

Something fishy...

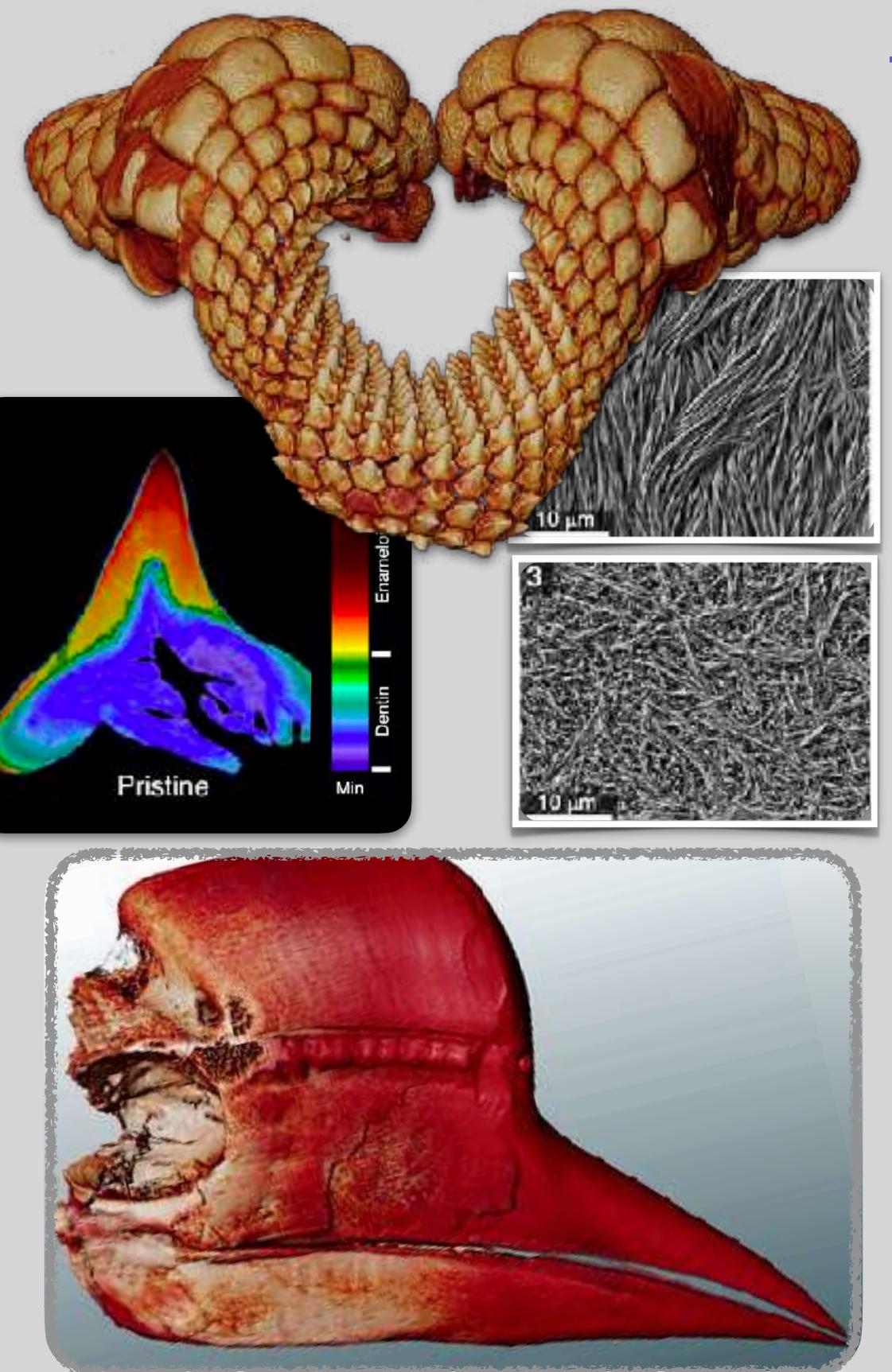
Mason Dean

Dept. of Infectious Diseases & Public Health, City University of HK

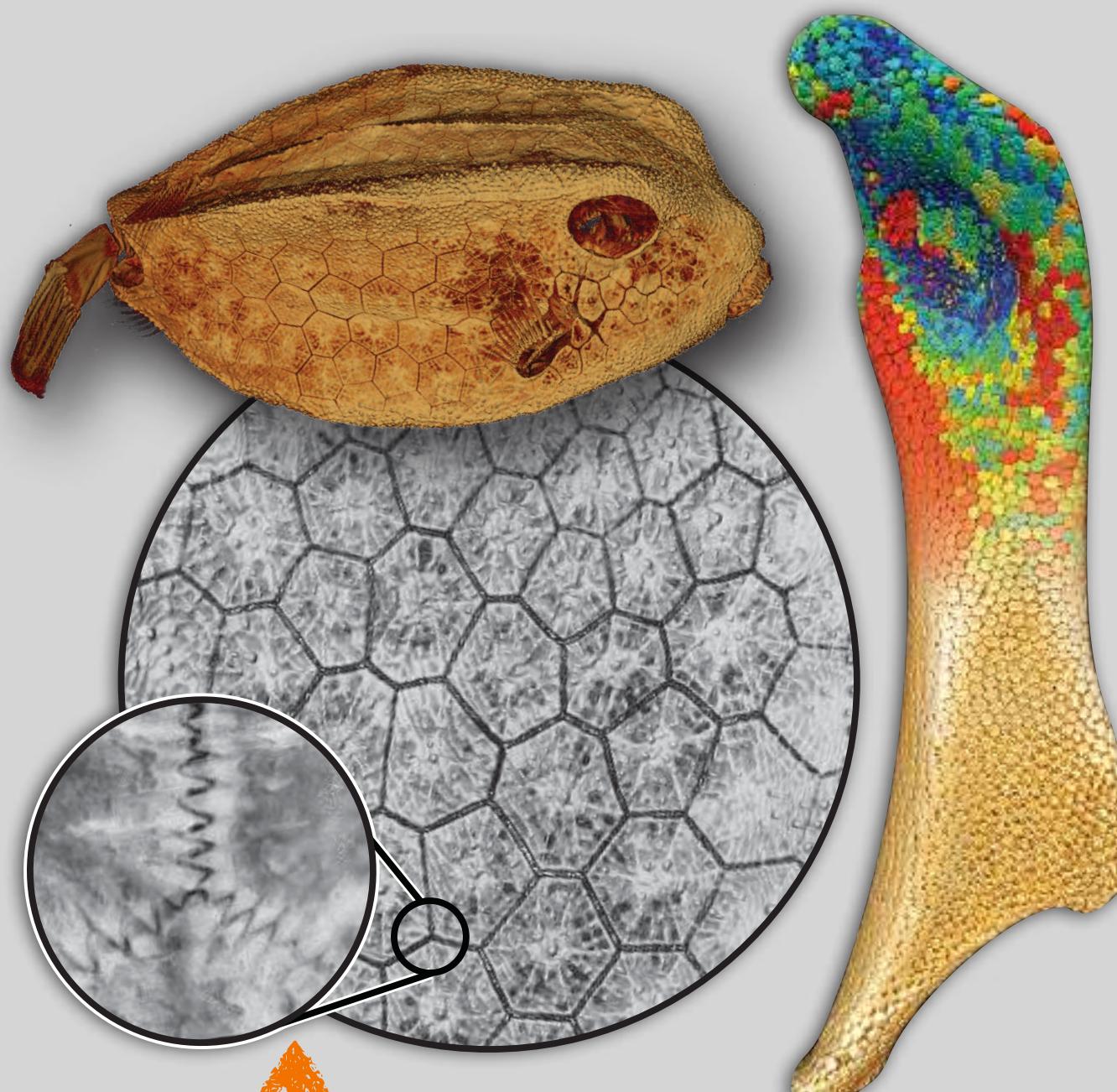
HKUST April 2025



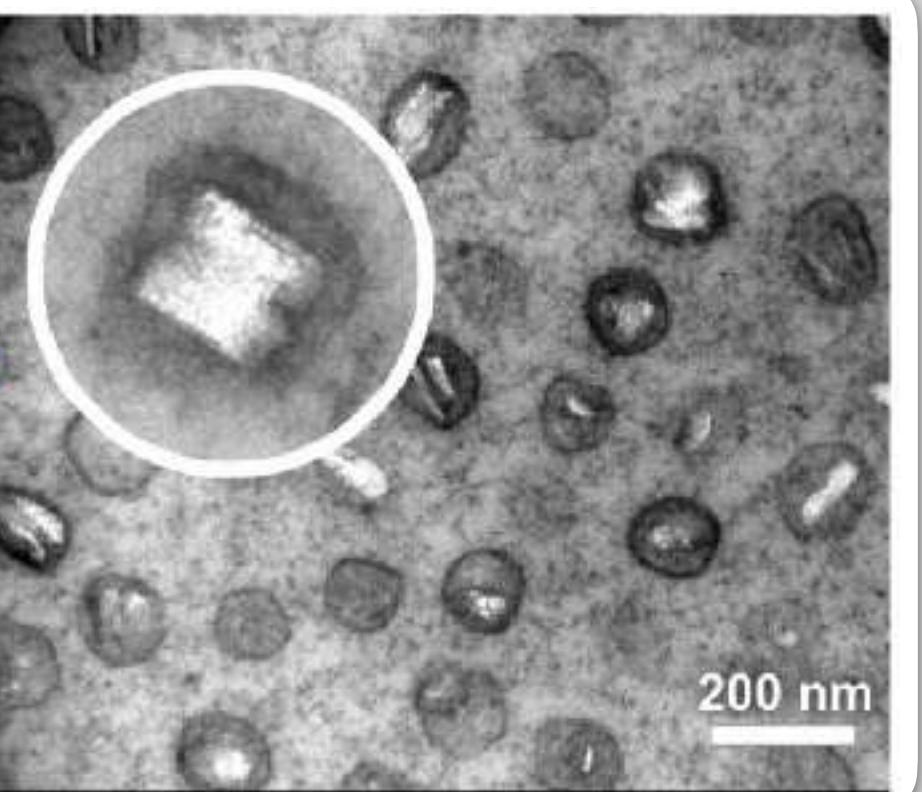
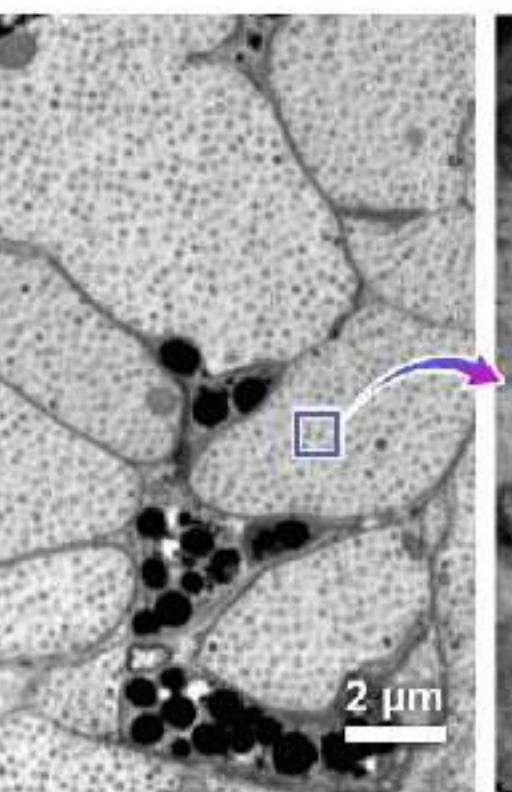
Dean Lab: Comparative anatomy, biomechanics & biomaterials



How are natural materials structured for extreme performance?



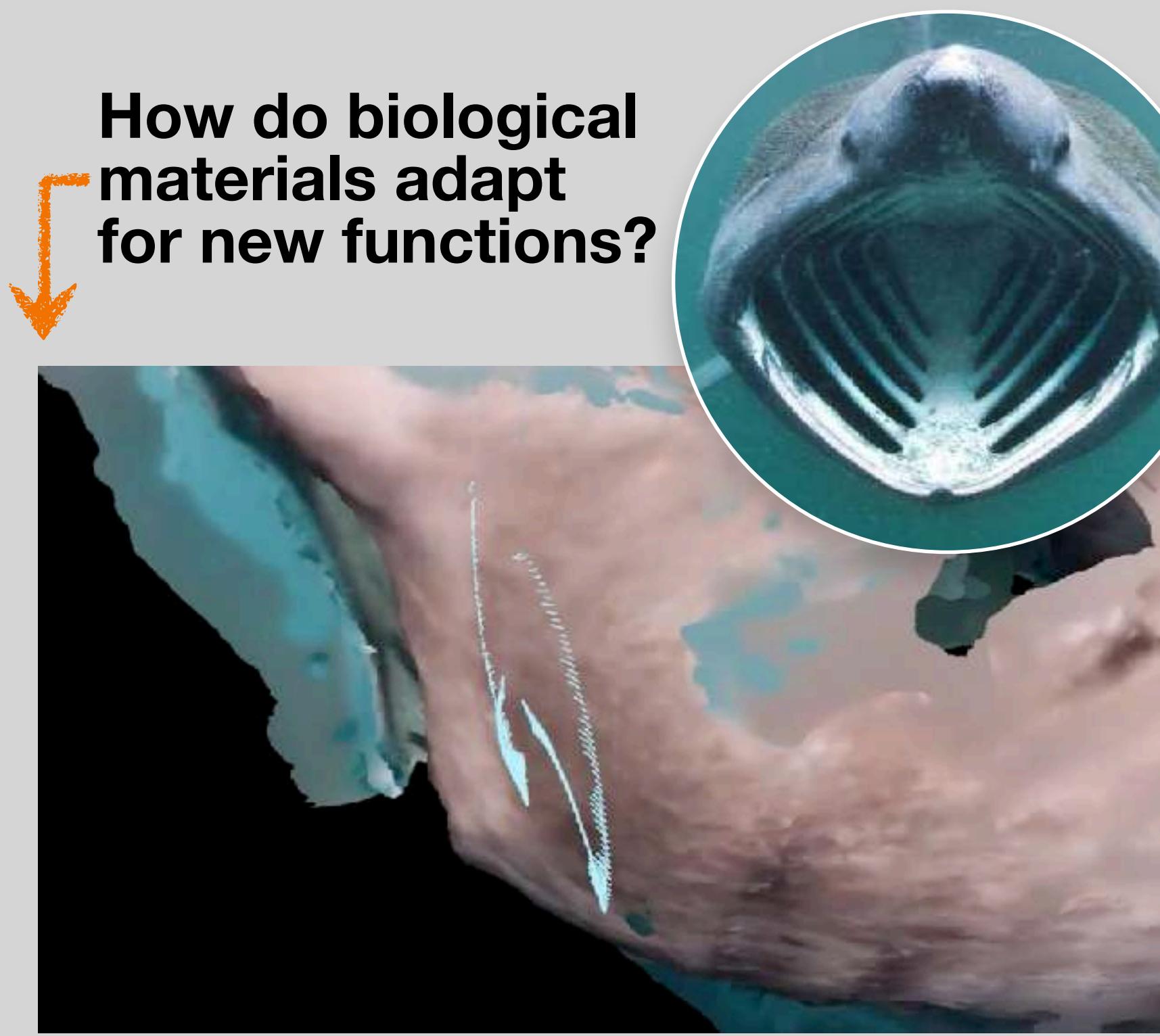
How do structurally-complex tissues grow & self-organize?



How do animals make color?

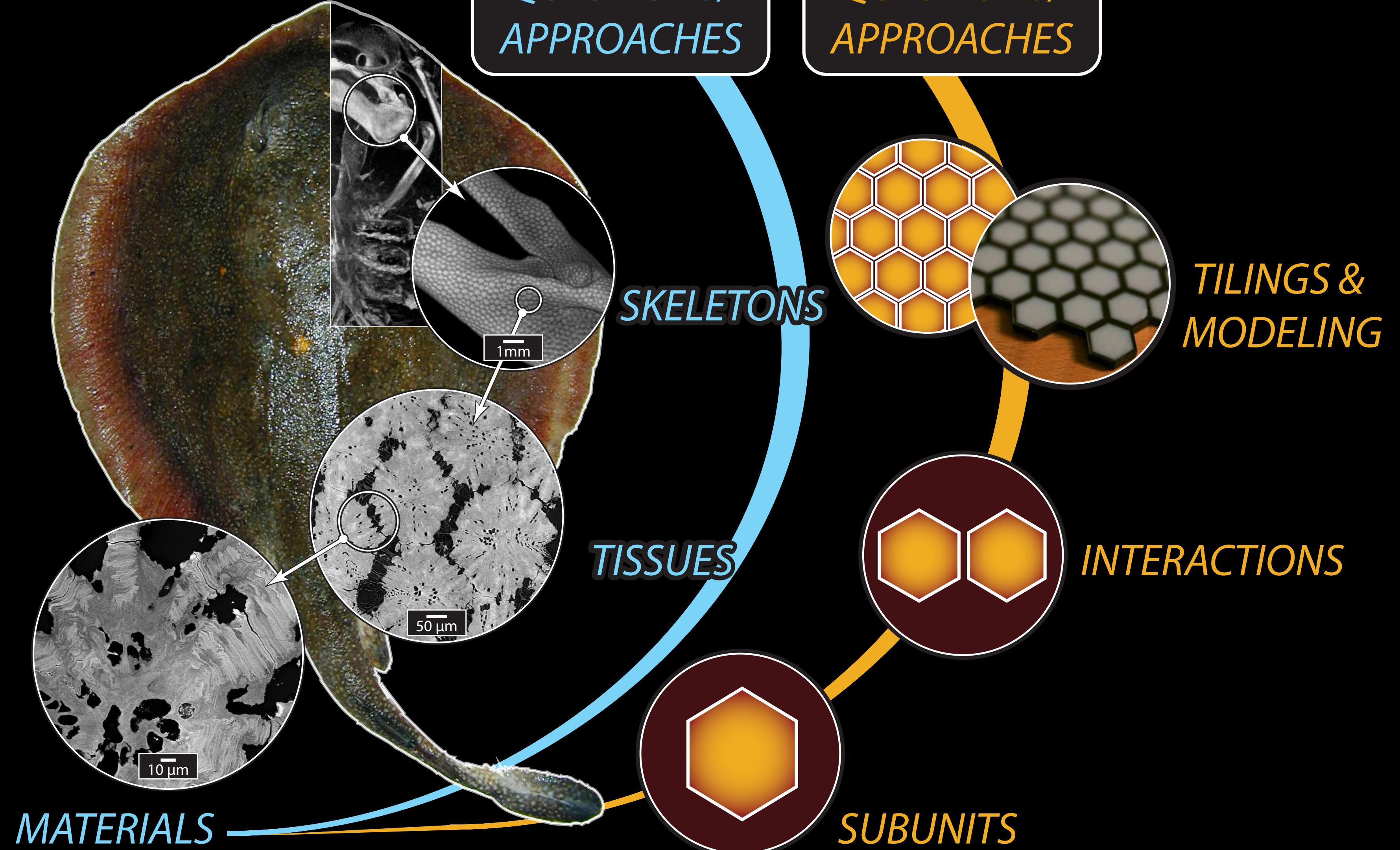


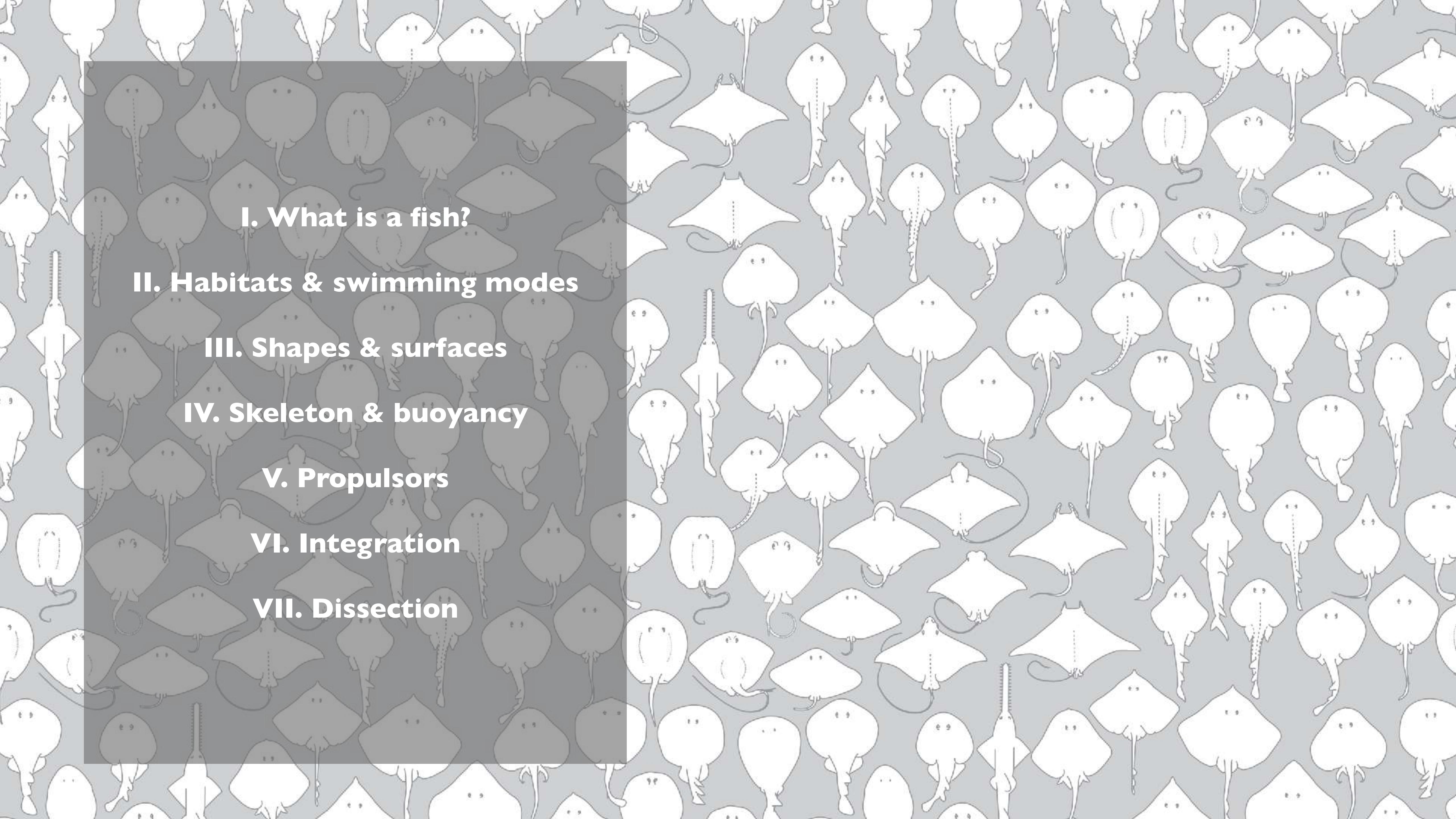
How do biological materials adapt for new functions?



@MasonDeanLab

www.masondeanlab.com





I. What is a fish?

II. Habitats & swimming modes

III. Shapes & surfaces

IV. Skeleton & buoyancy

V. Propulsors

VI. Integration

VII. Dissection

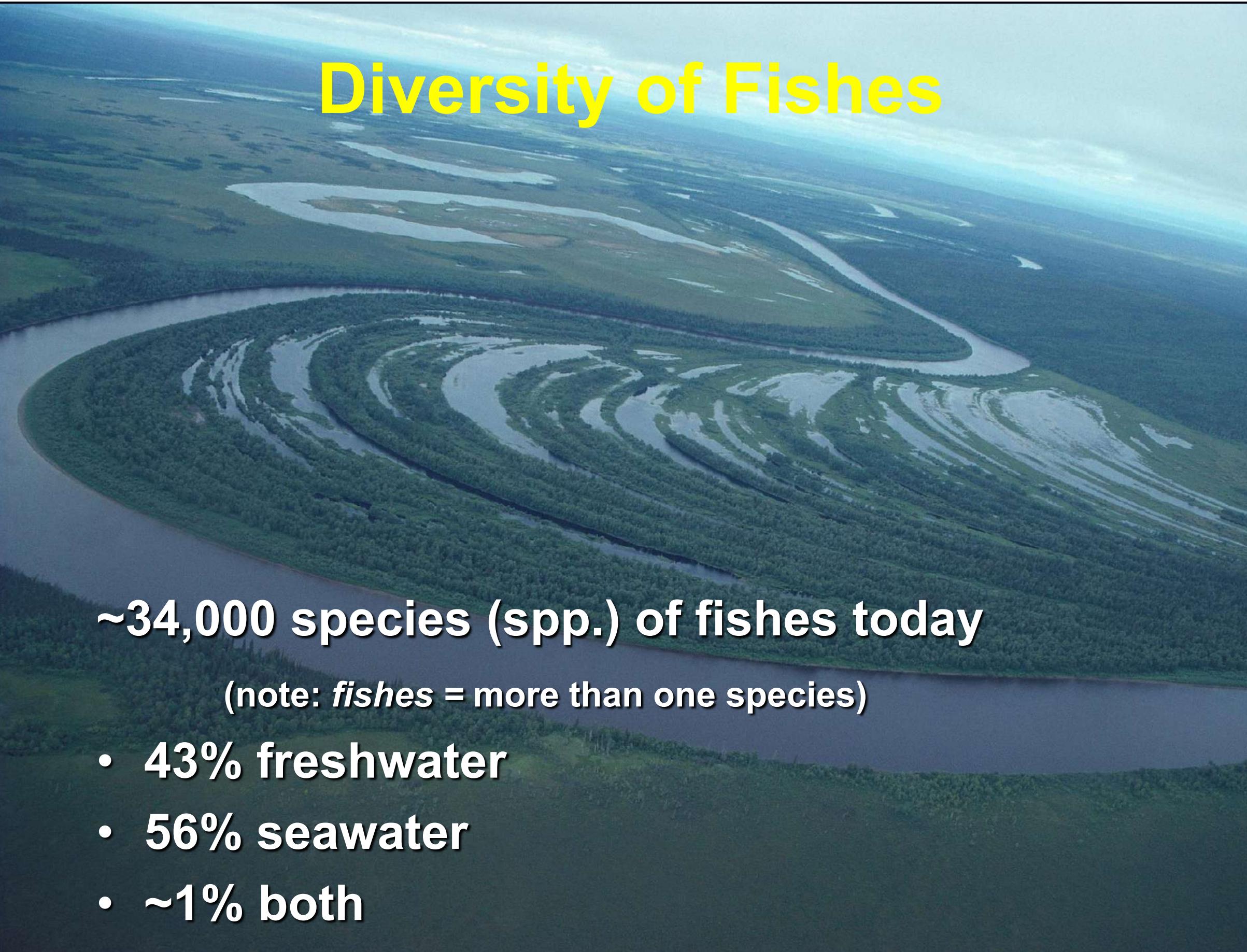


Diversity of Fishes

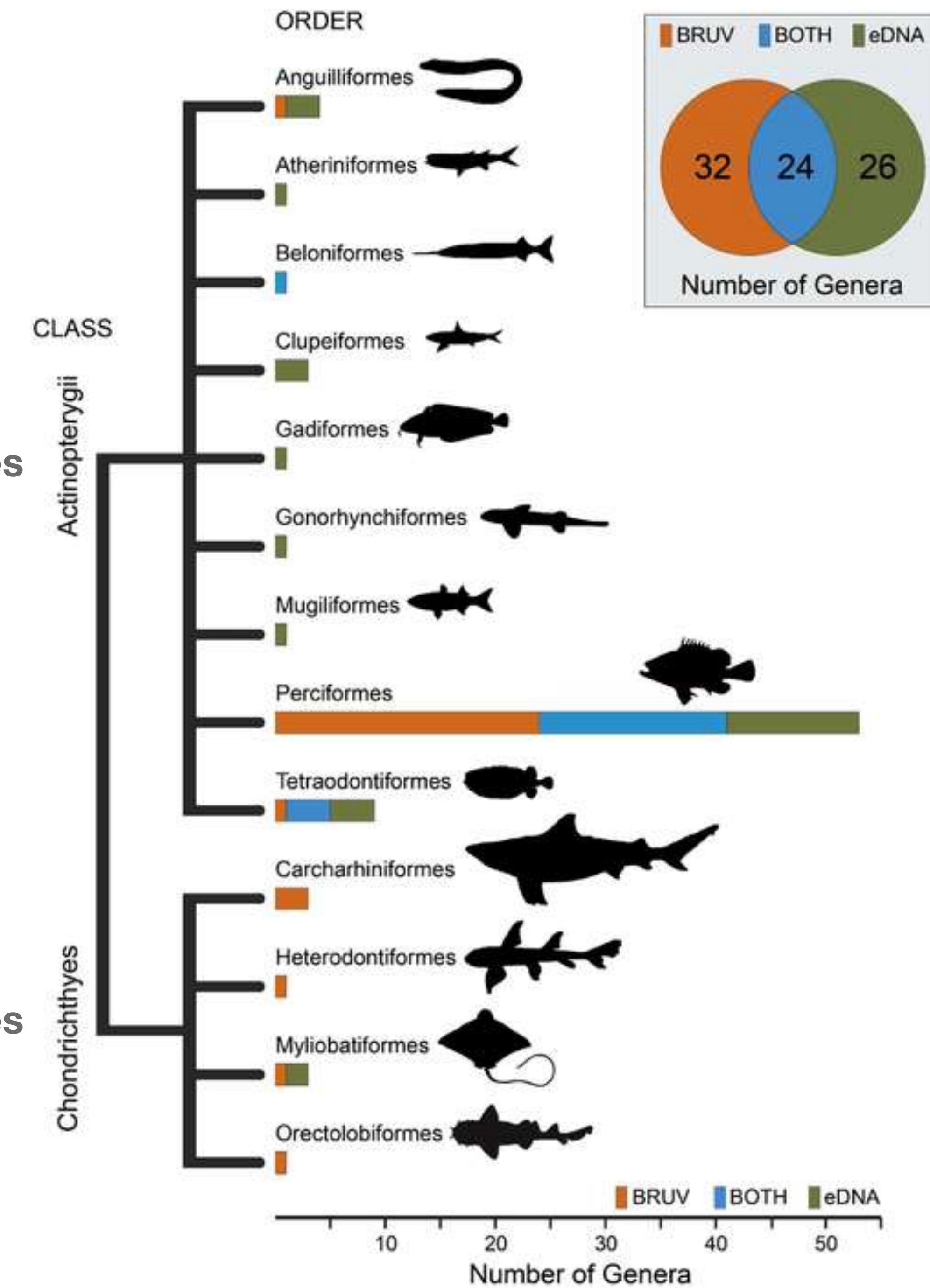
~34,000 species (spp.) of fishes today

(note: *fishes* = more than one species)

- 43% freshwater
- 56% seawater
- ~1% both

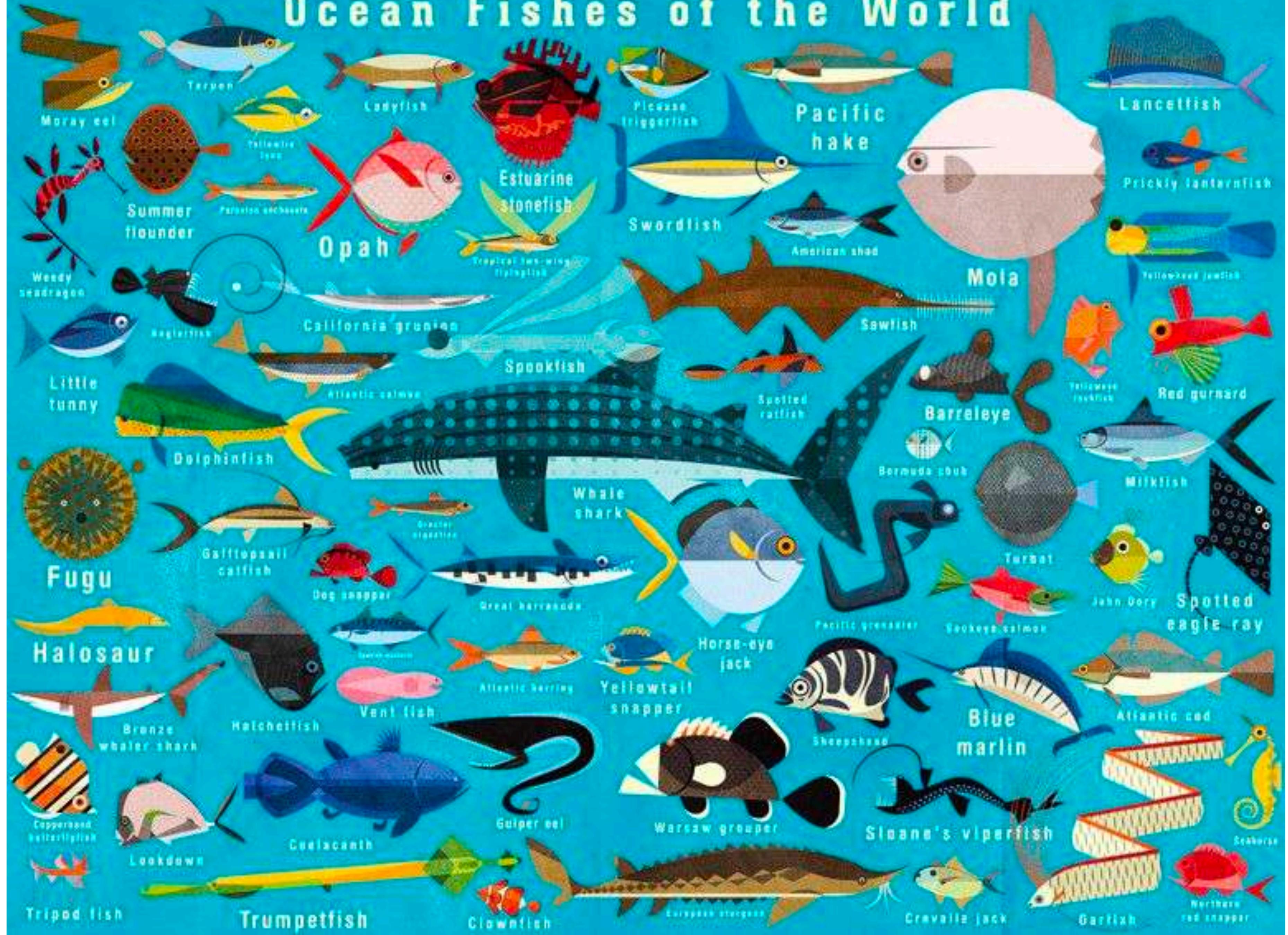


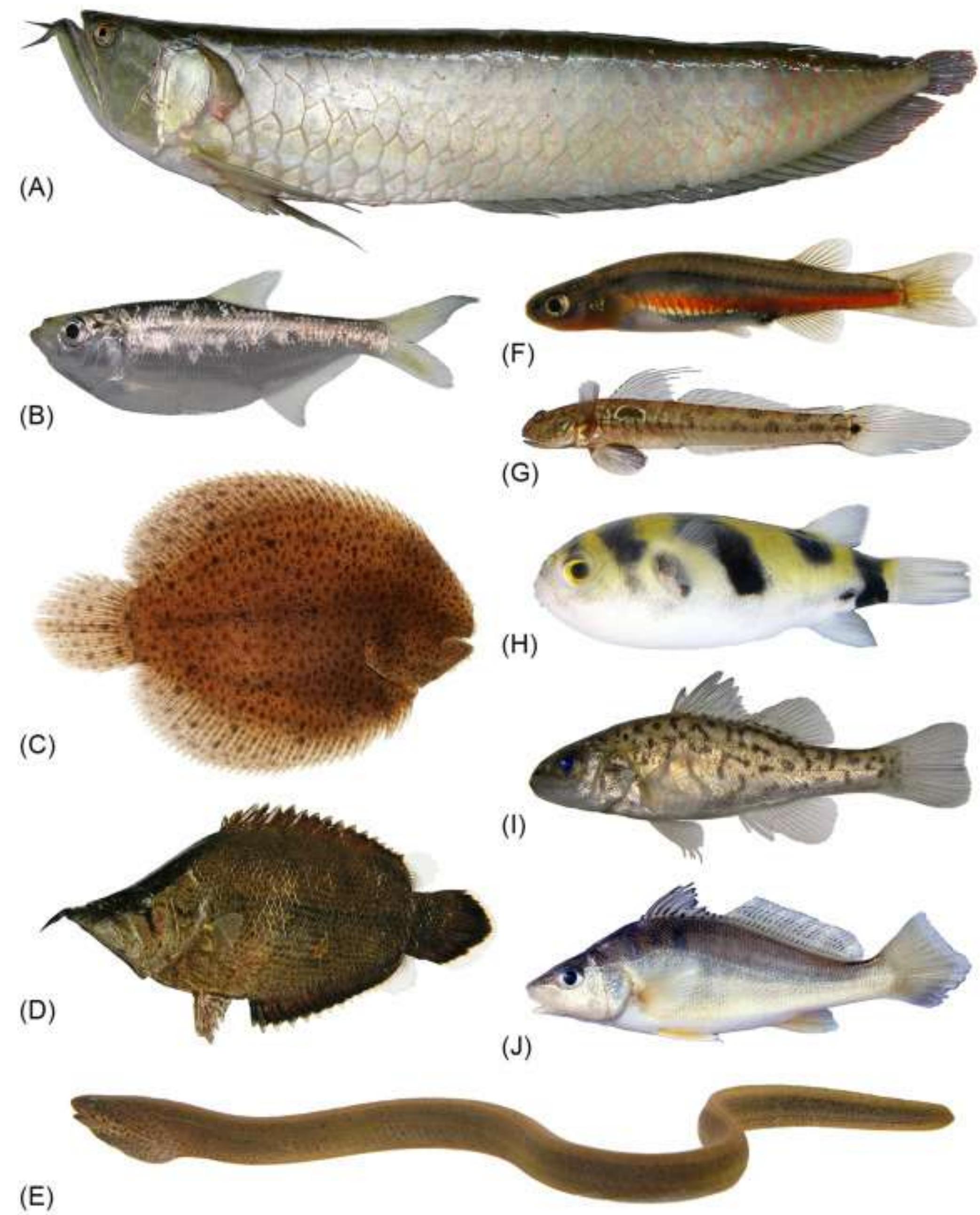
Bony fishes



Cartilaginous fishes

Ocean Fishes of the World





Fish can live about three miles above sea level (17,000 feet)

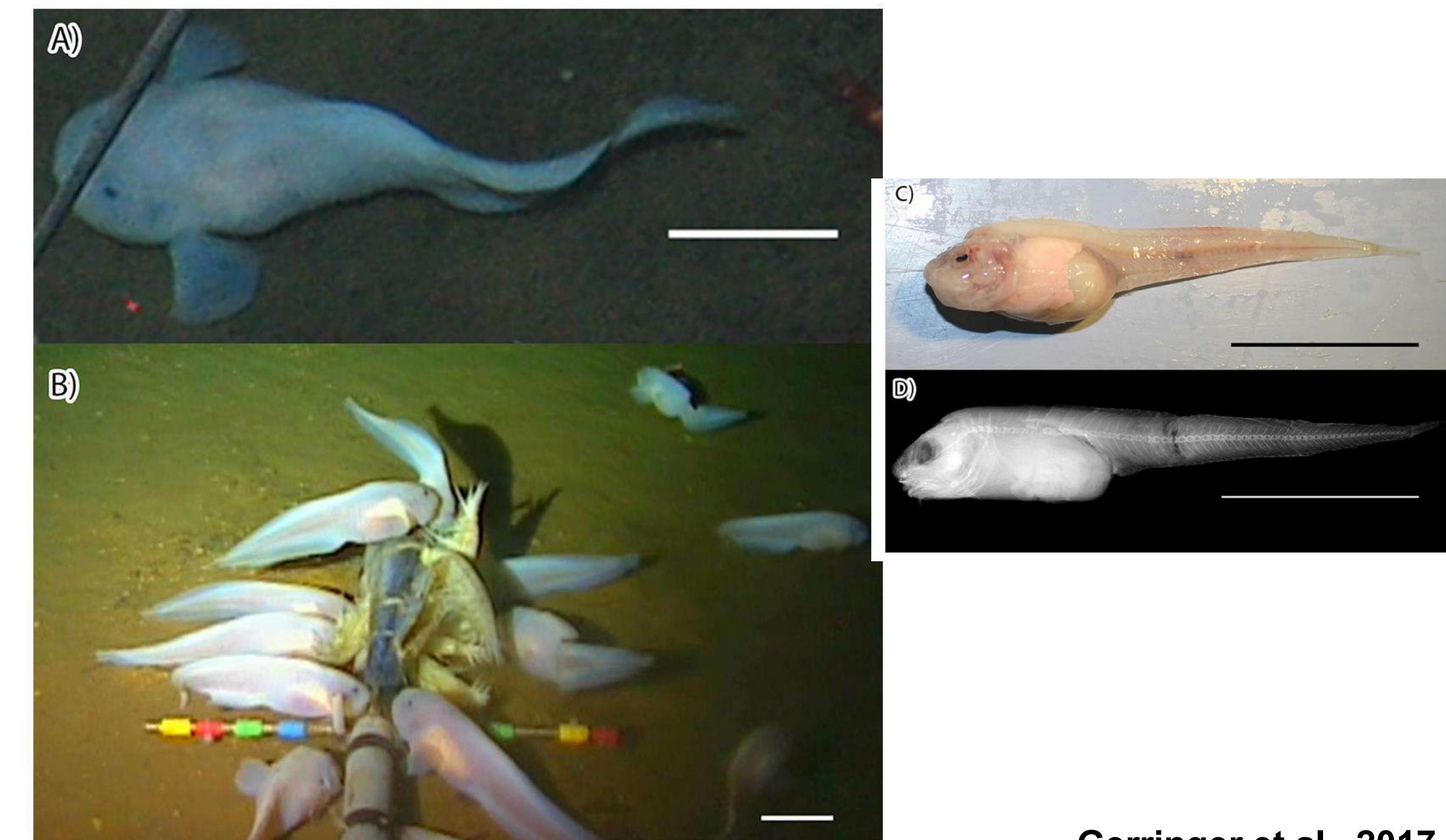
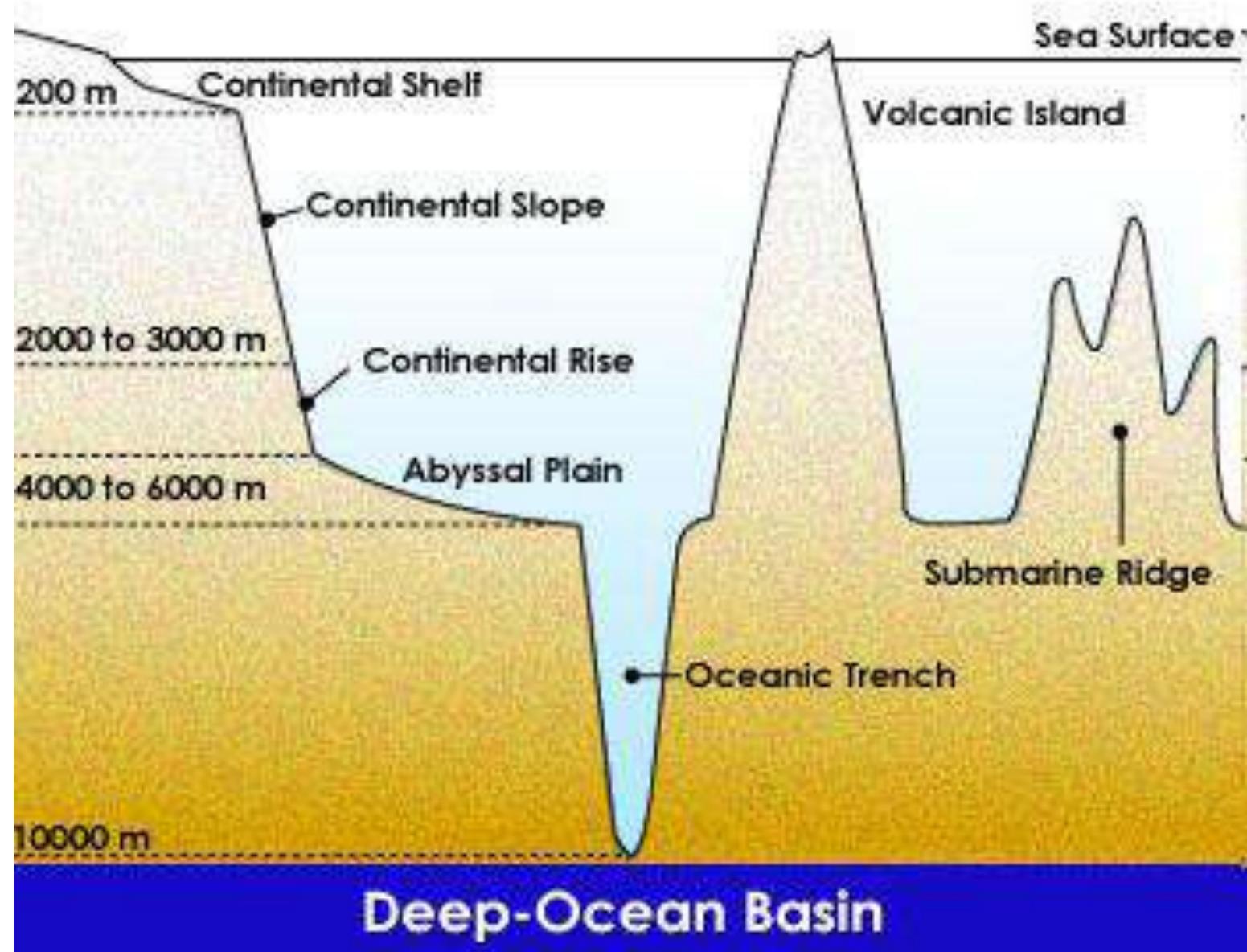


5,200m (17,000 feet)



and nearly seven miles beneath it (-35,000 feet).

The ocean environment



The really deep-sea!

In situ photograph of *Pseudoliparis swirei* sp. nov. at 6,198 m. B) a group at 7,485 m. C) Deck photograph. D) Radiograph

Amazing deep-sea fishes



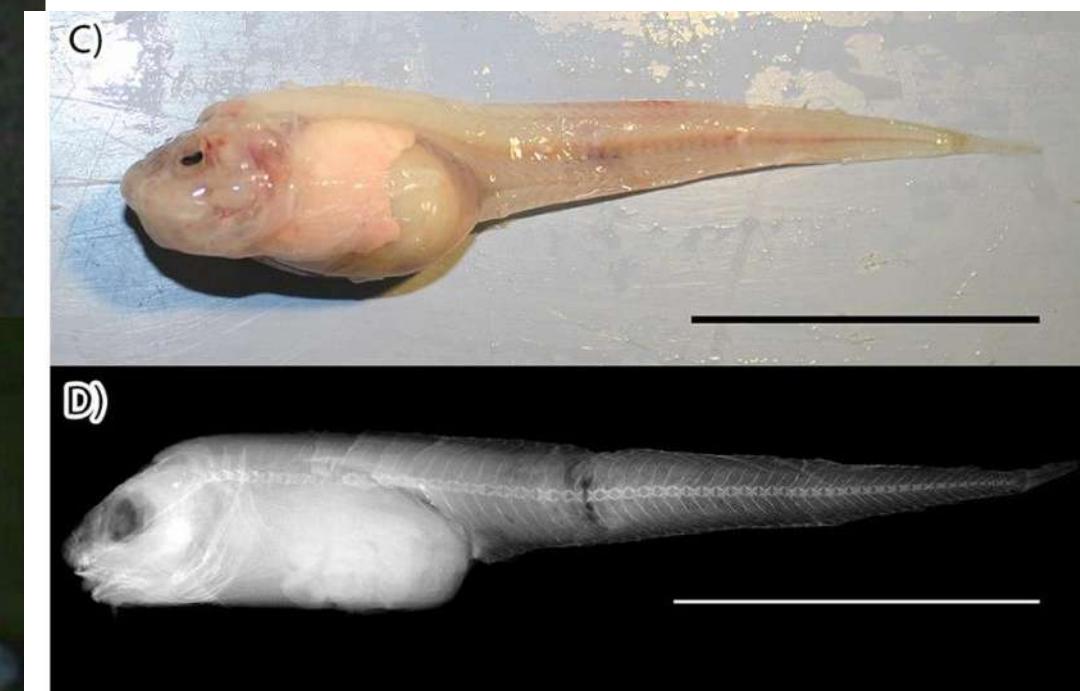
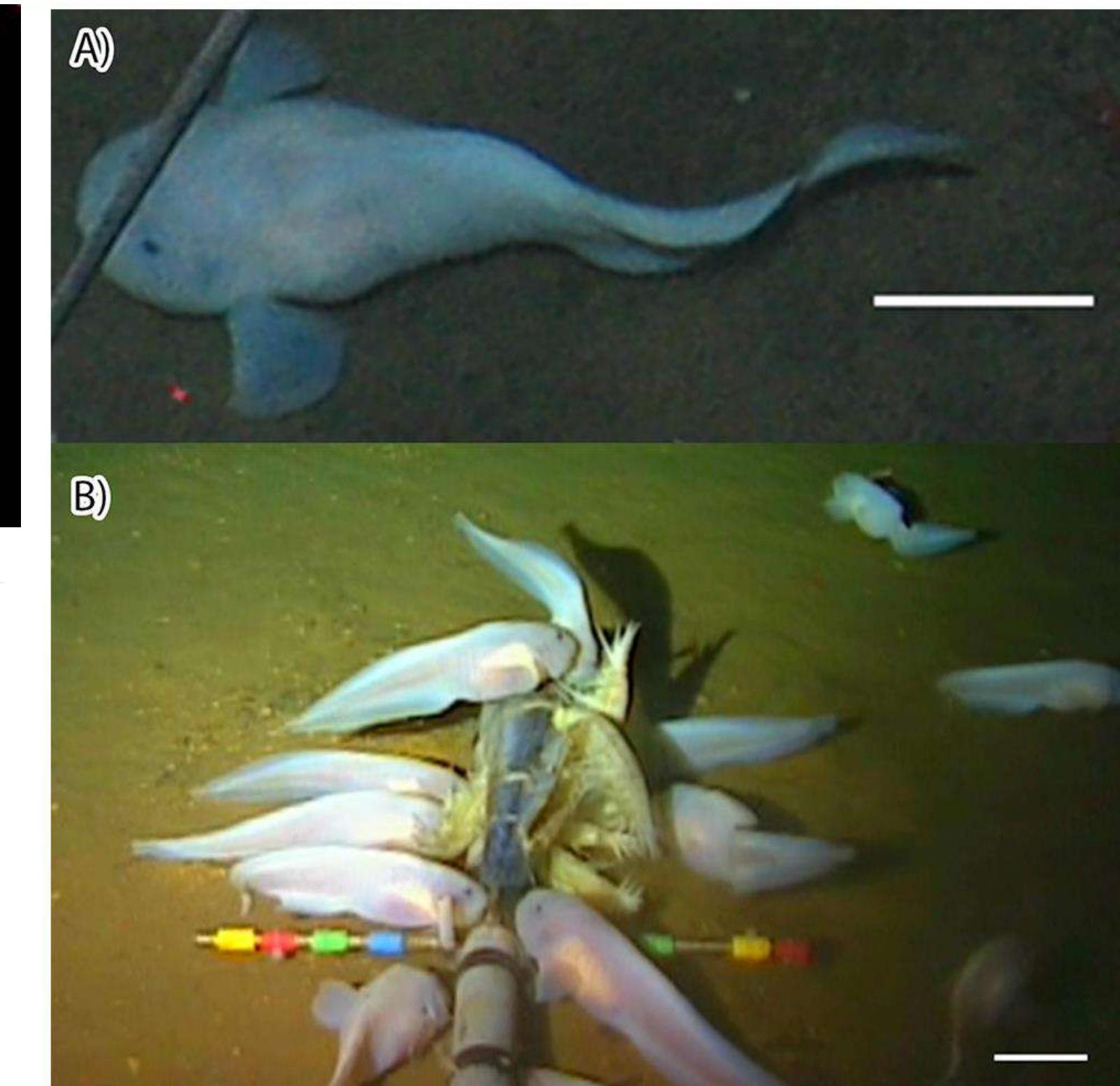
© E. Widder / HBOI 1999

**Bioluminescence,
Large jaws and teeth,
Poor ossification,
Lures to capture prey**



The really deep-sea!

In situ photograph of *Pseudoliparis swirei* sp. nov. at 6,198 m. B) a group at 7,485 m. C) Deck photograph. D) Radiograph



Gerringer et al., 2017



Fish live in sub-zero temperatures in Antarctica

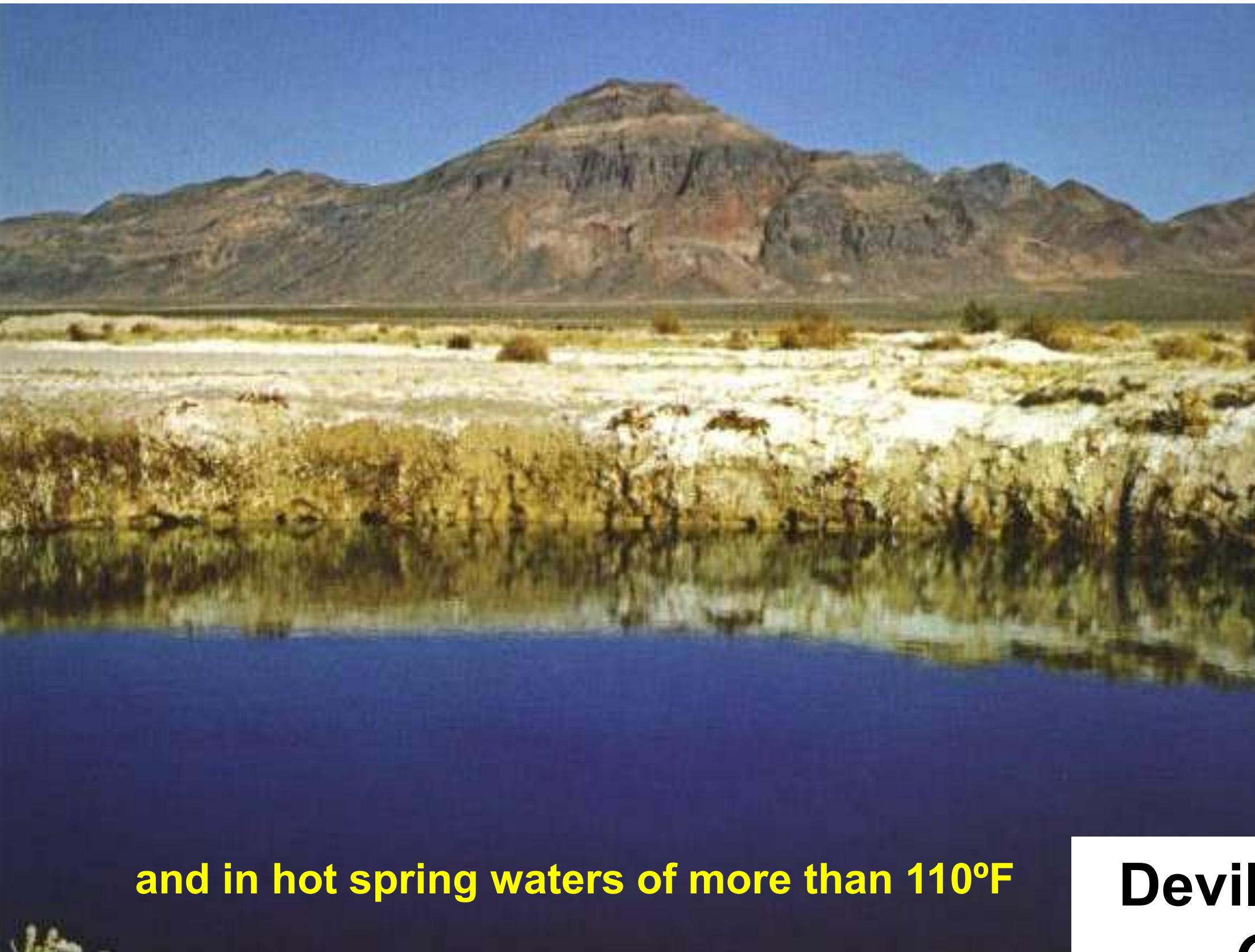
The Antarctic Icefish



**-1.86° C
(28.6° F)**

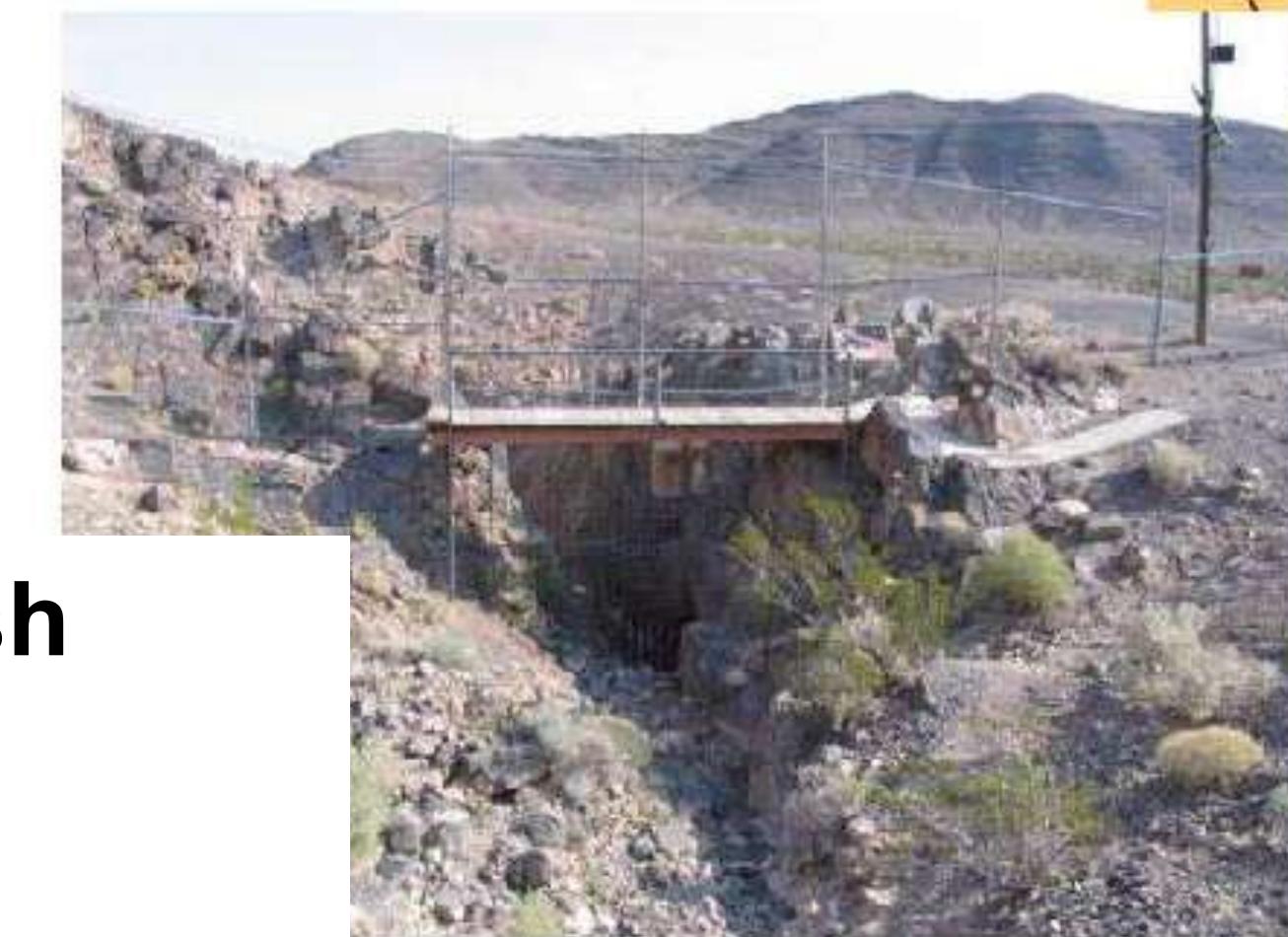
**No hemoglobin in red blood cells!
Anti-freeze proteins in blood**

Desert pupfishes



and in hot spring waters of more than 110°F

Devil's hole pupfish
Cyprinodon
Only 300-700 left



Devils Hole
43.8° C
(110.8°F)



Fish are big !



Fish are small !



Scientists have discovered a fish living in forest swamps on the Indonesian island of Sumatra that is only 7.9mm long and sexually mature. The species of fish belongs to the carp family and is called *Paedocypris progenetica*. It is the world's smallest vertebrate.

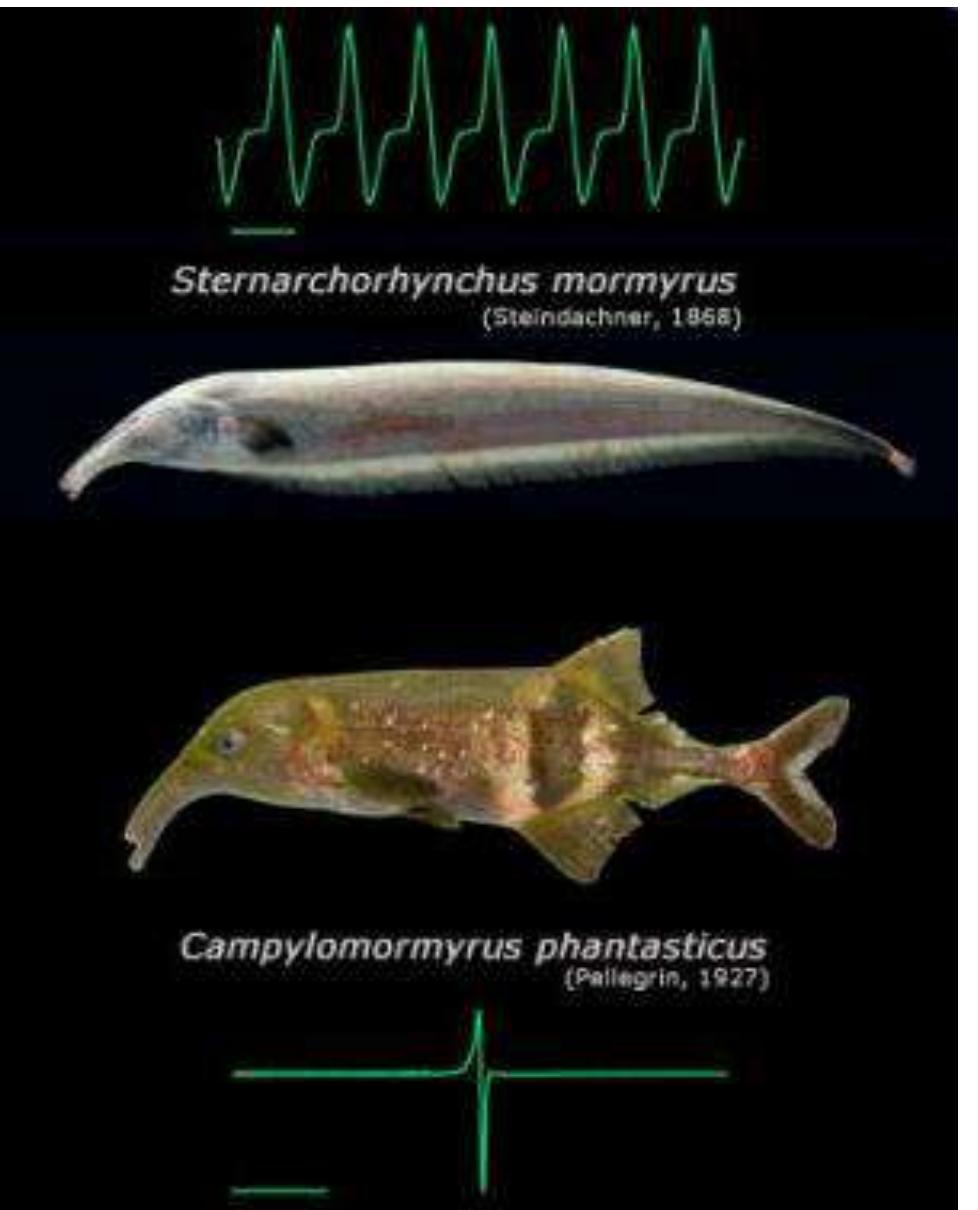
Fish can live a long time!



The Greenland shark (*Somniosus microcephalus*), an iconic species of the Arctic Seas, grows slowly and reaches >500 centimeters (cm) in total length, suggesting a life span well beyond those of other vertebrates. Radiocarbon dating of eye lens nuclei from 28 female Greenland sharks (81 to 502 cm in total length) revealed a life span of at least 272 years. Only the smallest sharks (220 cm or less) showed signs of the radiocarbon bomb pulse, a time marker of the early 1960s. The age ranges of prebomb sharks (reported as midpoint and extent of the 95.4% probability range) revealed the age at sexual maturity to be at least 156 ± 22 years, and the largest animal (502 cm) to be 392 ± 120 years old. Our results show that the Greenland shark is the longest-lived vertebrate known, and they raise concerns about species conservation.

Nielsen J. et al. (2016). Eye lens radiocarbon reveals centuries of longevity in the Greenland shark (*Somniosus microcephalus*). *Science*, 353(6300), 702-704.

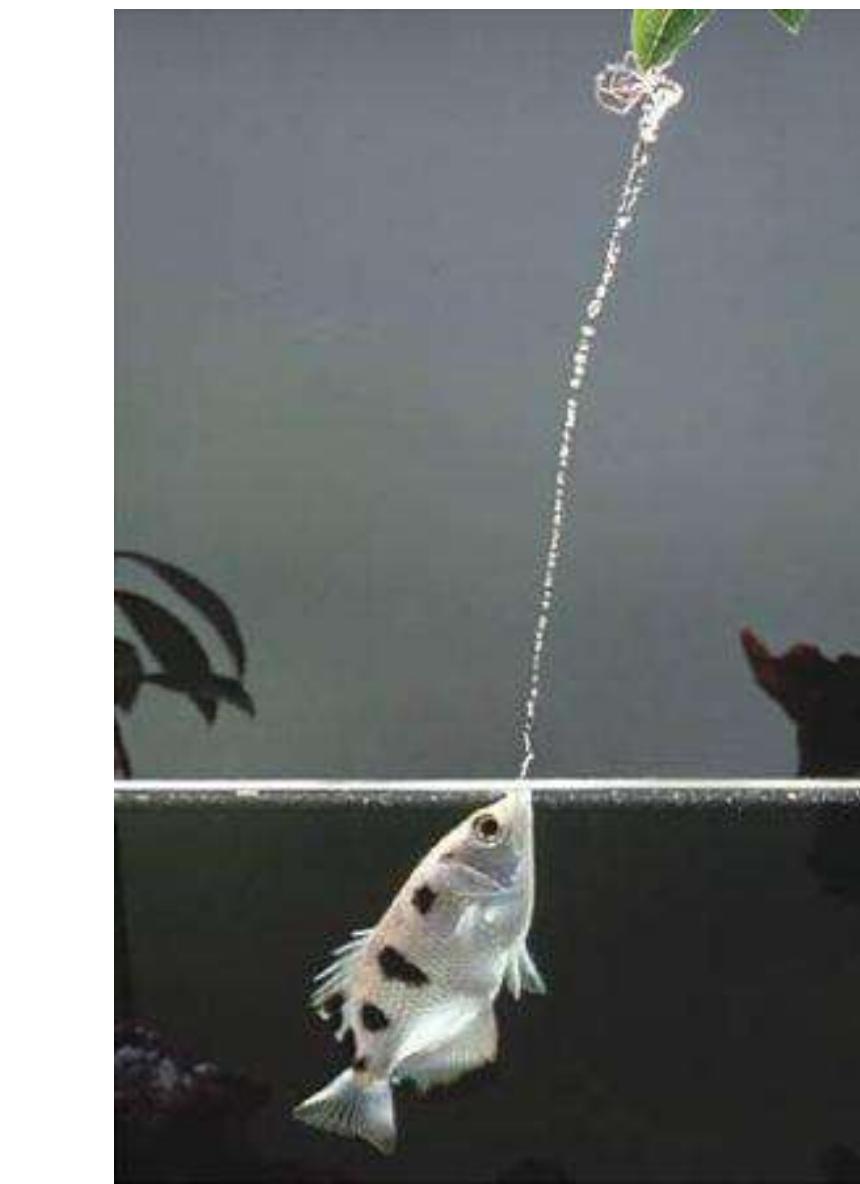
Remarkable sensory systems



Electroreception!



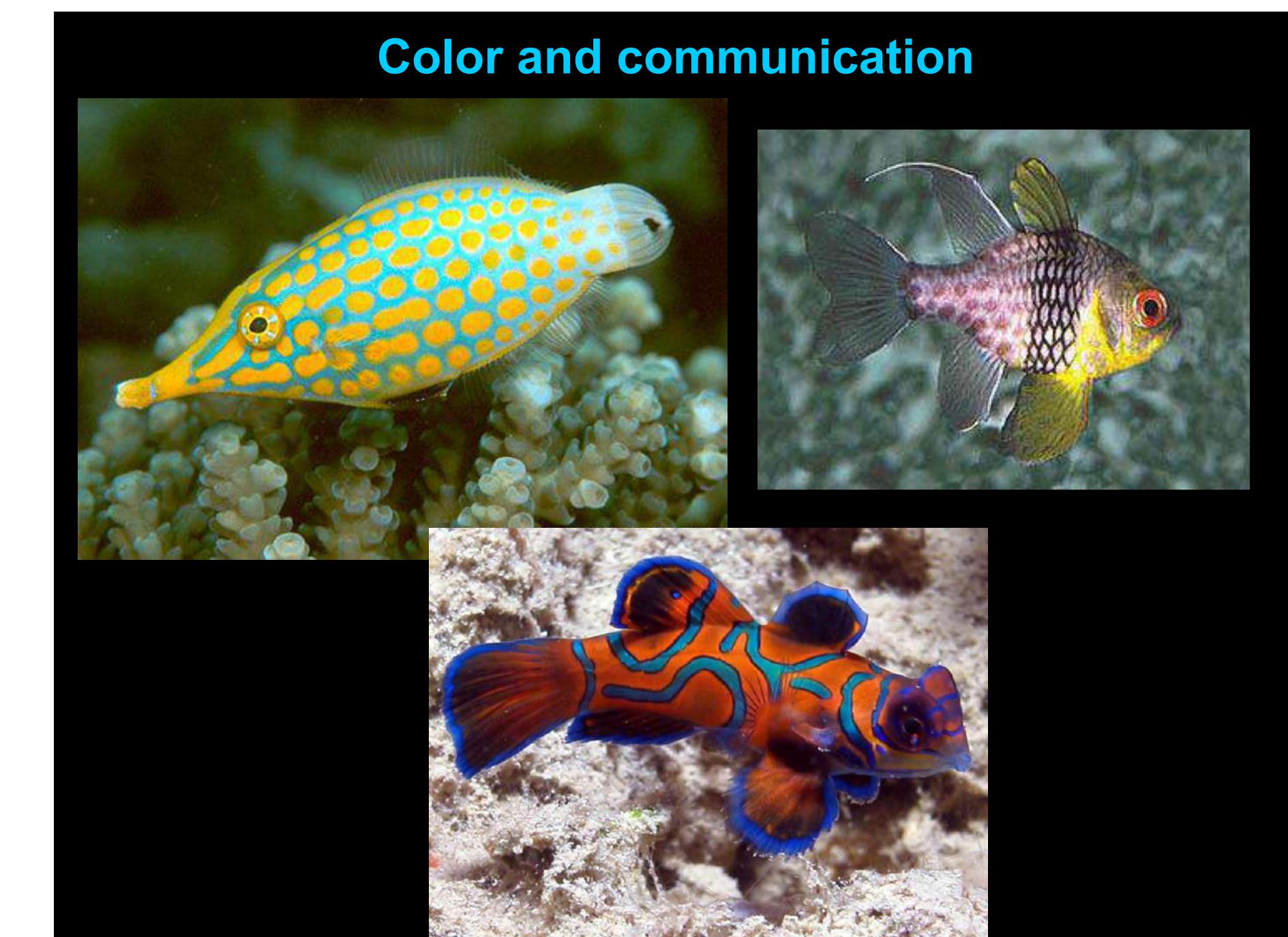
Remarkable sensory systems



Archerfish: *Toxotes*



Schooling / swarming behavior



Water ~800x denser and 50x more viscous than air



Great Sculpin

Myoxocephalus polyacanthocephalus

Video slowed down 10x

No gravity, neutral buoyancy

**More efficient swimmers:
Minimize drag, maximized
thrust**

**Body shape, size, surface
roughness, propulsors**

Tracking fish migrations with satellite tags

Bluefin tuna population structure

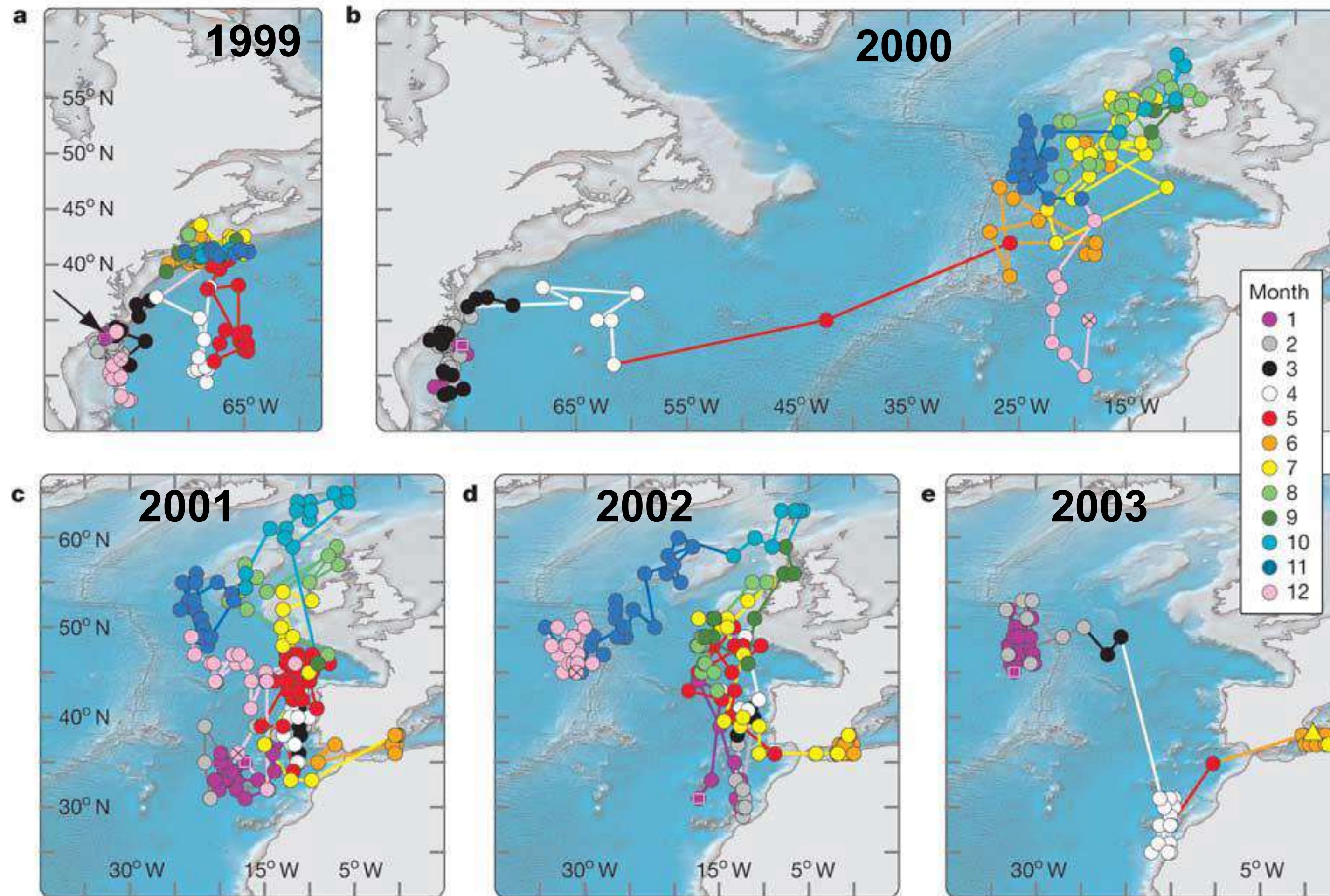
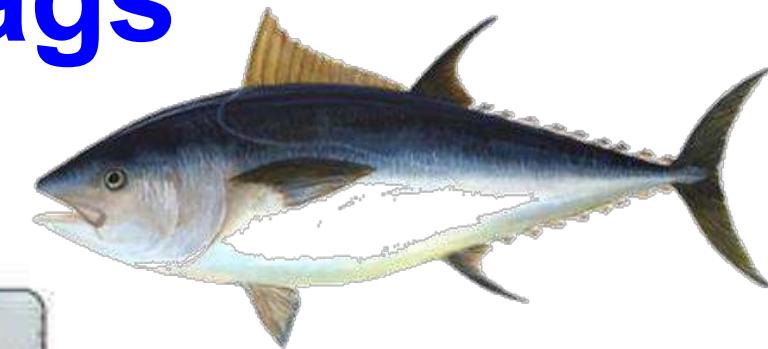
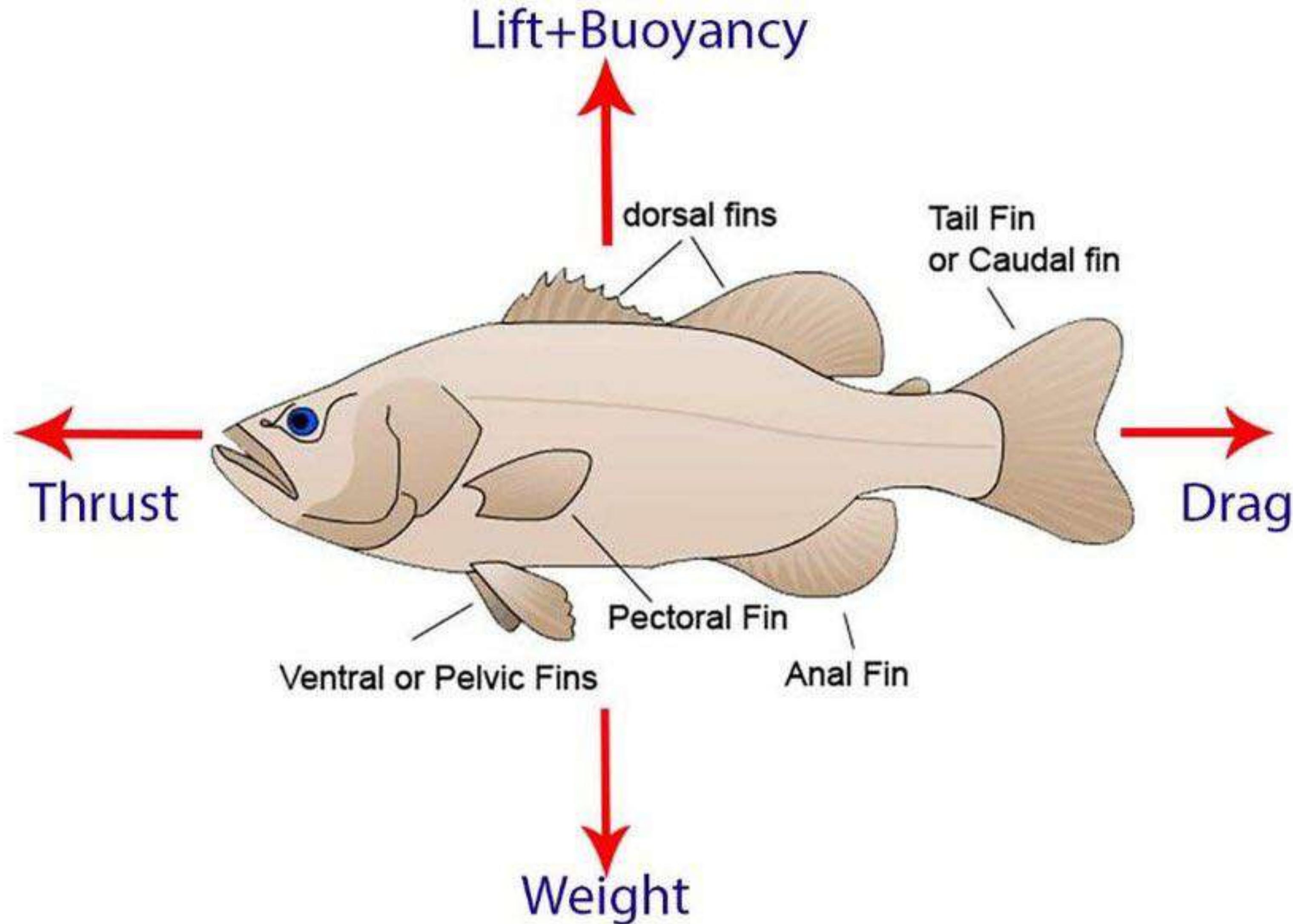


Figure 3 Movements over 4.5 years of one individual Atlantic bluefin tuna (603) that was tagged in the western Atlantic in 1999 and demonstrated site fidelity to a known spawning area in the Mediterranean Sea (2001–2003). Each panel shows a year of the fish's track; colour denotes month of each position. Start and end points for each year are denoted by a square and cross-hatched circle, respectively. **a**, The bluefin tuna was released off North Carolina on 17 January 1999 (arrow, 191 cm CFL) and showed a year of western

residency. **b**, In 2000, the bluefin tuna showed transatlantic movement to the eastern Atlantic. **c–e**, Three consecutive years of movements from the eastern Atlantic into the Mediterranean Sea, to the vicinity of the Balearic Islands, during the breeding season: **c**, 2001; **d**, 2002; **e**, 2003. The fish was recaptured on 2 July 2003 (yellow triangle).

An adult bluefin can cross the Atlantic Ocean, traveling over 8,000 km in a year, swim ~45 km/h, and accelerate faster than a Porsche.

https://www.ices.dk/PANDORA/Documents/PANDORA_s%20Toolbox/Assessment/atlantic-bluefin-tuna-factsheet.pdf



The location and diversity of fins are important!

Where are they on the body?
How flexible are they?

Locomotion types:

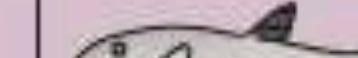
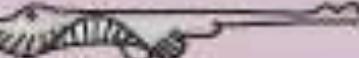
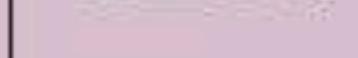
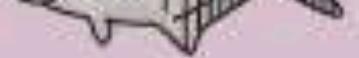
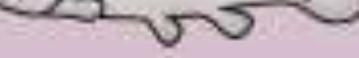
- how propulsion generated
- body flexibility
- body shape
- fin shape

Undulation:

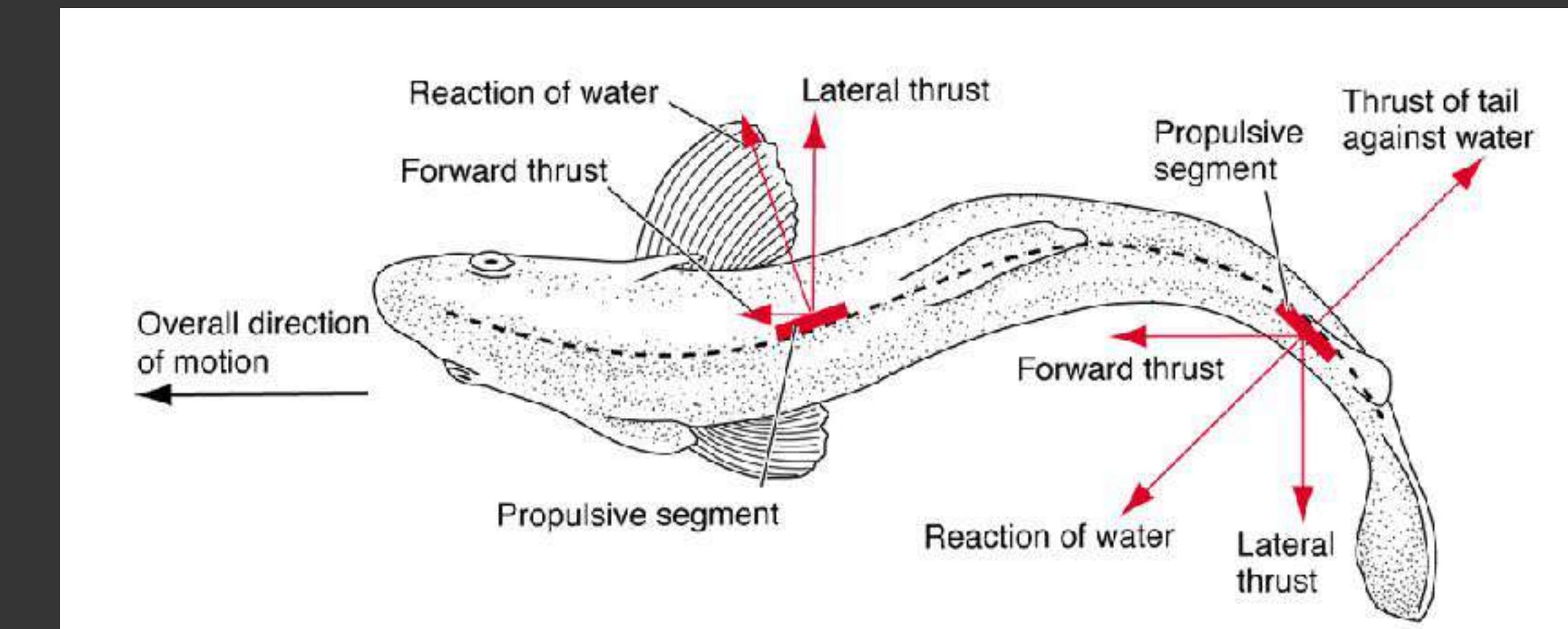
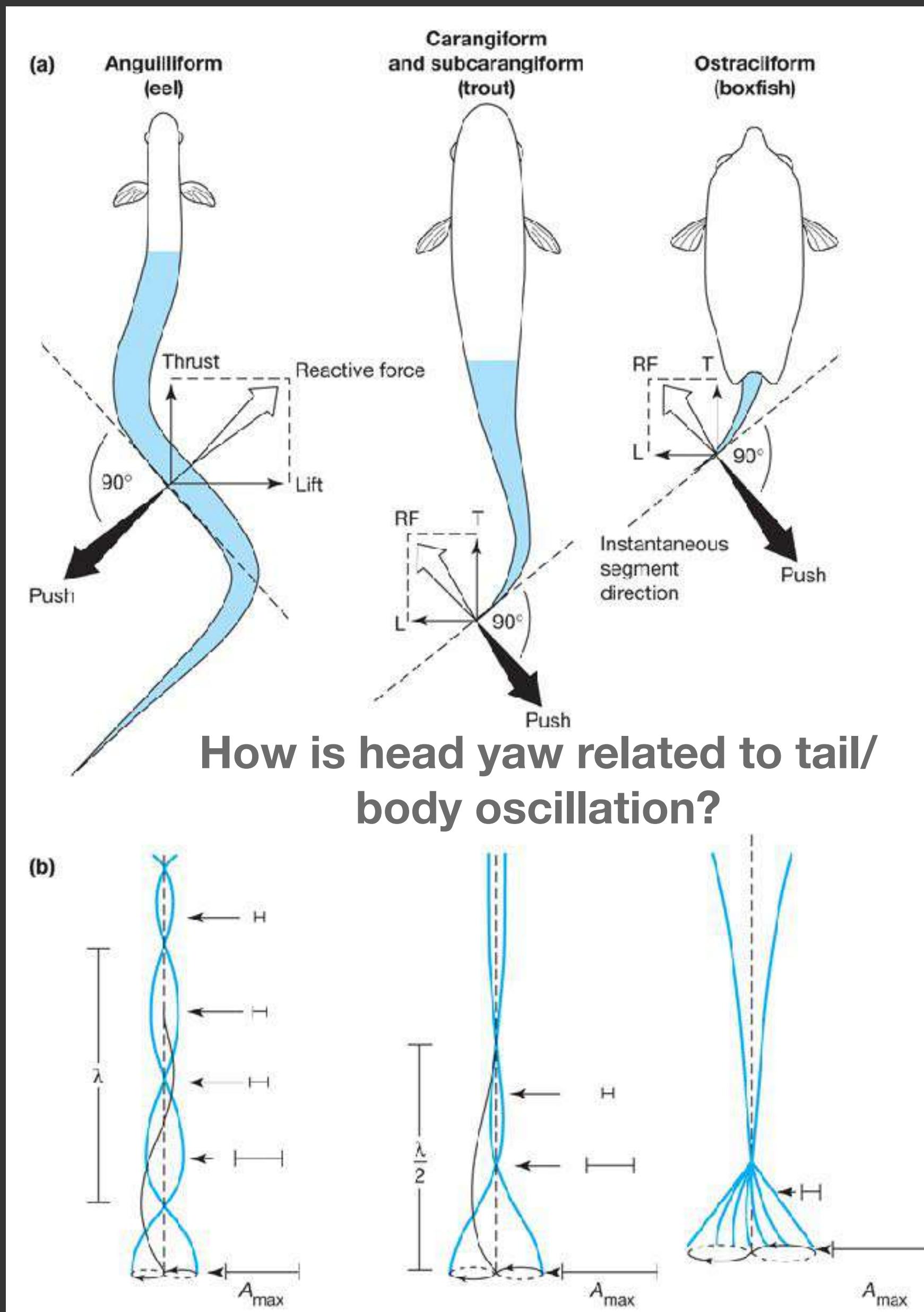
sinusoidal waves passing down the body or fins

Oscillation:

a structure moving back and forth

	Swimming type					
	Via trunk and tail			Via fins		
	Anguilliform	Via tail		Tetraodontiform	Rajiform ^b	Labriform ^c
		Subcarangiform ^a	Carangiform	Ostraciiform	Balistiform	Gymnotiform
						
						
						
Representative taxa	Eels, some sharks, many larvae	Salmon, jacks, mako shark, tuna	Boxfish, mormyrs, torpedo ray	Triggerfish, ocean sunfish, porcupinefish	Rays, Bowfin, knifefishes	Wrasses, surfperch
Propulsive force	Most of body	Posterior half of body	Caudal region	Median fin(s)	Pectorals, median fins	Pectoral fins
Propulsive form	Undulation	Undulation	Oscillation	Oscillation ^d	Undulation	Oscillation
Wavelength	0.5 to >1 wavelength	<1 (usually <0.5) wavelength			>>1 wavelength	
Maximum speed bl/s	Slow-moderate 2	Very fast – moderate 10–20	Slow?	Slow?	Slow to moderate 0.5	Slow 4
Body shape: lateral view cross-section	Elongate Round	Fusiform Round	Variable	Variable Often deep	Elongate Often flat	Variable
Caudal fin aspect ratio	Small Medium to low	Medium to large Low to high	Large Low	Small to medium Low	Variable Low	Large Low
Habitat	Benthic or suprabenthic	Pelagic, wc, schooling	Variable	wc	Suprabenthic	structure associated

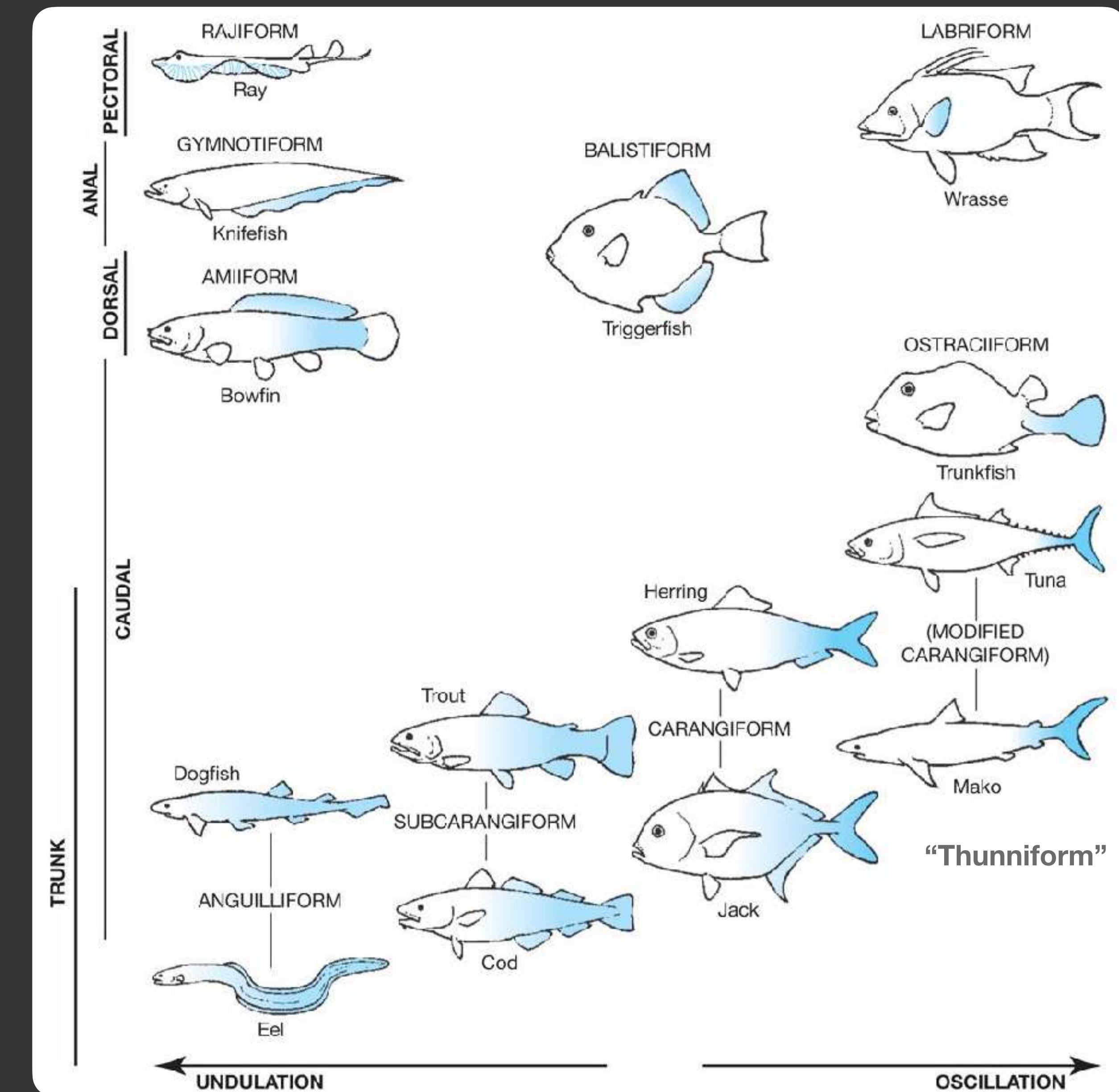
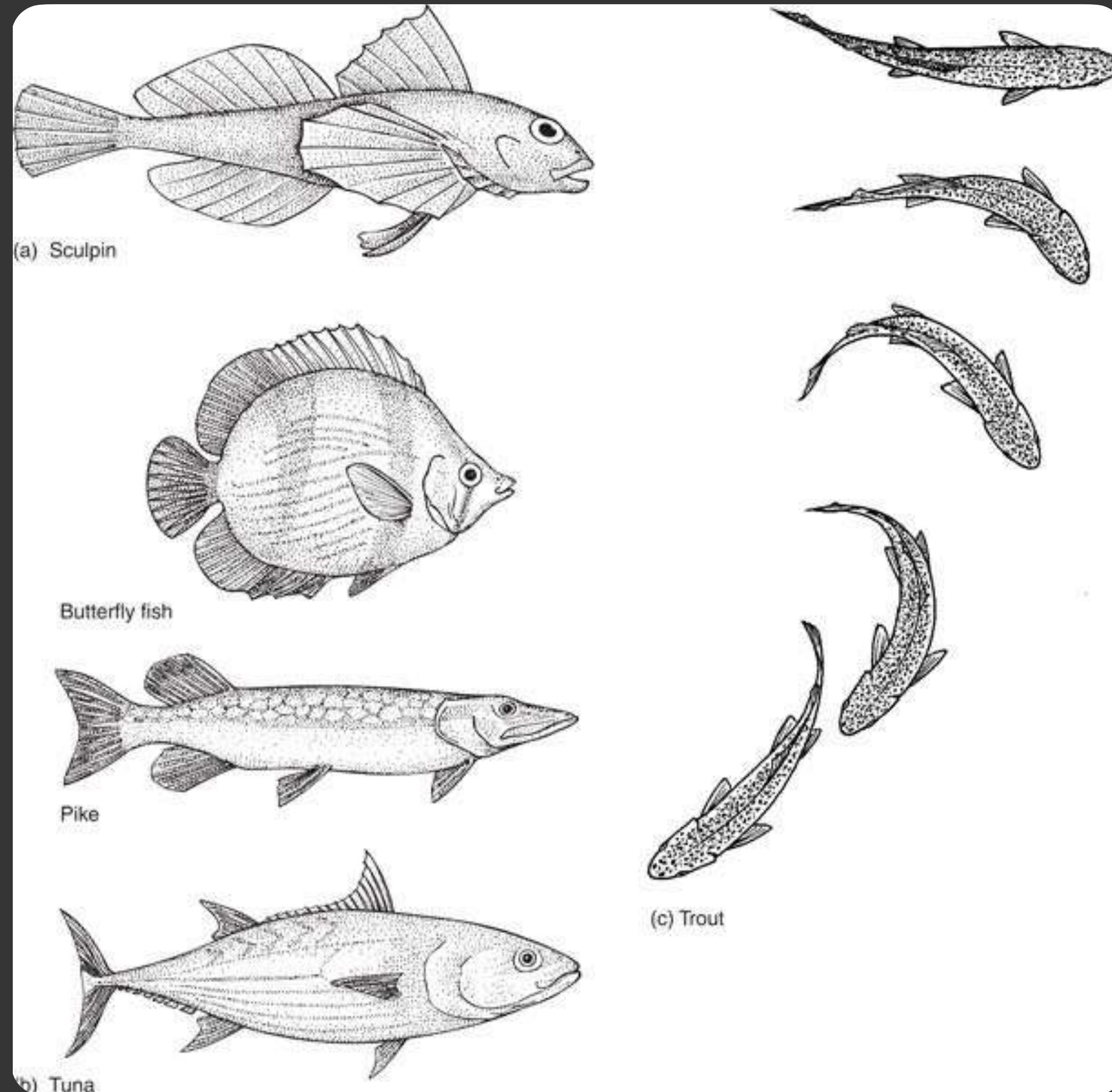
Functional Morphology of Fish Swimming



Thrust!
Body musculature, bending and use of fins
accelerate a mass of fluid to propel fish
forward

Pectoral fins produce larger vortices so they
are used more for equilibrium at lower
speeds, at higher speeds fishes use their
caudal fin

Swimming modalities



Caudal fins

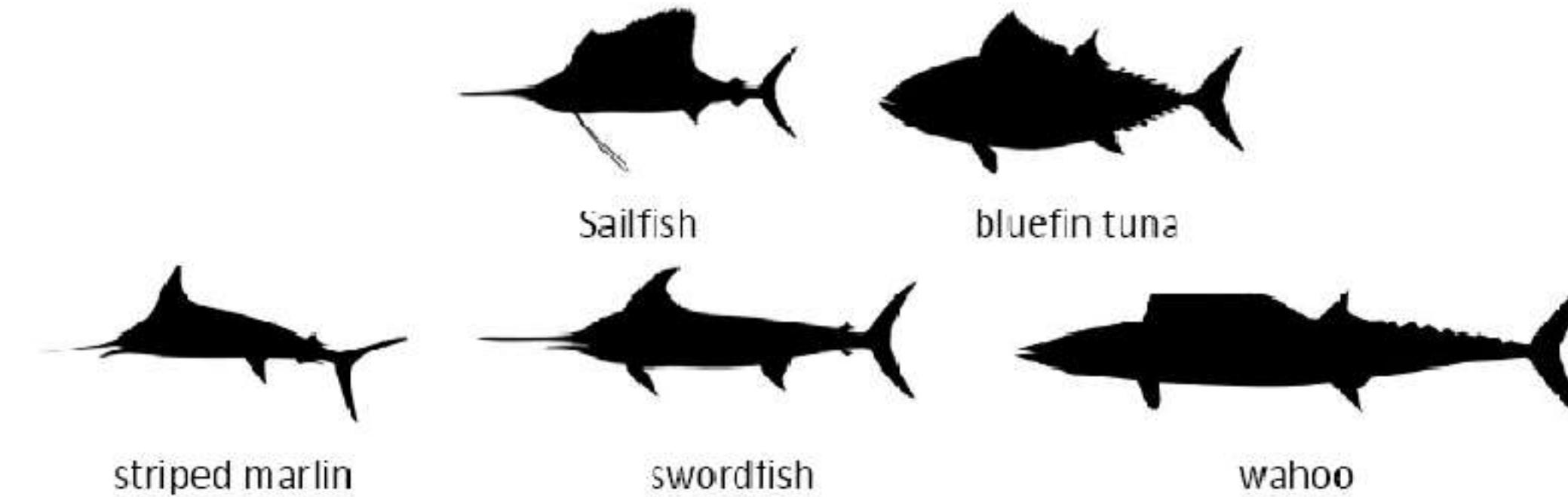
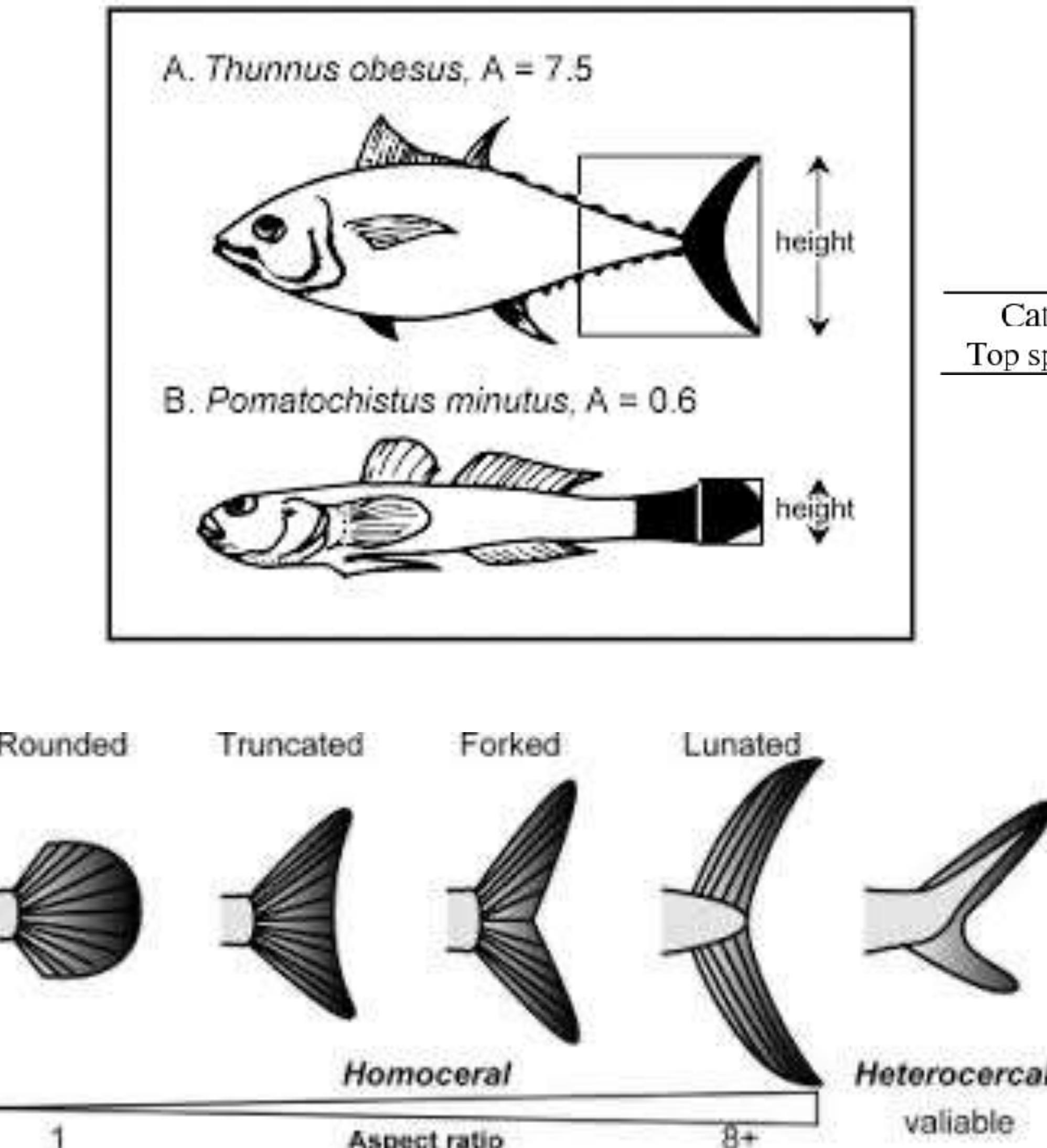
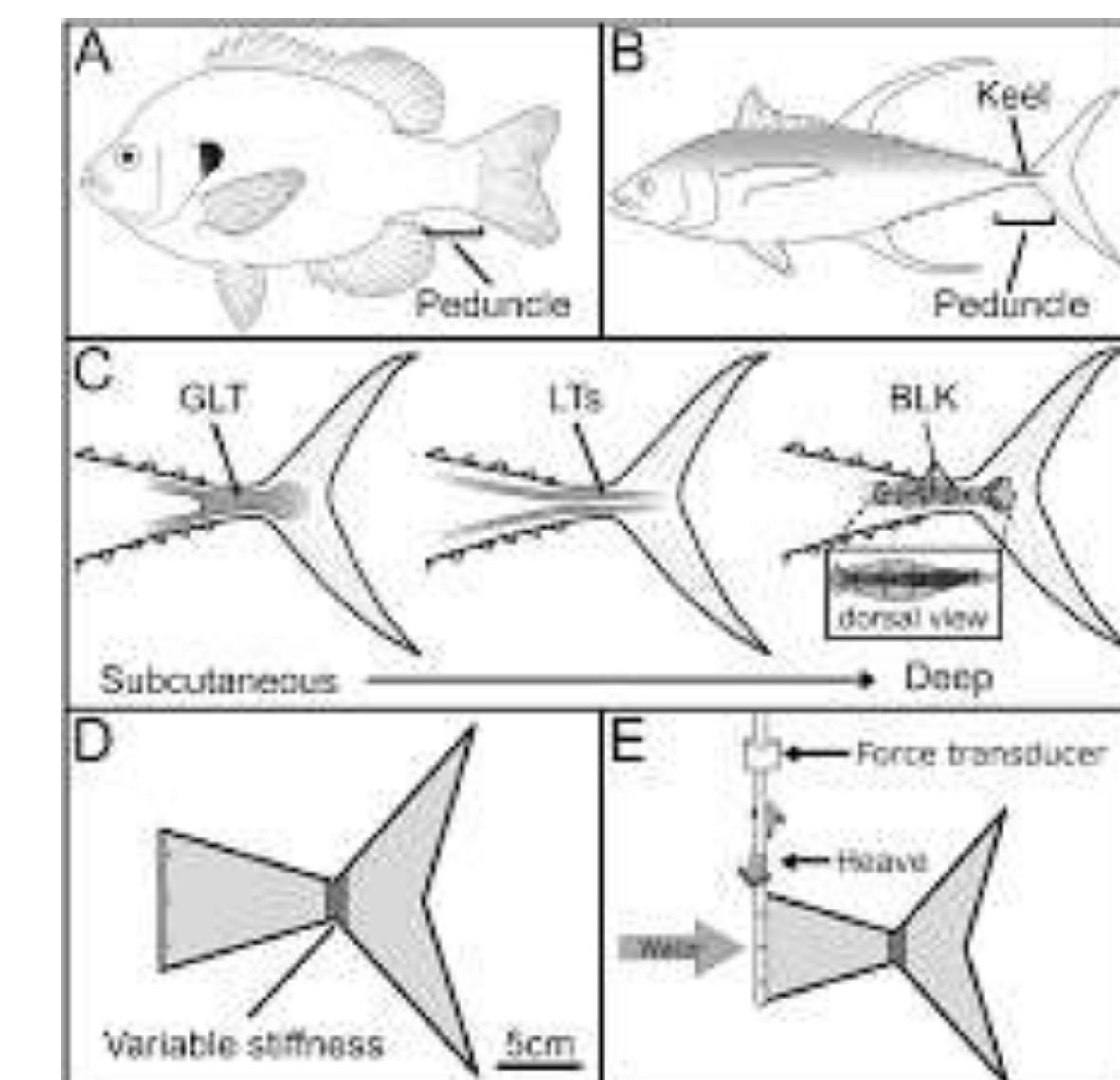
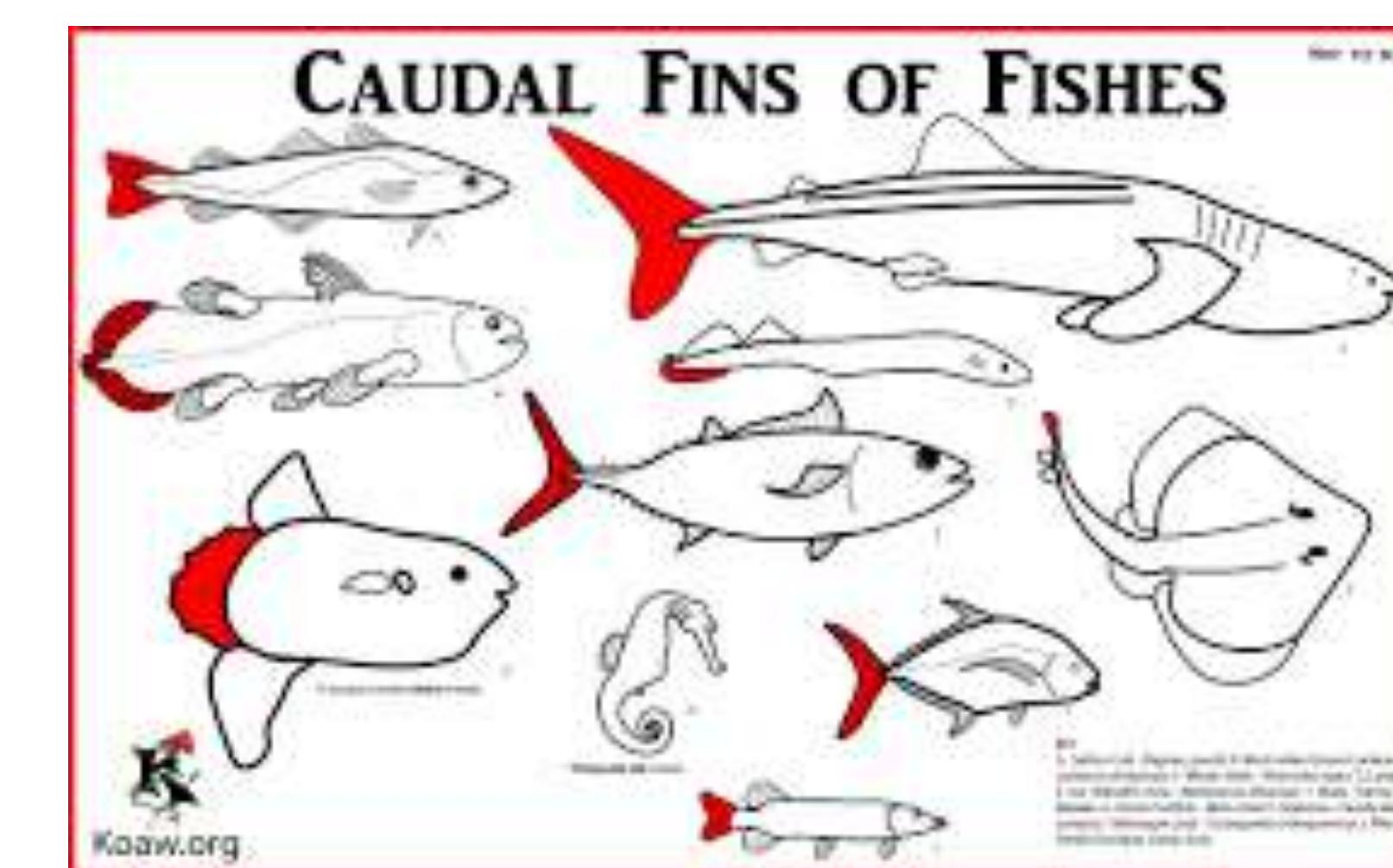


Fig. 1: Some high-speed fishes

Table 1: The top speed of some fish

Categories	Sailfish	Bluefin tuna	Striped marlin	swordfish	wahoo
Top speed (mph)	60.3	43.5	50.3	68.4	47.8

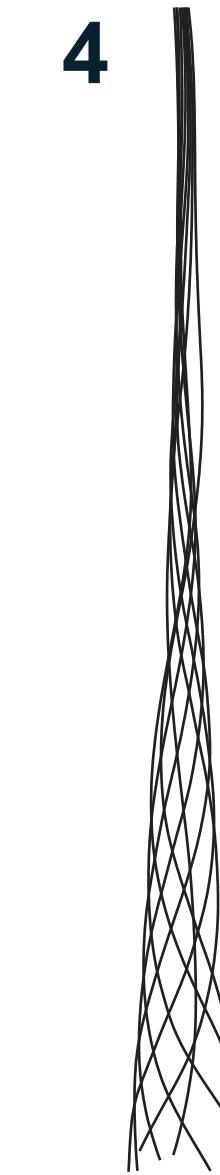
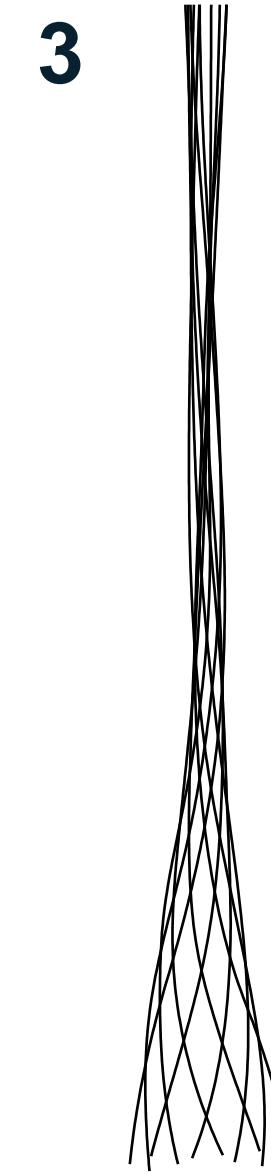
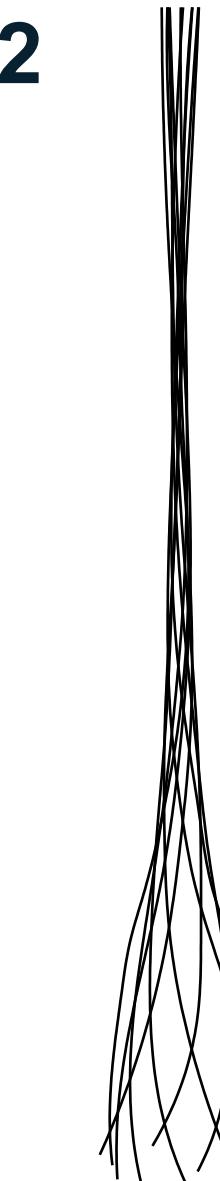
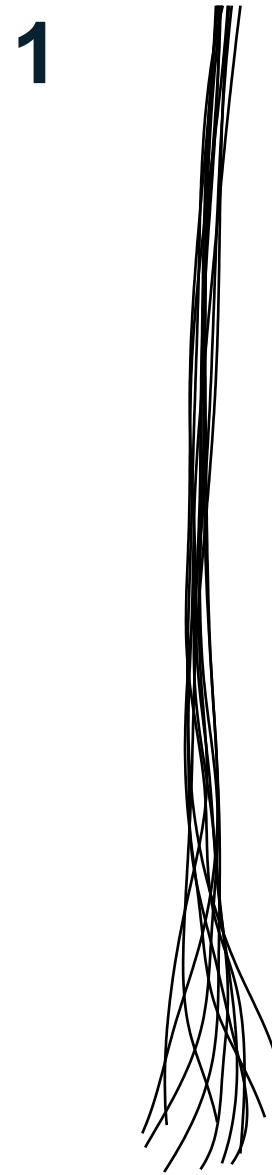


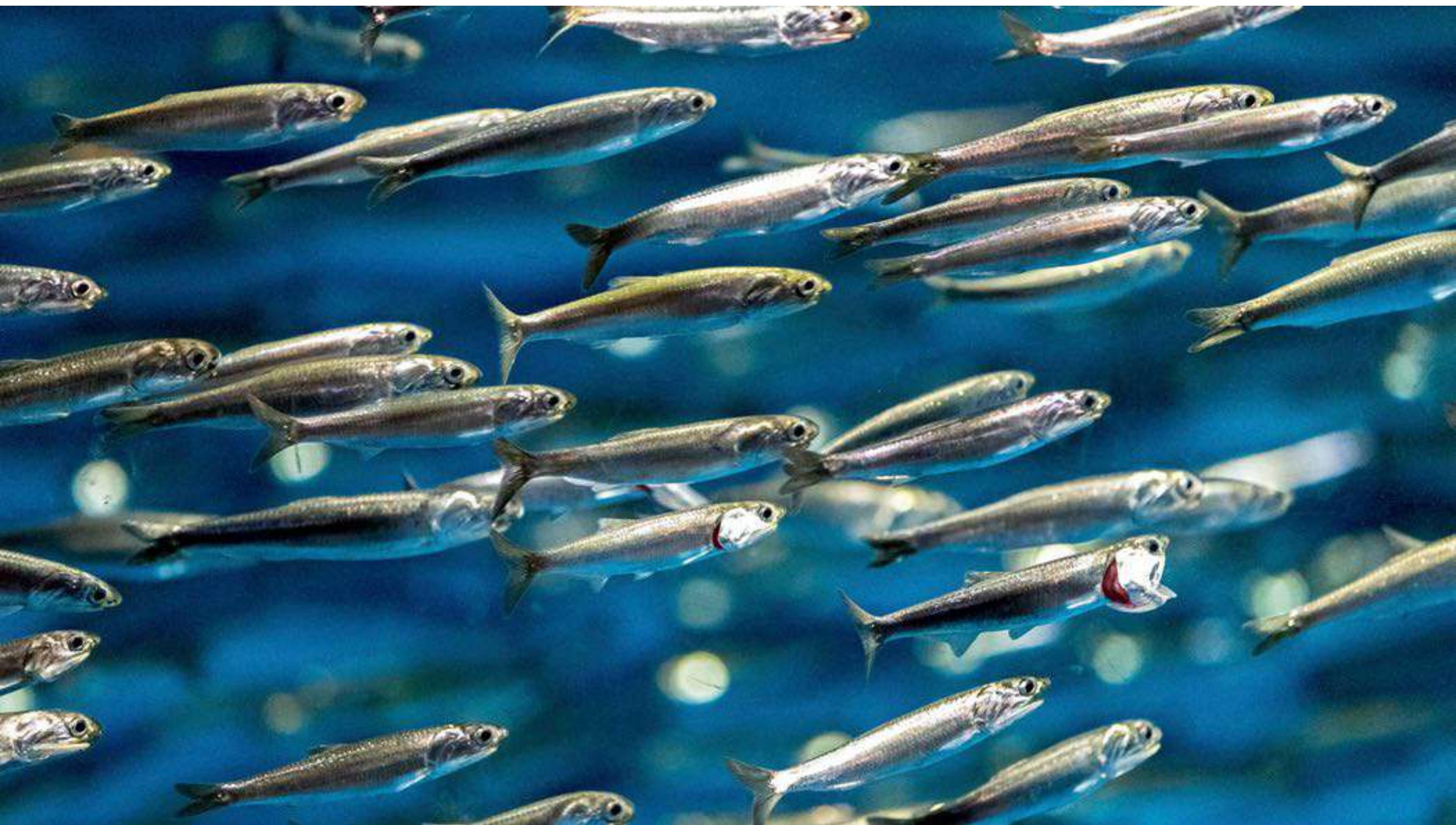
Rainbow Trout are able to increase the depth and hence produce a higher aspect ratio tail during high-speed swimming

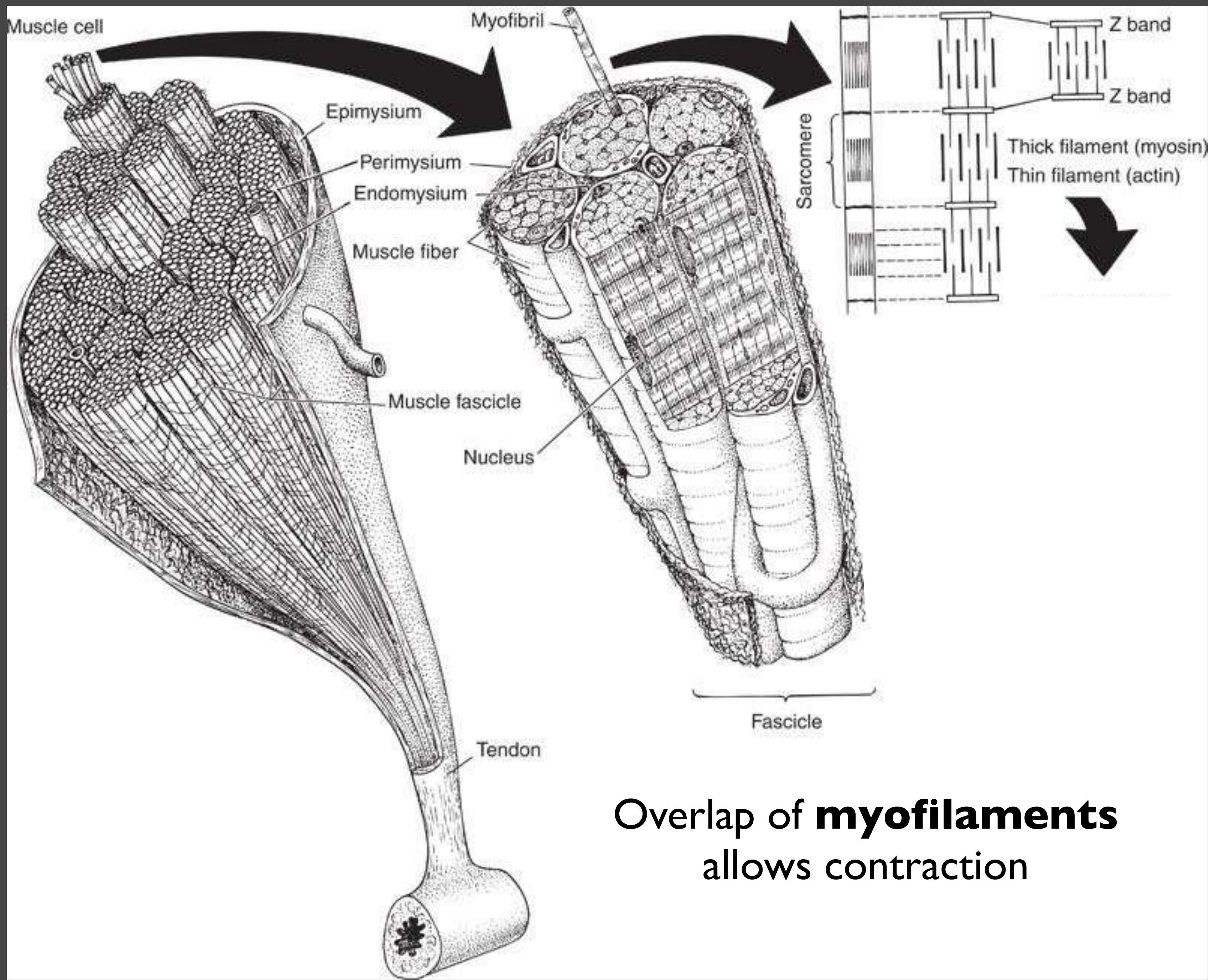
Quiz:

Undulatory locomotion in fishes

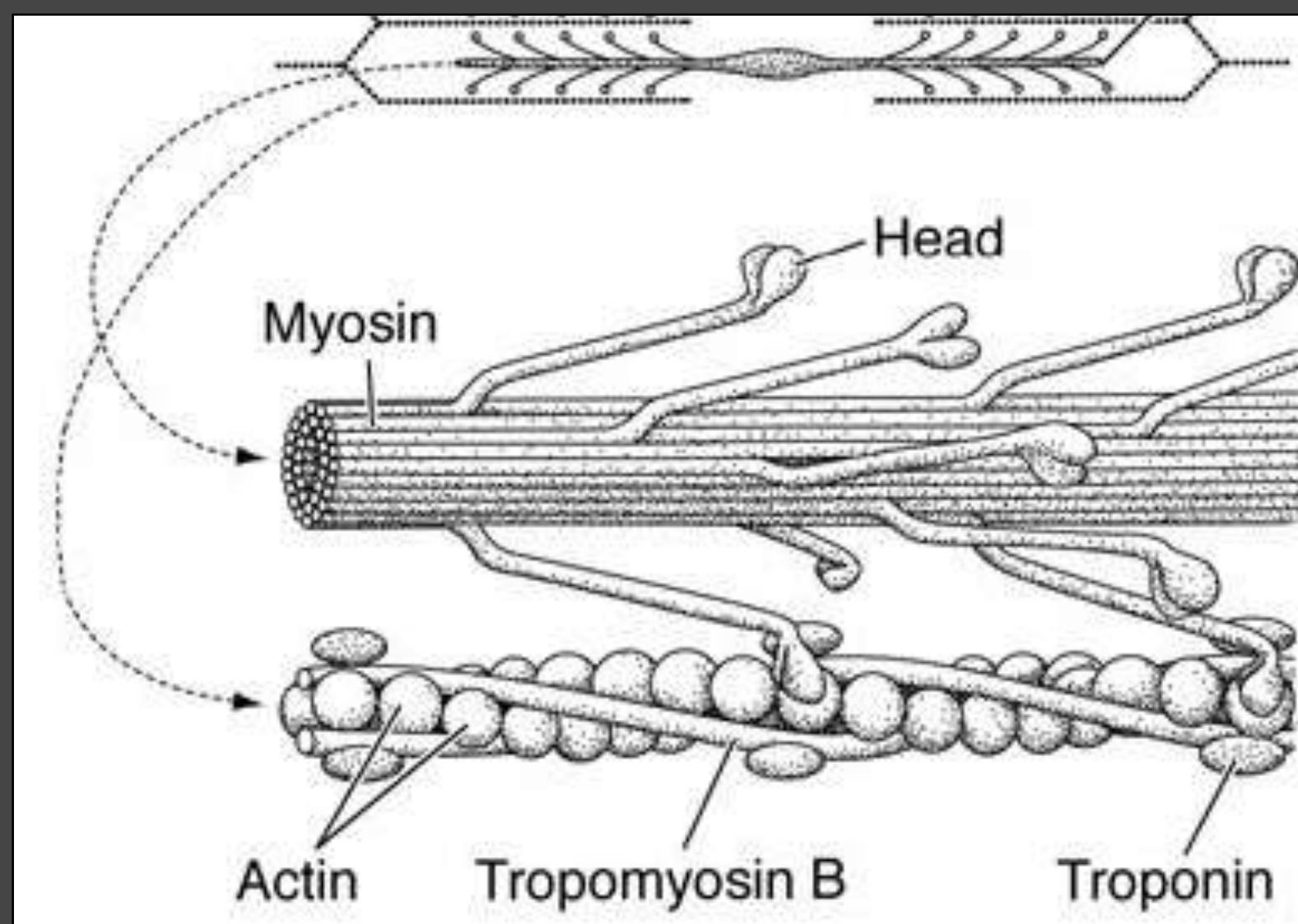
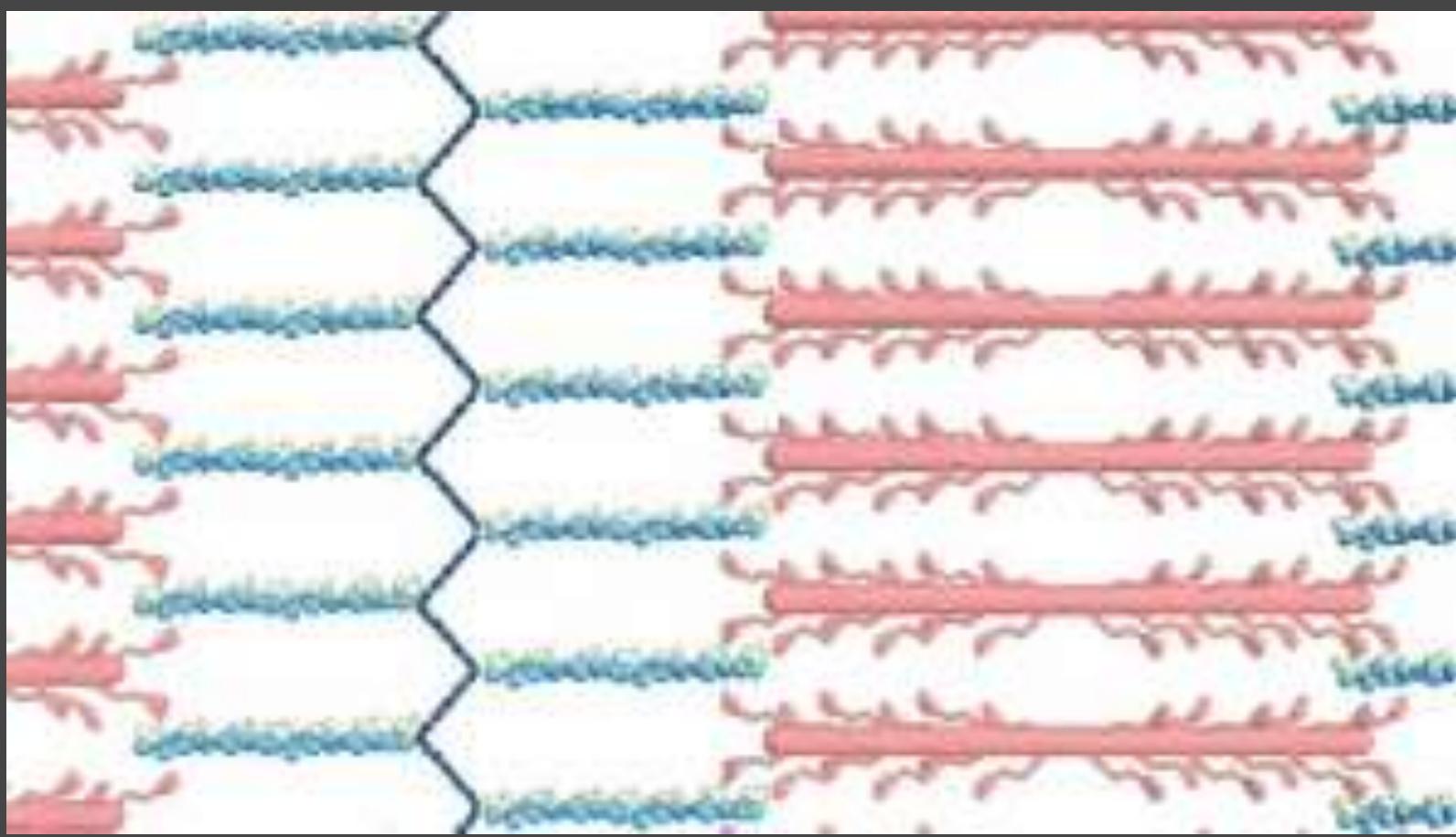
based on the classical swimming categories,
which midlines below are from: **eel, trout, jack, tuna**?



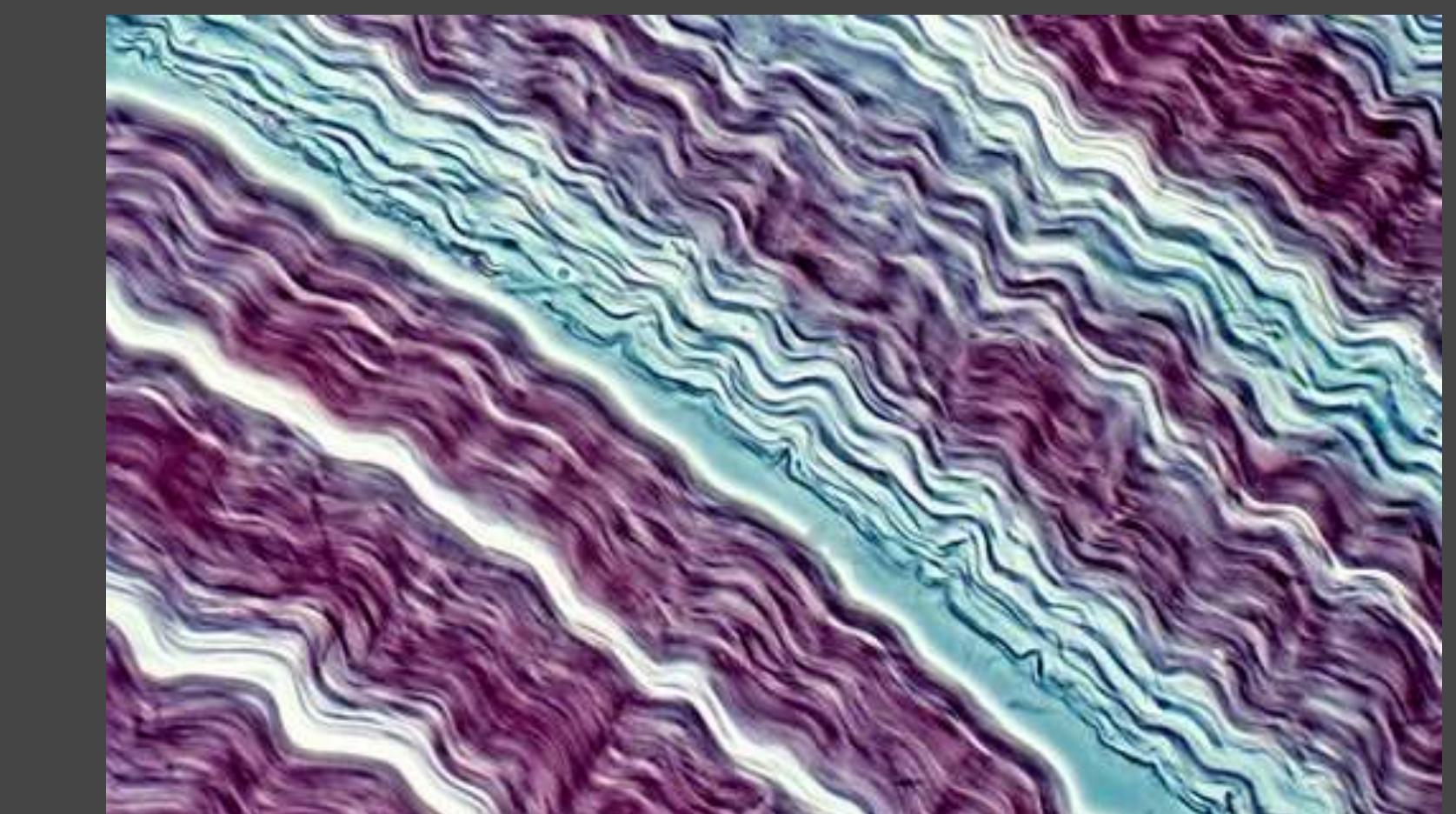
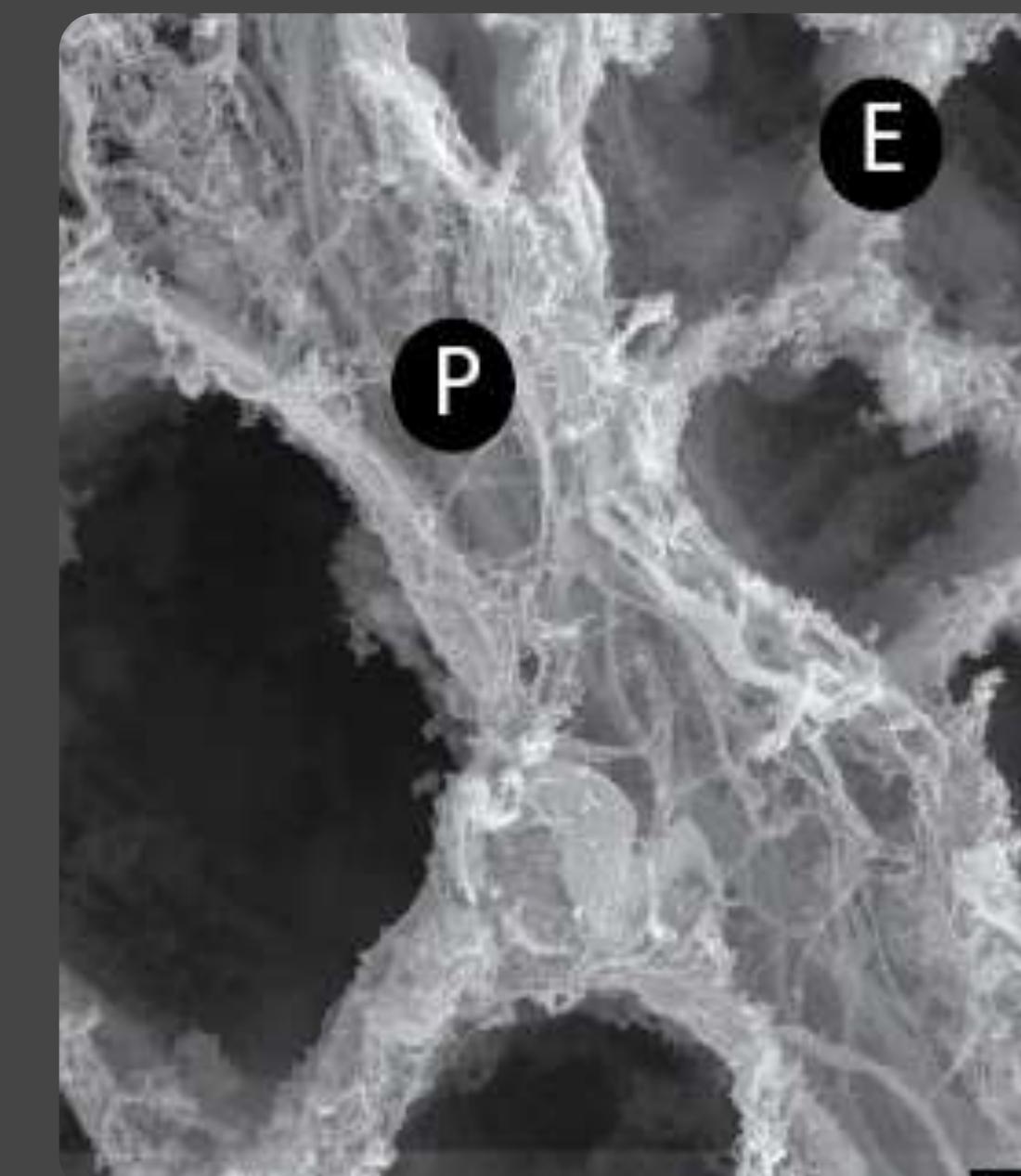
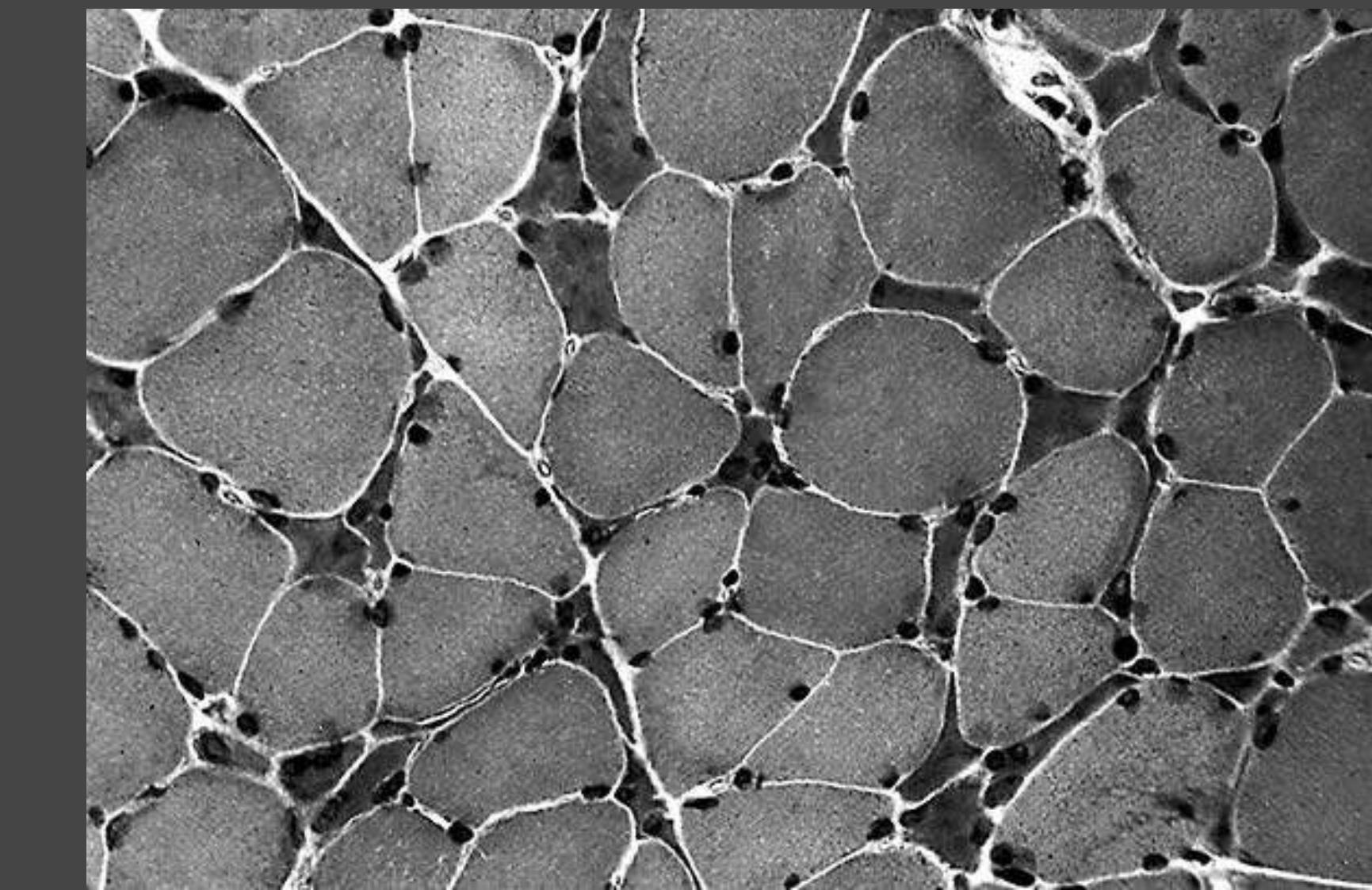
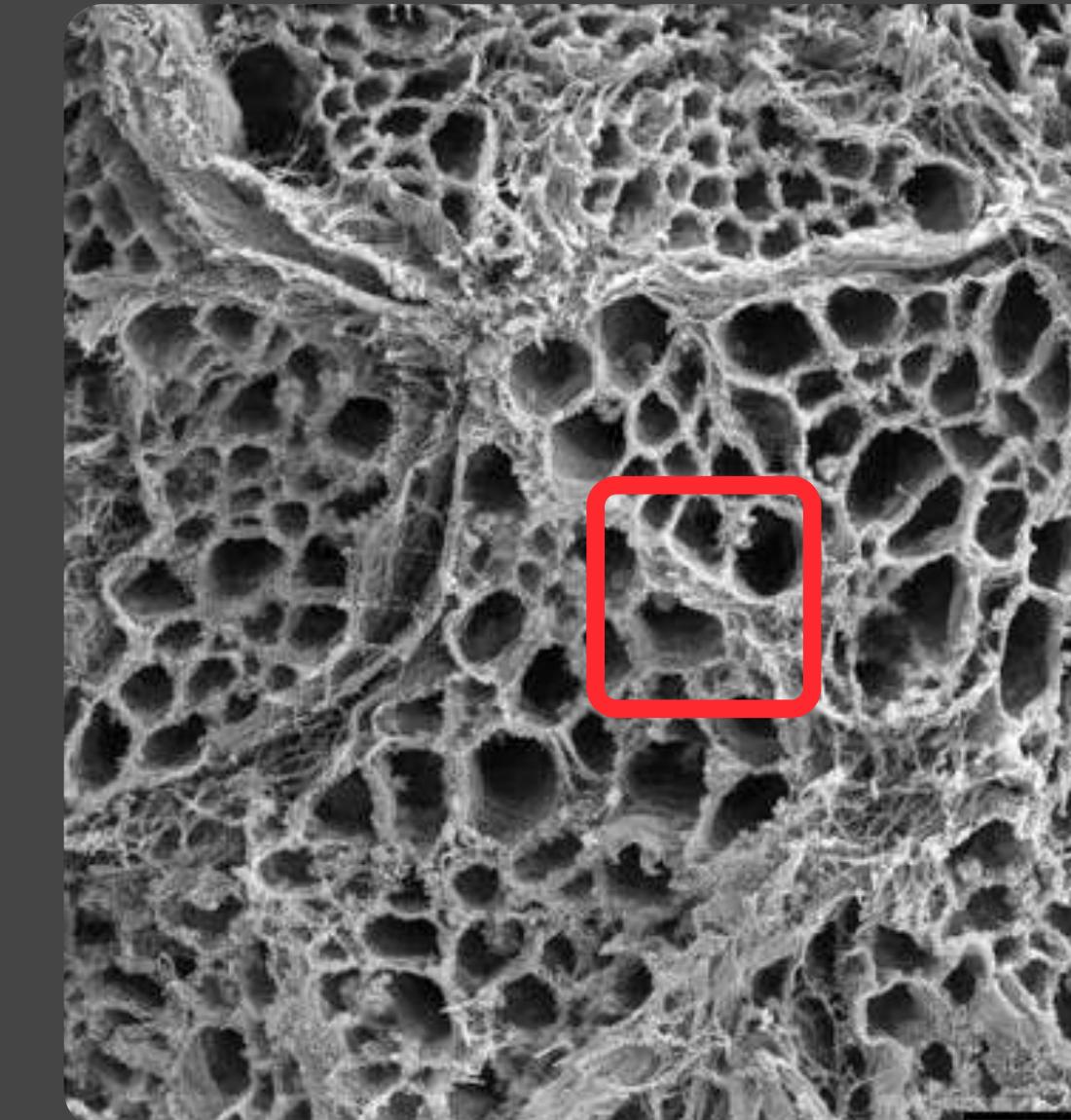
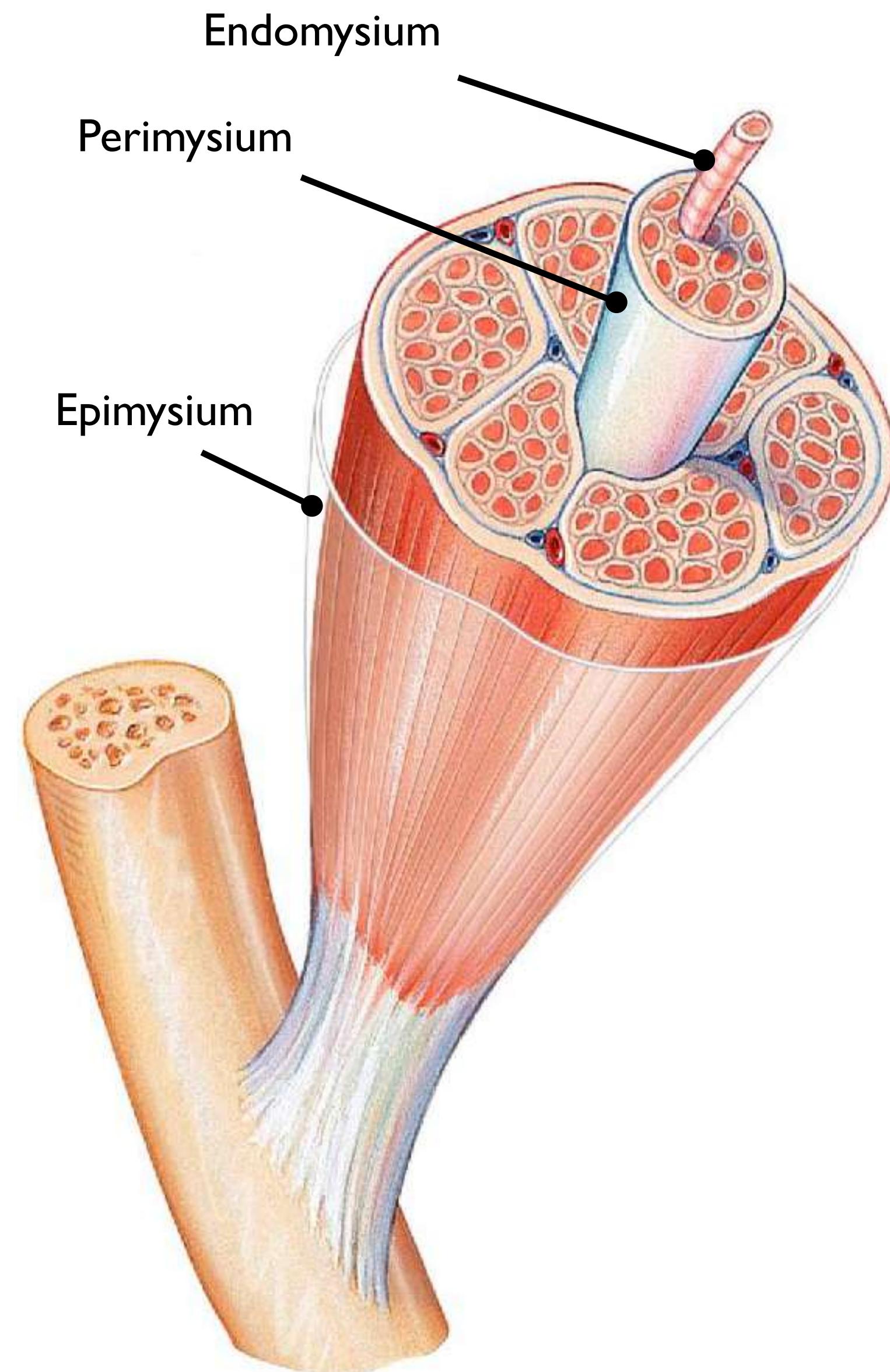




Overlap of myofilaments
allows contraction



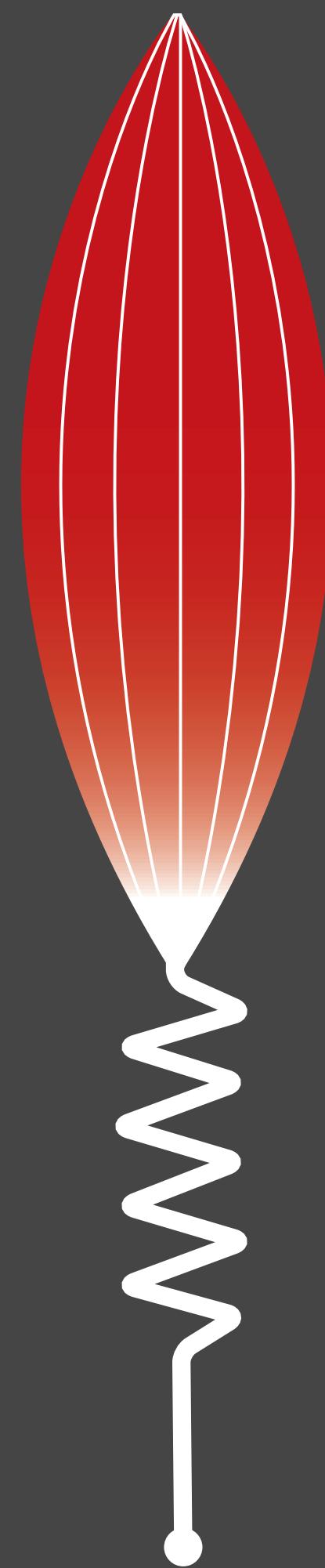
Connective tissue keeps skeletal muscle very organized



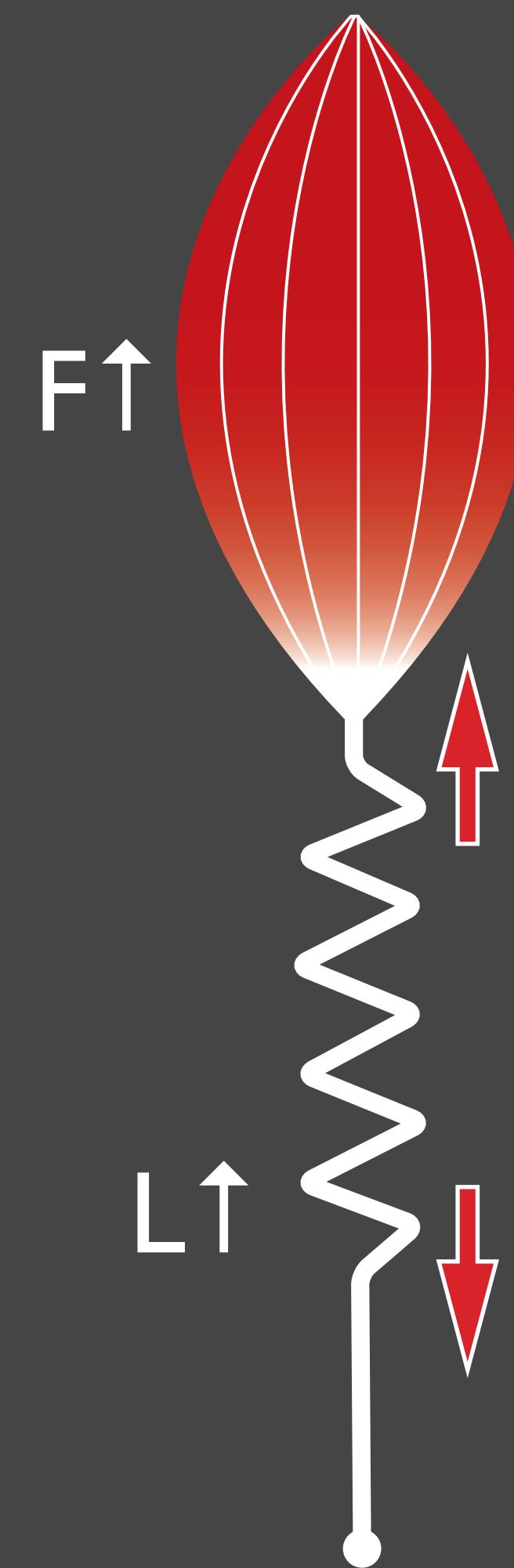
E- Endomysium

P- Perimysium

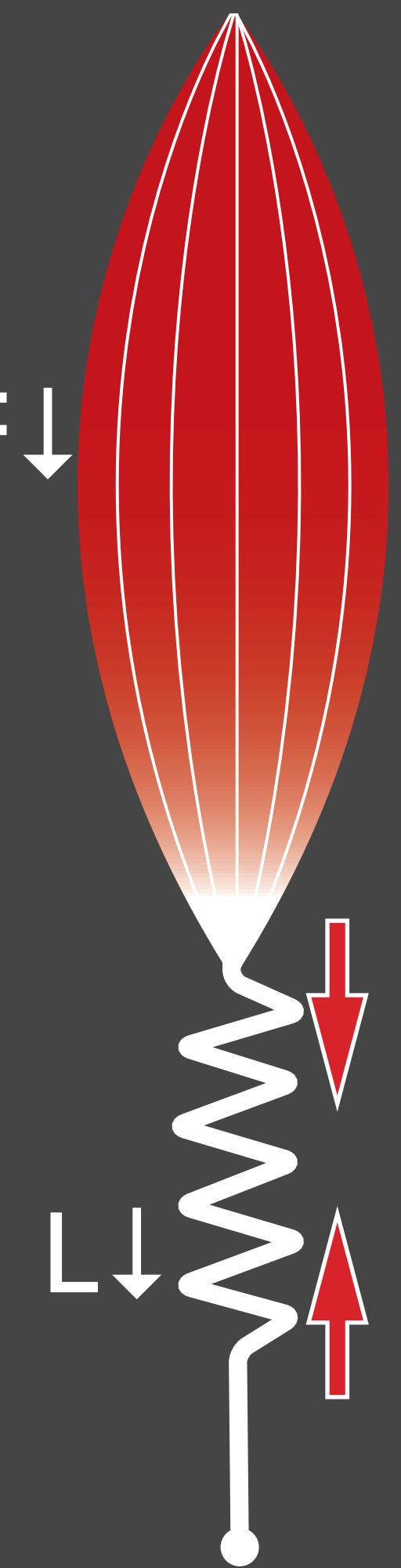
rest

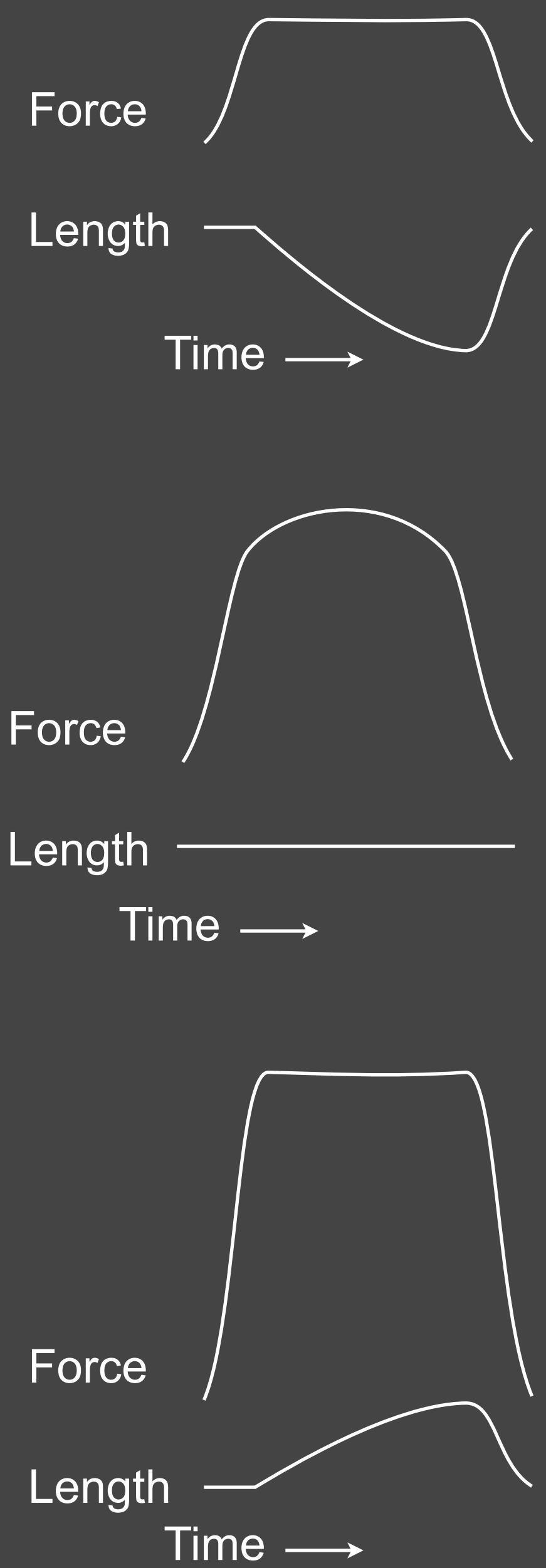
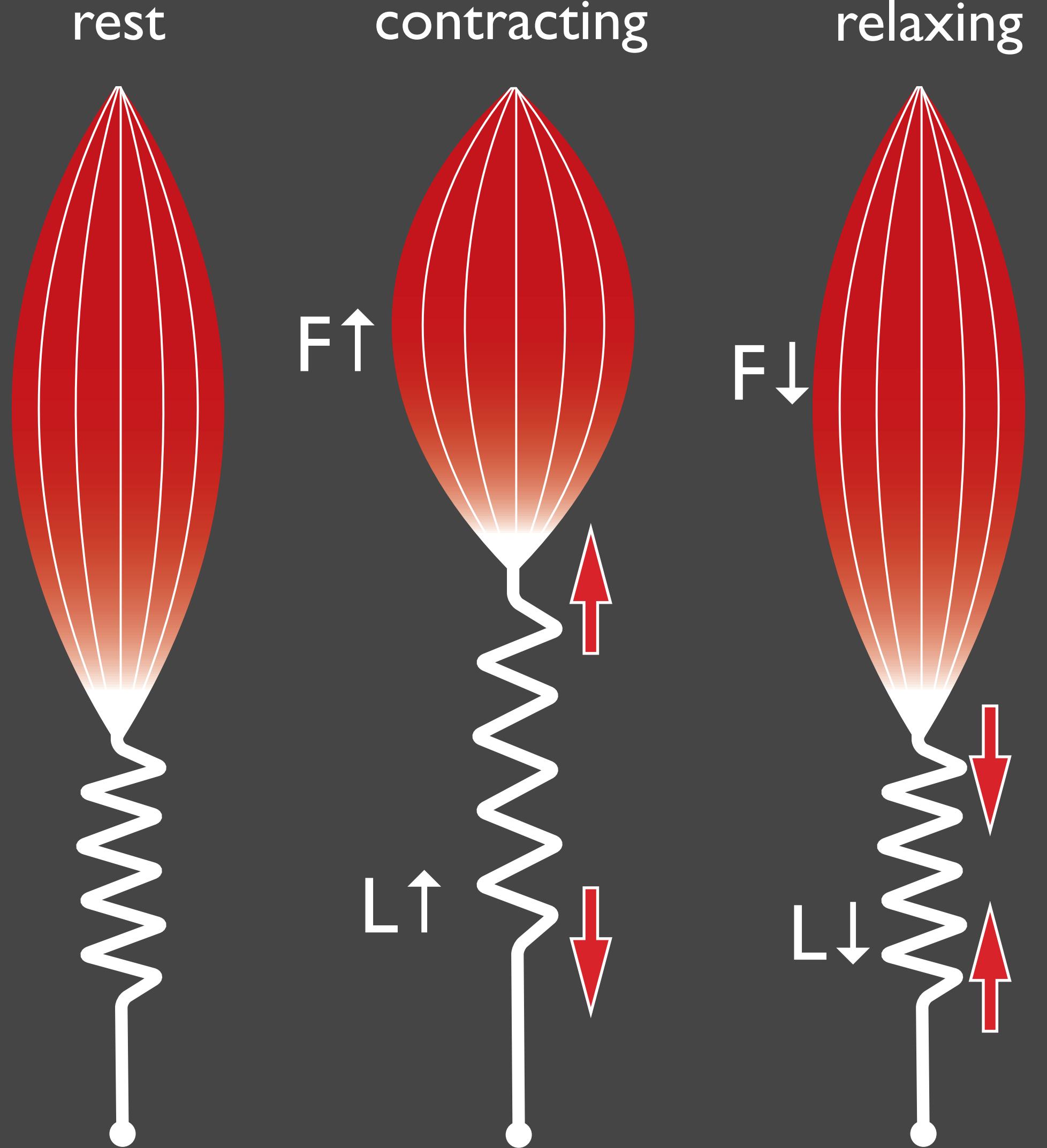


contracting



relaxing





Shortening contraction: Muscle produces mechanical work

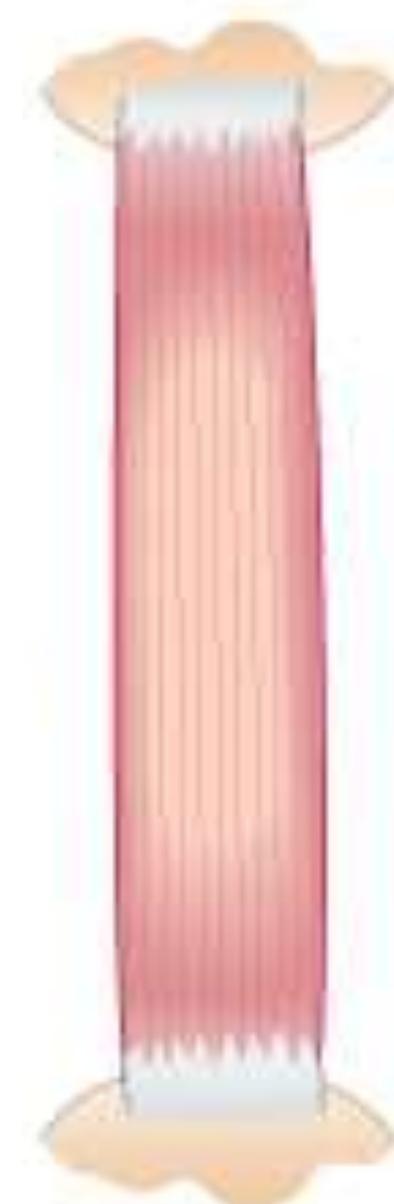
Motor

Isometric contraction: Muscle produces force

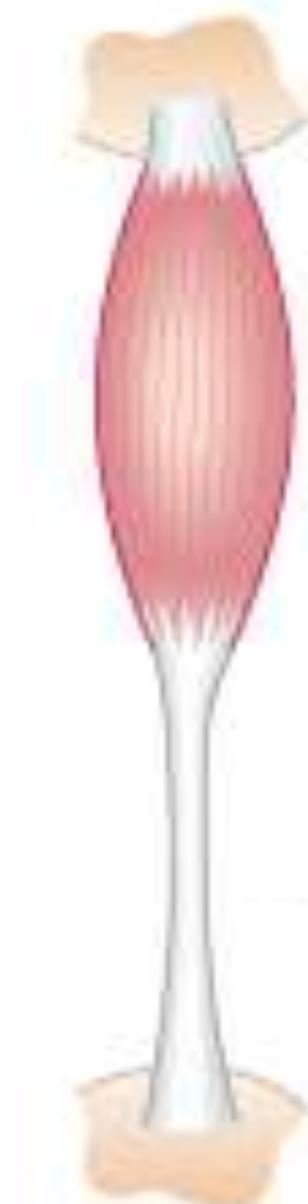
Strut

Lengthening contraction: Muscle dissipates mechanical work

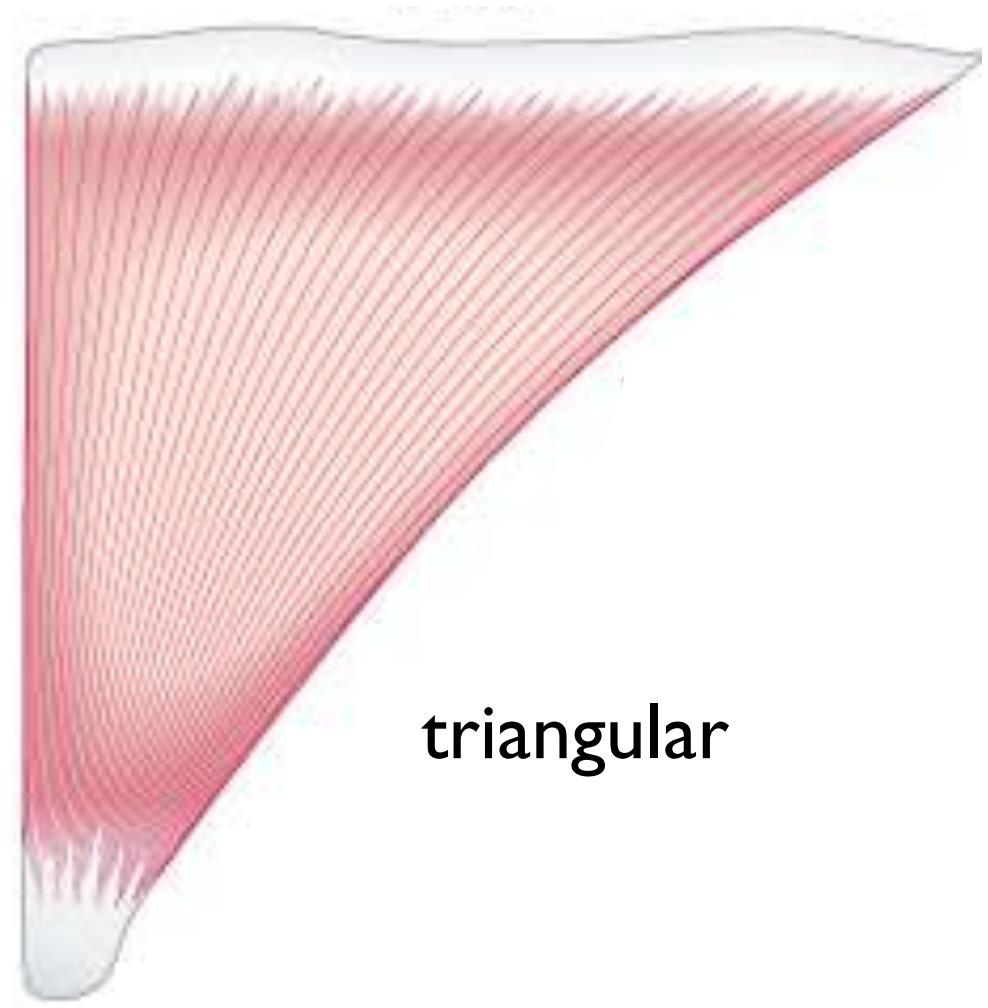
Brake



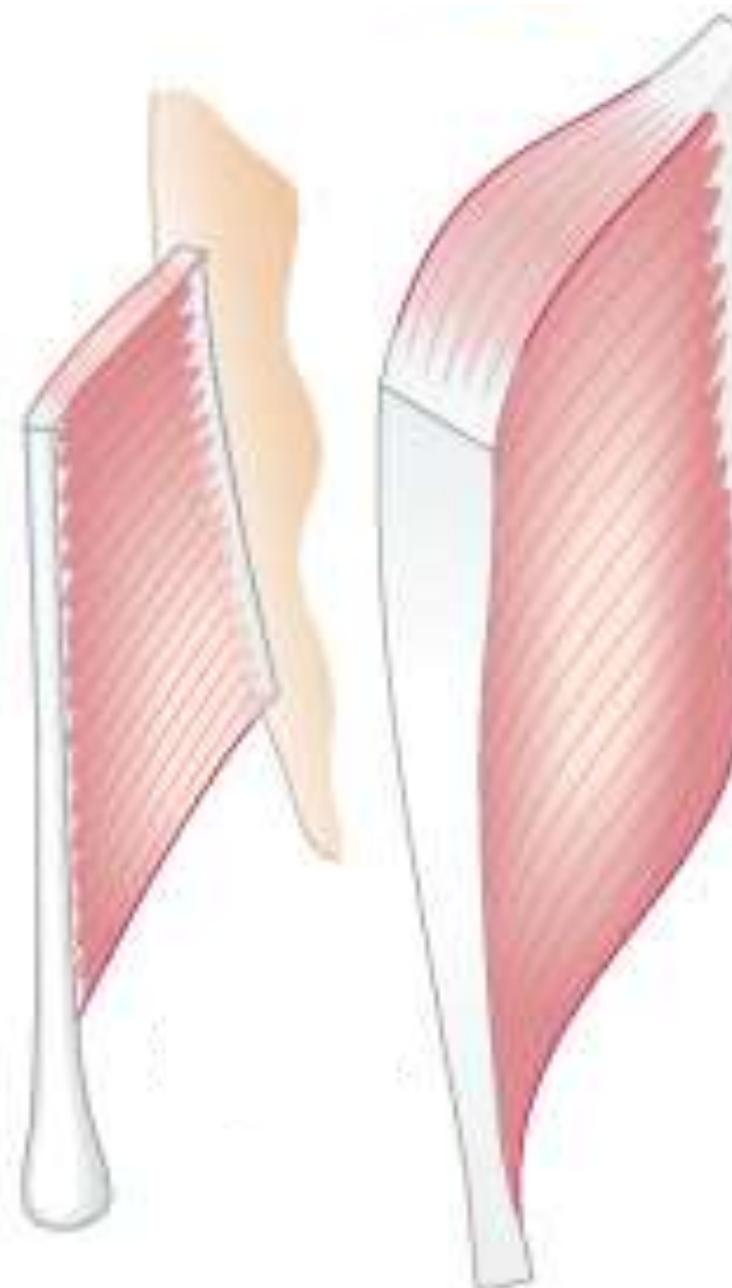
strap



fusiform



triangular



unipennate



bipennate

Variation in muscle architecture can alter:

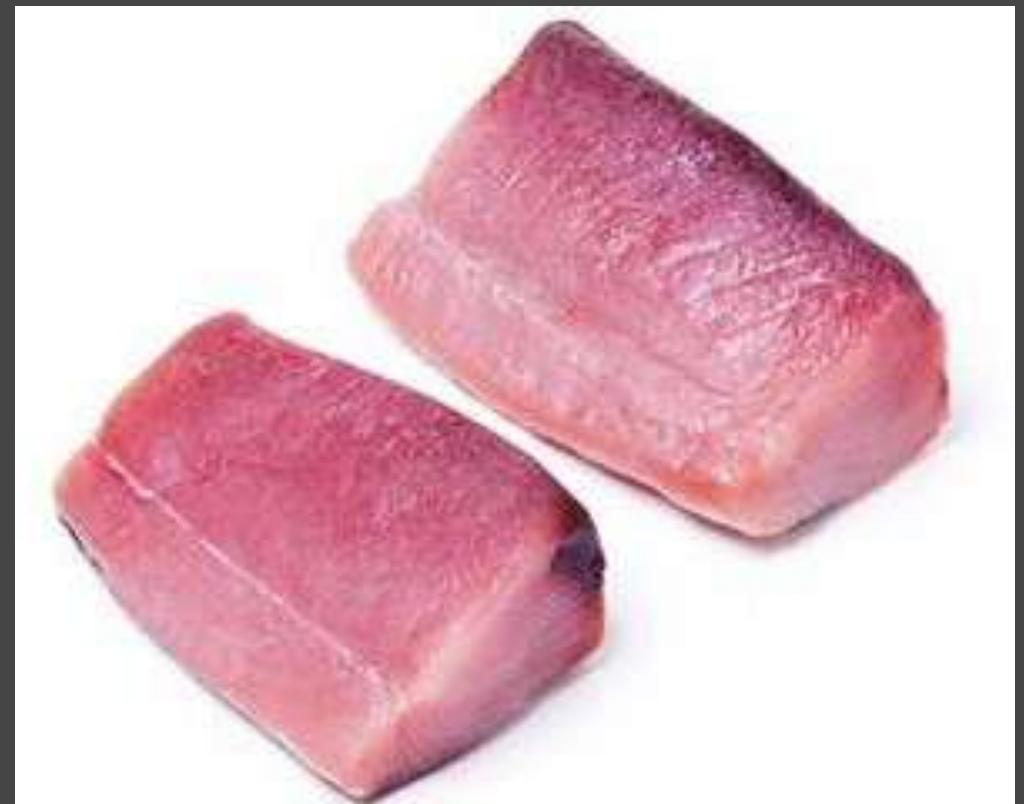
1. fascicle/fiber length
2. fascicle/fiber angle
3. cross-sectional area

Gross muscle architecture varies a lot, with fiber direction indicating line of action

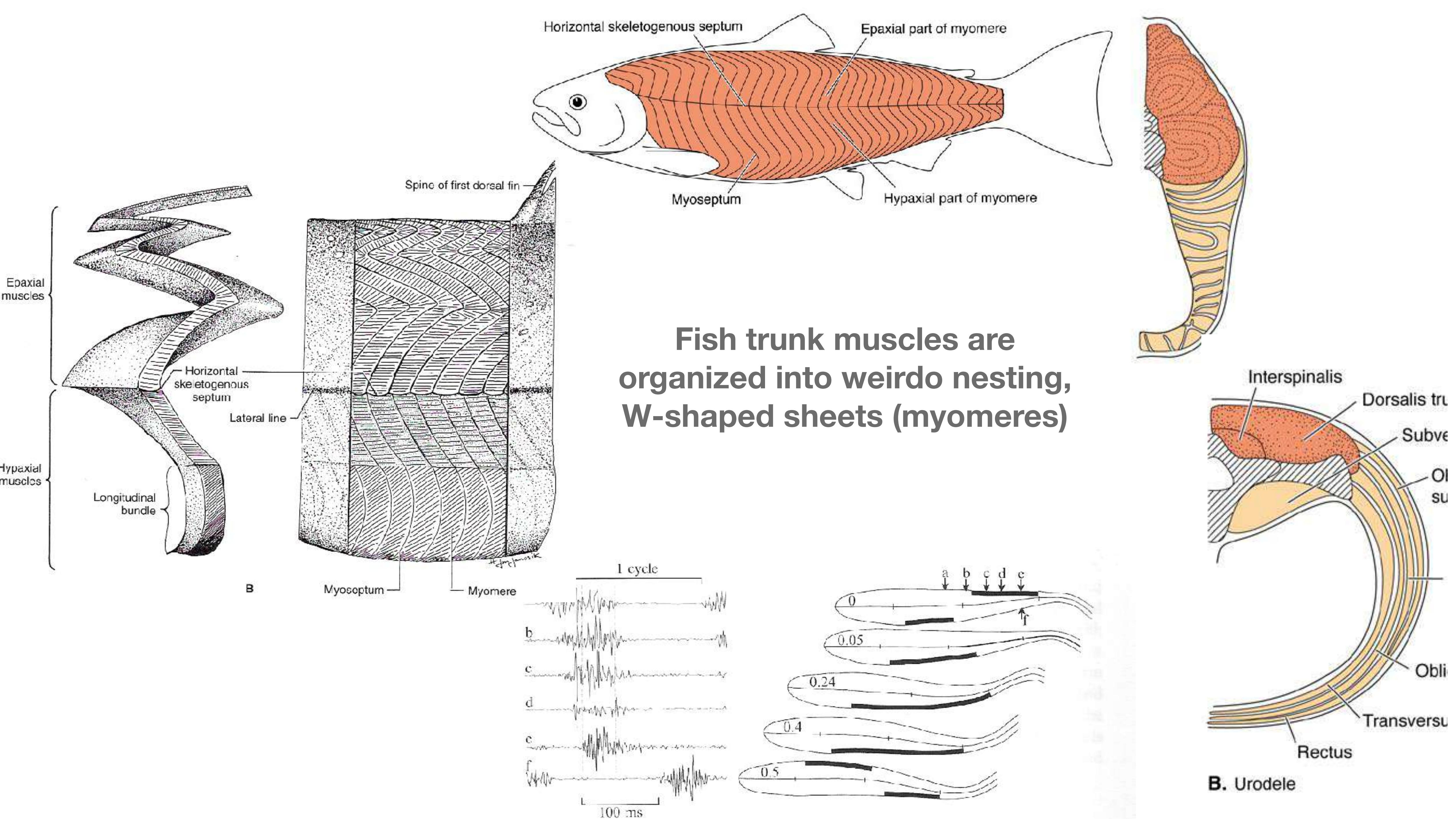
MUSCLE METABOLISM:

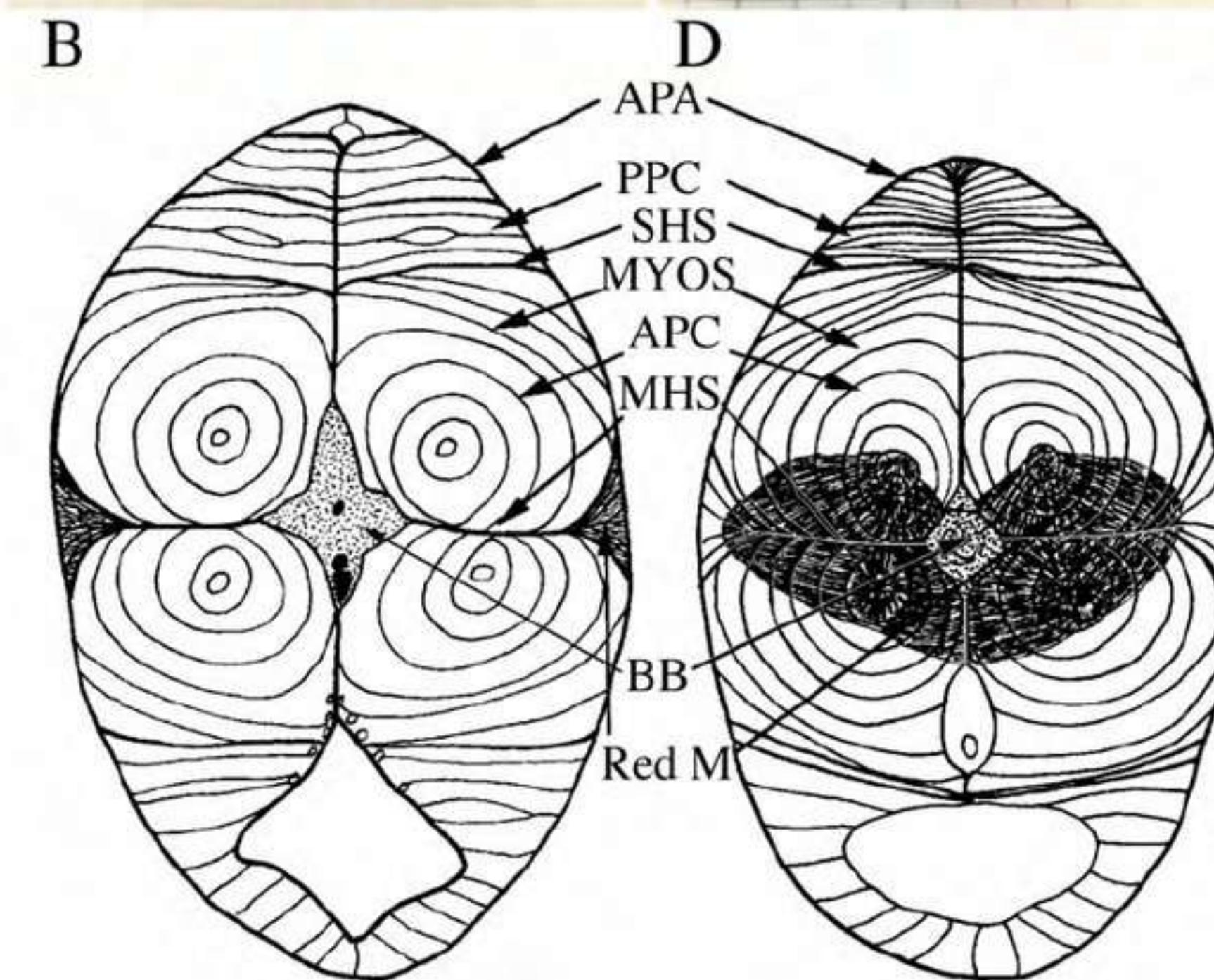
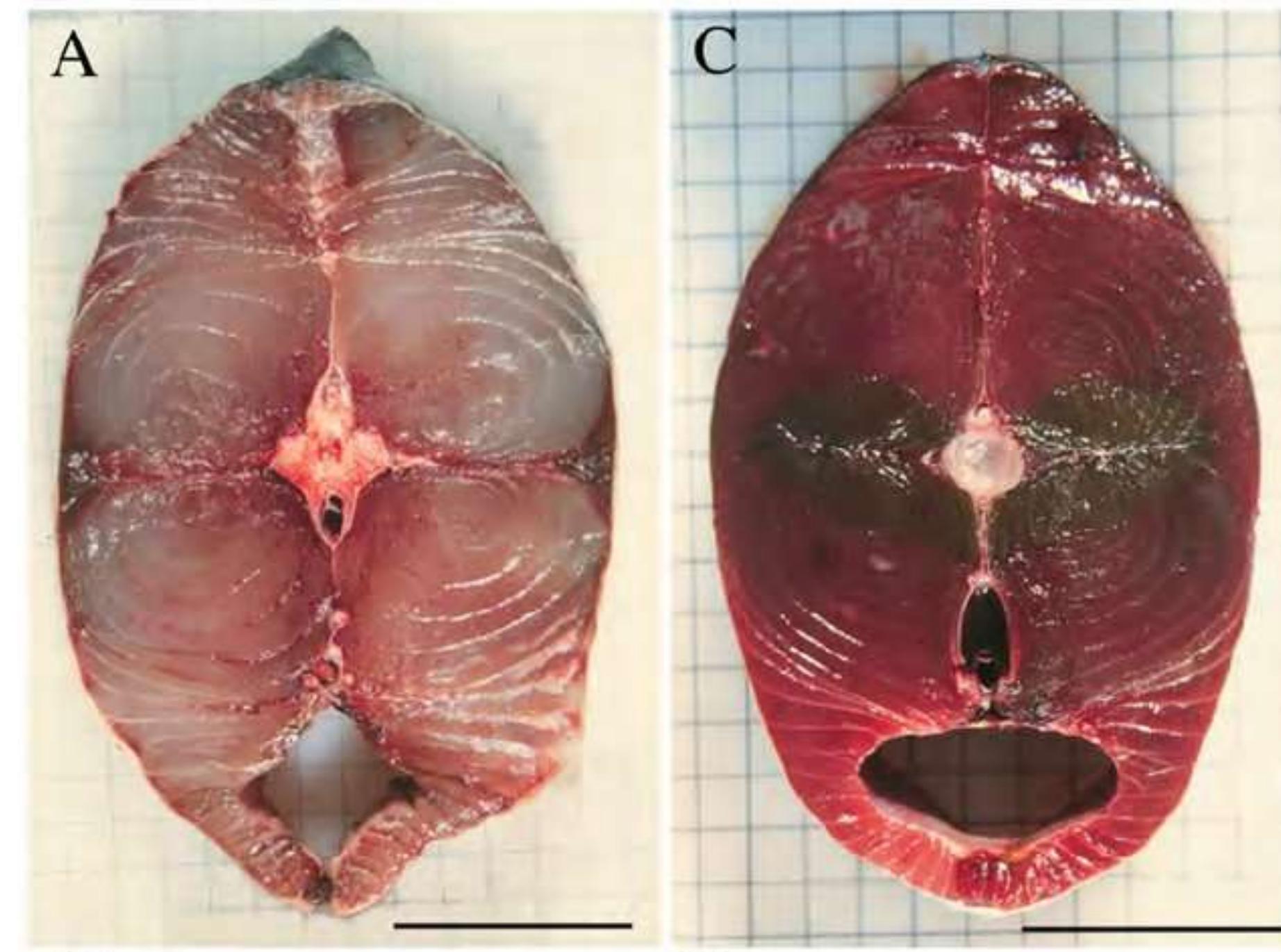
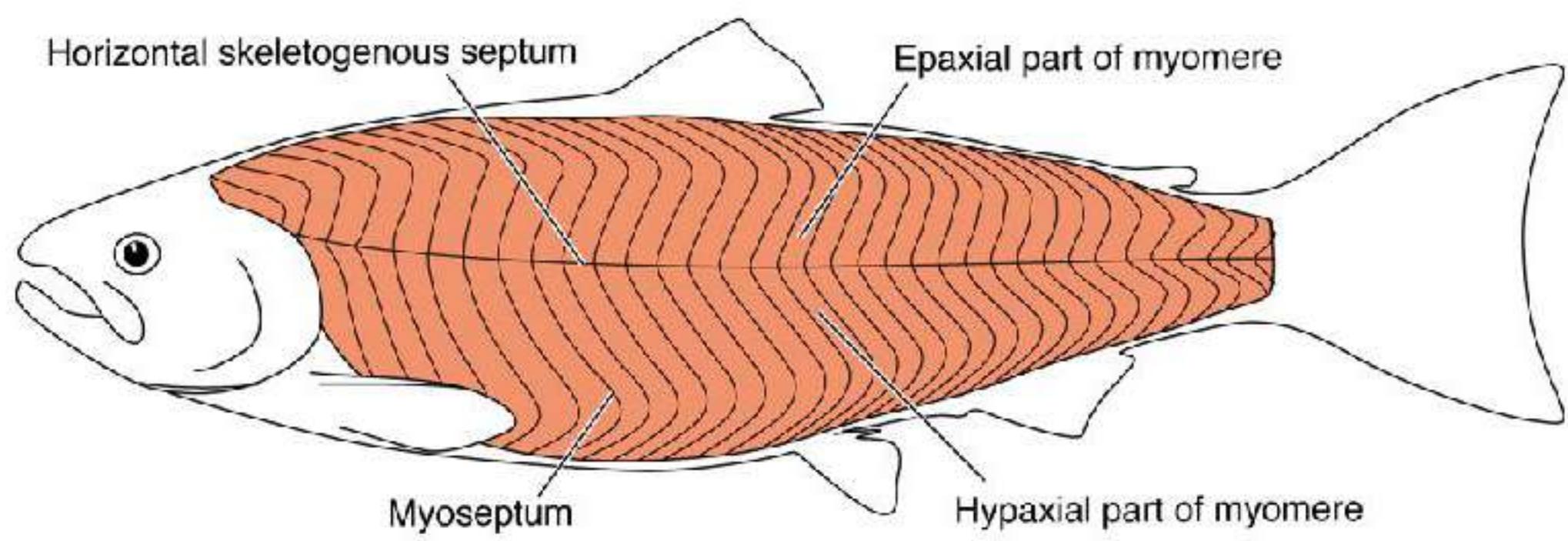
Color	RED	WHITE
Mitochondria	Abundant	Fewer
Blood supply	Rich	Lower
O ₂ /myoglobin	Rich	Lower
Contraction rate	Slow	Fast
Fatigue	Very slowly	Quickly
Examples	Fish red muscle Postural muscles	Fish white muscle Avian flight muscle

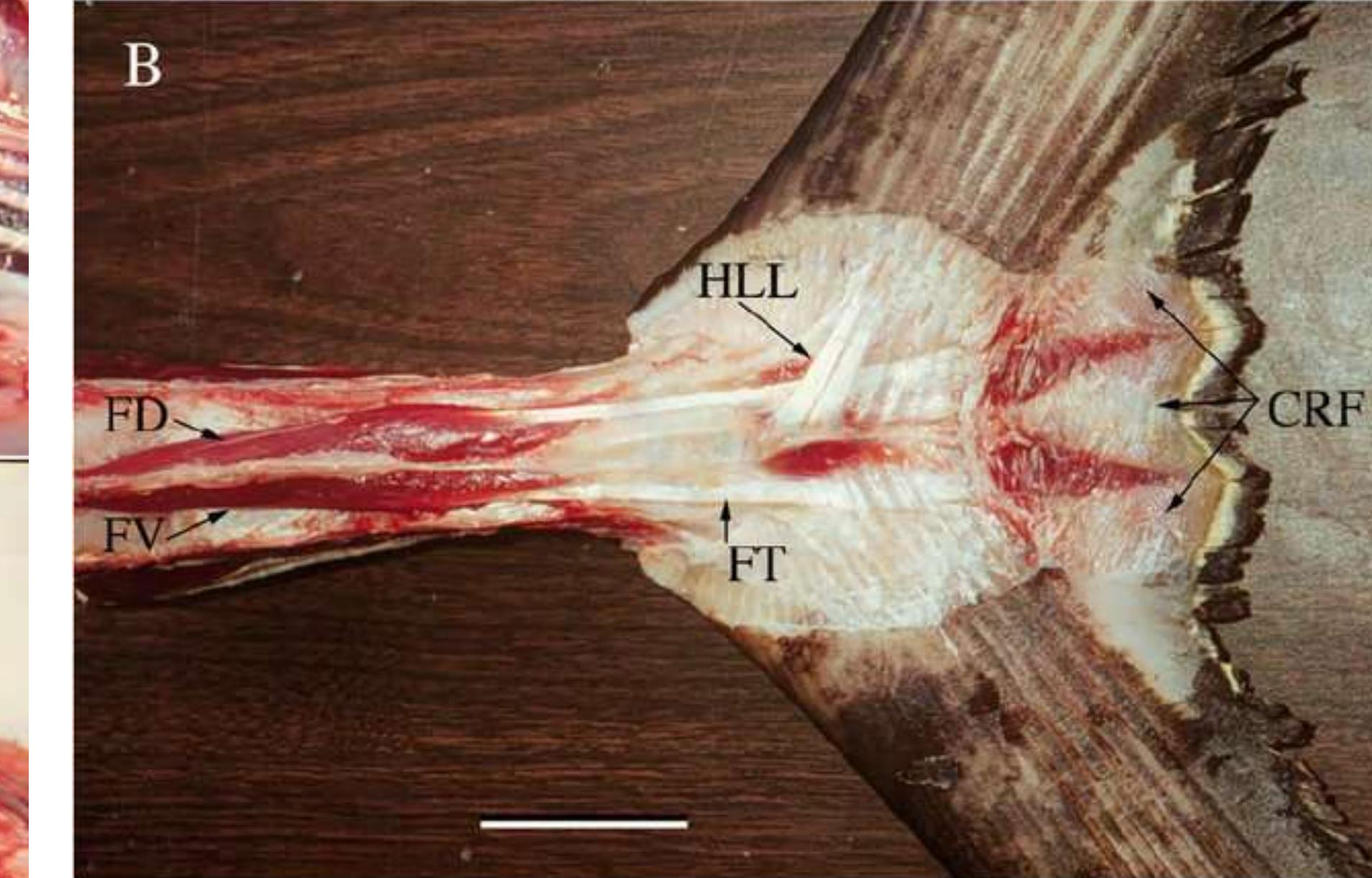
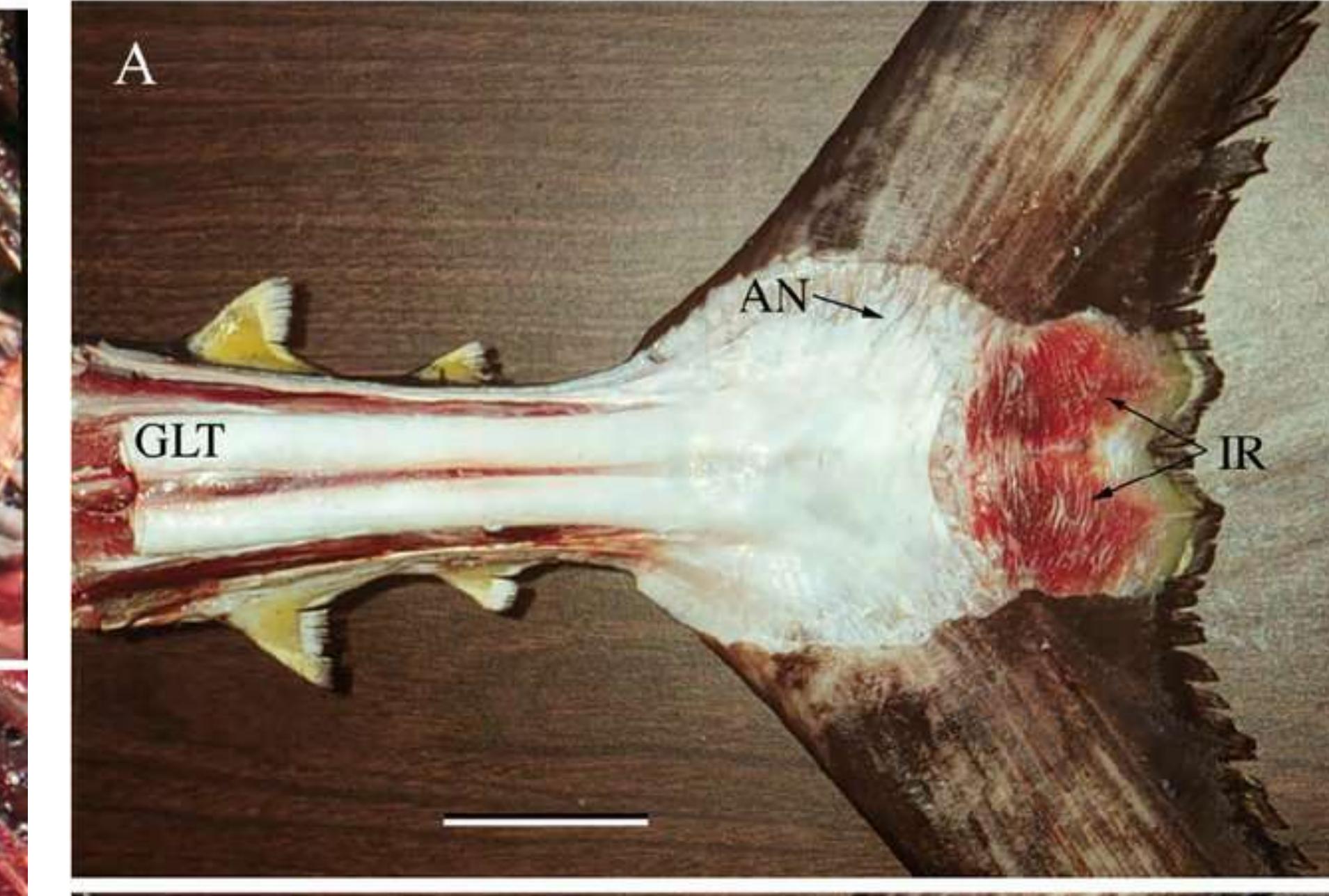
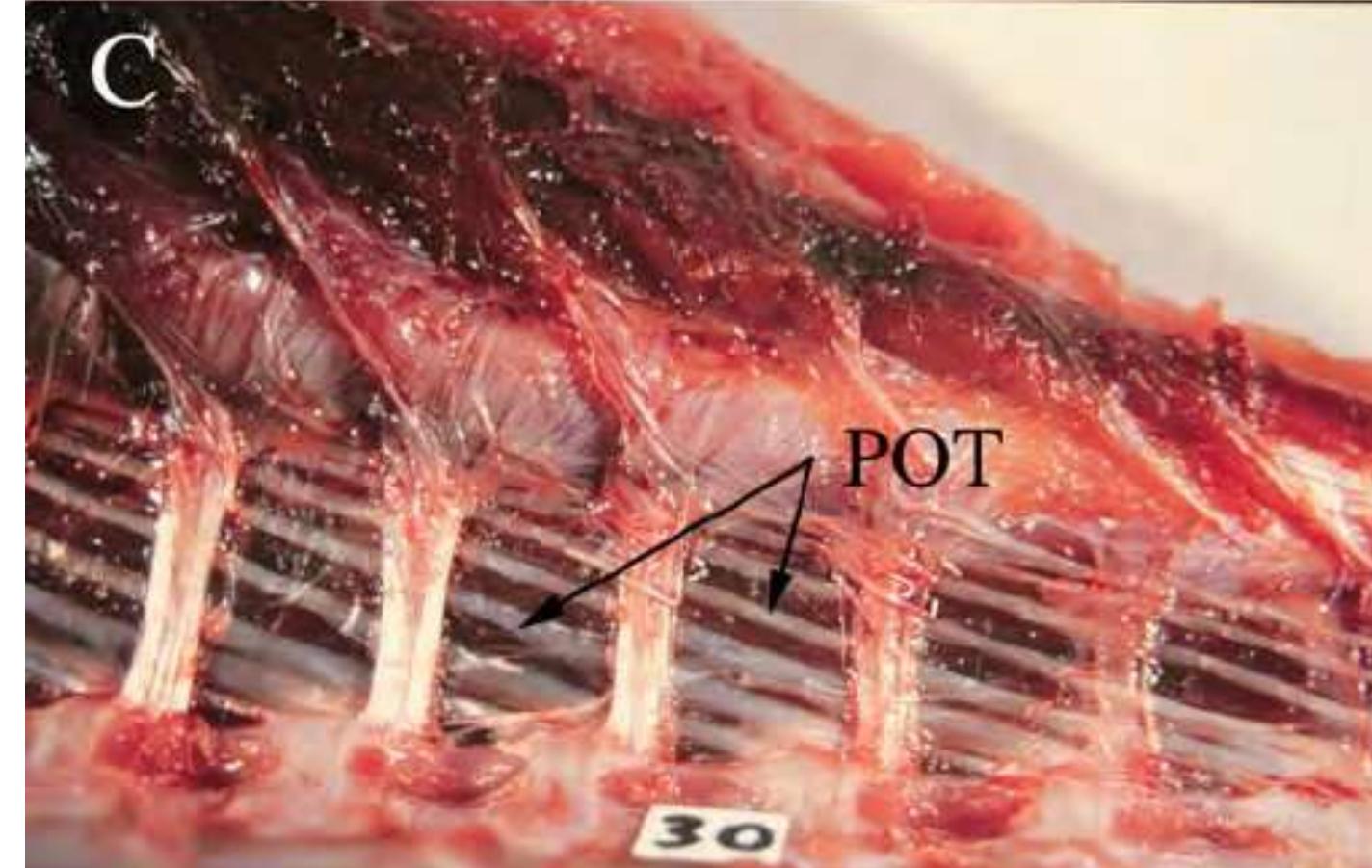
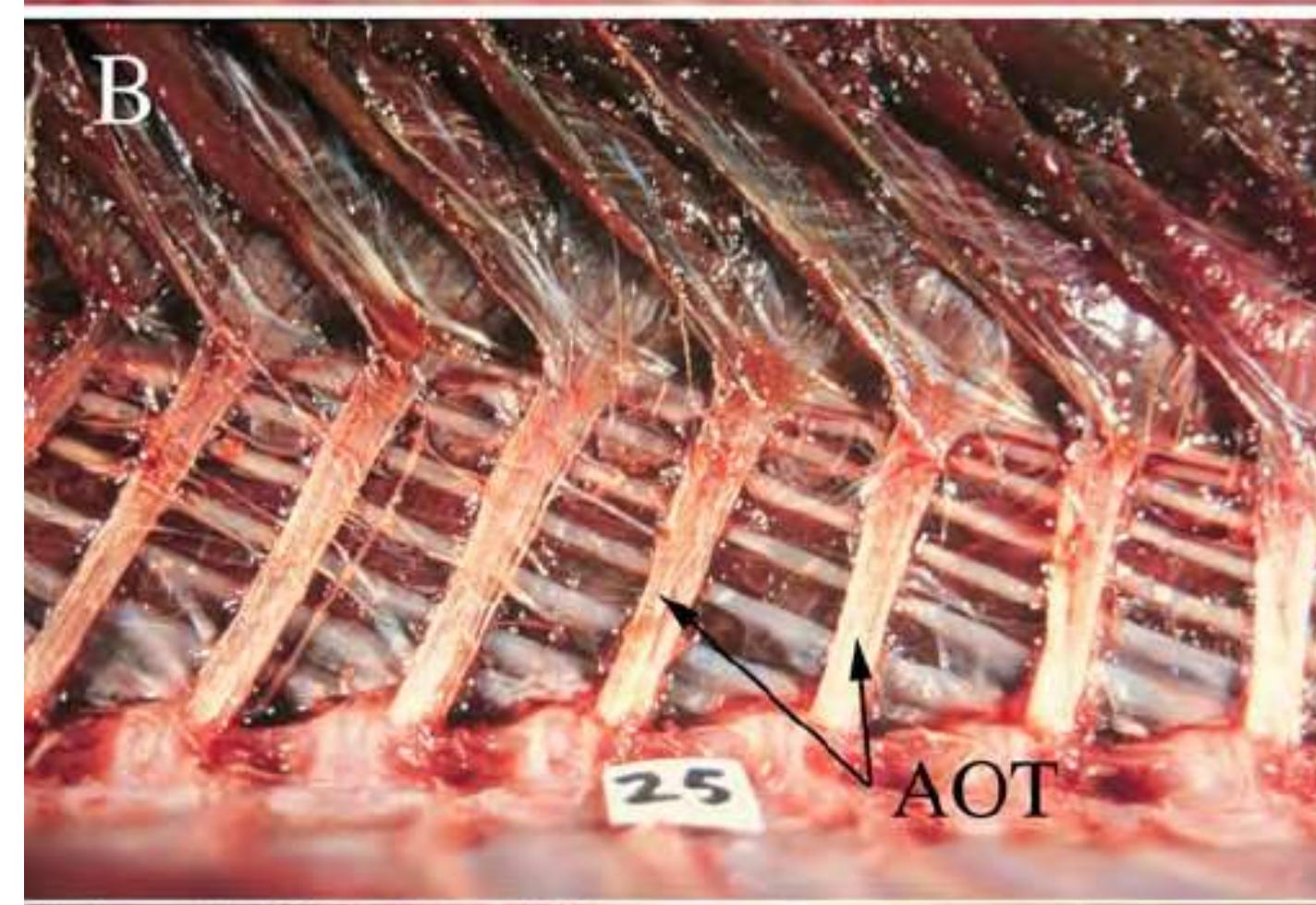
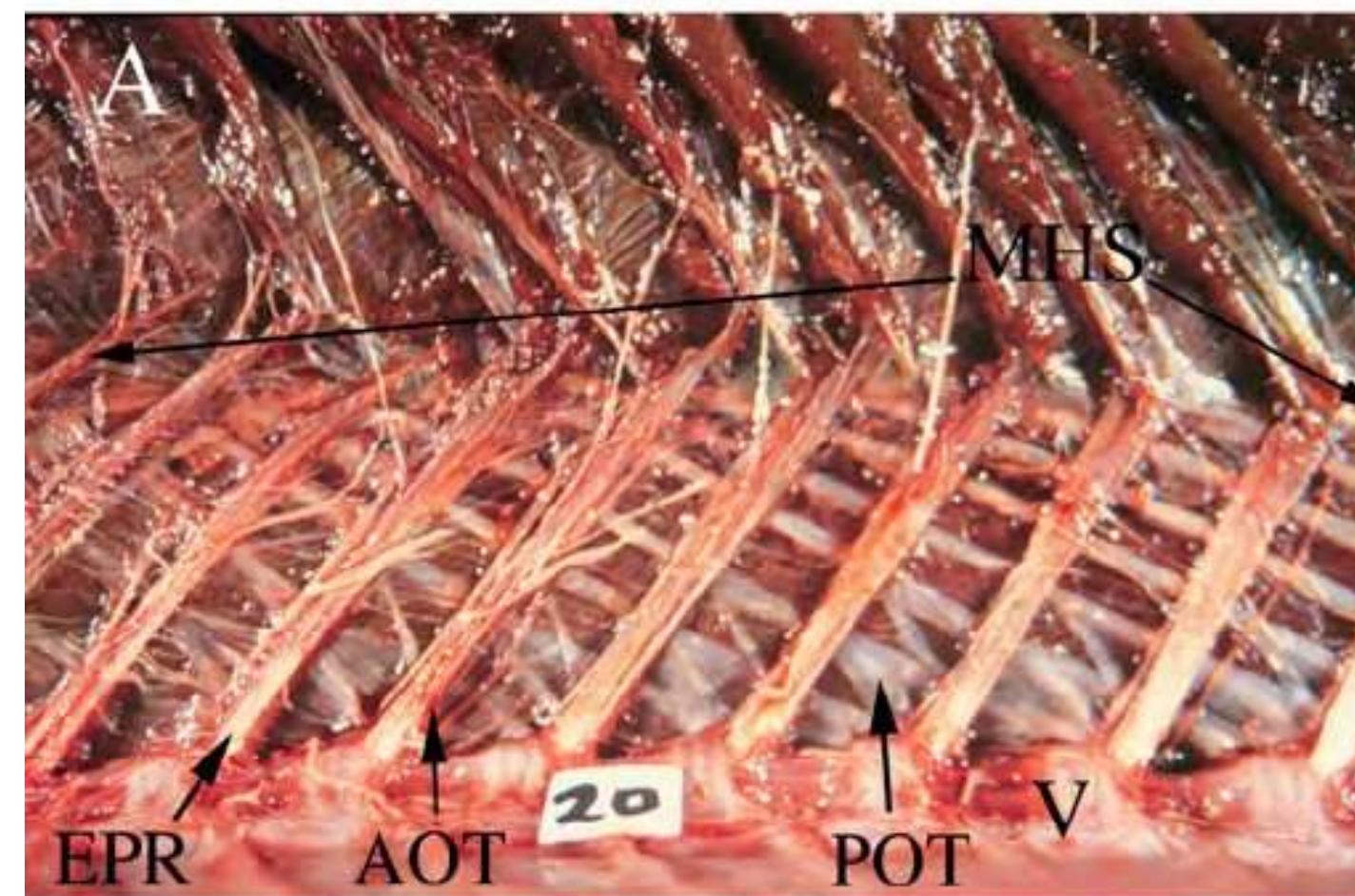
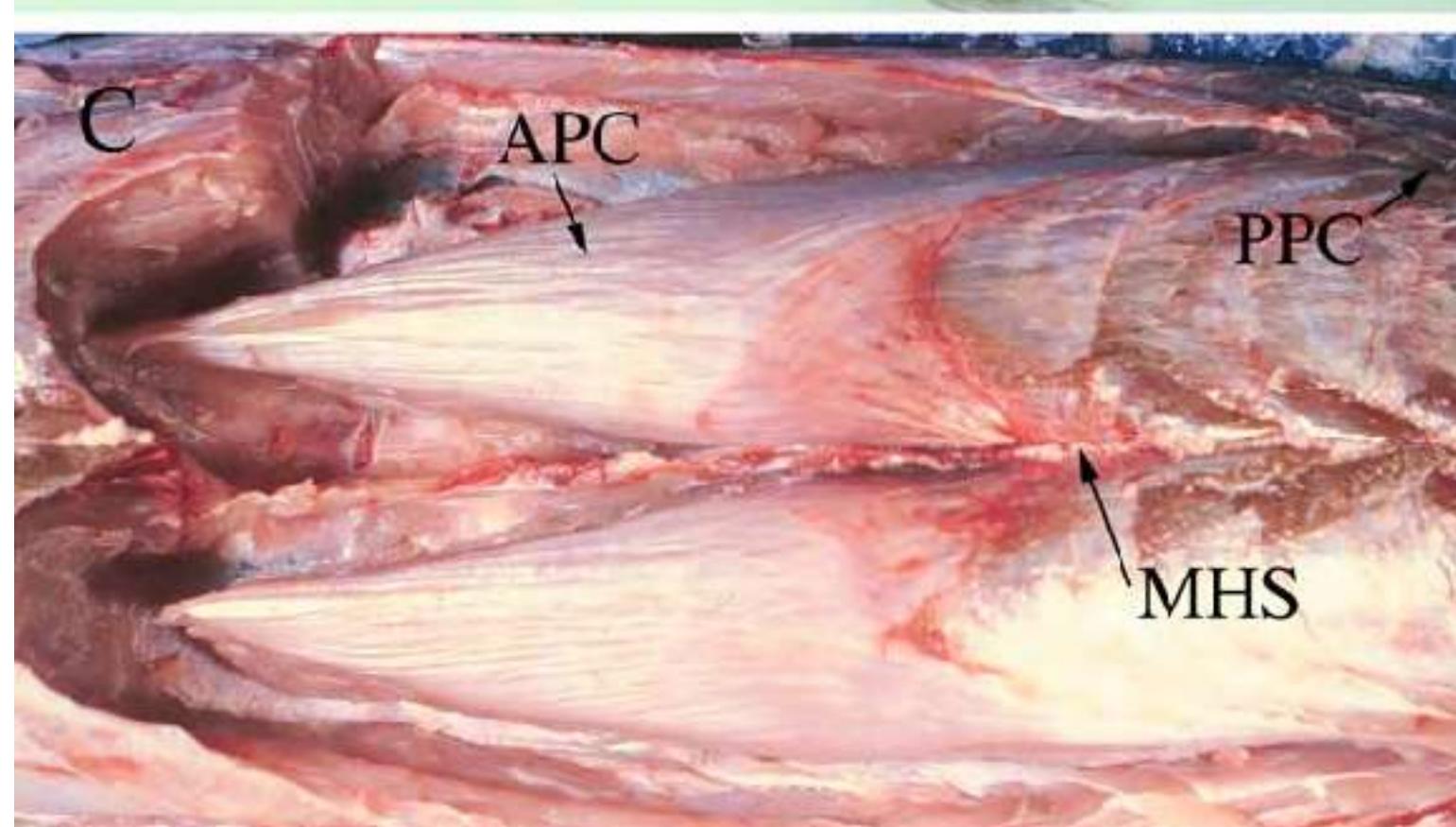
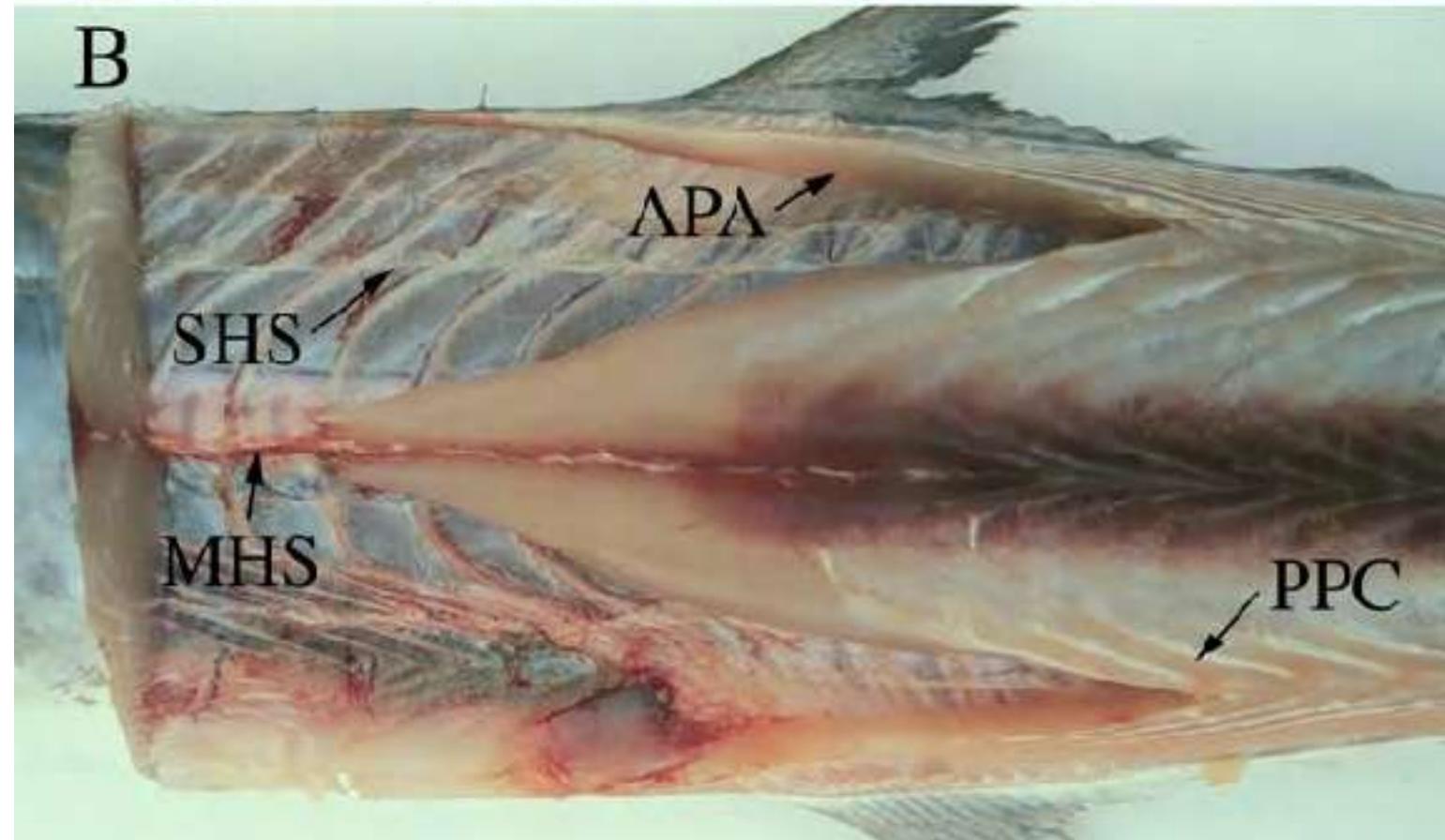
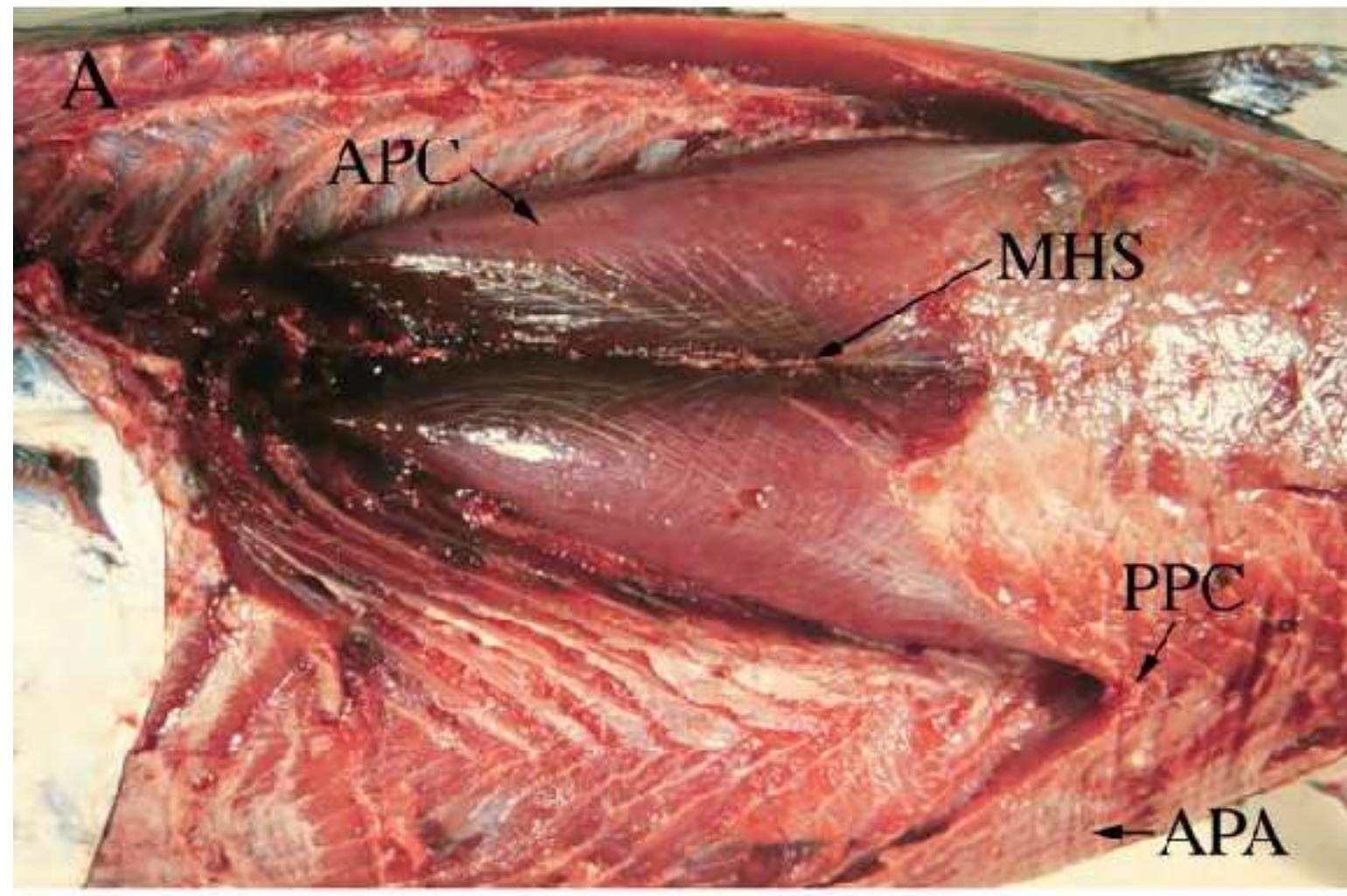
Most vertebrates have a mosaic of muscle types + intermediates

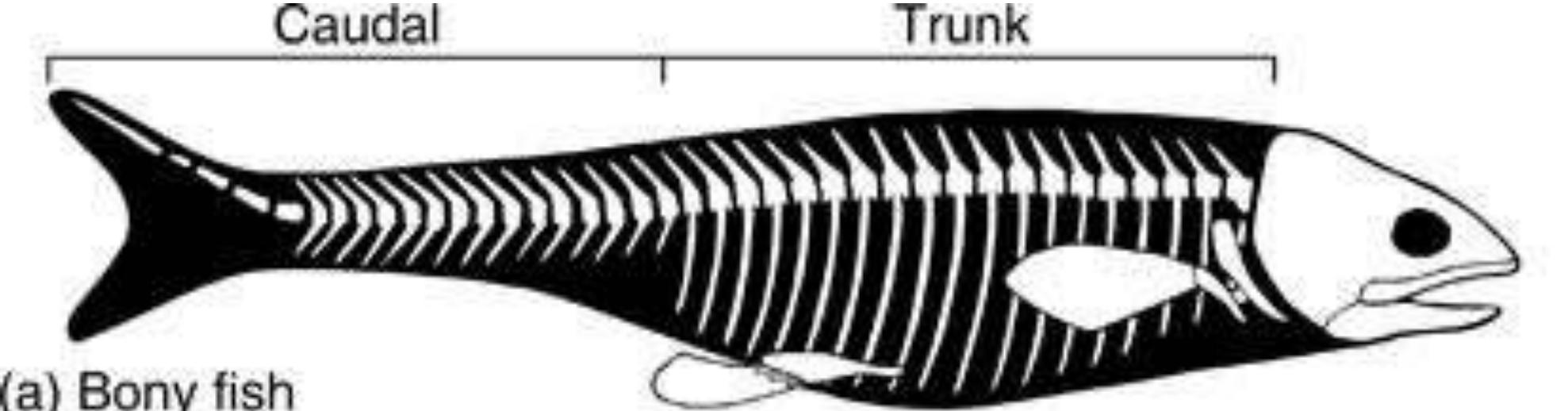


...now back to fishes...

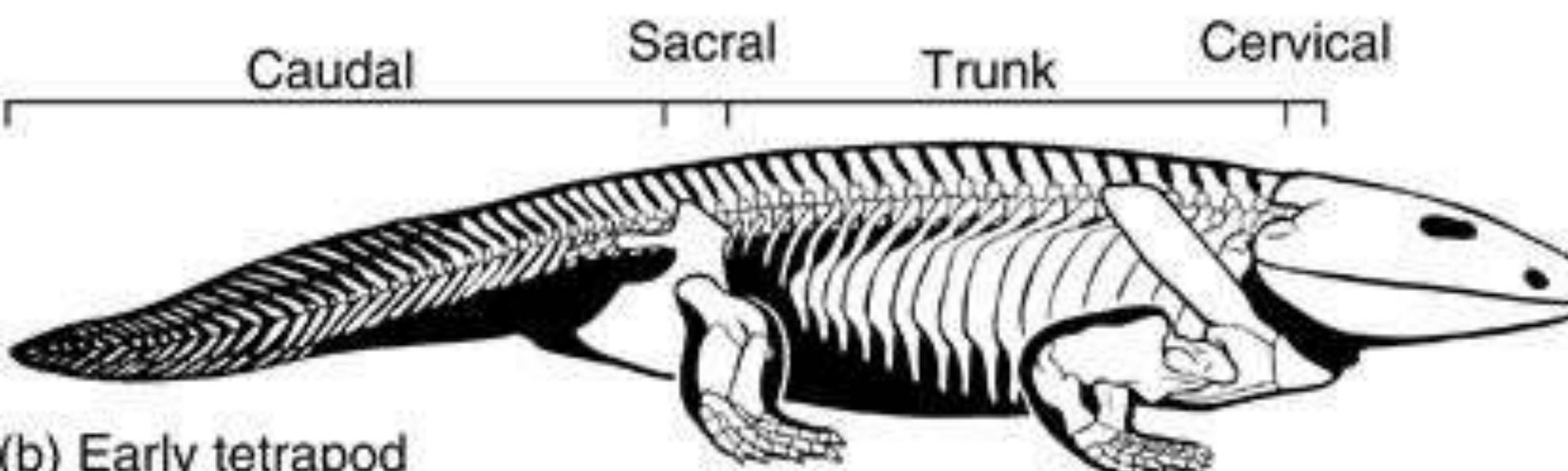




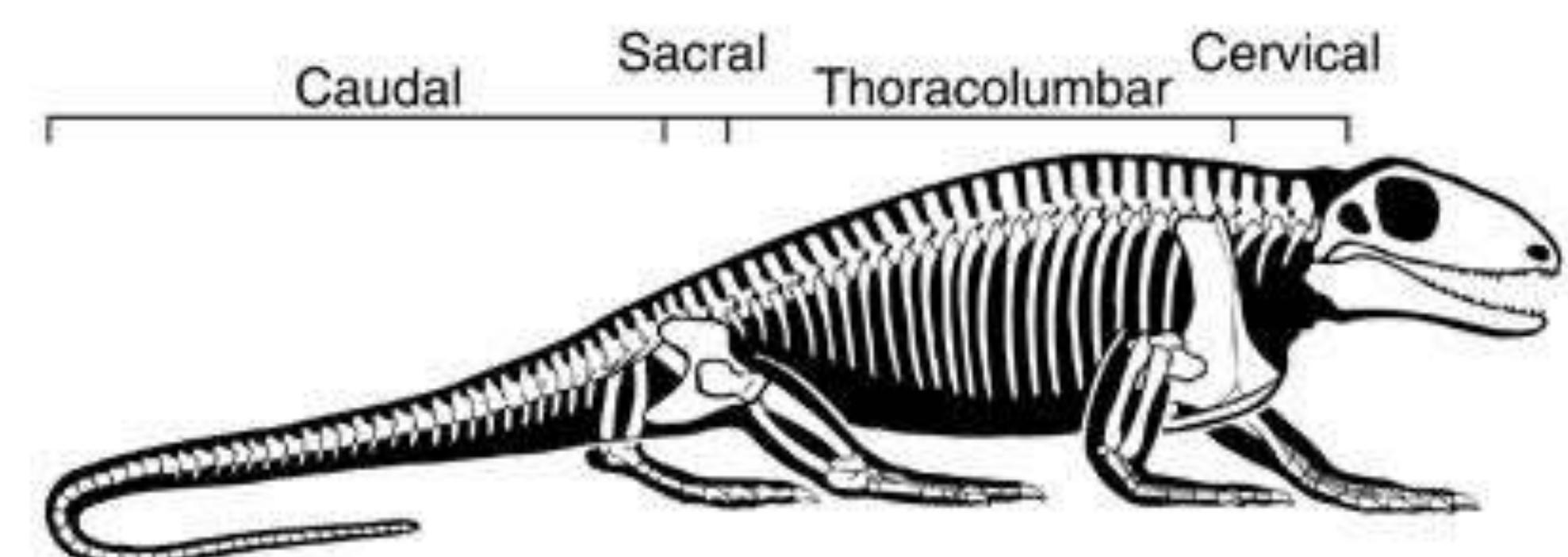




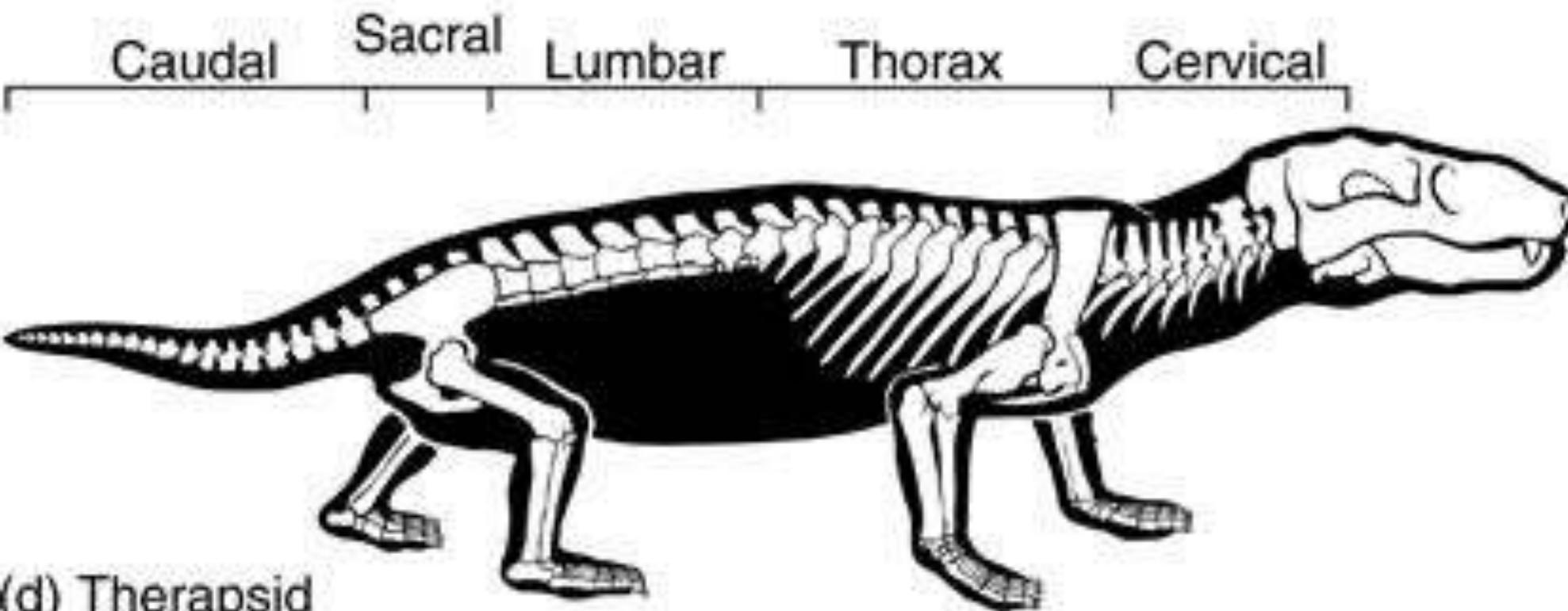
(a) Bony fish



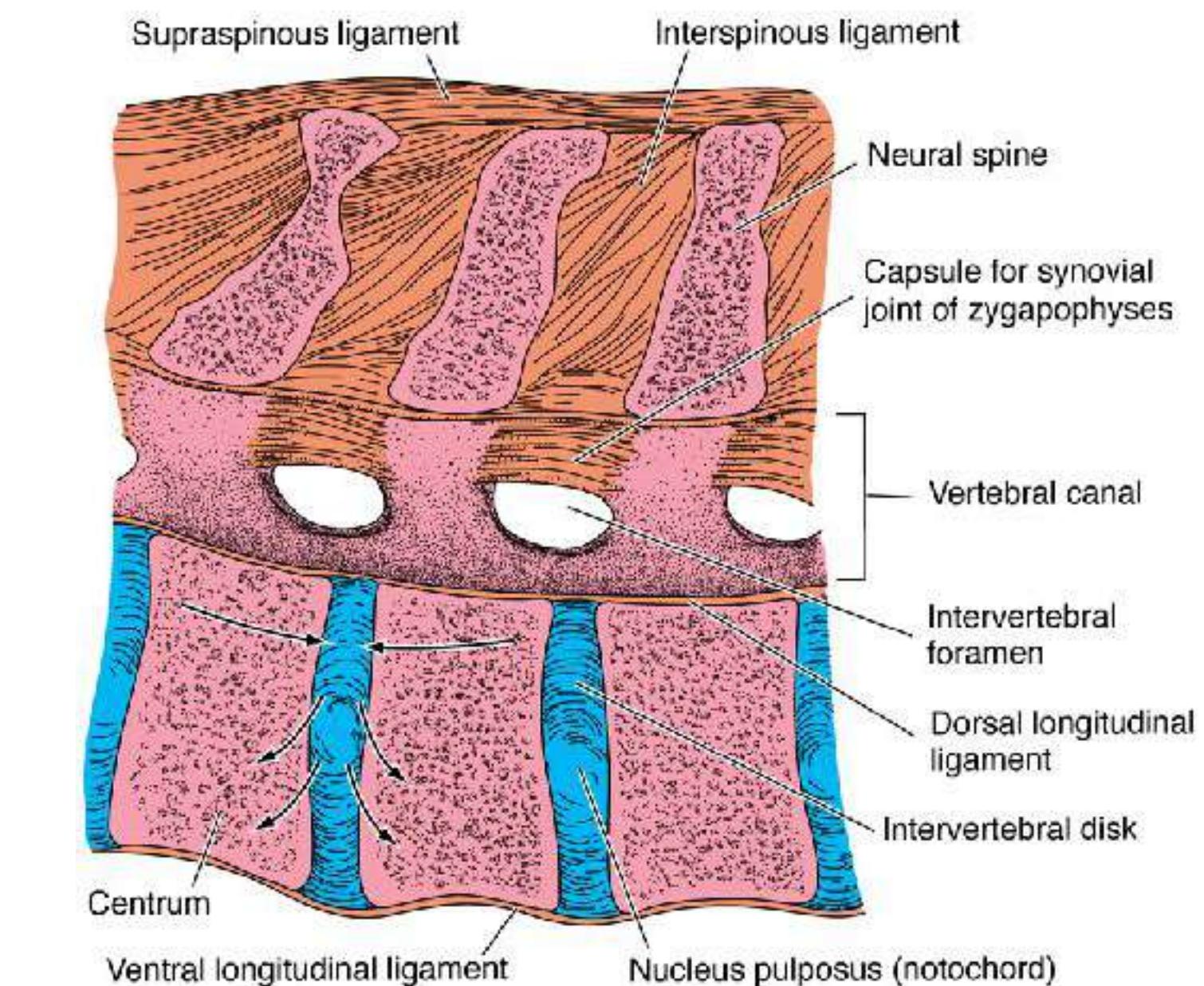
(b) Early tetrapod



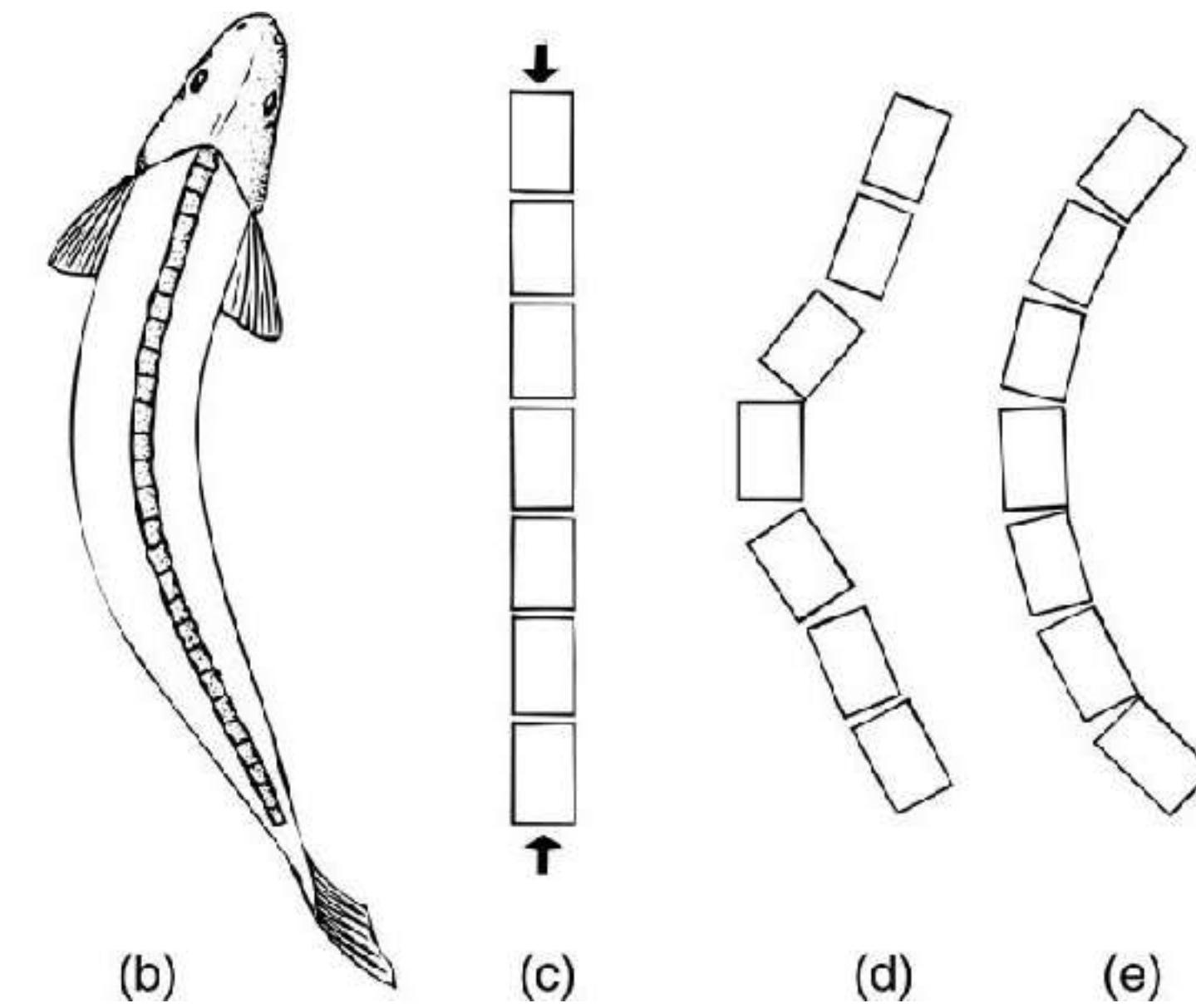
(c) Primitive amniote

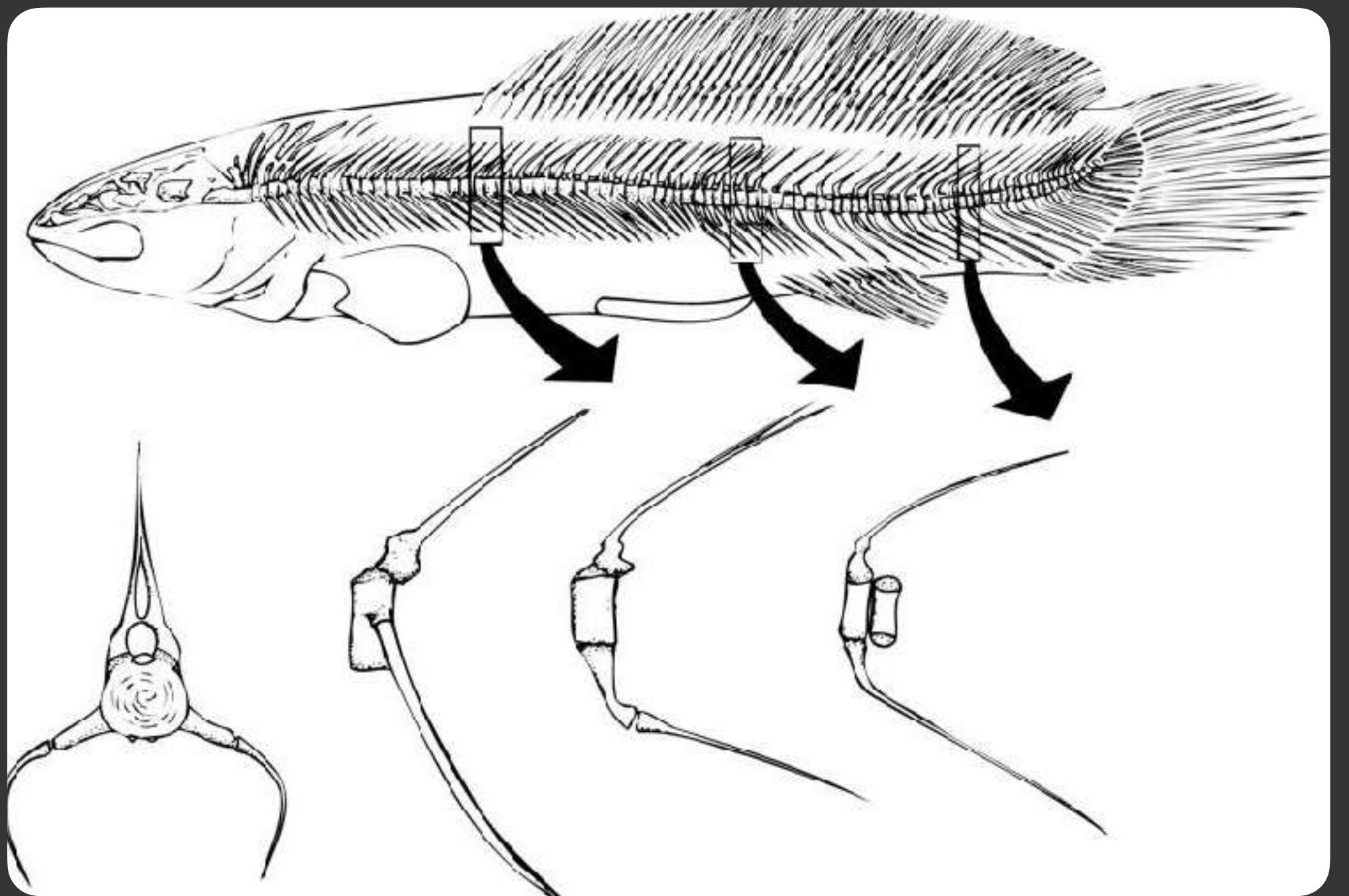


(d) Therapsid

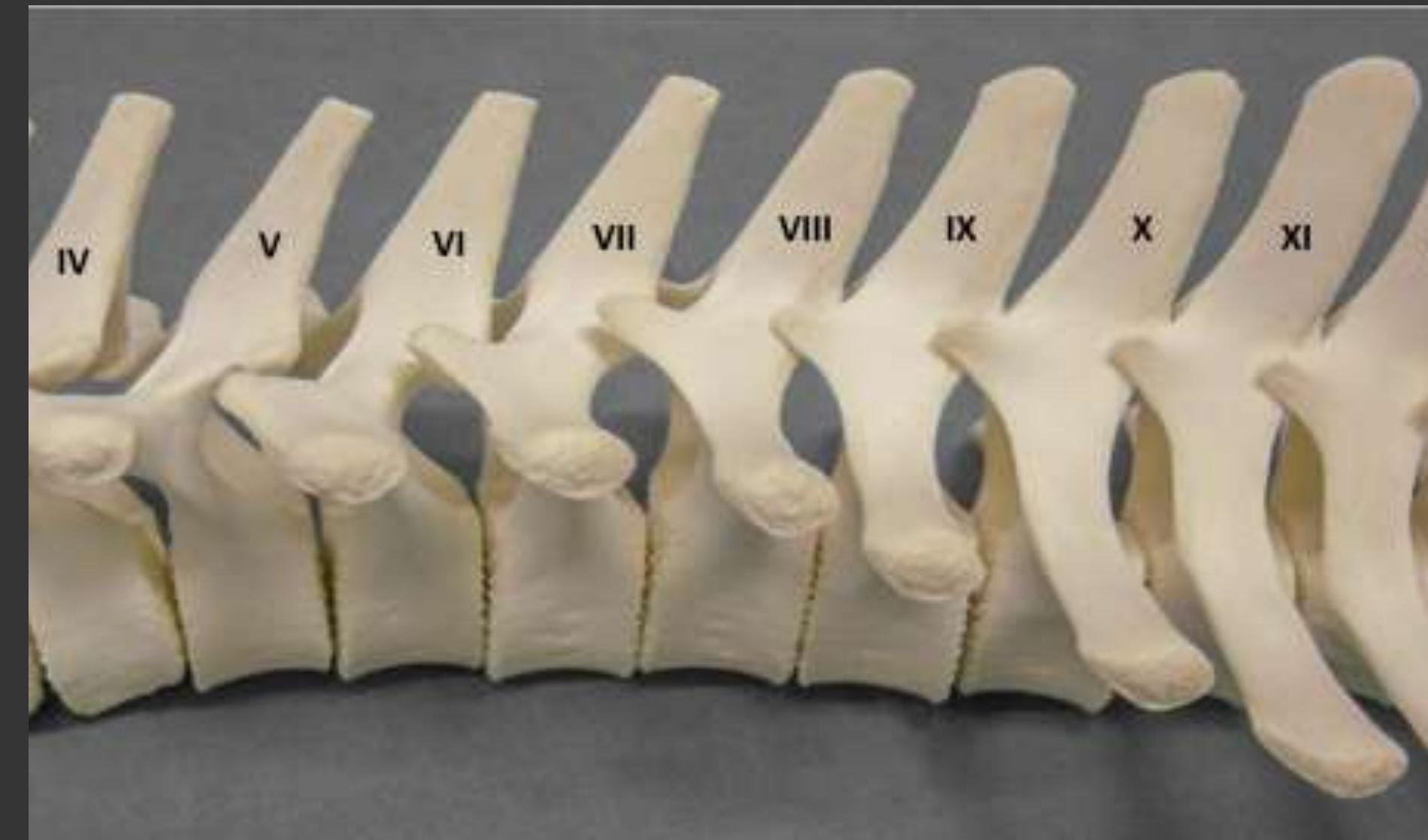


Ligaments keep things connected

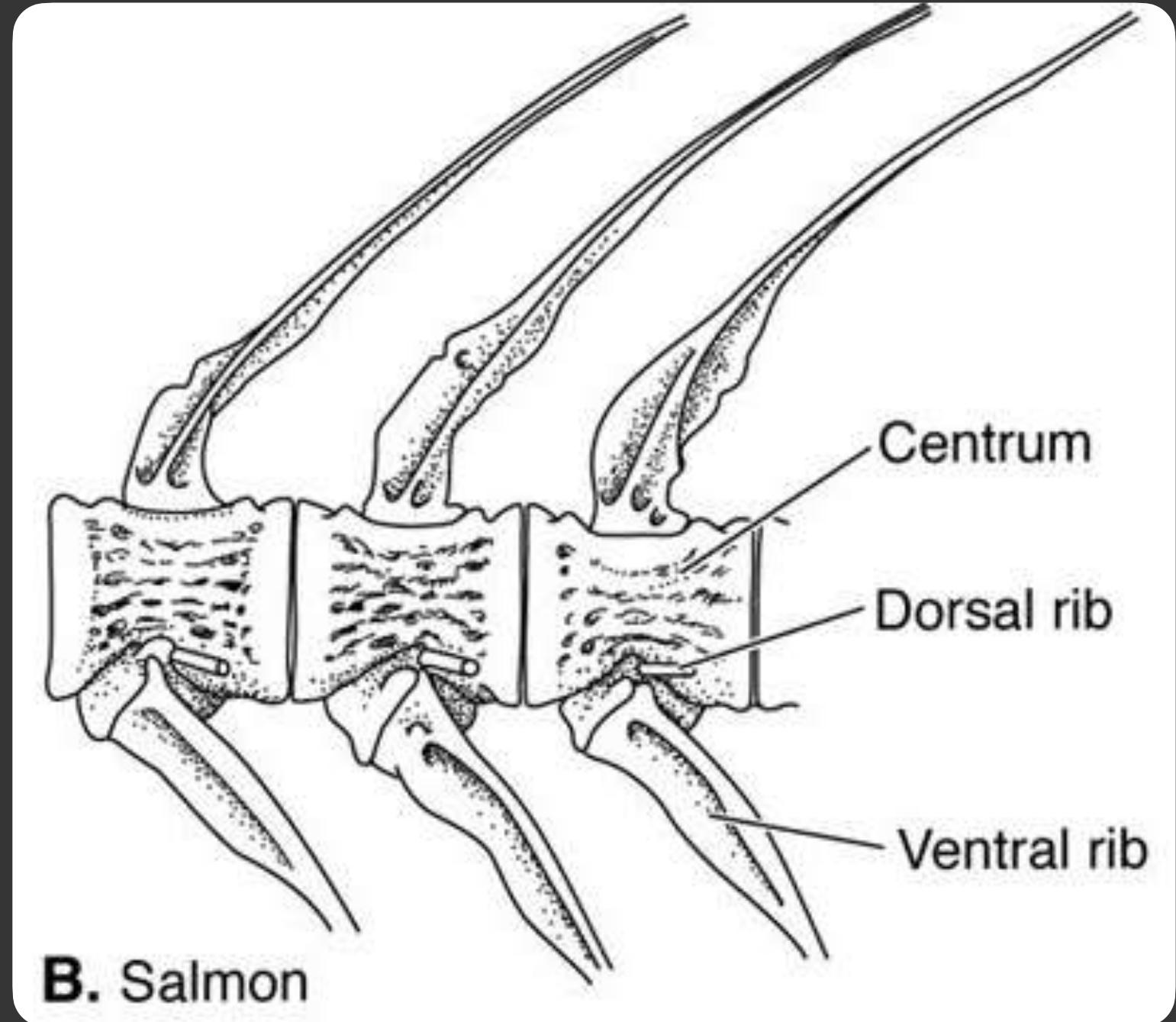




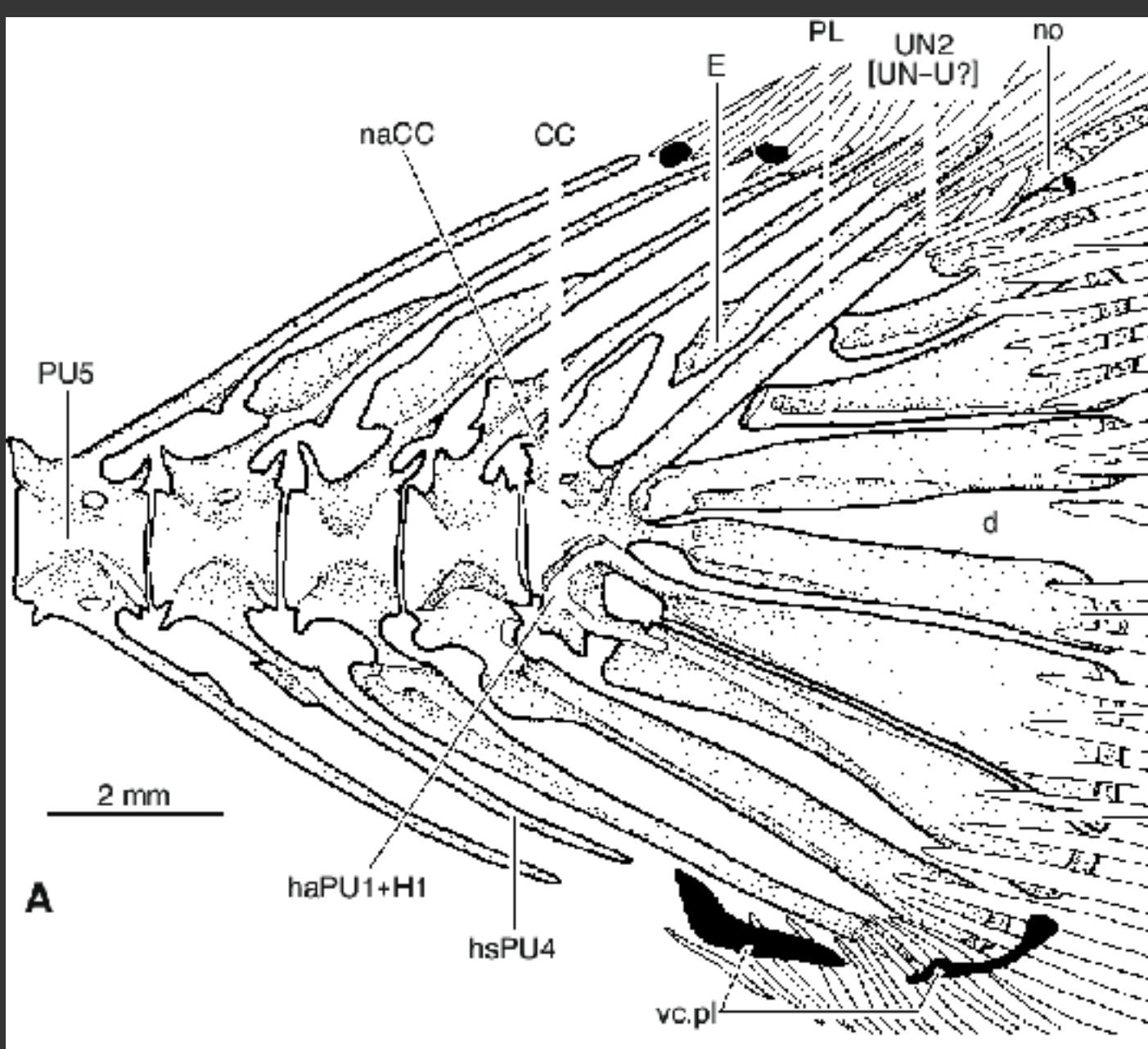
Fish vertebrae



Terrestrial vertebrae

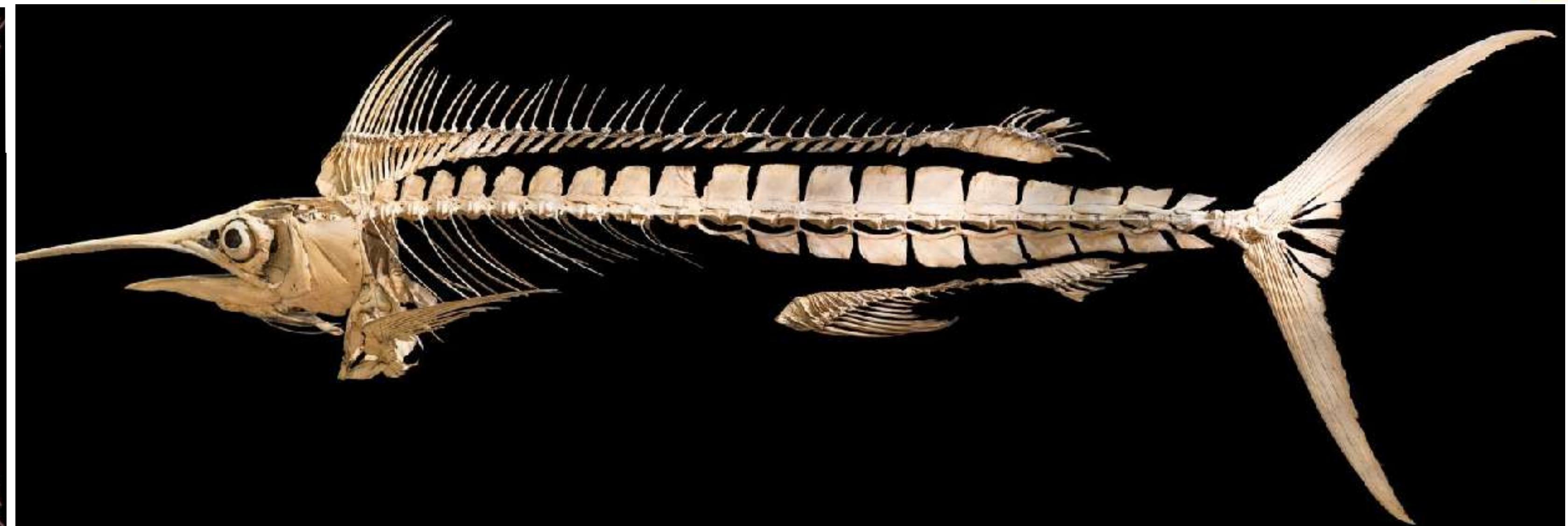
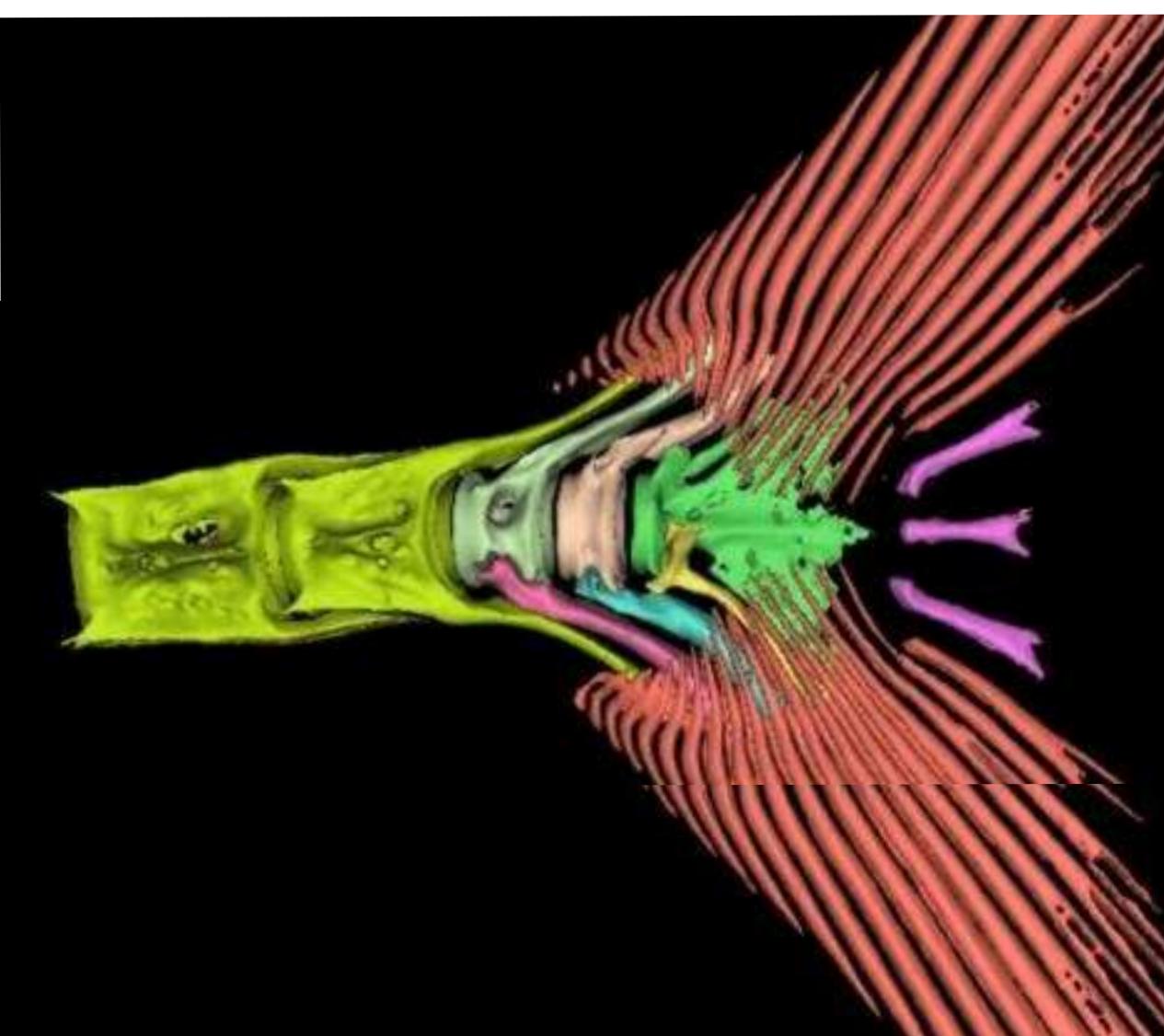
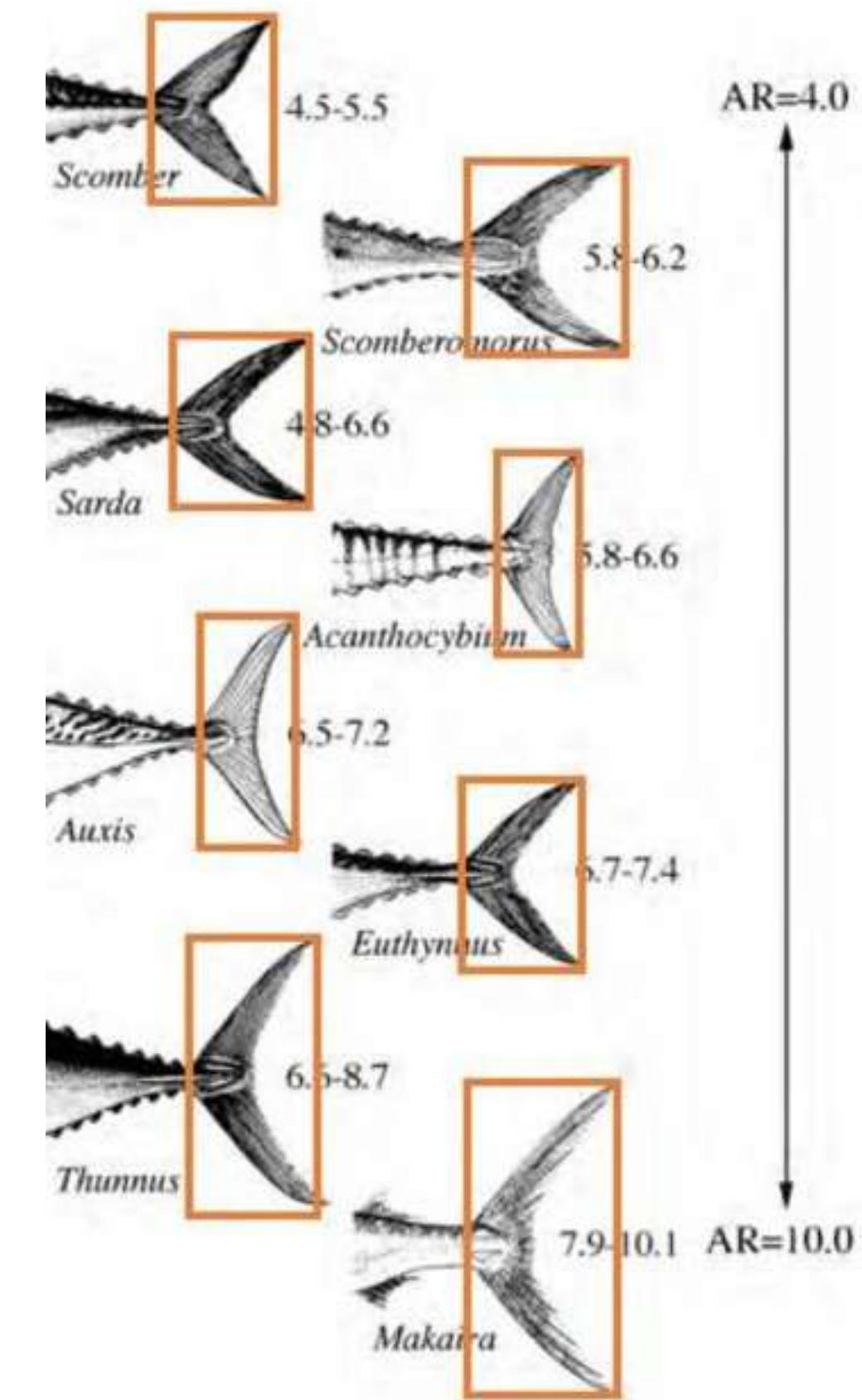
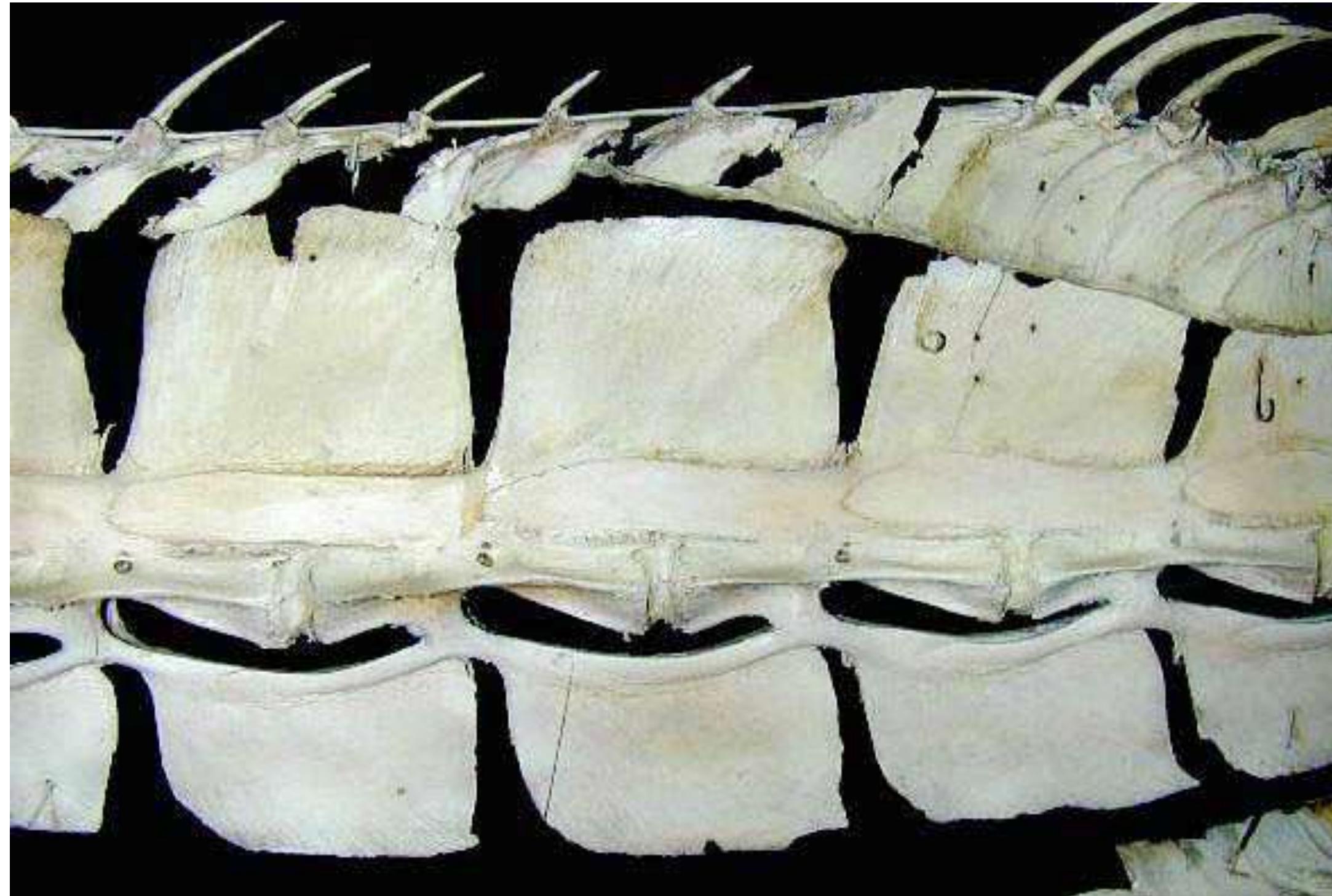
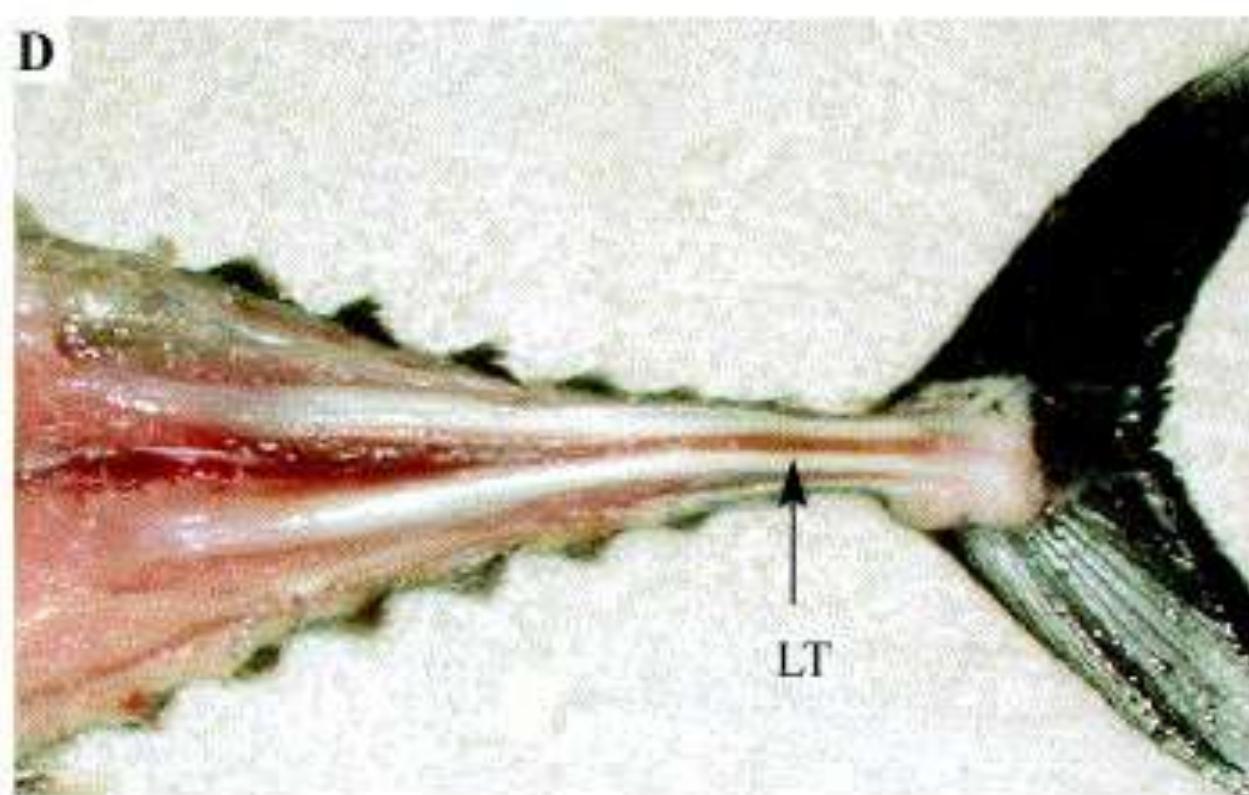
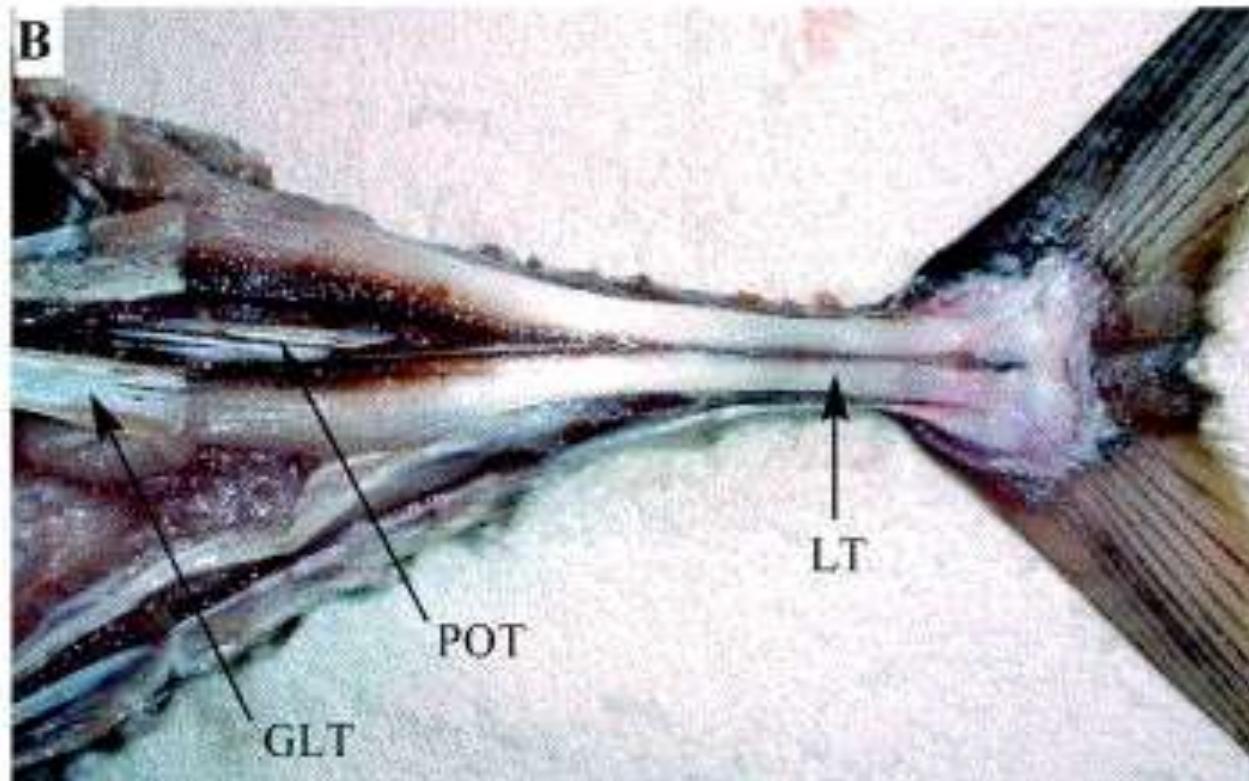


B. Salmon

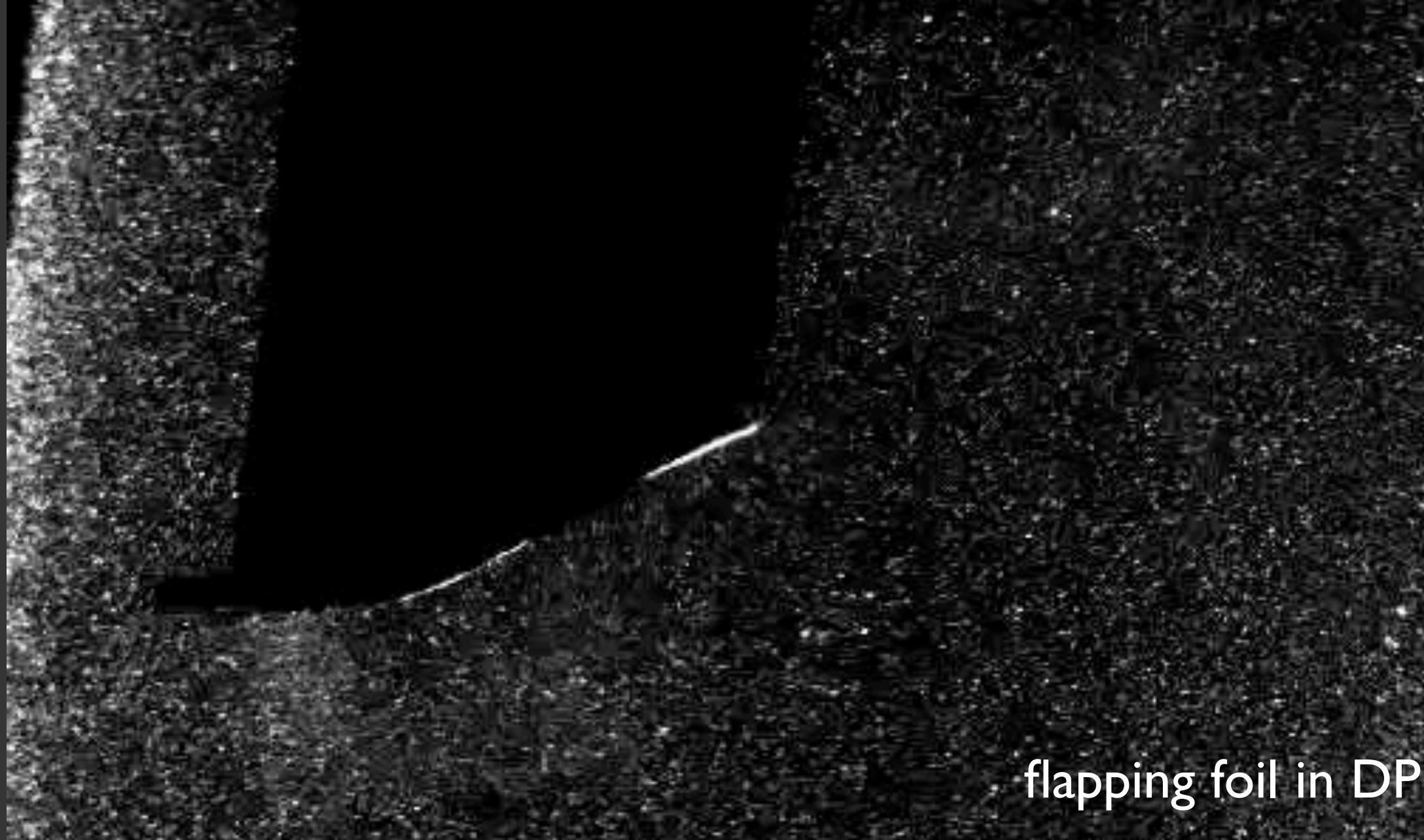


**Terrestrial animal
vertebrae often
interact and interlock
a lot more than fish
vertebrae**

Some fast swimmers interlock vertebrae





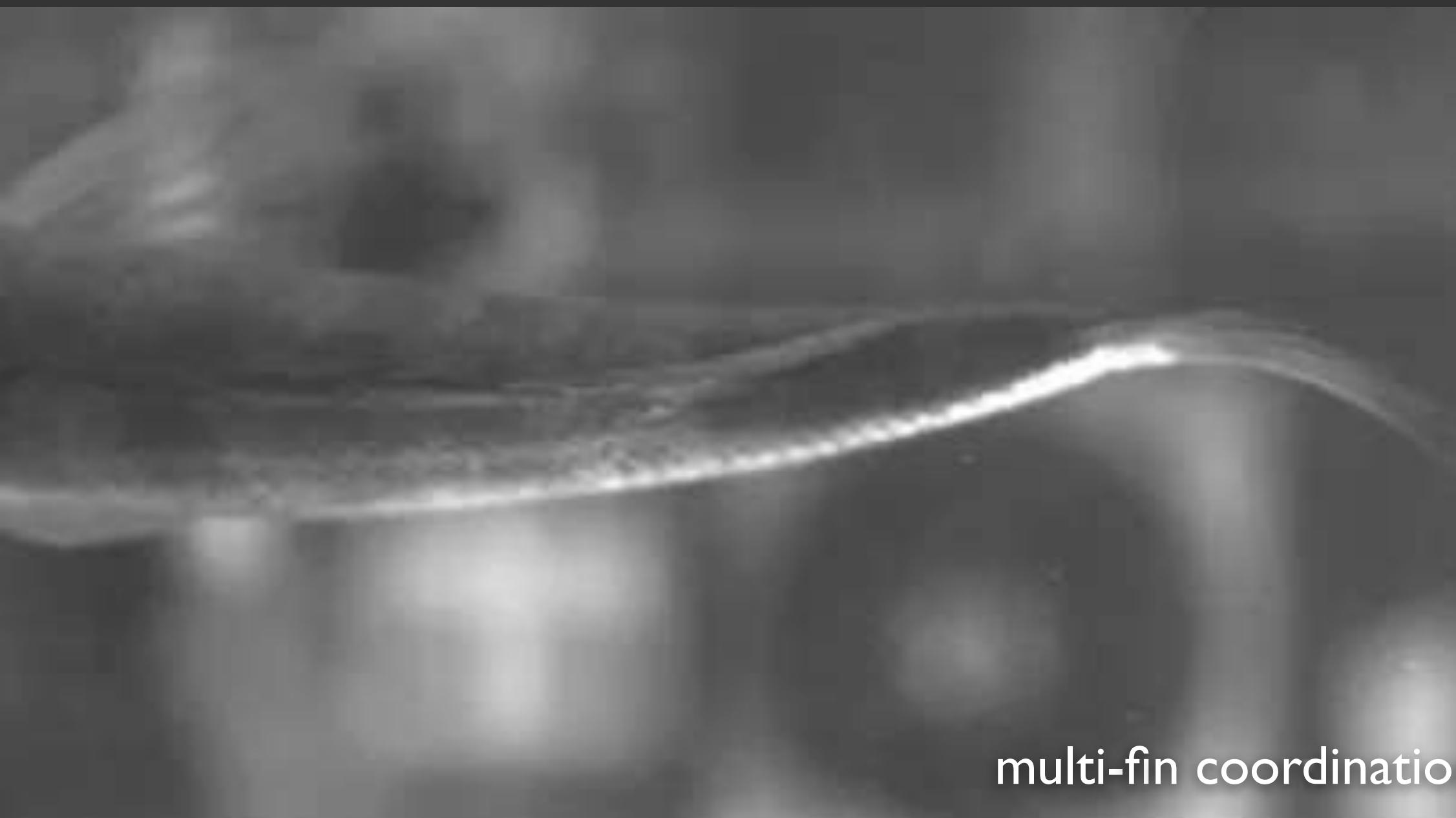


flapping foil in DPLV



pectoral fin coordination

Fins are deformable hydrofoils, complicated mixtures of active + passive elements

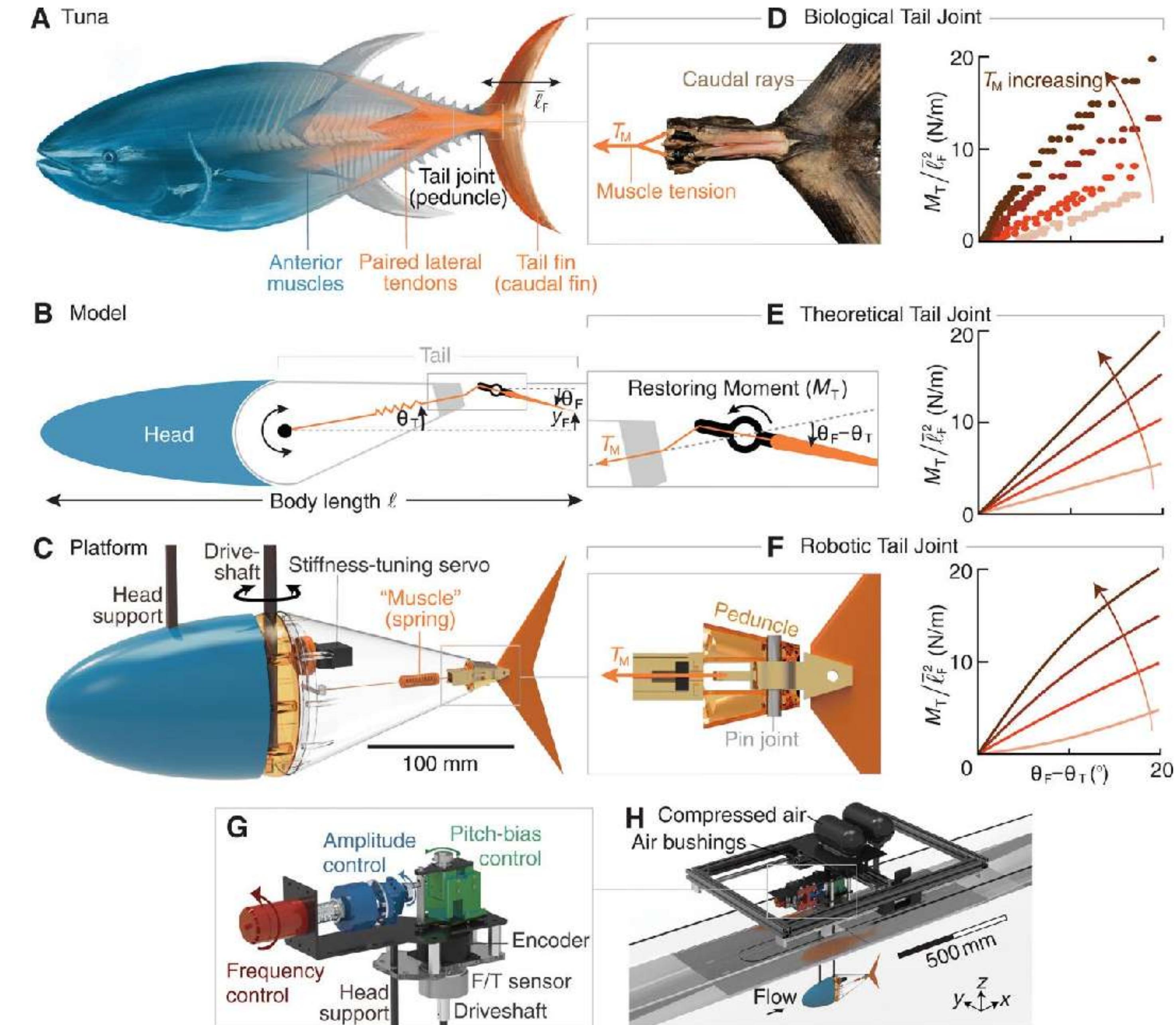
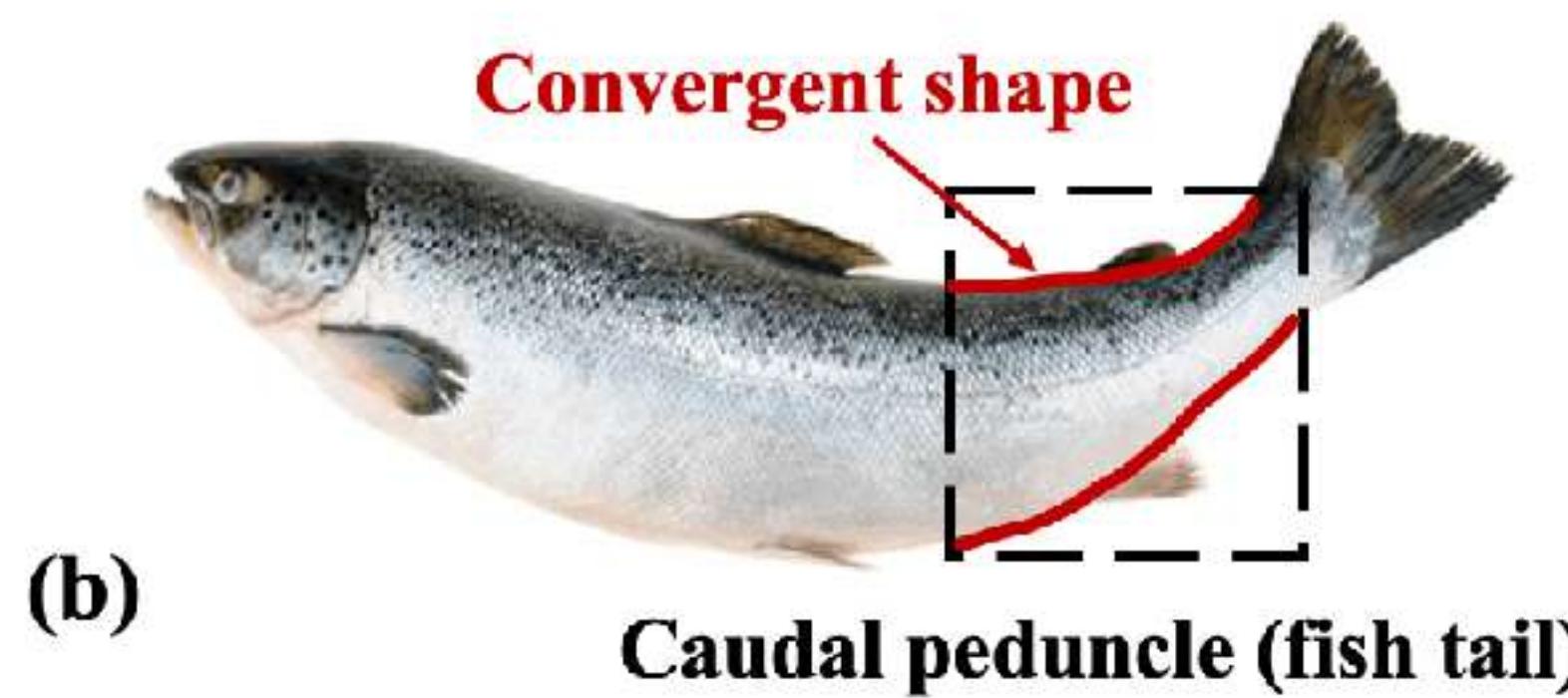
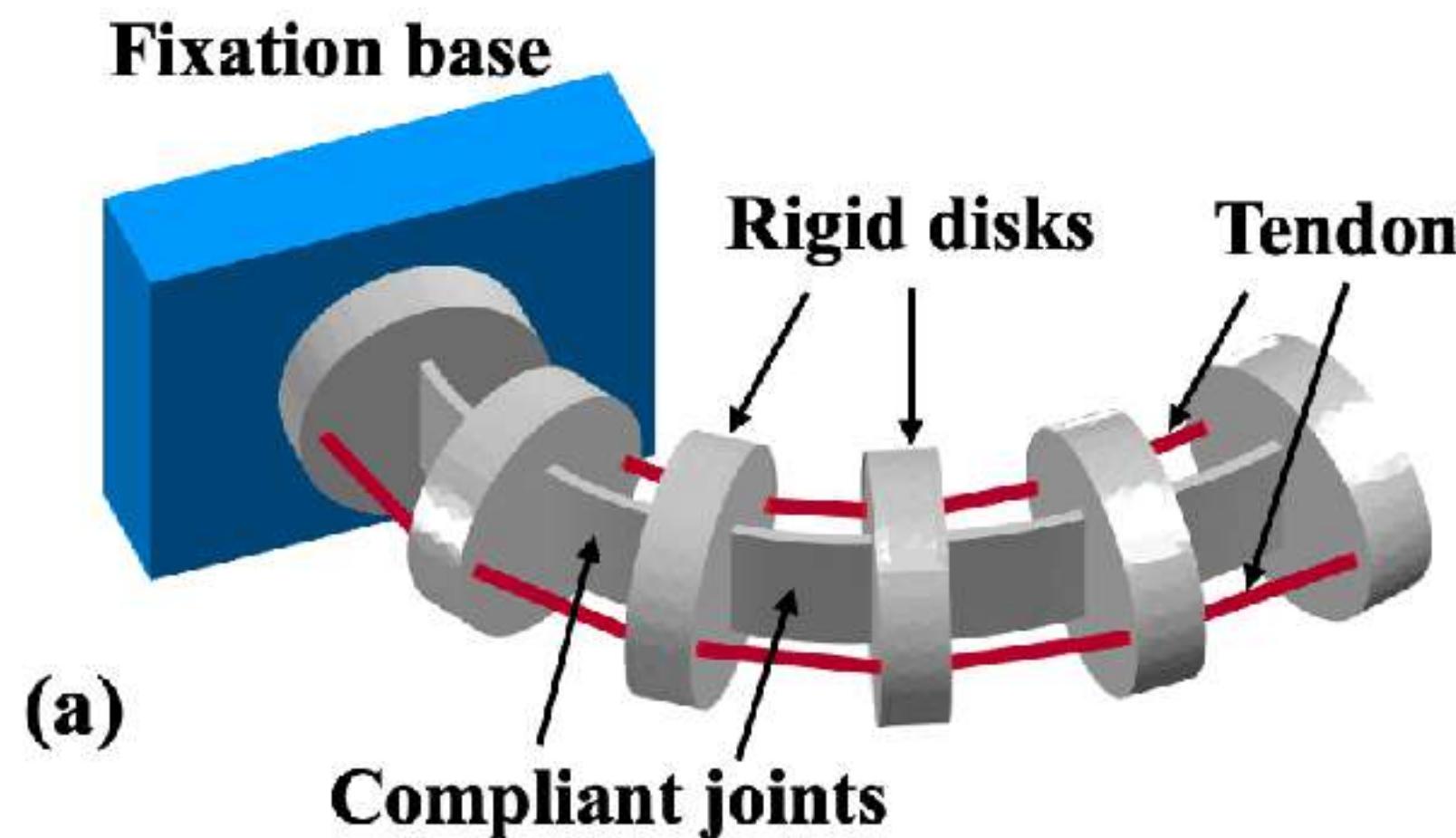


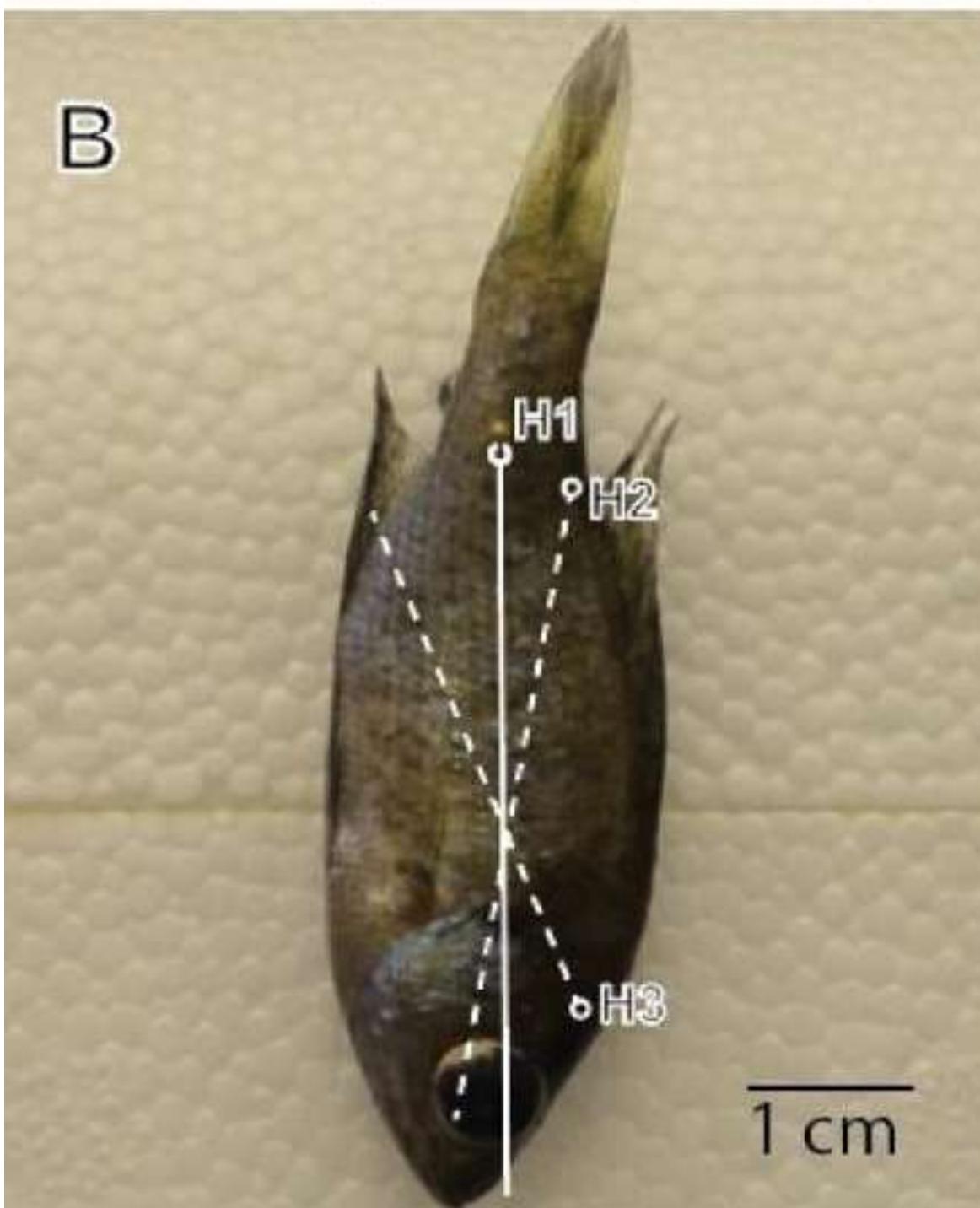
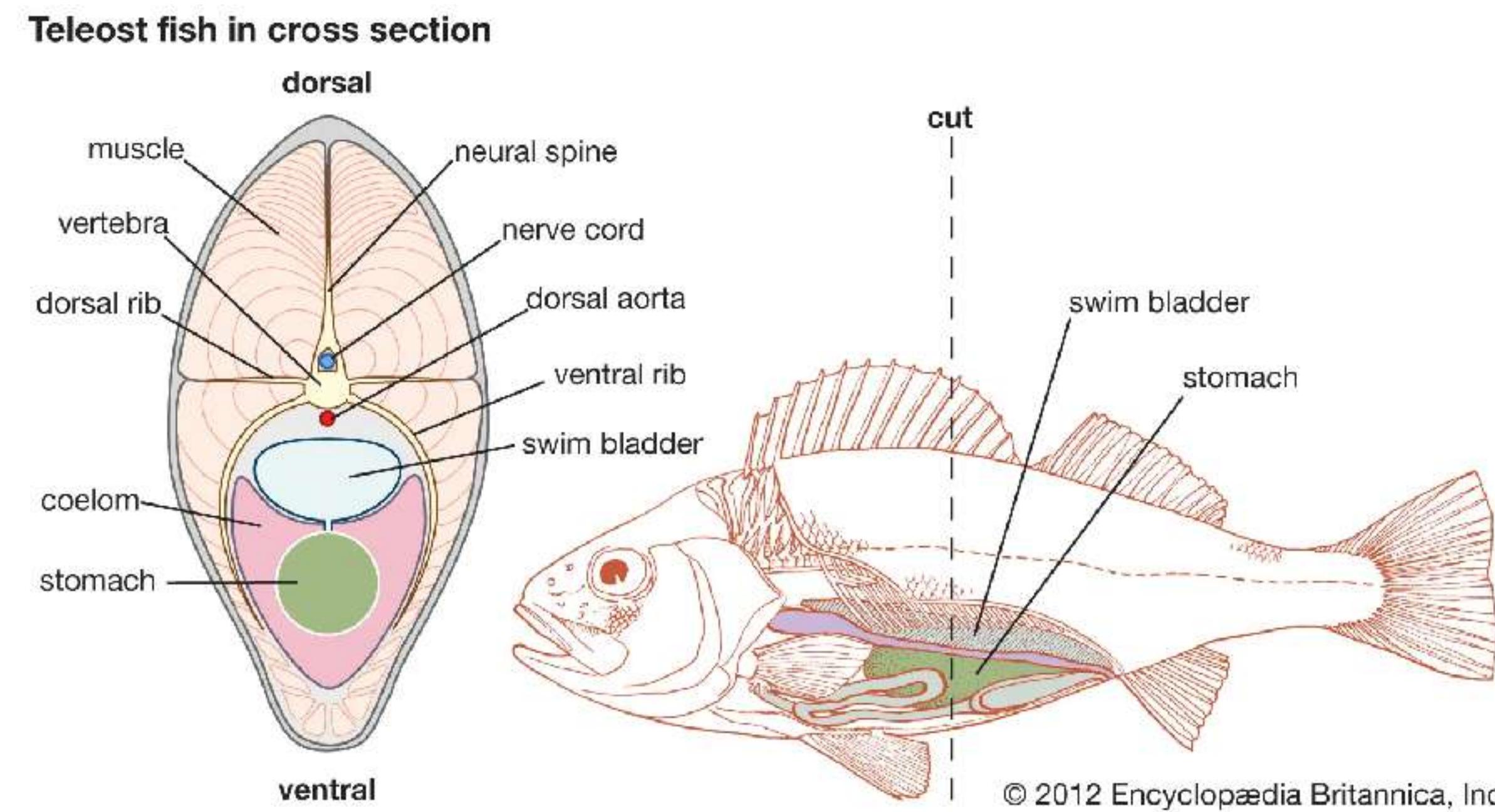
multi-fin coordination



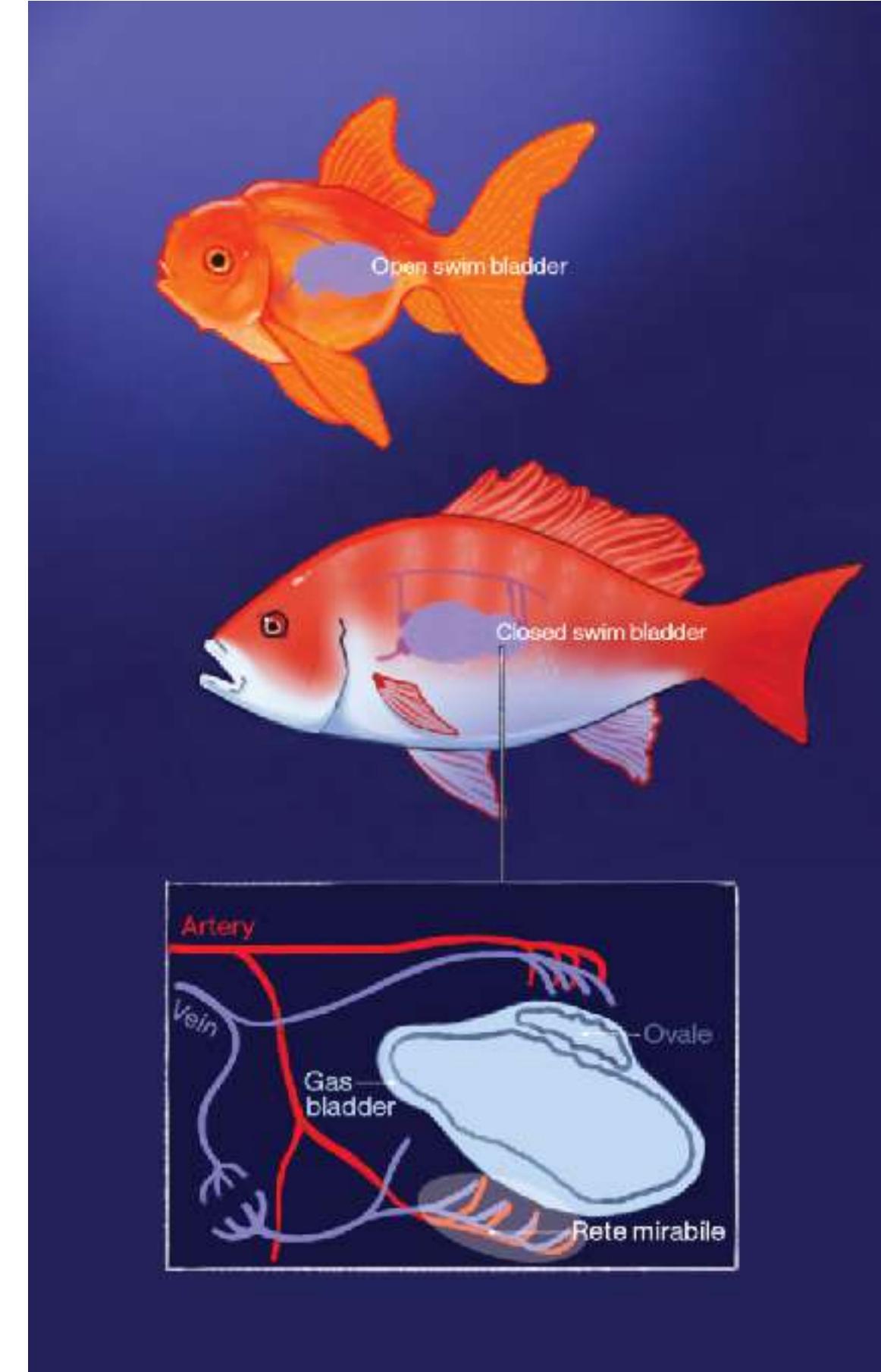
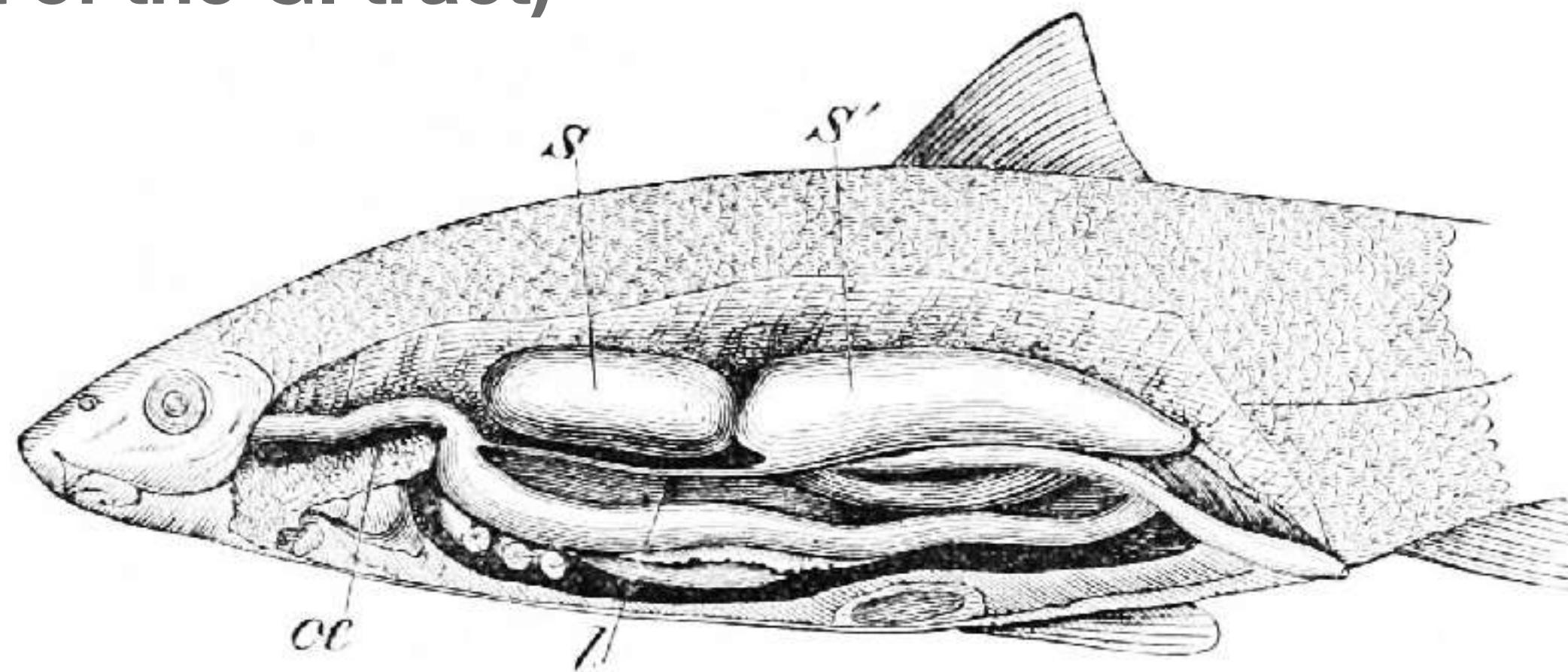
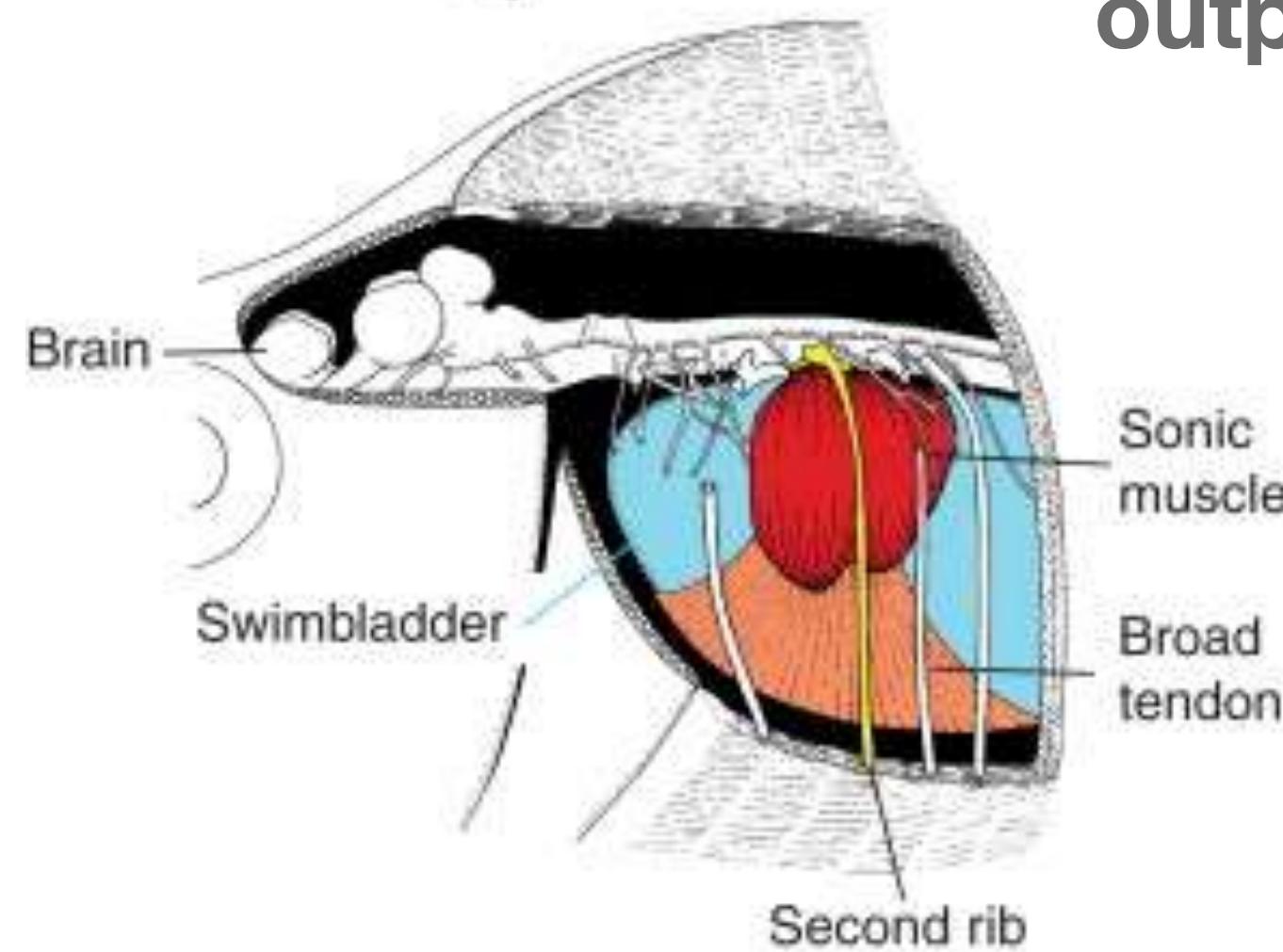
tuna finlet motion

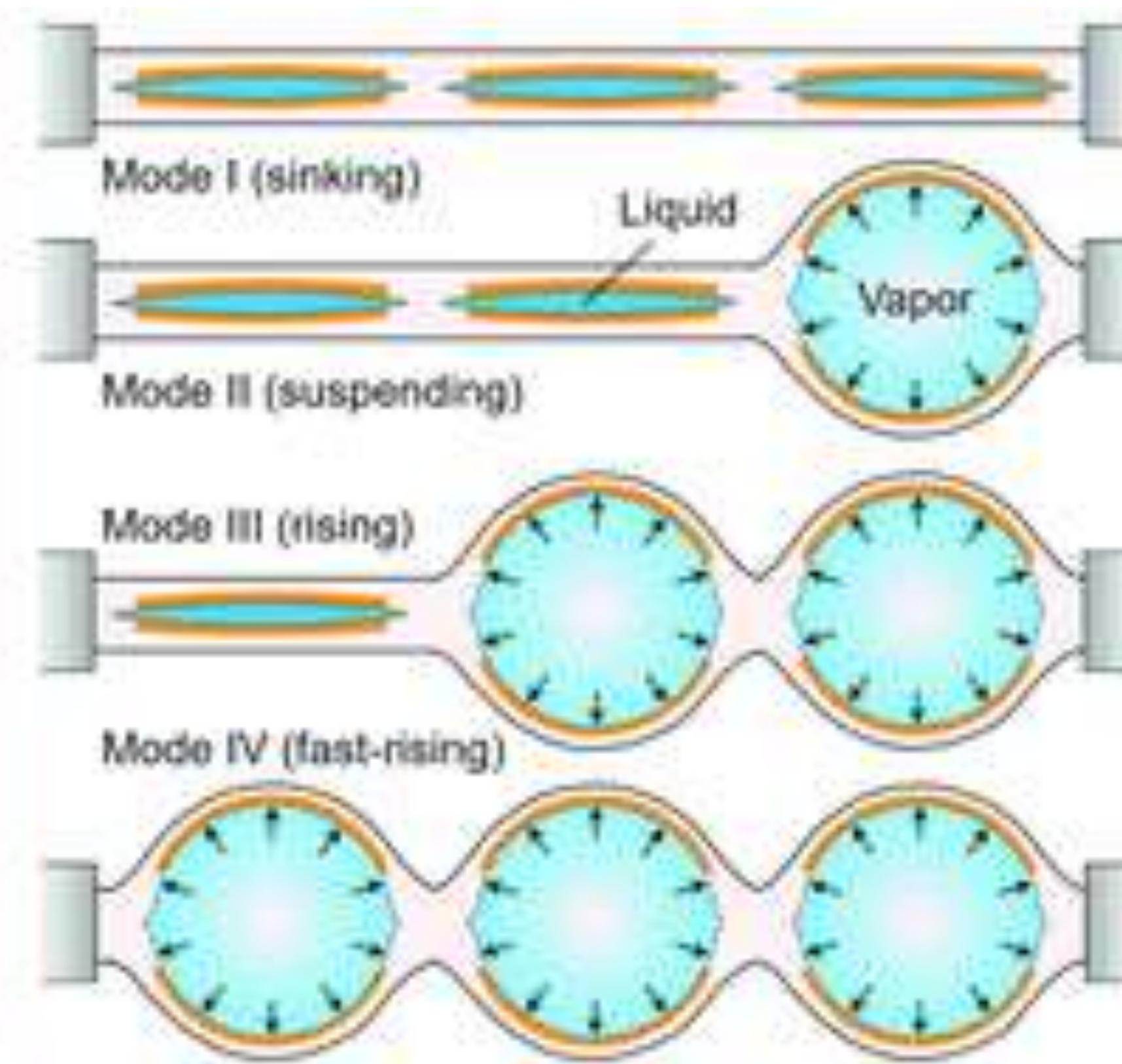
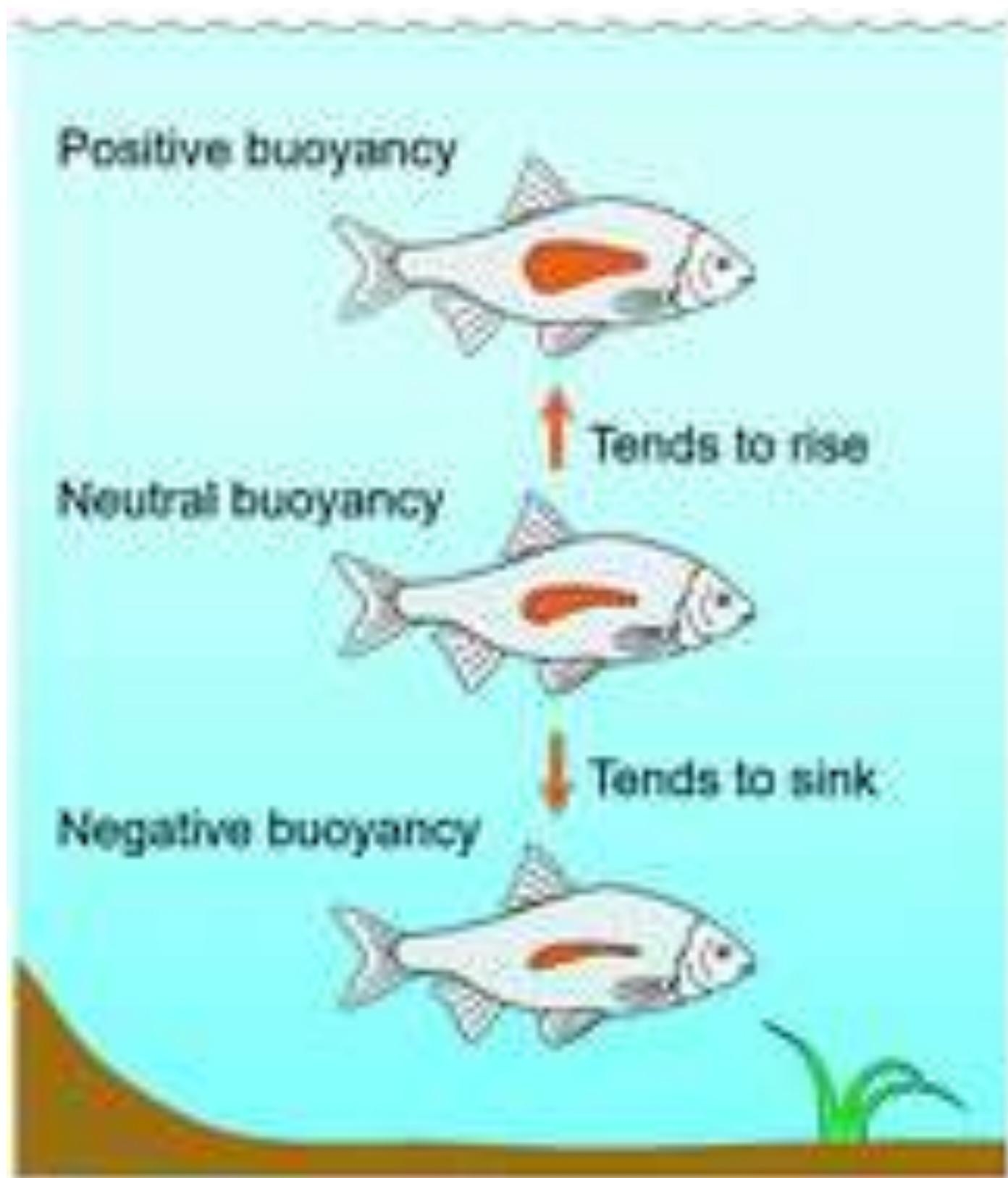
courtesy of
George
Lauder



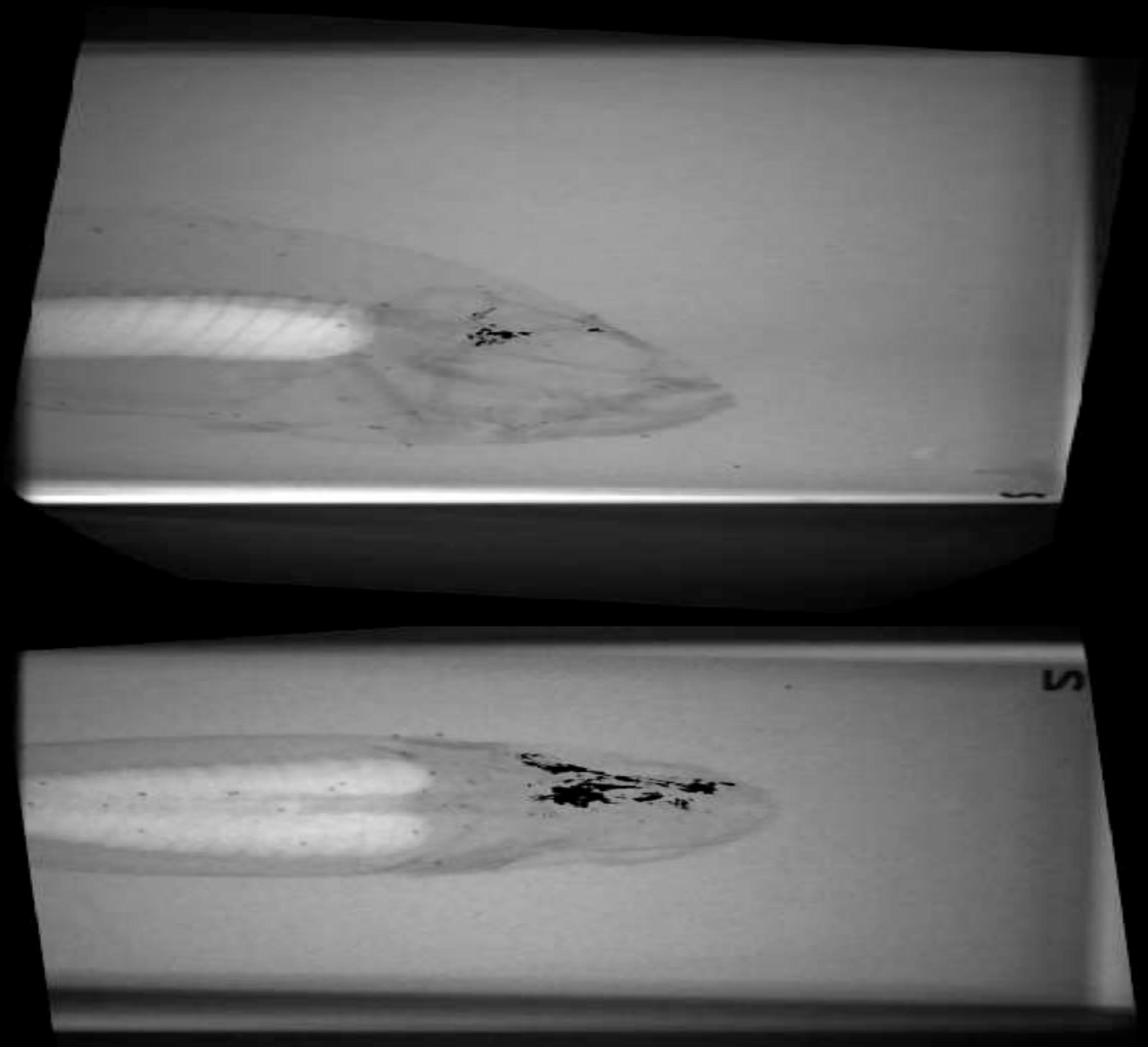


Bony fish control buoyancy via an air-filled “swim bladder” (an outpocket of the GI tract)

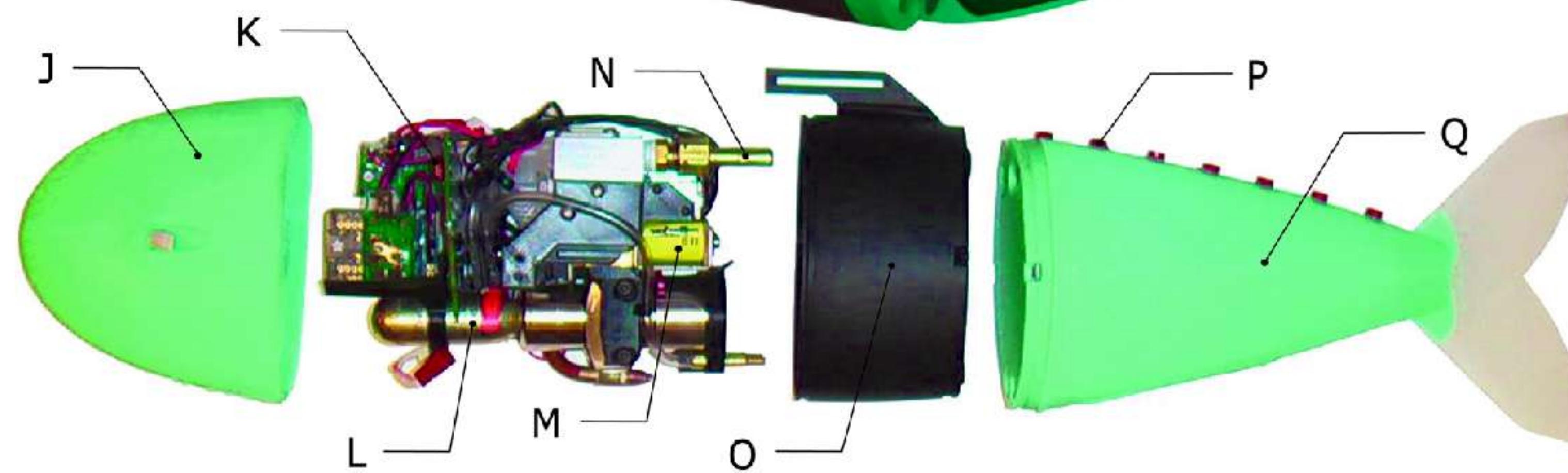
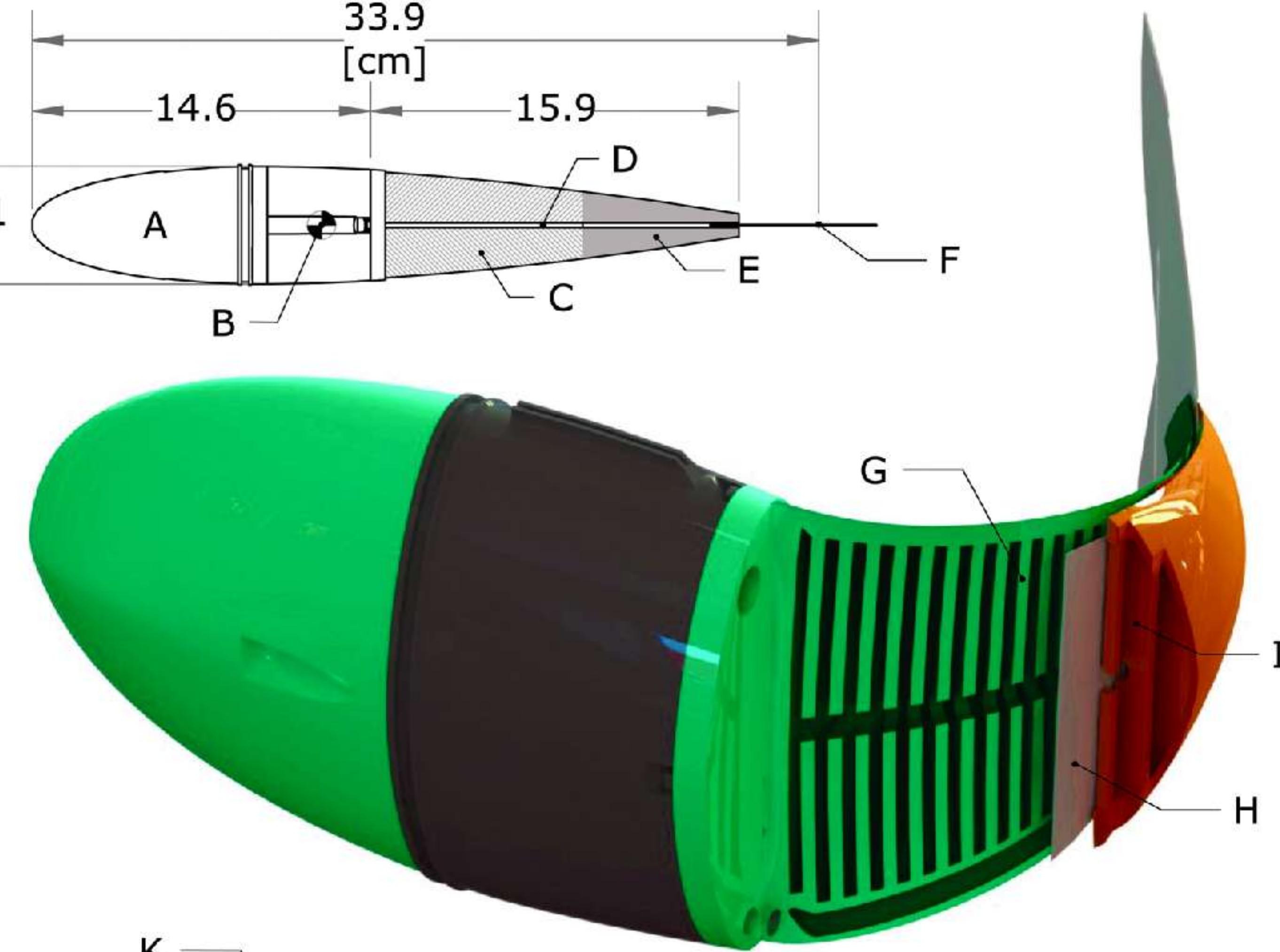
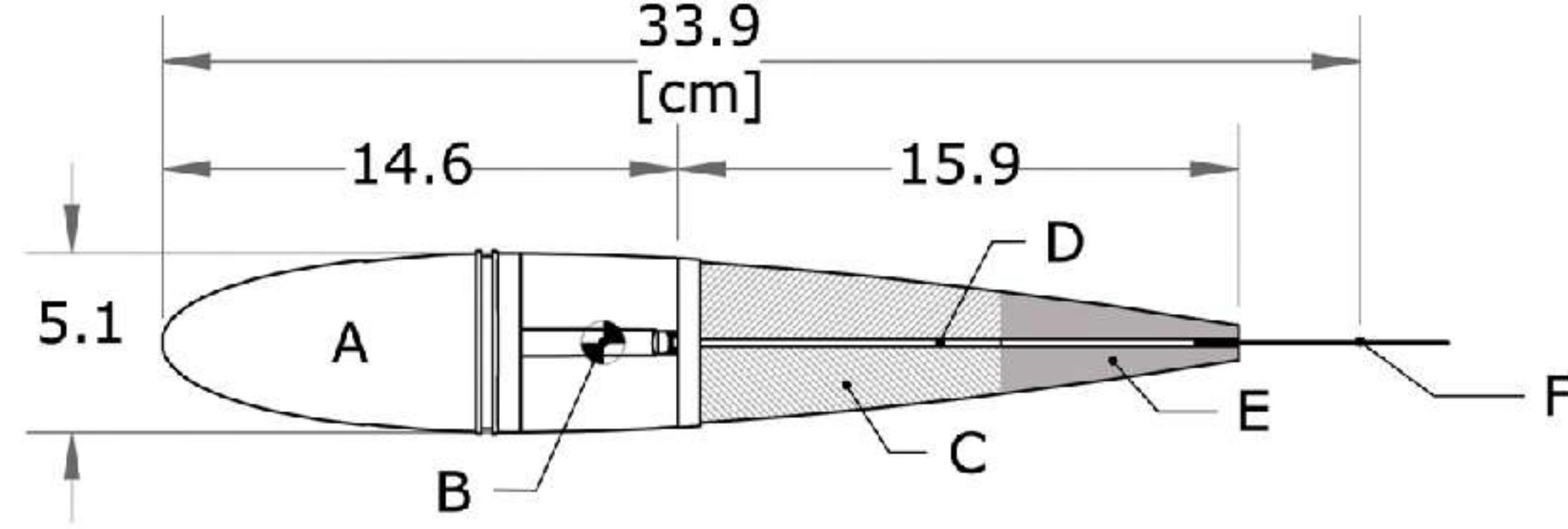




Reconstruction 3D skeletal motions

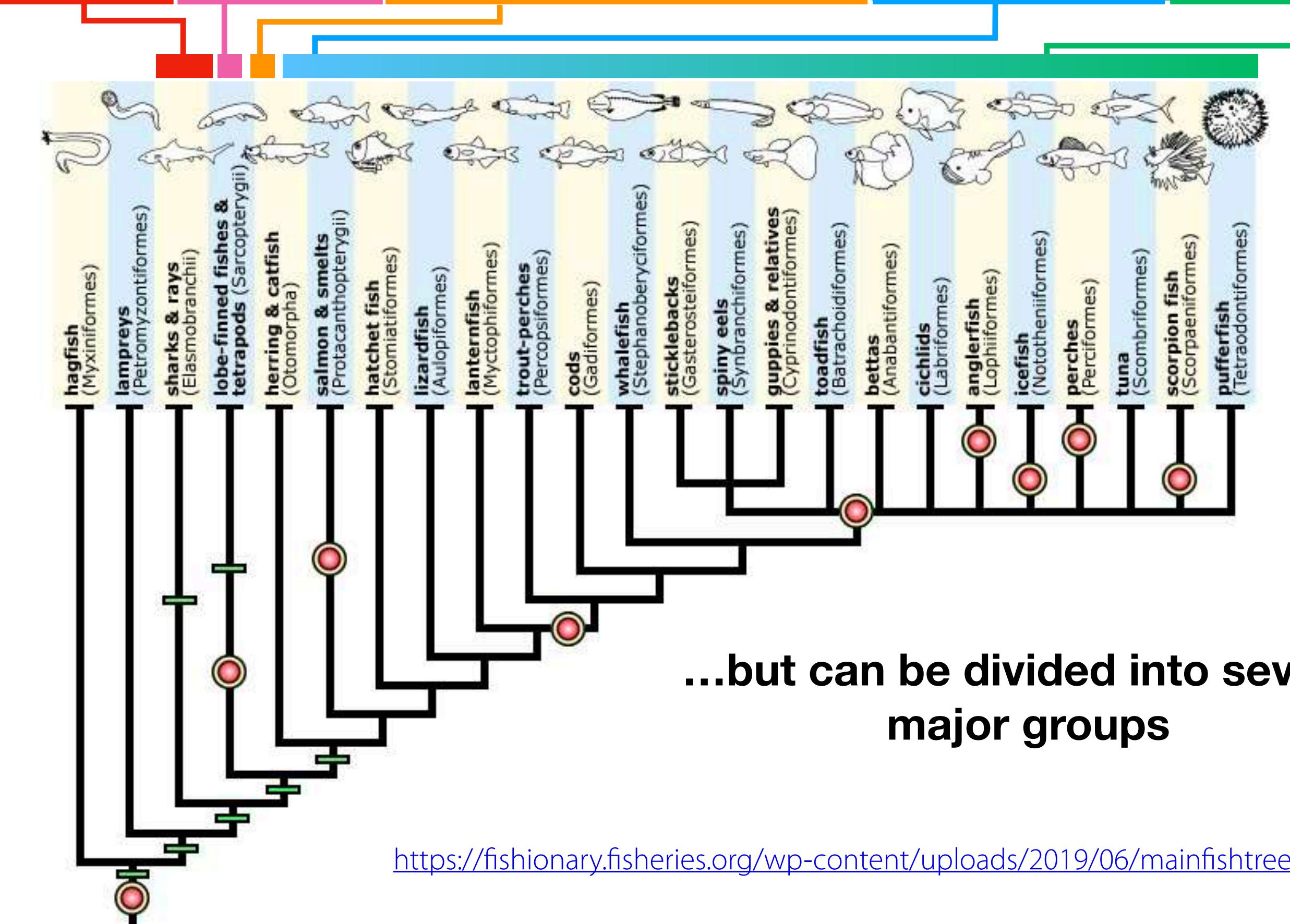
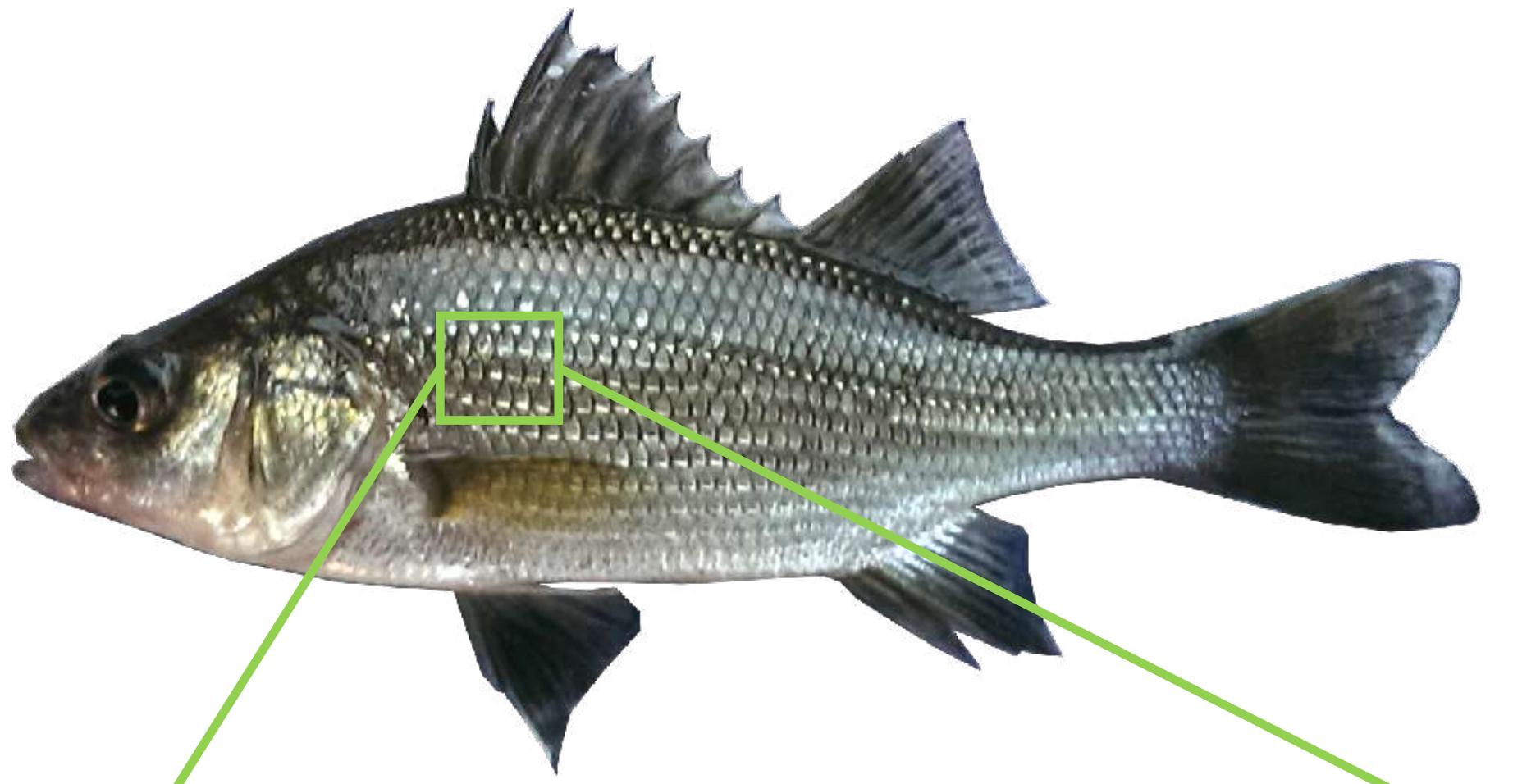


Camp et al., 2015



Many modern fishes are covered with scales

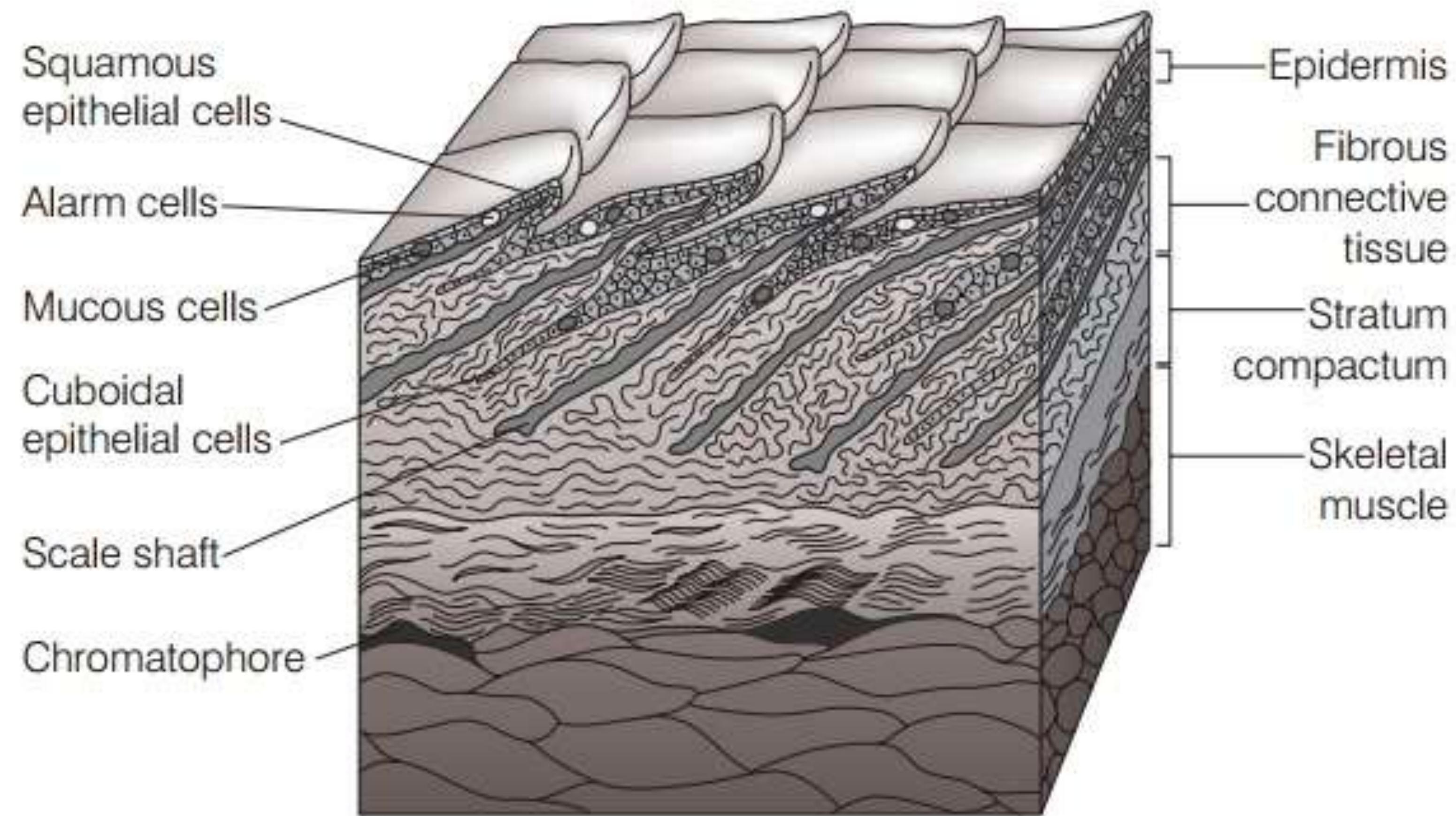
...which evolved multiple times and vary in form



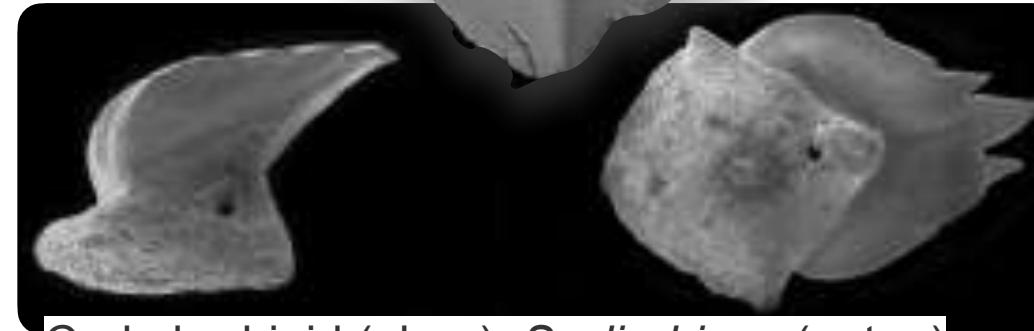
<https://fishionary.fisheries.org/wp-content/uploads/2019/06/mainfishtree.jpg>



Scales are anchored or in pockets in skin

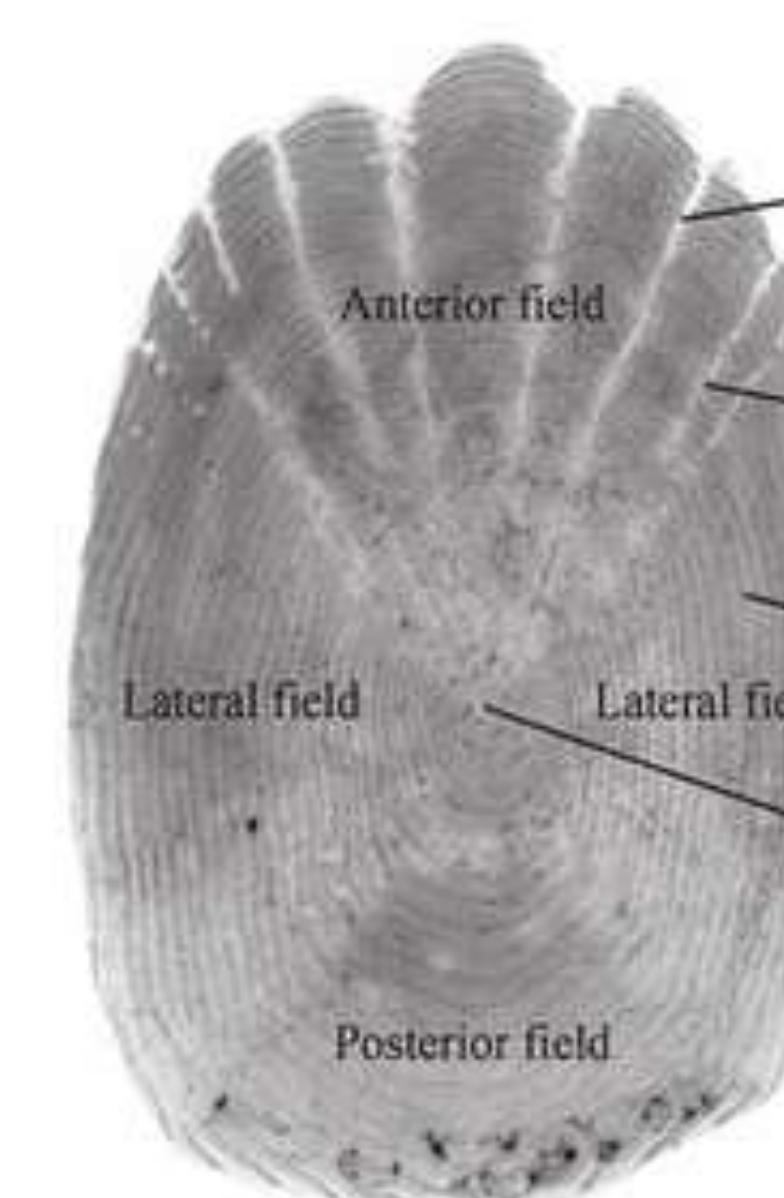


Placoid



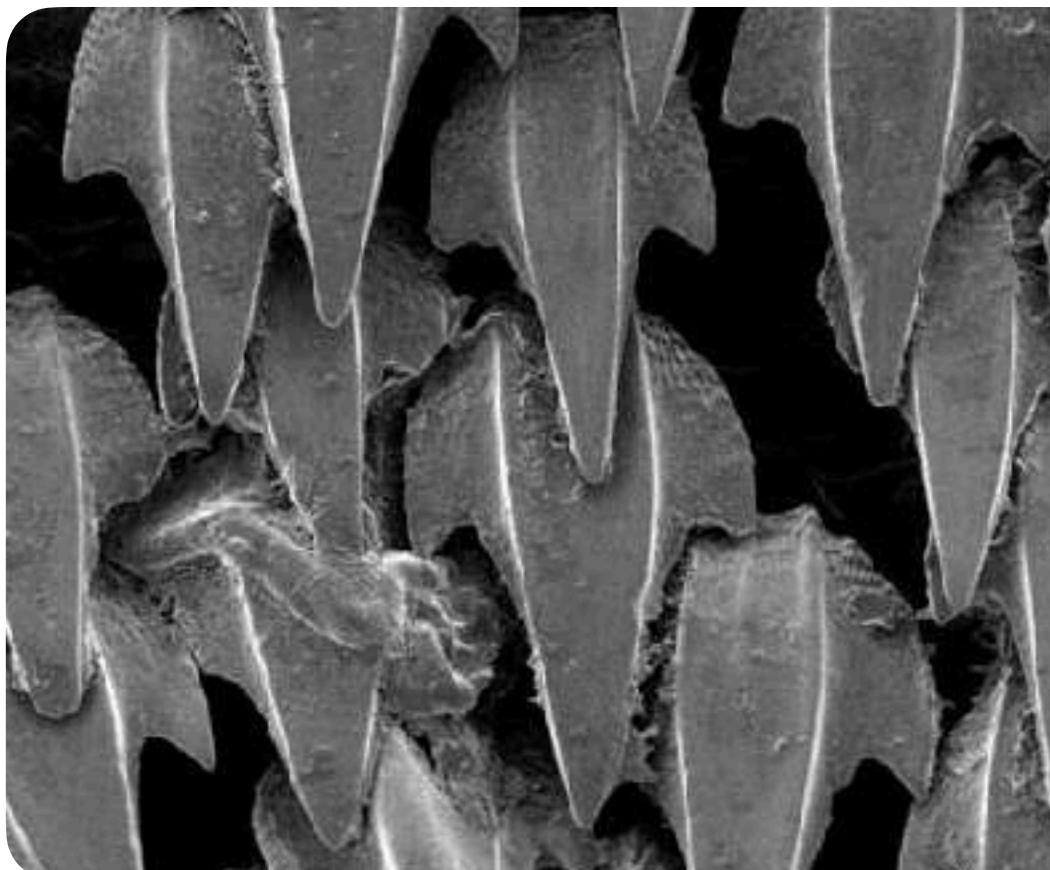
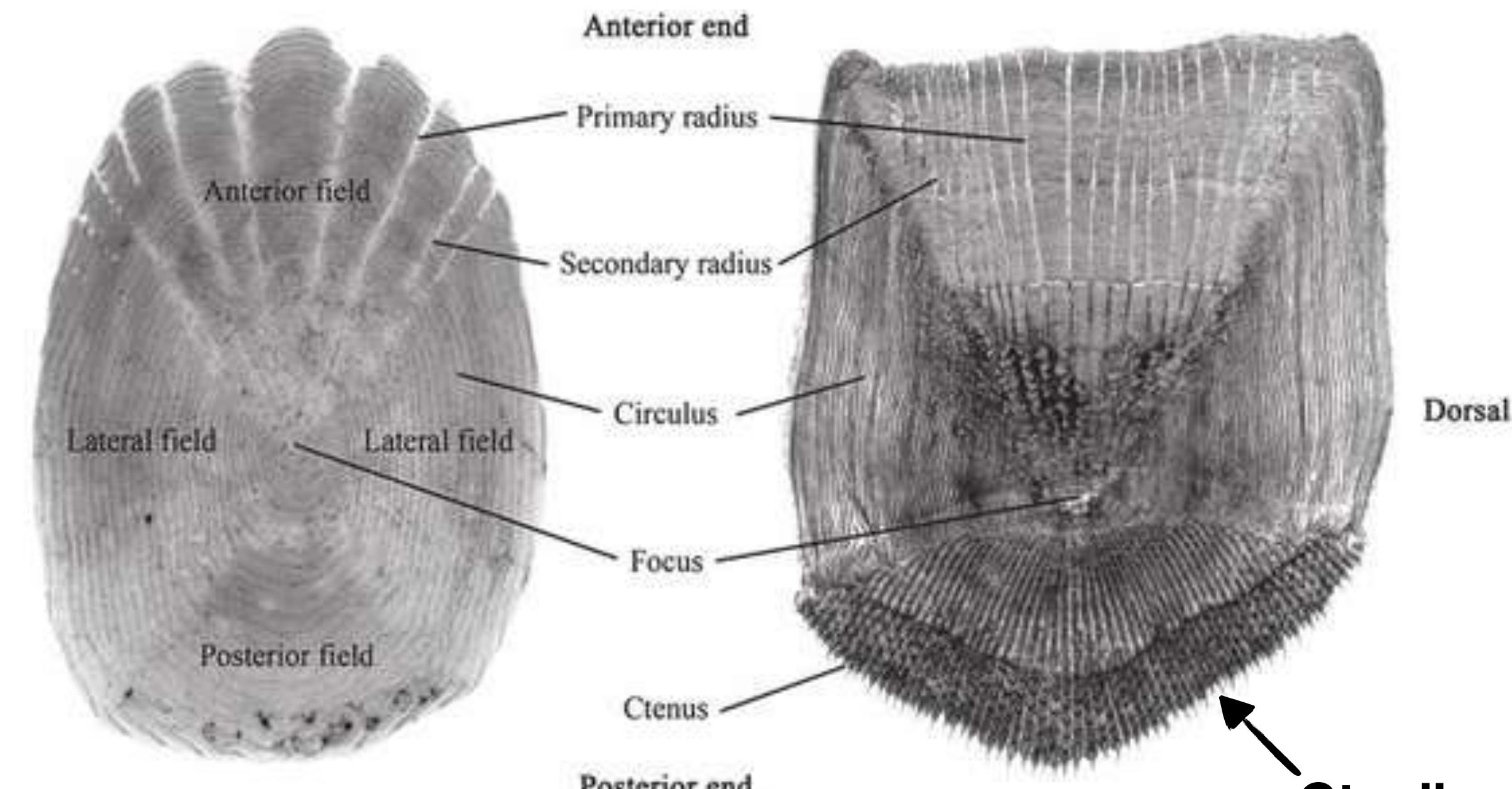
Carhcharhinid (oben), *Scyliorhinus* (unten)

Cycloid

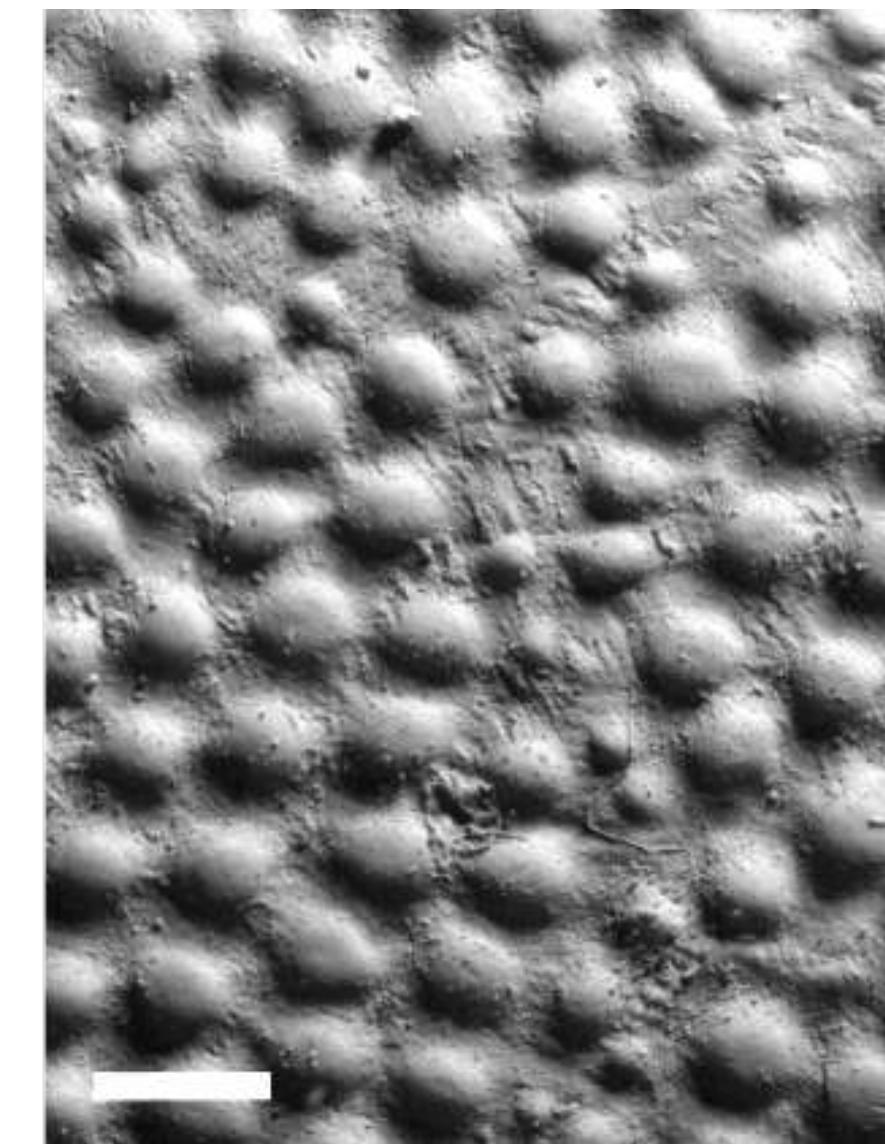
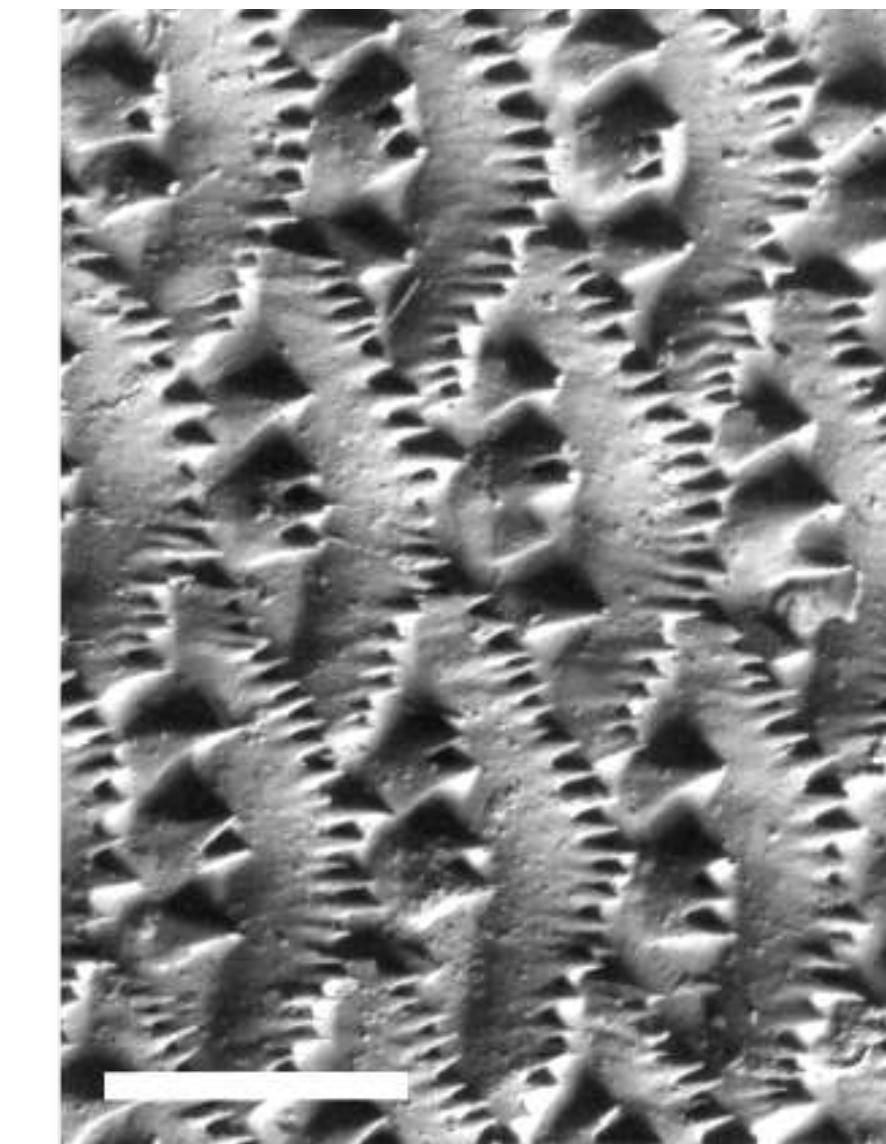
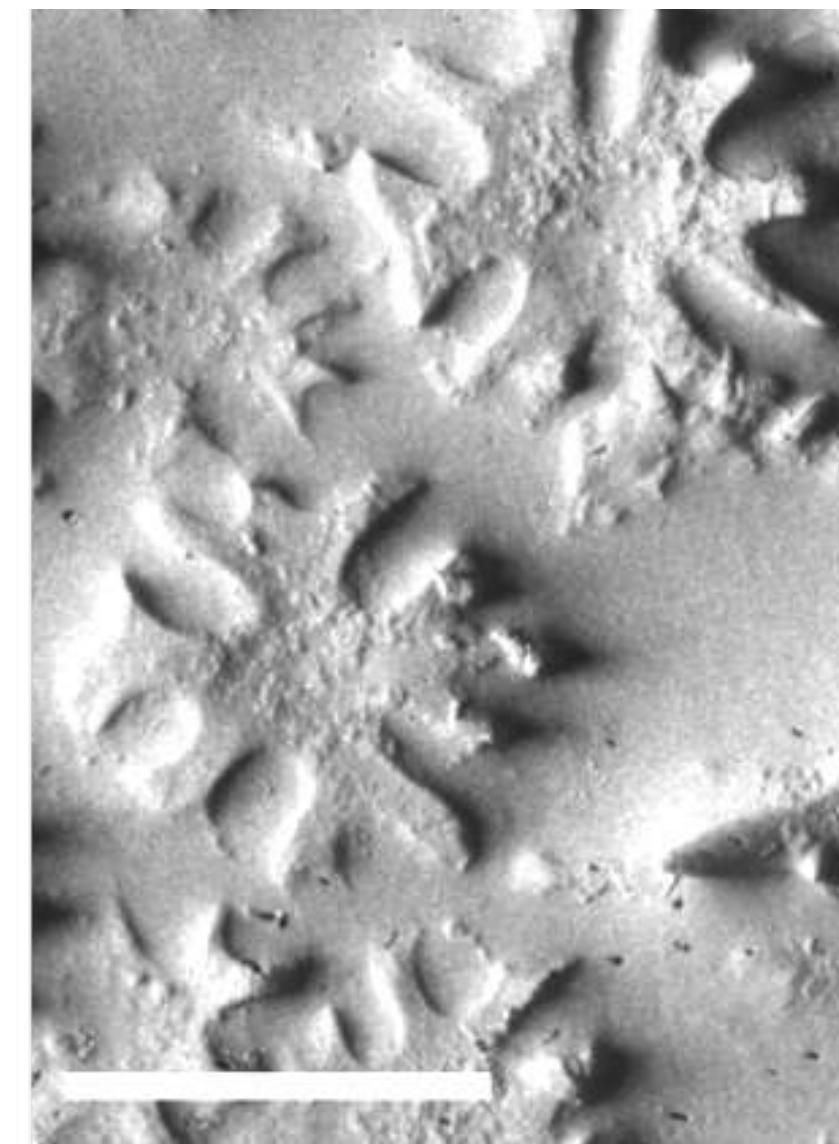
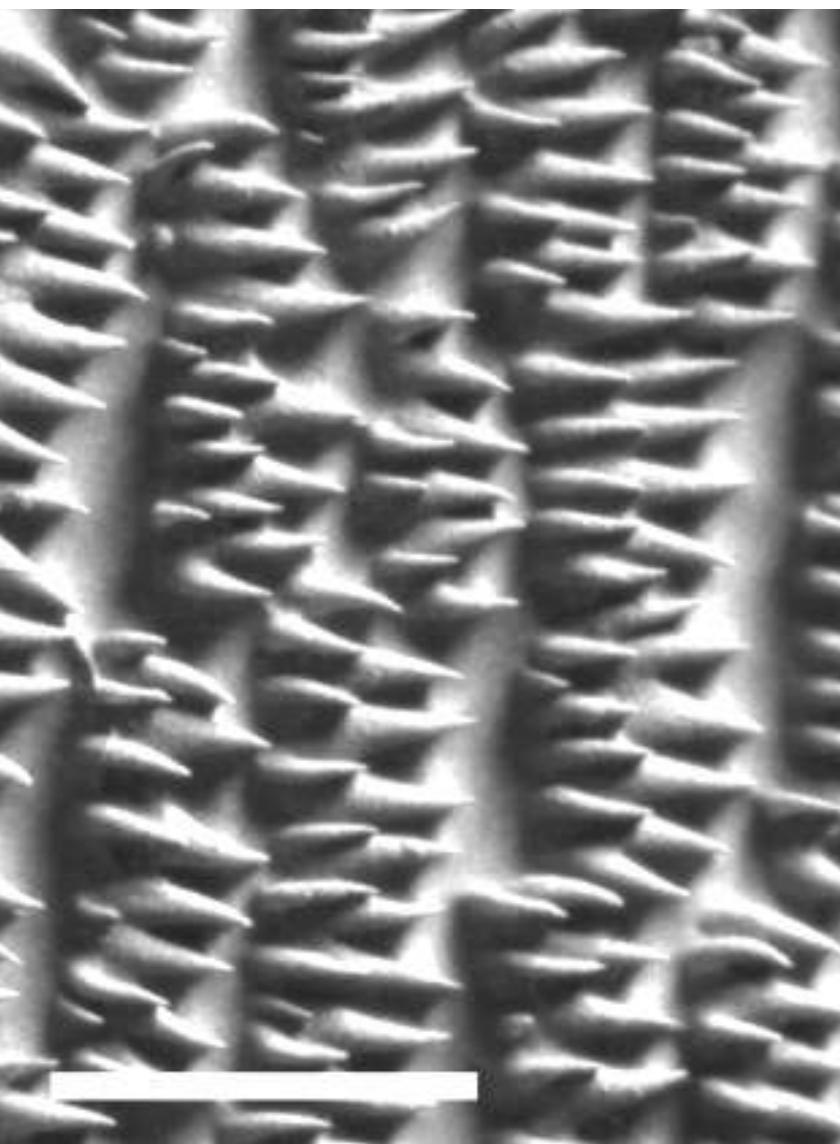


cycloid: *Seriola dumerili* (links); ctenoid: *Dicentrarchus labrax* (rechts)

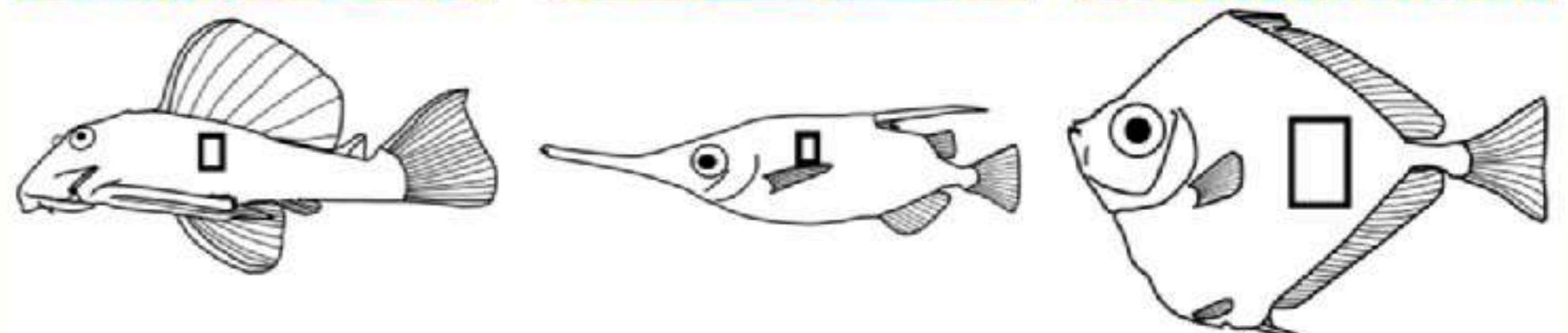
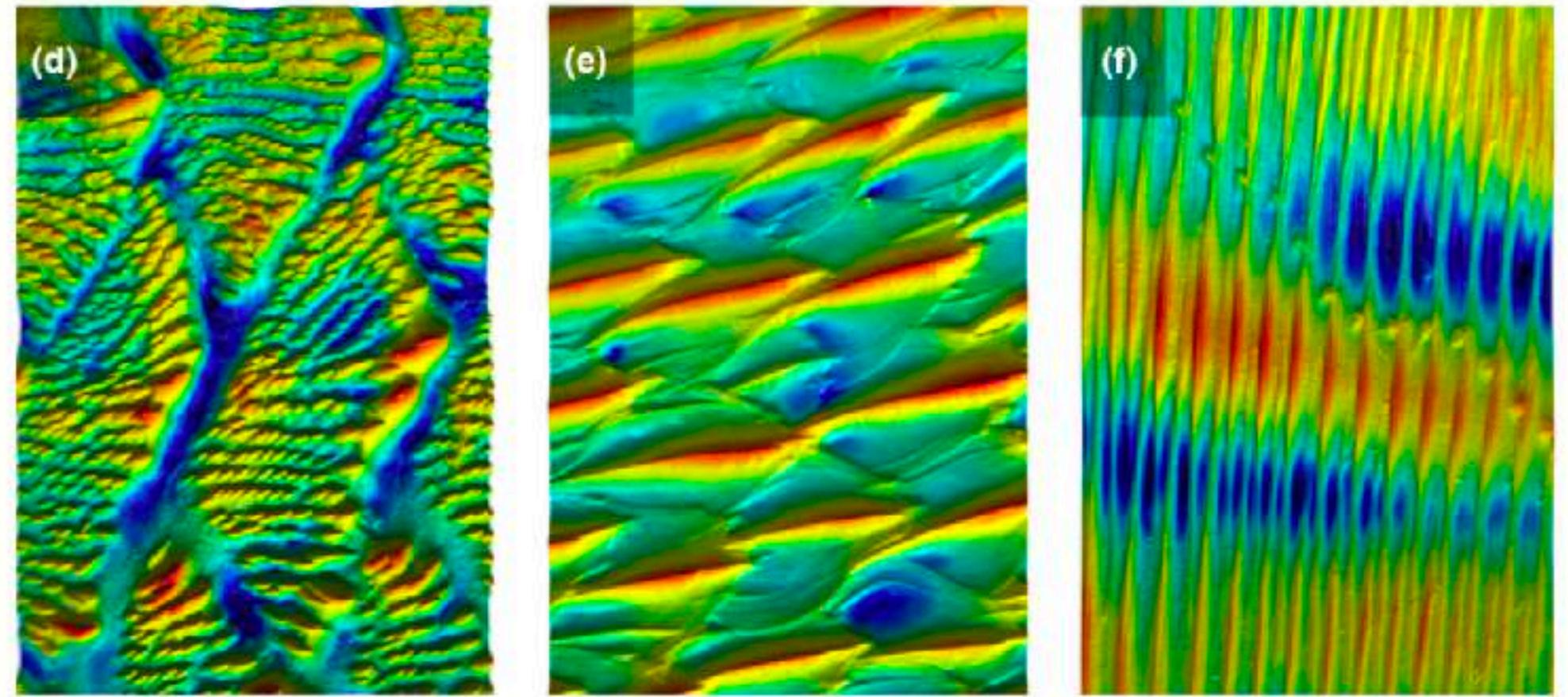
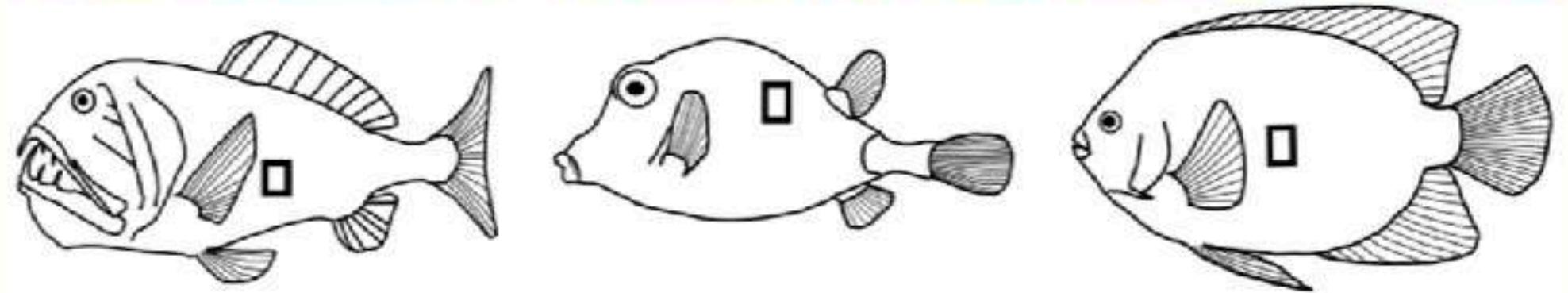
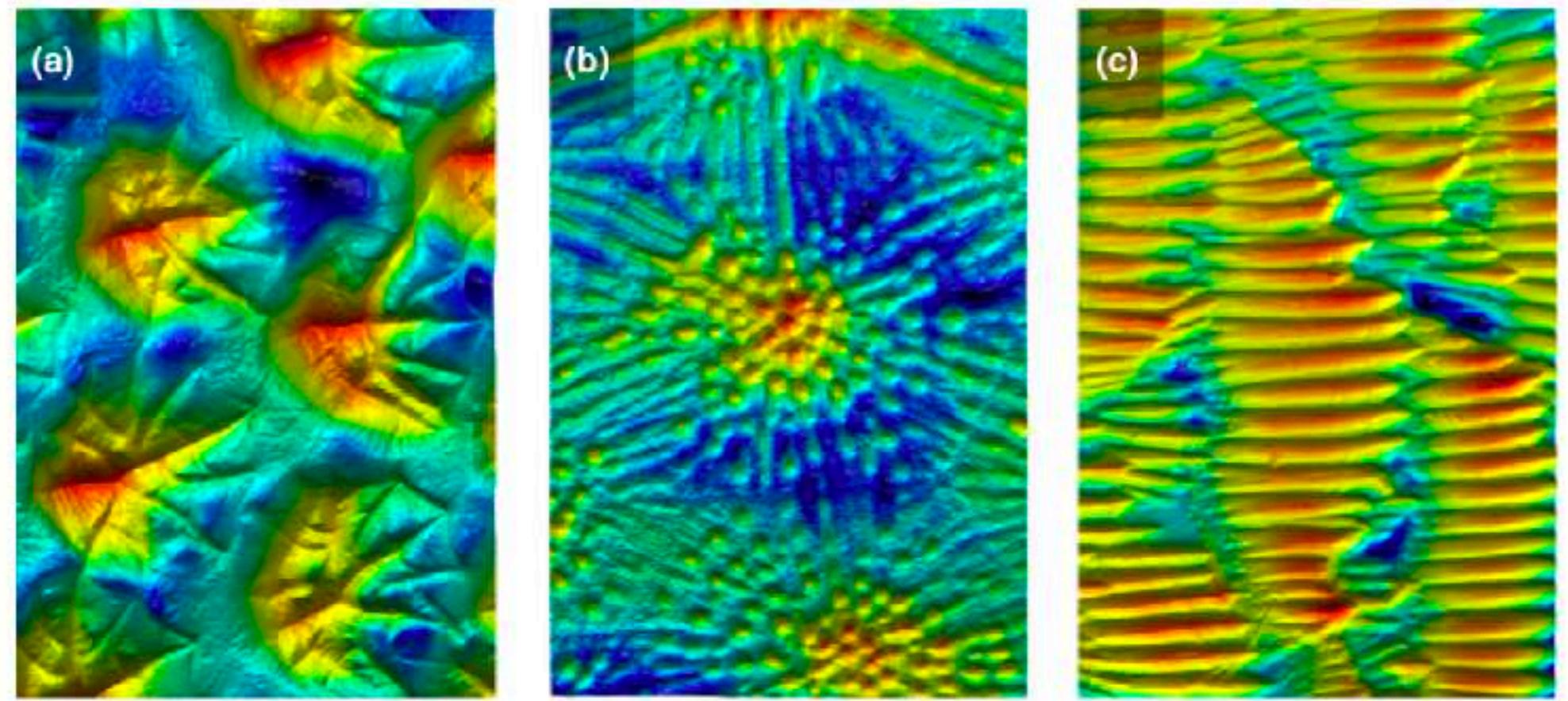
Ctenoid



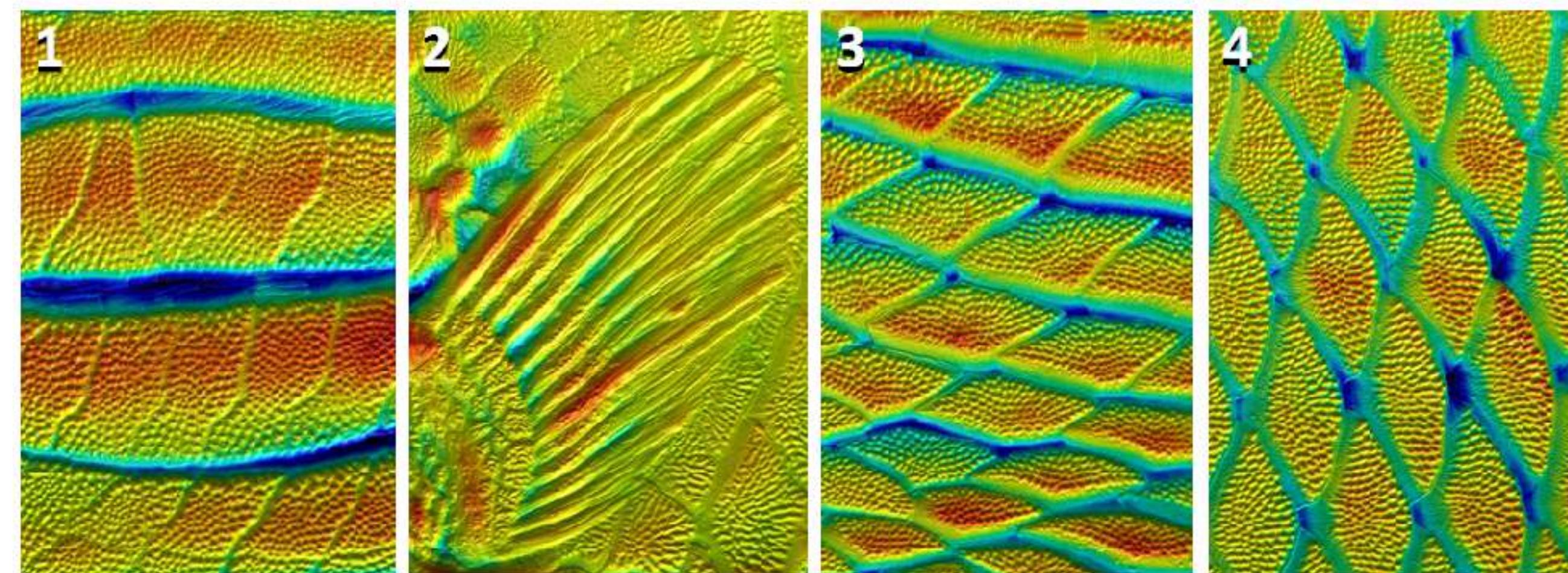
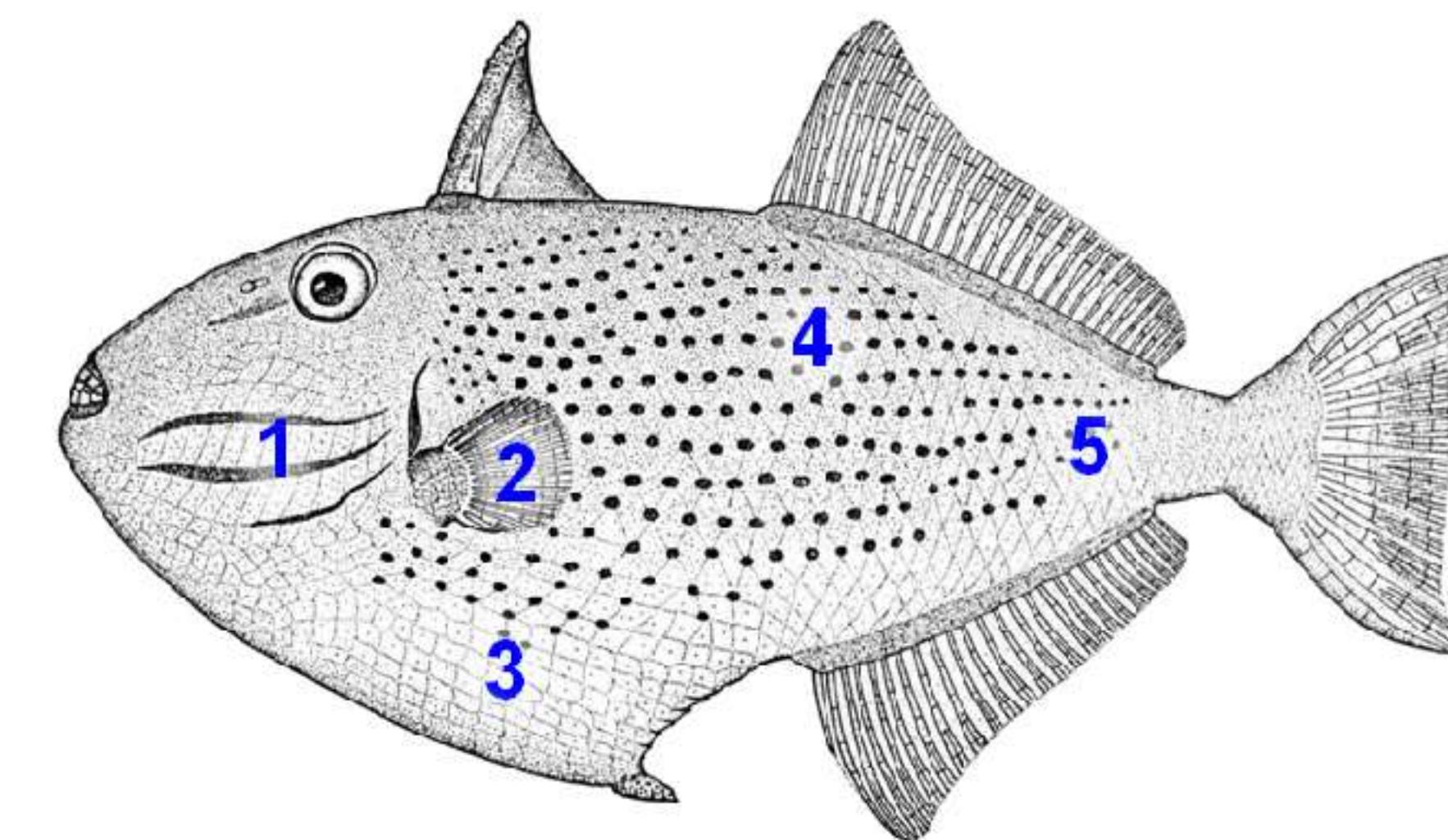
Many scales defy classification



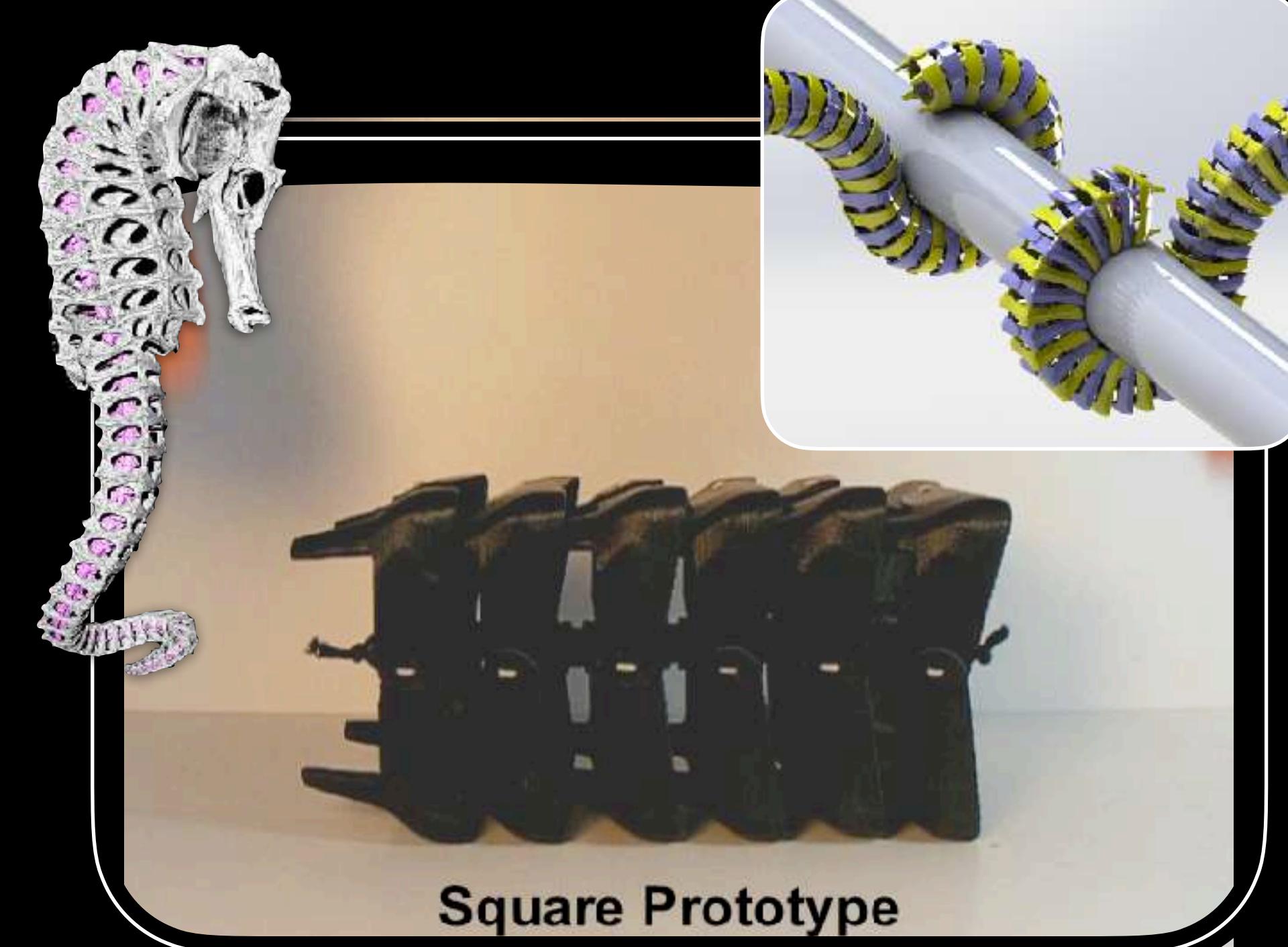
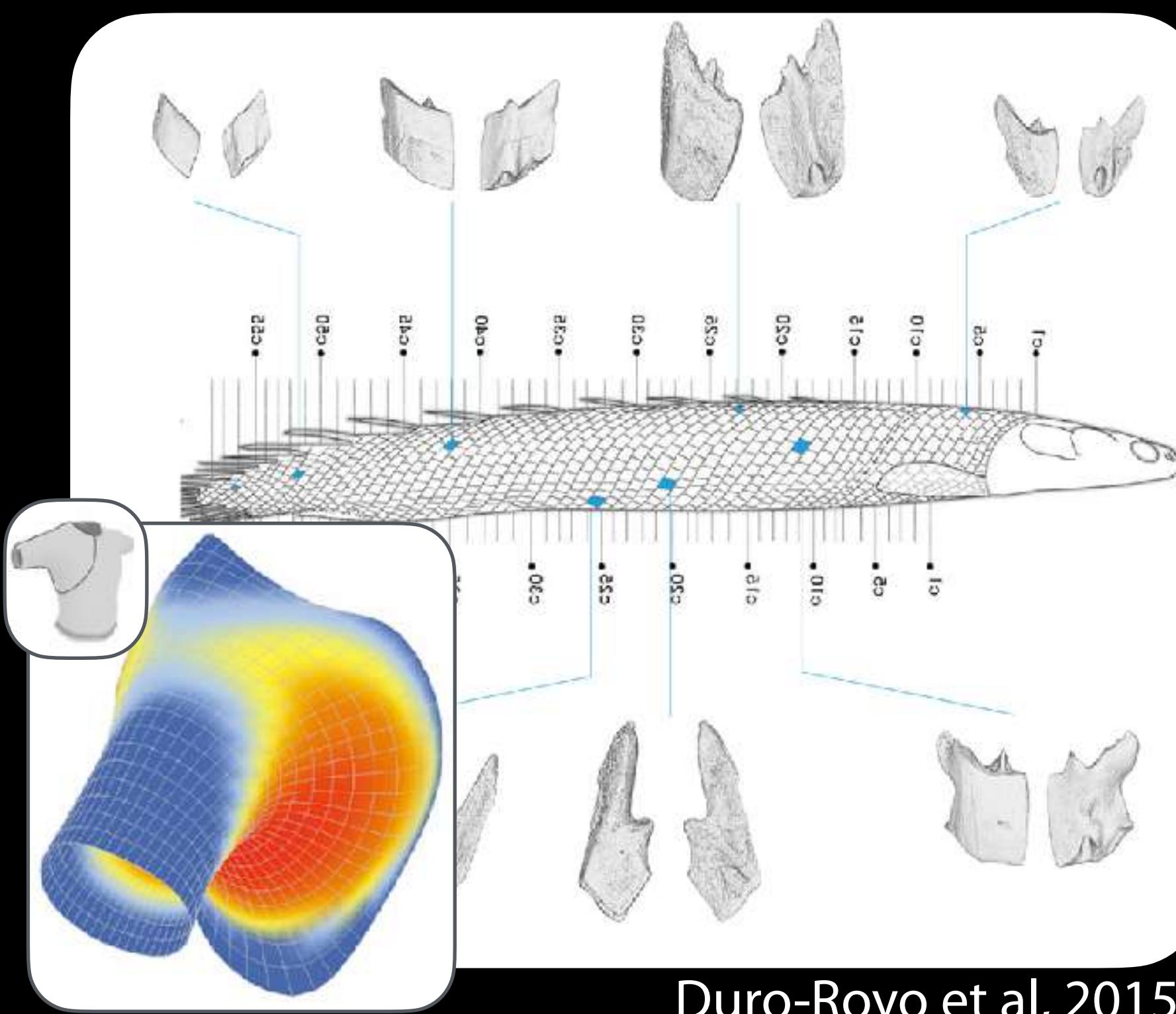
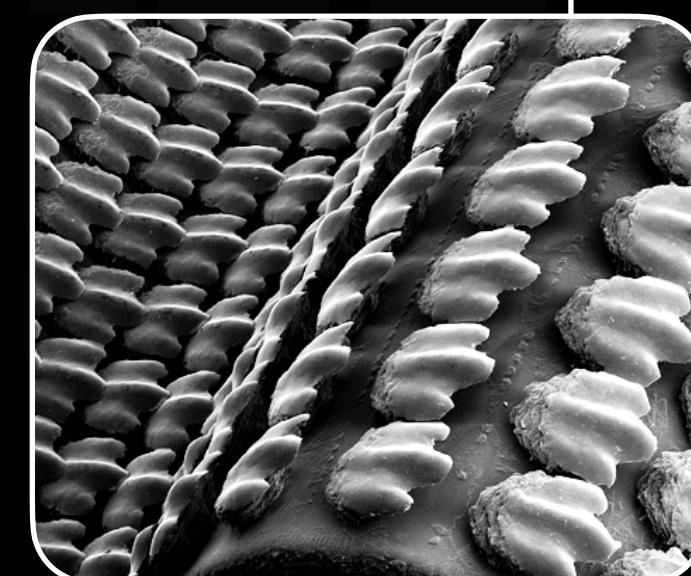
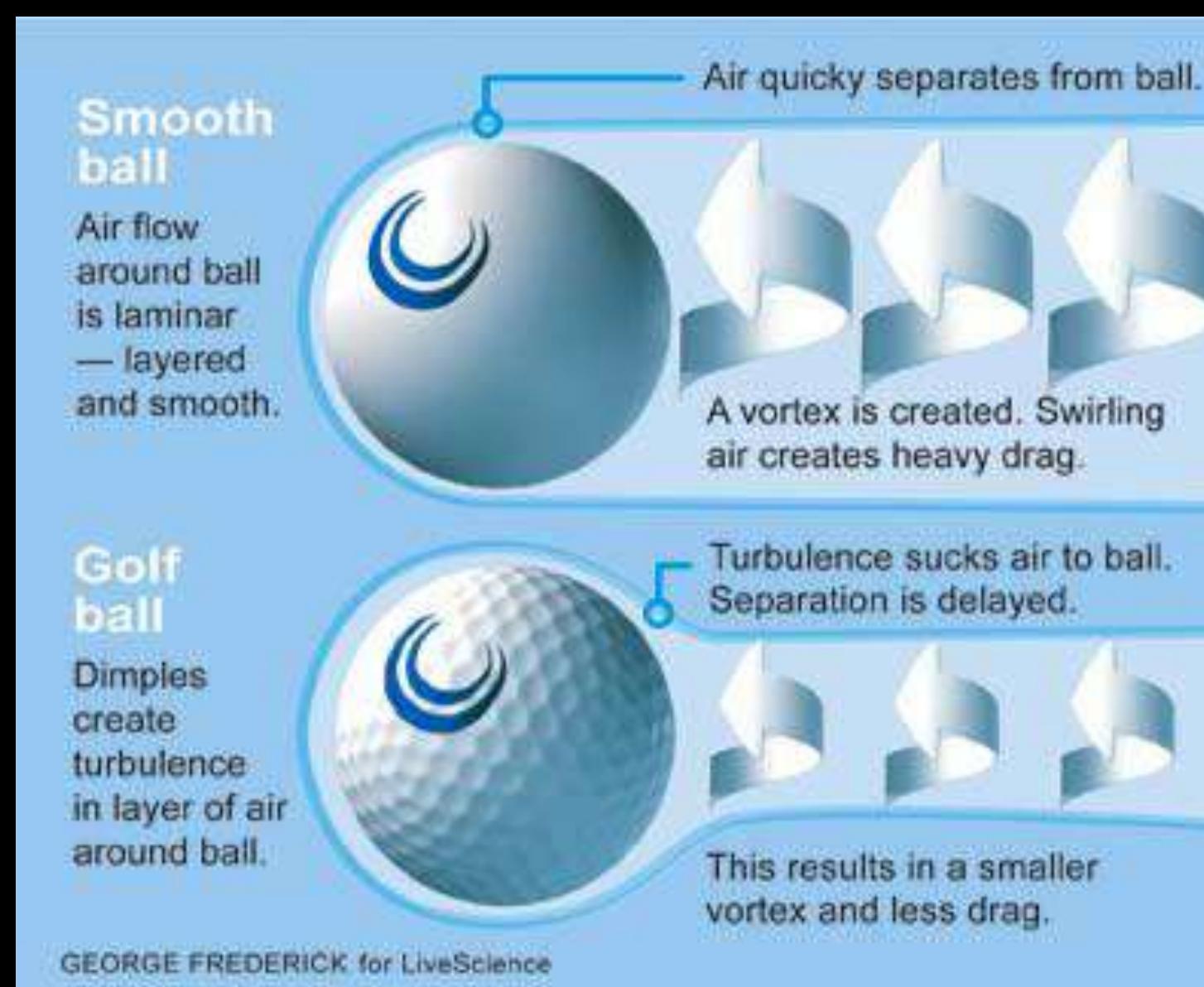
Scales differ among species

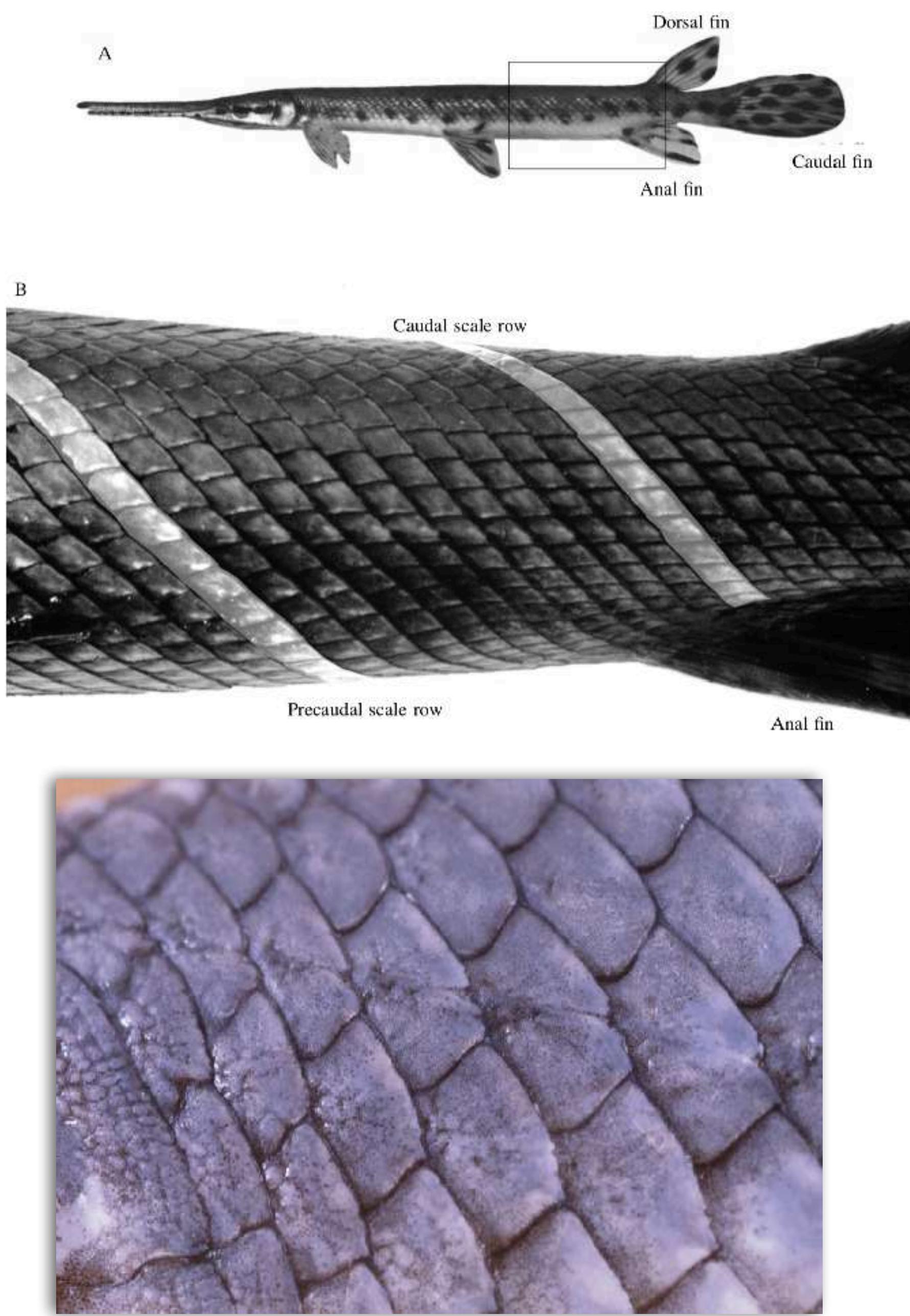


Scales differ among regions on an individual

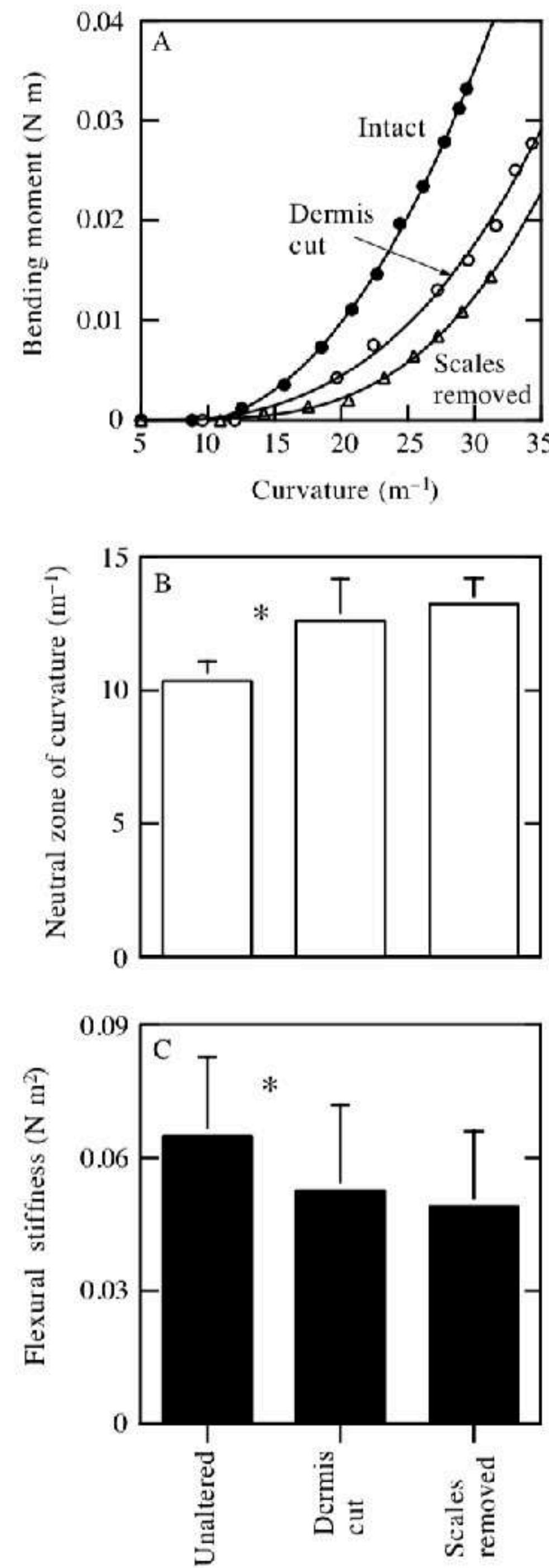


...but don't forget mucus!

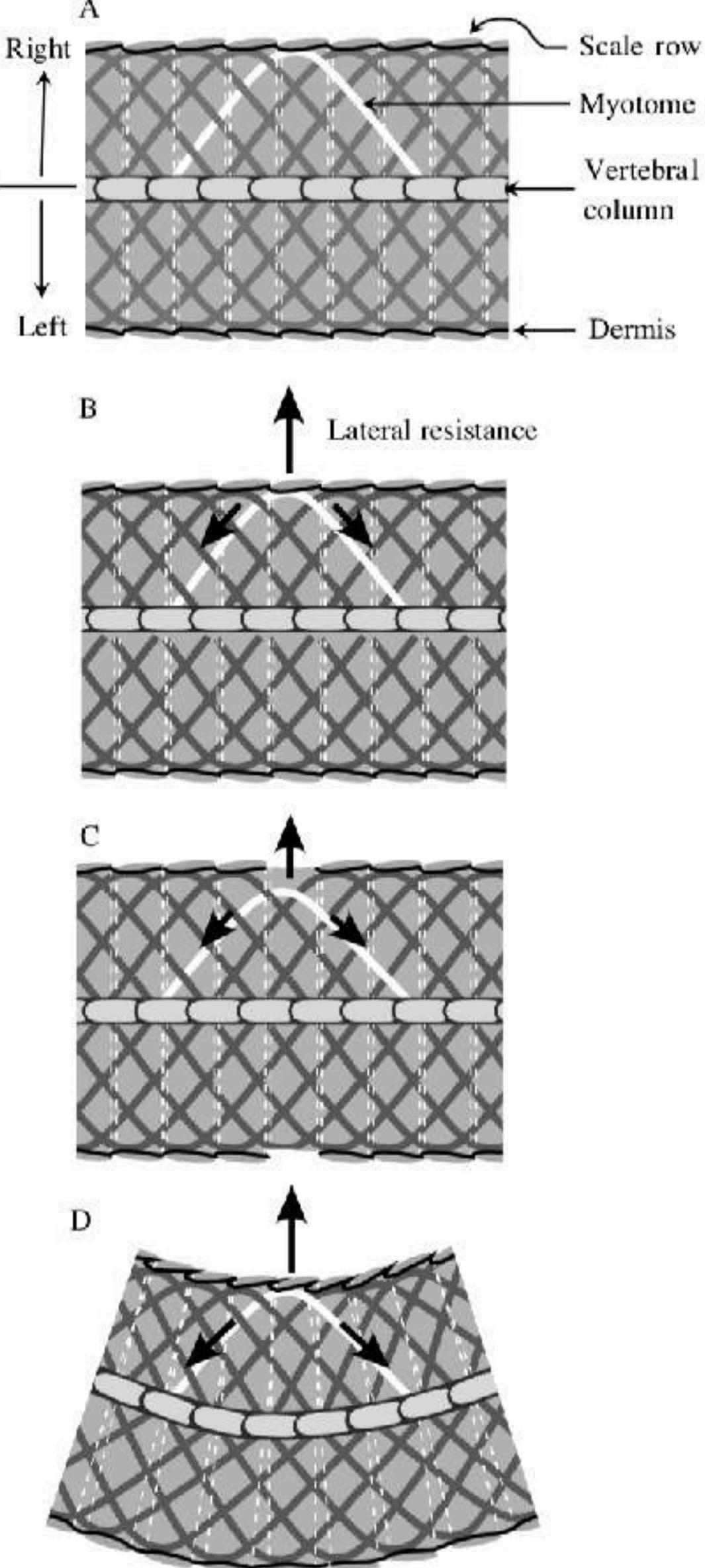




Scales can be important for body stiffness



Experimental manipulations



Long et al, JEB, 1996

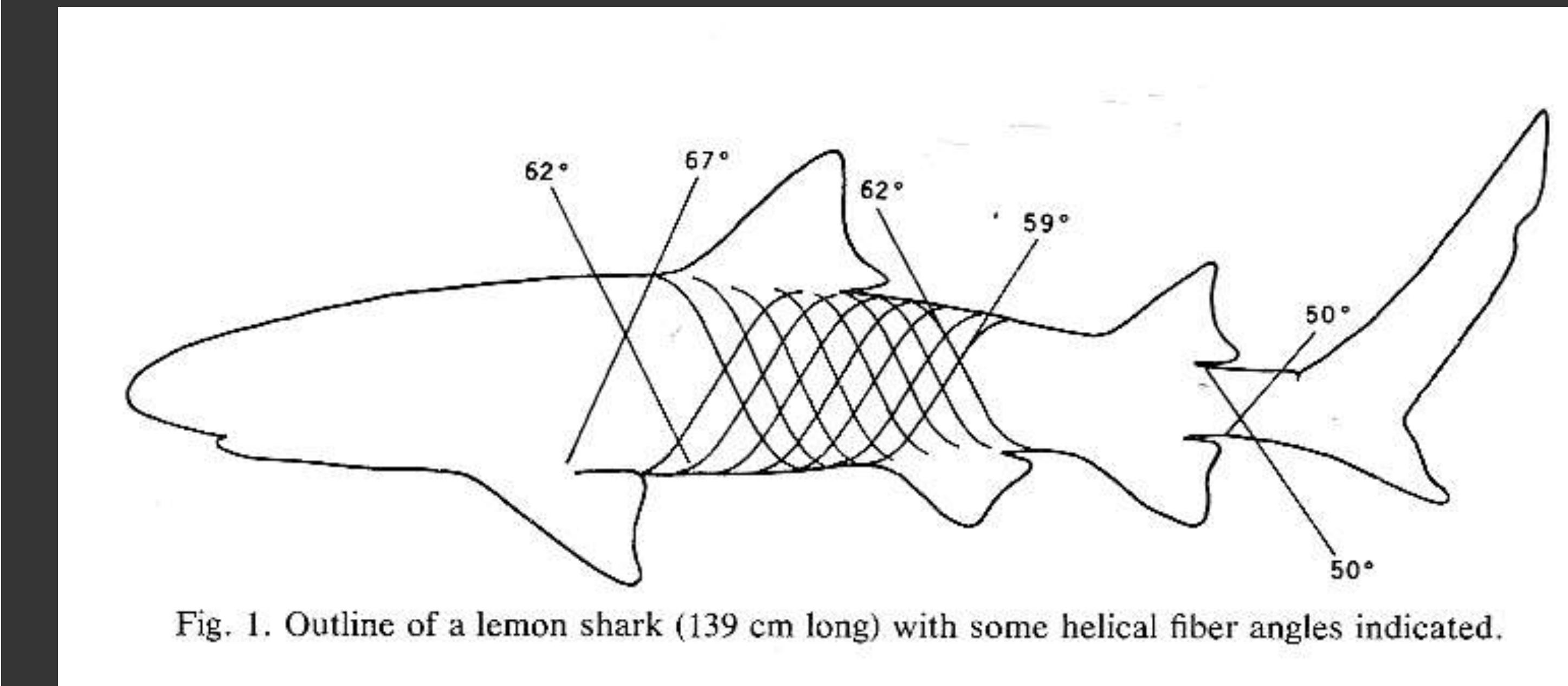
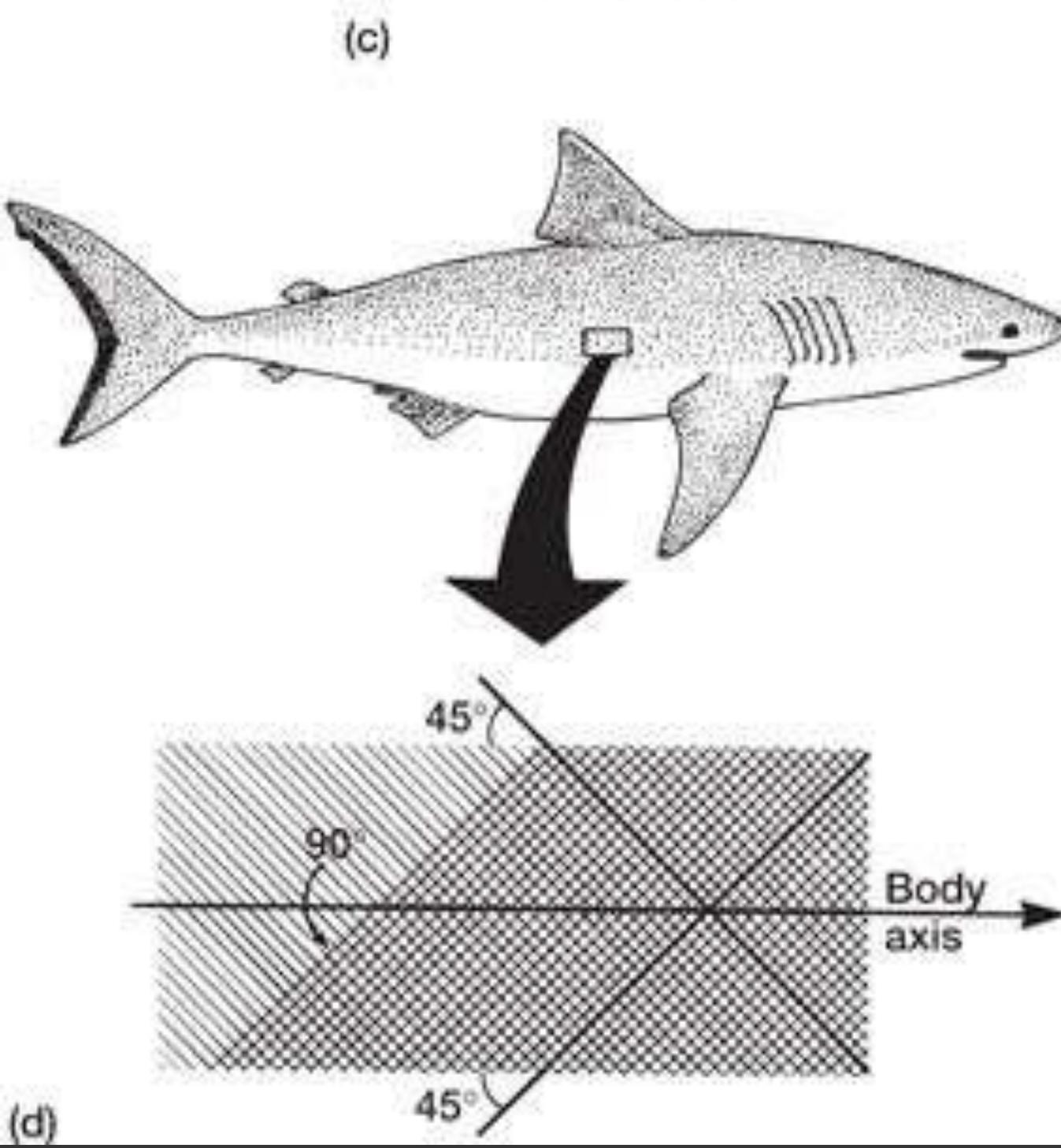
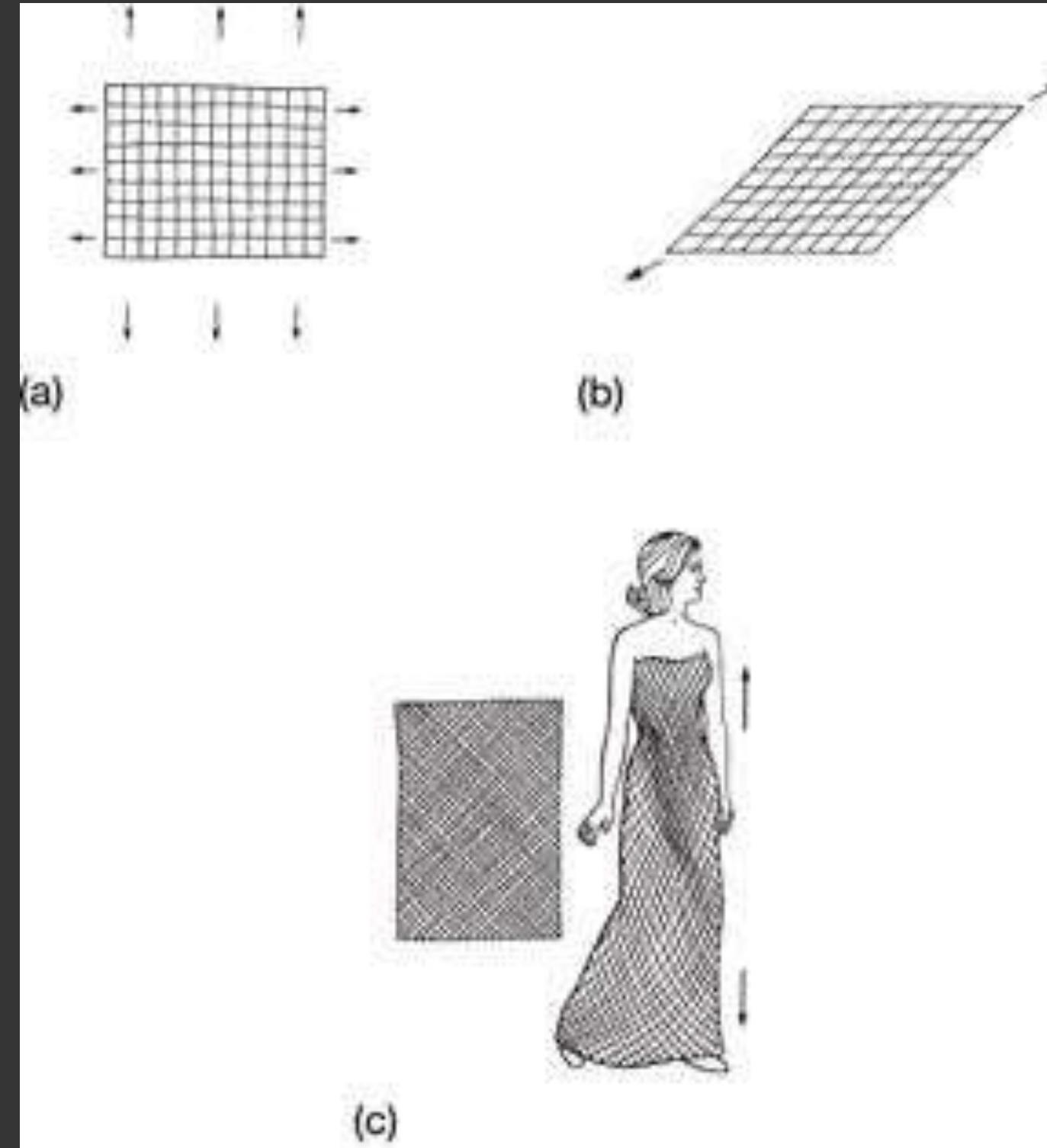


Fig. 1. Outline of a lemon shark (139 cm long) with some helical fiber angles indicated.

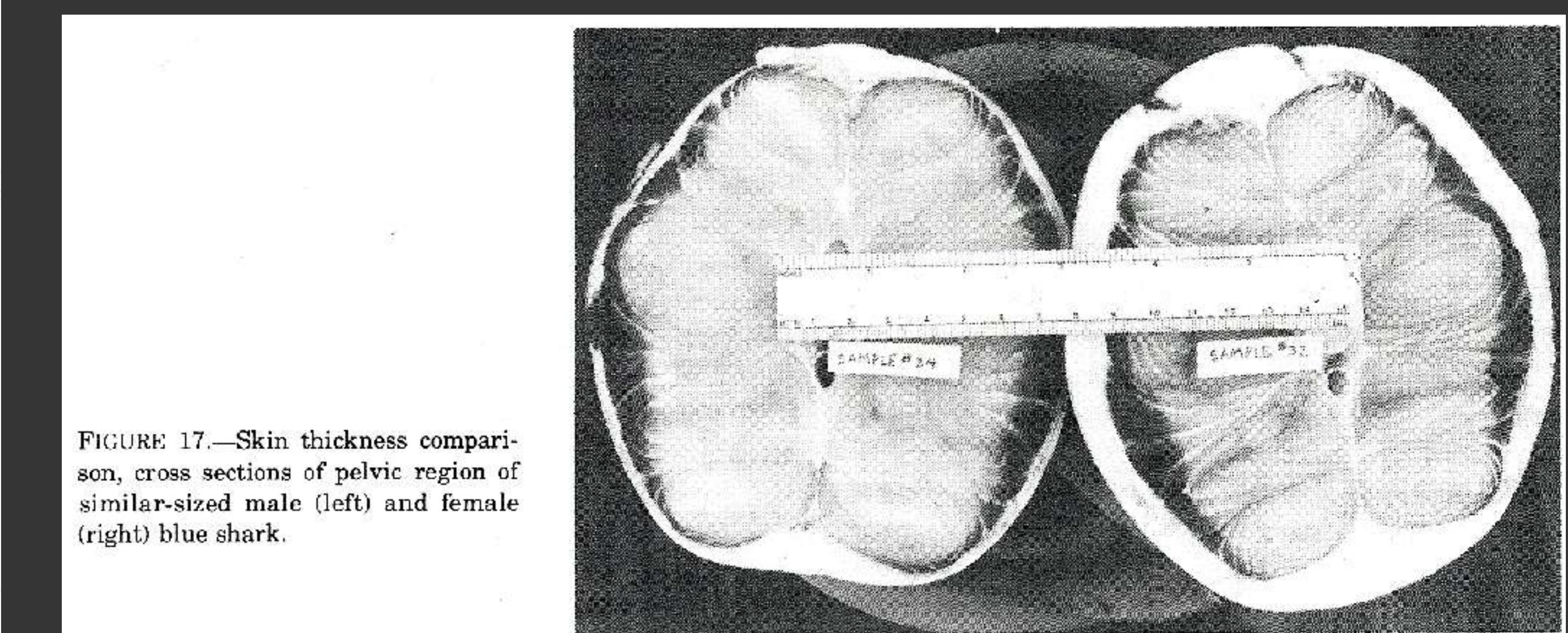
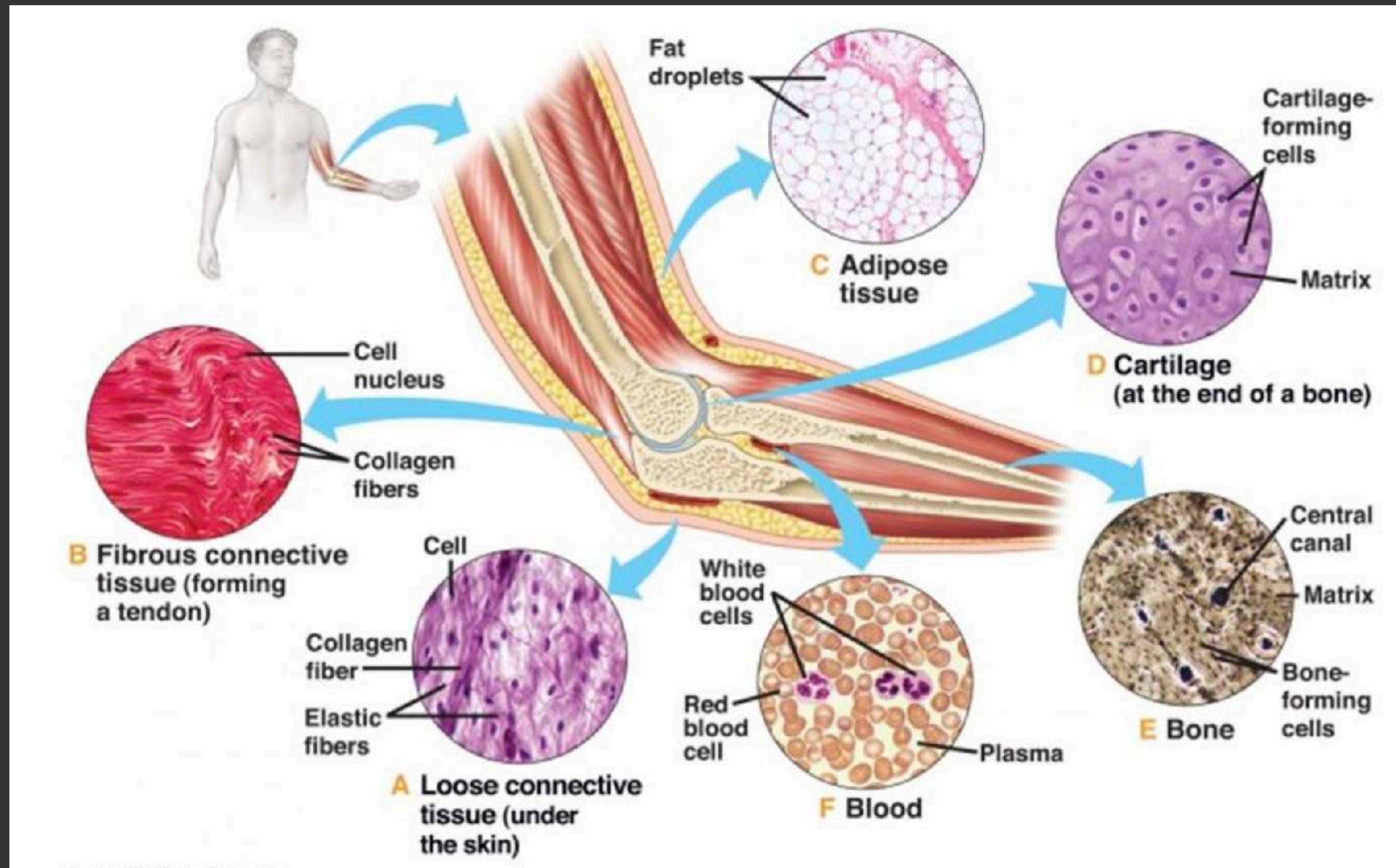


FIGURE 17.—Skin thickness comparison, cross sections of pelvic region of similar-sized male (left) and female (right) blue shark.

Putting it all together...



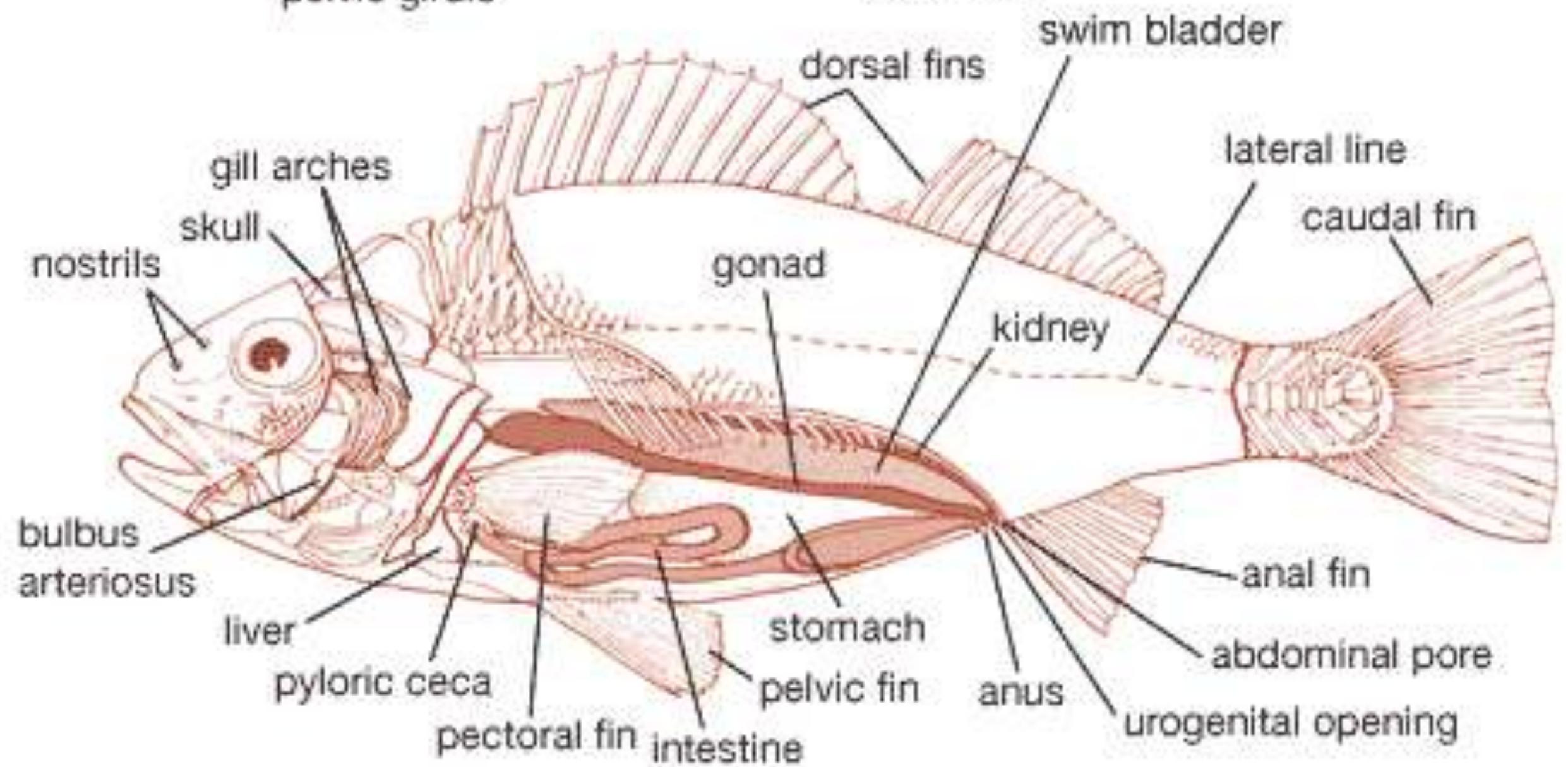
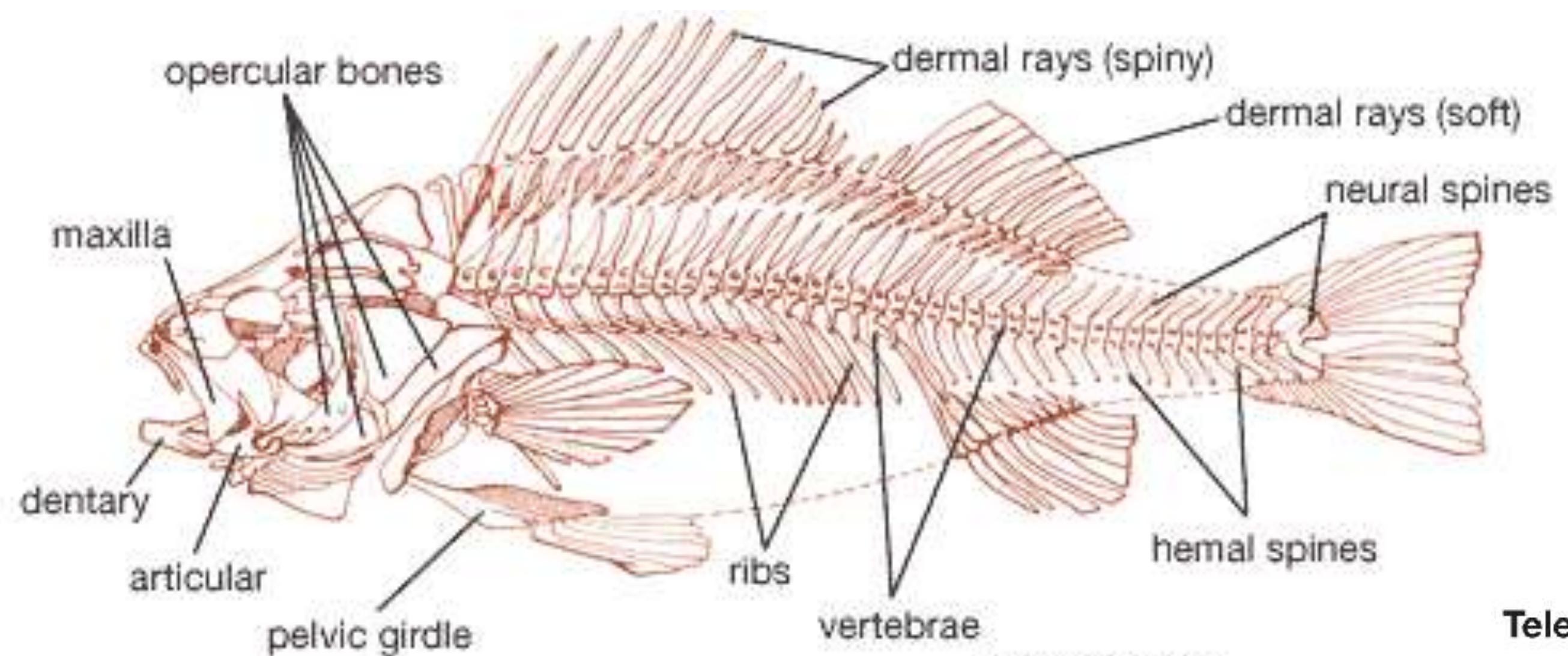


- Muscle/tendon/bone/scales perform different 'roles'...
- ...decided by architecture and composition...
- ...but the tissues work together (mostly)
- Biology is tricky

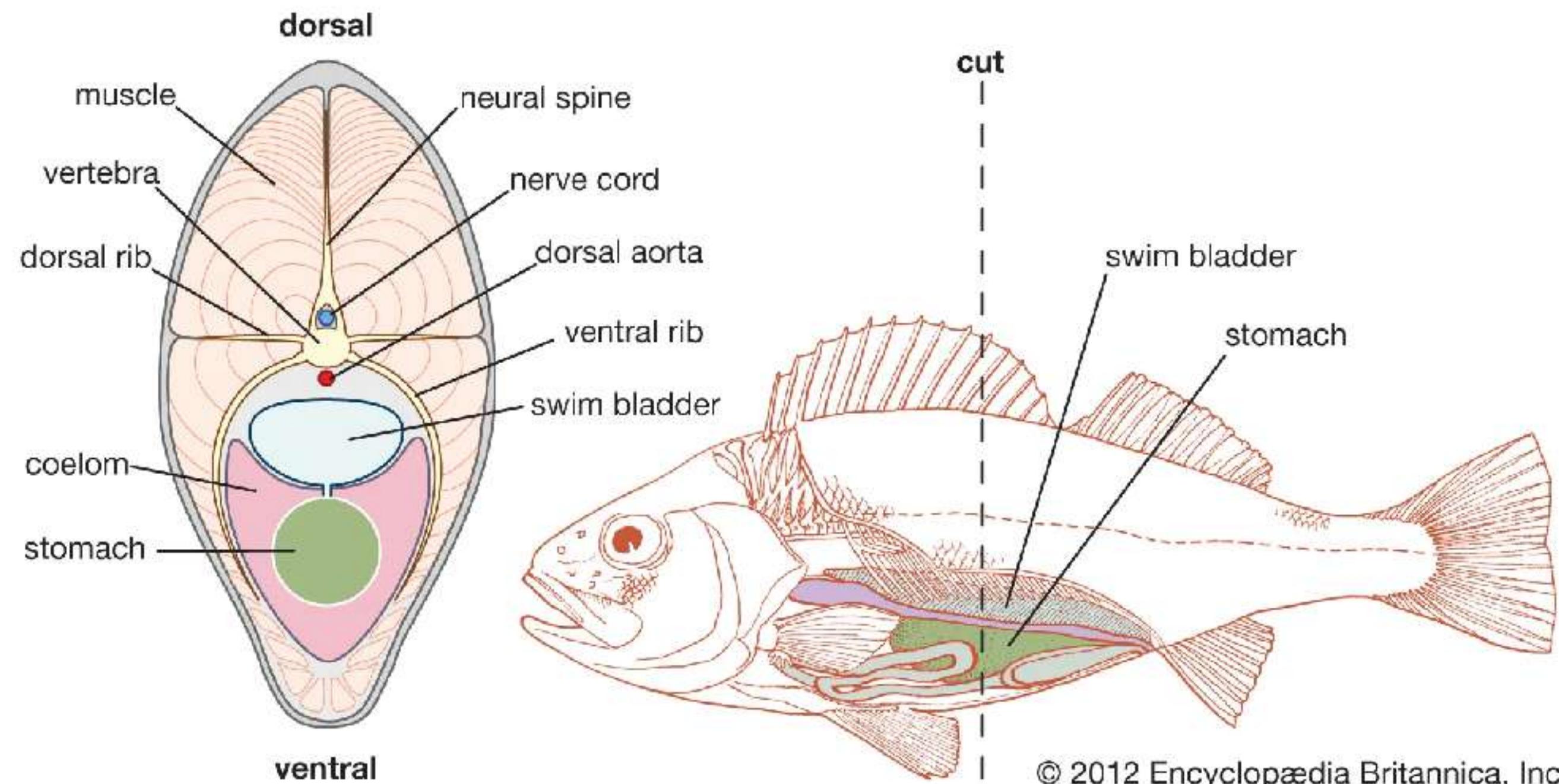
—Dissection—



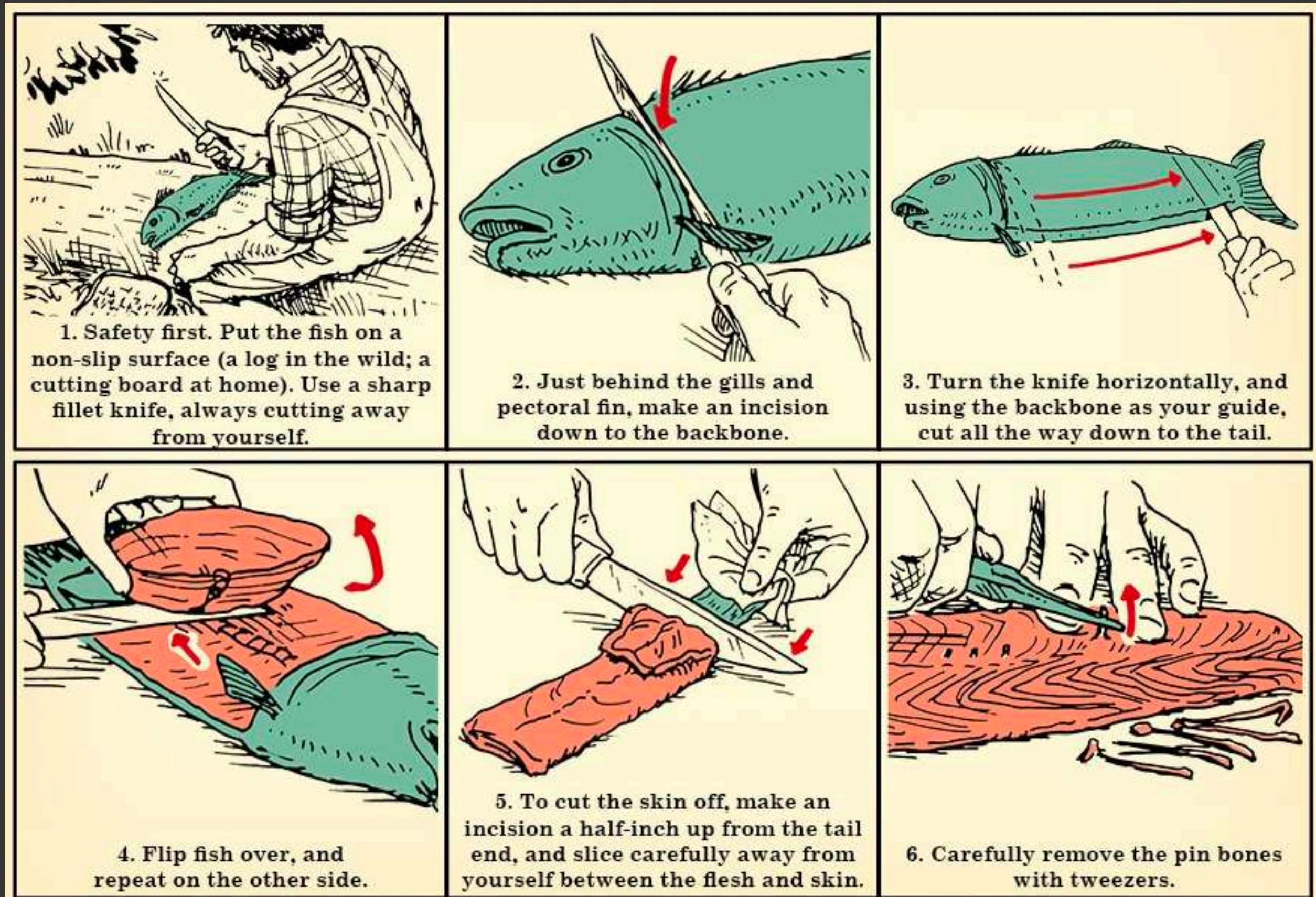
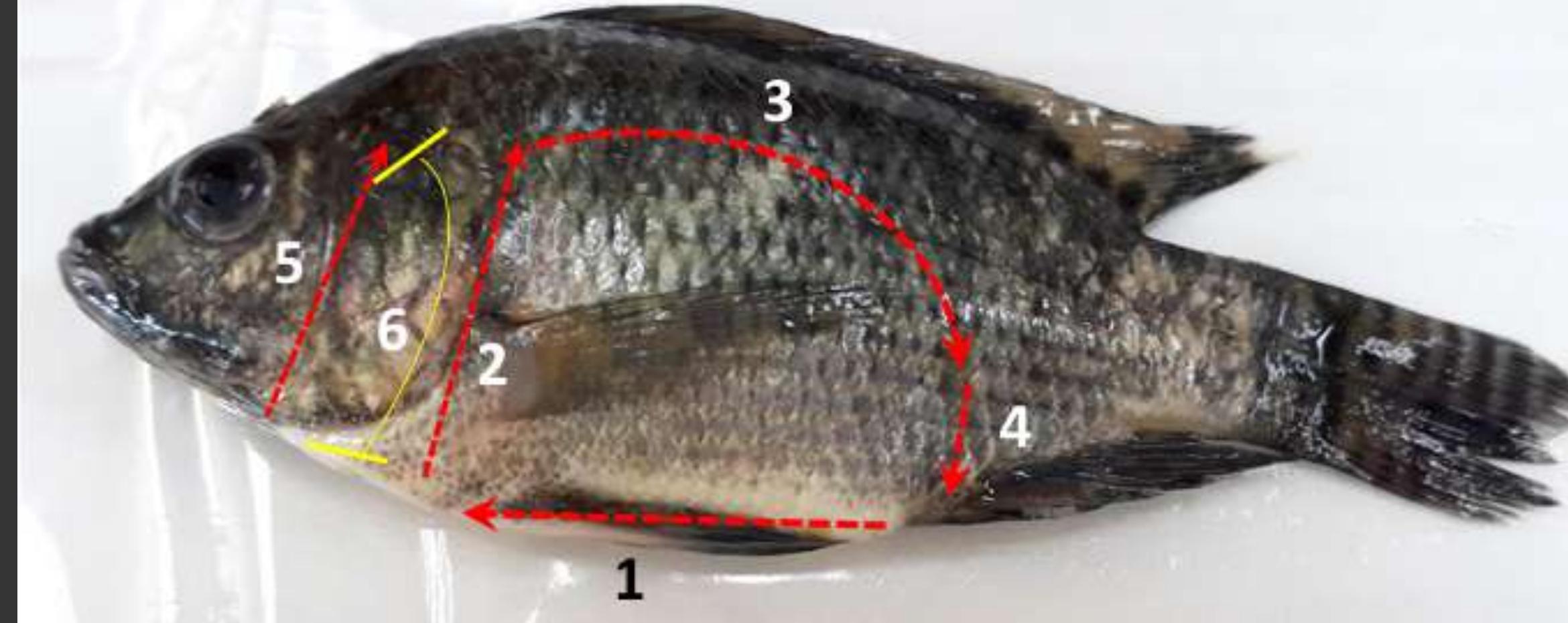
The goal is to get to know your fish....



Teleost fish in cross section



1. **Observe/draw/poke/bend fish**
2. **Remove muscle+skin**
3. **Observe/draw/poke muscle+skin**
4. **Observe/draw/poke/bend what's left of fish**



Food for thought:

**How does the skin surface feel,
rough or smooth?**

**Where does the body flex when you
hold the head or tail?**

**What shape are the fins?
Which movements are allowed or not?**

Where is the center of mass?

**What shape is the body in lateral view?
What is the cross-sectional shape?**

What type of swimmer is it?

How does it compare to others?

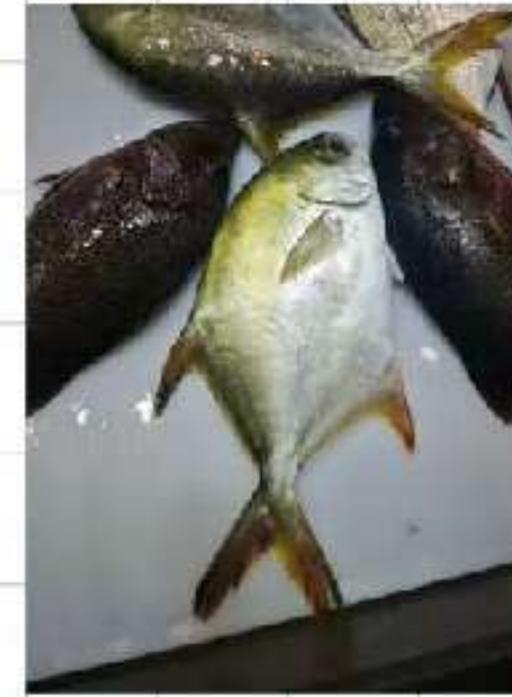
Mackerel x 2



Fels x 2



Pomfret x 2



Ribbon Fish x 1

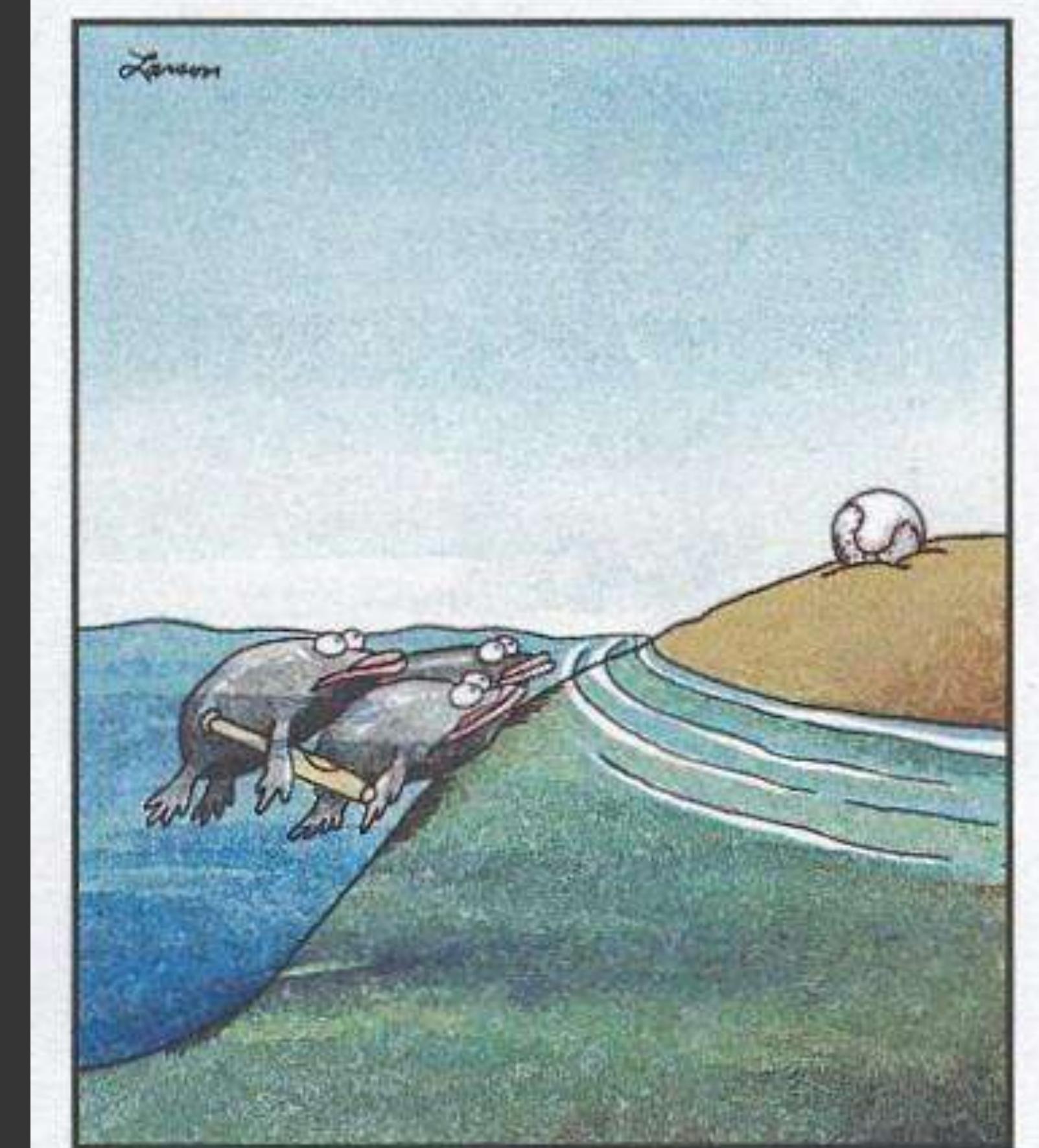


Catfish x 3





have fun!



Great moments in evolution

Thanks for many slides stolen:
M. Laura Habegger
George Lauder
Valentina Di Santo