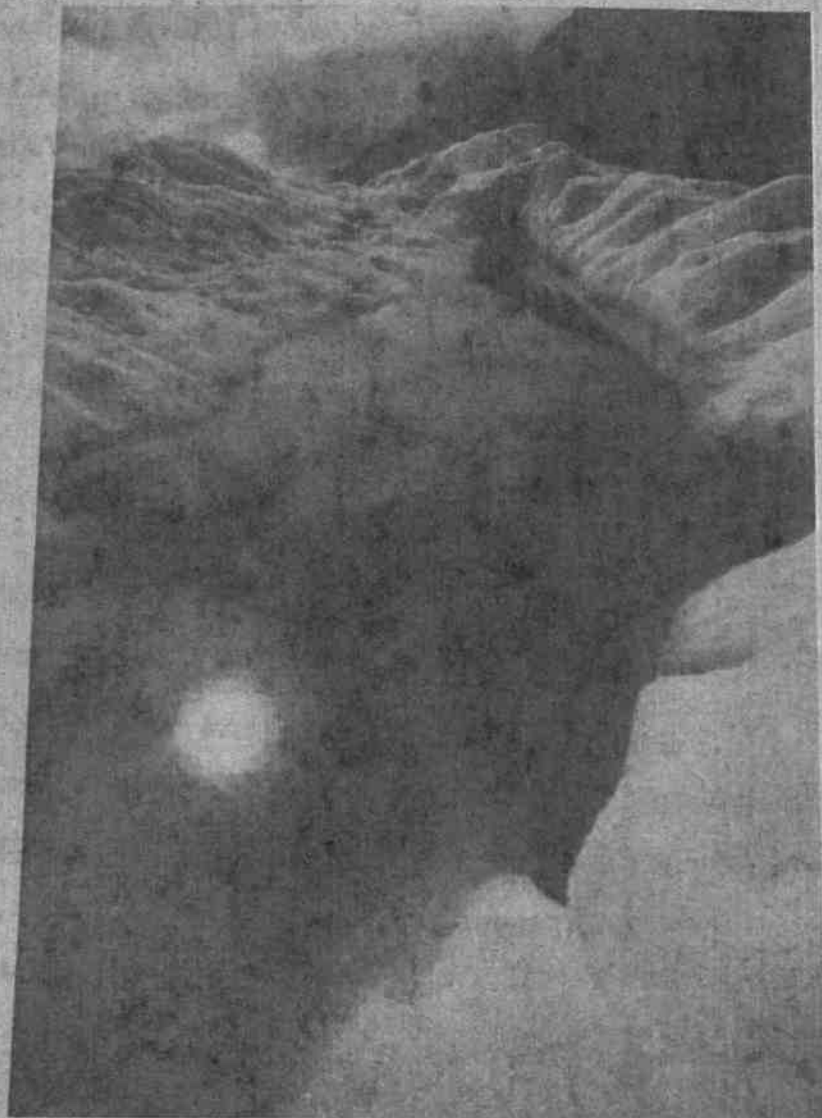
Brinkman

Marine Science
Weeks 3 & 4



Marine Science

LEARNING PACKET

Mrs. Brinkman | 4th Quarter Weeks 3 & 4 | April 13- 24, 2020

Keep up the great work and let's stay Connected!

By now you should be:

- Getting LIST SERV updates.
- Getting Remind updates from me.
- Finding the assignments digitally in FOCUS/Parent Portal
- Edit/Uploading the assignments to FOCUS (& graded within 24 hours!)
- In MS TEAMS and said Hello to me.

This week

- Stay Socially Connected
- There's lots of reading. IE don't automatically print all the pages out, just the ones you need.
- Feel free to reach me on email, on Remind or in TEAMS.
- I have a Google Voice number in Madison: 850-601-5040, if you can't reach me otherwise.
- Join MS TEAMS for a 30-minute live chat session on Tuesday or Thursday. This is NOT required.
- Finally, View and upload assignments in FOCUS or in MS Teams.

WEEK 3 SHARK WEEK

Day 1: Topic: Introduction to Fish Diversity

Assignment: Read pages 226-229 ending at cartilaginous fishes

Day 2: Topic: Cartilaginous Fishes (SHARKS!!!)

Assignment: Read pages 229 –235

Assignment: Complete questions on Agnatha and Chondrichthyes

Day 3: Topic: ELASMOBRANCH FISH DIVERSITY: Form & Function

Assignment: Complete page 50 "ELASMOBRANCH FISH DIVERSITY: Form & Function"

Day 4: Topic: ELASMOBRANCH FISH DIVERSITY: Sharks

Assignment: Complete page 51 " "ELASMOBRANCH FISH DIVERSITY: Sharks" & questions

Lab Day: Extra Credit Topic: Shark External feature Lab

Extra Credit Assignment: Complete the blanks in Figure 1. External features

WEEK 4 BONY FISH WEEK

Day 1: Topic: Introduction to Bony Fishes

Assignment: Read "Bony Fishes" beginning on page 235-239.

Assignment: Begin Study Guide questions on Class Osteichthyes

Day 2: Topic: Bony Fishes: Form & Function

Assignment: Complete page 43 "BONY FISH DIVERSITY: FISH MORPHOLOGY" & questions

Day 3: Topic: Bony Fish Locomotion

Assignment: Read pages239-240

Assignment: Complete page 44 Bony Fish Locomotion

Day 4: Topic: Bony Fishes Senses

Assignment: Read pages 240-244

Day 5: Topic: Fish Reproduction

Assignment: Read pages:244-249

Assignment: Complete questions in the back of this packet: Reproduction in Fish

Extra Credit Assignment: Complete page 49 "BONY FISH AND SHARK: Comparison of Structure"

THAT'S MORE THAN ENOUGH FOR THESE 2 WEEKS. #MASKS FOR ALL.

Questions on Agnatha and Chondrichthyes

1. What are the 2 basic classes of Agnathans?
2. Describe the feeding behavior of an adult lamprey.
3. What is perhaps the most primitive vertebrate alive today?
4. Make a simple sketch of a fish and label the following fins: dorsal, caudal, anal, pelvic, pectoral
5. Where is it thought that the cartilaginous and bony fishes first evolved?
6. What is the spiral valve in sharks? What is its function?
7. How does fertilization occur in sharks?
8. Name and explain 3 types of reproduction in sharks.
9. What is the name of the egg case laid by skates?
10. Name 10 unusual items found in the stomachs of sharks.
11. Why is it thought that Great White sharks on the Western coast of the U.S. sometimes attack humans?
12. About how many shark attacks occur worldwide each year?
13. What are the chances of being attacked and killed by a shark?
14. How do skates and rays swim?
15. What are 3 major differences between skates and rays?
16. What is the dorsal opening to the gills called on skates and rays? Where are the gills located?
17. What is the function of the spiracle?
18. Name 3 methods of defense evolved by skates and rays.
19. How do chimaeras feed? What do they eat?

ELASMOBRANCH FISH DIVERSITY: FORM AND FUNCTION

The elasmobranch fishes (sharks, skates, and rays) are characterized by flexible, cartilaginous skeletons. They differ from bony fishes in two other major ways. They possess gill slits instead of an operculum, and they lack a swim bladder. These characteristics have a profound influence on the mode of existence of the elasmobranch groups. This plate introduces the three elasmobranch forms.

Color the dogfish views, including the upper right inset drawing which illustrates a single row of teeth in the lower jaw moving forward with use and being discarded.

The spiny dogfish shark (1 meter, 3 ft) possesses a streamlined dusky gray *body* with a complement of both paired, *pectoral* and *pelvic fins*, and unpaired, *dorsal* and *caudal fins* similar to the bony fishes (Plate 43). However, there are some differences. The dorsal fin of sharks is more rigid and is incapable of being folded down flush against the back. While the spiny dogfish possesses two dorsal fins, they do not straddle the midline and are not properly considered as "paired." The dogfish caudal fin is asymmetrical (heterocercal), with a larger upper lobe. This larger lobe, supported nearly to its tip by the vertebral column, gives the shark an upward as well as forward movement that counteracts its tendency to sink. Similarly, the larger pectoral fins are more rigid than those of bony fishes and are held horizontally with a slight upward cant that provides lift. The pelvic fins of the male each have an elongated *clasper* on the inside; this is used in fertilization of the female (Plate 85).

The absence of an operculum means that sharks cannot actively pump water over their gills, and this suggests that they have to swim constantly to maintain a flow of oxygen-bearing water over their gill surfaces. However, many bottom-dwelling sharks possess *spiracles* from the dorsal body surface to the gills through which the gills can be ventilated. Each spiracle is fitted with a non-return valve that opens and closes as the fish breathes; water is drawn in only and expelled out the *gill slits*.

The shark's *mouth* is usually underslung, or subterminal, with a pointed snout extending above it. When a shark strikes, it raises its snout and projects its wide-open *jaws* forward, allowing it to take a substantial bite. Shark *teeth* are usually pointed and sharp. As they break off or are worn down, they are continuously replaced from behind, as the arrows in the inset indicate. Unlike other vertebrates, the teeth of sharks are mounted in skin, not jaw bone. Shark teeth are actually modified placoid scales, or *denticles*, the same basic structure that covers the shark's body, giving it a texture like sandpaper. Teeth are lined up in five or six rows (fewer in some cases; more in others) and grow forward as the leading tooth wears or falls out.

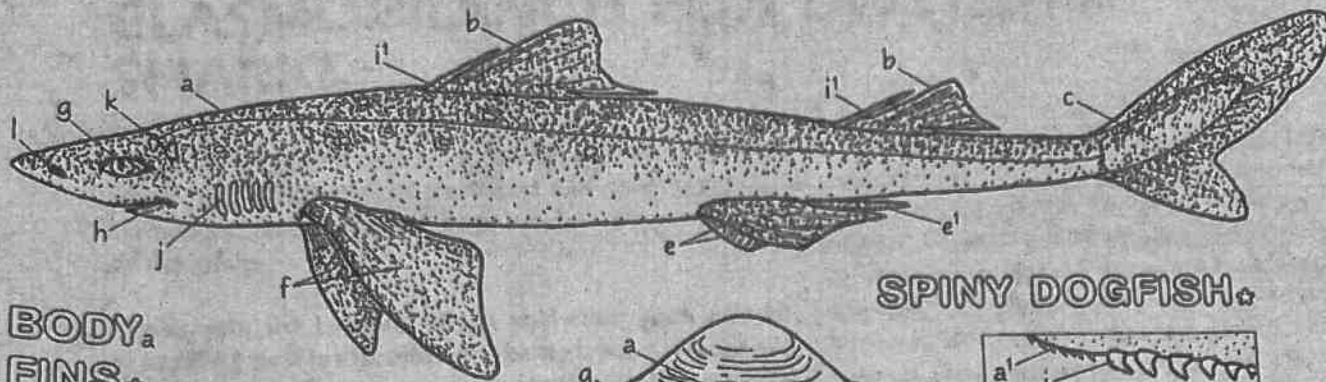
Color the underside (ventral side) of the big skate.

The skate is a much flattened (depressed) elasmobranch that spends its daylight hours buried in the sand on the bottom, with only the eyes and large gill-ventilating spiracles uncovered. At night, the skate emerges and swims, using undulations of its long pectoral fins like wings. The skate feeds on bottom-dwelling crustaceans and molluscs that it captures in its ventrally located mouth and crushes with its flat, block-shaped teeth. The skate's body is moderately slender and often has rows of enlarged denticles along the back. The male's pelvic fins possess long claspers for mating. The anal and caudal fins are absent, and the dorsal fins are very small. Skates are found in all seas, and species range in size from one meter to the "barndoor" skate which is over three meters (10 ft) long. They are white ventrally and tan to dark dorsally.

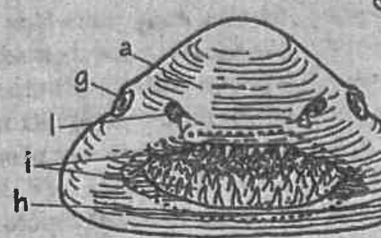
Color the stingray, including the enlarged spine at lower right.

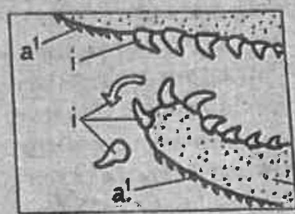
The southern stingray inhabits Atlantic and Caribbean waters. Stingrays are similar to skates in the shape of the pectoral fins, position of the mouth, spiracle, and gill slits, and in behavior, feeding, and diet. They spend the daylight hours buried in soft substrata and the nighttime foraging for bottom-dwelling crustaceans and molluscs. Rays differ from skates in having a long whiplike tail that lacks dorsal fins and possesses one or more spines at its base. The spines are modified denticles and, like the shark's teeth, are replaced in series when broken or pulled out. Buried in the sand, these rays are almost invisible, and the unwary wader who steps on one is often impaled on one of the spines by the lashing motion of the tail. Stingray "stings" are complicated by the presence of venom glands on each side of the spine; the venom flows along grooves in the spine and into the wound. The pain is often excruciating, and some stings have proven fatal to humans. Southern stingrays are medium brown dorsally and white ventrally.

FORM AND FUNCTION

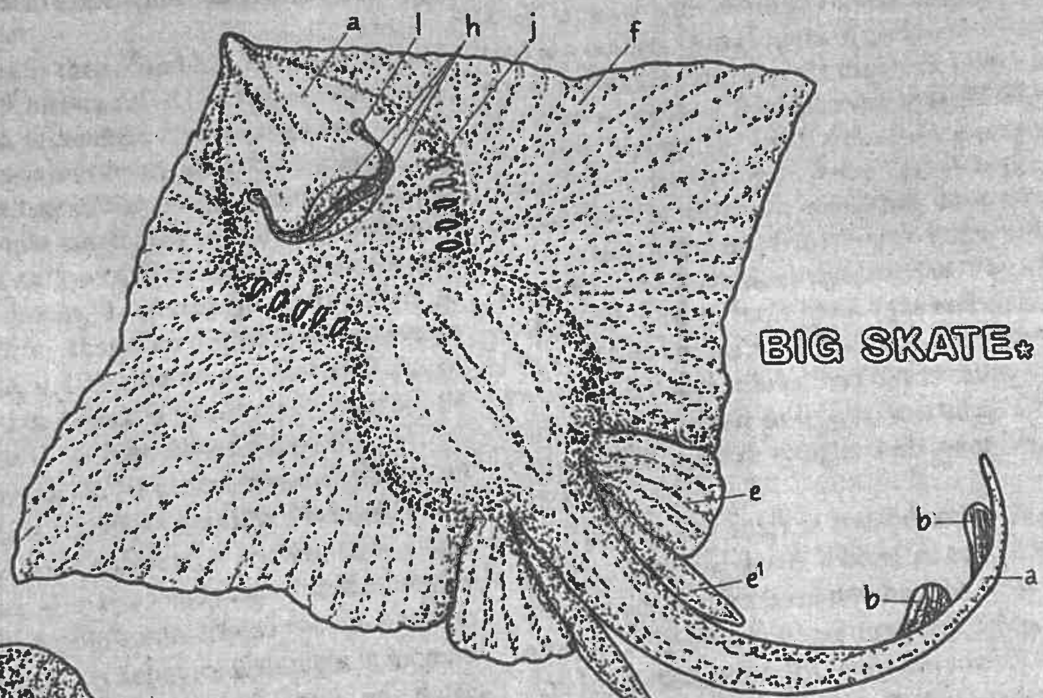


SPINY DOGFISH*

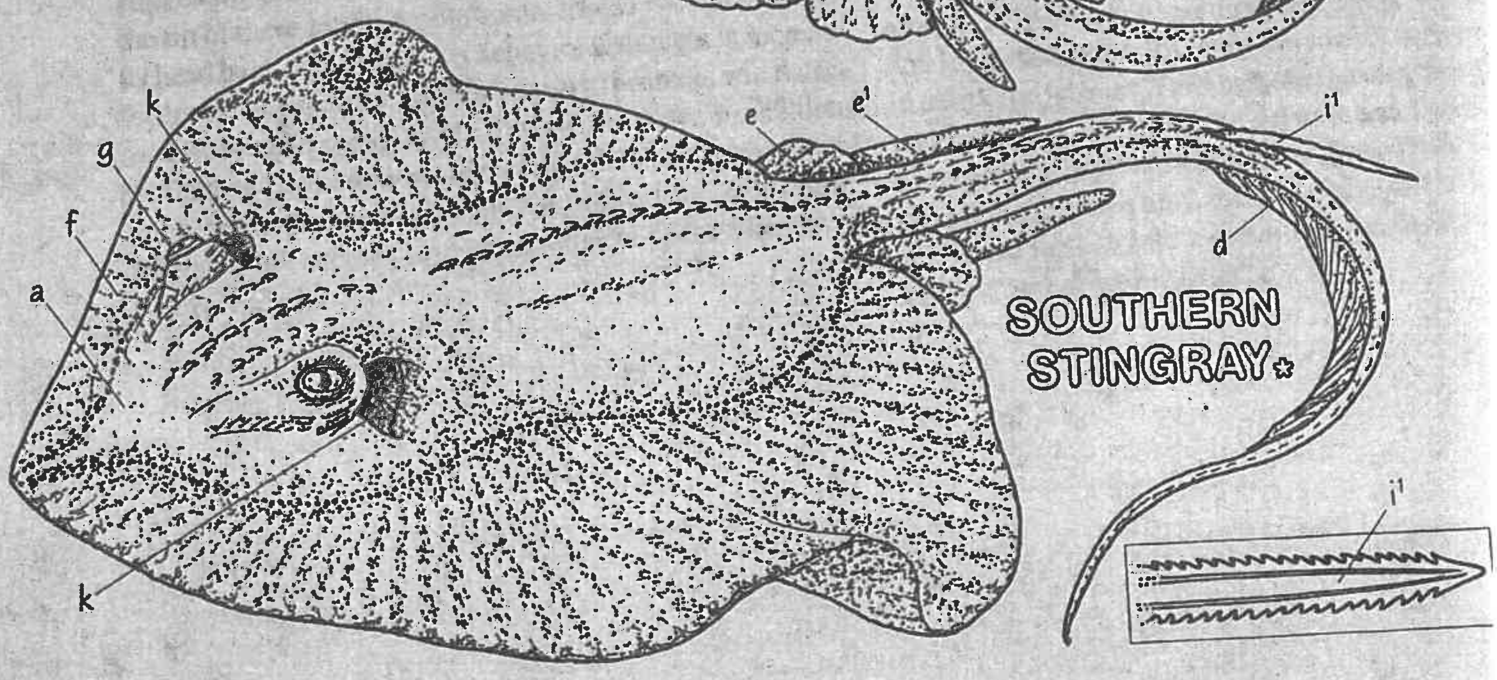




BODY a
FINS*
DORSAL b
CAUDAL c
ANAL d
PELVIC e
CLASPERS e1
PECTORAL f
EYE g
JAWS/MOUTH h
DENTICLES a1
TEETH i
SPINE i1
GILL SLIT j
SPIRACLE k
NOSTRIL l



BIG SKATE*



SOUTHERN STINGRAY*

51
ELASMOBRANCH FISH DIVERSITY: SHARKS

There are about 250 species of sharks, and many of these are widely distributed in the world's oceans. This plate introduces some of the unusual or more notorious members of the group.

Begin with the basking shark and color each animal separately as it is discussed in the text. Most sharks are gray in color. The arrows indicate the feeding current in the basking shark. Note that the jaws/mouth of the hammerhead do not show in the larger view, and it and the thresher shark lack a keel. The lower half of the great white shark is not to be colored in either drawing so as to give the natural appearance of countershading.

The basking shark is the second largest fish in the sea, reaching lengths of 9 meters (30 ft) or longer. The filter-feeding basking shark is depicted with its cavernous *mouth* open, in feeding position as it swims slowly along, engulfing large zooplankters and small fish. Water passes out through the large *gill slits* while small prey are caught on the gill raker surfaces, then swallowed. Basking sharks are thought to be harmless to humans. Traveling in schools of up to 100 individuals, basking sharks are found in the temperate zones of the Atlantic and Pacific oceans on both sides of the equator. The basking shark is sometimes hunted for its oil-rich liver because of its high vitamin content.

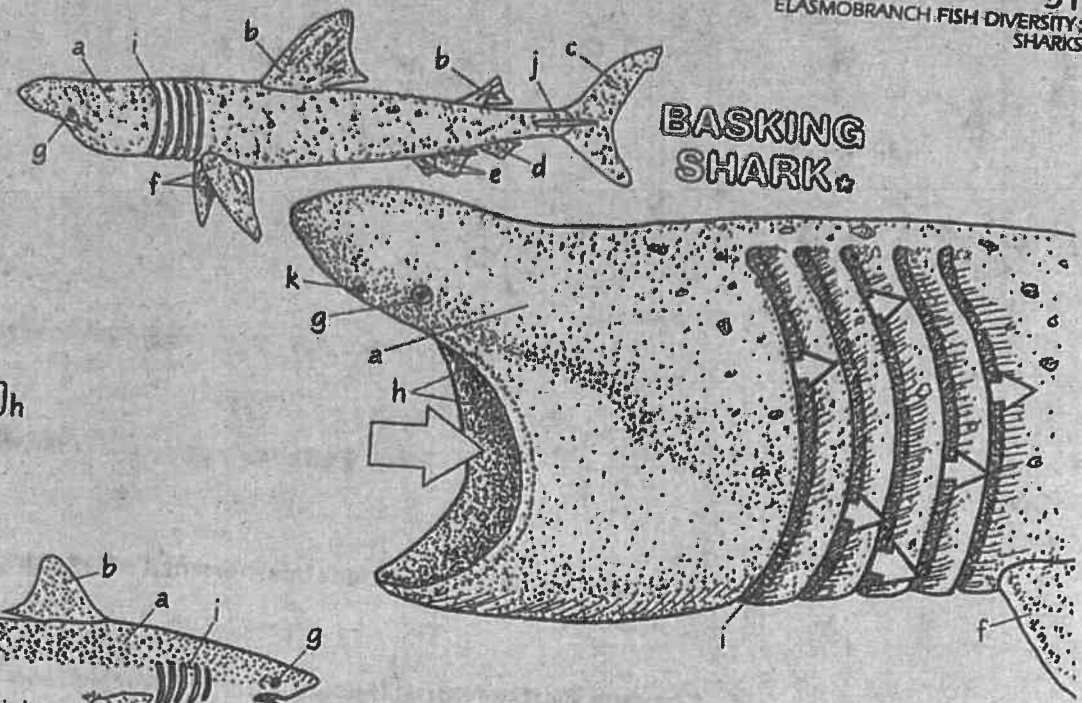
The large (6 meters, 20 ft) hammerhead shark has all the typical shark characteristics except for the head, where flattened cephalic lobes create a rectangular shape suggesting a hammer. The *eyes* and *nostrils* are located at the tip of these lobes. As the hammerhead swims, it swings its head back and forth. This behavior is thought to increase the likelihood that the shark's sensory receptors will detect food by broadening its swath through the water. In addition, the flattened head may act to increase the shark's maneuverability. Hammerheads are found in tropical and subtropical waters of all oceans, and some attacks on humans have been recorded.

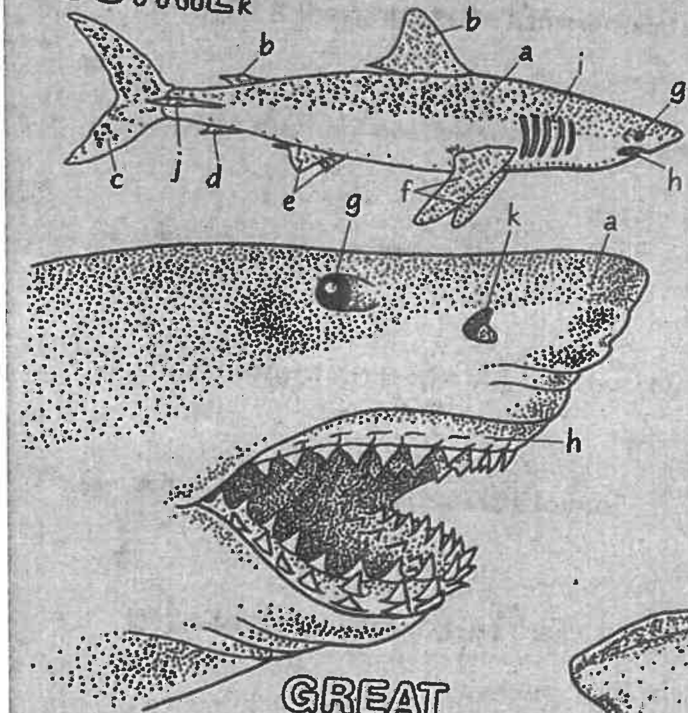
The great white shark has a cosmopolitan, temperate water distribution, ranging into cool waters like those found off central California. The great white accounts for the majority of verified shark attacks on humans, but the reasons for this are not agreed upon. Some experts believe great whites are territorial and see humans as intruders in their territory. Others feel divers and surfers are mistaken for seals or other marine mammals; still others feel that the movements of swimmers, mistaken for those of distressed fish, attract the shark. Another plausible theory is that the great white shark is mainly curious and, unlike most sharks that "feel" an unknown substance by bumping it with their snouts, the great white "feels" with its mouth. Even a gentle "feel" or taste with its mighty tooth-studded *jaws* can be fatal to a human. Observations of great white shark attacks on seals and sea lions suggest the shark lunges at its prey and takes a large bite. Backing away to avoid the dangerous thrashing flippers, the shark waits for the prey to bleed to death before devouring it. If the "prey" happens to be a human diver or surfer, the victim may have time to get out of the water before the shark returns. Perhaps this explains why many shark attack victims survive. The great white is recognizable by its large black eyes and its lunate *caudal fin*, which is not the typical shark heterocercal form. The great white is also stouter than most sharks. A record great white, over 6 meters in length, was taken off the coast of Cuba. Such a shark weighs well over 1600 kilograms (3500 lb).

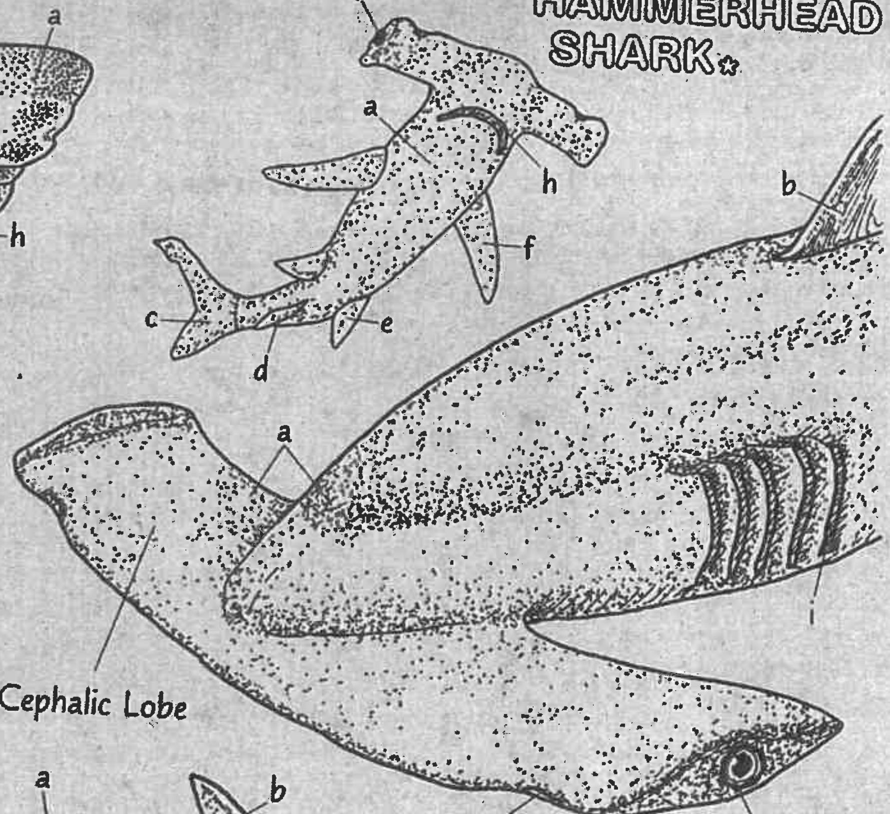
The thresher shark is immediately recognized by the greatly elongated dorsal lobe of its caudal fin. The caudal fin may account for up to one-half the shark's body length, which may reach 6 meters; threshers weigh up to 450 kilograms (1000 lb). They have never been implicated in attacks on humans. Threshers are found in the subtropical and temperate waters of the Atlantic and Pacific oceans, often feeding in groups on schools of small fish. They swim circles around their prey, using the large caudal fins to stun and scare the fish into a group that can be fed upon more easily ("threshing behavior").

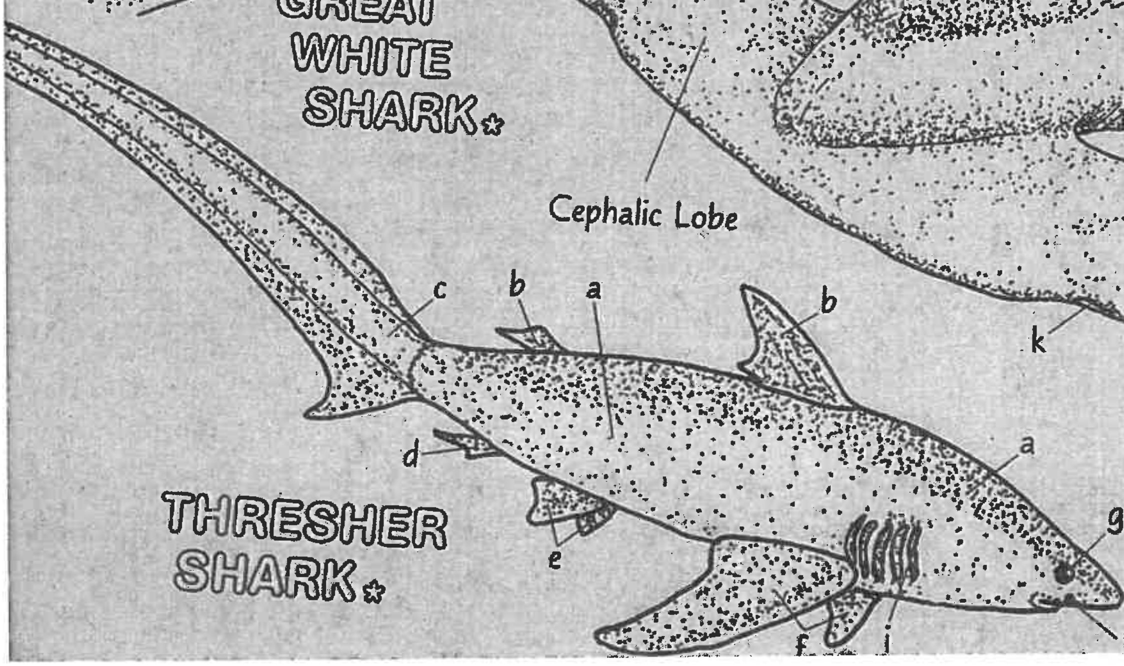
SHARKS

BODY$_a$
FINS*
DORSAL$_b$
CAUDAL$_c$
ANAL$_d$
PELVIC$_e$
PECTORAL$_f$
EYE$_g$
JAWS/MOUTH$_h$
GILL SLIT$_i$
KEEL$_j$
NOSTRIL$_k$









Elasmobranch Fish Diversity Questions

1. About how many species of sharks are there?
2. What is the second largest fish in the sea? How big does it get?
3. Where in the world can basking sharks be found?
4. Why is it thought that the hammerhead shark has a rectangular head?
5. What are three possible reasons that great white sharks attack humans?
6. How big can a great white shark get?
7. How much of the length of a thresher shark is due to its caudal fin?
8. Where can thresher sharks be found?
9. What do thresher sharks use their caudal fin for?

Shark External Features Lab

I. **Pre- Lab Questions (Answer on a separate sheet of paper)**

1. What phylum is the dogfish shark classified in?
2. What class is the dogfish shark classified in?
3. What type of symmetry does the dogfish shark have?
4. Name another organism that is the in the same phylum and class as the shark?
5. What is different about the skeleton of this organism compared to the skeleton of the fish in Class Osteichthyes?

II. **Procedure**

A. **External Examination**

1. **Familiarize yourself with the following structures:**
   External Nares, Spiracles, Mouth, Gill, Slits, Lateral Line, Cloaca, Clasper, Fins, Rostrum, Dorsal Spines

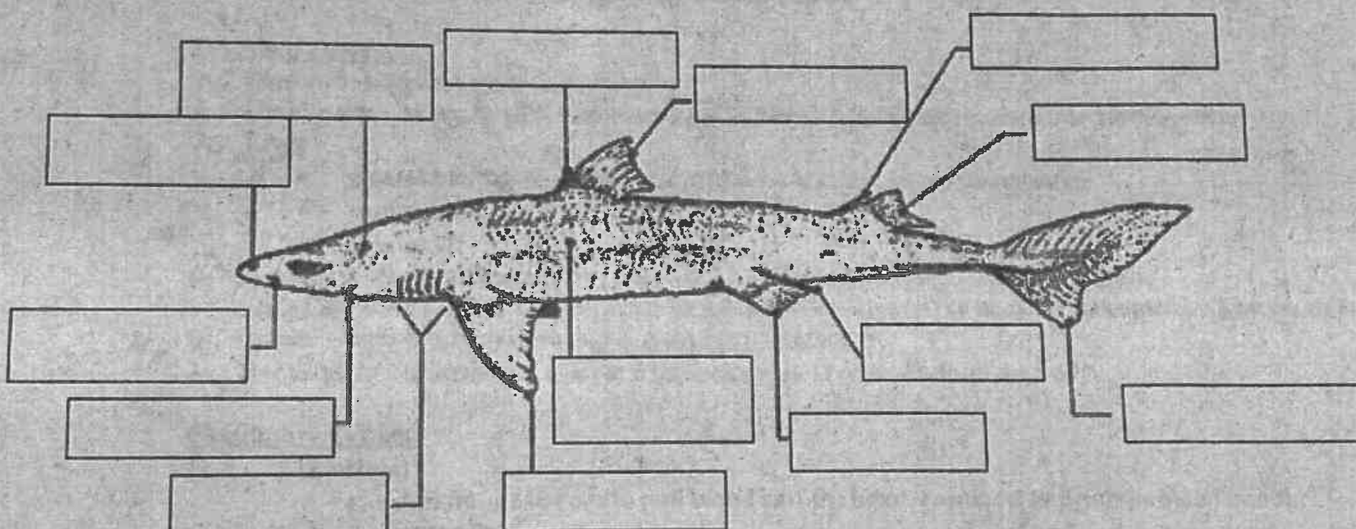


Figure 1. External features.

2. **Label the external structures in figure 1**

B. **External Anatomy Questions (Answer on a separate sheet of paper)**

1. What is the function of the nares?
2. What are the structures known as spiracles on the shark?
3. Which shark organism will have a structure called a clasper, female or male? Is your shark a male female?
4. What is the rostrum on the shark?
5. Is the lateral line visible on your shark? How many paired fins does the shark have? ________Nam
6. How many single fins does the shark have? Name them.
7. What is the function of the gill slits of the shark?

Shark Dissection Review

External Anatomy:

1. External nares – the nostrils, functions in chemoreception
2. Spiracles – allows water to pass to the gills
3. Mouth – feeding and intake of water to the gills
4. Gill slits – allows water to exit from the gills
5. Lateral line – detects vibrations in the water
6. Cloaca – exit opening for the digestive tract and reproductive organs
7. Claspers – (males only) transfers sperm during mating
8. Fins –
    - Dorsal Fins – balance
    - Caudal Fin – propulsion and lift
    - Pelvic fins – steering and balance
    - Pectoral fins – steering, balance and lift
9. Rostrum – holds the olfactory lobes and ampullae of Lorenzini
10. Dorsal Spines – venomous spines used for defense
11. Ampullae of Lorenzini – used to detect electrical fields

Digestive System:

1. Stomach – begins digestion of food
2. Duodenum – slows food before it enters the spiral intestine and receives bile from the liver
3. Liver –
    - creates bile which helps break down food molecules in the intestine
    - stores energy as oils
    - creates lift
4. Pancreas – creates digestive enzymes which help break down food in the intestine
5. Spiral intestine – spiral shaped to increase the surface area of the intestine; completes digestion of food
6. Spleen – circulatory system organ; stores excess blood
7. Rectal gland – circulatory system organ; removes excess salt from the body

Circulatory System:

1. The Heart –
    a. Atrium – expands to pull blood into the heart, contracts and pumps blood into the ventricle
    b. Ventricle – main contractile chamber of the heart, pumps blood throughout the body
    c. Conus Arteriosus – gives added pressure boost to the blood
2. Efferent brachial arteries – carry oxygenated blood from the gills to the dorsal aorta
3. Gills – deliver oxygen to the bloodstream
4. Dorsal aorta – carries oxygenated blood through most of the body

Nervous System:

1. Olfactory lobes – processes olfactory signals
2. Optic lobes – process signals from the eyes
3. Cerebellum – processes movement
4. Medulla oblongata – processes involuntary actions
5. spinal cord – carries nerve signals to and from the brain throughout the body

43
BONY FISH DIVERSITY: FISH MORPHOLOGY

To appreciate the diversity of marine bony fish, one needs to investigate the features that are common to most fish. The grouper, or sea bass, pictured here, is considered to be unspecialized, and has a basic fish morphology. In this plate, we will identify the major external body structures and introduce their function, and outline the internal support and muscle systems. In the next plate, we will explore the variety of body form and locomotion found in bony fish.

Begin by coloring the body of the sea bass in the two upper drawings. Color the external parts of the sea bass as they are mentioned.

The shape of the sea bass is fusiform—a streamlined shape offering the least resistance to movement through the water. The prominent fins are obvious in both the lateral and front view. The *caudal fin* usually provides the main thrust used in swimming. Also located in the midline are two unpaired fins, the *dorsal* and *anal fins*. These fins are used to stabilize the fish in the water and to lessen its tendency to pitch, especially while swimming slowly. They are also useful in preventing the fish from rolling over while turning at high speeds. The *pectoral fins* are located on the sides of the fish, behind the opening of the gill cavity, and *pelvic fins* are located ventrally, in front of the anal fin. These paired fins are used as stabilizers, but assist in turning and stopping as well. Fins are supported by fin rays of two types: bony pointed spines; and soft rays, which are jointed. The dorsal, anal, and pelvic fins have both spines and soft rays; the remaining fins consist of soft rays only.

In front of each pectoral fin is a large bony flap called the *operculum*, which covers the gill cavity that opens just behind it. Running the length of the fish, from the operculum to the base of the caudal fin, is the *lateral line*. The line consists of a series of very small canals that open to the surface and contain pressure-sensitive receptors. When the fish encounters movement in the water, such as the bow wave of an approaching fish, the water pressure pushes against the fish, entering the lateral line canals and triggering the pressure receptors. The lateral line, called the "sense of distant touch," is extremely sensitive and allows the fish to move in turbid water by "feeling" its way around obstacles, even when vision is greatly impaired. Other prominent external morphological features are the *eyes* (fish have fair vision), *nostrils*, and the bones of the *jaw*. Generally, fish have two nostrils on each side, which open to an olfactory pit and are used for scent, not for respiration.

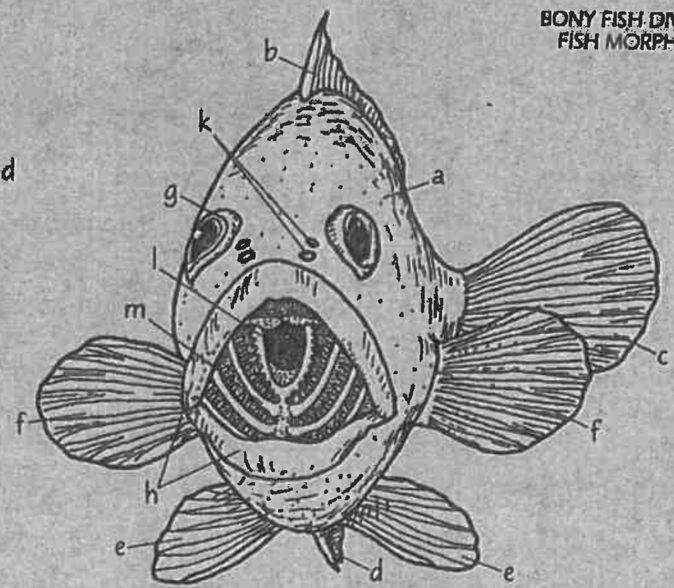
The shape, size, and position of the jaws vary considerably in different fish, and are related to the type of feeding. The sea bass is a generalist carnivore, feeding on a wide range of prey and has a large *mouth* that opens terminally (at the front). Inside the stout jaws of the sea bass is the folded opening of the *esophagus*, which leads to the gut. Adjacent to and in front of the esophagus are the *gills*, whose arched gill bars support the gill rakers, sometimes used in feeding, and gill filaments, which provide the respiratory surface (Plate 49).

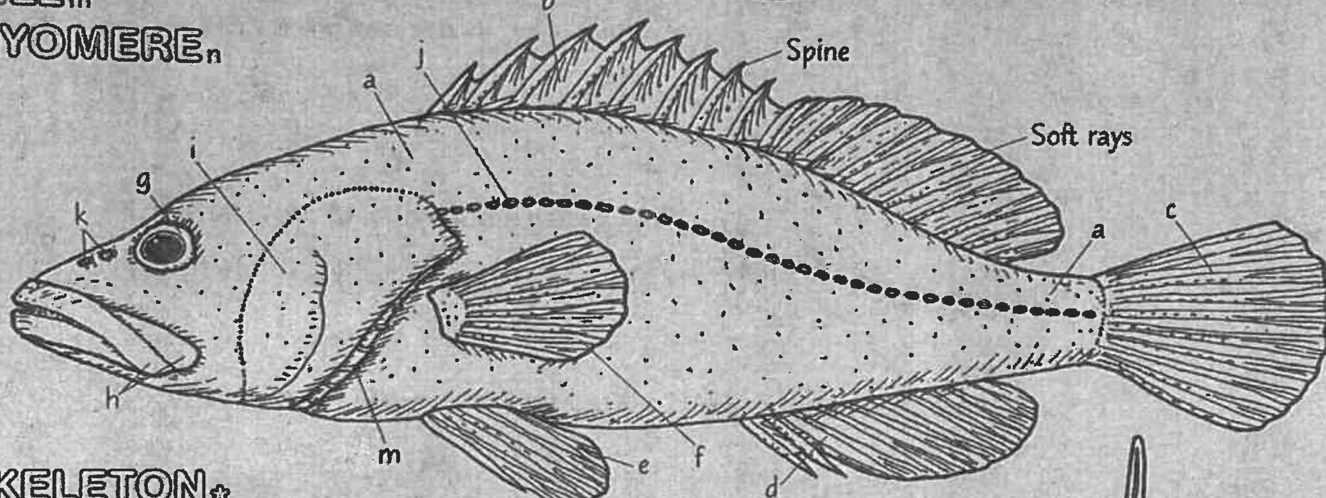
Now color the view showing the fish's skeleton. Note only a small region of the body musculature is illustrated. Color the fins the same colors as you used above. You may wish to color the pectoral and pelvic girdles with shades of the colors of their respective fins.

The bony fish's skeleton provides protection for the head and internal organs and support for the muscles. Prominent in the skeleton are the jaws, the fused bones of the *head*, the flat bones of the operculum, and the *supports* for the spinous and soft dorsal rays. The pectoral and pelvic fins are supported by girdles of bone, the *pectoral* and *pelvic girdles* respectively, that are anatomical homologues of our shoulders and hips. Also note the region just in front of the caudal fin known as the *caudal peduncle*, which is the pivoting point of the caudal fin. Notice how the vertebral column, or axial skeleton, is located towards the center of the fish instead of along the back as in ourselves and other terrestrial vertebrates. Because the fish lives in water, a buoyant medium, the skeleton does not have to support the body against the pull of gravity. Relieved of this chore, the axial skeleton is positioned more centrally to provide maximum support for the role of the trunk musculature in swimming (Plate 44). In the cross-sectional view of a single *vertebra*, the single *dorsal process* and articulated *ribs* show the sites of muscle attachment. The body musculature is organized into units called *myomeres*. The individual myomeres nest together like a series of stacked cones along the length of the fish.

FISH MORPHOLOGY

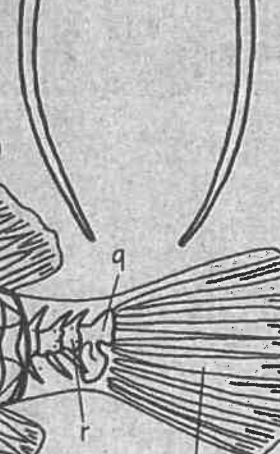
BODY$_a$
FINS$_☆$
DORSAL$_b$ CAUDAL$_c$ ANAL$_d$
PELVIC$_e$ PECTORAL$_f$
EYE$_g$
JAWS/MOUTH$_h$
OPERCULUM$_i$
LATERAL LINE$_j$
NOSTRIL$_k$
ESOPHAGUS$_l$
GILL$_m$
MYOMERE$_n$

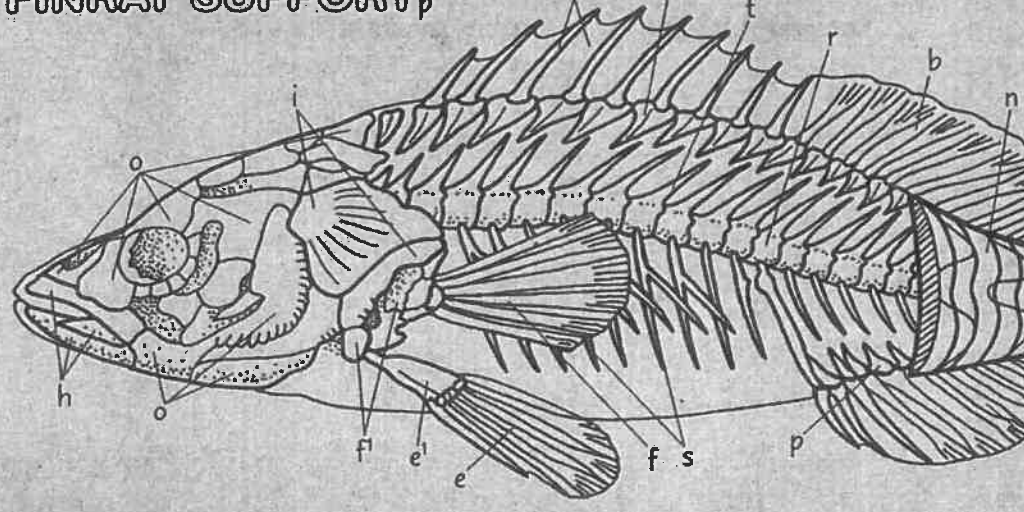




SKELETON$_☆$
JAW$_h$ HEAD$_o$
OPERCULUM$_i$
PELVIC GIRDLE$_{e^1}$
PECTORAL GIRDLE$_{f^1}$
FINRAY SUPPORT$_p$

CAUDLE PEDUNCLE$_q$
VERTEBRA$_r$ RIB$_s$
DORSAL PROCESS$_t$





Bony Fish Morphology Questions

1. What is the function of the caudal fin?

2. What are the two *unpaired* fins? What is their function?

3. What are the two sets of *paired* fins?

4. What is the function of the paired fins?

5. What is the function of the lateral line? Where is it located on the fish?

6. What bones support the pectoral and pelvic fins?

7. What is the area just in front of the caudal fin called?

44
BONY FISH DIVERSITY: LOCOMOTION

Moving through water requires more energy than moving through air. The forces of friction and drag resistance are much greater on a body moving through water. Also, as a fish moves, it displaces water that flows around the body. A streamlined body shape is required to improve this flow. The fusiform or tear-drop shape of the sea bass shown here represents an effective morphological compromise to meet these demands.

Color the illustration of the swimming sea bass at the top left, noting the flexing of the body and the resulting thrust forward. Note that the myomeres are exposed on either side of the curve in the fish's body. Those on the inside of the curve are contracted while those on the outside are relaxed and are being stretched. You may wish to color the fins the same colors as used in Plate 43. Color the small illustrations of the moray eel and tuna moving across a grid to show the body undulations.

Most fish swim by undulating their body so that the *caudal fin* is whipped very rapidly from side to side in a sculling motion resulting in a powerful forward *thrust*. Beginning at the head, there is a sequential contraction of blocks of *myomeres* along the length of the fish. These waves of contraction alternate on opposite sides of the fish causing the axial skeleton to flex, the body to undulate, and the caudal fin to pivot at the *caudal peduncle* and scull through the water. The degree of undulation varies among species and depends on the stiffness of the vertebral column and the connection between the myomeres. The extremes can be seen in the body movement of elongate fish like *moray eels*, which have serpentine undulations, compared to a *tuna* whose body remains very rigid with only the caudal fin undulating rapidly.

Now color the different types of caudal fins.

The caudal fin usually provides the main thrust used in swimming. The size and shape of the fin is an indicator of the fish's ability to move through the water. The sea bass has a *rounded* caudal fin that is soft and flexible, but it also has considerable surface area. This fin gives effective acceleration and maneuvering, but is inefficient for prolonged, continuous swimming as it creates too much drag which tires the fish. A *forked* caudal fin produces less drag, and is efficient for more rapid swimming. Long-distance, continuous swimmers such as the tuna have *lunate* caudal fins, which are rigid for high propulsive efficiency and have a relatively small surface area to reduce drag. However, the rigid fin is ineffective for maneuvering.

Color the illustrations of the tuna, barracuda, and butterflyfish, noting the differences in the body shape and caudal fin.

Not all fish are engaged in rapid, *continuous swimming* like the pelagic tunas whose sustained swimming speeds range from 8–16 km/h, 5–10 mph (Plate 45). A fish's unique lifestyle places other demands on its body form and locomotion abilities. A fish such as the barracuda that swims leisurely in wait, then runs down its prey (Plate 109), relies on quick *acceleration* and short bursts of rapid swimming provided by its elongate muscular body and large caudal fin. Barracudas have been estimated to accelerate to 80 km/h (50 mph) in pursuit of prey.

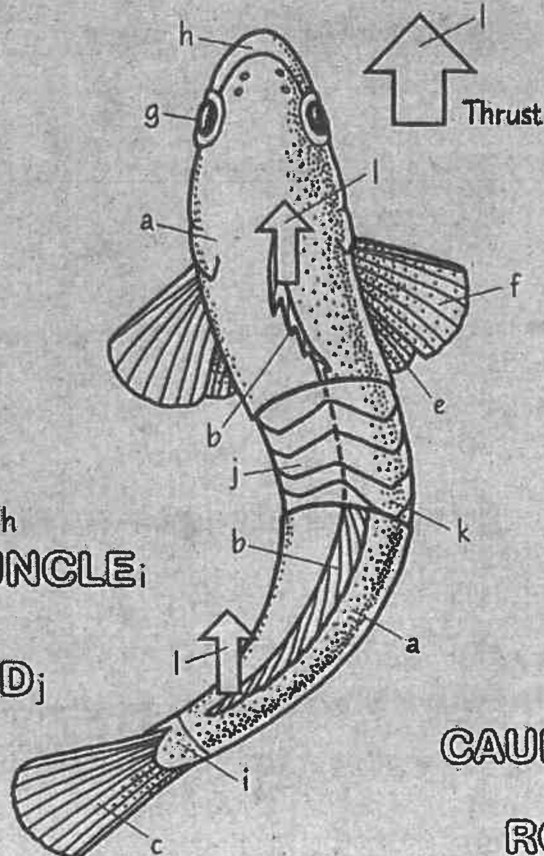
The butterflyfish (Plate 47) needs great dexterity and *maneuverability* to capture its small prey. The body is compressed (flattened laterally) and disc-shaped in outline. The *dorsal* and *anal fins* are large and run along most of the body, providing excellent control in turning. They can be rapidly flexed for quick acceleration should escape be necessary. The *pectoral* and *pelvic fins* are also very large and maneuverable.

Finally, color the drawings illustrating different methods of propulsion. Color only the fins involved in propulsion.

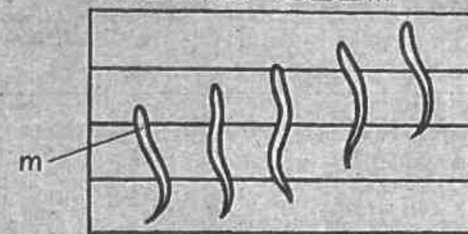
Locomotion, in most fish, is a compromise among the demands for sustained swimming, quick bursts of acceleration, and maneuverability. Not all fish rely on the caudal fin for swimming propulsion. Electric fish swim by waves of undulations along the anal fin. Triggerfish use their dorsal and anal fins for locomotion. Sculpins and wrasses propel themselves using the sculling action of their pectoral fins. Seahorses and pipefish swim vertically, sculling through the water with their dorsal fins.

LOCOMOTION

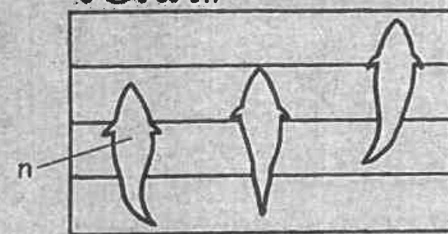
SWIMMING*
BODY$_a$
FINS*
DORSAL$_b$
CAUDAL$_c$
ANAL$_d$
PELVIC$_e$
PECTORAL$_f$
EYE$_g$
JAWS/MOUTH$_h$
CAUDAL PEDUNCLE$_i$
MYOMERE*
CONTRACTED$_j$
RELAXED$_k$
THRUST$_l$



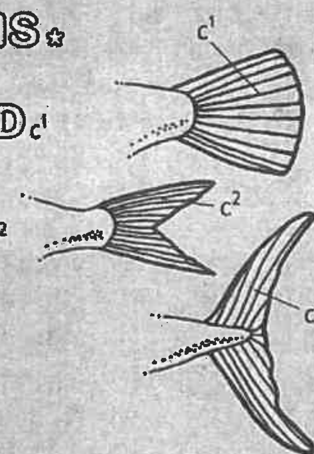
MORAY EEL$_m$



TUNA$_n$

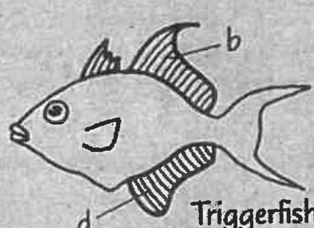


CAUDAL FINS*
ROUNDED$_{c^1}$
FORKED$_{c^2}$
LUNATE$_{c^3}$

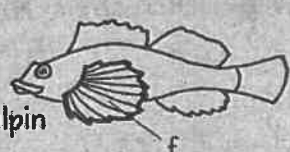


PROPULSION*

Electric fish



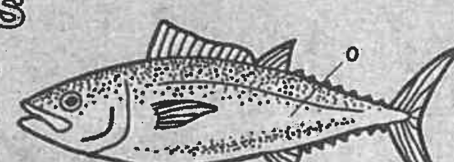
Triggerfish



Sculpin

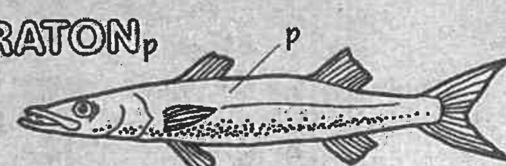
Seahorse

CONTINUOUS SWIMMING$_o$



Tuna

ACCELERATON$_p$



Barracuda

MANEUVERABILITY$_q$

Butterflyfish

Bony Fish Locomotion Questions

1. What shape is an effective morphological compromise between drag water displacement?

2. What type of movement is a rounded caudal fin best for? What is it *not* good for?

3. What type of movement is a forked caudal fin best for?

4. What type of movement is a lunate caudal fin best for? What is it *not* good for?

5. How fast do tuna usually swim?

6. How fast can a barracuda do?

7. What fins do triggerfish use for locomotion?

8. What fins do sculpins and wrasses use for locomotion?

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BONY FISH AND SHARK: COMPARISON OF STRUCTURE

The previous six plates dealt with the variety of forms found in the bony fishes. Before venturing forward in a study of the cartilaginous sharks and rays, a comparison of these two groups is in order. The major organs and systems, with special emphasis on the difference between the sharks and rays (elasmobranch fishes), and the bony fishes, are reviewed here.

This plate presents a highly diagrammatic comparison between the internal anatomy of a bony fish and that of a shark. Locate and color each organ or system in both illustrations as it is discussed in the text. Only those structures labeled and outlined with dark lines are to be colored.

Starting from the anterior, or mouth end of each fish, note the relatively small *brain*, which continues posteriorly as the *spinal cord*. The large *olfactory lobe* of the brain gives evidence of the importance of an acute sense of smell in both groups of fishes. The olfactory lobe terminates near the base of a blind sac, which opens at the *nostril*. Since the nostrils do not open to the throat—as they do in mammals for instance—most fishes must take in their respiratory water current through the mouth. Rays and other bottom-dwelling elasmobranch fishes take in water through an opening called the *spiracle*. Contraction of the throat musculature pumps water over the *tongue* and across the *gills*, which take up the sides of the throat. This oxygen-laden water passes over *gill filaments*, oxygenating the blood supply. *Gill rakers*, located on the inner face of the gill support (gill arch), prevent foreign matter from clogging the gills. Water is pumped out of the gill chamber past the operculum in bony fishes, or through the gill slits in sharks.

The relatively small *heart* is located near the base of the gills. It pumps blood through the gills and from there to the head and the rest of the body. *Kidneys* help regulate blood chemistry and deliver waste products to the exterior through the urogenital opening (not shown). The *gonads* (sex organs) also empty through this opening.

Another large organ linked to the circulatory system is the *liver*, whose main functions are to store surplus nutrients and to detoxify certain substances. In sharks and their relatives, the liver has an additional function: to contribute buoyancy to the body. This is because the liver stores oil which is considerably less dense than water. The presence of the oil in the shark liver is responsible for the latter being much larger in size than the liver of the bony fish. Most bony fish utilize a more efficient adaptation for buoyancy: the gas-filled *swim bladder*. Air is either gulped at the surface or secreted from the bloodstream into the swim bladder. Delicate regulation of the gas content in this organ allows a fish to maintain its position in the water column with a minimum expenditure of energy. By contrast, elasmobranchs function similarly to airplanes, requiring forward motion to keep from sinking.

The length and complexity of the gut has more to do with the diet of any particular species than with that species' relation to the bony fishes or shark group. The *spiral valve* is one gut structure found almost exclusively in sharks and their relatives. It serves to increase the surface area of the *intestine* for more efficient absorption of nutrients.

The characteristic difference between the two major groups, by which they are most commonly named, is the skeletal material. Elasmobranchs are cartilaginous fishes. Their skeletons are made of a relatively flexible material, but the skeletal structure is much less elaborately articulated than in bony fishes. The result is that the bodies of elasmobranchs are on the whole less maneuverable and adaptable than those of bony fishes. This is especially apparent in the structure and utilization of the fins.

Most fishes are covered by a protective layer of scales. In elasmobranchs, these are *placoid scales*, also called denticles. The word "denticle" indicates a relation to teeth, and sharks' teeth indeed originate from the skin layer, as do the scales. Placoid scales seen under a microscope have a sharp tooth-shaped projection, and collectively these scales give a sandpaper texture to the shark's skin. Bony fishes possess, as a group, several types of scales. The *ctenoid scales* shown here are thin and translucent. They lack the enamel and dentine layers of placoid scales, and instead have an outer surface marked with bony ridges that alternate with depressions. Ctenoid scales overlap to provide both protection and suppleness.

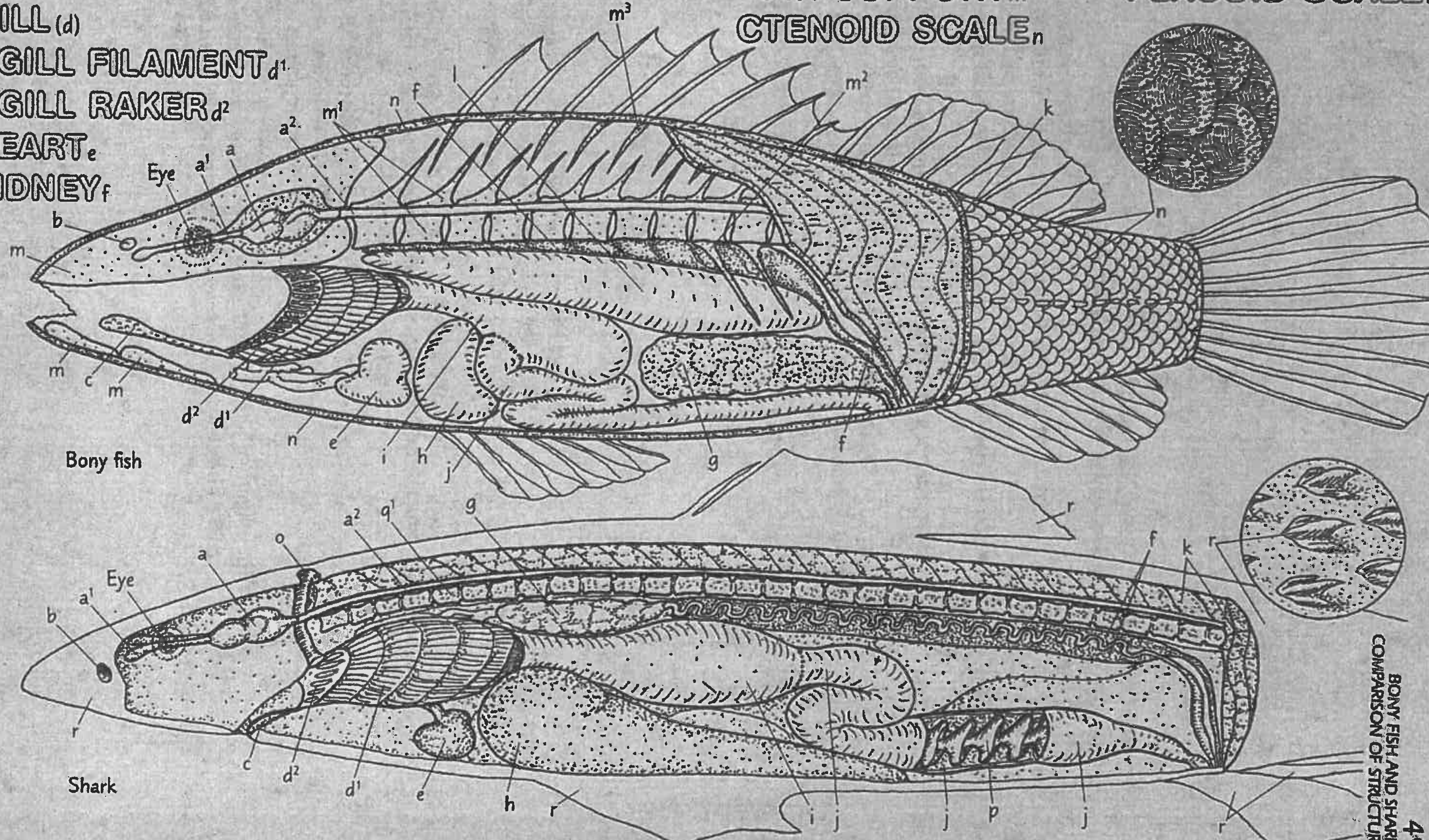
COMPARISON OF STRUCTURE

BRAIN$_a$
OLFACTORY LOBE$_{a^1}$
SPINAL CORD$_{a^2}$
NOSTRIL$_b$
TONGUE$_c$
GILL$_{(d)}$
GILL FILAMENT$_{d^1}$
GILL RAKER$_{d^2}$
HEART$_e$
KIDNEY$_f$

GONADS$_g$
LIVER$_h$
STOMACH$_i$
INTESTINE$_j$
MUSCLE$_k$

BONY FISH$_*$
SWIM BLADDER$_l$
BONE$_m$
VERTEBRA$_{m^1}$
RIB$_{m^2}$
FIN SUPPORT$_{m^3}$
CTENOID SCALE$_n$

SHARK$_*$
SPIRACLE$_o$
SPIRAL VALVE$_p$
CARTILAGE$_{(q)}$
VERTEBRA$_{q^1}$
PLACOID SCALE$_r$

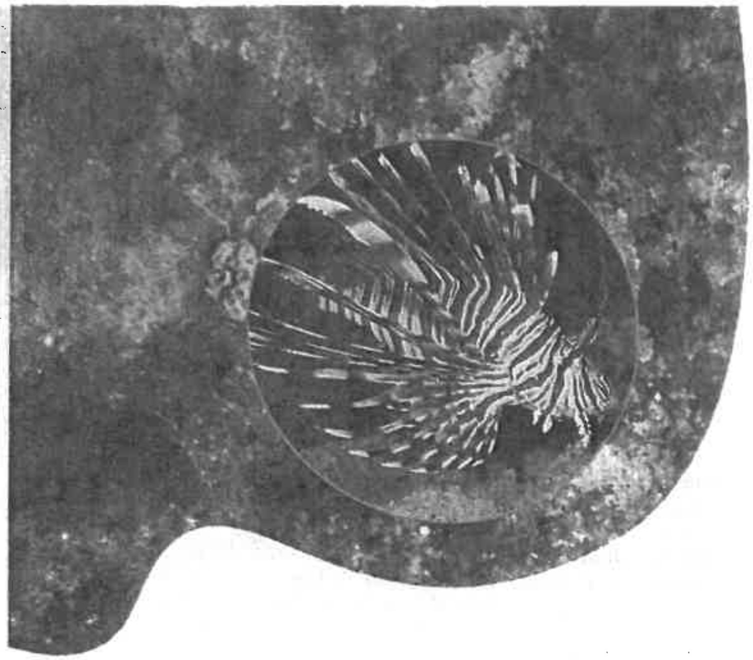


Questions on Class Osteichthyes

1. Why are marine sturgeons considered to be one of the most primitive bony fishes?
2. What is the difference between a heterocercal tail and a homocercal tail?
3. What is the difference between cycloid or ctenoid scales and ganoid scales?
4. Which fins on a fish are paired? Which fins are not paired?
5. What is the main determinate of a fish's body shape?
6. Describe the following fish shapes, make a rough sketch if helpful: Fusiform, laterally compressed, flattened (also known as dorso-ventrally compressed), and globular.
7. What are chromatophores?
8. What is obliterative countershading? What types of fish have it?
9. What is disruptive coloration? Give two examples.
10. What is a swim bladder? Do all fish have swim bladders? If not, what types of fish don't?
11. What are three mechanisms fish have for eliminating excess salt?
12. Why do fish have to eliminate excess salt?
13. Most bony fish show what type of reproductive strategy?
14. Describe catadromous and anadromous fish. Give an example of each.

Reproduction in Fish

1. What are claspers? What kinds of fish have claspers?
2. How does sperm get from the testes to the claspers?
3. How many ovaries do female sharks have? How does the egg get from the ovary to the uterus?
4. Where do the young develop in most species of sharks?
5. Describe viviparous, ovoviviparous, and oviparous reproduction.
6. What type of reproduction do most bony fish use?
7. Describe three strategies for reproduction in bony fish.
8. Describe how seahorses reproduce.
9. Describe the development of a larval fish.
10. When do fish stop growing?
11. What is hermaphroditism? Describe the two types of hermaphroditism.
12. What is the most common type of sequential hermaphroditism?



10

Fishes

Key Concepts

1. Hagfishes and lampreys are jawless fishes.
2. Sharks, skates, and rays have skeletons composed entirely of cartilage.
3. Sharks have streamlined bodies and highly developed senses that help them to be efficient predators.
4. Most marine fishes have skeletons composed primarily of bone.
5. The shape of a fish's body is primarily determined by the characteristics of its environment.
6. Many fishes exhibit coloration and color patterns that help them blend in with their environment.
7. Color in fishes functions in camouflage, species recognition, and communication.
8. Most bony fishes have a swim bladder that helps them maintain neutral buoyancy.
9. Most marine fishes are carnivorous, but herbivores, omnivores, and filter feeders also exist.
10. Most marine fishes are oviparous and produce large numbers of eggs.
11. Fishes such as salmon and eels migrate long distances sometime during their life cycle.

Although hagfish, lampreys, sharks, and bony fishes are traditionally termed *fishes*, these animals are at least as distinct from one another as they are from their chordate relatives, the amphibians, reptiles, birds, and mammals. All are members of the phylum Chordata, animals characterized, at least some time in their development, by the presence of pharyngeal gill slits, a dorsal hollow nerve cord, a notochord (a slender skeletal rod), and a tail lying posterior to the anus.

Marine fishes can be found from the surface waters of the ocean to its deepest trenches. Their species outnumber all other vertebrate species combined. They display an amazing array of adaptations that allow them to exploit virtually every niche. Fish are commercially important for human food, fertilizer, and other products. Indeed, commercial fishing has greatly depleted their stocks in many locations.

FISHES

The "fishes" along with amphibians, reptiles, birds, and mammals are classified as vertebrates. **Vertebrates** are distinguished from other chordates (tunicates and lancelets) by the presence of **vertebrae**, a series of bones or cartilages that surround the spinal cord and help support the body. The vertebrae also provide attachment sites for muscles, thereby increasing and improving the animal's mobility.

The first fishes to evolve lacked both paired fins and jaws. They probably spent their time scavenging food in the bottom sediments of early seas, a niche they filled for millions of years. About 425 million years ago, some fishes appeared that possessed jaws and paired fins. Fishes with these adaptations could more efficiently obtain food and ultimately replaced all but a few of the early jawless forms. Modern fishes now include most of the highest-level consumers in the sea.

MARINE ADAPTATION

Surviving in Near-Freezing Water

Of the approximately 25,000 species of fish on earth, only about 275 occur in the Antarctic Sea. Surviving the subfreezing temperatures is a major challenge to all organisms living here. Marine invertebrates that inhabit the bottom of Antarctica's continental shelf regularly encounter temperatures as low as −2.7°C. They don't freeze because their bodies contain the same concentration of salts and minerals as that of the surrounding seawater, as well as a variety of organic compounds, which depresses the freezing point of their body fluids. The blood and other body fluids of marine fishes, however, are more dilute than seawater, and their tissues freeze at approximately −0.2°C. At this temperature, if an ice crystal were even to brush a fish's skin, it would quickly propagate and pierce the skin like a spear. But most Antarctic fishes encounter ice without any difficulty. It was not until the 1960s that physiologists began to study how fishes in this environment can survive under such conditions. They discovered that the fish have developed a relatively simple solution to the problem. The fishes have glycoprotein molecules (molecules composed of sugar and protein) in their blood and other body fluids that act as antifreeze. These glycoproteins are 200 to 500 times more effective than an equivalent amount of sodium chloride in preventing the formation of ice crystals Glycoproteins do not actually decrease the temperature at which ice crystals form but lower the temperature at which they enlarge and destroy cells.

Another problem faced by fishes in the Antarctic Sea concerns hemoglobin, a molecule in the red blood cells of vertebrates. Hemoglobin is responsible for the red blood cell's ability to carry oxygen, and at low temperatures it functions very inefficiently. To transport enough oxygen at the low temperatures of the Antarctic waters would require large amounts of hemoglobin and large numbers of red blood cells. Unfortunately, this would make the blood too viscous to flow efficiently. Because of these environmental circumstances, Antarctic fishes gradually became more dependent on oxygen dissolved in their blood plasma, reducing their need for hemoglobin and red blood cells. Indeed, the 17 species of icefish (family Channichthyidae; Figure 10-A) generally lack red blood cells entirely. To compensate for the anemia that results from this condition, these fish have a large heart and wide blood vessels, creating a circulatory system that can handle a large volume of blood under low pressure. This allows the fish to expend minimal amounts of energy to pump the large volumes of blood necessary to carry oxygen in the absence of hemoglobin. ●

Figure 10-A Icefish. *This icefish from Antarctica lacks the oxygen-carrying protein hemoglobin. The oxygen that its cells need is carried dissolved in the relatively large volume of blood that circulates through its body.*

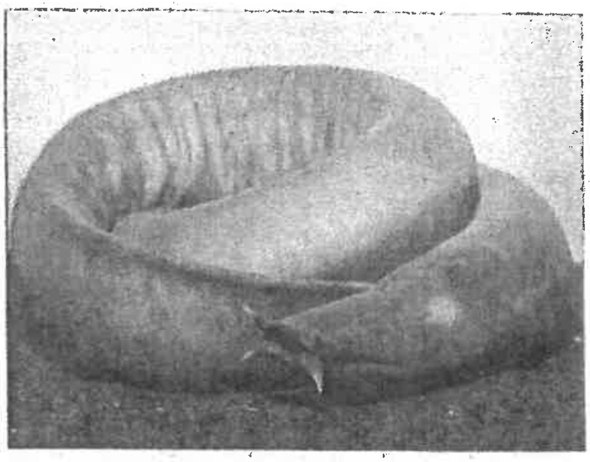
JAWLESS FISHES

Hagfish (class Myxini) and lampreys (class Cephalospidomorphi) lack both jaws and paired appendages. Their skeletons are entirely composed of cartilage and their bodies lack scales. Although superficially similar, hagfish and lampreys are as morphologically distinct from one another as they are from the jawed vertebrates. Because hagfish lack vertebrae, some scientists do not even consider them to be vertebrates. Recent comparisons of DNA sequences among fishes, however, indicate that hagfish are most closely related to the lampreys.

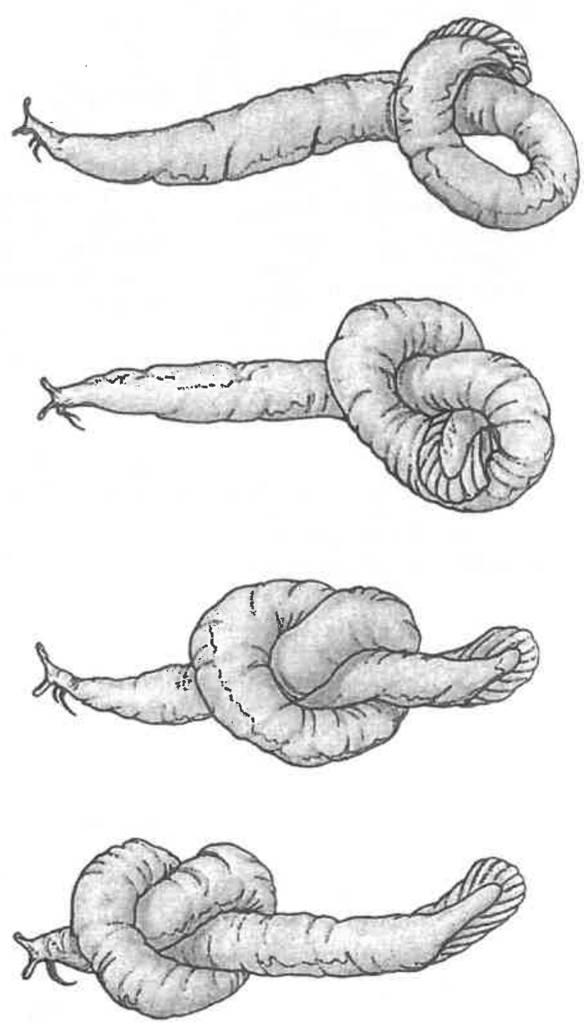
Hagfishes

Hagfish (Figure 10-1a), sometimes called "slime eels," are bottom-dwelling fish found in ocean waters throughout the world, with the possible exception of Arctic and Antarctic waters. Although they are seldom found at depths shallower than 600 meters (1,980 feet) in the tropics, some species enter the intertidal zone in the cold coastal waters off South Africa, Chile, and New Zealand. In some parts of the world, hagfish support a thriving commercial fishery, their tanned hide being used for leather goods. The demand for hagfish skin has risen to the point that many populations are depleted. Unfortunately, our knowledge of hagfish biology is insufficient to manage a sustainable fishery.

When feeding, hagfish extend a feeding apparatus composed of two structures, termed **dental plates**, containing horny cusps. They use these dental plates to grasp the flesh of their prey, usually small, soft-bodied invertebrates. As the feeding apparatus is withdrawn into the mouth, the dental plates close tightly, and the cusps tear away the flesh of the prey. A fang above the dental plates keeps live prey from wriggling away between bites. In addition to feeding on live prey, hagfishes act as scavengers on dead or dying whales and other large vertebrates. Because hagfish cannot penetrate the skin of whales or fish, they enter the body cavity


Tom Stack and Associates

(a)



(b)

Figure 10-1 Hagfish. (a) This jawless fish is a hagfish from the Pacific Ocean. (b) Hagfish have flexible bodies that they can tie into overhand knots. They tie the knot at their tail, then slide it forward and over their head. This behavior is used to remove excess slime from their body, to escape predators, and to gain leverage when tearing flesh from their prey.

through the mouth, anus, or openings made by other scavengers. They literally eat the carcass from inside out, leaving only the bones and skin.

Hagfishes possess slime glands positioned along their body that can produce large amounts of a milky gelatinous fluid when the animal is disturbed. Although some slime is produced during feeding, its most important function seems to be physical protection. When seized, they produce so much slime that it coats the gills of predatory fish and either suffocates them or encourages them to release their prey. Hagfishes can remove the slime from their bodies by tying their tails in an overhand knot and sliding the knot forward and over the head (see Figure 10-1b).

Little is known about reproduction in the approximately 60 species of hagfish. Although some individuals have both ovaries and testes, the sexes are normally separate. We still do not know where or when hagfish lay their eggs, and relatively few fertilized eggs or juveniles have ever been found. Why females outnumber males by 100 to 1 in some species is also a mystery.

Lampreys

Unlike hagfish, lamprey species inhabit both freshwater and the ocean. As adults, the approximately 40 species of lamprey possess an oral disk and rasping tongue covered with toothlike plates of keratin. Several species use these plates to grasp prey, rasp a hole in the body, and suck out both tissues and fluids. Marine lamprey species, such as *Petromyzon marinus* (Figure 10-2), spend their adult life in the ocean feeding on other fish but return to freshwater to spawn. In North America, spawning takes place in the spring. Males migrate up rivers and build nests from stones in the shallow riffles of clear streams. The females arrive later and attach to one of the stones of the nest by their oral sucker. The male then attaches to the back of the female, and as the eggs are shed, the male sheds his sperm. The fertilized eggs stick to stones in the nest and are ultimately covered by sand. The adults die shortly after reproducing. Larvae hatch in about 2 weeks and migrate downstream, where they burrow into the river bottom with their mouths directed toward the current. The larvae are filter feeders, and they remain burrowed for 3 to 7 years before finally metamorphosing into adults. Predatory forms travel to the sea where they live for up to 2 years before returning to freshwater to spawn. Many species of lamprey and even some populations of parasitic forms, however, do not feed as adults.

Although the invasion of the Great Lakes by the sea lamprey in the early part of the twentieth century brought

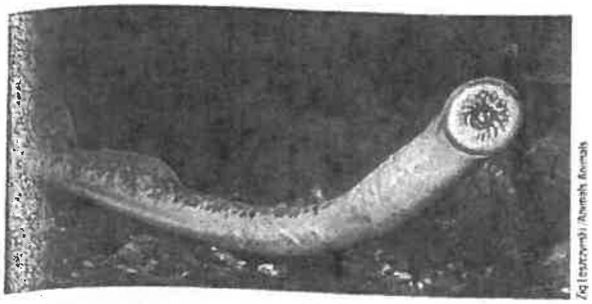


Figure 10-2 **Lamprey.** The marine lamprey *Petromyzon marinus.*

about the near extinction of many lake inhabitants, lampreys, in general, do not seriously deplete their prey populations. Currently, Great Lakes lamprey populations are controlled with the use of lampricides that destroy the larvae of parasitic and nonparasitic species alike. Lampreys have some commercial value as food, and their large nerves make them an excellent subject for neurobiological research.

In Summary

Hagfishes and lampreys are the only existing representatives of early jawless fishes. Hagfishes are bottom-dwelling predators of soft-bodied invertebrates and scavengers of large vertebrates. Very little is known about their natural history and reproduction. Some lamprey species are parasitic on other fish, rasping a hole in their bodies and sucking out both tissues and fluids. Other species do not feed as adults. The larval form is a filter feeder in freshwater. The invasion of the Great Lakes by the sea lamprey in the early part of the twentieth century brought about the near extinction of many lake inhabitants, but lampreys and their prey are able to coexist in other areas. ●

CARTILAGINOUS FISHES

Sharks, skates, rays, and chimaeras are the modern representatives of the cartilaginous fishes, or class Chondrichthyes. Their skeletons are composed entirely of cartilage, although it is often strengthened by the deposition of calcium salts. They possess jaws and paired fins, and their skin is covered with **placoid scales** (Figure 10-3). The teeth of cartilaginous fishes are modified placoid scales. Placoid scales can take several different forms, such as spines or large denticles (toothlike structures) on the back of skates and rays, but they usually form a sandpaper-like covering on sharks.

Cartilaginous fishes can be divided into two major groups, the **holocephalans** (chimaeras, or ratfish) and the **elasmobranchs**. The elasmobranchs have evolved into two general body forms, the typically streamlined bodies of sharks and the dorsoventrally flattened bodies of skates and rays. There are about 760 species of cartilaginous fish including, with the exception of whales, the largest living ver-

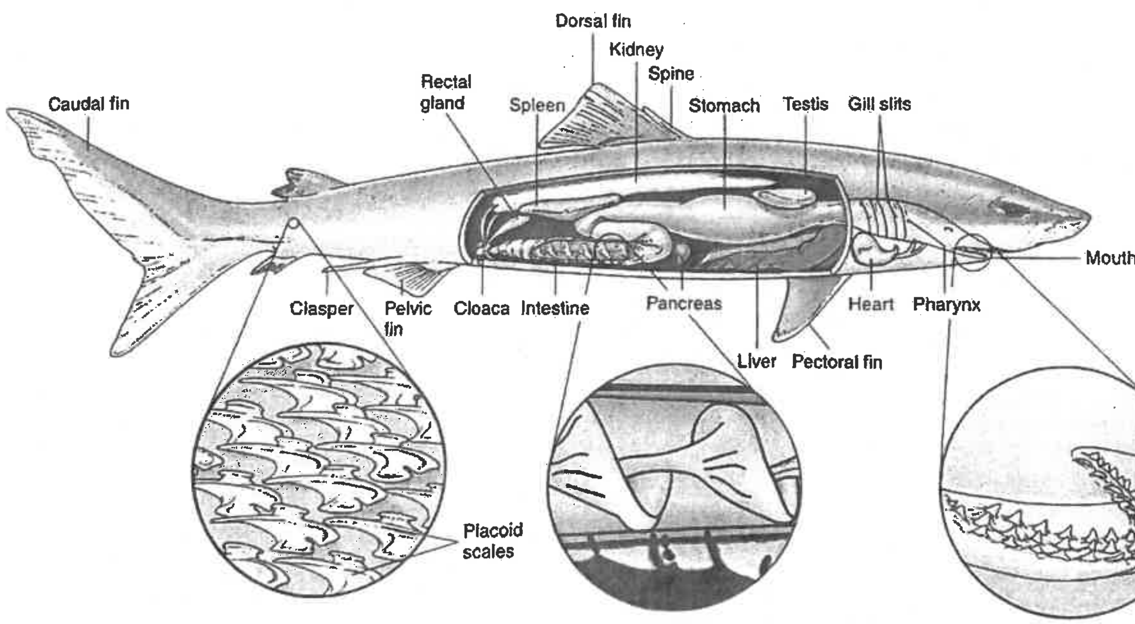


Figure 10-3 **Shark Anatomy.** The external and internal anatomy of a typical shark. Sharks have streamlined bodies and are well adapted for rapid swimming. Their skin is covered with placoid scales, which are similar to the teeth of other vertebrates. Modified placoid scales are found on the jaws and serve as teeth.

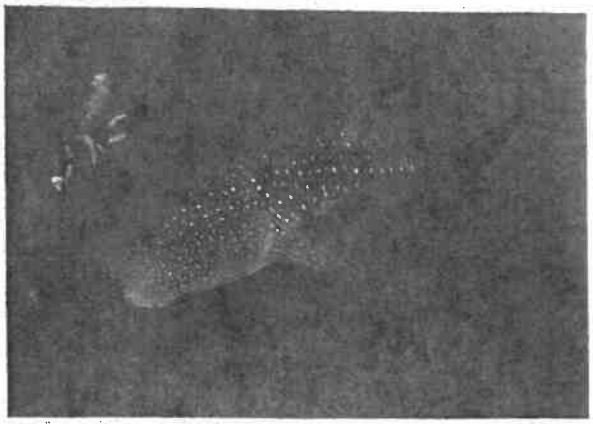


Figure 10-4 Whale Shark. A whale shark cruises a reef off Western Australia.

tebrate animals. The plankton-feeding whale shark (*Rhincodon;* Figure 10-4), for example, may exceed 15 meters (49 feet) in length and is the largest species of fish.

Sharks

Sharks generally have streamlined bodies and are excellent swimmers. Using their massive trunk muscles, sharks swim with powerful, sideways sweeps of the tail, or **caudal fin**. The caudal fin of many sharks is termed a **heterocercal tail**, the dorsal lobe being longer than the ventral. Additional fins include one or two dorsal fins as well as paired pectoral and pelvic fins. A sharp spine may be associated with the dorsal fins, as in the spiny dogfish (*Squalus acanthias*). The pelvic fins of male sharks are partly modified to form **claspers** (Figure 10-5). Claspers transfer sperm from the male to the female during reproduction.

Because sharks are slightly denser than water, they sink if they stop swimming. Many sharks are able to compensate for this buoyancy problem with their large livers (in some species the liver may account for 20% of the shark's weight). The shark's liver produces large quantities of an oily material called **squalene**. Squalene has a density less than seawater's (squalene's density is 0.8 g/cm^3; the density of seawater is 1.020 to 1.029 g/cm^3), and this helps to offset the shark's high density.

Shark Sensory Systems

A shark's eyes lack eyelids, having instead a clear **nictitating membrane** that covers the eye and protects it. The eyes of many species possess both rods and cones, indicating an ability to perceive color. In contrast to bony fishes, vision seems to be of less importance than **olfaction** (smell) in finding prey.

Olfaction The olfactory receptors are very well developed and located in sacs or pits that are usually located in front of the mouth. Almost two thirds of the cells in a shark's brain are involved in processing olfactory information. Indeed, these animals can detect the presence of a drop of blood diluted in one million parts of water and accurately find the source. It is no wonder that some biologists refer to sharks as "swimming noses." The role that the sense of smell plays in locating prey may explain the shape of the hammerhead shark's head (Figure 10-6). This shark has a nostril at the tip of each end of the "hammer," and as it swims, it moves its head from one side to the other. When the strength of a smell is equal in both nostrils, the shark senses that its prey is straight ahead.

Lateral Line System Another important sensory organ is the **lateral line system**, which consists of canals running the length of the animal's body and over the head (Figure 10-7). At regular intervals, the canals open to the outside and there

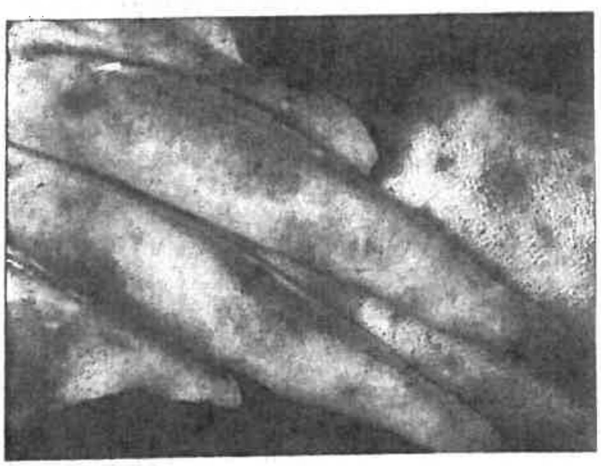


Figure 10-5 Claspers. Male sharks have modified pelvic fins termed claspers that are used to transfer sperm from the male to the female during sexual reproduction

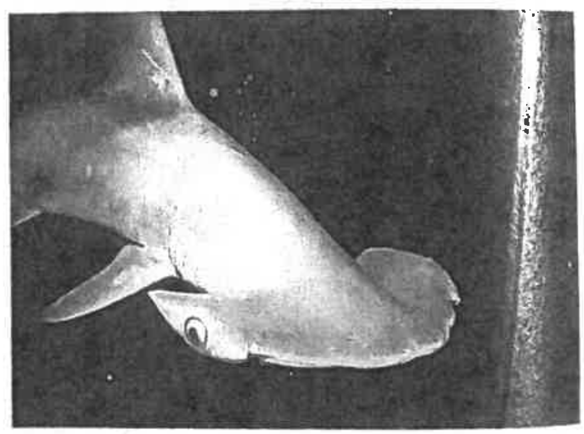


Figure 10-6 Hammerhead Shark. The hammerhead shark has a nostril at the tip of each end of its "hammer." As it swims, it moves its head from side to side. When the strength of a smell is equal in both nostrils, the shark senses that its prey is straight ahead

MARINE BIOLOGY AND THE HUMAN CONNECTION

Shark Attacks on Humans

Sharks have acquired a rather bad reputation in recent times because of accounts of attacks on humans in various movies, novels, and the popular press. In truth, the annual risk of death from lightning is 30 times greater than that from sharks. Although any large shark may be a potential risk to human beings, most species are actually rather timid and cautious animals. Of the approximately 350 shark species, only 32 have been documented in attacks on humans. The three species that seem to be most often involved in deadly attacks are the white shark (*Carcharodon carcharias*), tiger shark (*Galeocerdo cuvier*), and bull shark (*Carcharhinus leucas*) (Figure 10-B). All these sharks are large and cosmopolitan in distribution, and they feed on large prey such as marine mammals, sea turtles, and large fish. Other shark species that have been implicated in human attacks include the mako (*Isurus oxyrhynchus*), hammerhead (*Sphyrna*), oceanic whitetip (*Carcharhinus longimanus*), Galápagos (*Carcharhinus galapagensis*), and various "reef" sharks.

Since 1958, the International Shark Attack File, administered by the American Elasmobranch Society and the Florida Museum of Natural History at the University of Florida, has compiled data on shark attacks throughout the world. According to their data, most attacks (82%) have occurred in North American waters in recent years. Attacks have also been reported from Australia, Brazil, and South Africa. Surfers are the most common targets, followed by swimmers or waders and divers or snorkelers.

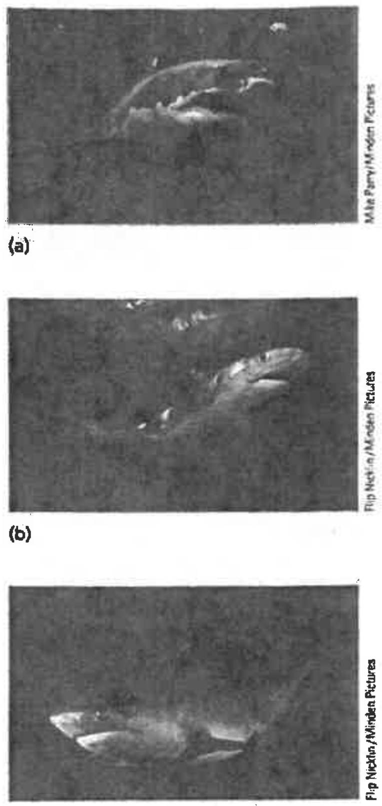


***Figure 10-B* Dangerous Sharks.** *The three shark species most often involved in shark attacks are the (a) great white shark (*Carcharodon carcharias*), (b) tiger shark (*Galeocerdo cuvier*), and (c) bull shark (*Carcharhinus leucas*).*

Types of Shark Attacks

Worldwide, there are usually less than 75 shark attacks and fewer than a dozen fatalities reported annually. Three types of attacks are often described, hit-and-run, bump-and-bite, and sneak attacks. **Hit-and-run attacks** occur most often in shallow water under conditions of low visibility on swimmers or surfers who are splashing the water. The shark bites and then releases the swimmer, usually causing relatively minor lacerations on the limbs that are seldom life threatening. **Bump-and-bite attacks,** in contrast, occur on swimmers or divers in deeper water. The shark bumps the victim before attacking. **Sneak attacks** differ in that they occur without warning. Both sneak and bump-and-bite attacks may occur repeatedly and cause deep lacerations that are severe enough to result in the death of the victim.

Preventing Shark Attacks

Preventing shark attacks involves such commonsense practices as never swimming alone and avoiding areas where people are fishing or where blood and human wastes may be in the water. Don't swim at dusk or at night or where the water is murky or turbid. Also, refrain from splashing. Don't wear shiny jewelry because it may be mistaken for the scales of prey fish. If sharks are sighted, leave the water quickly and calmly. ●

is a free movement of water in and out of them. Within the canals are sensory receptors called **neuromasts** that can detect vibrations in the fluid that fills the canals. Even the slightest movements in the water around the shark stimulate these lateral line sensory receptors. The shark uses its lateral line system to locate prey and potential predators. Some researchers have suggested that the vibrations produced by a swimming human may be similar to those produced by a seal or an injured fish and may account for some sharks being attracted to swimmers.

Ampullae of Lorenzini Sharks and their relatives use the **ampullae of Lorenzini** to sense electrical currents in the water. These organs are scattered over the top and sides of the animal's head. The ampullae of Lorenzini can sense changes of as little as a tenth of a microvolt in the electrical

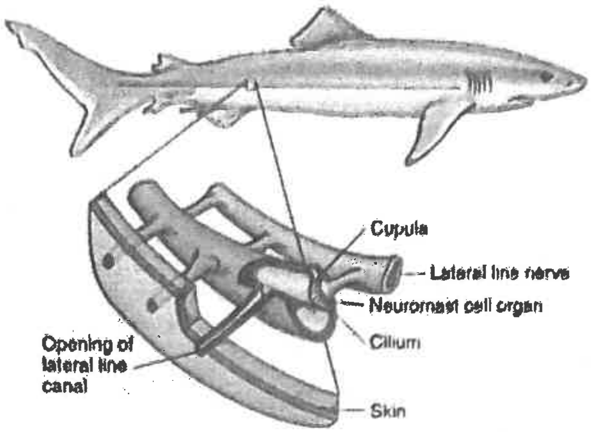


Figure 10-7 The Lateral Line System. The lateral line system consists of two canals, one on each side, that run the length of the animal's body. The fluid in the canals freely communicates with the water surrounding the animal. Even tiny vibrations in the surrounding water cause the fluid in the canals to move, moving the cupula of the neuromast cells and sending a signal to the animal's brain

fields in the water. Marine biologists have speculated that sharks use these organs to sense the tiny electrical fields created by the muscles of their prey.

Digestion in Sharks

A shark's mouth contains several rows of bladelike, triangular teeth that are used for grasping prey and tearing off large chunks. Shark teeth are continually lost and replaced, some species losing more than 30,000 in their lifetime. Sharks shake their heads when biting their prey, because they cannot move their jaws back and forth to chew. Food chunks are swallowed whole. After the food is swallowed, it passes first to the stomach (see Figure 10-3) and then on to a relatively short intestine that contains a structure called a **spiral valve**. The spiral valve aids in the absorption process by slowing the movement of food and increasing the surface area.

Osmoregulation in Sharks

Sharks maintain a solute concentration in their internal fluids greater than or equal to that of sea water by retaining large amounts of nitrogenous wastes, mostly **urea** and trimethylamine oxide (TMAO). If they did not balance the salt concentration of the sea, they would lose body water by osmosis. Both the gills and **rectal gland**, a large structure that empties into the intestine, are involved in the excretion of excess sodium chloride, but the kidney excretes other salts. Many species of shark have the ability to enter freshwater by reducing the levels of nitrogenous wastes in their body fluids.

Reproduction in Sharks

In males, sperm are produced in paired testes (see Figure 10-3) and transferred to the female through a groove in the claspers, the modified pelvic fins described earlier. The

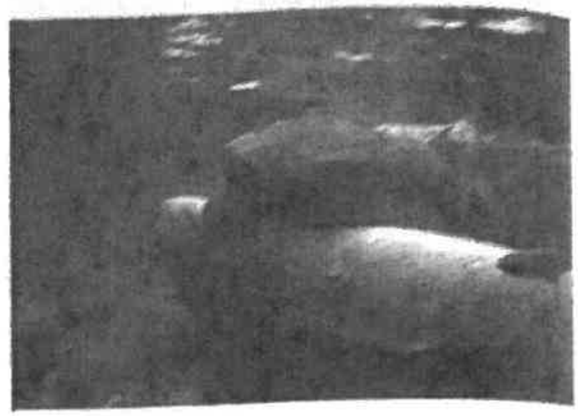


Figure 10-8 Shark Reproduction. When nurse sharks [illegible] male holds the pectoral fin of the female in his mouth [illegible] claspers to introduce sperm into the female's genital opening.

female reproductive system consists of paired ovar[illegible] oviducts. The oviducts carry eggs from the ovary [illegible] tion of the oviduct that is modified to function as a [illegible] Fertilization is internal in sharks (Figure 10-8). Th[illegible] productive modes are seen in sharks and other [illegible] oviparity, ovoviviparity, and viviparity.

Oviparity In oviparous reproduction, the most [illegible] mode, eggs are laid outside the body and the embr[illegible] velop in a protective case. These egg cases attach [illegible] surfaces on the seafloor. Shark pups produced [illegible] ner tend to be smaller than those produced by the [illegible] productive modes because of the limited availabi[illegible] trients within the egg case. Whale sharks, bullhe[illegible] and a few other shark species reproduce in this [illegible]

Ovoviviparity In ovoviviparity, the most commo[illegible] of shark reproduction, eggs hatch within the mothe[illegible] but no placental connection is formed. The develop[illegible] are nourished by yolk stored in the egg. In the [illegible] and a few other species, the yolk is quickly used [illegible] bryos then feed on unfertilized eggs or other embr[illegible] uterus. In these species, only a single pup may [illegible] born from each uterus. Sharks exhibiting ovovivip[illegible] clude basking sharks, thresher sharks, and [illegible]

Viviparity In viviparity, the most recent [illegible] evolve, either the young directly attach to the [illegible] ine wall or the mother's uterus produces "uterine [illegible] is absorbed by the embryo. Viviparous sharks [illegible] quiem and hammerhead sharks.

Skates and Rays

Skates and rays differ from sharks in having [illegible] ies, greatly enlarged pectoral fins that attach [illegible] reduced dorsal and caudal fins, eyes and spiracles [illegible] ings for the passage of water) on top of the [illegible] slits on their ventral side (Figure 10-9[illegible] of the spiracles on the dorsal surface and gill [illegible]

MARINE ADAPTATION

Megamouth Sharks

On November 15, 1976, a group of Navy researchers off the northeastern coast of Oahu in the Hawaiian Islands discovered an unknown species of shark entangled in a nylon drogue (used to position a boat in deep water) they were retrieving. The specimen, now at the Bishop Museum in Honolulu, was subsequently described as a new species (*Megachasma pelagios*) and member of a new genus and family (Figure 10-C). Recent studies indicate that it is the most primitive member of the order Lamniformes (containing mako, white, basking, and thresher sharks). These sharks have a huge head and a highly distensible mouth with a silvery lining. Like its relative the basking shark (*Cetorhinus maximus*), the megamouth shark is a plankton feeder. It is thought that this animal feeds on the plankton community of the deep scattering layer (see Chapter 17). They seem to migrate vertically, following their prey from deep water during the daytime to mid-water depths at night. When feeding, it is thought that the large jaws protrude forward and the mouth cavity expands to suck in the plankton. Elongated, denticle-covered structures filter the shrimp and other organisms from the incoming water.

Bruce Rasner/Jeffrey Rotman Photography

***Figure 10-C* Megamouth.** *Unknown to science until 1976, this unusual shark feeds on plankton.*

Worldwide, only 18 specimens have been captured or observed since 1976. The largest specimen examined was about 5.5 meters (17 feet) and may have weighed a half ton or more. Their mouth contains about 50 rows of relatively small teeth, but only 3 rows are functional. In contrast to other deepwater sharks, the cartilaginous skeleton is poorly calcified and soft. Little is known about their reproductive habits because only one mature female has ever been captured.

A large shark like the megamouth probably has few predators, but there is a documented case of an attack by sperm whales (*Physeter macrocephalus*) off Indonesia in 1998. Almost all specimens have scars, perhaps from the bites of cookie-cutter sharks (*Isistius brasiliensis*).

It may be surprising that an animal as large as megamouth could go unnoticed for so long. Part of the reason may be that the animal spends its days in the remote ocean depths. Another reason may be that, because it is a filter feeder, it would not strike at baited hooks like other sharks, and thus would go unnoticed by fishers. ●

ventral side is an adaptation for a bottom existence. Water is drawn in through the spiracles and passed out over the gills. This arrangement helps to prevent the delicate gill filaments from becoming clogged with sand or debris. Other characteristics include the lack of an anal fin and the presence of specialized pavementlike teeth that are used for crushing prey, usually invertebrates inhabiting sandy or muddy bottoms. In contrast to other rays, the manta (*Manta birostris*) feeds on plankton. Skates and rays, with the exception of sawfishes (*Pristis*) and guitarfishes (*Rhinobatos*), swim with their pectoral fins. Most of the approximately 500 species are adapted to a bottom existence, but a few species, like the eagle (family Myliobatidae) and manta rays live in open water.

Differences between Skates and Rays

Skates and rays differ from each other in several ways. Rays swim by moving their fins up and down as a bird moves its wings while flying. Skates, on the other hand, swim by creating a wave that begins at the forward edge of the fin and sweeps down the edge to the back of the fin, allowing the animal to glide easily along the bottom as its fins ripple. The tails of rays are streamlined and contain venomous barbs or spines. The tails of skates, in contrast, have small fins, lack venomous spines, and are fleshier. Some species of ray grow to a much larger size than skates. The manta ray, for example, can reach a width of 7 meters (22 feet) and weigh more than 1,360 kilograms (3,000 pounds). In contrast, the largest skate (*Raja binoculata*) reaches a length of about 2.4 meters (8 feet).

Most skates are oviparous, releasing their eggs in a leathery, rectangular egg case called a ***mermaid's purse*** (see Figure 10-9c). Rays are ovoviviparous. At birth, the young rays' tail barbs are flexible and covered with a sheath to prevent injury to the mother during the birth of the pup.

Defense Mechanisms

Skates and rays have evolved a variety of defenses to protect them from predators. Electric rays (*Torpedo* and *Narcine*) have a pair of electric organs in their head that can deliver up to 220 volts. In addition to defense, electric rays use their electric charge to navigate and to stun prey. Stingrays (*Dasyatis;* see Figure 10-9b) have hollow barbs connected to poison glands. These modified dorsal fin spines may be distributed along the tail or there may be a single barb at the base of the tail. When disturbed, stingrays whip their tails around. If the barb punctures the skin, it injects venom that causes swelling, cramping, and excruciating pain. A

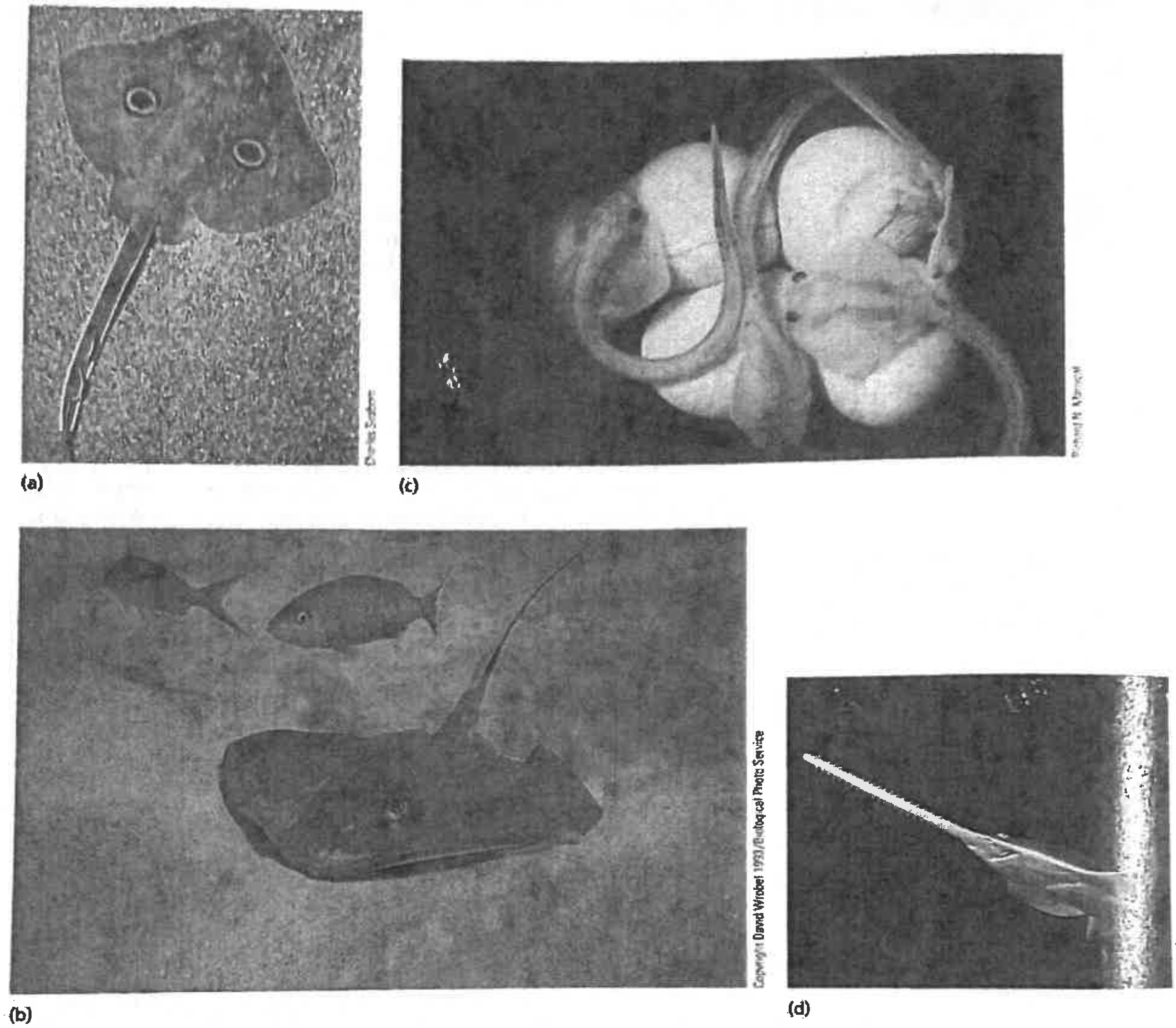


Figure 10-9 Skates and Rays. Both skates and rays have enlarged pectoral fins. (a) Skates lack a stinging spine associated with the tail, whereas (b) rays, like this stingray, have a spine that can inflict a painful injury. Rays are ovoviviparous, whereas skates are oviparous. (c) Skates release their eggs in a leathery egg case called a *mermaid's purse*. This one contains four developing young, each attached to a large yolk sac. (d) Sawfishes are related to skates and rays.

common treatment for stingray injuries is to submerge the injured area in hot water. The heat from the water breaks down the protein toxin. Wounds from stingrays heal very slowly and are prone to bacterial infections.

Sawfishes (see Figure 10-9d) and guitarfishes are very atypical-looking rays. Sawfish have a series of barbs along their pointed rostrums. When disturbed or when feeding, they shake their heads sideways, using the sharp points of the "saw" to inflict injury. Some sawfish can reach a length of 7.6 meters (24.7 feet) and weigh more than 600 kilograms (1,300 pounds).

Chimaeras

Chimaeras (subclass Holocephali; Figure 10-10) are given common names such as *ratfish*, *rabbitfish*, and *spookfish* because of their large pointed heads and long, slender tails. Unlike other cartilaginous fish, the gills are covered with an

Figure 10-10 Chimaeras. Relatives of the sharks, chimaeras like this female ratfish from Vancouver Island, Canada, are bottom dwellers that feed on a variety of fishes and invertebrates

operculum and water is taken in through the nostrils. Males have a clasper on the head as well as claspers on the pelvic fins. Chimaeras are oviparous, producing large eggs in a leathery case. Instead of teeth, chimaeras have flat plates that they use to crush their prey. They feed on a wide variety of foods, including crustaceans, molluscs, echinoderms, and fish. Generally bottom dwellers, they inhabit depths ranging from the shallows to 2,545 meters (8,400 feet) or deeper. Commercially, the 35 known species are of little value. Some are marketed as food in parts of China and New Zealand, and their oils make a fine lubricant.

In Summary

Sharks, skates, rays, and chimaeras are the modern representatives of the cartilaginous fishes, which comprise the class Chondrichthyes. Their skeletons are composed almost entirely of cartilage, although it is often strengthened by deposition of calcium salts. Sharks have streamlined bodies and are efficient swimmers. They have many highly developed senses and most are predators. Sharks maintain the concentration of solutes in their internal fluids at greater than or equal to that of seawater by retaining large amounts of urea and TMAO. Ovoviviparity is the most common reproductive mode of sharks.

Skates and rays are similar to sharks but have flattened bodies, greatly enlarged pectoral fins that attach to the head, reduced dorsal and caudal fins, and gill slits on their ventral side. They are bottom dwellers that feed primarily on molluscs and crustaceans. Some species of ray are able to generate electricity, which they use for protection and to stun prey. Others have sharp spines on their tails. Some of these spines are hollow, connected to poison glands, and capable of inflicting serious injury. Chimaeras, or ratfish, have large pointed heads and long, slender tails. Unlike other cartilaginous fish, the gills are covered with an operculum and water is taken in through the nostrils. They feed on crustaceans, molluscs, echinoderms, and fish, using flat plates to crush their prey instead of teeth. ●

BONY FISHES

The approximately 25,000 species of modern bony fishes (class Osteichthyes) are so diverse that no single characteristic separates them from the cartilaginous fishes. Most forms, however, can be characterized by the presence of a swim bladder (or lung), bone, bony scales, and fin rays. Bony fishes constitute about half of all vertebrates and more than 95% of all fishes. They can be divided into two major lineages, the lobefins (subclass Sarcopterygii), containing the coelacanths (*Latimeria*) and freshwater lungfish, and the ray-finned fishes (subclass Actinopterygii), containing all other species. In many new classifications, these subclasses have been raised to the class level, reflecting the significant differences between the two groups.

Coelacanths

Coelacanths (Figure 10-11a) are relicts of the evolutionary line that gave rise to the tetrapods, or land vertebrates. They are characterized by lobed, paired fins that resemble the limbs of tetrapods. Coelacanths were known from fossils until a living specimen was discovered in 1938. This specimen was given the scientific name, *Latimeria chalumnae*, and it created quite a stir in the scientific community. A second specimen was found in the deep waters of the Indian Ocean around the Comoro Islands in 1952, and several other specimens have since been taken there, in the Mozambique Channel, and as far south as Sodwana Bay, South Africa. In 1998 American and Indonesian scientists discovered a new species of coelacanth, *Latimeria menadoensis*, off Sulawesi, Indonesia, some 10,000 kilometers (6,000 miles) east of where they were originally known.

Most coelacanths live at depths of 150 to 250 meters (495 to 825 feet) in rocky areas with steep subsurface gradients. Their skeletons are made of both bone and cartilage, but the vertebral column is essentially cartilage. Their reduced skeleton along with a fat-filled swim bladder allows the coelacanth to maintain neutral buoyancy. Like sharks, coelacanths maintain high concentrations of urea in the blood to remain nearly isotonic to seawater. They are ovoviviparous.

Ray-Finned Fishes

The ray-finned fishes are by far the most numerous and dominant group of vertebrates in the ocean. There are so many specialized forms that it is difficult to define common characteristics, but typically, their fins are attached to the body by fin rays rather than fleshy lobes. We can divide them into two major groups. The first group (subclass Chondrostei) contains primitive forms such as the marine sturgeons (Figure 10-11b). Members of this group possess heterocercal tails like those in sharks, a skeleton made primarily of cartilage, and ganoid scales (Figure 10-12a). Ganoid scales are very thick and heavy, giving the fish an armored appearance. Members of the second group (subclass Neopterygii) typically have homocercal tails, cycloid or ctenoid scales (see Figure 10-12b), and more maneuverable

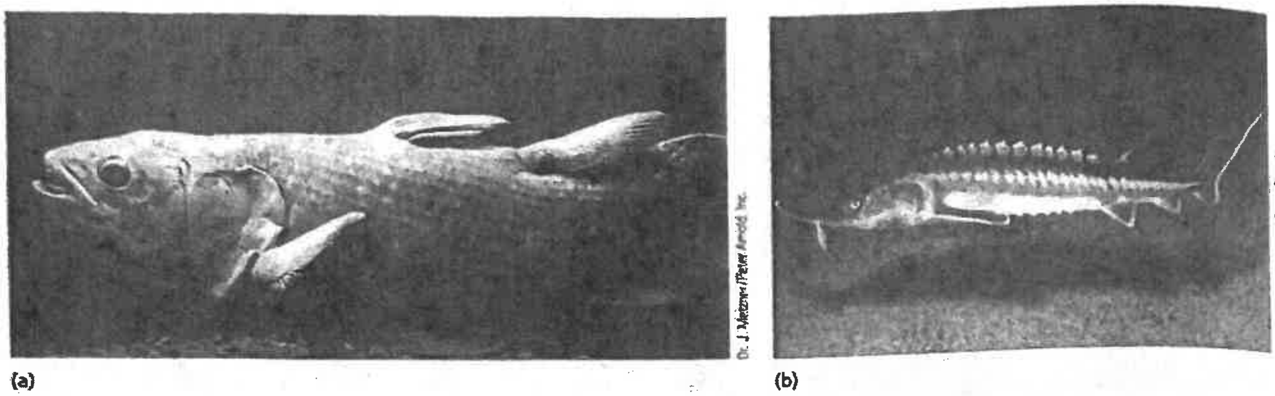


Figure 10-11 Primitive Bony Fishes. (a) A coelacanth. Notice the muscular bundles at the base of the fins. (b) The scales of this marine sturgeon are modified into bony plates that give the fish an armored appearance.

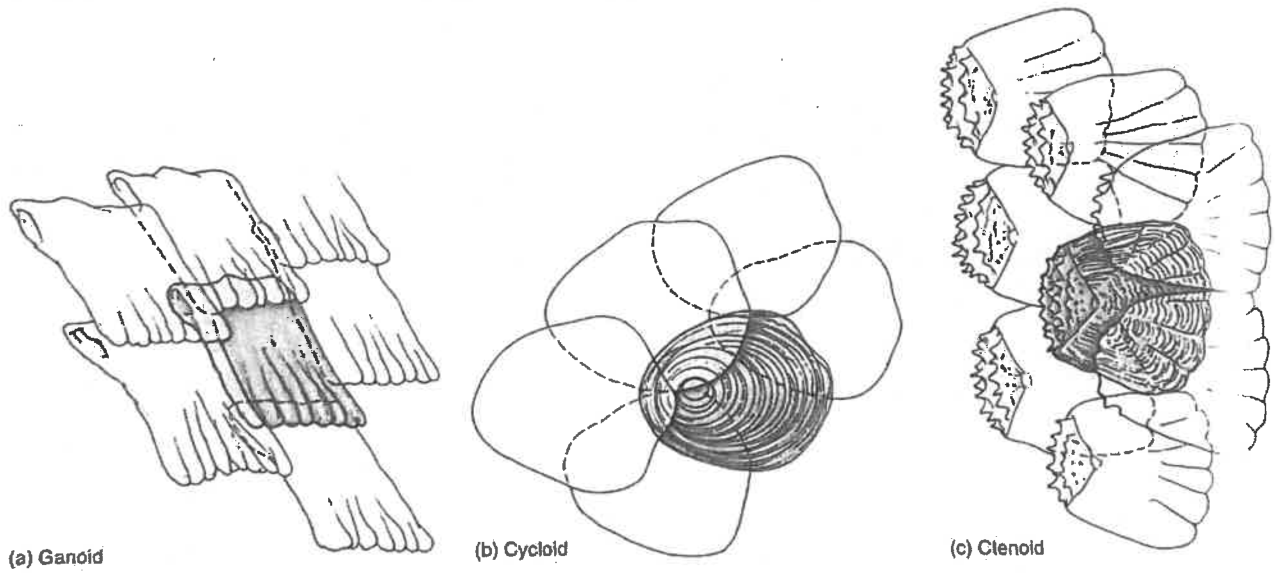


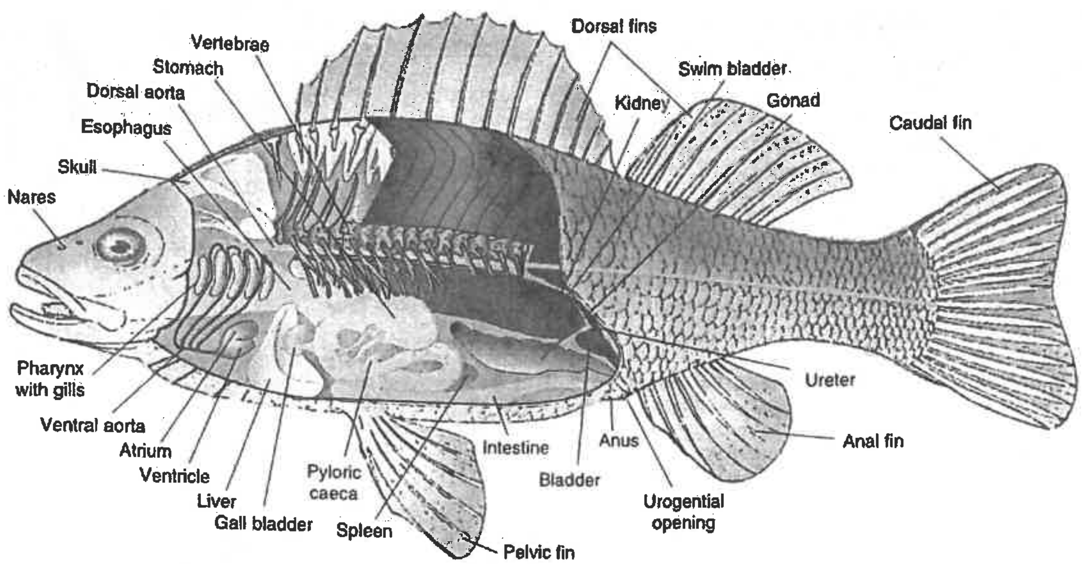
Figure 10-12 Fish Scales. (a) Thick, heavy, ganoid scales are characteristic of primitive bony fishes. More modern bony fishes have lighter, more flexible scales like (b) cycloid scales and (c) ctenoid scales.

fins. **Homocercal tails** have dorsal and ventral flanges that are nearly equal in size, and the vertebral column usually does not continue into the tail. Cycloid and ctenoid scales are thinner and more flexible than ganoid scales and are less cumbersome for active swimmers.

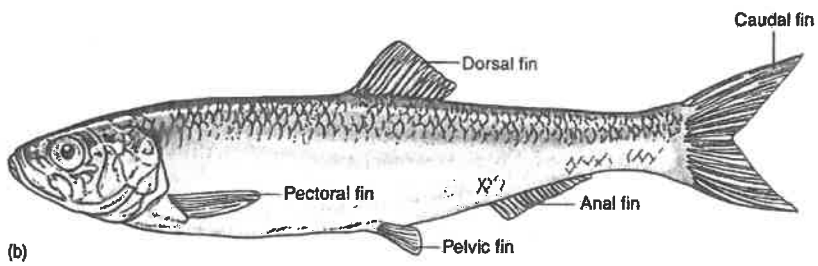
The structure of bony fish fins gives them better control of their movements. Bony fishes possess unpaired median fins and paired fins (Figure 10-13). The median fins consist of one or more **dorsal fins**, a caudal fin, and usually one **anal fin**. Median fins help fishes to maintain stability while swimming. The paired fins consist of pectoral and pelvic fins, both of which are used in steering. Pectoral fins also help to stabilize the fish.

Body Shape

The shape of a fish's body is mainly determined by the characteristics of its habitat. Fishes that are very active swimmers, such as the tuna (*Thunnus*) and marlin (*Makaira*), have a **fusiform body shape** (Figure 10-14a) with a very high and narrow tail. This streamlined body form allows these fishes to move through the water with great efficiency. Fishes that live in seagrass or on coral reefs, like butterflyfish



(a)



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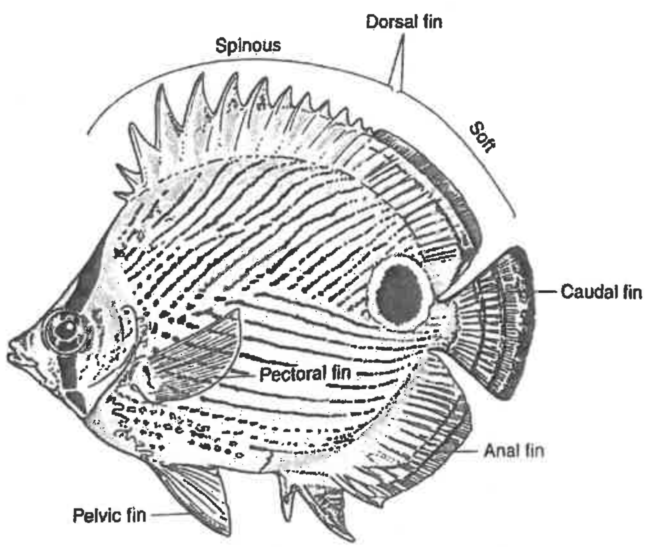
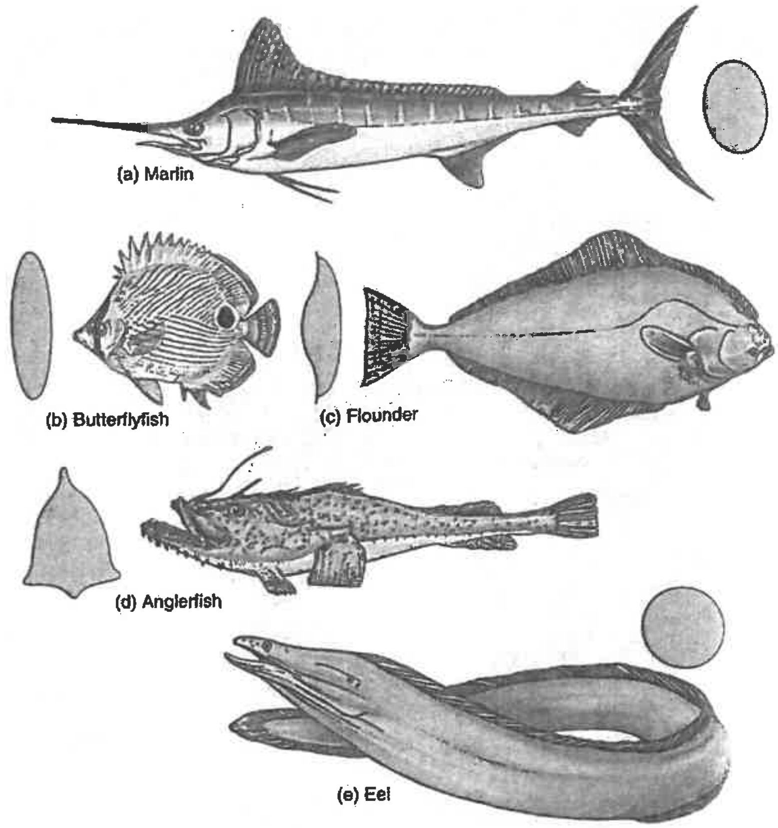


(c)

Figure 10-13 Bony Fish Anatomy. (a) The general internal and external anatomy of a bony fish. (b) In more primitive species, like the herring (Clupeidae), the pectoral fins are lower on the body and the pelvic fins are more posterior. (c) In more advanced species, like butterflyfishes (*Chaetodon*), the pelvic fins are closer to the throat and the pectoral fins are higher on the body and more vertical.

Figure 10-14 Fish Shapes. (a) Fishes that are active swimmers like this marlin have a fusiform body. (b) Reef fishes, such as this butterflyfish, that swim among the corals have laterally compressed or deep bodies. (c) Bottom dwellers like this flounder have horizontally compressed or depressed bodies. (d) Sedentary fishes such as this anglerfish have globular bodies. (e) Burrowing fishes and fishes, like this moray eel, that live in tight crevices have snakelike bodies.



(*Chaetodon*) and angelfish (*Pomacanthus*), have a laterally compressed or deep body that helps them to navigate more efficiently through their complex environment (see Figure 10-14b).

Bottom-dwelling fishes, such as the left-eye flounders (family Bothidae), have depressed or flattened bodies (see Figure 10-14c). Flounders begin life looking like normal fish, but early in the juvenile stage, they begin to swim on their side and an eye migrates from what will become the bottom side to the upper side.

Fishes such as the oyster toadfish (*Opsanus tau*), scorpionfish (*Scorpaena*), and anglerfish (*Antennarius*), which exhibit a more sedentary lifestyle, have globular bodies, and their pectoral fins are usually enlarged to help support the body (see Figure 10-14d). Burrowing fishes and fishes that live in tight spaces, such as moray eels (*Gymnothorax*), have long, snakelike bodies, and they lack or have reduced pelvic and pectoral fins (see Figure 10-14e).

Fish Coloration

Fish colors are of two basic types, **pigments** (biochromes) and **structural colors.** Because most bony fishes use vision as their primary sense in food finding and communication, color can be important in both concealment and species recognition.

Pigments Pigments are colored compounds found in **chromatophores,** irregularly shaped cells, usually appearing as a central cell body with radiating processes (for more information on chromatophores see Chapter 9). Fish are able to alter their color by moving pigments between the central core and these processes. The flounder, for example, is well known for its ability to alter body color and pattern to match its immediate environment. The control of pigment movement is complex but appears to be under both hormonal and nervous influence. The most common pigments in fishes are the melanins and carotenoids.

Structural Colors Structural colors are produced by light reflecting from crystals located in specialized chromatophores called **iridophores.** Unlike pigments, these crystals are colorless and relatively immobile within the cells. Depending on their orientation, they can produce the mirror-like silver color of many pelagic fish or the iridescent colors seen in many reef fishes.

Countershading Fishes that live in the open ocean, such as tuna, marlin, and swordfish (*Xiphius gladius*), display a type of coloration known as **obliterative countershading.** A fish with obliterative countershading has a back (dorsum) colored dark green, dark blue, or gray, and the shades graduate on the sides to the belly's pure white. When viewed from above, the dark back blends in with the surrounding dark water. When viewed from below, the white belly blends in with the brightly lit surface. This effectively camouflages the animal even though it is in open water. This same type of coloring is also found in sharks, many marine mammals, and penguins.

Disruptive Coloration Many species of coral reef fish exhibit **disruptive coloration** (Figure 10-15), in which the background color of the body is usually interrupted by vertical lines. This helps to break up the pattern and make it more difficult for predators to see the fish. Often, one of the lines passes through the eye, making it more difficult to be seen, and a dark dot, or eyespot, is present in the area of the tail. Many aquatic predators use the eye to determine which end of their prey is the head. The eyespot on the tail and the line through the eye draw a predator's attention to the wrong end of the fish, making it more likely that the prey will survive an attack.

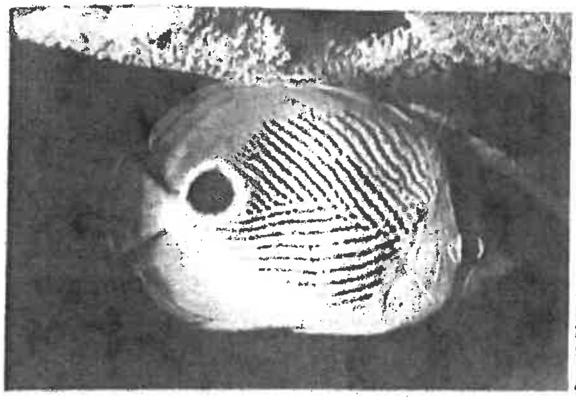


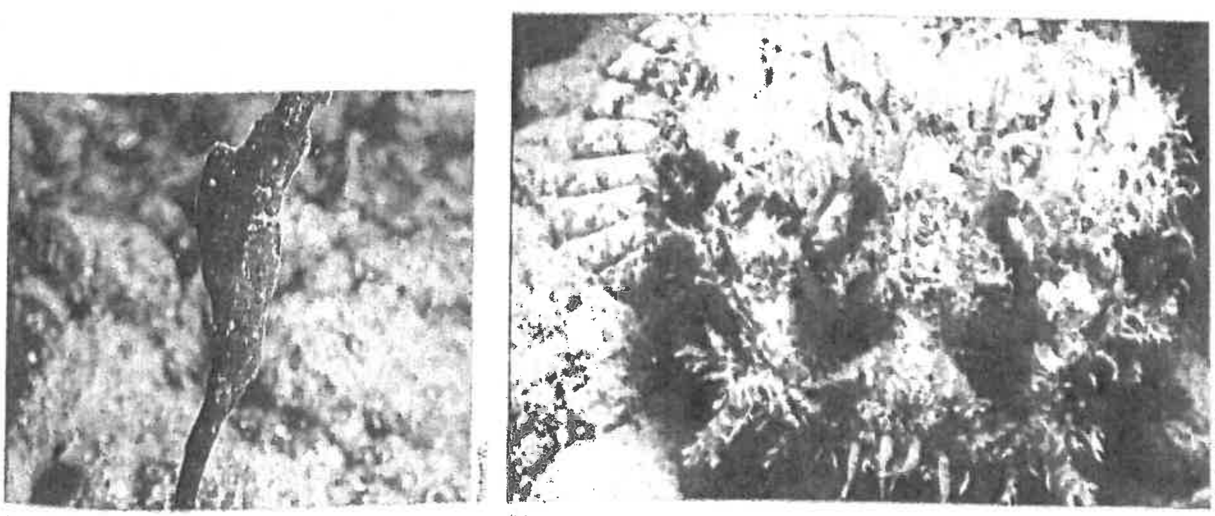
Figure 10-15 Disruptive Coloration. The vertical lines on this butterflyfish from the Pacific Ocean break up the background color, making the fish more difficult to see. Notice the band that runs through the eye and the eyespot on the opposite end of the body, which make it more difficult for a predator to identify the fish's head.

Cryptic Coloration Some fishes use **cryptic coloration** to blend with their environment, camouflaging themselves to avoid predators or ambush prey. Several pipefish species (*Syngnathus;* Figure 10-16a), for example, avoid predation by mimicking seaweed, both in body pattern and behavior. Many scorpionfish (family Scorpaenidae; see Figure 10-16b) use their irregularly shaped bodies and coloration to blend almost perfectly with the environment. Smaller fishes on which they prey do not see the hidden scorpionfish and on swimming too close become an easy meal.

Poster Colors Many fish associated with coral reefs exhibit **poster colors**, bright showy color patterns that may advertise territorial ownership, aid foraging individuals to keep in contact, or be important in sexual displays. Lionfish (*Pterois volitans*, Figure 10-17) and some other species seem to use bright colors as **warning**, or **aposematic, coloration** to advertise to predators that they are too venomous or spiny to be worth eating.

Locomotion in Bony Fishes

Bony fishes move about by drifting with the current, burrowing, crawling on the bottom, gliding, and swimming, the latter being the most common method. In swimming, the trunk muscles propel the fish through the water. These



(a) (b)

Figure 10-16 Camouflage. (a) This pipefish from the Solomon Islands in the Pacific Ocean resembles a piece of seaweed. (b) A scorpionfish from the Caribbean mimics its environment.

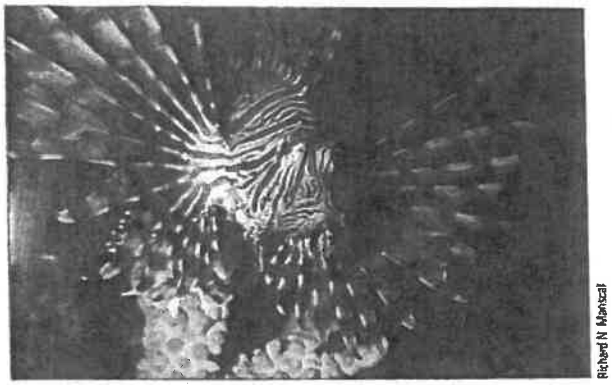


Figure 10-17 Warning (Aposematic) Coloration. Some species, like this lionfish, use bright colors to advertise to predators that they are too venomous or spiny to be worth eating.

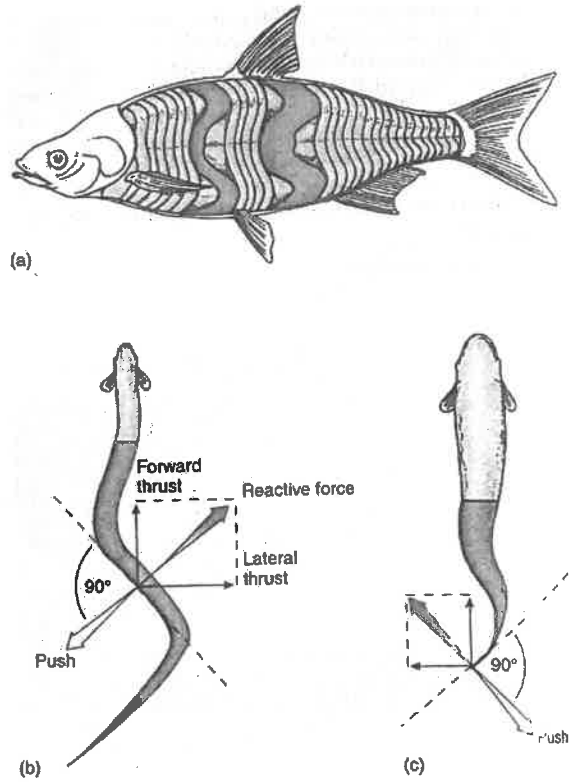


Figure 10-18 Fish Locomotion. (a) The trunk muscles of fishes are arranged as a series of W-shaped bands. These muscles contract in sequence from anterior to posterior and alternately from one side of the body to the other. By pushing the body against the water, the fish is propelled forward. (b) Eels undulate the body one full wavelength in swimming. (c) Jacks and other swift swimmers throw the body into a shallow wave of less than one-half wavelength.

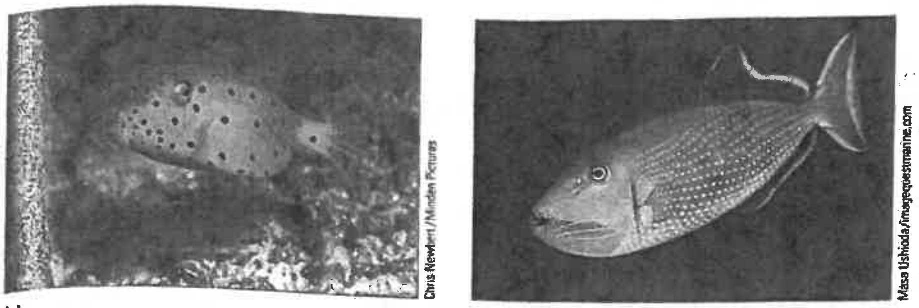
muscles are arranged as a series of muscle bands, and each band looks like a letter *W* lying on its side (Figure 10-18a). Movement results when the bands of muscles contract alternately from one side of the body to the other. The muscle contractions originate at the anterior end of the fish and move toward the tail, flexing the body and pushing against the water.

The type of swimming characteristic of elongate fish, such as eels, involves undulating the entire body (see Figure 10-18b). In contrast, swift swimmers such as jacks (family Carangidae), snappers (family Lutjanidae), tuna and mackerels (family Scombridae), and drums (family Sciaenidae) swim by flexing only the posterior portion of the body (see Figure 10-18c). Fishes like cods (family Gadidae) flex their bodies, making a movement somewhere between the full-body undulation of the eel and the posterior body flex of the jacks. Trunkfish (family Ostraciidae) are encased in a dermal skeleton so only the area before the caudal fin can be flexed (Figure 10-19a). Movement is relatively slow, but these fish have toxins and spines to protect them from predators. Many species swim by using their fins alone without body flexure. Triggerfish (family Balistidae, see Figure 10-19b), for example, can move by undulating only their dorsal and anal fins. Wrasses (family Labridae) sometimes move by using the pectoral fins as oars. Flying fish (family Exocoetidae) use their expanded pectoral fins when they glide through the air.

Respiration and Osmoregulation

Bony fishes use their gills to extract oxygen (O_2) from the water, to eliminate carbon dioxide (CO_2), and as an aid in maintaining proper salt balance within the body. Gills (Figure 10-20a) are composed of thin, highly vascularized, rod-like structures called **gill filaments**. In these structures, blood flows in the opposite direction from the incoming water (see Figure 10-20b), creating a countercurrent multiplier system. The countercurrent flow maintains a stable gradient that favors the diffusion of oxygen in to and carbon dioxide out of the body. Water passing over the gills, therefore, constantly meets blood coming from the body with a lower oxygen and higher carbon dioxide concentration. This mechanism is very efficient, studies having demonstrated that up to 80% of the oxygen in the incoming water can be extracted through this arrangement versus less than 10% when the flow is concurrent (in parallel).

Water must be continuously moved past the gills to keep the blood properly oxygenated. Most bony fishes ventilate their gills by pumping water across them. First, water enters the open and expanded mouth cavity. Water is then pushed across the gills by contracting the mouth cavity and expanding the chamber surrounding the gills. The gill chamber contracts and water is released from the opercula, moveable flaps of tissue covering the gills. In contrast to this mechanism, very active fishes, such as mackerel, ventilate their gills by ram ventilation, meaning they continuously swim forward at high velocity with their mouth open.



(a) (b)

Figure 10-19 Methods of Swimming. (a) Trunkfish are enclosed in a "box" made of dermal bone so only the caudal peduncle can be flexed. The entire muscle mass on each side is used to flex the short caudal peduncle, producing a sculling motion. (b) Triggerfish swim by undulating only their dorsal and anal fins.

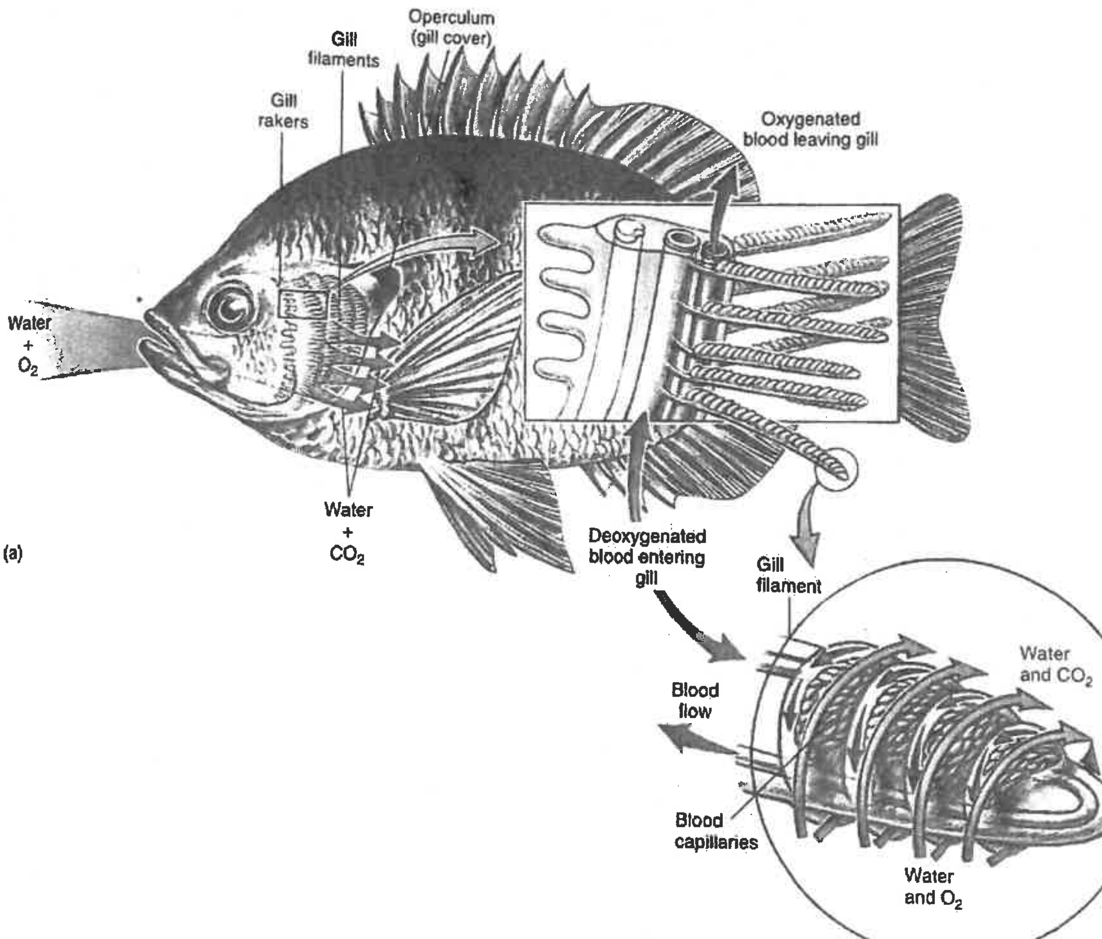


Figure 10-20 The Fish Gill. (a) A fish's gills consist of several layers of thin, delicate, fingerlike filaments. (b) The direction of blood flow through the gill filaments is opposite that of the water flow. The countercurrent arrangement allows gas exchange between the blood and the water to occur along the entire length of the blood vessel, resulting in the greatest amount of gas exchange.

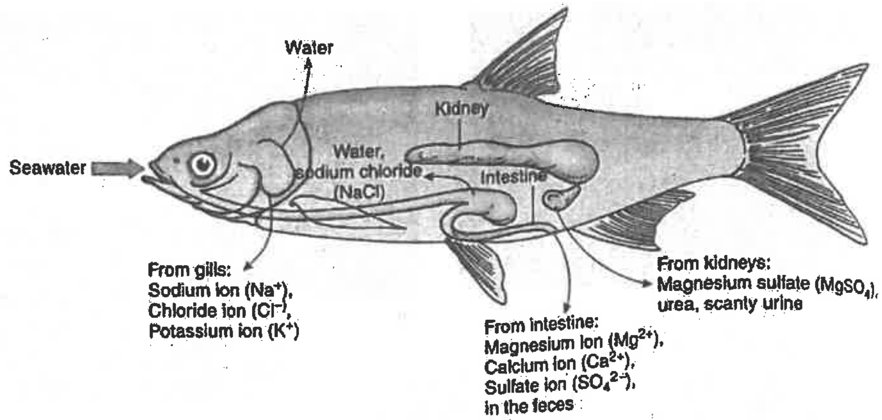


Figure 10-21 Osmoregulation in Bony Marine Fishes. Marine fishes tend to lose water to their surroundings, especially from the gills. In order to replace the water lost, they drink seawater. For this process to be useful, the fish must retain as much water as possible while eliminating the excess salt. Excess salt is eliminated by the gills, the intestine, and the kidneys.

Because the salt concentration of their blood is about one third the concentration of salts in seawater, marine fishes tend to lose much water to their environment. To compensate for this water loss, marine fish drink seawater, remove the excess salt, and retain the water (Figure 10-21). Specialized **chloride cells** on the gills eliminate most of this excess salt. The kidneys and digestive tract remove salts not excreted by this mechanism. Fishes that are adapted to seawater produce negligible amounts of urine, because they need to retain as much water as possible.

Cardiovascular System

The cardiovascular system of fishes consists of a heart, arteries, veins, and capillaries. Deoxygenated blood, initially collected from the veins by a thin-walled chamber (the **sinus venosus**), is passed to a second chamber (the **atrium**) and then to a muscular **ventricle** (see Figure 10-13a). The ventricle propels the blood forward to the gill capillaries where it is oxygenated. From the gills, the blood is collected by the dorsal aorta and passed to the rest of the body through arteries and the capillaries. Blood pressure is lower in fishes than other vertebrates because blood does not return to the heart after oxygenation. Veins collect blood from the capillaries to complete the circuit.

Many active swimmers, such as tuna, have a countercurrent arrangement of their blood vessels (Figure 10-22) to maintain body-core temperature at 2° to 10°C above that of the surrounding water, thereby increasing the efficiency of their swimming muscles. The veins containing relatively cool blood from the body's surface, pass close to and in the opposite direction from the arteries containing warm blood coming from the body's core. Heat is transferred from the blood in the arteries to blood in the veins. In this way warmed venous blood flows into the core of the body, helping to maintain a higher internal temperature.

Buoyancy Regulation

Most bony fishes, with the exception of some pelagic species, bottom dwellers, and deep-sea fishes, use a gas-filled sac called a **swim bladder** (see Figure 10-13a) to help them offset the density of their bodies and regulate buoyancy. By

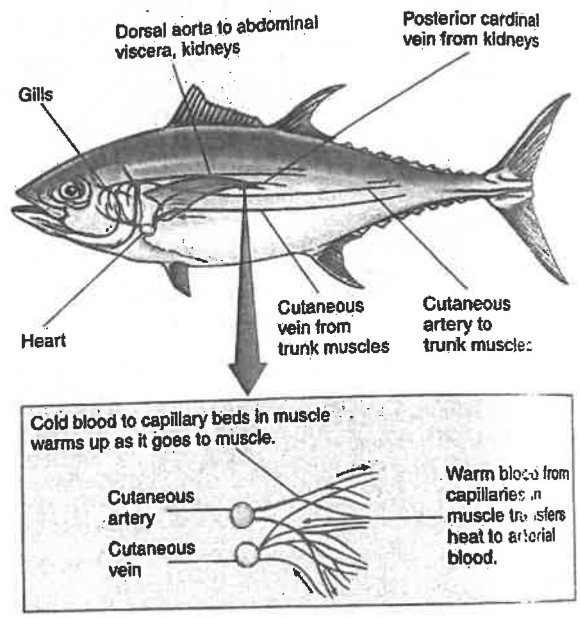


Figure 10-22 Countercurrent Heat Exchange in Tuna. Tuna are able to use a countercurrent heat exchange to keep the core of the body several degrees higher than their environment and thereby improve muscle efficiency.

adjusting the amount of gas in the swim bladder, a fish can remain indefinitely at a given depth without any muscular movement and with minimal expenditure of energy. When the fish descends, more gas must be added to the swim bladder, or else the bladder will compress and the fish become denser and sink. On the other hand, as the fish ascends, it must remove gas from the swim bladder, or else the gas will expand and the fish become less dense and rise too rapidly.

Two mechanisms have evolved to allow adjustments in the gas volume of the swim bladder. Some fish, like herrings and eels, adjust the gas volume of their swim bladders by gulping air from the surface or "spitting it out" as needed. Others use a specialized gas gland to fill the swim bladder from gases dissolved in the blood. In these fishes, the swim bladder is deflated by diffusion of gases directly into the bloodstream.

Pelagic fishes that are active swimmers, such as mackerels (*Scomber*) and skipjacks (*Katsuwonus pelamis*), do not have swim bladders. Like sharks, these animals must keep swimming or they sink. Bottom dwellers, such as scorpionfishes, lack a swim bladder because they do not need to maintain buoyancy in the water column. Many fishes that live in the deep ocean also lack a swim bladder. We will discuss these fishes and their adaptations in more detail in Chapter 18.

Nervous System and Senses

Like other vertebrates, the nervous system of bony fishes consists of a brain, spinal cord, associated peripheral nerves, and various sensory receptors. The brain can be divided into several regions, each involved in coordinating an important body function. Areas associated with the senses of smell (olfaction) and vision are particularly well developed.

Olfaction The olfactory receptors of bony fishes are located in **olfactory pits,** blind sacs that open to the external environment. Swimming, movement of cilia within the pit, or constriction of the nasal sacs themselves allows water to move across the olfactory receptors of most fishes. The olfactory sacs and their receptors may be greatly elongated in some fishes, such as eels, that rely heavily on olfaction to find their prey. Some puffers (family Tetraodontidae), in contrast, have greatly reduced olfactory organs, most likely a result of their primary reliance on sight for feeding.

Taste and Hearing Taste receptors of bony fishes may be located on the surface of the head, jaws, tongue, mouth, and **barbels,** whiskerlike processes about the mouth. These receptors are used to detect both food and noxious substances. Like sharks, bony fishes have a lateral line system, which helps them to detect movement in the water. The ears of bony fishes are internal and capable of detecting sounds in the range of 200 to 13,000 hertz. In comparison, humans hear sounds ranging from 20 to 20,000 hertz.

Vision Bony fishes, as a group, rely on vision more than sharks and rays. Their eyes lack eyelids, and they generally do not need to adjust the size of the pupil, because the quantity of light in water is relatively low. If a fish needs to adjust its vision for distance, the entire lens moves backward or forward, much like focusing a camera.

The eyes of most fishes are set on the sides of the head instead of the front. It is believed that a fish sees only a narrow field directly in front of it with each eye. For the most part, fishes have monocular vision, with each eye seeing its own independent field. In addition to possessing black-and-white vision, shallow water species are able to perceive color.

Feeding Types

The great diversity of bony fishes is reflected in their ability to exploit virtually every food resource available in the marine environment. Included among marine fishes are detritivores, herbivores, carnivores, and omnivores. Various specializations have also evolved that aid in acquiring energy. Herbivorous fishes, for example, typically have longer guts than carnivores, providing them a greater surface area to absorb nutrients from foods containing a high percentage of indigestible matter. Teeth may be highly specialized and positioned on several of the head and face bones.

Carnivores Most bony fishes are carnivores. Prey are usually seized and swallowed whole, because spending time chewing food would block the flow of water past their gills. Many species, such as pufferfish (*Sphoeroides*) and boxfish (*Ostracion*), crush their prey with powerful jaws. Some butterflyfish (*Chaetodon*) use their tiny mouths to feed on individual coral polyps. Groupers (*Epinephelus*) have large mouths with small teeth. They lie in wait in their lairs until their prey comes along. When a mullet (*Mugil*), grunt (*Haemulon*), or large crustacean comes by, the grouper will open its huge mouth, creating suction that draws in the prey. If the prey is too large to fit completely into its mouth, the grouper holds the prey's tail with its small teeth while pharyngeal teeth in the grouper's throat crush, grind, and shear the victim. Flounders lie camouflaged on the bottom, motionless, until a meal in the form of a crustacean, worm, or small fish comes along. The flounder then springs up and grabs the unsuspecting victim.

Herbivores Herbivorous fishes feed on a variety of plants and algae. Surgeonfishes (*Acanthurus*) feed on the algae that grow on rocks and coral. In most species, the teeth are broad and flat with a sharp edge (like a shovel), making them ideal tools for scraping food from these surfaces. In addition, several species have a gizzardlike stomach to grind the vegetable matter. Parrotfish (*Scarus;* Figure 10-23) have teeth that are fused to form a beaklike structure that scrapes algae from the hard surfaces of coral reefs. Some parrotfish species bite off and ingest pieces of coralline algae or hard coral along with the coral's inhabitants. As the material passes through the fish's digestive tract, it is pulverized.

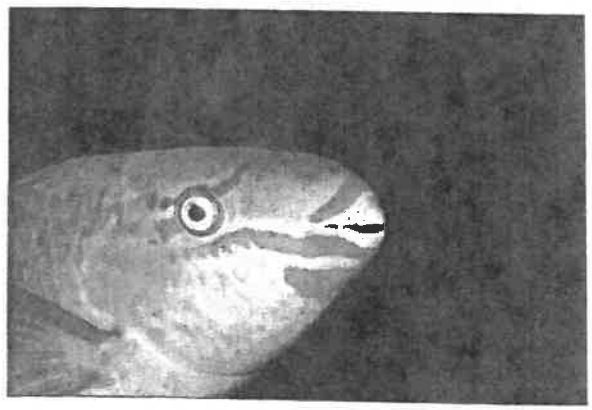


Figure 10-23 Parrotfish. Some parrotfish feed on the symbiotic algae of corals. Their beaklike mouthparts allow them to crush the coral to extract the algae.

The algae are extracted and digested, and fine white sand is passed as part of the indigestible wastes. Because they extract so little organic material from each mouthful of food, parrotfish feed almost constantly. A large parrotfish may weigh as much as 27 kilograms (59 pounds) and expel as much as 2 or 3 tons of sand per year. Parrotfish have contributed sand to many of the white sand beaches of the world. Obvious scars on the reef surface are an indication of active parrotfish feeding.

Filter Feeders Fish larvae as well as pelagic fishes such as anchovies (*Engraulis*) are filter feeders, feeding on the abundant plankton in the sea. Filter feeders typically use projections from the gill arches called gill rakers (see Figure 10-20a) to filter both phytoplankton and zooplankton from seawater. Most filter-feeding fishes travel in large schools and are an important source of food for larger carnivores.

Adaptations to Avoid Predation

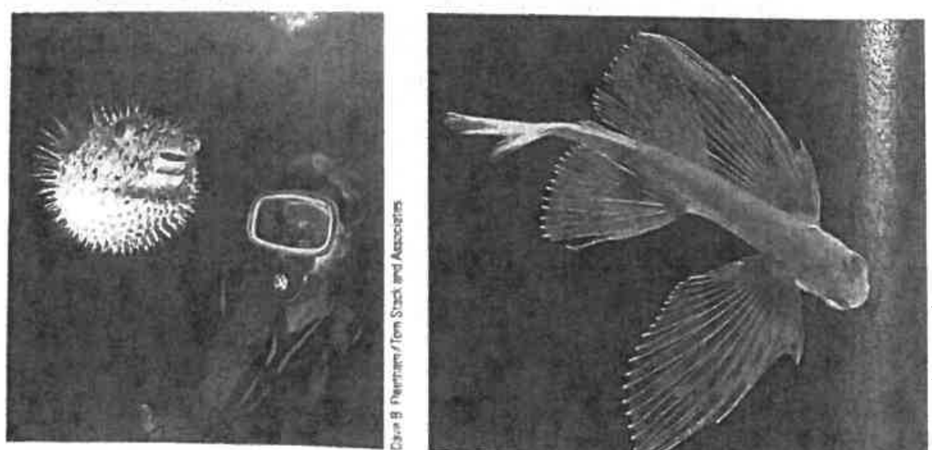
Just as fishes have evolved a variety of feeding styles, they have also evolved many clever strategies to avoid being eaten. Although many marine fishes exhibit elaborate camouflage that obscures their presence, others have evolved more direct methods of avoiding predation. The pufferfishes and porcupinefish (*Diodon hystrix*), for example, can swallow large amounts of air or water and inflate their bodies to a size that deters potential predators (Figure 10-24a). The rapid change in size frightens some potential predators, whereas others now find the fish too large to fit in their mouths. In the case of the porcupinefish, or spiny boxfish, not only does the fish enlarge itself but also in the process extends spines that normally lie flat against the body, adding an extra measure of protection.

Flying fishes (*Cypselurus*) avoid predation by using enlarged pectoral fins to glide through the air (Figure 10-24b). When frightened or disturbed, these fishes swim forward very quickly and leap out of the water, spreading their large pectoral fins at the same time. This behavior allows the flying fish to glide out of the range of many predators. Pearlfish (*Carapus*) avoid being eaten by slipping into the bodies of such animals as sea cucumbers or bivalve molluscs. At night, some species of parrotfish secrete a mucous cocoon about them, perhaps to discourage nocturnal predators. The surgeonfish is so named because of a pair of razor-sharp spines located on the sides of its tail. When this herbivorous fish is disturbed, the spines snap out like a switchblade knife and cut or stab the intruder. Clingfishes (*Gobiesox*) have a powerful sucker (formed from modified pelvic fins) that it uses to secure its body to rocks in tidal pools, where it feeds on crustaceans that are washed into its jaws. Predators have a difficult time dislodging the clingfish and thus tend to leave it alone. The many species of triggerfish (*Balistes*) have dorsal fins that have the first three spines modified. These spines can be pulled flat against the body or projected up. When a predator tries to swallow a triggerfish, it projects the spines and is rejected as a possible meal. The spines also help the triggerfish to wedge itself into the tight nooks and crannies of coral reefs, making it nearly impossible to be dislodged by a predator. Some fishes have venomous spines that protect them from predators. Scorpionfish and stonefish, for example, have venom glands associated with the dorsal, anal, and pelvic spines. The venom of the Indo-Pacific stonefishes (*Synanceia*) is extremely toxic. There are many recorded instances of people accidentally stepping on them and being severely injured or killed.

Reproduction in Bony Fishes

Bony fishes exhibit an amazing variety of reproductive strategies. Spawning fish release their eggs into the water column or deposit them on the bottom. Some species hide their eggs, whereas others guard them until they hatch. Still others brood the eggs in their body until the eggs hatch. Most marine bony fishes are oviparous, but a few groups, such as rockfishes (family Scorpaenidae), exhibit ovoviviparity. The surfperches (family Embiotocidae), found along the Pacific coasts of North America and Asia, exhibit viviparity. Their young develop in a uterus-like structure in the ovary and obtain nutrition from the mother through enlarged, highly vascularized fins.

The gonads of bony fishes are paired structures sus-



(a) (b)

Figure 10-24 Avoiding Predation. (a) A porcupinefish inflates itself to become a large, prickly mouthful. (b) The large pectoral fins of the flyingfish help it to avoid predators by allowing it to leave the water and glide through the air.

MARINE ADAPTATION

Fish Toxicity

To deter predators, many fish species produce toxic substances. Others accumulate toxic substances from their environment in the course of their normal feeding activities. Scorpionfishes (family Scorpaenidae), for example, use the neurotoxins produced in specialized venom glands associated with grooved spines to discourage potential predators. Likewise, species such as parrotfish (family Scaridae) and surgeonfish (family Acanthuridae) produce toxic secretions from their skin, and puffers (family Tetraodontidae) store toxic substances produced by symbiotic bacteria in their internal organs. Barracuda, groupers, and other reef fish may accumulate toxins while feeding in areas associated with blooms of dinoflagellates such as *Gambierdiscus toxicus*.

Although few humans encounter the venom of scorpionfish, more than 50,000 are sickened annually from eating toxic fish flesh. Most cases of fish poisoning are due to eating reef fish containing various forms of a toxin called *ciguatoxin*, the result being termed *ciguatera poisoning*. Spanish explorers in Cuba first reported symptoms of the disorder more than 500 years ago after eating snails they called *cigua*. The physician on the HMS *Bounty* (of *Mutiny on the Bounty* fame) is said to have died after consuming toxic fish. Most people do not die from ciguatera poisoning, but symptoms may persist for weeks, months, and in some cases, years. Symptoms include joint and muscle pain, weakness, intense itching, numbness in the extremities, and reversal of cold and hot sensations. Abdominal cramps, diarrhea, vomiting, and heart arrhythmia may accompany these symptoms. Most treatments have been unsuccessful, although physicians have recently reported some success with injections of mannitol, a sugar alcohol.

Gambierdiscus toxicus grows on dead coral surfaces colonized by filamentous and calcareous algae. Relatively few cases of ciguatera are reported from reefs with living coral. Large groupers, snappers, amberjack, barracuda, and Spanish mackerel are most commonly associated with ciguatera poisoning, but more than 400 species are known to carry the toxin. The fish acquire toxic levels of the ciguatoxin through food-chain amplification. Grazing fish ingest the toxin and are eaten by carnivorous fish that are, in turn, eaten by humans. Cooking has no effect on the toxin and there are no safe, reliable methods to detect it in fish flesh. Cases are reported from Australia, the tropical Pacific, and the Caribbean. In the United States, most cases occur in Hawaii and Florida.

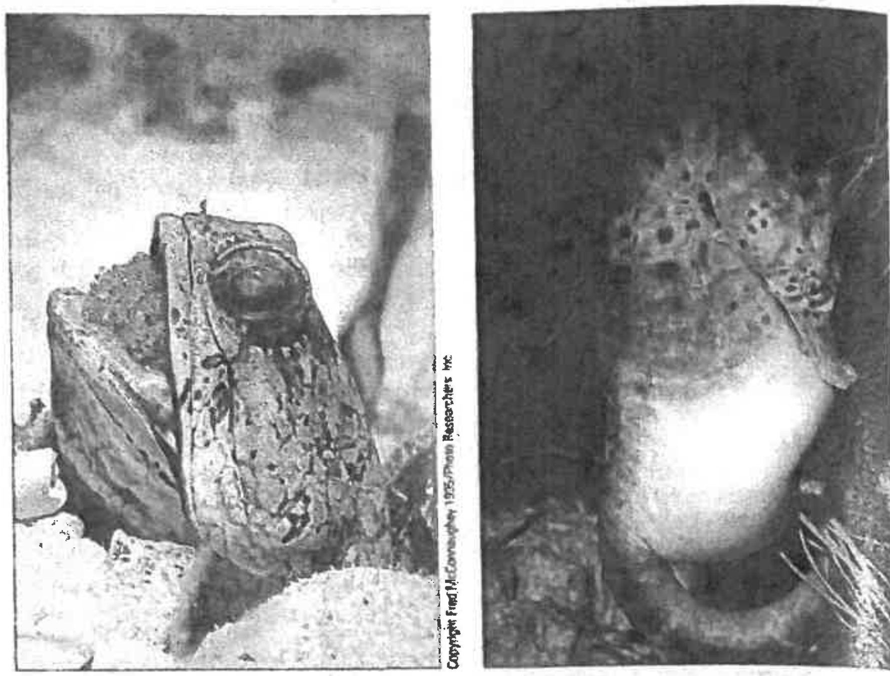
Approximately 100 people die every year, primarily in Japan and the Philippines, from consuming fugu, or Japanese puffer fish (*Takifugu rubripes*). The liver and other internal organs contain a powerful toxin, tetrodotoxin, which blocks nerve-impulse transmission. It is supposedly 1,200 times more lethal than cyanide. Fugu is considered a delicacy; a meal may cost up to $200. Licensed chefs must prepare the fish, and there is usually a ritual associated with consuming the meal. Most deaths occur outside the main cities, where chefs may not be as well trained in proper fugu preparation. ●

pended from the roof of the body cavity by membranes called mesenteries. Sperm from the testes and eggs from the ovaries pass to the outside through special ducts, except in salmon and their relatives, where gametes are shed directly into the body cavity and exit via abdominal pores. In contrast to most land vertebrates, there is typically no association of the reproductive and excretory systems. Development of eggs and sperm is usually seasonal (except in some tropical species), the timing of the reproductive period being influenced by temperature and photoperiod. As in other vertebrates, variation in the level of pituitary and gonadal hormones controls the reproductive process. Courtship varies from none to elaborate ritual displays.

Pelagic Spawners Pelagic spawners include such commercially important species as cod, tuna, and sardines and coral reef species such as parrotfish and wrasses. These species release vast quantities of eggs into the water, the males fertilize them, and the fertilized eggs drift with the currents. There is no parental care. An advantage of this strategy is that the offspring are widely dispersed, but its disadvantage is that mortality is very high. These species compensate by producing large numbers of offspring over a lengthy spawning period.

Benthic Spawners Benthic spawners, such as smelt (family Osmeridae), live closer to shore and produce eggs that are generally larger than those of pelagic spawners and have a large quantity of yolk. These eggs are usually nonbuoyant and are spread over surfaces such as vegetation or rocks. Large numbers of eggs are produced, and there is no parental care. When hatched, the embryos and larvae may be either pelagic or benthic.

Brood Hiders The grunion (*Leuresthes tenuis*) is classified as a brood hider, a species that hides its eggs in some way but exhibits no parental care. Grunions swim ashore at high tide during a full moon, burrow partially into the sand, and deposit their eggs. Males curl around the partially buried female and fertilize the eggs as they are laid. The eggs remain in the sand until the next high tide, when they hatch and are washed out to sea.



(a) (b)

Figure 10-25 Males Incubating Eggs. In some fish species it is the job of the male to incubate and care for the eggs. (a) The male jawfish incubates the eggs in its mouth until they hatch. (b) Male seahorses have a special abdominal pouch in which the eggs are incubated.

Guarders Guarders care for their offspring until they hatch and, frequently, through their larval stages. Many species of damselfish, blennies, and gobies exhibit this behavior. Some species of damselfish defend territory, both as spawning sites and sites to cultivate algae. Spawning sites may be prepared nests or simply a bare surface. Females lay eggs at these spawning sites, but only the male guards the offspring. The amount of time spent guarding the eggs varies from a few days to more than 4 months, as in the Antarctic plunderfish (*Harpagifer bispinis*).

Bearers Jawfish (*Ophistognathus macrognathus*; Figure 10-25a) and seahorses (*Hippocampus*) are examples of bearers. The female jawfish lays her eggs in the mouth of the male, who incubates them in his mouth until they hatch. When the male must feed, he temporarily deposits the eggs in his protected burrow. The female seahorse lays eggs in a special pouch on the male's abdomen (see Figure 10-25b). After the eggs are deposited, the male fertilizes them and then carries and incubates them until the young hatch.

Larval Development In many species, the currents carry the larvae as members of the plankton. Initially, larval fish are nourished by a yolk sac attached to their abdomen (Figure 10-26). As the larva develops, a mouth and digestive tract form, and ultimately the yolk sac is absorbed. When the larva transforms into a juvenile, it leaves the planktonic community and begins to feed as an adult. Unlike birds and mammals that cease to grow or grow very little after achieving maturity, fishes grow for as long as they live.

Hermaphroditism Hermaphroditism, in which individuals have both testes and ovaries at some time in their lives, is known in at least 14 families of bony fishes. Hermaphrodites may be **synchronous**, possessing functional gonads of both sexes at one time, or **sequential**, changing from one sex to another.

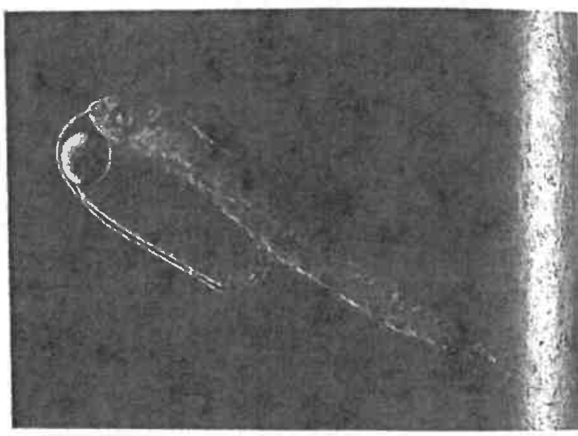
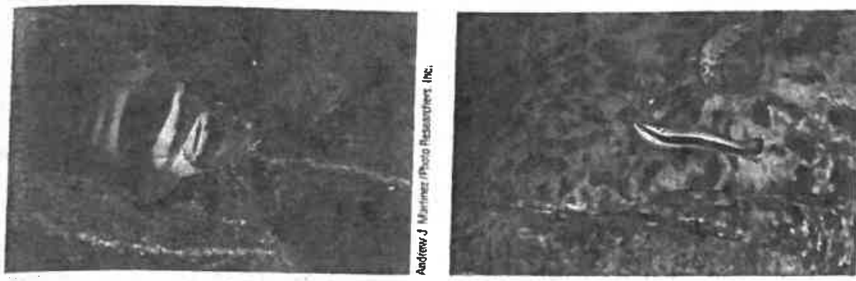


Figure 10-26 Fish Larva. After hatching, many fishes still have a yolk sac containing nutrients attached to their abdomen. The size of the yolk sac impairs the larva's ability to swim, and it remains a member of the plankton until the mouth and digestive tract are fully formed and the yolk sac is absorbed.

Hamlets (*Hypoplectrus*; Figure 10-27a), a small group of tropical fish in the sea bass family (family Serranidae), are synchronous hermaphrodites. A partner in a monogamous pair alternately has its eggs fertilized and fertilizes its partner's eggs. Sexual roles may change up to four times during a single mating encounter.



(a) (b)

Andrew J. Martinez/Photo Researchers, Inc.

Scott Tuason/imagequestmarine.com

Figure 10-27 Hermaphroditism. (a) Hamlets are synchronous hermaphrodites. Members of monogamous pairs alternately offer eggs to be fertilized and, in turn, fertilize their partner's eggs (b) The striped cleaner wrasse (*Labroides dimidiatus*) is a sequential hermaphrodite practicing protogyny. If a male controlling a harem of females dies, the largest female changes to a male and replaces him.

Sequential hermaphrodites may change from females to males (**protogyny**) or from male to female (**protandry**). The most common pattern is a change from female to male, exhibited in members of at least seven fish families, including the wrasses (family Labridae), parrotfish (family Scaridae), and sea bass (family Serranidae). Typically, a large, dominant male of a species like the striped cleaner wrasse (*Labroides dimidiatus;* see Figure 10-27b) controls a harem of females. If this male dies, the largest female changes to a male and replaces him. Males, therefore, may be primary, beginning as a male, or secondary, resulting from a female. Smaller primary males may occasionally contribute their gametes to the next generation by "sneaking" into group spawning aggregations.

The reverse occurs in the anemone fish (*Amphiprion*, family Pomacentridae), a species that inhabits large sea anemones, where it is protected from predators by the host's stinging cells. Each inhabited anemone contains a single large female, a smaller adult male, and many juvenile males. If the female dies or is removed, the adult male changes to a female and is replaced by the largest of the juvenile males. The large female–smaller male combination seems to result in a higher per capita production of offspring and thus has an evolutionary advantage.

Fish Migrations

Migratory movements of marine fish are common and may occur daily or seasonally. Daily migrations are usually associated with feeding and predator avoidance. Grunts (family Haemulidae), for example, hover over reefs during the day but at night move to surrounding seagrass beds to feed. Lanternfish (family Myctophidae) are known to perform rapid vertical migrations of 200 meters (660 feet) or more as they follow their planktonic prey. Seasonal migrations of marine fish are usually associated with spawning, changing temperatures, or feeding. In some species migrations occur entirely within saltwater. In other species migrations occur between freshwater and saltwater. The North Pacific population of albacore tuna (*Thunnus alalunga*), for example, winters in midocean but travels to the California-Oregon coast or the coast of Japan for the summer months. Many other species, such as the herring (*Clupea harengus*), annually travel north and south, following sea temperature variation.

Some fish species move between freshwater and saltwater for a purpose other than reproduction. Young mullets (*Mugil cephalus*), for example, spend part of their time in freshwater or estuaries. But as adults, they live most of their life in the ocean and spawn there. Fishes that move from freshwater to seawater to spawn are **catadromous**, whereas those that move from seawater to freshwater to spawn are **anadromous**.

Freshwater Eels The freshwater eels of North America (*Anguilla rostrata*) and Europe (*A. anguilla*) are probably the best-studied catadromous fishes. Adult eels of both species migrate down coastal rivers to the sea during the fall, changing from a dull olive color to silver and acquiring larger eyes. The American species take about 2 months to reach the deepwater spawning grounds in the Sargasso Sea, which lies southeast of Bermuda (Figure 10-28). The European species takes approximately 1 year to make the journey. Here the eels spawn at depths of 300 meters (990 feet) or more, and the adults die after reproducing.

After the young hatch, they develop into leaflike leptocephalus larvae that begin their migration back to the rivers of Europe and North America. It takes approximately 3 years for larvae to reach Europe but only a year for the North American species to complete the trip. When they arrive at the coastal rivers, they undergo a metamorphosis, becoming juvenile eels, called "elvers," that migrate into streams and estuaries. Males usually remain in fresh water for 4 to 8 years, whereas females require up to 12 years or more to reach sexual maturity. During the fall season following sexual maturity, the eels migrate downstream and return to the breeding grounds of the Sargasso Sea.

The Japanese freshwater eel (*Anguilla japonica*) has a similar pattern, spawning near the Mariana Islands and drifting back to the Orient via prevailing currents. Unlike the American and European eels, some populations of the Japanese eel never enter freshwater but remain in the sea or estuaries. These populations, along with those inhabiting freshwater, all seem to contribute individuals to the populations that return to the waters near the Mariana Islands to spawn.

Salmon The Atlantic and Pacific species of salmon (Figure 10-29) are examples of anadromous fishes. The six species of Pacific salmon (*Onchorhyncus*) return to their spawning grounds only once and then die after reproducing. In contrast, the single Atlantic species of salmon (*Salmo salar*) may spawn more than once in the streams where it was hatched. Salmon lay their eggs in a shallow depression in

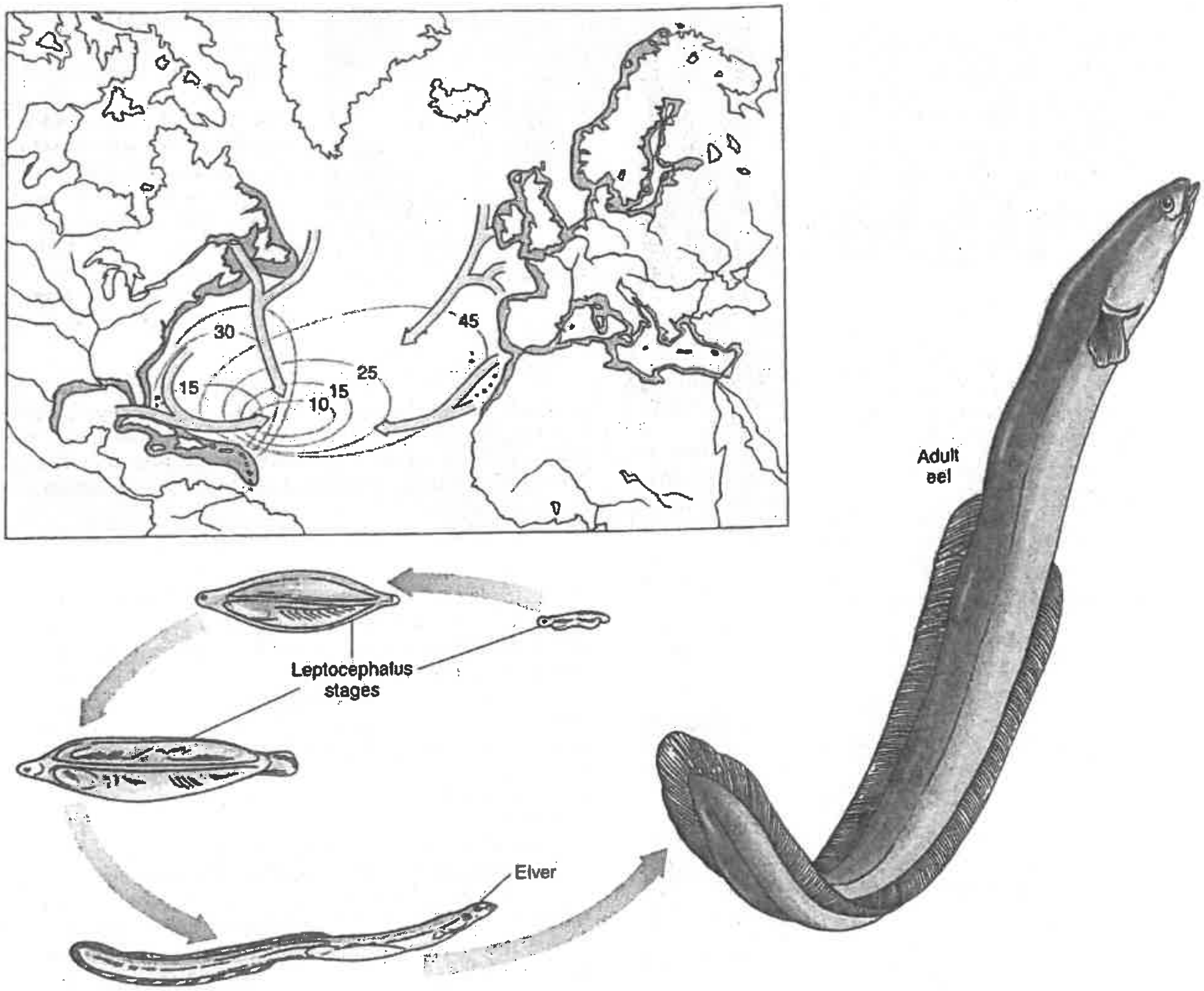


Figure 10-28 Life Cycle of the American and European Eels. Both the American eel (*Anguilla rostrata*) and the European eel (*Anguilla anguilla*) breed in the Sargasso Sea. Yellow arrows indicate the migratory paths the eels follow to the Sargasso Sea. Curved lines and numbers in the ocean indicate larval distribution and size of the larva in millimeters. Colored coastal areas show where the elvers enter rivers.

the gravel of a freshwater stream termed a **redd**. The hatchlings of some species return to the sea immediately, but others may spend up to 5 years in freshwater. Populations of some species never return to the sea but remain landlocked. The young salmon mature at sea and eventually return to the headwaters of their native stream to spawn and complete their life cycle.

Populations of salmon have been greatly reduced because of the damming of rivers, pollution, and the transformation for human use of land bordering streams. The Chinook salmon (*O. tshawytscha*), which once ascended the Columbia River for more than 1,600 kilometers (1,000 miles), has been particularly affected by these activities. Hatcheries have had limited success in maintaining stocks, but there is concern about the loss of the genetic diversity of the wild stock (for more information on salmon hatcheries see Chapter 19).

Experiments have shown that salmon are guided upstream by the characteristic odor of their native stream. The odor is thought to be from chemicals in the soil and plants along the stream's edge. There is some controversy as to how the salmon locate the mouth of their river from the open sea. Some suggest that the fish use cues such as the sun and the earth's magnetic field to find the portion of the

Figure 10-29 Salmon. Salmon are anadromous fishes. They reproduce and mature in fresh water but spend their adult lives in the marine environment. This Pacific salmon has just returned to its native river to breed.

coast near their home stream. Others suggest that currents, temperature gradients, and food supplies ultimately bring a salmon to the mouth of its native stream.

In Summary

Bony fishes move about by drifting with the current, burrowing, crawling on the bottom, gliding, and swimming, the latter being the most common method. Swimming movement results when the bands of muscles contract alternately from one side of the body to the other.

Bony fishes use their gills to extract oxygen from the water and eliminate carbon dioxide. Blood flows in the direction opposite from the incoming water, creating a countercurrent multiplier system that improves the uptake of oxygen from the water. Most bony fishes ventilate their gills by pumping water across them. Gills are also used to maintain salt balance. The kidneys excrete salts that are not removed by other mechanisms.

The cardiovascular system of fishes consists of a heart, arteries, veins, and capillaries. Blood pressure is lower in fishes than other vertebrates because blood is not returned to the heart after oxygenation. Some fish, such as the tuna, use a countercurrent arrangement of their blood vessels to conserve heat in the core of the body and improve muscle efficiency.

Most bony fishes, with the exception of some pelagic species, bottom dwellers, and deep-sea fishes, use a gas-filled sac called a swim bladder to help them offset the density of their bodies and maintain neutral buoyancy. By adjusting the amount of gas in the swim bladder, a fish can remain indefinitely at a given depth without any muscular movement and with minimal expenditure of energy.

Bony fishes have a keen sense of smell, and most species have very good vision. In general, they rely on vision more than sharks and rays. They also possess sense organs for hearing and a lateral line system for sensing vibrations in the water.

Bony fishes exploit virtually every food resource available in the marine environment. Included among marine fishes are detritivores, herbivores, carnivores, and omnivores. Various adaptations have evolved to aid fishes in capturing and processing their prey. Herbivores, for example, have longer guts, providing greater surface area to absorb nutrients from foods containing a high percentage of indigestible matter. Filter feeders use gill rakers to filter both phytoplankton and zooplankton from seawater.

Marine fishes have evolved a variety of adaptations for avoiding predation. These adaptations include sudden changes in size or color; sharp, sometimes poisonous spines; special behaviors, such as rapidly changing size or darting into crevices; and eluding predators by speed or gliding.

Most marine fishes are oviparous, although both ovoviviparity and viviparity occur in a few groups. Fishes also exhibit an amazing variety of reproductive strategies, from the number of eggs produced to the level of parental care. Hermaphroditism is known in at least 14 families of bony fish. Hermaphrodites may be synchronous or sequential.

Migratory movements of marine fish are common and may occur daily or seasonally. Daily migrations are usually associated with feeding and predator avoidance, whereas seasonal migrations are usually associated with spawning, changing temperatures, or feeding. The movements of freshwater eels and salmon are excellent examples of seasonal migrations. North American and European freshwater eels migrate to the Sargasso Sea in the Atlantic Ocean to reproduce. Many salmon live their adult lives in the sea but return to spawn to the freshwater streams where they hatched. ●