UNIT 9

VERTEBRATES

CHAPTERS

"Nature discloses the secrets of her past with the greatest reluctance. We paleontologists weave our tales from fossil fragments poorly preserved in incomplete sequences of sedimentary rocks. Most fossil mammals are known only from teeth—the hardest substance in our bodies—and a few scattered bones."

From "History of the Vertebrate Brain," from *Ever Since Darwin: Reflections in Natural History,* by Stephen Jay Gould. Copyright © 1973, 1974, 1975, 1976, 1977 by the American Museum of Natural History; copyright © 1977 by Stephen Jay Gould. Reprinted by permission of *W. W. Norton & Company, Inc.*, www.norton.com

SCIENTIFIC AMERICAN

References to *Scientific American* project ideas are located throughout this unit.

internet connect

National Science Teachers Association *sci*LINKS Internet resources are located throughout this unit.

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Opossums are the only North American marsupial mammals.

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This blue-spotted stingray, Taeniura lymna, *is one of about 100 species of stingrays that belong in the class Chondrichthyes.*

Antlers, such as those on this caribou, are bony outgrowths that are shed each winter.

These colorful rainbow lorikeets, also known as brush-tongued parrots, can be found in eastern Australia, where they feed on eucalyptus flowers.

Flap-necked chameleon, Chamaeleo delipis

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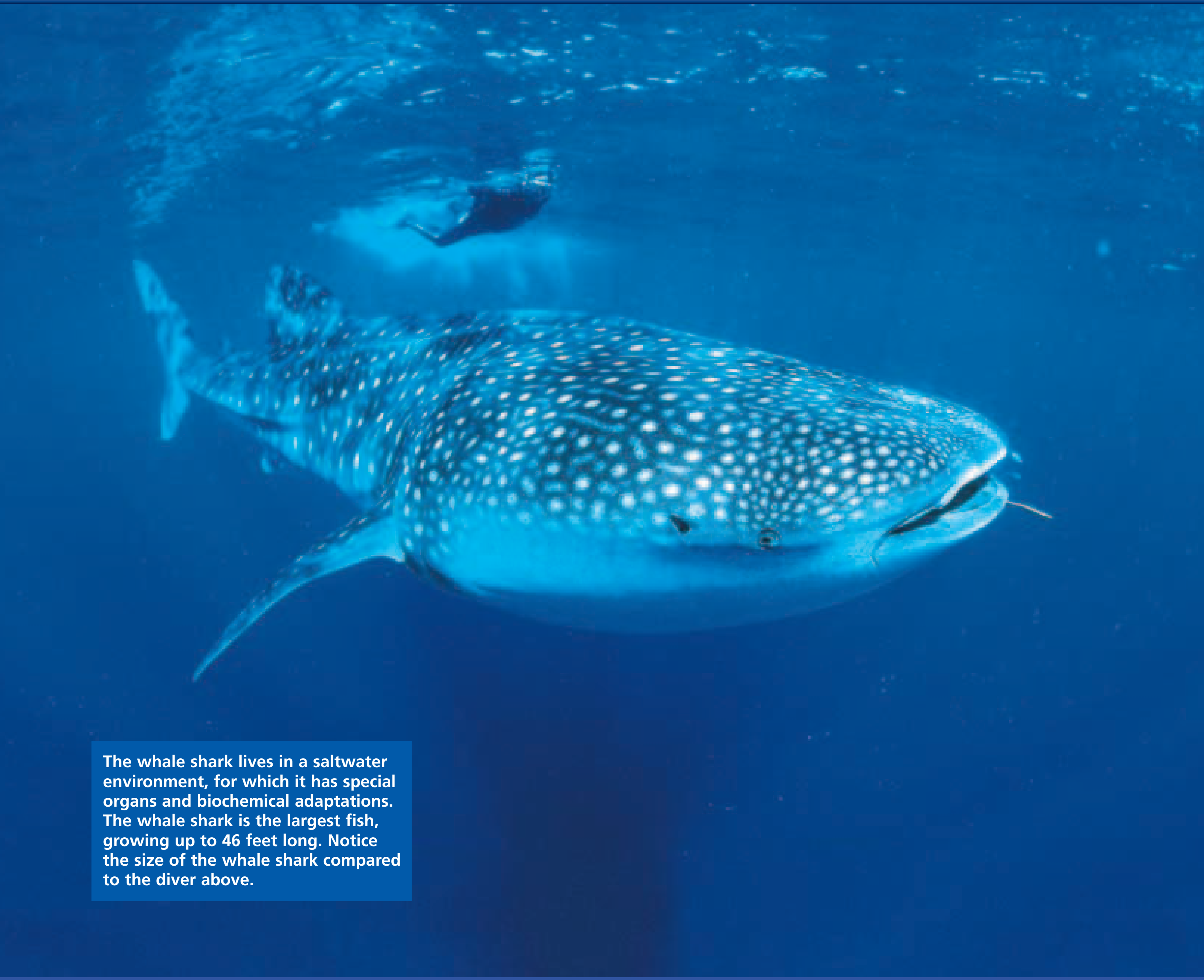
CHAPTER 39

FISHES



The whale shark lives in a saltwater environment, for which it has special organs and biochemical adaptations. The whale shark is the largest fish, growing up to 46 feet long. Notice the size of the whale shark compared to the diver above.

SECTION 1 *Introduction to Vertebrates*

SECTION 2 *Jawless and Cartilaginous Fishes*

SECTION 3 *Bony Fishes*

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INTRODUCTION TO VERTEBRATES

Although the vertebrates are not the most diverse or numerous group of animals, they are the most familiar to us. Vertebrates are an important part of our diet, and many are pets.

CHARACTERISTICS

Members of the subphylum Vertebrata, within the phylum Chordata (kawr-DAY-tuh) have, at some stage of life, a notochord (a rod-shaped supporting axis below the nerve cord), a dorsal hollow nerve cord, pharyngeal pouches (paired structures in the throat region), and a post-anal tail (a tail that extends beyond the anus). Vertebrates have three characteristics that distinguish them from other chordates. First, vertebrates have **vertebrae** (singular, *vertebra*), bones or cartilage that surround the dorsal nerve cord and form the spine. Second, vertebrates have a **cranium,** or skull, that protects the brain. Third, all vertebrates have an endoskeleton (an internal skeleton) composed of bone or cartilage.

Vertebrate Classes

Today, there are about 45,000 species of vertebrates. They occupy all but the most extreme terrestrial habitats. The nine classes of vertebrates are summarized below.

- **Hagfishes** (class Myxini)—These fishes have elongated, eel-like bodies. They lack jaws, paired fins, and bone. The notochord remains throughout life. Hagfishes do not have vertebrae. Many scientists do not consider them vertebrates. They are included with vertebrates because they do have a cranium and an endoskeleton.
- **Lampreys** (class Cephalaspidomorphi)—Lampreys lack jaws, paired fins and bone, and retain a notochord throughout life. However, unlike hagfishes, lampreys have a primitive vertebral column composed of cartilage that surrounds the notochord.
- **Sharks, Rays, Skates, and Ratfishes** (class Chondrichthyes)—These predatory fishes have jaws and paired fins. Their skeleton is made of cartilage, not bone, and many have skin covered by a unique kind of scale.
- **Ray-finned Fishes** (class Actinopterygii)—Most familiar fishes are ray-finned fishes. All have jaws and paired fins, most have a skeleton composed of bone. These fish have fins supported by rays of bone that fan out from a central bony axis.

SECTION 1

OBJECTIVES

- **Identify** the distinguishing characteristics of vertebrates.
- **List** an example for each of the nine classes of vertebrates.
- **Describe** the characteristics of the early vertebrates.
- **Explain** the importance of jaws and paired fins for fishes.

VOCABULARY

vertebrae
cranium
gill arches

Word Roots and Origins

vertebra

from the Latin *vertebra,* meaning "a joint"

internet connect

www.scilinks.org
Topic: Fishes
Keyword: HM60579

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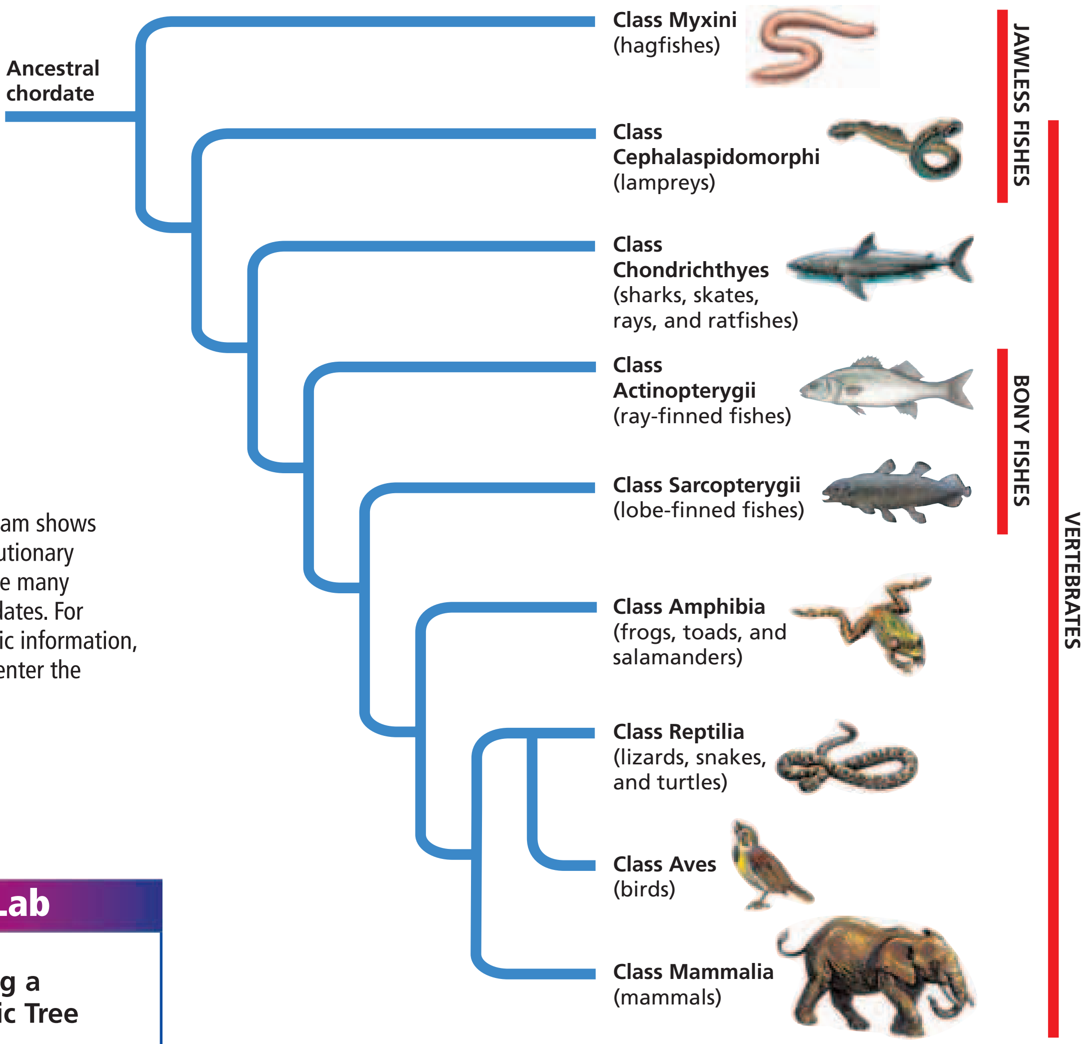

FIGURE 39-1

This phylogenetic diagram shows hypotheses of the evolutionary relationships among the many diverse groups of chordates. For updates on phylogenetic information, visit **go.hrw.com** and enter the keyword **HM6 Phylo.**

Quick Lab

Analyzing a Phylogenetic Tree

Materials paper, pencil

Procedure

1. Draw the phylogenetic tree shown on this page on your paper.
2. Using the information on pp. 779 and 780, determine the key characteristics that distinguish each vertebrate group. Indicate these evolutionary changes on the branches of the tree to make a diagram of the relationship that exists among vertebrates. Begin at the bottom of the tree with the key characteristics that distinguish vertebrates from other chordates.

Analysis Which characteristics are shared by all vertebrates? Which key characteristic separates the classes Chondrichthyes and Actinopterygii? Which adaptations led to the divergence of mammals?

- **Lobe-finned Fishes** (class Sarcopterygii)—These fishes have fins that are supported by a main axis of bone. There are two living groups of lobe-finned fishes: lungfishes and the coelacanth. Extinct lobe-finned fishes are thought to be the ancestors of amphibians.
- **Amphibians** (class Amphibia)—About 4,880 species of frogs, toads, and salamanders belong to this group. Their skin is thin and is permeable to gases and water. Most species lay their eggs in water and pass through an aquatic larval stage.
- **Reptiles** (class Reptilia)—This group includes turtles, crocodiles, alligators, lizards, and snakes. The skin of reptiles is dry and scaly. The eggs of reptiles protect the embryo from drying out and can be laid on land. There are about 8,000 species.
- **Birds** (class Aves)—Birds are characterized by adaptations that enable flight, including feathers, hollow bones, and a unique respiratory system. There are over 10,000 species.
- **Mammals** (class Mammalia)—Humans, cats, mice, and horses are among the members of this group. All mammals have hair and nurse their young with milk. There are about 4,400 species.

Figure 39-1 shows the relationships among the nine classes of living vertebrates.

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VERTEBRATE EVOLUTION

Most biologists think that vertebrates originated about 560 million years ago, shortly after the first chordates appear in the fossil record. The oldest known vertebrate fossils are those of tadpole-like jawless fishes. They appear in the fossil record about 560 million years ago. Figure 39-2 shows an artist's reconstruction of one of these fishes. Jawless fishes were the only vertebrates for more than 50 million years. The survivors became the ancestors of today's jawless fishes.

FIGURE 39-2

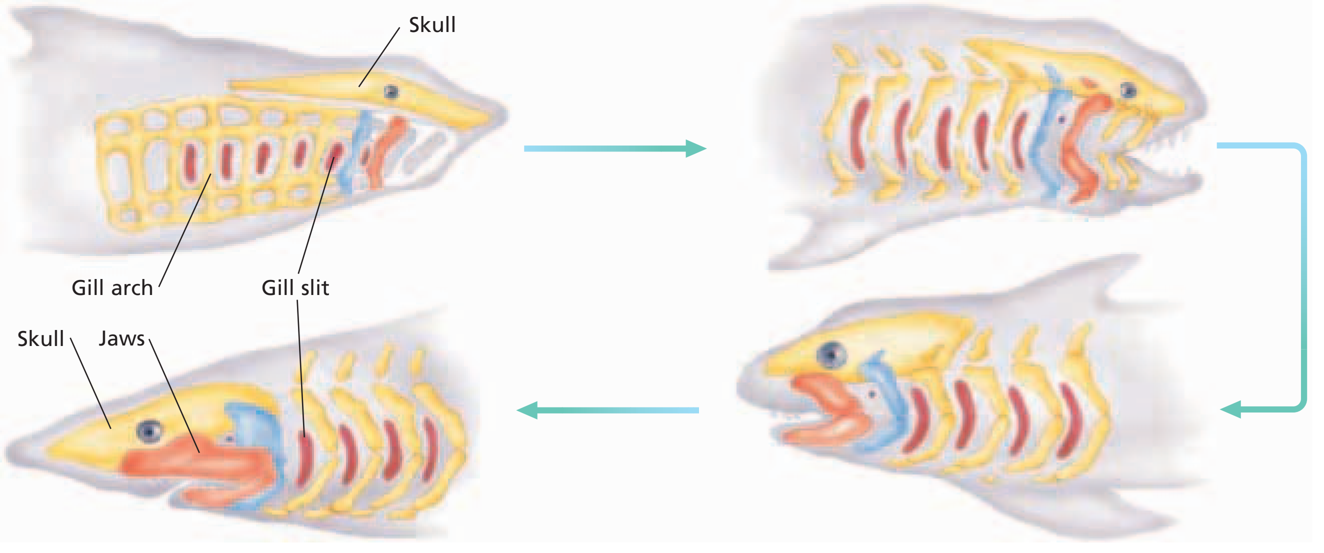
Early jawless fishes, such as this *Pharyngolepis,* lacked paired fins and probably fed on small invertebrates. Most species of early jawless fishes were less than 15 cm (6 in.) in length.

Origin of Jaws and Paired Fins

Almost 450 million years ago, the first fishes with jaws and paired fins appeared. Paired fins increased fishes' stability and maneuverability, and jaws allowed them to seize and manipulate prey. Jaws are thought to have evolved from the first pair of **gill arches,** the skeletal elements that support the pharynx. Figure 39-3 shows three possible stages in this transformation. Modern fishes—the sharks and rays and the bony fishes—make their first appearance in the fossil record about 400 million years ago.

FIGURE 39-3

Jaws are thought to have developed from the anterior gill arches of early jawless fishes. These figures represent hypothesized stages of evolution.



SECTION 1 REVIEW

1. List three distinguishing characteristics of vertebrates.
2. List the nine classes of vertebrates, using both their scientific and common names.
3. State the characteristics of early jawless fishes.
4. Identify the advantages for fish of having jaws and paired fins over not having these structures.

CRITICAL THINKING

5. **Analyzing Information** Why is it important to use unique characteristics to classify animals?
6. **Applying Information** Explain why early jawless fishes might have been awkward swimmers.
7. **Recognizing Relationships** Explain why scientists think that vertebrates evolved from chordates in the sea.

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SECTION 2

OBJECTIVES

- **Identify** three characteristics that make fishes well suited to aquatic life.
- **Describe** three sensory systems in fishes.
- **Evaluate** the similarities between jawless fishes and early vertebrates.
- **Identify** two characteristics of cartilaginous fishes.
- **Contrast** reproduction in lampreys with reproduction in cartilaginous fishes.

VOCABULARY

chemoreception
lateral line
external fertilization
cartilage
placoid scale
internal fertilization

Eco Connection

Hagfish Depletion

Hagfishes are economically important. Most "eelskin" products, such as wallets, are actually made from the tanned skin of hagfishes. The demand for these products is so high that hagfish populations in some parts of the world have been almost wiped out by overfishing.

JAWLESS AND CARTILAGINOUS FISHES

The term fish generally refers to three distinct groups of living vertebrates: jawless fishes; cartilaginous fishes; and bony fishes. Fishes are the most numerous and widespread of all vertebrates.

FISH ADAPTATIONS

The body plan of a fish makes it well suited to live in water. A streamlined shape and a muscular tail enable most fishes to move rapidly through the water. Paired fins allow fishes to maneuver right or left, up or down, and backward or forward. Unpaired fins on the back and belly increase stability. In addition, most fishes secrete a mucus that reduces friction as they swim, and that helps protect them from infections.

Most of the tissues in a fish's body are denser than water. By controlling the amount of gas in their bodies, many fishes can regulate their vertical position in the water. Some fishes also store lipids, which are less dense than water and therefore add buoyancy.

Fishes need to absorb oxygen and rid themselves of carbon dioxide. However, scales on fishes limit diffusion through the skin. Instead, most exchanges between water and blood take place across the membranes of gills—the internal respiratory organs of fishes.

Homeostasis

The concentration of solutes in a fish's body usually differs from the concentration of solutes in the water in which the fish swims. The body of a freshwater fish is *hypertonic.* It has a higher concentration of solutes than the surrounding water does, so the fish tends to gain water and lose ions, such as sodium and chloride ions, through diffusion. Most saltwater fishes are *hypotonic;* they contain lower concentrations of solutes than their surroundings do. Thus, saltwater fishes tend to lose water and gain ions.

Like all organisms, fishes must also rid themselves of the waste products produced by metabolism. The kidneys and gills play important roles in maintaining homeostasis in the tissues and in getting rid of metabolic wastes. The kidneys filter the blood and help regulate the concentration of ions in the body. The gills release wastes, such as carbon dioxide and ammonia, and either absorb or release ions, depending on whether the fish lives in fresh water or in salt water.

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Sensory Functions

Fishes have a variety of organs that allow them to sense the world around them. Fish can sense light, chemicals, and sound. Some can also sense electrical and magnetic fields. Fish eyes are similar to eyes of land vertebrates. Many bony fishes have color vision, but most cartilaginous fishes do not.

Chemoreception is the ability to detect chemicals in the environment. Chemoreception includes the senses of smell and taste. Most fish have one or two nostrils, which lead to sensory cells located in olfactory sacs on both sides of the head. Sharks and salmon are examples of fish with a well-developed sense of smell. Fishes have taste buds located in their mouths. They may also have taste buds on their lips, fins, and skin and on whisker-like organs near their mouths called *barbels*.

Fishes have a unique organ called the **lateral line,** which allows them to sense vibration in the water. The lateral line is made of a system of small canals in the skin. The canals are lined with cells that are sensitive to vibration. Fishes also perceive sound waves with their inner ears, which contain a fluid-filled set of canals that contain sensory cells similar to those in the lateral line canals.

Cartilaginous fishes also have sense organs called the *ampullae of Lorenzini* that can detect weak electrical fields, such as those given off by muscles when they contract. This system has been shown to help them locate prey.

Word Roots and Origins

agnatha

from the Greek *gnathus,* meaning "jaws," and *a,* meaning "without"

JAWLESS FISHES

The only existing jawless fishes are the 80 species of hagfishes and lampreys. These fish were formerly grouped together in the class Agnatha. They are now divided into two classes: Myxini (hagfishes) and Cephalaspidomorphi (lampreys). Their skin has neither plates nor scales. Hagfishes and lampreys have an eel-like body, a cartilaginous skeleton, and unpaired fins. The notochord remains throughout life. Hagfishes live only in the oceans. Many lampreys live permanently in fresh water, and all lamprey species reproduce in fresh water.

Hagfishes

Hagfishes, shown in Figure 39-4, are bottom dwellers in cold marine waters. Hagfishes are unique in that they do not have vertebrae. Hagfishes are also unique because they are *isotonic,* which means that their body fluids have nearly the same ion concentration as sea water. They feed on small invertebrates or on dead and dying fish. Because the hagfish lacks jaws, it cannot bite, but within its mouth are two movable plates and a rough tonguelike structure that it uses to pinch off chunks of flesh. Hagfishes often burrow into the body of a dead fish through the gills, skin, or anus. Once inside, they eat the internal organs.

FIGURE 39-4

Hagfishes are modern jawless fishes. Hagfishes lack paired fins, which allows them to burrow into the bodies of the dead fish on which they feed.

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FIGURE 39-5

A lamprey's mouth is adapted for latching onto prey and feeding on body fluids of other fishes.

Lampreys

About half the species of lampreys are free-living (non-parasitic). The other half are parasites as adults and feed on the blood and body fluids of other fishes. Once a suitable host is located, a lamprey uses its disk-shaped mouth, shown in Figure 39-5, to attach to the host. Then, it scrapes a hole in the host with its rough tongue and secretes a chemical that keeps the host's blood from clotting. After feeding, the lamprey drops off. The host may recover, bleed to death, or die from an infection.

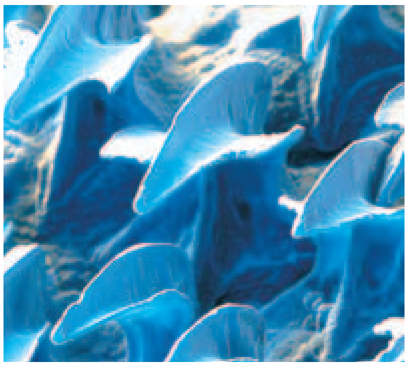
Some lamprey species spend most of their adult lives in the ocean. Others live in rivers or lakes and never enter salt water. All lampreys breed in fresh water. Fertilization occurs outside the body of either parent, a process known as **external fertilization.** The eggs hatch into larvae that resemble an amphioxus, an invertebrate chordate. The larvae eventually transform into adults.

CARTILAGINOUS FISHES

Sharks, skates, and rays belong to the class Chondrichthyes. Because the fishes in this class have skeletons composed of cartilage, they are also called *cartilaginous fishes.* **Cartilage** is a flexible, lightweight material made of cells surrounded by tough fibers of protein. Sharks, skates, rays, and ratfishes differ from lampreys and hagfishes in that they have movable jaws, skeletons, and paired fins. Almost all of the approximately 800 species of sharks, skates, rays, and ratfishes live in salt water. All species are carnivores, and some are scavengers. The skin of cartilaginous fishes is covered with **placoid** (PLAK-OYD) **scales**—small, toothlike spines that feel like sandpaper. Placoid scales, shown in Figure 39-6, probably reduce turbulence of the water flow and thus increase swimming efficiency.

FIGURE 39-6

These teethlike placoid scales are found on the skin of cartilaginous fishes. What advantage might they give a shark in swimming?



Sharks

Sharks have smooth, torpedo-shaped bodies that reduce turbulence when swimming. This shape is called a *fusiform* body shape. Figure 39-7 shows the smooth, fusiform body of a shark.

The largest sharks, the whale shark (up to 18 m, or 59 ft, long) and the basking shark (up to 15 m, or 49 ft, long), feed on plankton, floating plants and animals. Like other filter-feeding fishes, the whale and basking sharks filter the water with slender projections on the inner surface of the gills, called *gill rakers.*

The mouth of a typical shark has 6 to 20 rows of teeth that point inward. When a tooth in one of the front rows breaks or wears down, a replacement moves forward to take its place. One shark may use more than 20,000 teeth over its lifetime. The structure of each species' teeth is adapted to that species' feeding habits. Sharks that feed primarily on large fish or mammals have big, triangular teeth with sawlike edges that hook and tear flesh.

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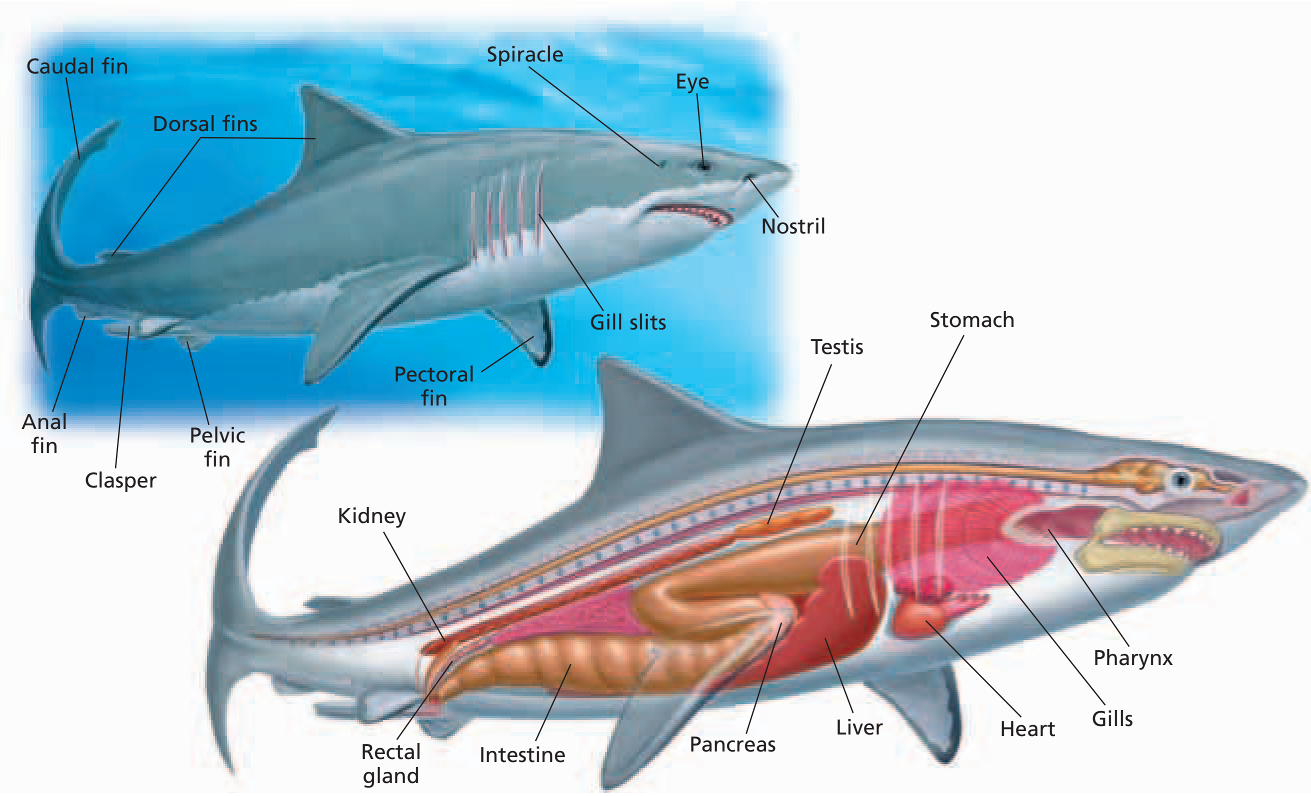


FIGURE 39-7

A fusiform body shape allows sharks to slip through the water with little resistance. The dorsal fins provide stability. The pectoral fins provide lift similar to the way airplane wings function in the air. The shark's internal anatomy includes organs for digestion, reproduction, and maintaining homeostasis.

Rays and Skates

Rays and skates have flattened bodies with paired winglike pectoral fins and, in some species, whiplike tails. Rays have diamond- or disk-shaped bodies, but most skates have triangular bodies. Most rays and skates are less than 1 m (3.3 ft) long. Rays and skates are primarily bottom dwellers. Their flat shape and coloration camouflage them against the floor of their habitat. Most rays and skates feed on mollusks and crustaceans. Figure 39-8 shows an example of a ray.

Ratfishes

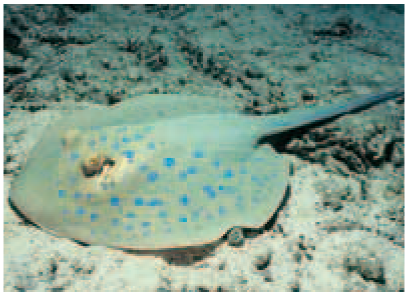
There are about 25 species of strange-looking, mostly deep-water cartilaginous fishes that are grouped separately because of their unique features. The ratfishes, or *chimaeras,* have gill slits covered by a flap of skin. Some have a long, ratlike tail. They feed on crustaceans and mollusks.

Adaptations of Cartilaginous Fishes

In cartilaginous fishes, gas exchange occurs in the gills, which lie behind the head. Efficient gas exchange requires a continuous flow of water across the gills. Some fast-swimming sharks are able to push water through their mouth, over their gills, and out of their gill slits by swimming. However, most cartilaginous fishes pump water over their gills by expanding and contracting their mouth cavity and pharynx. When lying on the bottom, rays and skates cannot bring in water through their mouth, which is located on the ventral surface of their body; instead, they draw water in through their spiracles, which are two large openings on the top of the head, just behind the eyes.

FIGURE 39-8

This blue-spotted stingray, *Taeniura lymna,* is an example of a bottom dweller. This stingray was photographed in the Red Sea near Egypt.



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Quick Lab

Modeling a Shark Adaptation

Materials 8 cm dialysis tubing, 8 cm length of string (2), 100 mL salt solution (5 percent), 250 mL beaker, 10 mL distilled water, scale, graduated cylinder

Procedure

1. Tightly tie one end of the dialysis tubing with string. Place 10 mL of distilled water inside the dialysis tubing, and tie the other end of the tube tightly with string.
2. Record the initial weight of the filled tube.
3. Add the filled dialysis tubing to a beaker filled with 100 mL of salt solution.
4. After 10 minutes, remove the tubing from the beaker, blot the outside, and reweigh it. Record your observations.

Analysis Explain the reason for the change in the weight of the tube, if any. Are sharks likely to lose or gain ions? What physical structures of a shark play a key role in maintaining ionic homeostasis in sharks?

Instead of releasing ammonia, cartilaginous fishes use energy to convert ammonia into a compound called *urea,* which is much less toxic. Sharks retain large amounts of urea in their blood and tissues, thus raising the concentration of solutes in their body to at least the same level as that found in sea water. Because the concentration of sodium and chloride in the body of a shark is less than the concentration found in sea water, these ions still diffuse into the body across the gills and are absorbed with food. The *rectal gland,* located in the posterior portion of the intestine, removes excess sodium and chloride ions from the blood and releases them into the rectum for elimination. Sharks that periodically migrate to fresh water excrete sodium, chloride, and urea along with any excess water that enters their bodies.

Cartilaginous fishes maintain their position in the water in two ways. First, because the caudal and pectoral fins generate lift, or upward force, as a fish swims, it can remain at the same level in the water, counteracting the tendency to sink, as long as it keeps moving. Second, many cartilaginous fishes store large amounts of low-density lipids, usually in the liver. A shark's lipid-filled liver may account for 25 percent of its mass. Lipids give these sharks buoyancy by reducing the overall density of the body.

Reproduction in Cartilaginous Fishes

Cartilaginous fishes differ from jawless fishes in that fertilization occurs inside the body of the female. This type of fertilization is called **internal fertilization.** During mating, the male transfers sperm into the female's body using modified pelvic fins called *claspers.* In a few species of sharks and rays, the females lay large yolky eggs right after fertilization. The young develop within the egg, are nourished by the yolk, and hatch as miniature versions of the adults. The eggs of many species develop in the female's body, and the young are born live. In some of these species, the mother nourishes the developing sharks while they are in her body. No cartilaginous fishes provide parental care for their young after birth or hatching.

SECTION 2 REVIEW

1. Identify each characteristic of fishes that makes them well suited to aquatic life.
2. Describe two unique sensory systems that can be found in fishes.
3. Contrast the feeding behavior of hagfish to the feeding behavior of lampreys.
4. List three characteristics that distinguish cartilaginous fishes from living jawless fishes.
5. Identify the advantages of internal fertiization versus external fertilization.

CRITICAL THINKING

6. **Forming a Hypothesis** A student takes fish A from a saltwater tank and fish B from a freshwater tank. The student returns each fish to the wrong aquarium, and the next day both fish are dead. Form a hypothesis that explains why.
7. **Evaluating Differences** Organisms that use external fertilization usually produce more eggs at one time than organisms that use internal fertilization. What might explain this difference?
8. **Inferring Relationships** Explain why all scales point toward a fish's tail.

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BONY FISHES

Of the 25,000 known species of fishes, about 95 percent are bony fishes, formerly grouped in the class Osteichthyes. Bony fishes account for most of the vertebrates living in fresh water and in salt water. In this section, you will study some of the adaptations of this group.

SECTION 3

OBJECTIVES

- **List** three characteristics of bony fishes.
- **Distinguish** between lobe-finned fishes and ray-finned fishes.
- **Describe** three key features of bony fishes' external anatomy.
- **Summarize** the major body systems in bony fishes.
- **Describe** the function of the swim bladder.
- **Discuss** reproduction in bony fishes.

VOCABULARY

swim bladder
lobe-finned fish
ray-finned fish
operculum
countercurrent flow
optic tectum
spawning

CHARACTERISTICS

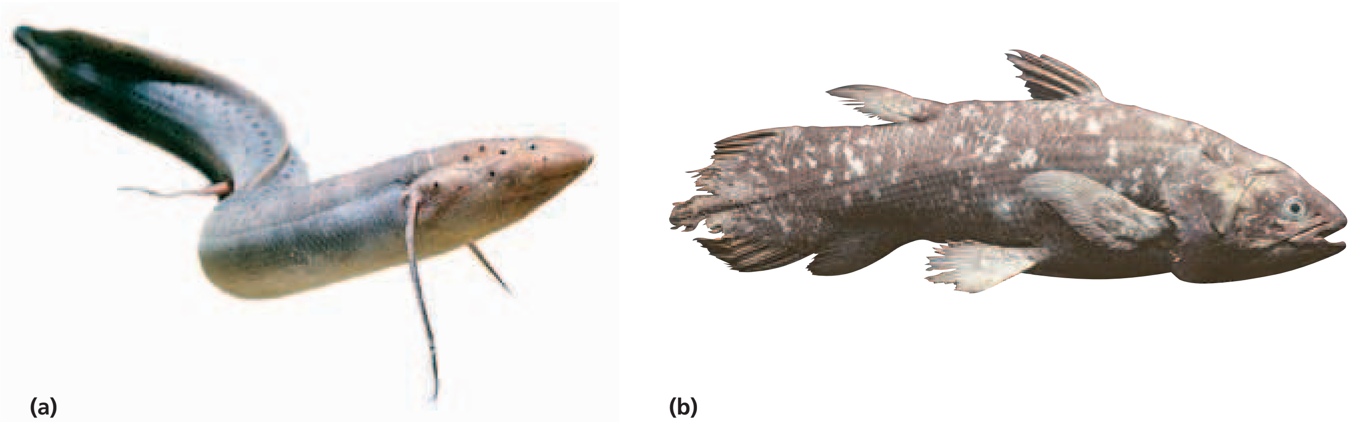
The bony fishes are characterized by three key features:

- **Bone—**This material is typically harder and heavier than cartilage. The skeletons of most bony fishes contain bone.
- **Lungs or swim bladder—**Early bony fishes had *lungs,* internal respiratory organs in which gas is exchanged between the air and blood. Only a few species of bony fishes have lungs today. Most bony fishes have a **swim bladder,** a gas-filled sac that is used to control buoyancy. The swim bladder is thought to have evolved from the lungs of the early bony fishes.
- **Scales—**The body of a bony fish is usually covered with scales. Scales protect the fish and reduce friction when swimming.

There are two main groups of bony fishes. These are the lobe-finned fishes and the ray-finned fishes.

Characteristics of Lobe-Finned Fishes

The **lobe-finned fishes** have fleshy fins that are supported by a series of bones. Two groups of lobe-finned fishes exist today, six species of lungfishes and one species of coelacanth. Lungfishes, shown in Figure 39-9a, exchange gases through both lungs and gills. They live in shallow tropical ponds that periodically dry up. The coelacanth, shown in Figure 39-9b, lives deep in the ocean and was thought to be extinct until 1938. Extinct lobe-finned fishes are ancestors of amphibians.



(a) (b)

FIGURE 39-9
Lobe-finned fishes have fleshy fins that are supported by a series of bones. Lungfishes (a) have the ability to gulp air into lungs as an oxygen source. Coelacanths (b) have muscular fins with stout bones.

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Characteristics of Ray-Finned Fishes

Ray-finned fishes do not have fins with a central bony axis—they have fins that are supported by long, segmented, flexible bony elements called *rays.* Rays probably evolved from scales. Ray-finned fishes are diverse in appearance, behavior, and habitat. Ray-finned fishes include most familiar fishes, such as, yellow perch, trout, salmon, guppies, bass, herring, goldfish, and eels.

EXTERNAL ANATOMY

Figure 39-10 shows the external anatomy of a yellow perch, a bony fish common in freshwater lakes of the eastern United States and Canada. The yellow perch, like all bony fishes, has distinct head, trunk, and tail regions. On each side of the head is the **operculum** (oh-PUHR-kyoo-LUHM), a hard plate that opens at the rear and covers and protects the gills.

Word Roots and Origins

operculum

from the Latin *operculum,* meaning "cover"

Fins

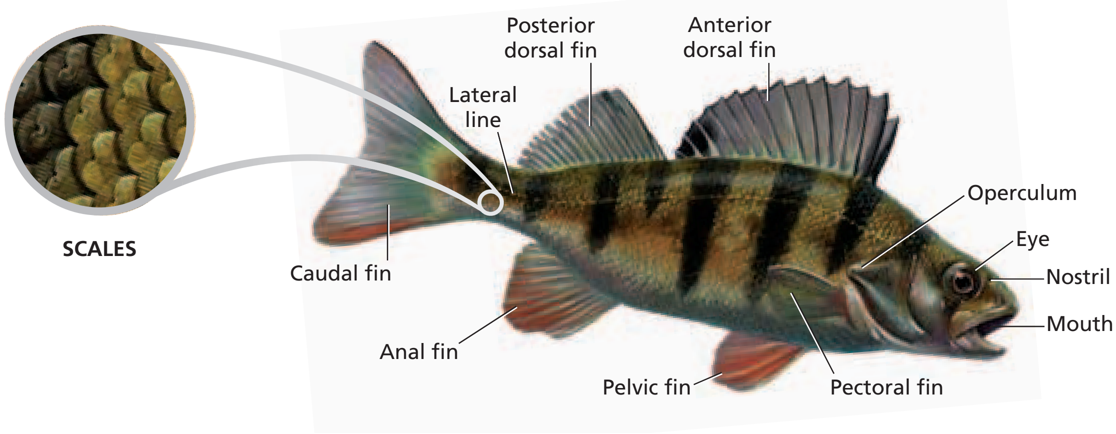
The fins of the yellow perch are adapted for swimming and navigating through the water. The caudal fin extends from the tail. It moves from side to side and amplifies the swimming motion of the body. Two dorsal fins, one anterior and one posterior, and a ventral anal fin help keep the fish upright and moving in a straight line. The fish uses paired pelvic fins and pectoral fins to navigate, stop, move up and down, and even back up. The pelvic fins also orient the body when the fish is at rest. The fins are supported by either rays or spines. Rays are bony yet flexible, while spines are bony and rigid.

Skin

The skin of the yellow perch is covered with scales. Scales are thin, round disks of a bonelike material that grow from pockets in the skin. As Figure 39-10 shows, scales overlap like roof shingles. They all point toward the tail to minimize friction as the fish swims. Scales grow throughout the life of the fish, adjusting their growth pattern to the food supply. The scales grow quickly when food is abundant and slowly when it is scarce.

FIGURE 39-10

The external features of the yellow perch, *Perca flavescens,* are representative of bony fishes. Note the growth rings on the scales shown in the inset. They indicate the fish's approximate age.



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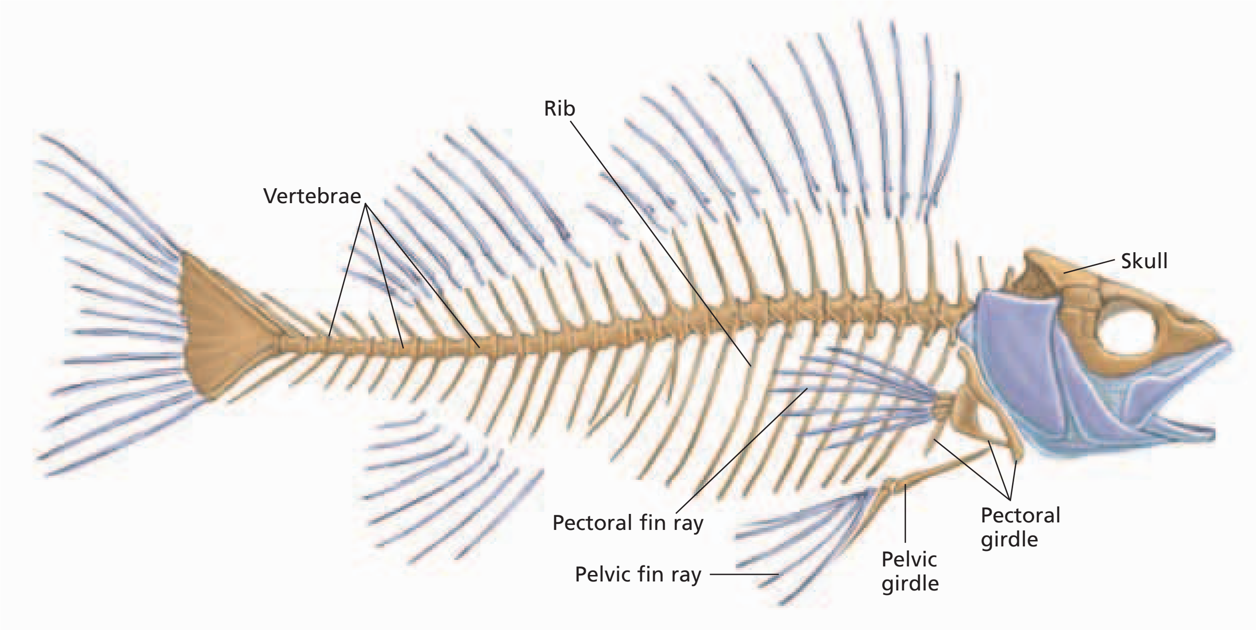

FIGURE 39-11

The skeleton of *Perca flavescens* is similar to that of other bony fishes. The general structure of the vertebrae, rib cage, and fins is found in many fishes.

INTERNAL ANATOMY

The major parts of a fish's skeleton, shown in Figure 39-11, are the skull, spinal column, pectoral girdle, pelvic girdle, and ribs. The spinal column is made up of many bones, called vertebrae, with cartilage pads between each. The spinal column also partly encloses and protects the spinal cord. The *pectoral girdle* supports the pectoral fins, and the *pelvic girdle* supports the pelvic fins. In a human skeleton, the pectoral girdle is the shoulder and its supporting bones, and the pelvic girdle is the hips. A fish's skull is composed of a large number of bones (far more than are in the human skull) and is capable of a wide range of movements. Note the pectoral fin rays and pelvic fin rays that are key characteristics of ray-finned fishes.

Digestive System

Bony fishes have diverse diets but commonly are carnivores. The jaws of predatory fishes are lined with many sharp teeth that point inward to keep prey from escaping. Strong muscles operate the jaws, which are hinged to allow the mouth to open wide.

Figure 39-12 on the next page shows the internal anatomy of a bony fish. Food passes from the mouth into the pharynx, or throat cavity, and then moves through the *esophagus* to the stomach. The *stomach* secretes acid and digestive enzymes that begin to break down food. From the stomach, food passes into the *intestine,* where digestion is completed and nutrients are absorbed.

The *liver,* located near the stomach, secretes *bile,* which helps break down fats. The *gallbladder* stores bile and releases it into the intestine. The *pancreas,* also located near the stomach, releases digestive enzymes into the intestine. The lining of the intestine is covered with fingerlike extensions called villi that increase the surface area for absorption of digested foods. Undigested material is then eliminated through the *anus.*

internet connect

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Topic: Anatomy of a Bony Fish
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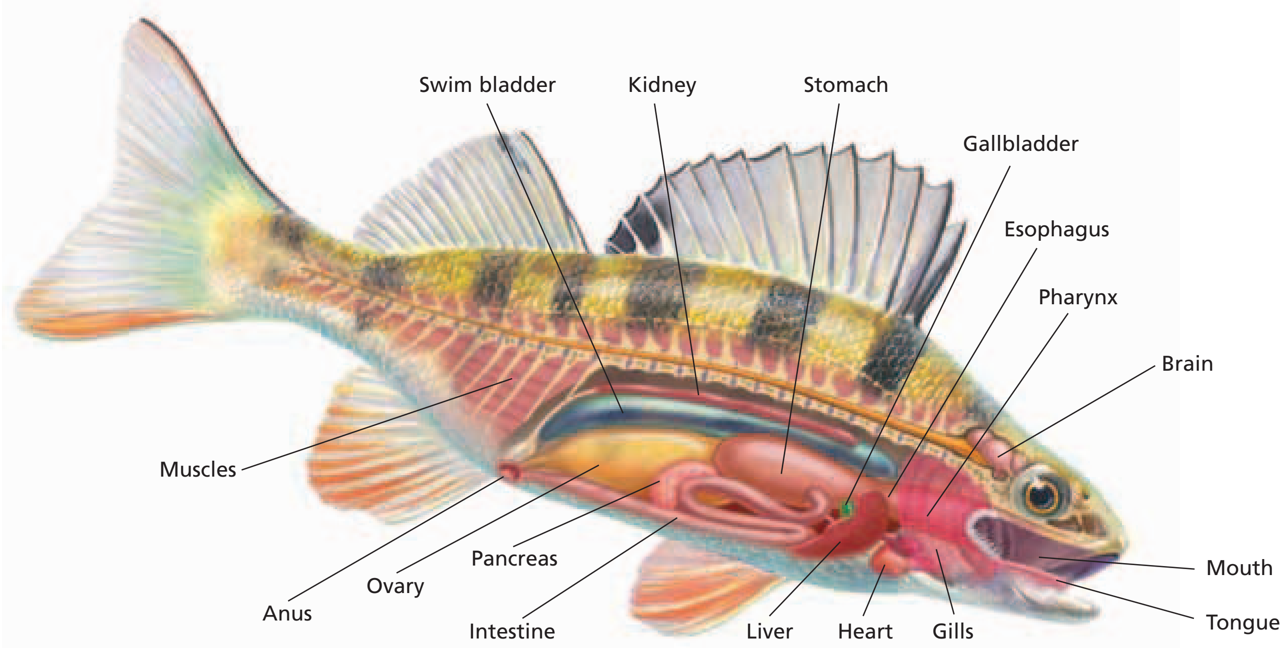


FIGURE 39-12

The internal anatomy of a bony fish, such as this perch, is a model for the arrangement of organs in all vertebrate descendants of fish. Food passes first from the mouth through the esophagus, then to the stomach and intestines. Finally, undigested waste is eliminated through the anus. Digestion of protein occurs in the stomach, and absorption of nutrients occurs in the intestine.

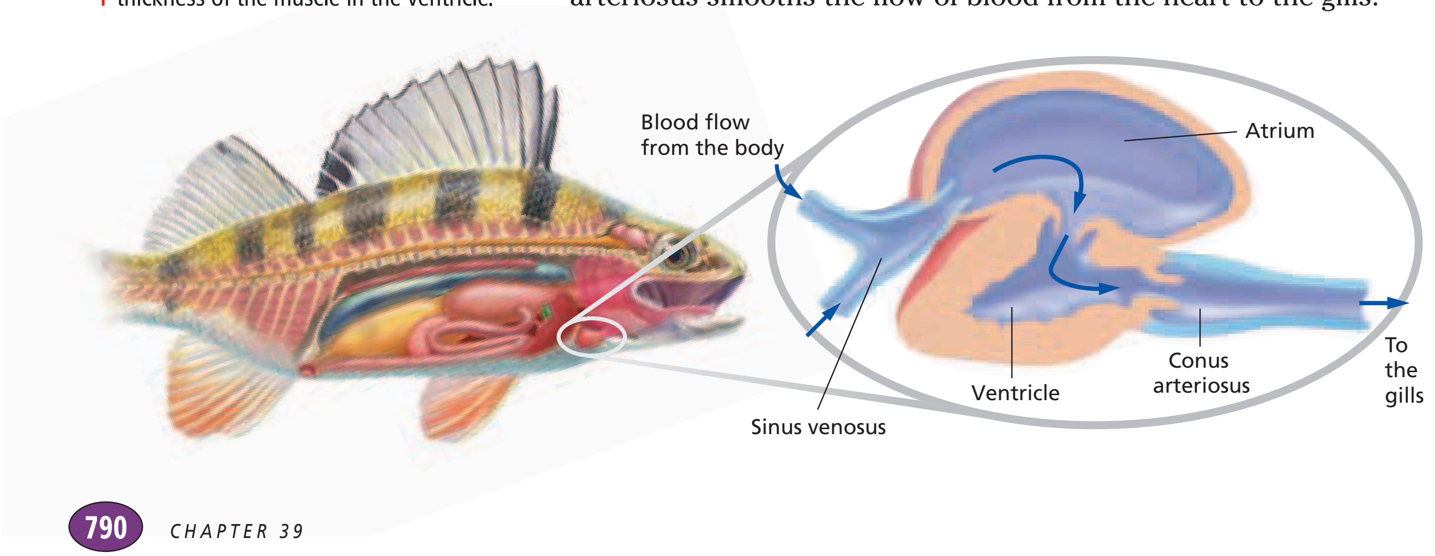
Circulatory System

The circulatory system of a fish delivers oxygen and nutrients to the cells of the body. It also transports wastes produced by metabolism—carbon dioxide and ammonia—to the gills and kidneys for elimination. The circulatory system consists of a heart, blood vessels, and blood. The heart pumps blood through *arteries* to small, thin-walled vessels, called *capillaries,* in the gills. There the blood picks up oxygen and releases carbon dioxide. From the gills, the blood then travels to the body tissues, where nutrients and wastes are exchanged. The blood returns to the heart through *veins.*

The heart of a bony fish has two chambers in a row, as you can see in Figure 39-13. Deoxygenated blood from the body empties into a collecting chamber called the *sinus venosus.* Next, blood moves into the larger *atrium.* Contraction of the atrium speeds up the blood and drives it into the muscular *ventricle,* the main pumping chamber of the heart. Contraction of the ventricle provides most of the force that drives the blood through the circulatory system. The *conus arteriosus* is a thickened, muscular part of the main artery leaving the heart. It has an elastic wall and usually contains valves to prevent blood from flowing back into the ventricle. The conus arteriosus smooths the flow of blood from the heart to the gills.

FIGURE 39-13

A fish's heart is a series of two chambers that act in sequence to move blood through the body, transporting oxygen to the cells and wastes to organs for elimination. Note the thickness of the muscle in the ventricle.



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Respiratory and Excretory Systems

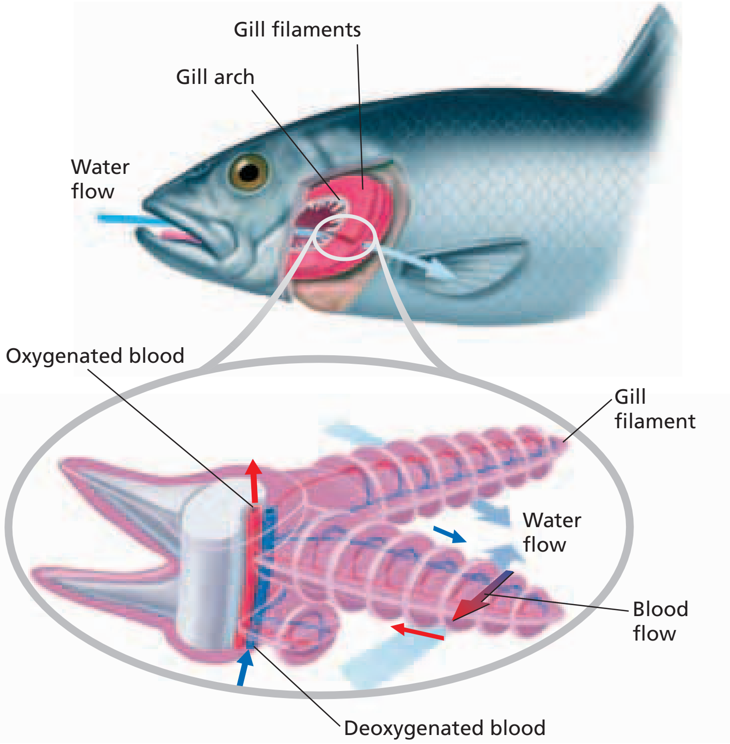

FIGURE 39-14

The gills are located directly behind the head and interior to the operculum. The gill filaments provide the organism with a large surface area, thus enabling gas exchange to occur quickly.

The large surface area of a fish's gills allows for rapid gas exchange. Gills are supported by four sets of curved bones on each side of the fish's head. Each gill has a double row of thin projections, called *gill filaments.* In most bony fishes, water is taken into the mouth and pumped over the gills, where it flows across the gill filaments before exiting behind the operculum. As you can see in Figure 39-14, water flows across the gill filaments in a direction opposite to blood flow. This arrangement is known as **countercurrent flow.** Countercurrent flow causes more oxygen to diffuse into the blood than would be possible if blood and water flowed in the same direction.

A fish's kidneys filter dissolved chemical wastes from the blood. The resulting solution, called *urine,* contains ammonia, ions such as sodium and chloride, and water. Urine is carried from the kidneys through a system of ducts to the *urinary bladder,* where it is stored and later expelled. By varying the amount of water and salts in the urine, the kidneys help regulate the water and ion balance in fresh and saltwater fishes.

As blood flows through the gill filaments, ammonia generated by metabolism diffuses from the blood into the water passing over the gills and is removed from the body. The gills also regulate the concentration of ions in the body. Recall that saltwater fishes have lower ion concentrations than sea water has. Therefore, they lose water through osmosis and gain ions, such as sodium and chloride ions. Saltwater fishes make up for this water loss by excreting small amounts of concentrated urine and by drinking sea water, but this increases their internal concentration of sodium and chloride ions. Both kinds of ions are actively transported out through the gills. Freshwater fishes tend to gain water and lose ions. They respond by producing large amounts of dilute urine and actively transporting sodium and chloride ions in through the gills.

Swim Bladder

Most bony fishes have a swim bladder. This thin-walled sac in the abdominal cavity contains a mixture of oxygen, carbon dioxide, and nitrogen obtained from the bloodstream. Fish adjust their overall density by regulating the amount of gas in the swim bladder, enabling them to move up or down in the water.

Swim bladders evolved from balloonlike lungs, which ancestral bony fishes may have used to supplement the oxygen absorbed by the gills. In some fishes, the swim bladder is known to amplify sound by vibrating and transmitting sound to the inner ear.

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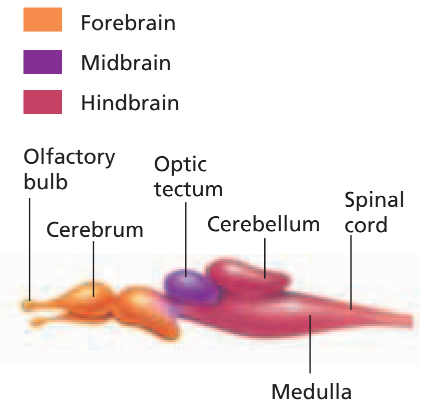

FIGURE 39-15

The fish brain, like the shark brain, has a well-developed medulla to coordinate muscle control.

FIGURE 39-16

This male ringtailed cardinal fish, *Apogon aureus,* is carrying fertilized eggs in its mouth. This behavior lowers losses of eggs to predators and contributes to the success of the species.

Nervous System

The nervous system of a bony fish includes the brain, spinal cord, nerves, and various sensory organs. The fish brain is illustrated in Figure 39-15. The most anterior part of the brain, the forebrain, contains the olfactory bulbs, which process information on smell. The forebrain also includes the *cerebrum,* which has areas that integrate information from other parts of the brain. Behind the forebrain lies the midbrain, which is dominated by the **optic tectum.** The optic tectum receives and processes information from the fish's visual, auditory, and lateral-line systems.

The most posterior division of the brain is the hindbrain, which contains the *cerebellum* (SER-uh-BEL-uhm) and the *medulla oblongata* (mi-DUL-uh AHB-lahng-GAHT-uh). The cerebellum helps coordinate muscles, movement, and balance. The medulla oblongata helps control some body functions and acts as a relay station for stimuli from sensory receptors throughout the fish's body. From the medulla oblongata, the spinal cord extends the length of the body and carries nerve impulses to and from the brain.

REPRODUCTION

Eggs are produced by ovaries in the female, and sperm are produced by the testes in the male. Eggs and sperm are released through an opening behind the anus. Fertilization in most species takes place externally. Mortality among the eggs and young fishes is often very high. Many species of fishes lay large numbers of eggs, which ensures that at least a few individuals survive to become adult fish.

Some bony fishes bear live young. Using a modified anal fin, the male inserts sperm into the female, and fertilization is internal. The female carries the eggs in her body until the young are born. Other species care for the eggs as shown in Figure 39-16.

The reproductive, or **spawning,** behavior of bony fishes varies widely. Some species build crude nests from plants, sticks, and shells. Many species migrate to warm, protected shallow water to spawn.

SECTION 3 REVIEW

1. List three key features that characterize bony fishes.
2. Contrast ray-finned and lobe-finned fishes.
3. Describe the external anatomy of a bony fish.
4. Identify the organs of four internal organ systems found in fishes.
5. Name two functions of the swim bladder.
6. Describe two methods of reproduction that can be found in bony fishes.

CRITICAL THINKING

7. **Applying Information** Which is the most muscular chamber of the fish heart? Explain why.
8. **Forming a Hypothesis** Bottom-dwelling fish often lack a swim bladder. Explain why lack of a swim bladder is an adaptive advantage.
9. **Recognizing Relationships** Explain how countercurrent flow allows the diffusion of more oxygen into the blood than would be possible if blood and water flowed in the same direction.

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CHAPTER HIGHLIGHTS

SECTION 1 Introduction to Vertebrates

- Vertebrates are chordates and have a hollow dorsal nerve cord, notochord, pharyngeal pouches, and a post-anal tail at some stage of life.
- The characteristics that distinguish vertebrates from other chordates are vertebrae, a cranium, and an endoskeleton.
- Vertebrates are classified into nine classes: hagfish (class Myxini); lampreys (class Cephalaspidomorphi); sharks and rays (class Chondrichthyes); lobe-finned fishes (class Sarcopterygii); ray-finned fishes (class Actinopterygii); amphibians (class Amphibia); reptiles (class Reptilia); birds (class Aves); and mammals (class Mammalia).
- Early vertebrates were jawless fishes, which had bony scales, cartilaginous skeletons, and no paired fins.
- Paired fins increased stability and maneuverability in fishes; jaws allowed fish to seize and manipulate prey.

Vocabulary

vertebrae (p. 779) **cranium** (p. 779) **gill arches** (p. 781)

SECTION 2 Jawless and Cartilaginous Fishes

- Fishes have streamlined bodies, paired fins, and secrete mucus that reduces friction when swimming. The fish body plan makes them well suited to aquatic life.
- Fishes have a variety of organs that allow them to sense their environment. Fish can see, smell, and taste the world around them. They can also sense vibration, and some can sense electrical fields.
- Like early vertebrates, living agnathans lack jaws and paired fins and retain a notochord throughout life.
- Lampreys and hagfish are two types of jawless fishes that are alive today. Hagfishes burrow into and eat dead fish. Parasitic lampreys attach themselves to their host with their disc-shaped mouths and feed on the host's blood.
- Cartilaginous fishes have internal skeletons made of cartilage, and their skin is covered with placoid scales.
- Jawless fishes reproduce by external fertilization (fertilization occurs outside of the body of either parent). Most cartilaginous fishes reproduce by internal fertilization (the male inserts sperm into the female's body, and the young develop in an egg inside the female).

Vocabulary

chemoreception (p. 783) **external fertilization** (p. 784) **placoid scale** (p. 784)
lateral line (p. 783) **cartilage** (p. 784) **internal fertilization** (p. 786)

SECTION 3 Bony Fishes

- Bony fishes are characterized by three key features: scales on the body, lungs or a swim bladder, and bone in the skeleton.
- Lobe-finned fishes have fleshy fins with a central bony axis, while ray finned fishes have non-fleshy fins supported by long flexible bones called rays.
- The external anatomy of a bony fish has several distinct characteristics—an operculum, fins, and scales.
- A fish's heart has two chambers that work together to move blood through the body.
- Water flows over fishes gills in a direction opposite to blood flow. Oxygen diffuses from the water into the blood very efficiently as a result of this process, which is called *countercurrent flow.*
- Fish adjust their overall density by regulating the amount of gas in the swim bladder, enabling them to move up or down in the water.
- Unlike cartilaginous fishes, most bony fishes reproduce by external fertilization in a process called *spawning.*

Vocabulary

swim bladder (p. 787) **ray-finned fish** (p. 787) **countercurrent flow** (p. 791) **spawning** (p. 792)
lobe-finned fish (p. 787) **operculum** (p. 788) **optic tectum** (p. 792)

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USING VOCABULARY

1. For each pair of terms, explain how the meanings of the terms differ.
   a. *atrium* and *ventricle*
   b. *caudal fin* and *anal fin*
   c. *internal fertilization* and *external fertilization*
   d. *operculum* and *gill*
2. Use the following key terms in the same sentence: *cerebrum, optic tectum, cerebellum,* and *medulla oblongata.*
3. Explain the relationship between olfactory bulbs and lateral line system.
4. **Word Roots and Origins** The word *Actinopterygii* comes from the Greek *actinos,* meaning "ray," and *pteryx,* meaning "wing" or "fin." Using this information, explain why *Actinopterygii* is a good name for these fish.

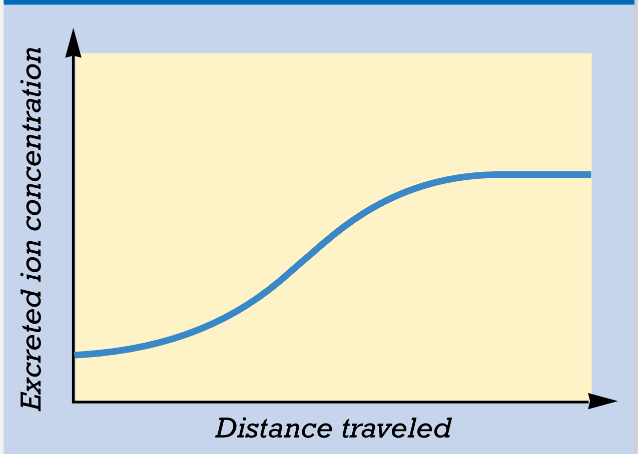
UNDERSTANDING KEY CONCEPTS

5. **List** the characteristics that would be found in a typical vertebrate.
6. **Identify** the class of vertebrates to which each of the following organisms belong: goldfish, sand sharks, pigeons, dogs, Pacific lamprey, bullfrog.
7. **Name** the characteristics that distinguish early vertebrates from modern vertebrates.
8. **Describe** two major changes in fish anatomy over millions of years.
9. **Evaluate** the relationship between fishes' body form and function in an aquatic environment.
10. **Identify** the structures that are involved in sensory systems in fishes.
11. **Name** one characteristic of early chordates that distinguishes hagfishes from lampreys.
12. **Describe** the key characteristics that distinguish cartilaginous fishes.
13. **Contrast** the reproductive strategy of lampreys with the reproductive strategy of sharks.
14. **Identify** the characteristics that distinguish bony fishes from cartilaginous fishes.
15. **Explain** the differences between the two main groups of bony fishes.
16. **State** how the caudal, dorsal, pectoral, and pelvic fins function in helping fish swim.
17. **Explain** how the heart and gills function in fish.
18. **Propose** a possible explanation for the evolution of primitive lungs into swim bladders.
19. **Compare** the advantages and disadvantages of internal fertilization and spawning.
20. **CONCEPT MAPPING** Use the following terms to create a concept map that describes the characteristics of jawless, cartilaginous, and bony fishes: *bony fishes, gills, cartilage, operculum,* and *countercurrent flow.*

CRITICAL THINKING

21. **Applying Information** Sometimes fish develop a swim bladder disorder when they are overfed and food displaces the swim bladder. How might displacement of the swim bladder by food impair the function of this organ?
22. **Analyzing Research** A famous study showed that a shark could locate and capture a stationary fish buried in the sand at the bottom of its tank. When the fish was enclosed in electrical insulation and then buried, however, the shark could not locate it. From this information can you conclude that the shark is using only its electrical sense to locate the buried fish?
23. **Recognizing Relationships** Cod fishes lay eggs near the surface of the water. In contrast, the male largemouth bass scoops out a nest in a river bottom and waits for a female to deposit her eggs. What hypothesis would you make regarding the relative number of cod and bass eggs?
24. **Analyzing Graphics** Study the chart below, which shows the excreted ion concentration of a fish as it travels from one body of water to another. Is the fish traveling from fresh water to salt water or salt water to fresh water?

Effect of Environment on Ion Excretion



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Standardized Test Preparation

DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. Which of the following is true of sharks and rays?
A. They have lungs.
B. They have placoid scales.
C. Most species live in fresh water.
D. They do not have a lateral line system.

2. Which of the following is not involved in controlling buoyancy?
F. a fat-filled liver
G. the rectal gland
H. the swim bladder
J. continuous swimming

3. What is the function of the lateral line system?
A. initiates migration
B. detects vibrations
C. acts as camouflage
D. keeps fish moving in a straight line

4. What do sharks use claspers for?
F. startle other fish
G. increase maneuverability
H. transfer sperm while mating
J. hold on to prey while feeding

INTERPRETING GRAPHICS: The table below shows the salinity of fresh water, salt water, and the body fluids of fish. Use the table to answer the questions that follow.

Salinity of Water and Fish Body Fluids

	Salinity of fresh water	Salinity of salt water	Salinity of body fluids
Freshwater fish	<0.1%	—	0.8 – 1%
Saltwater fish	—	3.5%	0.8 – 1.4%

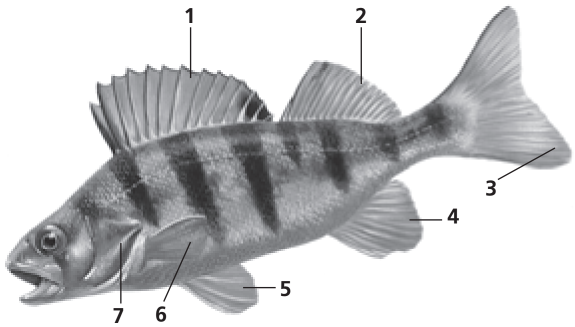
5. What tendency do freshwater fish have in a freshwater environment?
A. lose water and salts
B. take on water and salts
C. take on water and lose salts
D. lose water and take on salts

6. What tendency do saltwater fish have in a saltwater environment?
F. lose water and salts
G. take on water and salts
H. lose water and take on salts
J. take on water and lose salts

DIRECTIONS: Complete the following analogy.

7. Hagfish : Myxini :: Sharks :
A. Aves
B. Agnatha
C. Mammalia
D. Chondrichthyes

INTERPRETING GRAPHICS: The figure below shows the external anatomy of a bony fish. Use the figure to answer the following question.



8. Which of the fins shown on the fish are dorsal fins?
F. 1 & 2
G. 2 & 4
H. 5 & 6
J. 5 & 4

SHORT RESPONSE

Countercurrent flow enhances the diffusion of oxygen from the water into the bloodstream of fishes.

Explain the meaning of countercurrent flow in gills.

EXTENDED RESPONSE

Humans have a four chambered heart with two ventricles. One ventricle pumps blood to the lungs and the other pumps blood that returns from the lungs to the body.

Part A Compare the structure and blood flow of the fish heart to the human heart.

Part B Which heart is able to pump blood more forcefully around the body? Why?

Test TIP For a question involving experimental data, determine the constants, variables, and control **before** answering the questions.

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EXPLORATION LAB

Observing Structure and Behavior in Fishes

OBJECTIVES

- Observe body shapes, camouflage, and feeding behavior in various species of fish.
- Relate observed adaptations to the survival of each species.

PROCESS SKILLS

- making observations
- collecting data
- identifying and recognizing patterns
- interpreting data
- predicting
- analyzing results
- drawing conclusions

MATERIALS

- clipboard and paper or notebook
- live fish in an aquarium tank
- pencil or pen

Background

1. Identify the three major categories of modern fish.
2. State some key characteristics of bony fish.
3. Define an adaptation.
4. How are fish adapted to life in water?

PART A Observing Body Shapes

1. CAUTION **To avoid injuring live fish do not touch or frighten them.** Find a tank that contains several types of tropical fish.
2. Identify the species of fish in the tank. In Table 1, record the common and scientific names of the species.
3. Describe the shape of the fish's body. In Table 1, record your description.
4. Observe the activity of the fish. How does it spend most of its time? In Table 1, record your observations.
5. Repeat steps 2–4 with another species of fish.

PART B Observing Body Color and Patterns

6. Find three examples of fish that use body colors, markings, or postures to blend with their surroundings.
7. For each species, record its common and scientific names in Table 2, and describe the type of camouflage it uses.

TABLE 1 *BODY SHAPES AND ACTIVITY*

Species	Body shape	Activity

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TABLE 2 *CAMOUFLAGE*	
Species	**Type of camouflage**

PART C Observing Feeding Behaviors

8. Find three examples of fish that use different methods for feeding.
9. For each species, record its common and scientific names in Table 3, and describe its feeding method.

Analysis and Conclusions

1. How are the body shapes of the fishes you observed related to the types of activities that those fishes engage in?
2. What structural adaptations are associated with the different feeding behaviors that you observed?
3. How does camouflage help fish to survive in the cases where you observed it?
4. Would you expect camouflage to be more important for fish that live in shallow water or for those that live in very deep water? Explain your reasoning.

Further Inquiry

Design an experiment about fish behavior using fish sold at a local pet store and materials available in your classroom. Report the results of your experiment in an oral presentation.

TABLE 3 *FEEDING BEHAVIOR*	
Species	**Type of feeding behavior**

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