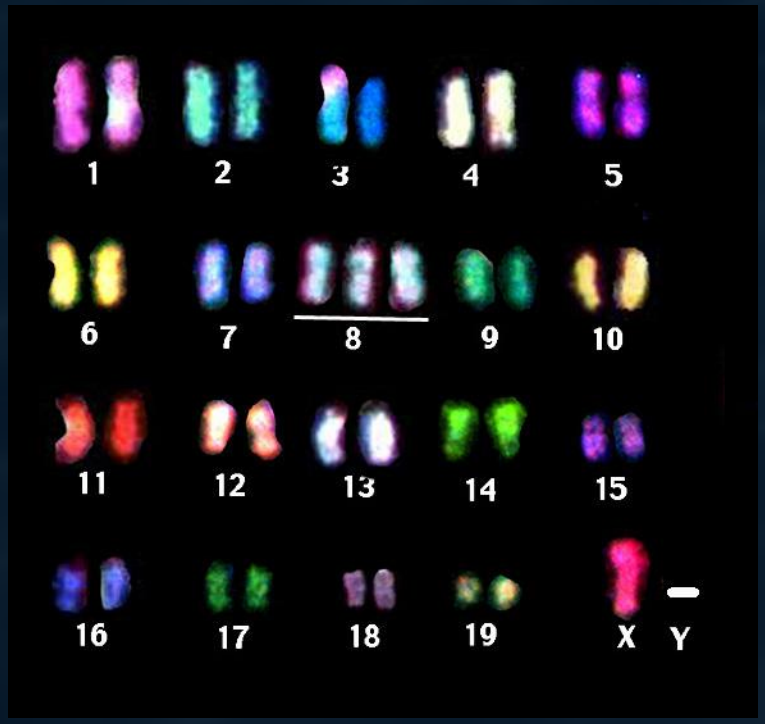
Figure 1 - Morphometric measurements obtained in Nile tilapia from ponds and net-cages.

2. Meristic traits

3. Anatomical traits

4. Color patterns

5. Karyotypes



Genetic variaiton

- Largely exhibited in fish
- **Phenotypic and genotypic**
  - Phenotypic = expressed
  - Genotypic = genetic makeup
- Heterozygosity
- Environmental influences


American Eel- *Anguilla rostrata*
averages 24-40 inches

Break 1

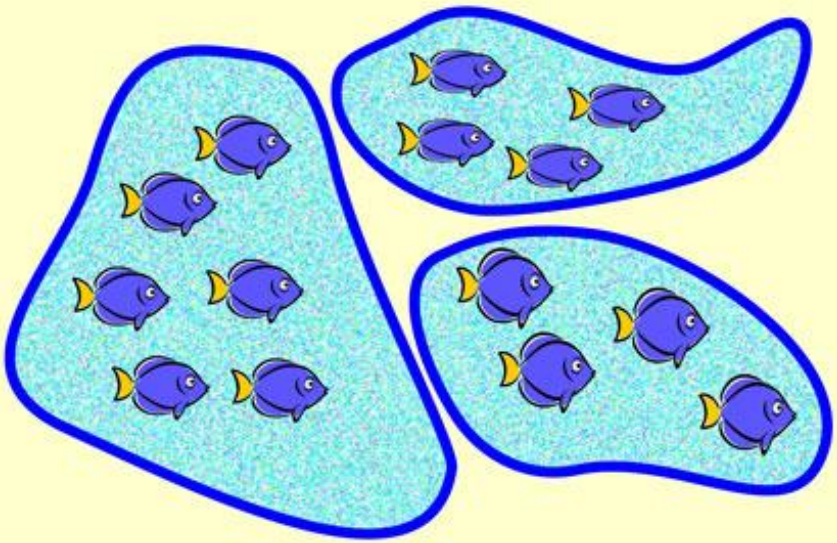
Local adaptation

“a process that increases the frequency of traits which enhance the survival and reproductive success of individuals in a particular environment

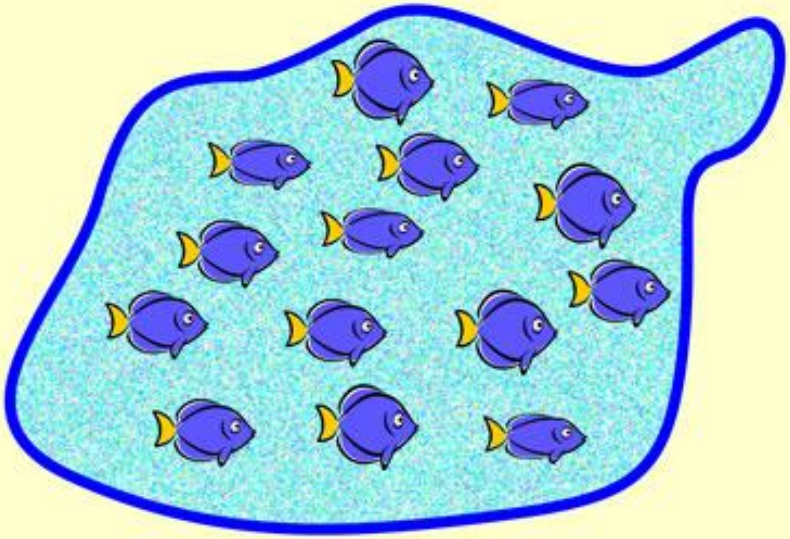
-Carvalho, 1993

Speciation

- Allopatric – different geographic regions
- Sympatric – same geographic region

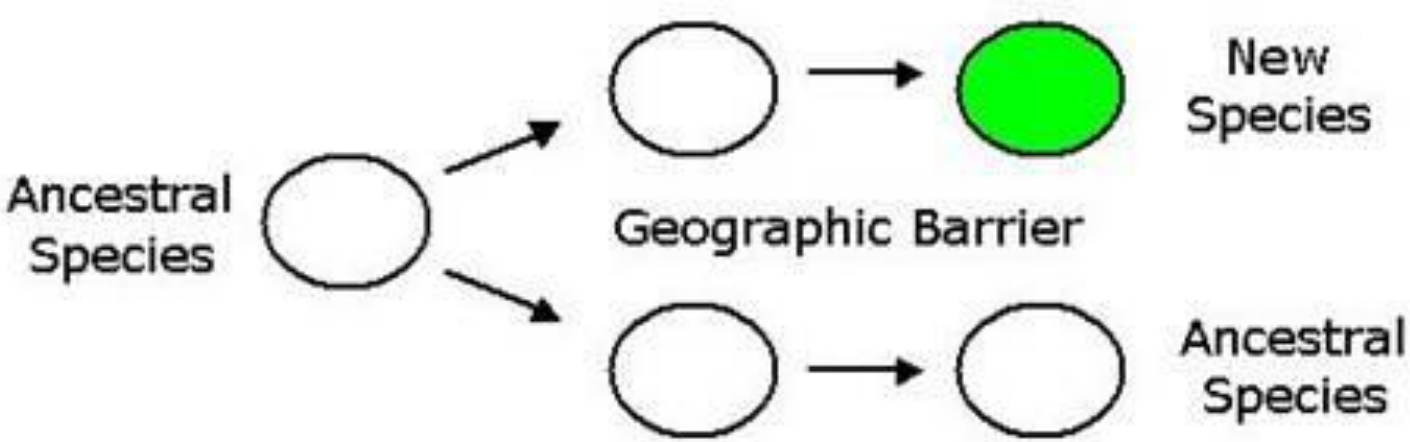


Allopatry:
Each variety in its own range
Become species due to drift and
local adaptation

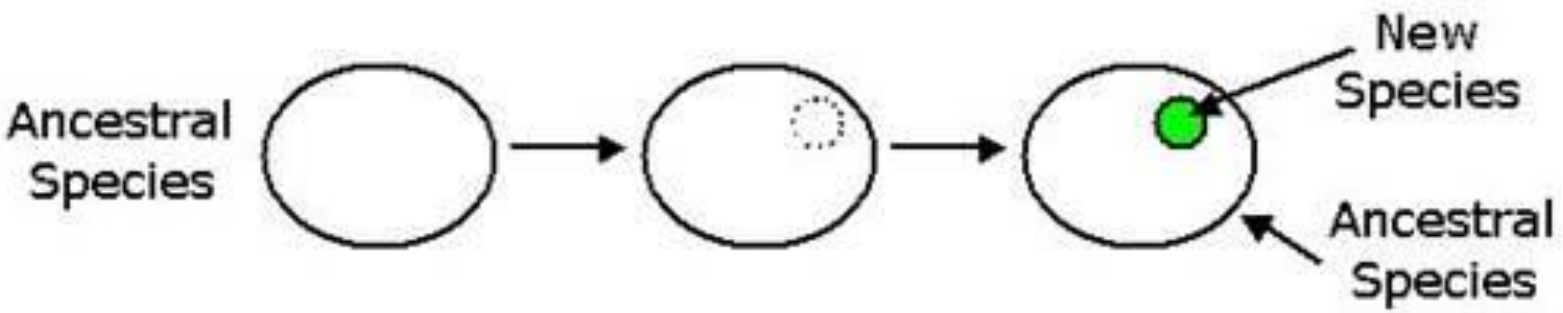


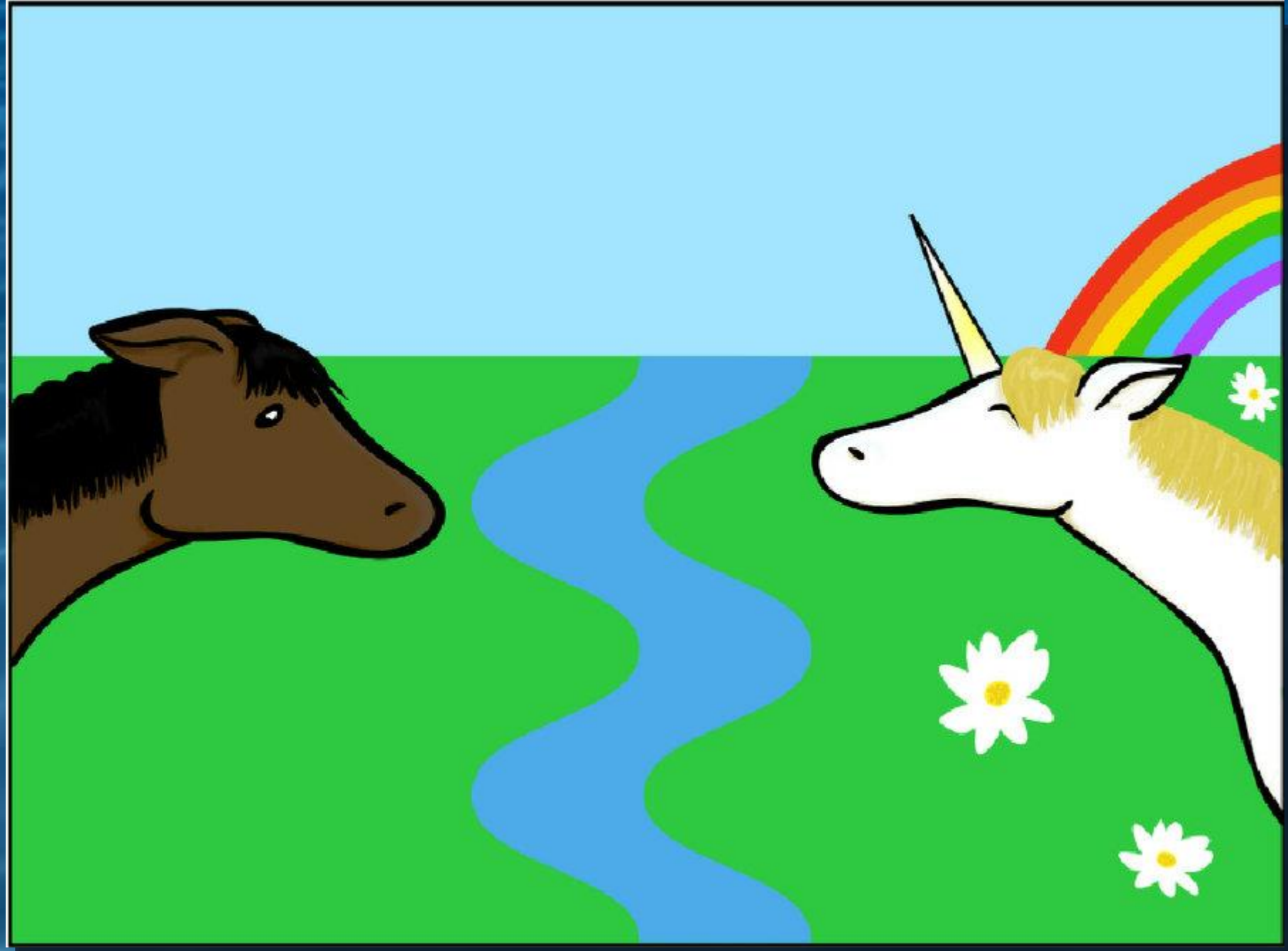
Sympatry:
Many varieties in one range
Become species through adaptation
to different aspects of the range

Allopatric Speciation



Sympatric Speciation





Character displacement

- Concept of a fish changing to meet external changes or challenges


© Nature's Images Inc.

How do species evolve?

- Allopatric vs sympatric speciation
- Ecological speciation – growing in acceptance as reason for speciation

How long does it take?

- Can occur rapidly
- For changes to reach adaptive differentiation to species level, estimates range from 100,000 to several million years
- But we see fish responding to recent glacial events –
- Three spine sticklebacks in BC diverged in 8,000-10,000 years; some South African lake fishes in <12,000 years
- Some freshwater spp occur in just a few hundred years

Hybrids

- More common in fresh water
- Significant gene flow?
- Natural Conditions?
- Hybrid sterility common in fishes

Fish bio is dynamic

- Nomenclature always changing!
- Heavily debated
- Taxonomic system used:
- Kingdom – Phylum – Class – Order – Family – Genus – Species

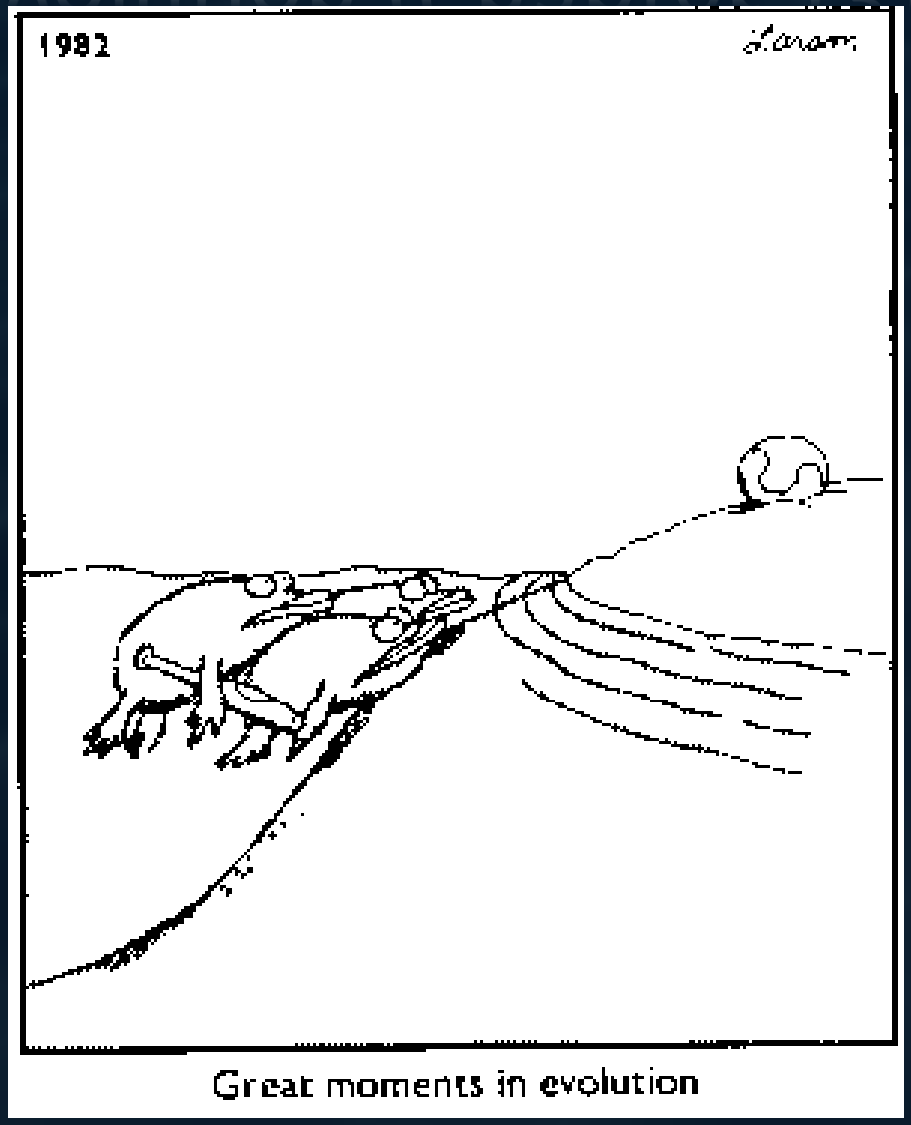
Species Names

- Common names used often
- Scientific names Genus and species
- Mix of latin and greek
- Coho Salmon –
- *Oncorhynchus kisutch* (Walbaum, 1792)

- Genetic drift - http://www.youtube.com/watch?v=tYOG3HzJvak

Break 2

Evolution (Chapter 13)



Understanding the past

Fish Story

FISH WERE THE FIRST ANIMALS WITH backbones. They are the ancestors of all vertebrates, including people. Fish eventually became the greatest predators in the sea, but the earliest ones couldn't even bite–they didn't have jaws!

Where Did Fish Come From?

The first vertebrates may have come from a sea creature like the modern tunicate (TOON-ih-kate), or sea squirt. When tunicates reproduce, they release tiny larvae into the water. These larvae have a primitive spinal cord that usually disappears when they become adults. Tunicates that never grew up might have been the ancestors of all animals with backbones, including you.

Coccosteus

Early fish evolved armor plates of bone to cover their bodies.

Bothriolepis

Pteraspis

Thelodus

Arandaspis

Over millions of years, some plates became fish scales, skull bones, skeletons, and other things.

Fish have long, narrow shapes that are ideal for cutting through the water.

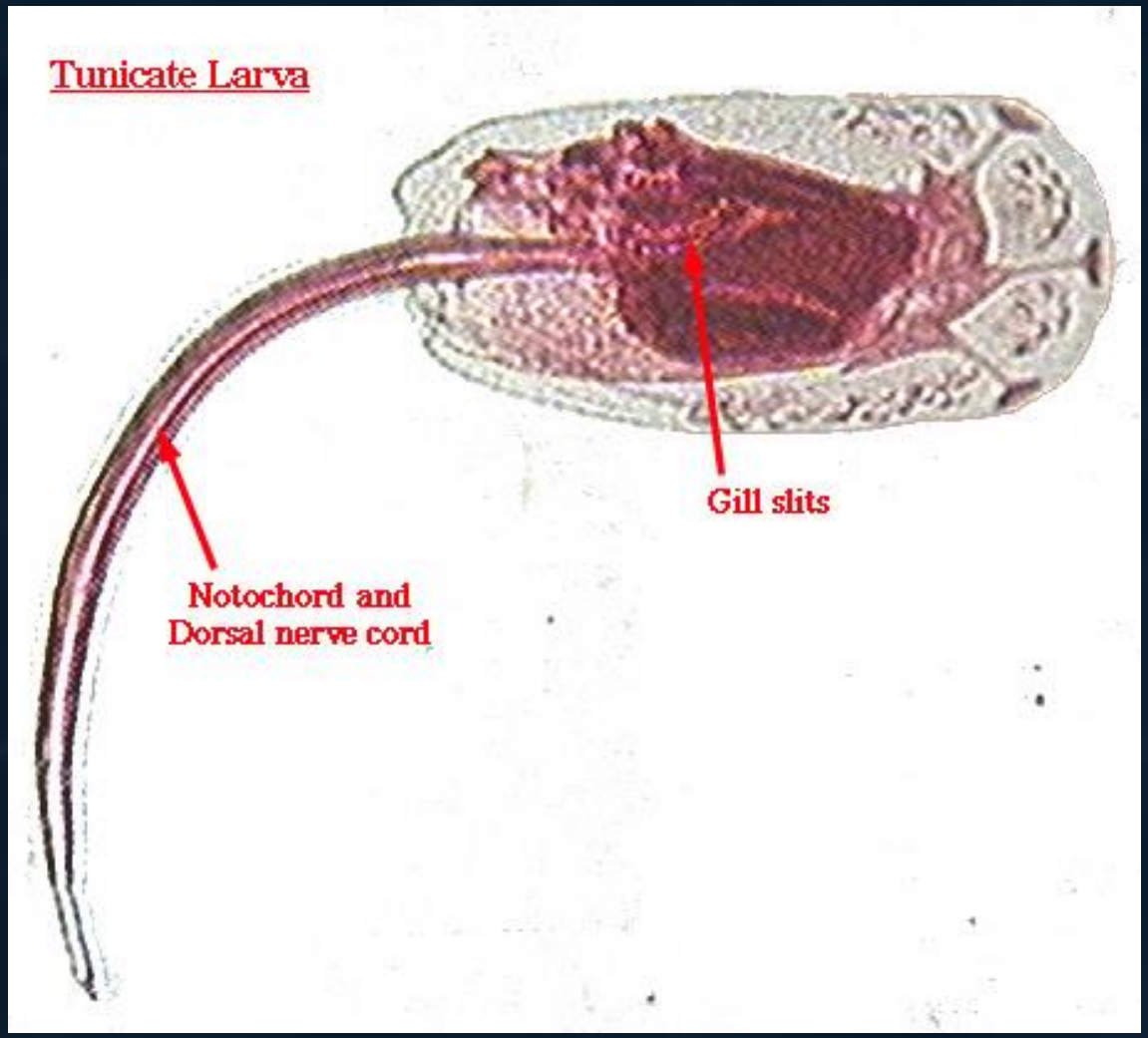
Ichthyodus

Some jawless fish swallowed sediment with their suckerlike mouths. Their intestines digested food within the sediment.

Fish were the first animals with skeletons made of bone. [illegible] fish developed strong jaws to help them swim fast and [illegible]

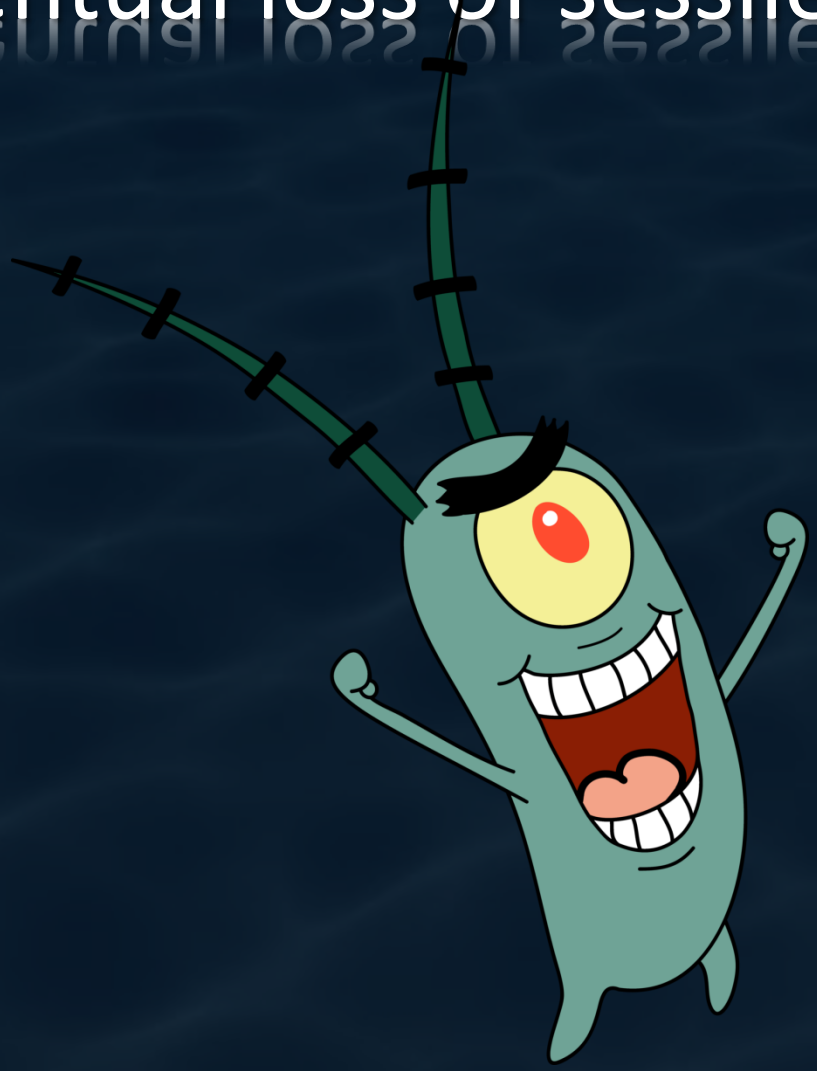
Your teeth evolved from scales!

1st forms were sessile chordates

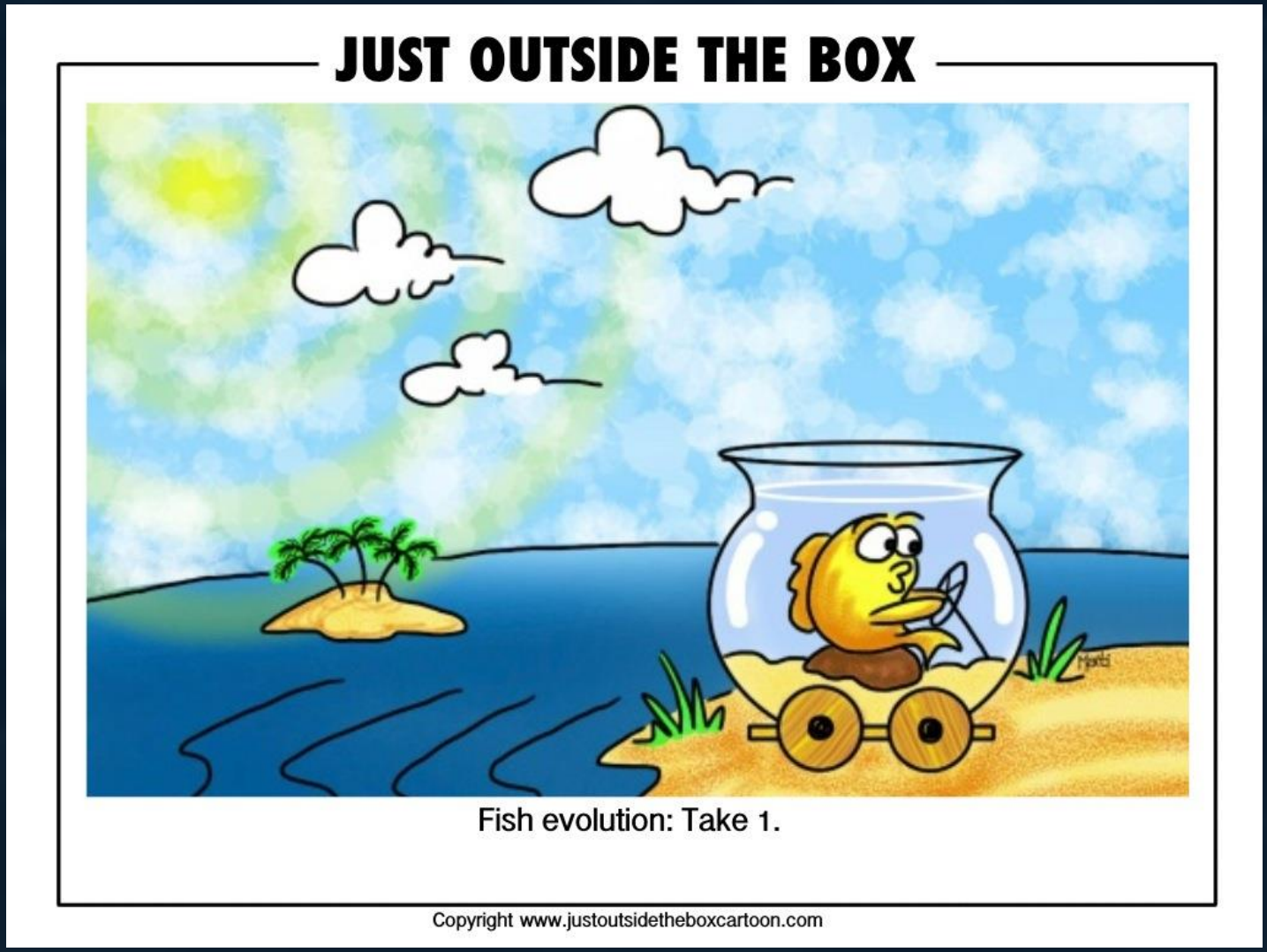


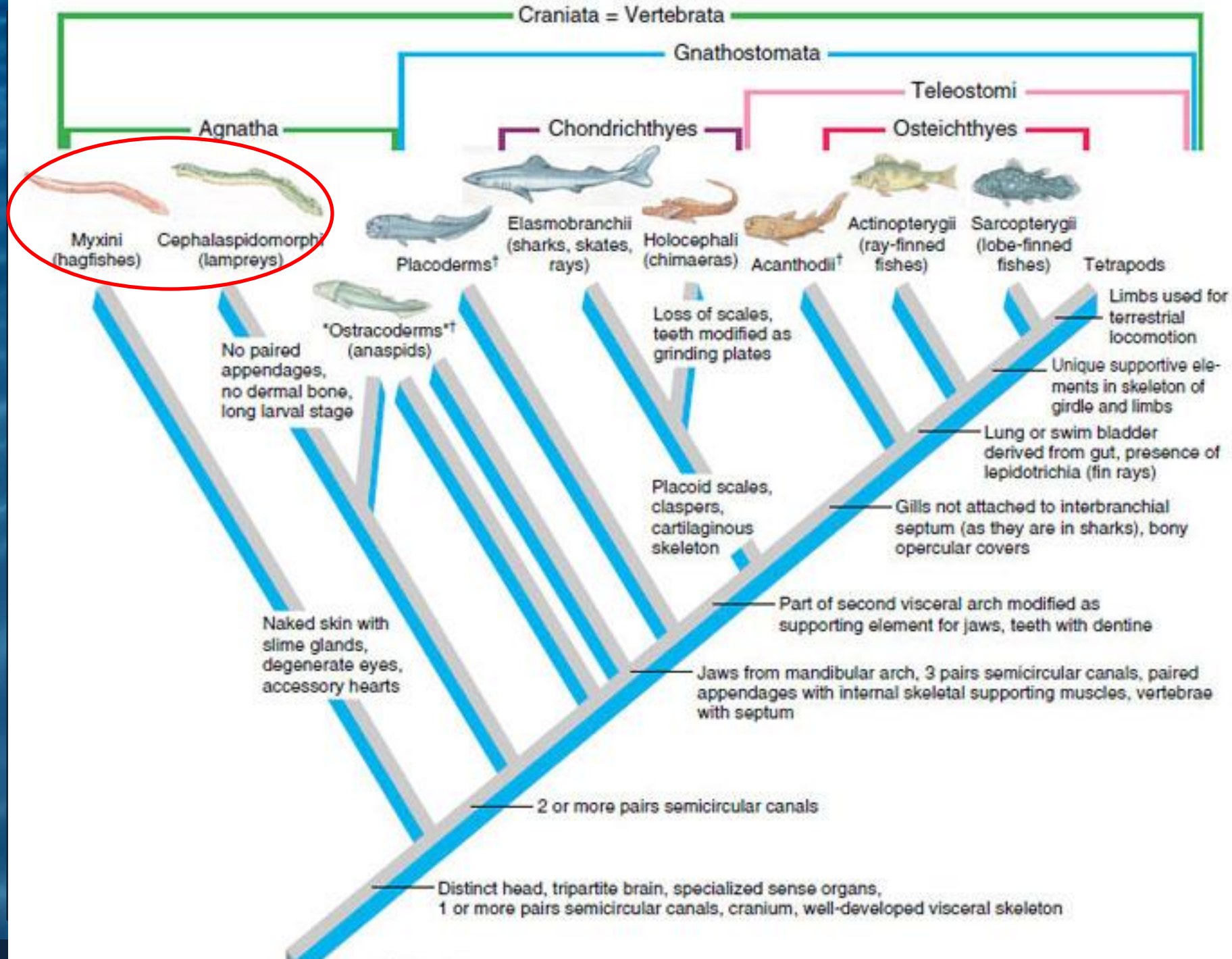
Actively swimming larvae could ensure success

Eventual loss of sessile stage



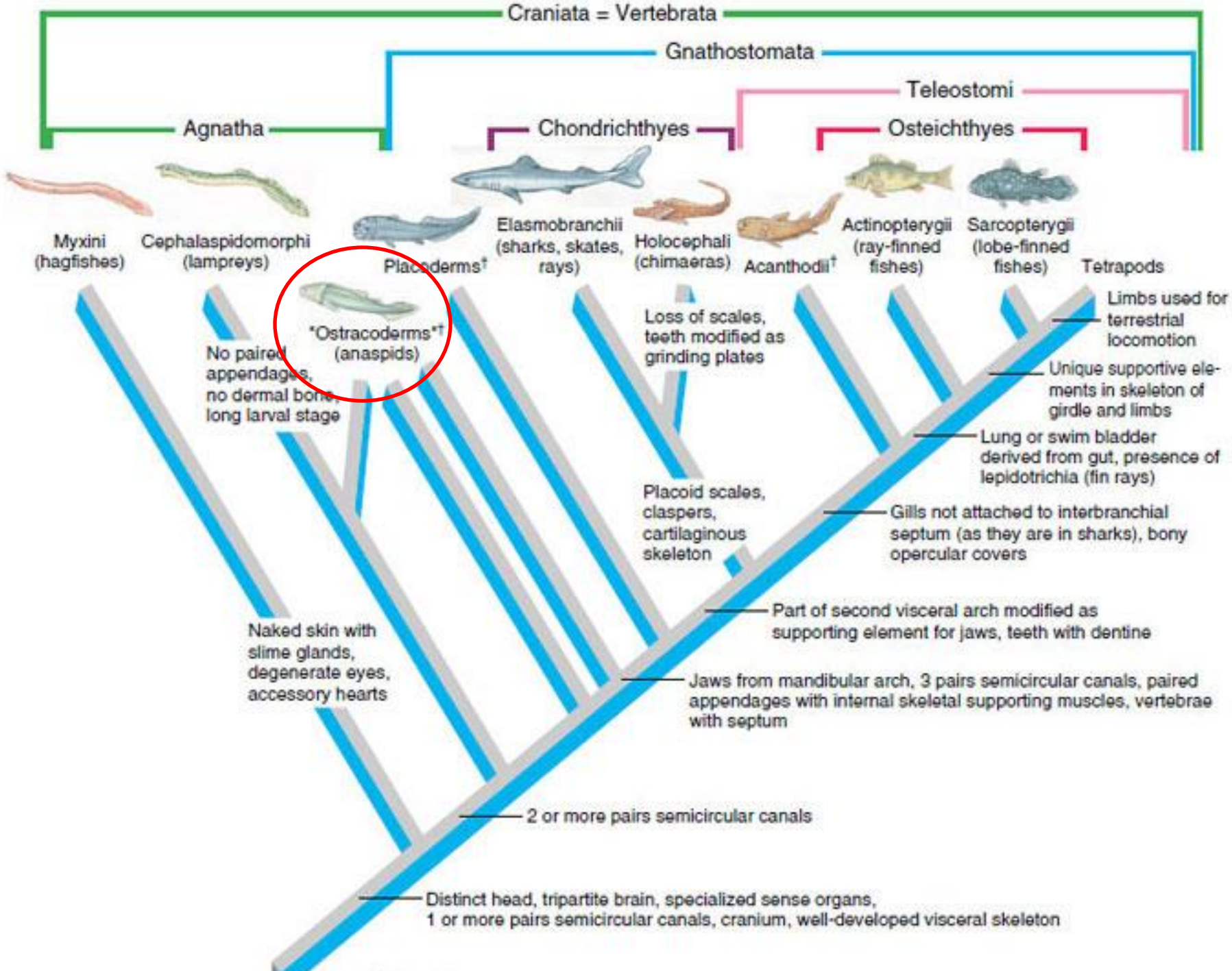
Where did this occur?



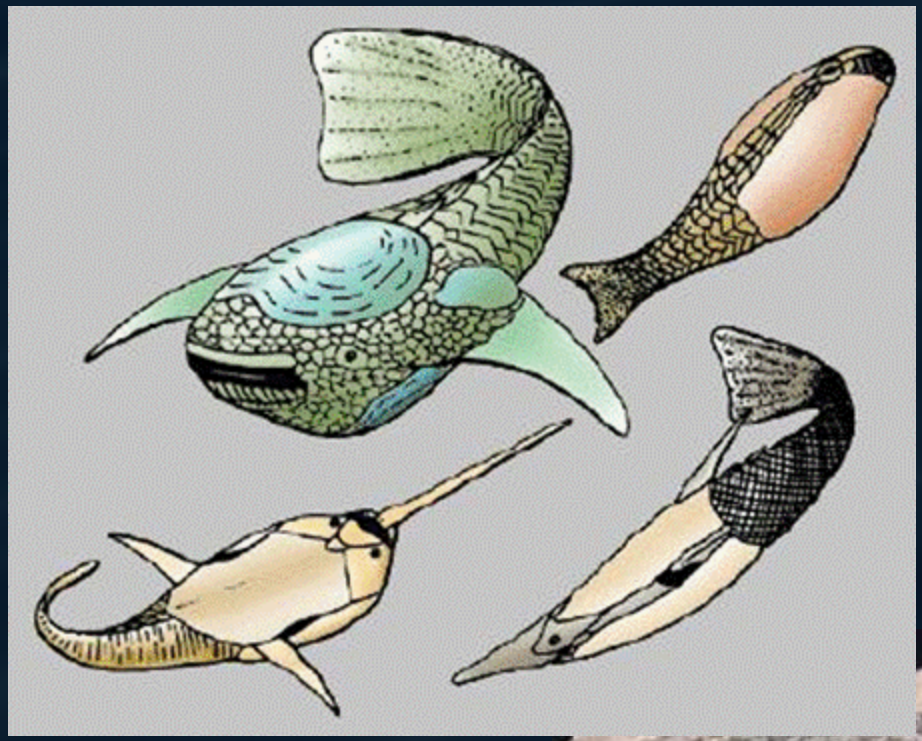

Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms†
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
Ostracoderms† (anaspids)
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, paired appendages with internal skeletal supporting muscles, vertebrae with septum
2 or more pairs semicircular canals
Distinct head, tripartite brain, specialized sense organs, 1 or more pairs semicircular canals, cranium, well-developed visceral skeleton

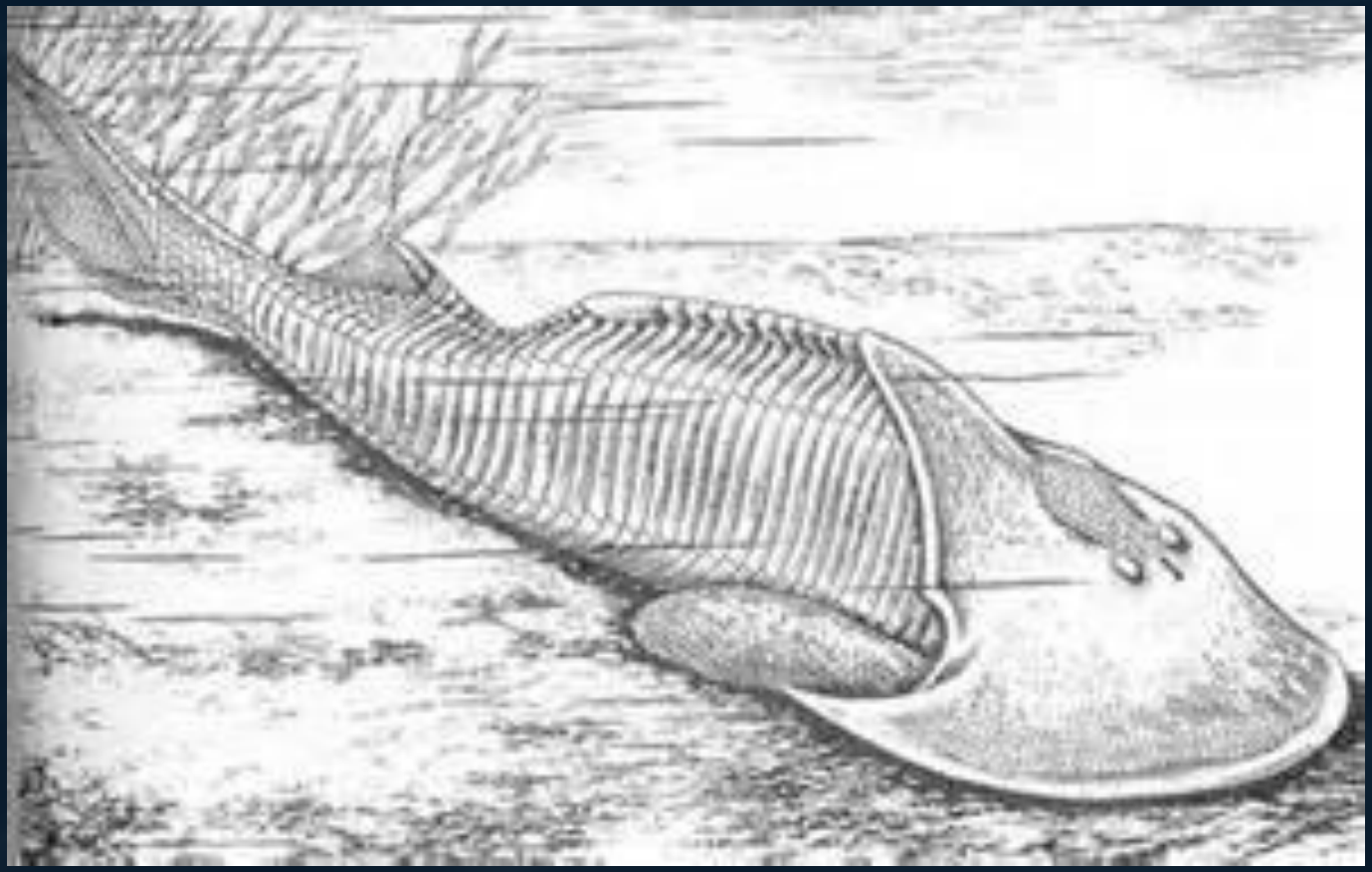
Agnatha – jawless fish

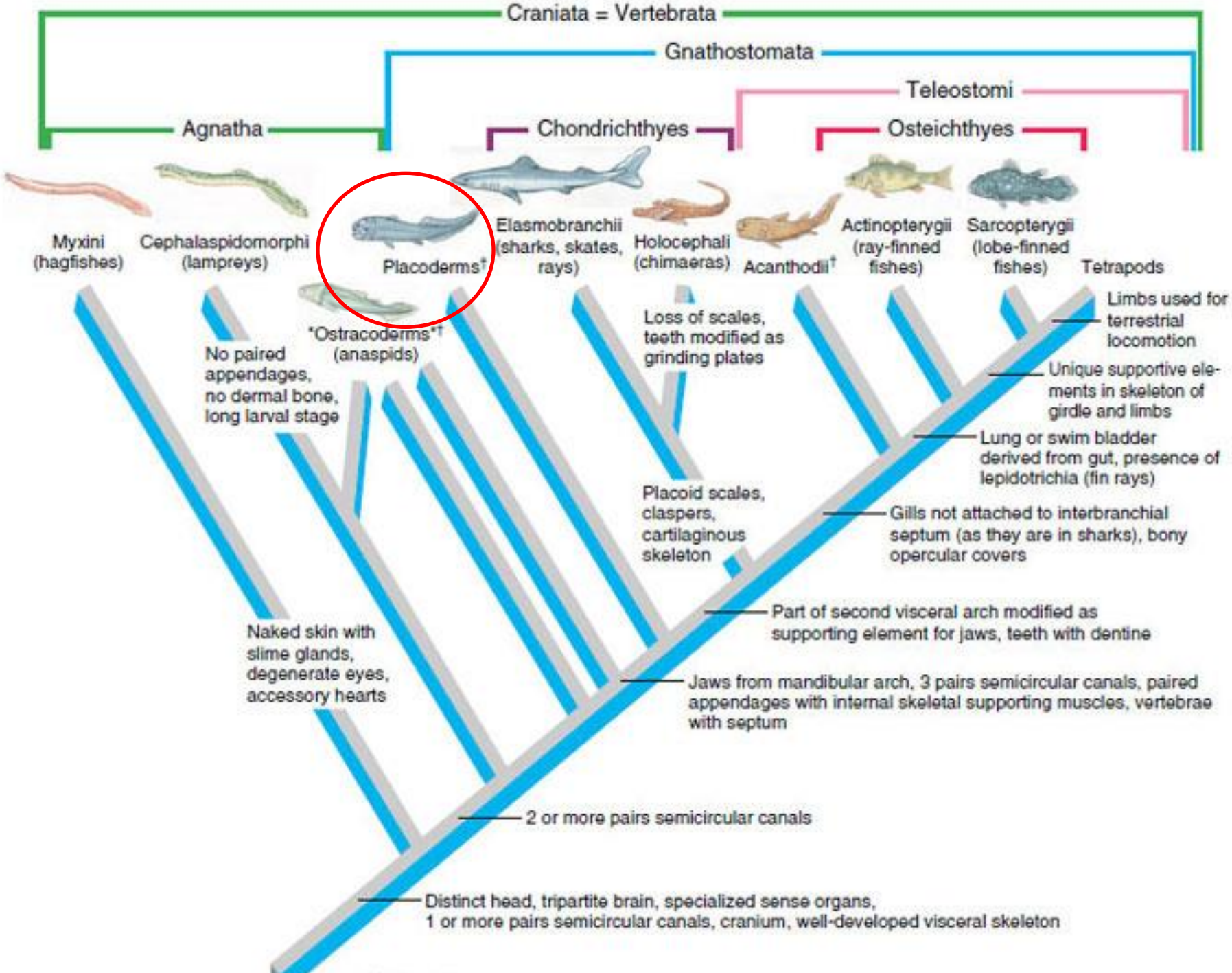
- Jawless
- No scales
- Produce slime
- External fertilization
- No paired appendages


Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms†
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
Ostracoderms† (anaspids)
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, paired appendages with internal skeletal supporting muscles, vertebrae with septum
2 or more pairs semicircular canals
Distinct head, tripartite brain, specialized sense organs, 1 or more pairs semicircular canals, cranium, well-developed visceral skeleton

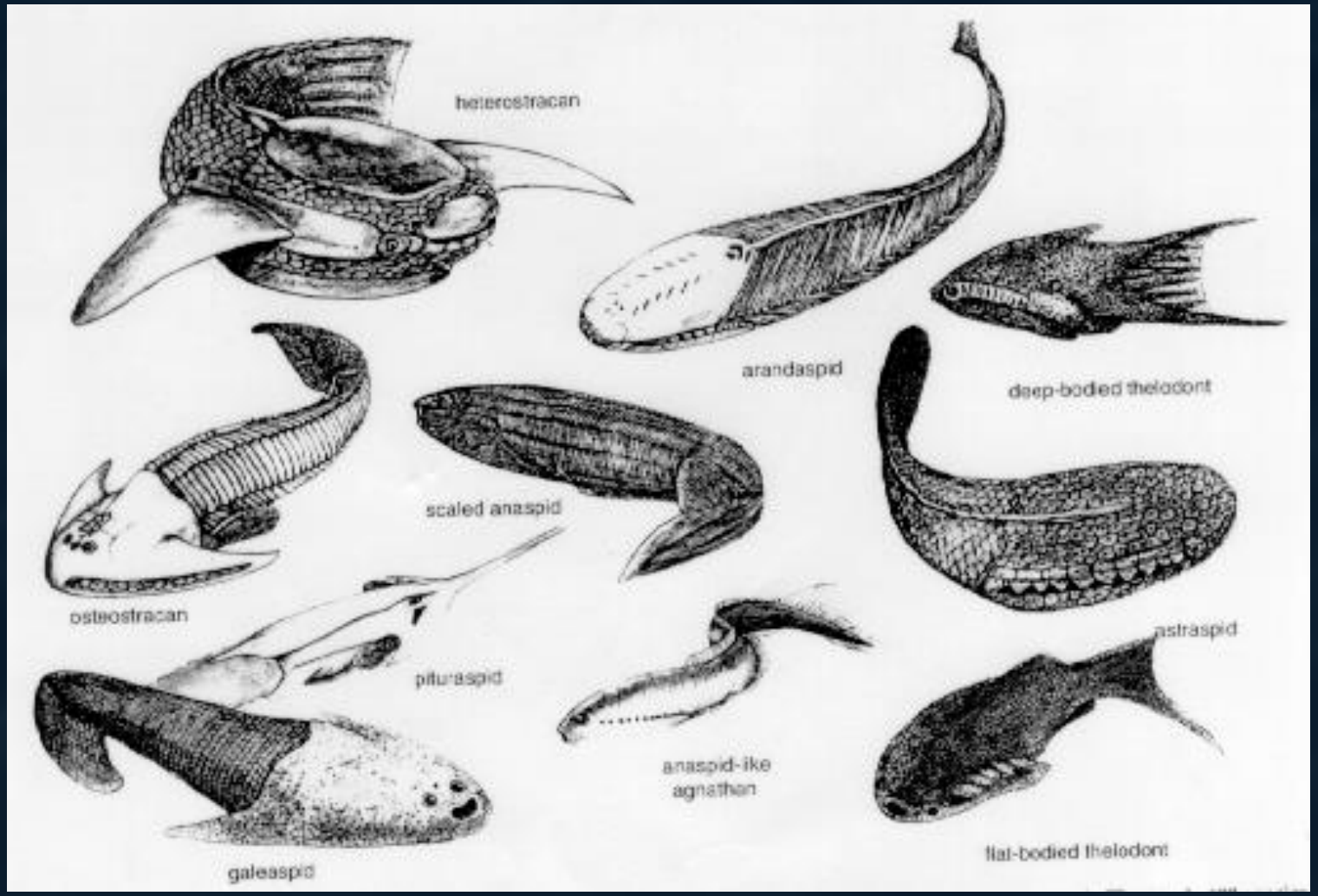
Ostracoderms – shell skinned

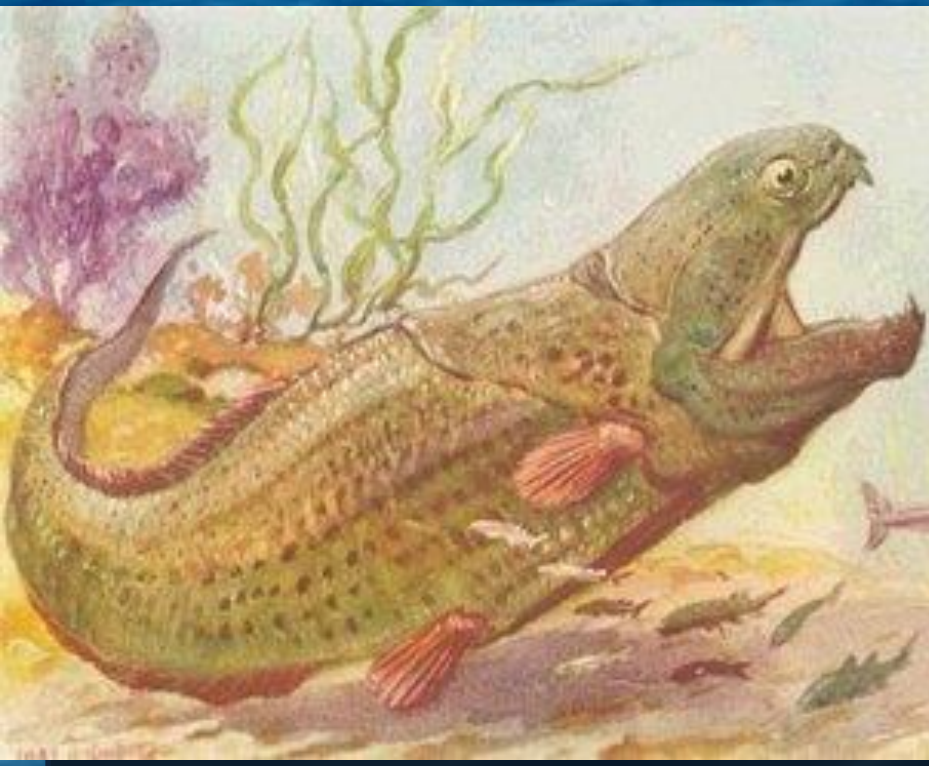


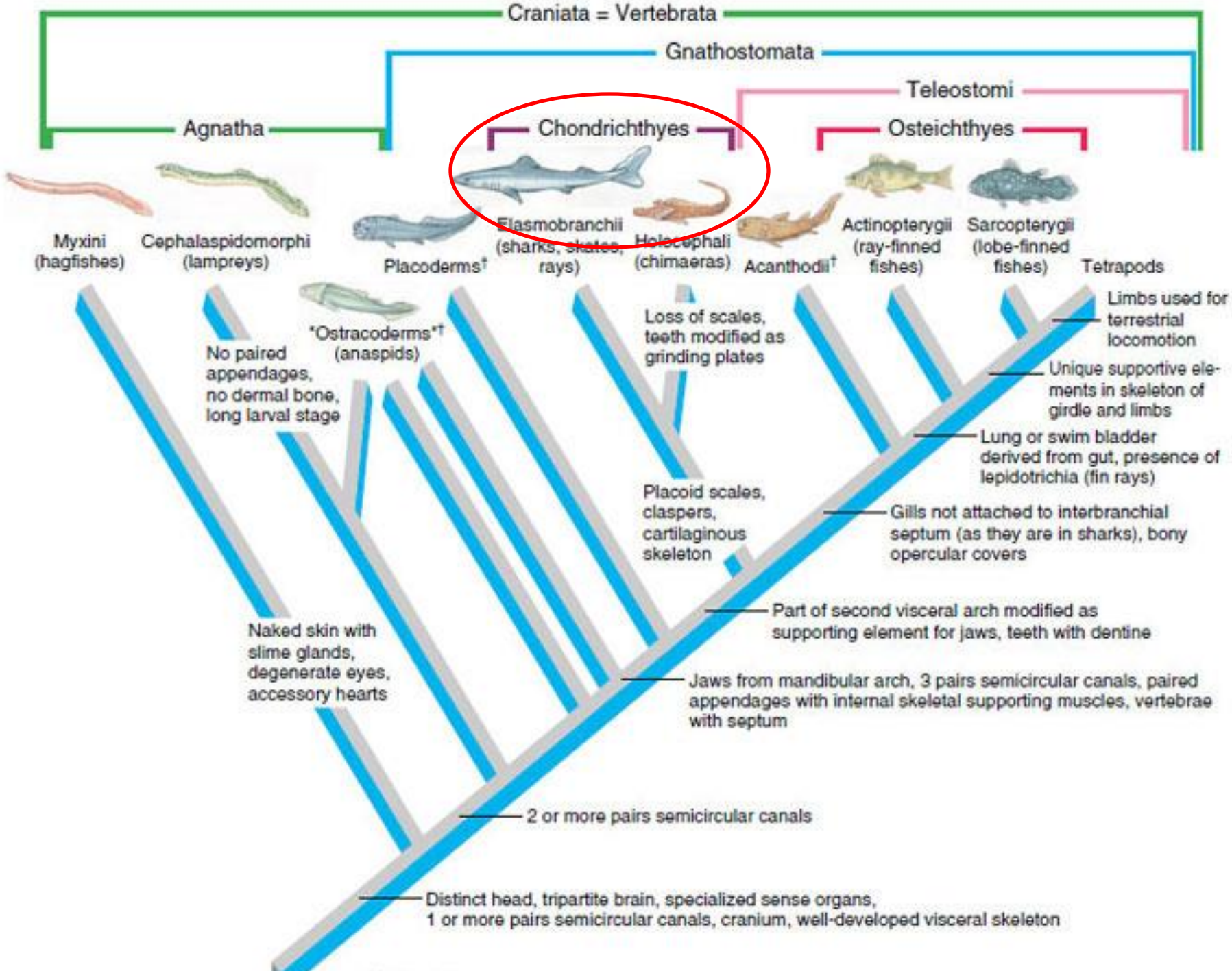



Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms*
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
Ostracoderms† (anaspids)
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, paired appendages with internal skeletal supporting muscles, vertebrae with septum
2 or more pairs semicircular canals
Distinct head, tripartite brain, specialized sense organs, 1 or more pairs semicircular canals, cranium, well-developed visceral skeleton

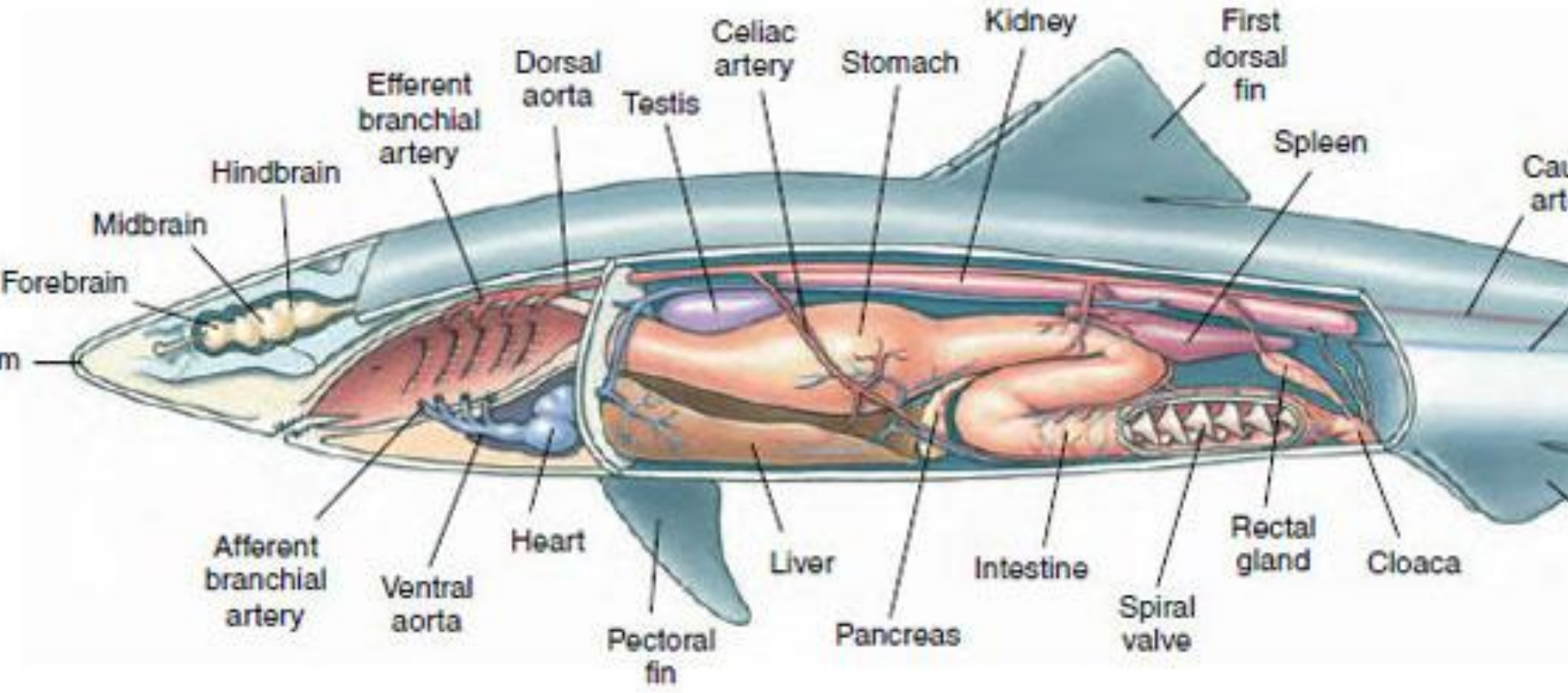
Placoderms – plate skinned






Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms†
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
Ostracoderms† (anaspids)
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, paired appendages with internal skeletal supporting muscles, vertebrae with septum
2 or more pairs semicircular canals
Distinct head, tripartite brain, specialized sense organs, 1 or more pairs semicircular canals, cranium, well-developed visceral skeleton

Chondrichthyes


Celiac artery
Kidney
First dorsal fin
Dorsal aorta
Efferent branchial artery
Testis
Stomach
Spleen
Hindbrain
Midbrain
Forebrain
Afferent branchial artery
Ventral aorta
Heart
Liver
Intestine
Rectal gland
Cloaca
Spiral valve
Pancreas
Pectoral fin

Two distinct evolutionary lines

- Elasmobranchii

Holocephali

Elasmobranchii (“*metal plate and gills*”)

Cartilagenous skeleton = few remains except teeth

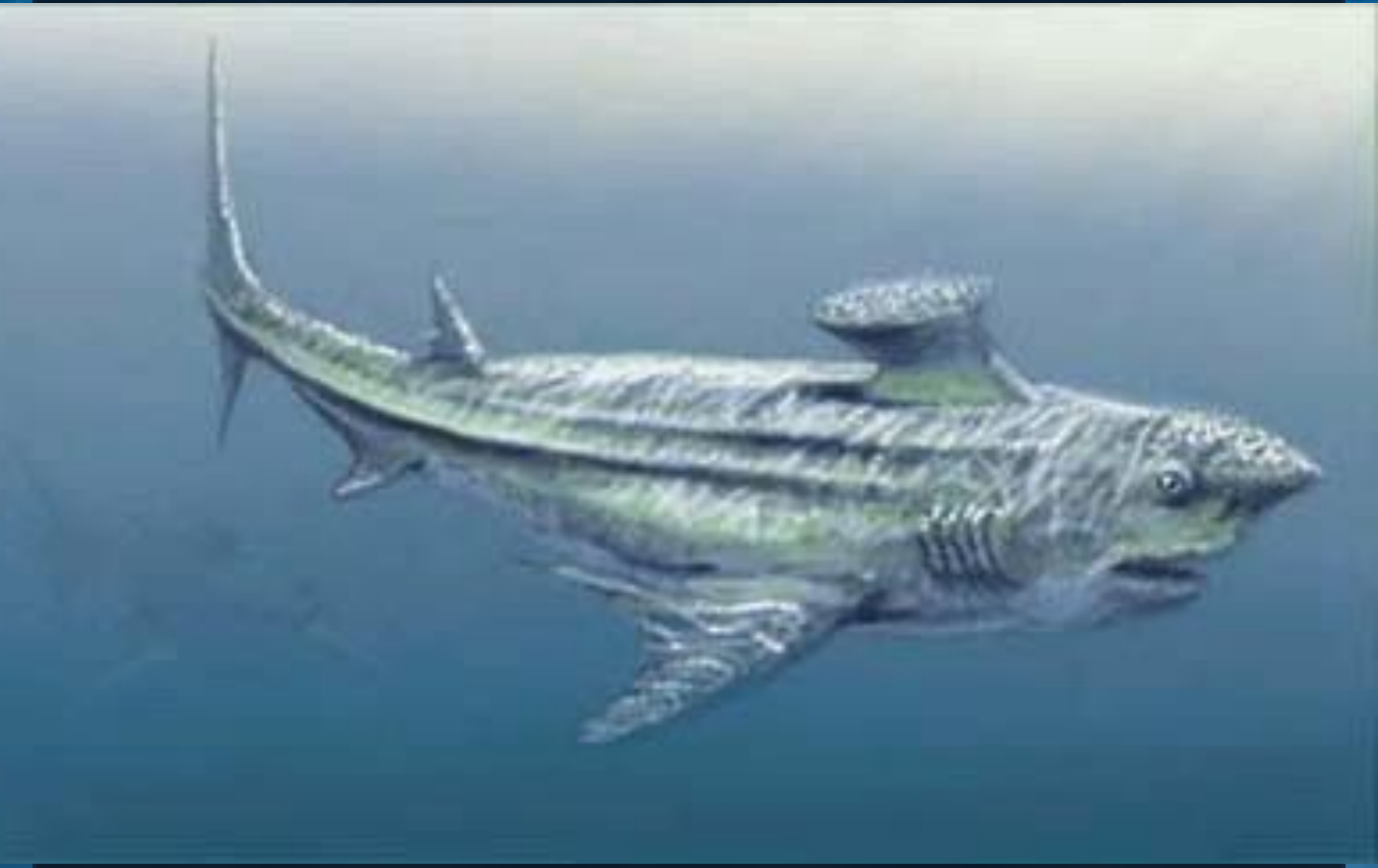
Key characteristics =

1. 5 to 7 gill openings
2. spiracle
3. placoid scales
4. upper jaw not fused to cranium
5. lower jaw attached
6. teeth numerous and replaced rapidly

Top level carnivores that are not particularly dependent upon sight for prey capture

Shark evolution is poorly understood

http://www.newark.osu.edu/facultystaff/personal/jstjohn/Documents/Cool-fossils/Paleozoic-fish.htm



Holocephali (“*complete head*”)

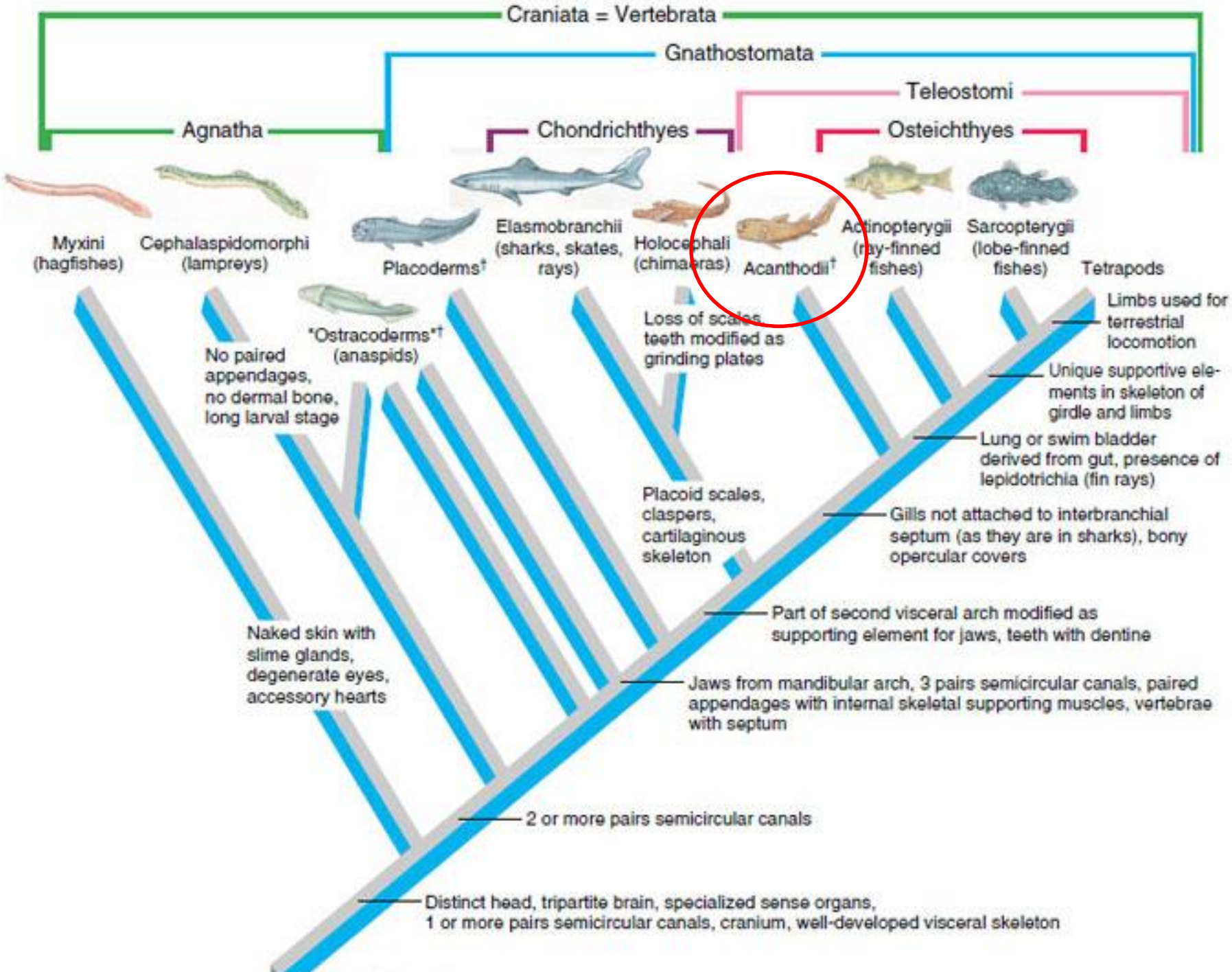
Also known as the Chimerans

Bottom dwelling

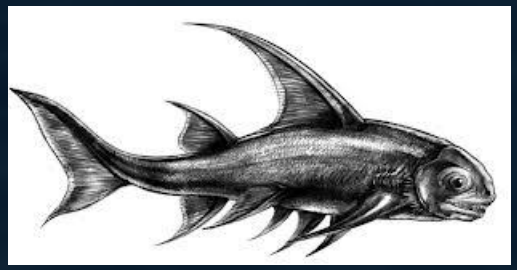
Invertebrate feeding

Characteristics include:

1. Single gill cover
2. 4 gill openings
3. no spiracle
4. upper jaw fused to cranium
5. only a few teeth that are flat and platelike
6. no scales
7. males have a clasper on their head as well as the ones on the pelvic fins


Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms†
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
Ostracoderms† (anaspids)
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, paired appendages with internal skeletal supporting muscles, vertebrae with septum
2 or more pairs semicircular canals
Distinct head, tripartite brain, specialized sense organs, 1 or more pairs semicircular canals, cranium, well-developed visceral skeleton

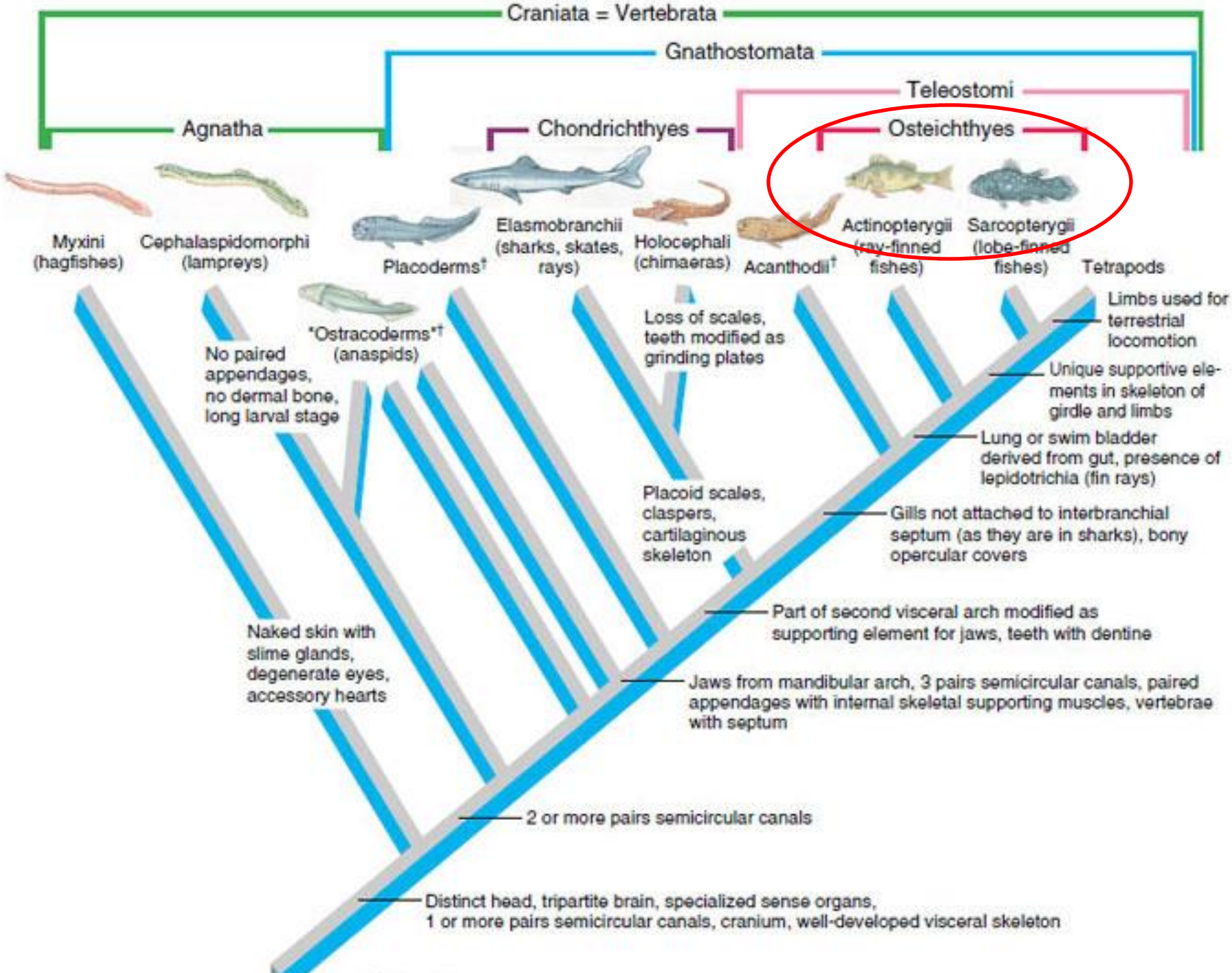
Acanthodii (“*spiny sharks*”)



Oldest known jawed vertebrates

Key characteristics:

1. Most were small (<20cm)
2. Large eyes
3. Flexible, streamlined bodies covered with bony dentine-tipped scales
4. Stout ornamented spines in front of all fins
5. Paired fins


Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms†
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
Ostracoderms† (anaspids)
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, paired appendages with internal skeletal supporting muscles, vertebrae with septum
2 or more pairs semicircular canals
Distinct head, tripartite brain, specialized sense organs, 1 or more pairs semicircular canals, cranium, well-developed visceral skeleton

Osteichthyes (“*Bony Fishes*”)

Very diverse

Key characteristics:

1. presence of lungs -derived swim bladder (lungs are still found in South American lungfish and tetrapods

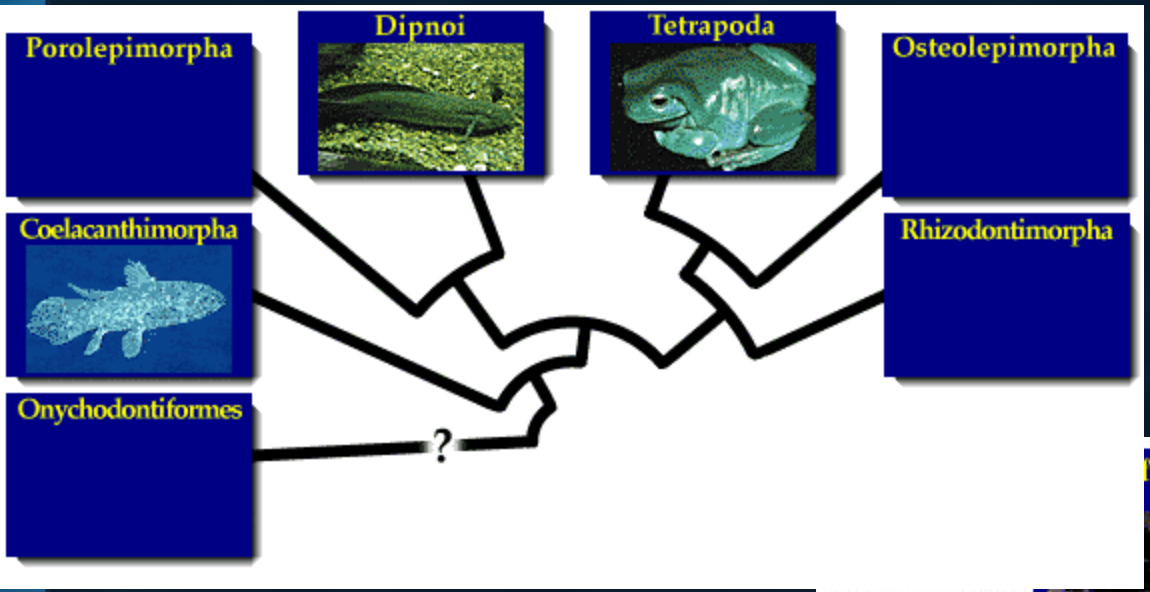
2. presence of bone – lost in some spp, most have dermal bone in skull and jaws

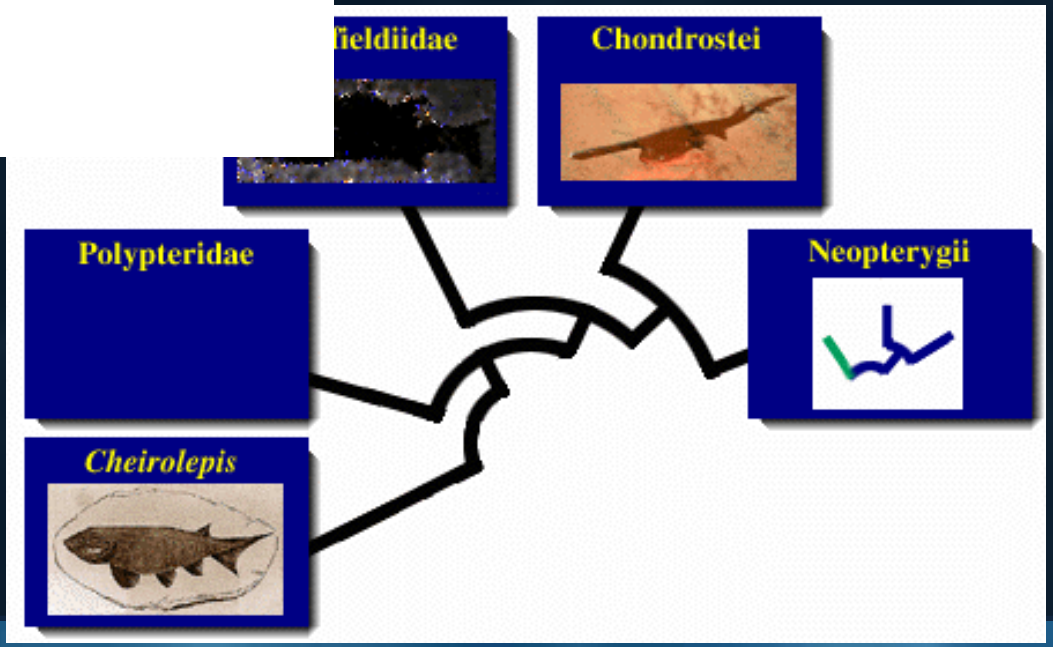
3. bony scales – heavy bone is lost and replaced by flexible, thin and strong scales made of isopedine.

4. lepidotrichia – probably derived from scales, are the soft, segmented fin rays


© D. Randle 2002

Sarcopterygii vs Actinopterygii



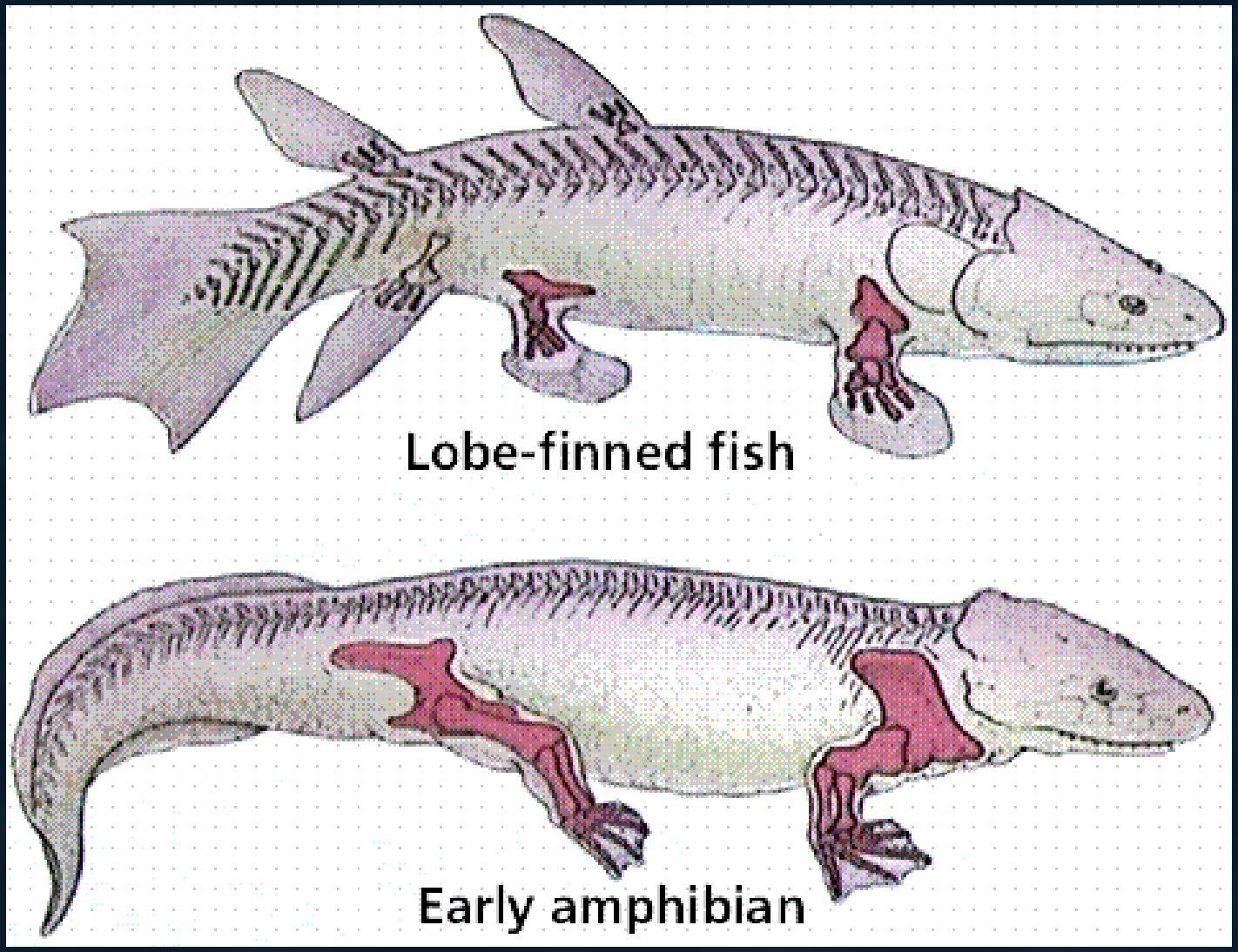


Sarcopterygii (“*lobe-finned fish*”)

Make up the coelacanths, lungfish and osteolepids

Key characteristics:

1. fins with bony leg-like structures

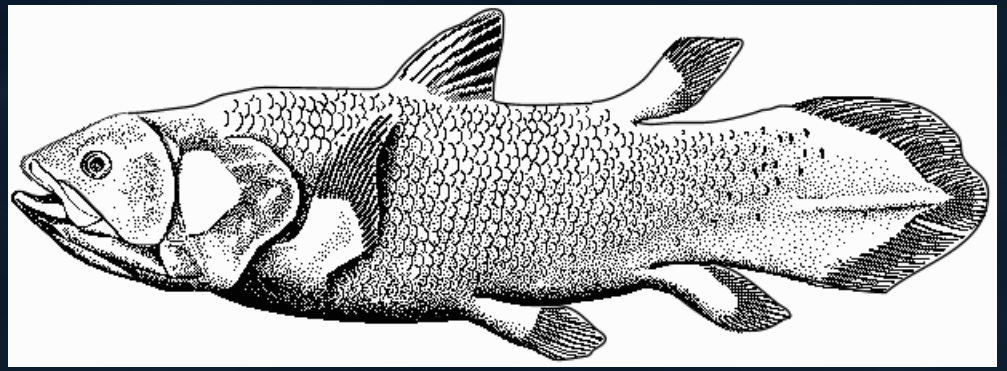

Lobe-finned fish
Early amphibian

Coelacanths

Key characteristics:

1. 3 lobed tail
2. Forward-placed dorsal fin
3. Large cosmoid scales
4. external nostrils

Evolved initially in FW, moved to shallow water marine habitats, disappeared from the fossil record, and then were re-discovered in 1938 off the African and Indian costs



Lungfish

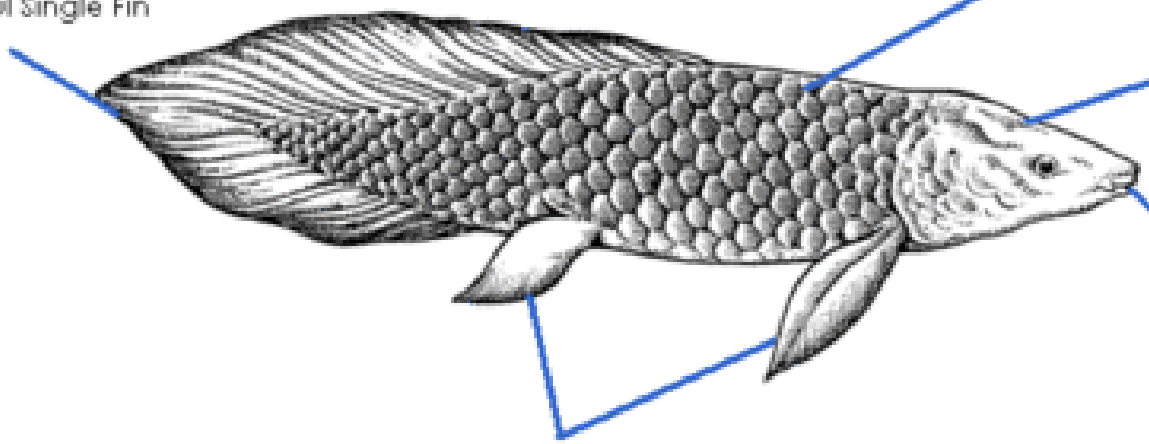
Live in freshwater and are prone to stagnation

Key characteristics:

1. lungs
2. cartilagenous skeleton
3. internal nostrils
4. plate-like teeth
5. spiral valve intentine

Closest piscine relatives of the tetrapods

Average Length: 115cm



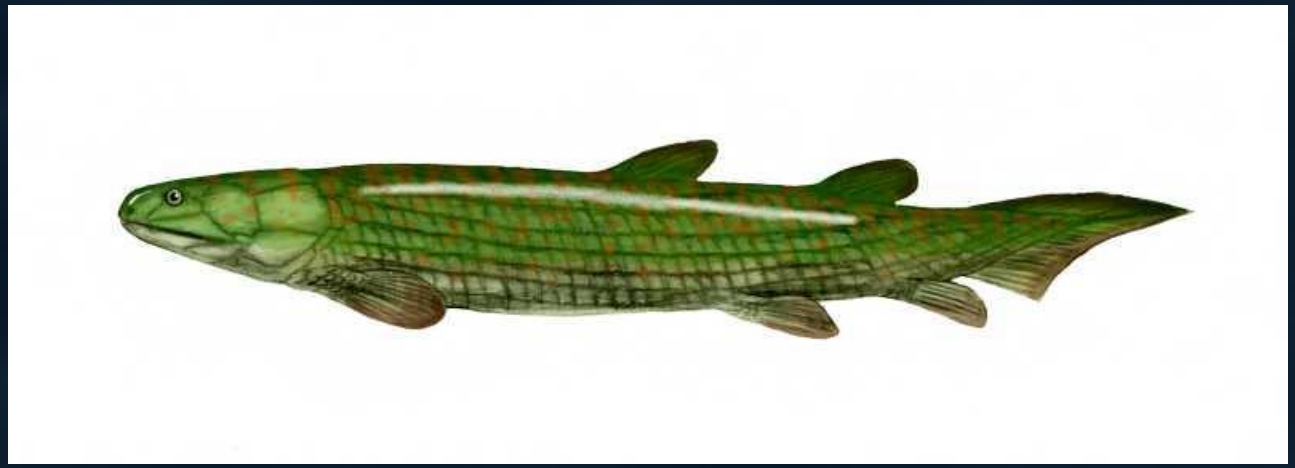
Source:http://www2.dpi.qld.gov.au/images/1877.gif

Osteolepids

Thought to be the intermediary between fish and amphibians
Key characteristics:

1. lobed fins
2. means of jaw suspension
3. structure of teeth
4. bony elements in lobed fins that link them to tetrapods

Most were armored, air-breathing predators of tropical freshwater environments




The Virtual Fossil Museum
www.fossilmuseum.net

- http://www.youtube.com/watch?v=tYOG3HzJvak

Actinopterygii (“*ray-finned fish*”)

Chondrostei

Original ray-finned fish

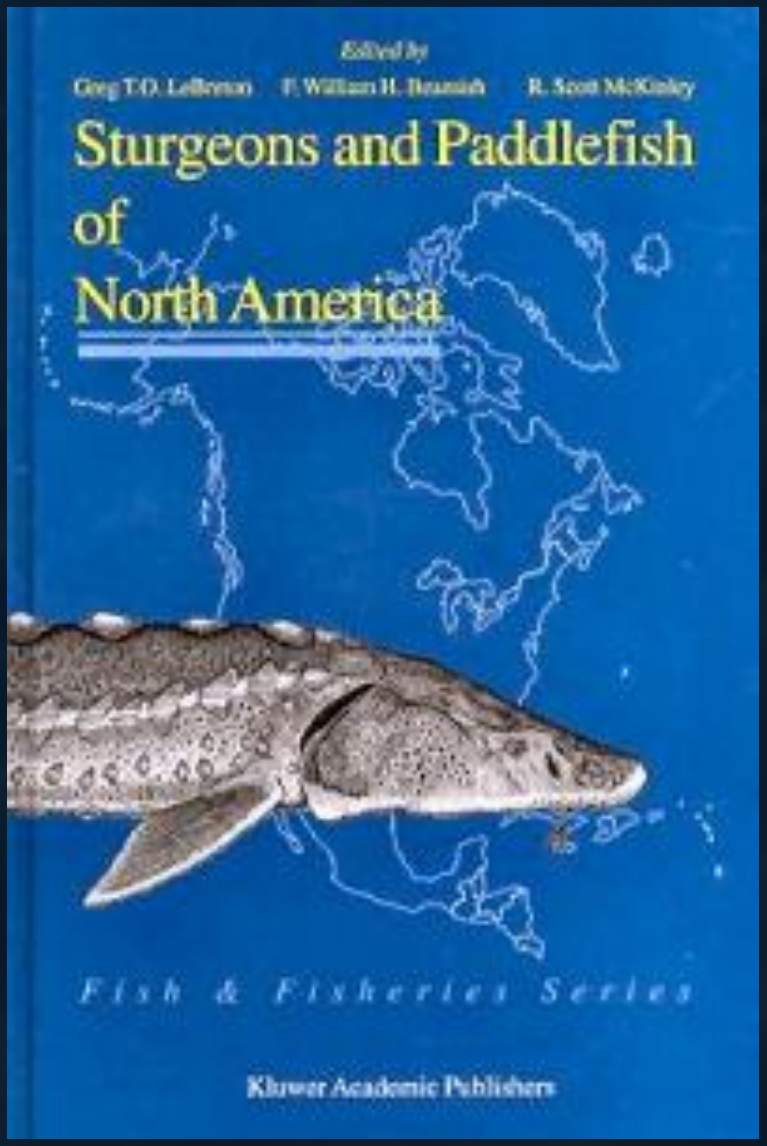
Primarily cartilaginous showing some ossification

25 species in two families

the sturgeons and the paddle fishes

Key features:

1. presence of a spiracle
2. heterocercal tail
3. cranium composed of 3 fused units of bone
4. bones of upper jaw fused to cranium


Edited by
Greg T.O. LeBreton
F. William H. Beamish
R. Scott McKinley
Sturgeons and Paddlefish of North America
Fish & Fisheries Series
Kluwer Academic Publishers

Holostei

Holostei are considered an intermediate stage consisting of gars and bowfin, but up for controversy

More advanced jaws than chodrosteans (free posterior maxilla allow for suction)

Now largely extince

Teleostei

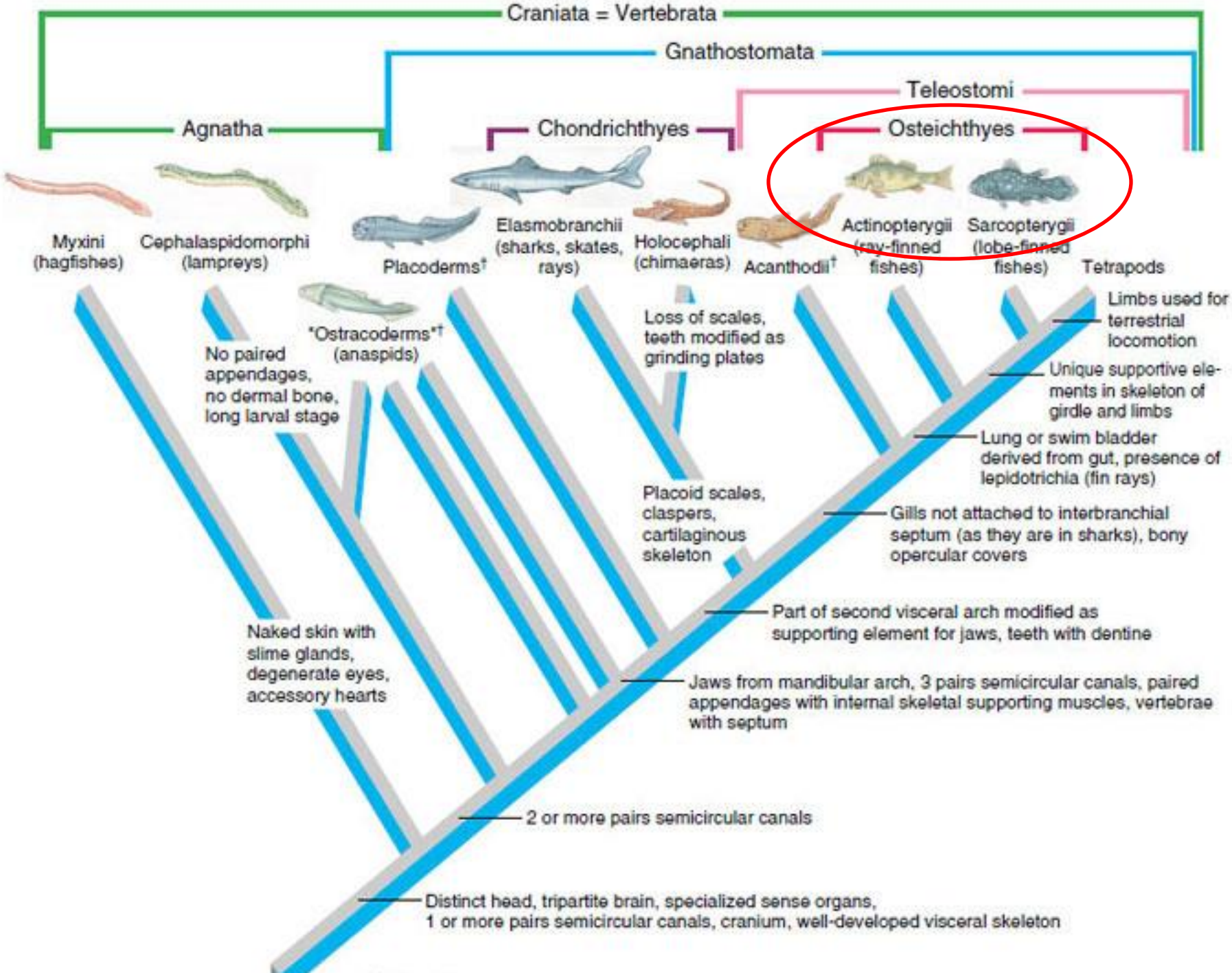
Teleosts are modern

Key Teleost characteristics are:

1. operculum consists of four bones
2. tail is homocercal
3. elasmoid scales
4. vertebrae are completely ossified
5. swimbladder reduced in size
6. both premax and max bones in jaw are moveable
7. fins are highly maneuverable
8. variety of body shapes

Teleostei

- 96% of living fishes
- Found in Antarctic, alkaline lakes, acid streams, deep sea and shallow rivers.
- Teleosts include eels, catfish, tarpon, tuna, halibut, flounder, trout, cod, herring, salmon, and many other fishes


Craniata = Vertebrata
Gnathostomata
Teleostomi
Agnatha
Chondrichthyes
Osteichthyes
Myxini (hagfishes)
Cephalaspidomorphi (lampreys)
Placoderms†
Elasmobranchii (sharks, skates, rays)
Holocephali (chimaeras)
Acanthodii†
Actinopterygii (ray-finned fishes)
Sarcopterygii (lobe-finned fishes)
Tetrapods
Ostracoderms† (anaspids)
No paired appendages, no dermal bone, long larval stage
Loss of scales, teeth modified as grinding plates
Limbs used for terrestrial locomotion
Unique supportive elements in skeleton of girdle and limbs
Lung or swim bladder derived from gut, presence of lepidotrichia (fin rays)
Placoid scales, claspers, cartilaginous skeleton
Gills not attached to interbranchial septum (as they are in sharks), bony opercular covers
Part of second visceral arch modified as supporting element for jaws, teeth with dentine
Naked skin with slime glands, degenerate eyes, accessory hearts
Jaws from mandibular arch, 3 pairs semicircular canals, paired appendages with internal skeletal supporting muscles, vertebrae with septum
2 or more pairs semicircular canals
Distinct head, tripartite brain, specialized sense organs, 1 or more pairs semicircular canals, cranium, well-developed visceral skeleton