Montogue

Quiz BI108

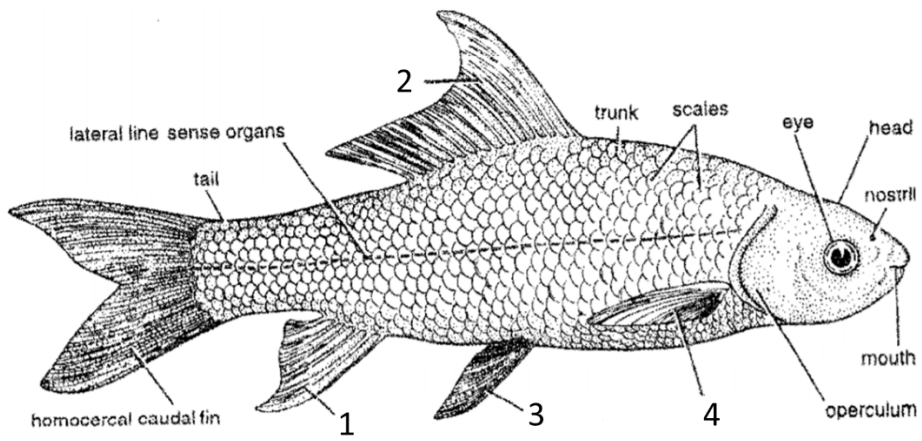
FISH BIOLOGY

Lucas Monteiro Nogueira

PROBLEMS

Problem 1

The following is an illustration of rohu (*Labeo rohita*), a carp species that serves as a model for typical bony fish. Choose the alternative that correctly defines numbers 1 to 4.



A) 1. Anal fin, 2. Pectoral fin, 3. Pelvic fin, 4. Dorsal fin;
B) 1. Pelvic fin, 2. Dorsal fin, 3. Anal fin, 4. Pectoral fin;
C) 1. Anal fin, 2. Dorsal fin, 3. Pelvic fin, 4. Pectoral fin;
D) 1. Pelvic fin, 2. Pectoral fin, 3. Dorsal fin, 4. Anal fin;

Problem 2

Associate the types of scale with the fish in which they occur.

W. Placoid scales	**I.** Sturgeons, gars, bichirs
X. Ganoid scales	**II.** Most teleosts
Y. Cycloid scales	**III.** Sharks and rays
Z. Ctenoid scales	**IV.** Trouts, herrings, carps

A) W.II, X.III, Y.I, Z.IV
B) W.I, X.II, Y.IV, Z.III
C) W.III, X.I, Y.II, Z.IV
D) W.III, X.I, Y.IV, Z.II

Problem 3

Associate the type of swimming motion to the corresponding fish types.

P. Anguilliform	**I.** Tunas and mackerels
Q. Carangiform	**II.** Eels
R. Subcarangiform	**III.** Trouts
S. Ostraciiform	**IV.** Boxfishes and trunkfishes

A) P.II, Q.I, R.IV, S.III
B) P.II, Q.I, R.III, S.IV
C) P.I, Q.IV, R.III, S.II
D) P.I, Q.III, R.II, S.IV

▶ Problem 4

Regarding aspects of fish biology, true or false?

1.( ) The fossil record suggests that the earliest jawless fishes, grouped in the superclass Agnatha, first appeared during the Ordovician.

2.( ) The Chondrichthyes class, which includes sharks and rays, dates back from the Late Ordovician, while the Osteichthyes class, which encompasses bony fish, appeared in the Late Silurian.

3.( ) To maintain osmoregulation, marine fish drink water and excrete hypertonic urine.

4.( ) The elongate teleost kidneys are composed of typically segmented mesonephrons. Glomerular filtration rate (GFR) is higher in freshwater teleosts than in marine teleosts. Since urine filtration is proportional to GFR, we surmise that freshwater teleosts produce more urine than marine teleosts.

5.( ) Most teleosts contain retain high levels of trimethylamine oxide (TMAO) to compensate their high concentrations of urea, which is highly perturbing of enzyme systems activity. The typical odor of rotting fish stems from TMAO.

6.( ) One disadvantage of use of lipids as a means of static lift is that the lift provided varies substantially with depth, hindering fish from migrating vertically as efficiently as species that produce static lift by use of gases.

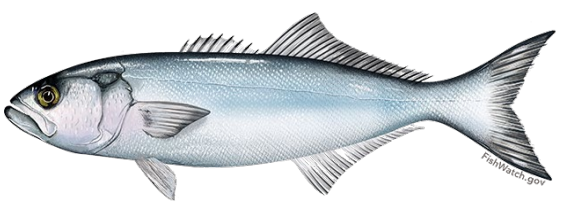
7.( ) Sea squaloid sharks are some of the earliest fish to use lipid as a means of lift adjustment. Buoyancy regulation in these fish is maintained by an unsaturated, aromatic hydrocarbon named squalene.

8.( ) The swimbladder is an efficient means of achieving buoyancy control and static lift. In some ancient fish, the swimbladder served as a lung or respiratory aid instead of merely a means for hydrostatic balance. No extant species presents this function.

9.( ) The swimbladder may be viewed as a gas-containing sac. Embryonically, the bladder originates as an outgrowth of the foregut. In physostomous fishes the connection of the bladder to the gut persists after embryonic development; physostomes include herrings and eels.

10.( ) Mass kills of freshwater teleosts resulting from accidental run-off of farm chemicals have been depicted in saddening photographs, which show that dead teleosts float bottom up. This occurs because the center of volume of the swimbladder is below the dense vertebral skeleton. In hydrostatic terms, the center of gravity lies below the center of buoyancy.

11.( ) An adult bluefish (shown below: *Pomatomus saltatrix*) with mass of 5 kg floats motionless in seawater of 1030 kg/m^3 density. The volume occupied by the fish, deducting the swimbladder volume, is 4720 cm^3. We surmise that, in order to maintain the fish neutrally buoyant, the swimbladder should have a volume greater than 150 cm^3. In your analysis of this statement, assume the fish is close to the surface and the weight of the water column and atmosphere above it can be neglected.



12.( ) The stomach of bony fish can be a straight tube, U-shaped or Y-shaped. Food leaves the esophagus and enters the stomach, distending its walls and activating a cholinergic response that triggers secretion of hydrochloric acid by the gastric mucosa. This lowers the pH of the stomach and provides an optimal environment for pepsin, an important proteolytic enzyme.

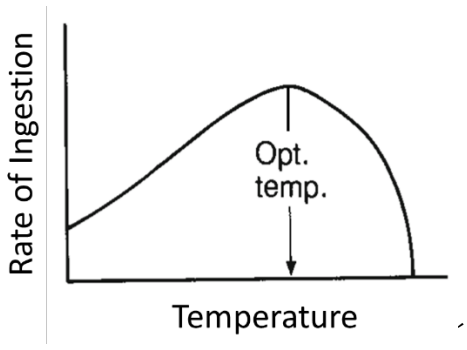
13.( ) Although the stomach may provide fish with a medium for initial protein digestion, many herbivorous fish, including many Cyprinidae and Scaridae, feature no stomach at all. Instead, these fish rely on other solutions to begin the digestion of protein, such as a pharyngeal apparatus that processes these molecules before food enters the intestine. Presence of a stomach, however, is

indispensable for carnivorous fish, as they consume copious amounts of protein. No extant carnivorous fish species with no stomach are known to man.

14.( ) The spiral valve is an unusual anatomical feature that constitutes the digestive system of primitive jawed fishes such as elasmobranchs, coelacanths and bichirs. Its function is to provide an extended surface area for digestion of nutrients, thereby counterbalancing the inherently short intestine encountered in these primitive fish.

15.( ) Many teleosts have blind tubes connected with the anterior end of the intestine. These intestinal structures, commonly known as *pyloric caeca*, vary in number from one to as much as a thousand. Since they originate from that region of the intestine where bile and pancreatic juices are released, the caeca apparently offer a medium for digestion of specific nutrient types. However, the caeca do not just passively receive enzymes from elsewhere, as their walls possess cells of ectodermal origin that release their own proteolytic enzymes, particularly aminopeptidase.

16.( ) The rate of food ingestion by a typical fish is a function of temperature. The following graph correctly outlines the rate of ingestion as a function of temperature; "Opt. temp." denotes optimal temperature.



▶ Problem 5

The gill rakers in a typical bony fish have, as a function:

A) Promote the entry of food into gill chambers.
B) Prevent the entry of food into gill chambers.
C) Promote regurgitation of food into the buccal chamber.
D) Prevent regurgitation of food into the buccal chamber.

▶ Problem 6

The following are traits of chondrichthyes (cartilaginous fish) and osteichthyes (bony fish). Attribute *C* to the characteristics that apply to cartilaginous fish, and *B* to those that better define bony fish.

(C) Cartilaginous fish
(B) Bony fish

6.1.( ) Usually dorsoventrally flattened.
6.2.( ) Homocercal or diphycercal caudal fin.
6.3.( ) Mouth opening ventral on head. Large and crescentic.
6.4.( ) Five pairs of gill-slits covered by an operculum.
6.5.( ) No spiracles.
6.6.( ) Midventral cloacal opening between two pelvic fins.
6.7.( ) Dermal placoid scales.
6.8.( ) Presence of a swimbladder.
6.9.( ) Retina has cones.
6.10.( ) Presence of ampullae of Lorenzini.

▶ Problem 7

The following are traits of fish myotomes. Attribute *R* to the characteristics that apply to red fibers, and *W* to those that better define white fibers.

(R) Red fiber
(W) White fiber

7.1.( ) Small fiber diameter, usually no greater than 150 µm.
7.2.( ) Fibers are poorly vascularized.

7.3.( ) No myoglobin.
7.4.( ) Abundant large mitochondria.
7.5.( ) Low activity of Ca^{2+}-activated myosin ATPase.
7.6.( ) Glycogen store, usually little lipid.
7.7.( ) Long-lasting contractions evoked by polarizing agents.

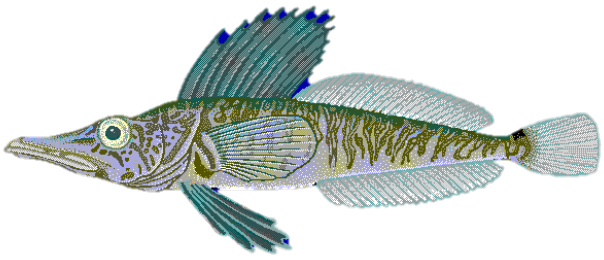
▶ Problem 8

Regarding further aspects of fish biology, true or false?

1.( ) Fish hearts are S-shaped and four-chambered with, from behind forwards, sinus venosus, atrium, ventricle and either a conus or bulbus leading to the ventral aorta. The conus arteriosus of elasmobranchs is contractile, contracting in sequence with the rest of the heart, whereas the bulbus of teleosts functions passively, enlarging radially by blood driven forwards out of the ventricle.

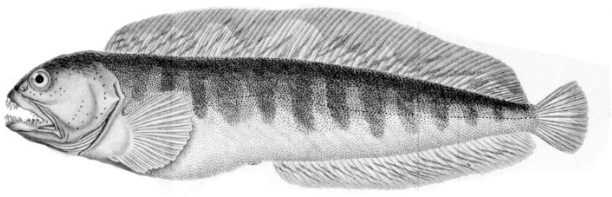
2.( ) A teleost has a circulatory system with five aortic arches instead of six, as in the case of most gnathostomes.

3.( ) The crocodile icefish (Channichthyidae; shown below: *Pagetopsis macropterus*) are a family of teleosts that inhabit the Antarctic Ocean. One of the remarkable characteristics of these fishes is that their respiratory-gas carrying pigment is hemocyanin, as in large crustaceans and some mollusks, instead of the hemoglobin encountered in vertebrates. Hemocyanin is blue when bound to oxygen, and hence explains the distinctive blue color of Antarctic icefish blood.



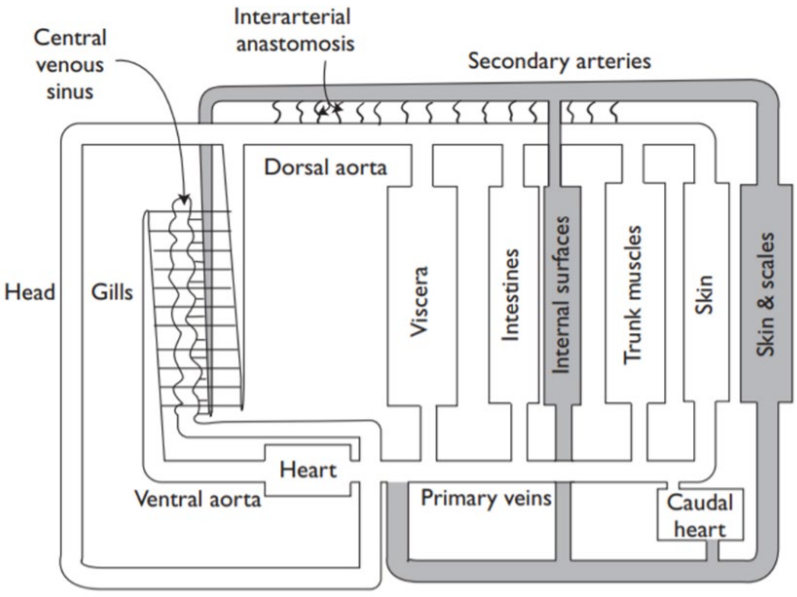
4.( ) The presence of solutes in seawater depresses its freezing point to −1.9°C, while ordinary teleost blood freezes at −0.4°C. Accordingly, cold water fish must employ some mechanism to prevent their blood from freezing. One common solution is production of anti-freeze proteins, small molecules steadily synthesized by the walls of the esophagus. The esophagus is richly innervated and, under exceptionally low temperatures, reacts to a cholinergic stimulus by triggering the production of AFPs and releasing them into the circulation.

5.( ) The red muscle of fish are richly endowed with myoglobin, the oxygen-binding protein found in the muscle of vertebrates. The concentration of myoglobin among teleosts is particularly pronounced in the heart; extreme examples occur in the Northern Atlantic, where species such as the Atlantic wolffish (shown below: *Anarrhicas lupus*) and some types of lumpfish have developed hearts so richly populated with myoglobin that the organ exhibits a vivid purple coloration, instead of the dark red shade encountered in other vertebrates.



6.( ) Unlike mammals, fish have nucleated red blood cells. What's more, in fish the RBCs exhibit a number of roles besides mere transportation of respiratory gases; fish erythrocytes can respond to different pathogen associated molecular patterns (PAMPs), modulate leukocyte activity, release cytokine-like factors, and perform phagocytosis.

7.( ) In addition to the primary circulation, many kinds of fish, including elasmobranchs and euteleosts, possess a secondary network of lymphatic vessels connected to the primary circulation by fine-bore coiled arterio-arterial anastomoses. In the following schematic, the secondary lymphatic circulation is shown in a darkened color.



8.( ) In marine teleosts, ionocytes help maintain ionic balance, secreting sodium and chloride ions against seawater concentration gradients. Conversely, the ionocytes of freshwater teleosts take up ions to maintain osmoregulation. Some freshwater teleosts also use these cells to absorb calcium ions.

9.( ) Calcium in fish participates in many essential functions, including muscle contraction and maintenance of the potential difference across cell membranes. Calcium levels are regulated by the ultimobranchial gland, which secretes calcitonin, thereby increasing blood calcium levels.

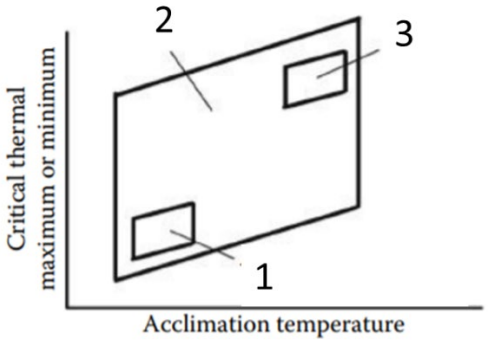
10.( ) In fishes, like in other vertebrates, the thyroid is composed of a group of follicles. The follicular cells synthesize thyroglobulin, a protein that serves as a substrate for the synthesis of the thyroid hormones thyroxine (T4) and triiodothyronine (T3). Fish metabolic activity is actively regulated by T4, which is carried in the bloodstream attached to binding proteins, but not by T3, which is not produced at all in most teleosts and elasmobranchs.

11.( ) In addition to normal epithelial cells, fish epidermis contains various types of unicellular glands. Most studied are the goblet or mucous cells, which secrete mucus as a means of physical and biochemical defense. The most abundant components of the mucus layer are the so-called *mucins*, high molecular weight, filamentous, highly glycosylated glycoproteins.

12.( ) Cycloid scales are smooth-edged scales predominantly found in lower order teleosts such as salmons and carps. These scales contain concentric rings that are distributed differently in males and females; accordingly, the morphology of the scales can be used to determine the sex of the fish.

13.( ) In general, there are two types of fish bone, cellular and acellular. Cellular bone contains osteocytes and is found in lower orders, such as the salmoniformes, while fish of higher orders, such as the perciformes, have acellular bones, with no osteocytes. Further, it is noteworthy that, unlike mammals, fish have no hematopoietic elements within their bones.

14.( ) The following graph shows the thermal tolerance polygons for three hypothetical types of fish. We can surmise that polygon 3 applies to an Antarctic stenotherm species.

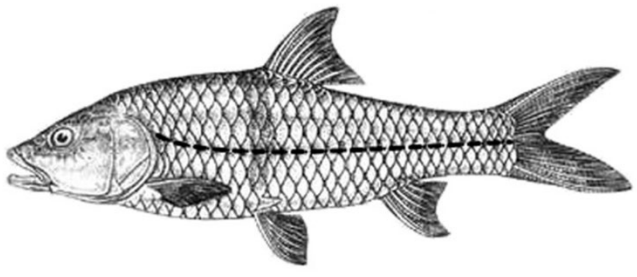


15.( ) Fish migration can be *catadromous*, when a species leaves fresh water to spawn in the sea, as in the case of a number of salmon species, or *anadromous*, when a species leaves the sea to spawn in fresh water, as in the case of eels.

16.( ) Any fish species living in an area with circa annual rhythms in rainfall could experience a loss of water habitat as a result of long periods without rain. Dry environments impose a number of adverse conditions on fish, including reductions in food availability, increase predation risk, and accumulation of toxic metabolic end products. To avoid these conditions, the fish may migrate to an environment not affected by drought or, alternatively, adapt itself to drought. In the latter case, the animal may undergo a radical set of behavioral and physiological modifications, including, most importantly, a reduction in metabolic rate so that stored substrates can last as long as possible. This set of modifications as an answer to drought is aptly called *hibernation*.

17.( ) The internal ears of teleosts possess three semicircular canals involved in determining the angular movements of the fish.

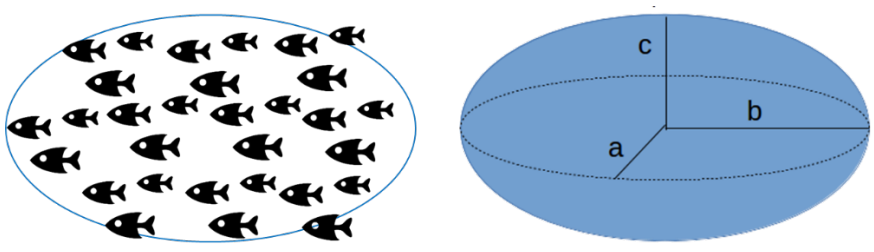
18.( ) Fish are endowed with various adaptations used to receive and extract information from mechanical signals. For one, most teleosts have superficial neural cells named neuromasts distributed as lines that traverse the body of the fish, as illustrated below. Together, this system of neuromasts is known as the *ampulla of Lorenzini*.



19.( ) Bioluminescence, the emission of ecologically functional light by an organism, is a feature of many species of fish. Teleosts usually achieve bioluminescence by means of symbiotic relationships with amoeboid protozoans such as *P. phosphoreum* and *V. fischeri*.

20.( ) A common carp swims at 6 km/h in water at 20°C, which has a kinematic viscosity of 10^{-6} m^2/s. The carp has a longitudinal length of 80 cm. We can surmise that the carp is swimming against a turbulent flow of water.

21.( ) A school of herrings swimming in the sea takes the shape of an ellipsoid. The semiaxes of the ellipsoid have dimensions a = 3 m, b = 5 m, and c = 4 m (refer to the illustration below). Each herring occupies a volume of 800 cm^3, and water constitutes 45% of the volume of the formation. Accordingly, we surmise that the school consists of more than 600 herrings per cubic meter.



22.( ) Vitellogenin is a protein involved in the production of yolk nutrients for eggs in numerous vertebrates, including fish. The protein is produced by hepatocytes in the liver after being stimulated by estradiol from granulosa cells of ovarian follicles.

23.( ) One of the many characteristics that prevent teleosts and sharks from conquering terrestrial environments is their dependence on external fertilization, as breeding is only possible with an aqueous medium for a male gamete to reach the female oviduct.

24.( ) Fishes are more sexually pliant than other vertebrates, as some species may exhibit both male and female gonads either simultaneously or alternatively at different points of their life cycles. Hermaphroditism is not uncommon, and self-fertilization has been observed in some species of the Brazilian Amazon and Western Australia.

▶ Problem 9

Most teleosts hatch as small larvae depending on cutaneous respiration across the body surface. As the larvae develop and increase in size, two changes take place that affect respiration profoundly, making use of gills indispensable. Which of the following alternatives indicates these two changes?

A) The body surface-to-volume ratio becomes larger, and the pathways for the diffusion of gases and metabolites become longer.
B) The body surface-to-volume ratio becomes larger, and the pathways for the diffusion of gases and metabolites become shorter.
C) The body surface-to-volume ratio becomes smaller; and the pathways for the diffusion of gases and metabolites become longer.
D) The body surface-to-volume ratio becomes smaller, and the pathways for the diffusion of gases and metabolites become shorter.

▶ Problem 10

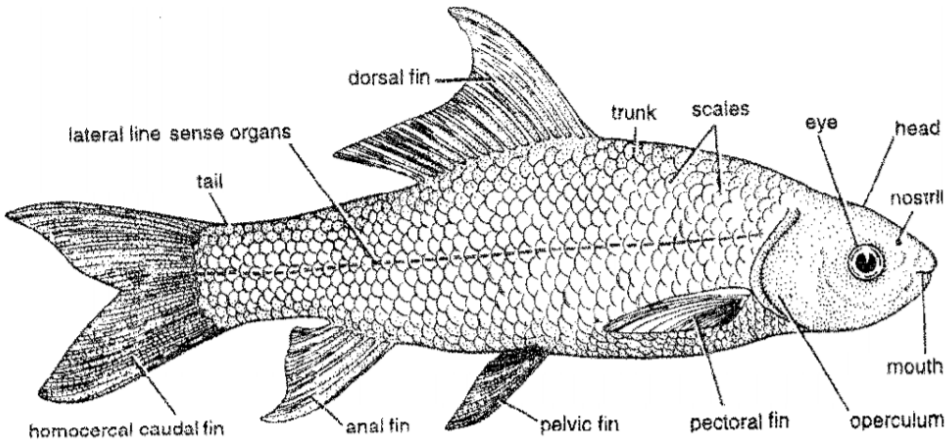
Regarding paternal care in fish, choose the correct alternative.

A) Paternal care is most often provided by the male, and is more common in freshwater than in seawater species.
B) Paternal care is most often provided by the male, and is more common in seawater than in freshwater species.
C) Paternal care is most often provided by the female, and is more common in freshwater than in seawater species.
D) Paternal care is most often provided by the female, and is more common in seawater than in freshwater species.

SOLUTIONS

P.1 ➡ *Solution*

Alternative C correctly defines the numbered fin types. The complete illustration is shown below.



♦ The correct answer is **C**.

P.2 ➡ *Solution*

Placoid scales are characteristic of elasmobranchs; each placoid scale consists of a backwardly directed *spine* arising from a rounded or rhomboidal *basal plate* embedded in dermis. Ganoid scales are inherent to sturgeons, paddlefishes, gars, and bichirs; they are thick, usually rhomboid or diamond-shaped plates closely fitted side by side in a tile-like fashion, conferring the fish with a tough armor. Cycloid scales are found among trouts, herrings, and carps; they are thin flexible translucent plates, rather circular in outline, thicker in the center and marked with several concentric lines of growth. Lastly, ctenoid scales occur in most extant teleosts; they are similar to cycloid scales in form, structure and arrangement, but more firmly attached and, in their exposed free, non-overlapped hind parts, bear numerous small comb-like teeth or spines (from Greek *ctenos*, "comb"). It should be realized that classification of fish according to which types of scale they carry is not always a valid concept, as some species may contain more than one type of scale (e.g., some species of flounder, which possess ctenoid scales dorsally and cycloid scales ventrally) or even no scales at all (e.g., electric rays).

♦ The correct answer is **D**.

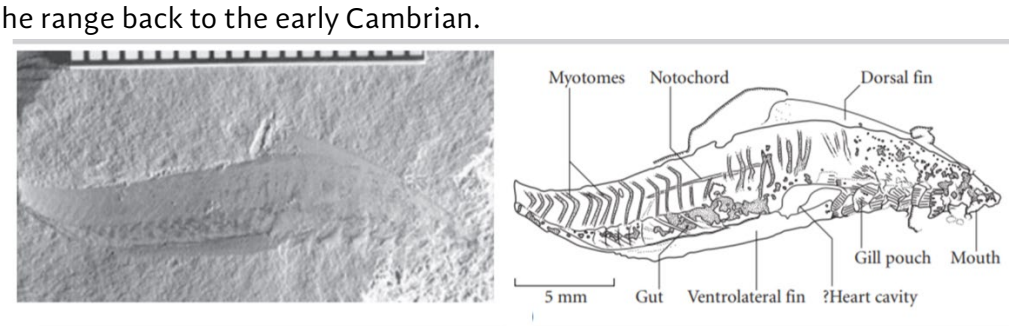
P.3 ➡ *Solution*

In an anguilliform motion, the whole body is flexed into lateral waves for propulsion; this is characteristic of 'eel-like' species such as eels, marine gunnels, and lampreys. In carangiform motion, the fish undulates its body into a shallow wave up to one-half wavelength within the body length, with the amplitude increasing from head to tail; this is characteristic of fast swimmers such as tunas, mackerels, and jacks. In subcarangiform motion, the fish undulates its body into less than one full wavelength, yet more than one-half body length at speeds greater than 1 BL/s; trouts employ this type of motion. Lastly, in ostraciiform motion the fish swims mainly by flexing the caudal peduncle; this kind of motion is inherent to fish that need armor for protection, including most species of the Ostraciidae family, e.g., boxfishes, trunkfishes, and cowfishes.

♦ The correct answer is **B**.

P.4 ➡ *Solution*

1. False. Until recently, paleontological evidence suggested that the Agnatha appeared in the Ordovician; however, discoveries such as the *Myllokunmingia* at the Chengjiang fossil site in China (shown below) pushed the range back to the early Cambrian.



2. True. Benton and Harper (2009) offer an excellent account of the origin of early vertebrates, including fish.

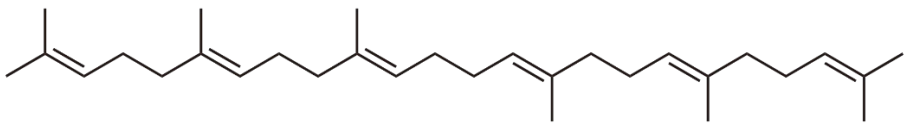
3. True. Seawater fish counterbalance continuous loss of water to the surrounding environment by drinking water, while salt uptake is equilibrated by release of hypertonic urine. Drinking rates vary among vary among marine teleosts; in *Serranus*, for example, 12% of the body weight is drunk each day. About 75% of this water drunk is absorbed in the gut, and since urine flow is small, this can maintain water balance. Freshwater fish, in contrast, do not drink water and excrete hypotonic urine.

4. True. The GFR of freshwater teleosts is indeed greater than that of marine teleosts, and freshwater fish tend to produce as much as ten times more urine than their oceangoing counterparts. The urine is much more diluted than the plasma and as much as 99.9% of the sodium and chloride ions passing the glomerular filtrate are resorbed. Most of the resorption of monovalent ions occurs in the distal tubules, which are impermeable to water.

5. False. There is not a single correct point in this statement. For starters, high concentrations of urea, albeit common in cartilaginous fish, are inherently rare in most teleosts, who mainly secrete unprocessed ammonia instead of converting it to urea beforehand. A high concentration of urea coupled with a compensatory presence of TMAO, often in a 2:1 ratio, is generally found only in elasmobranchs. Moreover, the strong odor of rotting fish actually comes from trimethylamine (TMA), which is synthesized in the bacterial degradation of choline and the reduction of TMAO.

6. False. On the contrary, one of the main advantages of lipid-based static lift is that the lift provided varies very little with depth. Thus, if a fish with lipid-based hydrostatic balance is neutrally buoyant at the surface of the sea, it will also remain close to neutral buoyancy at considerable depths. This allows the fish to perform fast vertical migrations.

7. False. While it is true that squalene is the lipid used by squaloid sharks, the statement errs by defining the molecule in question as an *aromatic* hydrocarbon; squalene is actually an unsaturated, *aliphatic* hydrocarbon. Its structure is shown below.



8. False. There exist several species of actinopterygian and sarcopterygian fish with swimbladders adapted for air breathing. However, a true lung with a separate pulmonary vein that empties directly into the atrium of the heart is present only among the Dipnoi (lungfish) subclass.

9. False. The other swimbladder structure is that of *physoclistous* fishes, in which the embryonic connection between the bladder and the digestive tract is lost.

10. True. Dead teleosts float bottom up because the center of gravity lies below the center of buoyancy. One may suppose that this is a design fault, because for the fish to remain upright in the water, constant trim movements have to be made. However, the arrangement in question confers maneuverability.

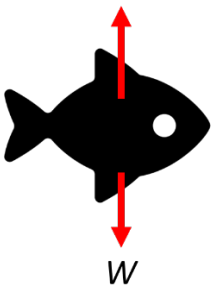
11. False. The weight of the fish is $W = mg = 5 \times 9.81 = 49.1$ N. The buoyancy force is given by Archimedes' law, namely $B = \rho(V_{fish} + V_{swimbladder})g$, where $V_{swimbladder}$ is the volume of the swimbladder. Equating W and B brings to

$$W = B \rightarrow 49.1 = 1030 \times \left(4720 \times 10^{-6} + V_{\text{swimbladder}}\right) \times 9.81$$

$$\therefore V_{\text{swimbladder}} = 1.39 \times 10^{-4} \text{ m}^3$$

$$\therefore \boxed{V_{\text{swimbladder}} = 139 \text{ cm}^3}$$

This rudimentary result corresponds to about 3% of the bluefish body volume, underestimating the 5% figure expected for most marine fish.



12. True. Pepsin functions best under highly acidic conditions, with an optimum pH ranging from 2.0 to 4.0. Having a stomach that maintains an acid internal medium by secreting hydrochloric acid is a physiological trait that fish share with most tetrapods.

13. False. Absence of a stomach is generally and adaptation encountered in herbivorous fish, including some members of the cyprinids (e.g., carps) and scarids (e.g., parrotfish), but there exist species of stomach-less carnivorous fish, including, for instance, the needlefish (family Belonidae).

14. True. The spiral valve indeed augments the surface area for nutrient absorption in sharks, coelacanths, bichirs, dipnoans, bowfins, gars, sturgeons, and the primitive teleosts, osteoglossids. How this structure compares with the digestive tract of other fish in terms of efficiency has been poorly studied.

15. False. The caeca walls do possess goblet cells, which secrete mucus, but light and electron microscopic studies indicate that they lack cells capable of secreting digestive enzymes.

16. True. As shown on the graph, a fish's rate of food ingestion grows in direct proportion to temperature until it reaches a maximum at the optimal temperature; then, it falls precipitously until the maximum temperature tolerated by the species is attained.

P.5 ➡ *Solution*

A gill raker is a set of bony or cartilaginous projections used by filter-feeders to trap food, all the while preventing it from entering the gill chambers. The *Fishionary* website observes that gill rakers vary substantially in length and

number; a plankton feeder, for example, has very tightly-packed, comb-like gill rakers to efficiently filter food from the water column, while a piscivore, on the other hand, has shorter, more widely-spaced gill rakers.

- The correct answer is **B**.

P.6 ➡ *Solution*

The answers are listed below.

6.1	C
6.2	B
6.3	C
6.4	B
6.5	B
6.6	C
6.7	C
6.8	B
6.9	B
6.10	C

The complete comparison of chondrichthyes and osteichthyes, adapted from Kotpal (2009), is provided in continuation.

Chondrichthyes	**Osteichthyes**
Mostly marine	Both marine and freshwater
Cartilaginous endoskeleton	Bony endoskeleton
Separate dermal placoid scales	Overlapping dermal cosmoid, ganoid, cycloid, or ctenoid scales
Usually dorsoventrally flattened	Usually bilaterally flattened
Heterocercal caudal fin	Homocercal or diphycercal caudal fin
Usually posterior pelvic fin; in males, the pelvic fins are adapted to form claspers for copulation	Usually anterior, sometimes posterior pelvic fin; claspers are usually absent, or, when present, are not formed by pelvic fins
Mouth opening is ventral on head; large and crescentic	Mouth opening is terminal on head; variable in shape and size
Five pairs of naked gill slits; no operculum	Five pairs of naked gill slits covered by a lateral flap of skin, the operculum, so that a single gill opening occurs on each side
First gill slits become spiracles, opening just behind the eyes	No spiracles
A cloaca occurs between the pelvic fins and serves as an opening for alimentary, urinary and reproductive products	Different openings for alimentary and reproductive products
Typically J-shaped stomach	Stomach with variable shape, sometimes absent
Retina lacks cones	Retina has cones
No swimbladder	Presence of a swimbladder
Presence of a rectal gland	No rectal gland
Liver usually has 2 lobes	Liver usually has 3 lobes
Presence of conus arteriosus	No conus arteriosus
Usually five pairs of afferent branchial vessels from ventral aorta to gills	Four pairs of afferent branchial vessels
Nine pairs of efferent branchial vessels	Four pairs of efferent branchial vessels
Presence of ampullae of Lorenzini	No ampullae of Lorenzini
Internal fertilization	Usually external fertilization
Few eggs, large with much yolk	Numerous eggs, small with less yolk

P.7 ➡ *Solution*

The answers are listed below.

7.1	R
7.2	W
7.3	W
7.4	R
7.5	R
7.6	W
7.7	R

The full list of characteristics, adapted from Hart and Reynolds (2002), is shown below.

Red fibers	White fibers
Diameter about 60 – 150 μm	Fibres more than 300 μm
Richly vascularized	Poorly vascularized
Abundant myoglobin, color red	No myoglobin, color white
Abundant, large mitochondria	Few, smaller mitochondria
Oxidative enzyme systems	Enzymes of anaerobic glycolysis
Low activity of Ca^{2+}-activated myosin ATPase	Rich in low molecular weight Ca^{2+}-binding protein
Lipid and glycogen stores	Glycogen store, usually little lipid
Sarcotubular system has lower volume than in fast fibers	Relatively larger sarcotubular systems
Distributed cholinergic innervation	Focal or distributed cholinergic innervation
No propagated muscle action potentials	Propagated action potentials; may not always occur in multiply innervated fibers
Long-lasting contractions evoked by polarizing agents	Brief contractions evoked by depolarizing agents

P.8 ➡ *Solution*

1. True. The conus arteriosus indeed has contractile capacity; it is found not only in elasmobranchs, but also among *Lepisosteus* gars and *Polypterus* bichirs. The bulbus arteriosus of teleosts, on the other hand, exhibits a passive mechanical behavior, bulging radially as it receives blood from the ventricle.

2. False. A typical teleost actually possesses *four* aortic arches. Most elasmobranchs, in turn, have five pairs of aortic arches, but there are distinctions: sharks in the *Hexanchus* genus have six, while those in the *Heptranchias* genus have seven.

3. False. There are no reports of fish that employ hemocyanin as a blood pigment. In actuality, the real remarkable physiological trait of Antarctic icefish is their lack of hemoglobin as adults, a feature that has not been observed in any other vertebrate family. Red blood cells are rare and often absent; oxygen is dissolved in the plasma and transported throughout the body without the hemoglobin protein. To overcome the low O_2 capacity of their blood, icefishes have relatively large gills, well-vascularized skin for cutaneous respiration, large hearts with large cardiac output, and large-diameter blood vessels.

4. False. To prevent tissues from freezing, marine cold water teleosts produce small anti-freeze proteins in the scales, skin, fins, gills, and the liver. There are five kinds of anti-freeze molecules, four proteins and one glycoprotein; the proteins are produced in the liver and the skin, while the glycoproteins come from the exocrine pancreas and enter the gut via the pancreatic gut, where they prevent the gut contents from freezing. The esophagus has no role in AFP biosynthesis.

5. False. Fish hearts are usually red owing to the myoglobin content of the auricle and (particularly) the ventricle, but, astonishingly, some sluggish benthic fishes of the North Atlantic, including the abovementioned wolffish and lumpfish, have pale hearts lacking myoglobin.

6. True. The functions mentioned in the statement indeed apply to fish erythrocytes.

7. False. The secondary circulation in indeed well-defined in the statement and in fact corresponds to the shaded part of the illustration, but one fatal mistake of the statement, which occurs even in some relatively recent ichthyology texts, is to consider this system as *lymphatic* in nature. This component of the circulation was discovered in 1929, but it was not until the 1980s that scanning microscopy revealed that the secondary circulation was not composed of lymphatics, but actual blood vessels. After receiving blood from the primary circulation via small arterioles whose connections are guarded by fingers from endothelial cells, the vessels of the secondary circulation form their own capillary beds in the fins, gills, mouth, skin, and peritoneum.

8. True. It has been reported that the ionocytes of *Tilapia* species may take up Ca^{2+} from solutions as dilute as 0.2 M. Water balance in freshwater bony fish can be maintained by the excretion of copious urine, but, to maintain salt balance, the fish must have a high affinity salt-uptake mechanism at the gills, promoting a vigorous assimilation of cations such as Ca^{2+}.

9. False. Calcitonin actually *lowers* blood calcium levels. Calcium levels in fish are also adjusted by the corpuscles of Stannius, small spherical bodies often lying on or within the kidneys, which produce stanniocalcin, a hormone that also lowers calcium levels by inhibiting gill and intestinal calcium transport.

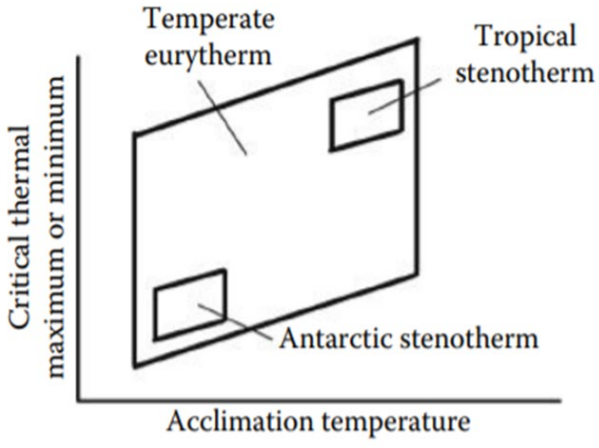
10. False. Fish follicular cells sequester iodide from the circulation and, in conjunction with thyroglobulin, employs it in the production of T4 and, yes, T3. Although T4 is found at much higher circulating concentrations than T3, T3 is considered the biologically active form, with T4 being deiodinated at the target tissues to T3. Although the thyroid hormones do not act upon the metabolic activity of fish as they do among endothermics, they play important roles in growth, development, osmoregulation, migratory behavior, and reproduction.

11. True. Mucins are long, thread-like polymers which are densely O-glycosylated. They are strongly adhesive, play a major role in the defense of the mucosa and impart viscoelastic and rheological properties to mucosal layers. Recent studies have shown that mucous goblet cells contain a considerable amount of glycoconjugates in all locations of the skin, while other unicellular gland types, the club cells, lack these glycoconjugates.

12. False. Cycloid scales say nothing about a fish's sex. It is true, however, that the rings grow and multiply as the fish develops, and hence can be counted to give an estimate of the fish's age.

13. True. Salmoniformes do possess cellular bones, but the concentration of osteocytes is generally much lower than in mammals; higher-order fish generally have acellular bones. Also true is the fact that fish do not possess hematopoietic elements.

14. False. The thermal tolerance polygons are obtained by plotting the temperatures at which fish begins to demonstrate a specific behavior (which are termed the "critical temperature maximum" or minimum) during an acute thermal ramp, for fish acclimated at a variety of temperatures. Typical end points include the onset of opercular spasms or loss of the ability to maintain equilibrium. The TTP is bounded at high and low temperatures by the maximum and minimum temperatures that can be tolerated for long periods, and the area enclosed by the polygon can be seen as a measure of the eurythermality of a species. For an Antarctic fish, the polygon should be displaced to the inferior left, while, for a stenothermal fish, the polygon should be small. These requirements are fulfilled by polygon 1. Polygons 2 and 3, in turn, could refer to a temperate eurytherm and a tropical stenotherm, respectively.



15. False. The statement correctly defines the two migration behaviors, but errs in the fish offered as examples: most salmon are anadromous, while eels are generally catadromous. There are more anadromous species than catadromous species.

16. False. This colossal statement begins smoothly, firstly by defining the adverse conditions that may be imposed on fish subjected to dry conditions and then by noting that the animal might counteract it by promoting a series of physiological changes. The paragraph ultimately errs, however, by attributing the term *hibernation* to this set of changes. A biological response to drought is more aptly named *aestivation*. Only a few species of fish are known to aestivate, and examples include some lungfishes, swamp eels, and salamander fishes.

17. True. The ear of a fish has three semicircular canals. These structures, along with the otoliths (calcareous accretions found within paired otolithic organs, namely the sacule, lagena, and utricle), constitute the inner ear of teleosts. Semicircular canals are said to detect angular acceleration, while otolithic organs are believed to be responsive to sound and vestibular movement of the head.

18. False. The neuromast network constitutes the so-called lateral line. The ampullae of Lorenzini are an altogether different means of physical perception, a type of electroreceptor found in many species of sharks and, in various modified forms, also in some freshwater teleosts, such as catfishes and knifefishes.

19. False. The two organisms mentioned in the statement, *Photobacterium phosphoreum* and *Vibrio fischeri*, are actually species of bacteria. *P. phosphoreum*, which has recently been relocated to the *Vibrio* genus, is the brightest light-emitter bacterium and can be found in light organs of deep sea teleosts; *P. phosphoreum* is psychrotolerant and can safely withstand the low temperatures faced by these fish. Likewise, *Vibrio fischeri* is a symbiont of bioluminescent fish and squids.

20. True. A velocity of 6 km/h equates to 1.67 m/s. The corresponding Reynolds number is then

$$\mathrm{Re} = \frac{VL}{\nu} = \frac{1.67 \times 0.8}{10^{-6}} = 1.34 \times 10^{6}$$

Most sources quote *Re* = 500,000 as a typical threshold for turbulent external flow, although some prefer 1,000,000 as an upper limit. The result above is greater than both reference values, and hence we surmise that the carp is swimming against a turbulent flow.

21. True. We begin by estimating the volume of the ellipsoid,

$$V = \frac{4}{3}\pi abc = \frac{4}{3}\pi \times 3 \times 5 \times 4 = 251 \text{ m}^3$$

However, only 55% of this volume, or $V_F = 0.55 \times 251 = 138$ m^3, is actually occupied by fish. Since each herring occupies 800 cm^3 = 800×10^{-6} m^3, the total number of herrings in the school follows as

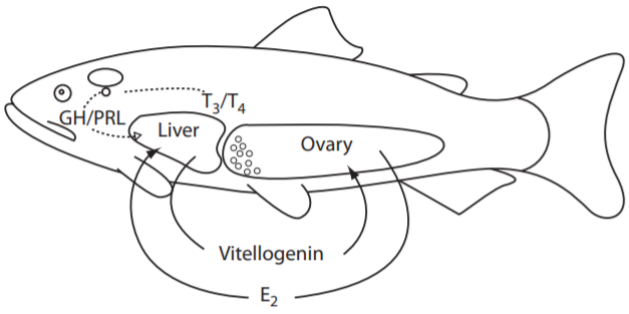
$$n = \frac{138 \text{ m}^3}{800 \times 10^{-6} \dfrac{\text{m}^3}{\text{herring}}} = 172{,}500 \text{ herrings}$$

Lastly, the density of herrings is calculated to be

$$\rho = \frac{172{,}500}{251} = 687 \text{ herrings/m}^3$$

In words, one cubic meter of school accommodates nearly seven hundred herrings, and the number of herrings in the school exceeds 170 thousand. This silly mental exercise illustrates how schools of fish can involve extremely high numbers of individuals. Agglomeration comes with a number of benefits: diversion of predators, better orientation, synchronized hunting. One disadvantage is the buildup of excretion products.

22. True. Indeed, production of vitellogenin is carried out by hepatocytes and can be enhanced by 17β-estradiol (E2) from granulosa cells of the ovarian follicles. In amphibians, there is evidence that growth hormone (GH) and prolactin (PRL) from the pituitary gland and thyroid hormones enhance the effect of estradiol; the same may hold true for fish.



23. False. Most bony fish copulate by external fertilization, but many elasmobranchs, such as the dogshark, in fact reproduce by internal fertilization. A typical shark is endowed with claspers, reproductive organs developed from the inner side of the pelvic fins; during copulation, one of the claspers is inserted into the oviduct orifice of the female. The sperm proceed from the cloaca of the male along the groove on the dorsal surface of the clasper into the female.

24. False. It is true that fishes are more sexually plastic than other vertebrates and hermaphroditism can be observed is some species, but self-fertilization does not occur in any known species of fish. Self-fertilization hampers genetic variability and would not favor fish in evolutionary terms.

P.9 ➡ *Solution*

Elasmobrachs, and teleosts with large eggs, such as salmon, hatch with functional gills, a well-developed circulatory system, and blood cells containing hemoglobin. Most teleosts, however, hatch as much smaller larvae depending on cutaneous respiration across the body surface. Since many of these small, transparent larvae live a pelagic existence, where oxygen is plentiful, cutaneous respiration suffices, so hemoglobin is not needed for respiratory activity and would even be a setback, luring blood-scenting predators. As the larvae grow, however, two important modifications take place, namely (1) the surface-to-volume ratio becomes smaller, and (2) the pathways for transport of gases and metabolites become longer. A size is reached in which the use of gills, which endow the fish with a much larger area for gas exchange, becomes essential.

♦ The correct answer is **C**.

P.10 ➡ *Solution*

About 30% of the 500 known fish families show some form of parental care. Male care (50%) is more common than female care (30%), while biparental care occurs in the remaining 20%. These numbers are not absolute, however, as a population of the same species may display male-only, female-only, and biparental care. Further, many more freshwater fishes provide care (57% of freshwater fish families) compared to marine species (only 16%).

♦ The correct answer is **A**.

ANSWER SUMMARY

Problem 1	C
Problem 2	D
Problem 3	B
Problem 4	T/F
Problem 5	B
Problem 6	Associative pb.
Problem 7	Associative pb.
Problem 8	T/F
Problem 9	C
Problem 10	A

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