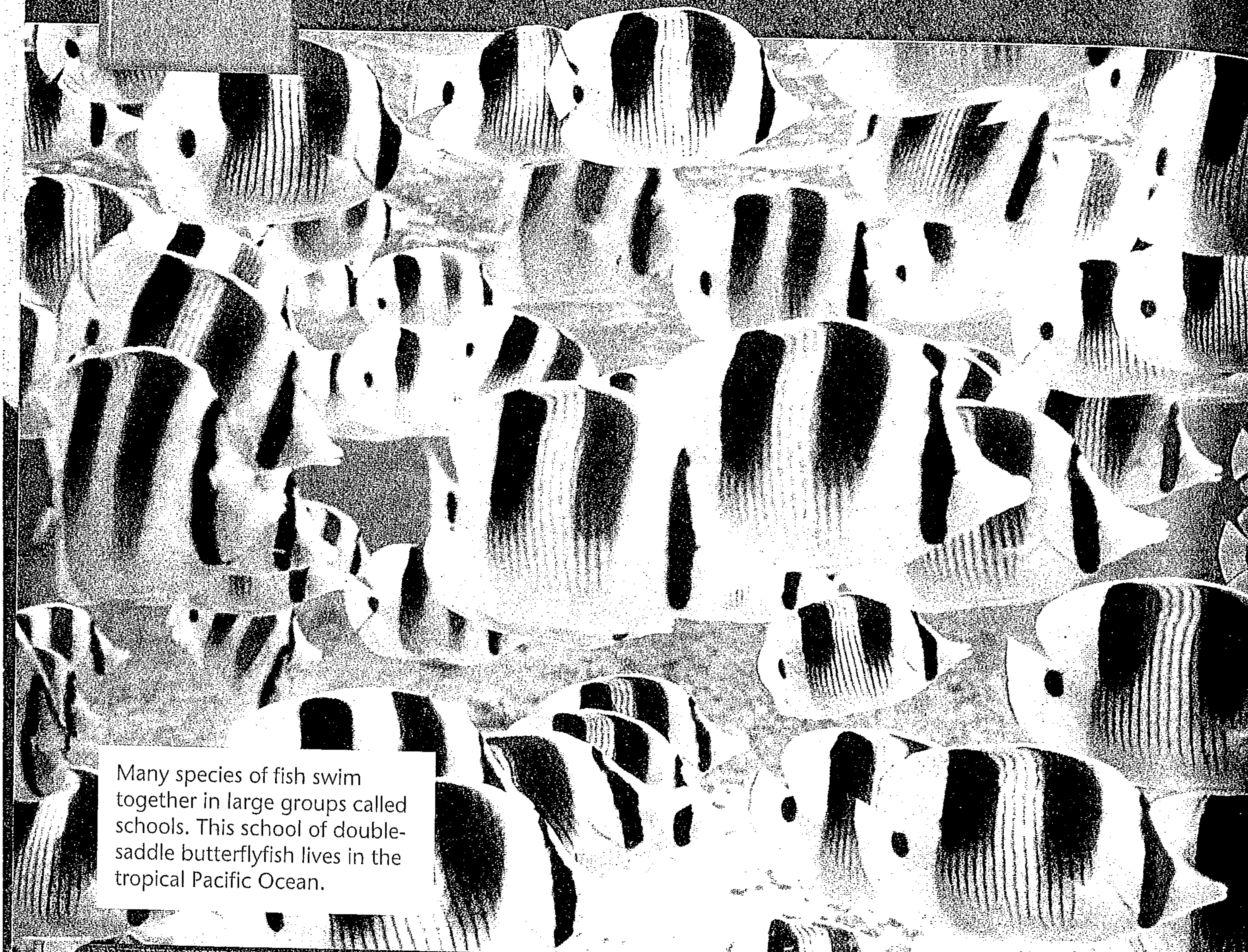
CHAPTER 30

Nonvertebrate Chordates, Fishes, and Amphibians



Many species of fish swim together in large groups called schools. This school of double-saddle butterflyfish lives in the tropical Pacific Ocean.

Inquiry Activity

Is a lancelet a fish?

Procedure

1. Put on plastic gloves. Closely examine a fish, using a hand lens if you like. Also look at a dissected fish. List the main characteristics of fishes.
2. Now, closely examine a preserved lancelet and a dissected lancelet. List the characteristics of lancelets. Wash your hands with soap and warm water.

Think About It

1. **Comparing and Contrasting** How are the fish and the lancelet similar? How are they different from each other?
2. **Classifying** Not all fishes have jaws or scales. Given this information, do you think the lancelet is a type of fish? Explain your answer.

30–1 The Chordates

At first glance, fishes, amphibians, reptiles, birds, and mammals appear to be very different from one another. Some have feathers; others have fins. Some fly; others swim or crawl. These variations are some of the characteristics that biologists use to separate these animals into different classes, yet all are members of the phylum Chordata (kawr-DAHT-uh).

What Is a Chordate?

Members of the phylum Chordata are called **chordates** (KAWR-dayts). To be classified as a chordate, an animal must have four key characteristics, although these characteristics need not be present during the entire life cycle. **A chordate is an animal that has, for at least some stage of its life, a dorsal, hollow nerve cord; a notochord; pharyngeal (fuh-RIN-jee-ul) pouches; and a tail that extends beyond the anus.** Refer to **Figure 30–1** as you read about each of these characteristics.

The hollow nerve cord runs along the dorsal (back) part of the body. Nerves branch from this cord at regular intervals and connect to internal organs, muscles, and sense organs.

The **notochord** is a long supporting rod that runs through the body just below the nerve cord. Most chordates have a notochord only when they are embryos.

Pharyngeal pouches are paired structures in the throat (pharynx) region. In some chordates—such as fishes and amphibians—slits develop that connect the pharyngeal pouches to the outside of the body. These slits may then develop gills that are used for gas exchange.

At some point in their lives, all chordates have a tail that extends beyond the anus. The tail can contain bone and muscle and is used in swimming by many aquatic species.

CHECKPOINT *What is a notochord?*

Guide for Reading

Key Concepts
- What characteristics do all chordates share?
- What are the two groups of nonvertebrate chordates?

Vocabulary
chordate
notochord
pharyngeal pouch
vertebra

Reading Strategy: Building Vocabulary
Before you read, preview new vocabulary by skimming the section and making a list of the highlighted, boldface terms. As you read, make notes next to each term.

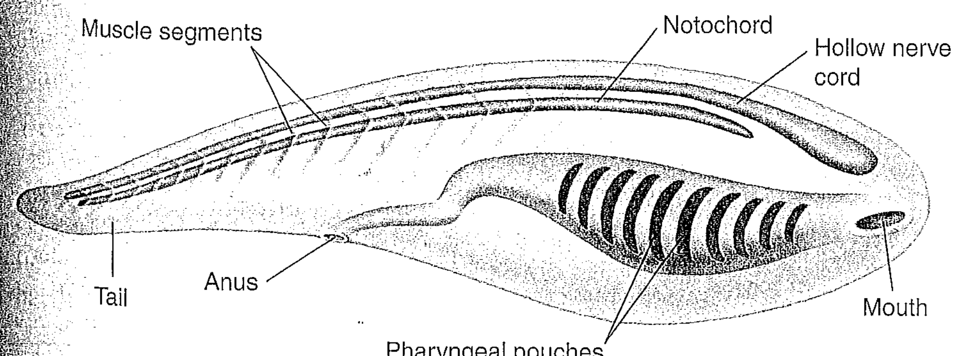


Figure 30–1 All chordates share four characteristics: a dorsal, hollow nerve cord; a notochord; pharyngeal pouches; and a tail that extends beyond the anus. Some chordates possess all these characteristics as adults; others possess them only as embryos.

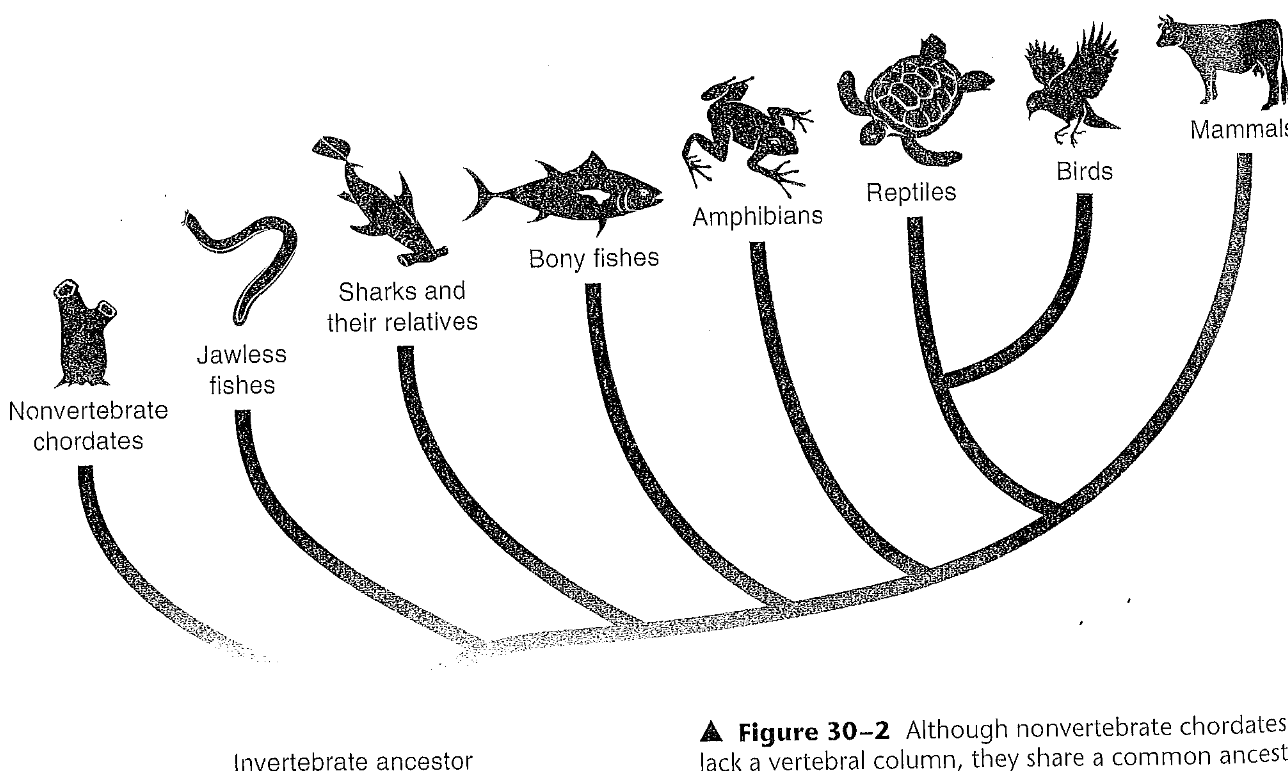
Go Online
NSTA SCI LINKS
For: Links on nonvertebrate chordates
Visit: www.SciLinks.org
Web Code: cbn-9301

Most Chordates Are Vertebrates

The diagram in **Figure 30–2** shows the current understanding of the phylogeny, or evolutionary relationships, of chordates. About 96 percent of all chordate species are placed in the subphylum Vertebrata and are called vertebrates. Most vertebrates have a strong supporting structure known as the vertebral column, or backbone. In vertebrates, the dorsal, hollow nerve cord is called the spinal cord. As a vertebrate embryo develops, the front end of the spinal cord grows into a brain. The backbone, which replaces the notochord in most developing vertebrates, is made of individual segments called **vertebrae** (singular: vertebra). In addition to providing support, vertebrae enclose and protect the spinal cord.

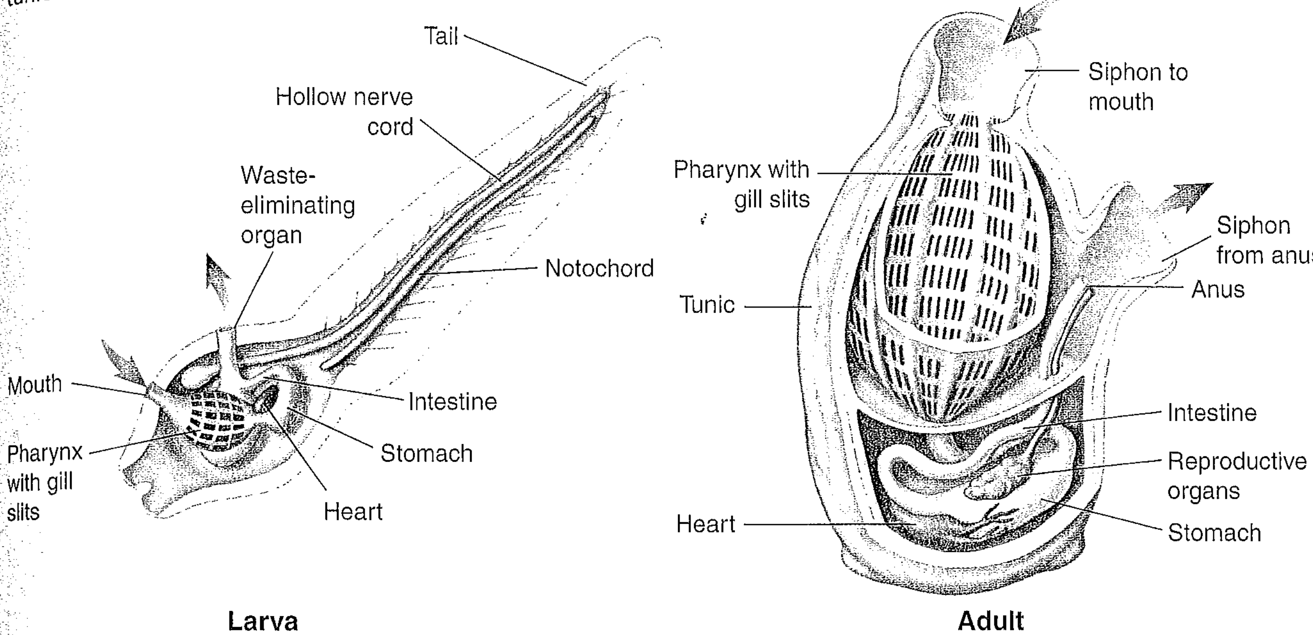
A vertebrate's backbone is part of an endoskeleton, or internal skeleton. Like an arthropod's exoskeleton, a vertebrate's endoskeleton supports and protects the animal's body and gives muscles a place to attach. However, unlike an arthropod's exoskeleton, a vertebrate's skeleton grows as the animal grows and does not need to be shed periodically. In addition, whereas an arthropod's skeleton is made entirely of nonliving material, a vertebrate's skeleton contains living cells as well as nonliving material. The cells produce the nonliving material in the skeleton.

✓CHECKPOINT *What is the function of the vertebral column?*



▲ **Figure 30–2** Although nonvertebrate chordates lack a vertebral column, they share a common ancestor with vertebrates. **Interpreting Graphics** *To which other vertebrate group are birds most closely related?*

▼ Figure 30–3 Tunicates are one of two groups of nonvertebrate chordates. The tadpole-shaped tunicate larva (left) has all four chordate characteristics. When most tunicate larvae grow into adults, they lose their tails and attach to a solid surface. Adult tunicates (right) look nothing like the larvae, or even like other adult chordates. Both larvae and adults are filter feeders. The blue arrows show where water enters and leaves the tunicate's body.

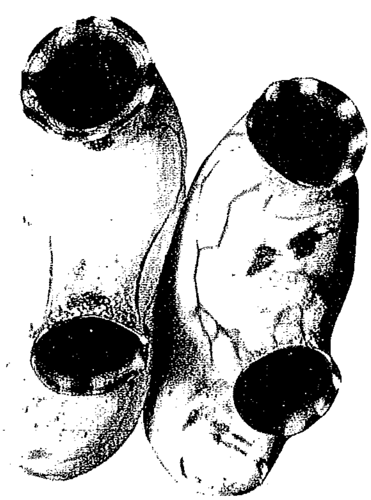


Nonvertebrate Chordates

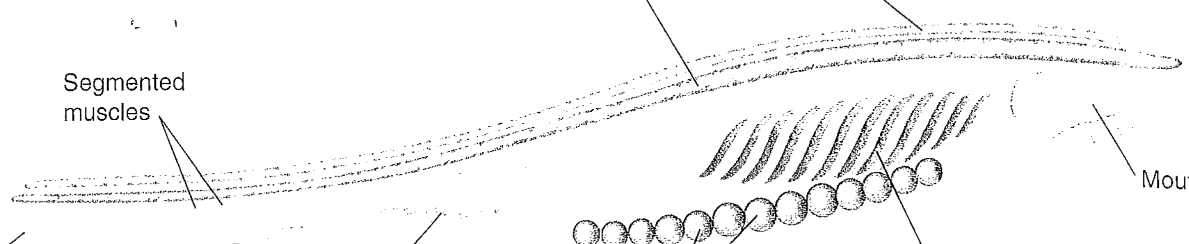
There are two subphyla of chordates that do not have backbones. **The two groups of nonvertebrate chordates are tunicates and lancelets.** Both are soft-bodied marine organisms. Like all chordates, these animals have a hollow nerve cord, a notochord, pharyngeal pouches, and a tail at some stage of their life cycle.

In some ways, studying nonvertebrate chordates is like using a time machine to investigate the ancestors of our own subphylum, Vertebrata. Similarities in anatomy and embryological development indicate that vertebrates and nonvertebrate chordates evolved from a common ancestor. Fossil evidence from the Cambrian Period places this divergence at more than 550 million years ago. Although they seem to be simple animals, tunicates and lancelets are relatives of ours—very distant ones.

Tunicates Filter-feeding tunicates (subphylum Urochordata) certainly do not look as if they are related to us. **Figure 30–3** shows the body structure of a tunicate larva and an adult. Observe that the larval form has all of the chordate characteristics. In contrast, adult tunicates, like the ones in **Figure 30–4**, have neither a notochord nor a tail.



▲ Figure 30–4 Tunicates get their name from the adult's body covering—the tough, nonliving tunic. Most tunicates are commonly known as sea squirts, because of the stream of water they sometimes eject. **Inferring** *In what kind of ecosystem are you likely to find tunicates?*



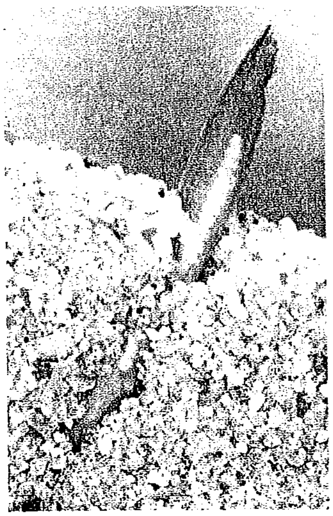


Figure 30–5 Lancelets are small nonvertebrate chordates that often live with their bodies half buried in sand. Because lancelets do not have fins or legs, they can move only by contracting the paired muscles on their bodies. **Interpreting Graphics** *Which chordate characteristics do lancelets have?*

Lancelets The small, fishlike creatures called lancelets form the subphylum Cephalochordata. Lancelets live on the sandy ocean bottom. You can see a lancelet's body structure in **Figure 30–5.** Observe that, unlike an adult tunicate, an adult lancelet has a definite head region that contains a mouth. The mouth opens into a long pharynx with up to 100 pairs of gill slits. As water passes through the pharynx, a sticky mucus catches food particles. The lancelet then swallows the mucus into the digestive tract. Lancelets use the pharynx for gas exchange. In addition, lancelets are thin enough to exchange gases through their body surface.

Lancelets have a closed circulatory system. They do not have a true heart. Instead, the walls of the major blood vessels contract to push blood through the body. The fishlike motion of lancelets results from contracting muscles that are organized into V-shaped units. The muscle units are paired on either side of the body.

30–1 Section Assessment

1. **Key Concept** Describe four characteristics of chordates.
2. **Key Concept** How do lancelets and tunicates differ?
3. What one characteristic distinguishes most vertebrates from the other chordates?
4. How is a vertebrate's skeleton similar to that of an arthropod? How is it different?
5. Describe two ways in which lancelets obtain oxygen.
6. **Critical Thinking Inferring** How would a free-swimming larval stage be an advantage for tunicates?

Writing in Science

Creative Writing
Imagine that a scientist has just discovered the existence of one of the nonvertebrate chordate groups. Write a short newspaper article describing what the scientist has discovered. *Hint:* Before you write, list the characteristics of the chordate group. Then, identify these characteristics in the article.

30–2 Fishes

If you think of Earth as land, then the name "Earth" is not particularly appropriate for the planet on which you live, for more than two thirds of its surface is water. And almost anywhere there is water—fresh or salt—there are fishes. At the edge of the ocean, blennies jump from rock to rock and occasionally dunk themselves in tide pools. Beneath the Arctic ice live fishes whose bodies contain a biological antifreeze that keeps them from freezing solid. In some shallow desert streams, pupfishes tolerate temperatures that would cook almost any other animal. Evolution by natural selection and other processes has resulted in a great diversity of fishes.

What Is a Fish?

You might think that with such extreme variations in habitat, fishes would be difficult to characterize. However, describing a fish is a rather simple task. **Fishes are aquatic vertebrates; most fishes have paired fins, scales, and gills.** Fins are used for movement, scales for protection, and gills for exchanging gases. You can observe most of those characteristics in **Figure 30–6.**

Fishes are so varied, however, that for almost every general statement there are exceptions. For example, some fishes, such as catfish, do not have scales. One reason for the enormous diversity among living fishes is that these chordates belong to very different classes. Thus, many fishes—sharks, lampreys, and perch, for example—are no more similar to one another than humans are to frogs!

CHECKPOINT *What are the basic functions of fins, scales, and gills?*

Guide for Reading

Key Concepts
- What are the basic characteristics of fishes?
- What were the important developments during the evolution of fishes?
- How are fishes adapted for life in water?
- What are the three main groups of fishes?

Vocabulary
cartilage • atrium • ventricle
cerebrum • cerebellum
medulla oblongata
lateral line system
swim bladder • oviparous
ovoviviparous • viviparous

Reading Strategy: Using Prior Knowledge
Before you read, make a list of the things you already know about fishes. After you have finished reading, check the list. Correct any errors and add new facts.

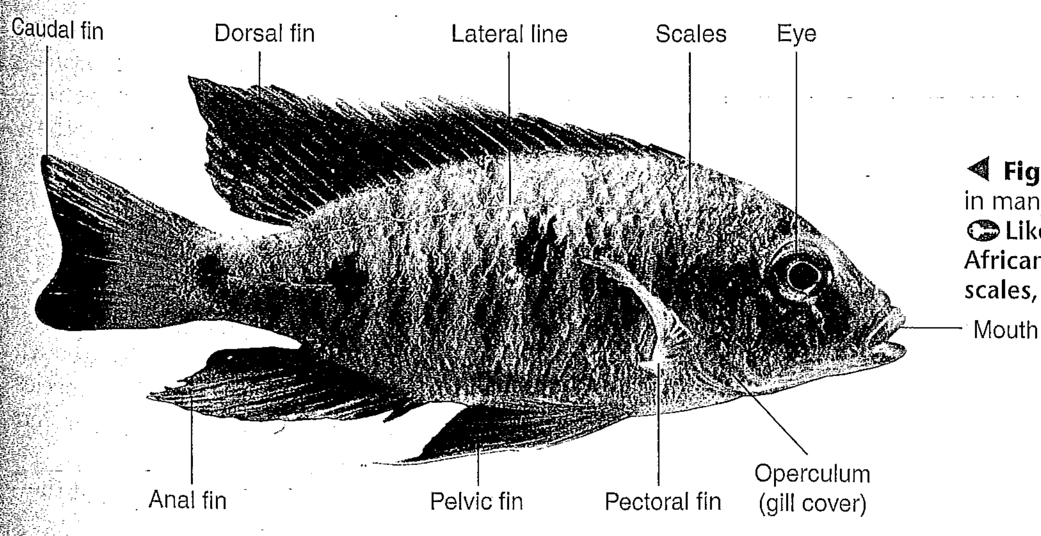
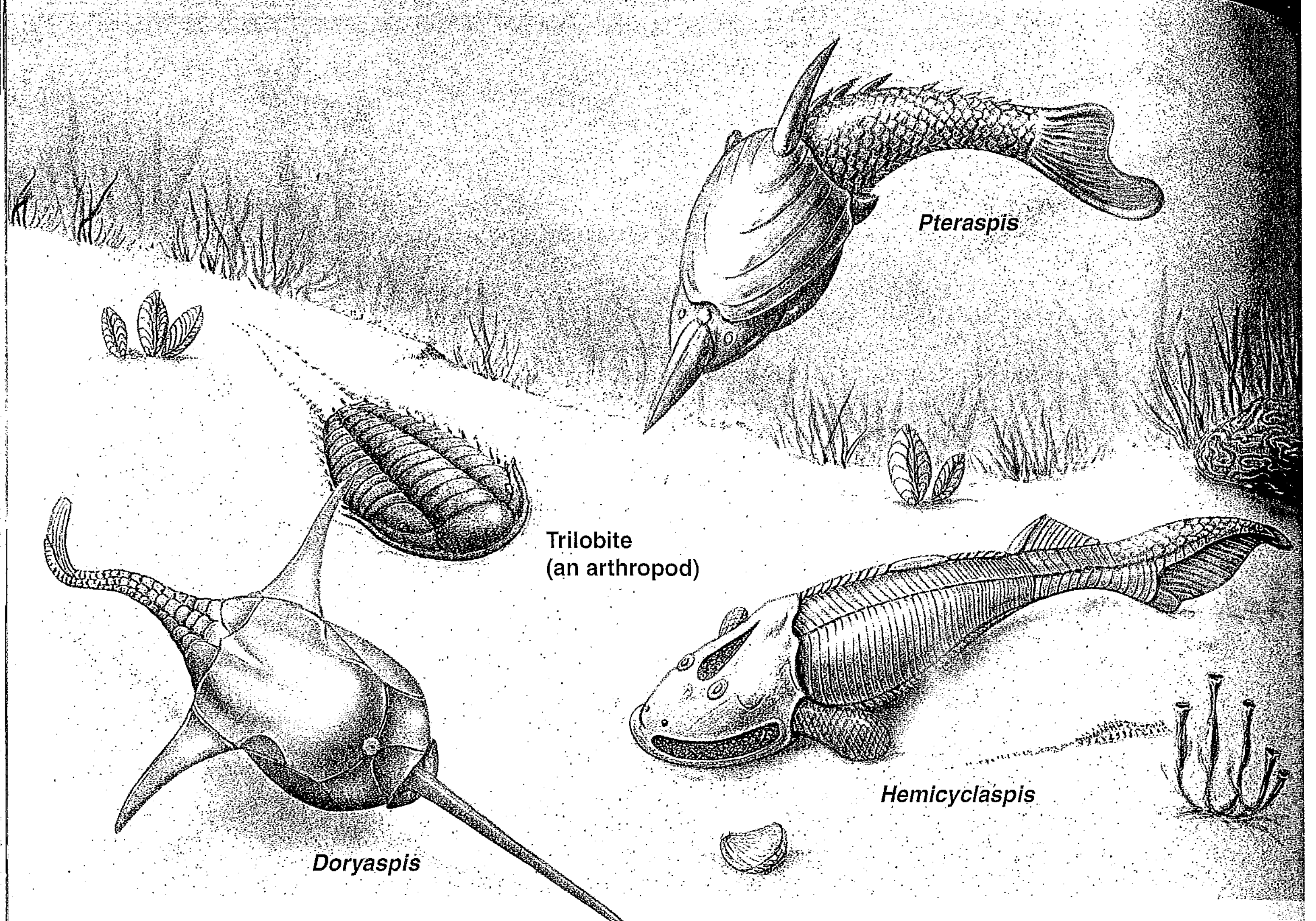


Figure 30–6 Fishes come in many shapes and sizes. **Like most fishes, this African cichlid has paired fins, scales, and gills.**



▲ **Figure 30–7** Ancient jawless fishes swam in shallow seas during the early Devonian Period, about 400 million years ago. Lacking jaws, early jawless fishes were limited in their ability to feed and to defend themselves against predators. **The evolution of paired fins, however, gave these fishes more control over their movement in the water.**

Evolution of Fishes

Fishes were the first vertebrates to evolve. They did not arise directly from tunicates or lancelets, but fishes and nonvertebrate chordates probably did evolve from common invertebrate ancestors. During the course of their evolution, fishes underwent several important changes. **The evolution of jaws and the evolution of paired fins were important developments during the rise of fishes.**

The First Fishes The earliest fishes to appear in the fossil record were odd-looking, jawless creatures whose bodies were armored with bony plates. They lived in the oceans during the late Cambrian Period, about 510 million years ago. Fishes kept this armored, jawless body plan for 100 million years.

The Age of Fishes During the Ordovician and Silurian Periods, about 505 to 410 million years ago, fishes underwent a major adaptive radiation. The species to emerge from the radiation ruled the seas during the Devonian Period, which is often called the Age of Fishes. Some of these fishes were jawless species that had very little armor. These jawless fishes were the ancestors of modern hagfishes and lampreys. Others, such as those in **Figure 30–7,** were armored and ultimately became extinct at the end of the Devonian Period, about 360 million years ago.

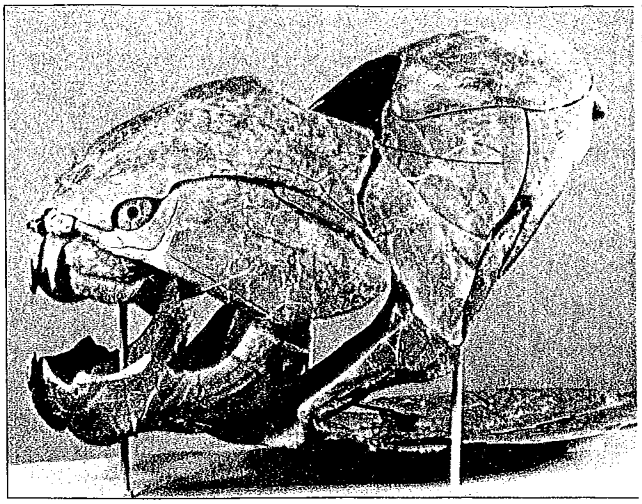
The Arrival of Jaws and Paired Fins Still other ancient fishes kept their bony armor and possessed a feeding adaptation that would revolutionize vertebrate evolution: These fishes had jaws. Observe the powerful jaws of the ancient fish in **Figure 30–8.** Jaws are an extremely useful adaptation. Jawless fishes are limited to eating small particles of food that they filter out of the water or suck up like a vacuum cleaner. Because jaws can hold teeth and muscles, jaws make it possible for vertebrates to nibble on plants and munch on other animals. Thus, animals with jaws can eat a much wider variety of food. They can also defend themselves by biting.

The evolution of jaws in early fishes accompanied the evolution of paired pectoral (anterior) and pelvic (posterior) fins. These fins were attached to girdles—structures of cartilage or bone that support the fins. **Cartilage** is a strong tissue that supports the body and is softer and more flexible than bone. **Figure 30–9** shows the fins and fin girdles in one ancient fish species.

Paired fins gave fishes more control of body movement. In addition, tail fins and powerful muscles gave fishes greater thrust when swimming. The combination of accuracy and speed enabled fishes to move in new and varied patterns. This ability, in turn, helped fishes use their jaws in complex ways.

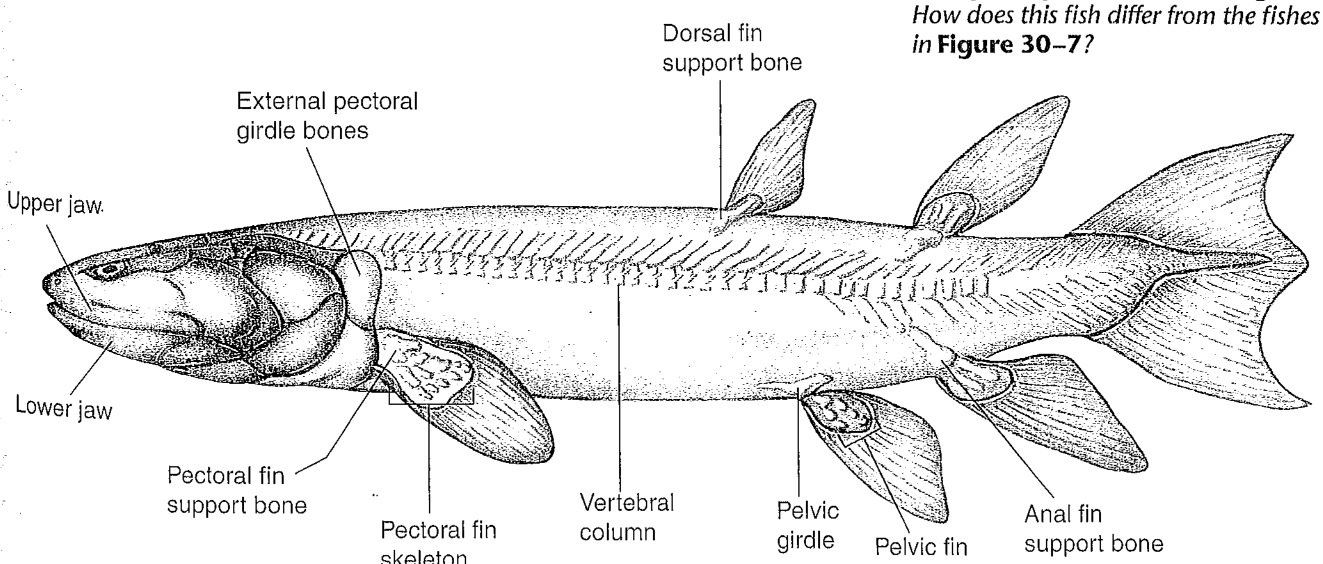
The Rise of Modern Fishes Although the early jawed fishes soon disappeared, they left behind two major groups that continued to evolve and still survive today. One group—the ancestors of modern sharks and rays—evolved a skeleton made of strong, resilient cartilage. The other group evolved skeletons made of true bone. A subgroup of bony fishes, called lobe-finned fishes, had fleshy fins from which the limbs of chordates would later evolve.

✓CHECKPOINT *Which two groups of early jawed fishes still survive today?*



▲ **Figure 30–8** This photograph shows a reconstruction of an ancient armored fish called *Dunkleosteus,* an enormous predator that lived in the inland seas of North America during the late Devonian Period. **Drawing Conclusions** *What feature made this fish a successful predator in its time?*

▼ **Figure 30–9** This ancient Devonian fish is called *Eusthenopteron.* Although its skeleton differs from those of most modern fishes, its basic features—vertebral column, fins, and fin girdles—have been retained in many species. **Comparing and Contrasting** *How does this fish differ from the fishes in* **Figure 30–7**?



▲ **Figure 30–10** **Adaptations to aquatic life include various modes of feeding.** This deep-sea anglerfish has a built-in "fishing pole" that it uses to attract prey.

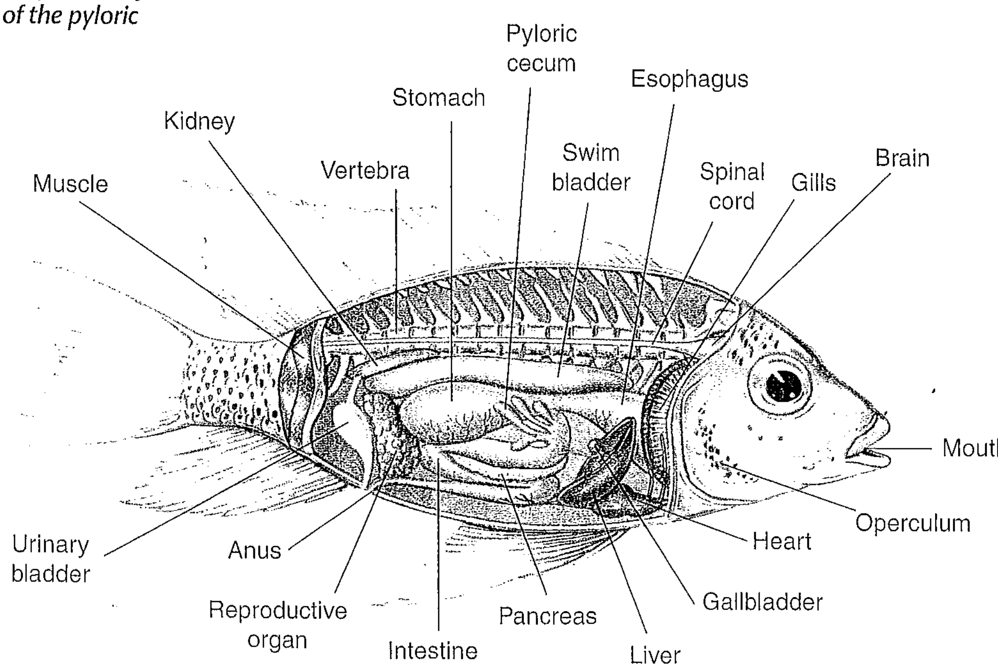
Form and Function in Fishes

Over time, fishes have evolved to survive in a tremendous range of aquatic environments. **Adaptations to aquatic life include various modes of feeding, specialized structures for gas exchange, and paired fins for locomotion.** Fishes have other types of adaptations, too, as you will learn.

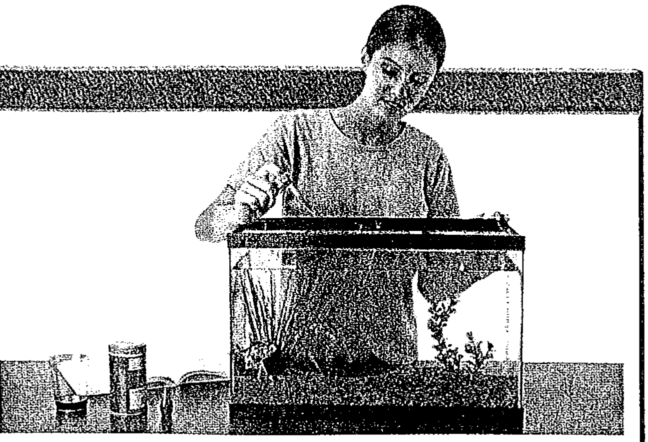
Feeding Every mode of feeding is seen in fishes. There are herbivores, carnivores, parasites, filter feeders, and detritus feeders. In fact, a single fish may exhibit several modes of feeding, depending on what type of food happens to be available. Certain carp, for example, eat algae, aquatic plants, worms, mollusks, arthropods, dead fish, and detritus. Other fishes, such as barracuda, are highly specialized carnivores. A few fishes, such as some lampreys, are parasites. **Figure 30–10** shows a fish that even uses a fleshy bait to catch its meals!

Use **Figure 30–11** to locate the internal organs that are important during the fish's digestion of its food. From the fish's mouth, food passes through a short tube called the esophagus to the stomach, where it is partially broken down. In many fishes, the food is further processed in fingerlike pouches called pyloric ceca (py-LAWR-ik SEE-kuh; singular: cecum). The pyloric ceca secrete digestive enzymes and absorb nutrients from the digested food. Other organs, including the liver and pancreas, add enzymes and other digestive chemicals to the food as it moves through the digestive tract. The intestine completes the process of digestion and nutrient absorption. Any undigested material is eliminated through the anus.

▼ **Figure 30–11** The internal organs of a typical bony fish are shown here. **Applying Concepts** *What is the function of the pyloric cecum?*



Quick Lab



How do fishes use gills?

Materials fish food, food coloring, plastic cup, dropper pipette, live fish in an aquarium

Procedure

1. Mix some fish food and food coloring in a small volume of aquarium water in a plastic cup.
2. Use a dropper pipette to release the mixture near a fish in an aquarium. Release the mixture gently so that it does not scatter.
3. Observe what happens when the fish approaches the mixture. Watch the fish's gills especially closely.

Analyze and Conclude

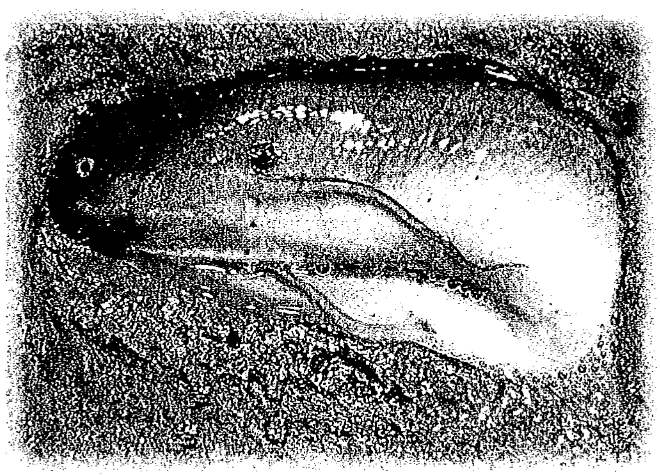
1. **Drawing Conclusions** Describe what happened to the food coloring. What does this tell you about how water moves through a fish's body?
2. **Inferring** Why do most fishes seem to move or swallow continuously? What might happen if a fish were not able to move or stopped "swallowing"?

Respiration Most fishes exchange gases using gills located on either side of the pharynx. The gills are made up of feathery, threadlike structures called filaments. Each filament contains a network of fine capillaries that provides a large surface area for the exchange of oxygen and carbon dioxide. Fishes that exchange gases using gills do so by pulling oxygen-rich water in through their mouths, pumping it over their gill filaments, and then pushing oxygen-poor water out through openings in the sides of the pharynx.

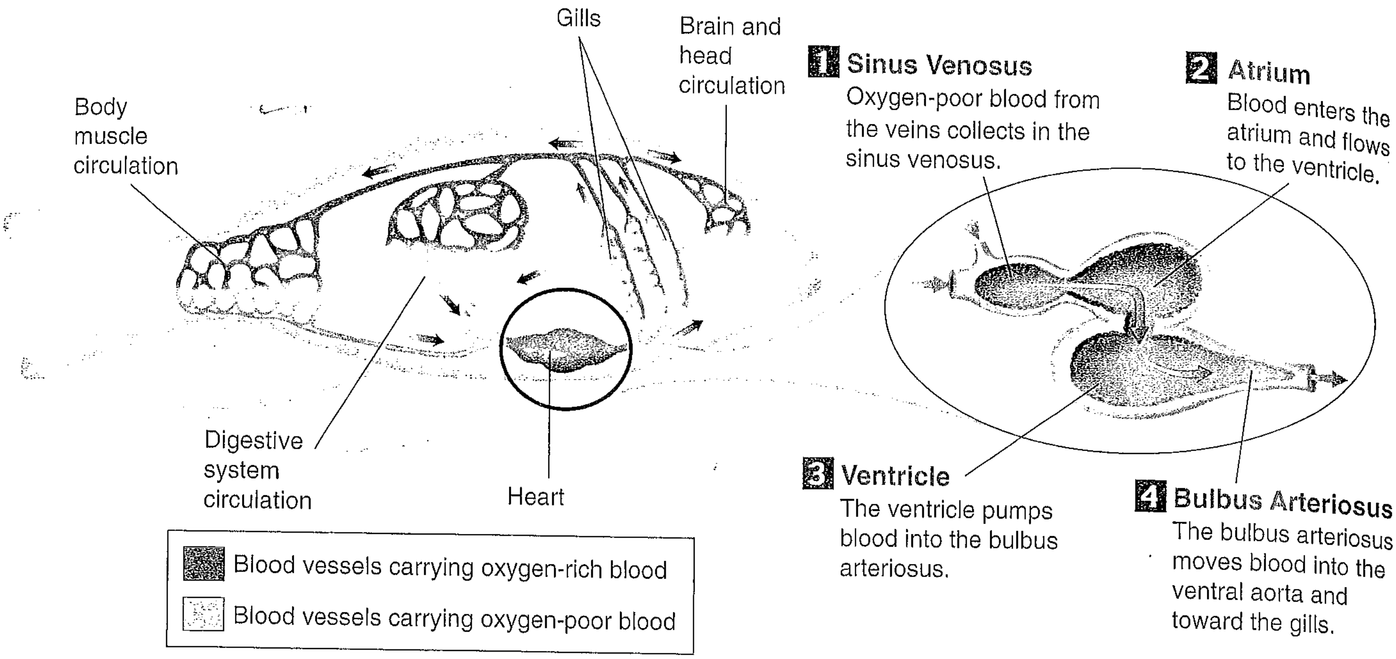
Some fishes, such as lampreys and sharks, have several gill openings. Most fishes, however, have a single gill opening on each side of the body through which water is pumped out. This opening is hidden beneath a protective bony cover called the operculum.

A number of fishes have an adaptation that allows them to survive in oxygen-poor water or in areas where bodies of water often dry up. These fishes have specialized organs that serve as lungs. A tube brings air containing oxygen to this organ through the fish's mouth. Some lungfishes are so dependent on getting oxygen from the air that they will suffocate if prevented from reaching the surface of the water.

✓CHECKPOINT *What structures do fishes use for gas exchange?*



▶ **Figure 30–12** This African lungfish has a breathing adaptation that allows it to survive in shallow waters that are subject to drought. It burrows into mud, covers itself with mucus, and becomes dormant. For several months until the rains fall, the lungfish breathes through its mouth and lungs. **Drawing Conclusions** *How is it an advantage for this lungfish to cover itself with mucus?*



▲ **Figure 30–13** Blood circulates through a fish's body in a single loop—from the heart to the gills to the rest of the body, and then back to the heart again. (Note that in diagrams of animals' circulatory systems, blood vessels carrying oxygen-rich blood are red, while blood vessels carrying oxygen-poor blood are blue.) **Interpreting Graphics** *Is the blood that flows from the heart to the gills oxygen-rich or oxygen-poor?*

Circulation Fishes have closed circulatory systems with a heart that pumps blood around the body in a single loop—from the heart to the gills, from the gills to the rest of the body, and back to the heart. **Figure 30–13** shows the path of blood and the structure of the heart.

In most fishes, the heart consists of four parts: the sinus venosus (SYN-us vuh-NOH-sus), atrium, ventricle, and bulbus arteriosus (BUL-bus ahr-teer-ee-OH-sus). The sinus venosus is a thin-walled sac that collects blood from the fish's veins before it flows to the **atrium,** a large muscular chamber that serves as a one-way compartment for blood that is about to enter the ventricle. The **ventricle,** a thick-walled, muscular chamber, is the actual pumping portion of the heart. It pumps blood to a large, muscular tube called the bulbus arteriosus. At its front end, the bulbus arteriosus connects to a large blood vessel called the aorta, through which blood moves to the fish's gills.

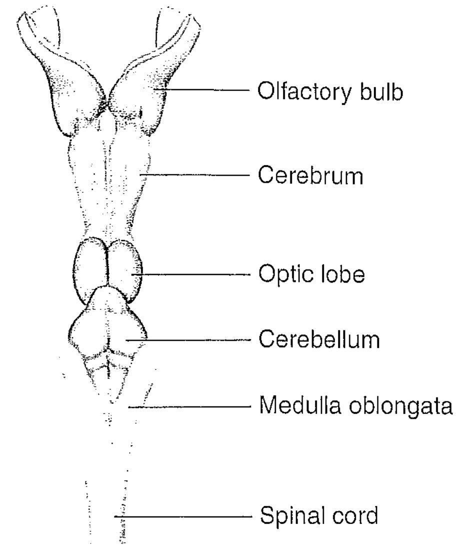
Excretion Like many other aquatic animals, most fishes rid themselves of nitrogenous wastes in the form of ammonia. Some wastes diffuse through the gills into the surrounding water. Others are removed by kidneys, which are excretory organs that filter wastes from the blood.

Kidneys help fishes control the amount of water in their bodies. Fishes in salt water tend to lose water by osmosis. To solve this problem, the kidneys of marine fishes concentrate wastes and return as much water as possible to the body. In contrast, a great deal of water continually enters the bodies of freshwater fishes. The kidneys of freshwater fishes pump out plenty of dilute urine. Some fishes are able to move from fresh to salt water by adjusting their kidney function.

Go Online
NSTA SCILINKS
For: Links on fishes
Visit: www.SciLinks.org
Web Code: cbn-9302

Response Fishes have well-developed nervous systems organized around a brain, which has several parts, as shown in **Figure 30–14.** The most anterior parts of a fish's brain are the olfactory bulbs, which are involved with the sense of smell, or olfaction. They are connected to the two lobes of the cerebrum. In most vertebrates, the **cerebrum** is responsible for all voluntary activities of the body. However, in fishes, the cerebrum primarily processes the sense of smell. The optic lobes process information from the eyes. The **cerebellum** coordinates body movements. The **medulla oblongata** controls the functioning of many internal organs.

Most fishes have highly developed sense organs. Almost all fishes that are active in daylight have well-developed eyes and color vision that is at least as good as yours. Many fishes have specialized cells called chemoreceptors that are responsible for their extraordinary senses of taste and smell. Although most fishes have ears inside their head, they may not hear sounds well. Most fishes can, however, detect gentle currents and vibrations in the water with sensitive receptors that form the **lateral line system.** Fishes use this system to sense the motion of other fishes or prey swimming nearby. In addition to detecting motion, some fishes, such as catfish and sharks, have evolved sense organs that can detect low levels of electric current. Some fishes, such as the electric eel shown in **Figure 30–15,** can even generate their own electricity!

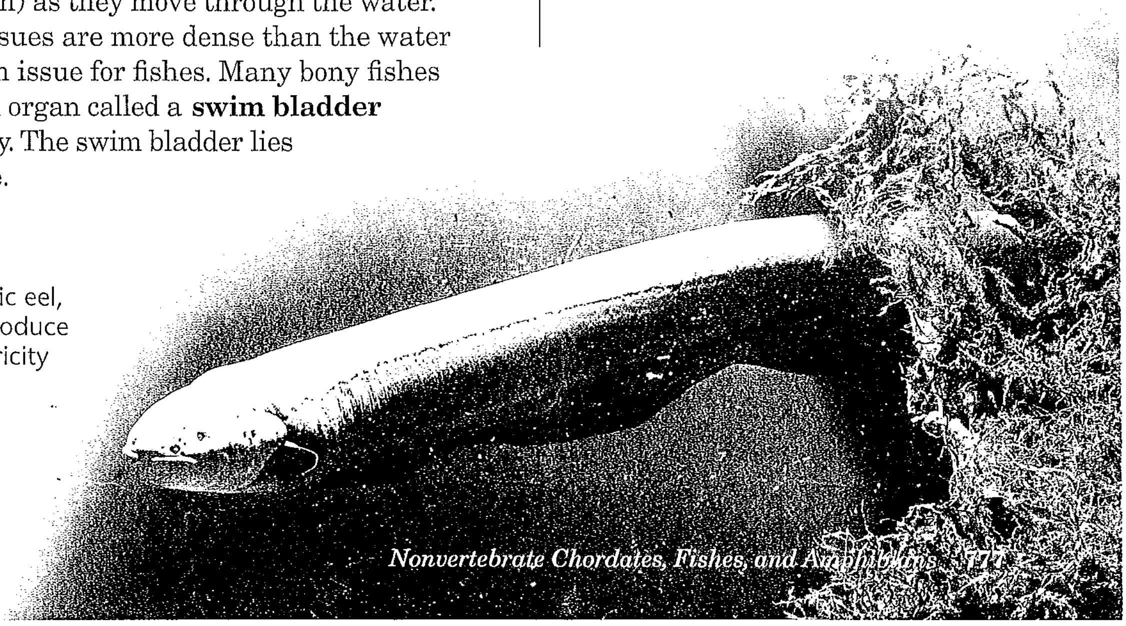


▲ **Figure 30–14** The brain of a fish, like all vertebrate brains, is situated at the anterior end of the spinal cord and has several different parts. **Inferring** *How might the size of the various parts of the brain differ in a blind cave fish that relies primarily on its sense of smell?*

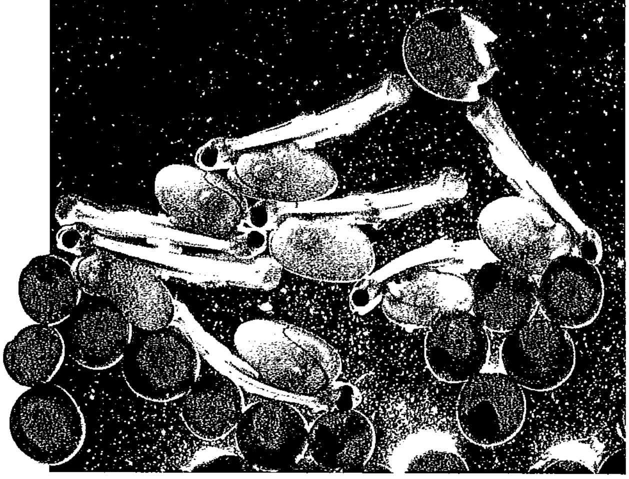
✓CHECKPOINT *What are the parts of a fish's brain?*

Movement Most fishes move by alternately contracting paired sets of muscles on either side of the backbone. This creates a series of S-shaped curves that move down the fish's body. As each curve travels from the head toward the tail fin, it creates backward force on the surrounding water. This force, along with the action of the fins, propels the fish forward. The fins of fishes are also used in much the same way that airplanes use stabilizers, flaps, and rudders—to keep on course and adjust direction. Fins also increase the surface area of the tail, providing an extra boost of speed. The streamlined body shapes of most fishes help reduce the amount of drag (friction) as they move through the water.

Because their body tissues are more dense than the water they swim in, sinking is an issue for fishes. Many bony fishes have an internal, gas-filled organ called a **swim bladder** that adjusts their buoyancy. The swim bladder lies just beneath the backbone.



▶ **Figure 30–15** The electric eel, *Electrophorus electricus,* can produce several hundred volts of electricity in brief bursts. **Formulating Hypotheses** *What function might such powerful electric bursts serve?*



▲ **Figure 30–16** Some newly hatched fishes, such as these coho salmon, are nourished by yolk sacs on their bellies. **Inferring** *What are the orange spheres at the bottom of the photograph?*

Reproduction The eggs of fishes are fertilized either externally or internally, depending on the species. In many fish species, the female lays the eggs and the embryos in the eggs develop and hatch outside her body. Fishes whose eggs hatch outside the mother's body are **oviparous** (oh-VIP-uh-rus). As the embryos of oviparous fishes develop, they obtain food from the yolk in the egg. The salmon in **Figure 30–16** are oviparous. In contrast, in **ovoviviparous** (oh-voh-vy-VIP-uh-rus) species, such as guppies, the eggs stay in the mother's body after internal fertilization. Each embryo develops inside its egg, using the yolk for nourishment. The young are then "born alive," like the young of most mammals. A few fish species, including several sharks, are viviparous. In **viviparous** (vy-VIP-uh-rus) animals, the embryos stay in the mother's body after internal fertilization, as they do in ovoviviparous species. However, these embryos obtain the substances they need from the mother's body, not from material in an egg. The young of viviparous species are also born alive.

✓CHECKPOINT *What are the three different modes of fish reproduction?*

Groups of Fishes

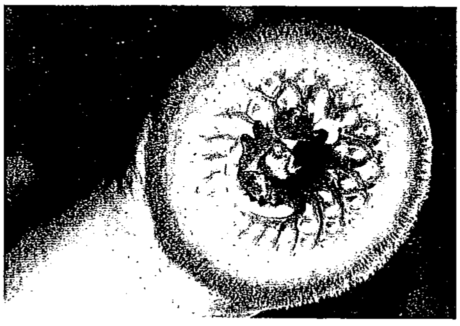
With over 24,000 living species, fishes are an extremely diverse group of chordates. These diverse species can be grouped according to body structure. **When you consider their basic internal structure, all living fishes can be classified into three groups: jawless fishes, cartilaginous fishes, and bony fishes.**

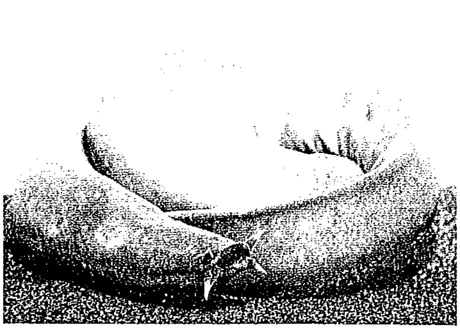
Jawless Fishes As their name implies, jawless fishes have no true teeth or jaws. Their skeletons are made of fibers and cartilage. They lack vertebrae, and instead keep their notochords as adults. Modern jawless fishes are divided into two classes: lampreys and hagfishes.

Lampreys are typically filter feeders as larvae and parasites as adults. An adult lamprey's head is taken up almost completely by a circular sucking disk with a round mouth in the center, which you can see in **Figure 30–17.** Adult lampreys attach themselves to fishes, and occasionally to whales and dolphins. There, they scrape away at the skin with small toothlike structures that surround the mouth and with a strong, rasping tongue. The lamprey then sucks up the tissues and body fluids of its host.

Hagfishes have pinkish gray, wormlike bodies and four or six short tentacles around their mouths. Hagfishes lack eyes, although they do have light-detecting sensors scattered around their bodies. They feed on dead and dying fish by using a toothed tongue to scrape a hole into the fish's side. Hagfishes have other peculiar traits: They secrete incredible amounts of slime, have six hearts, possess an open circulatory system, and regularly tie themselves into knots!

Figure 30–17 **Jawless fishes make up one of three major groups of living fishes.** Modern jawless fishes are divided into two classes: lampreys (top) and hagfishes (bottom).





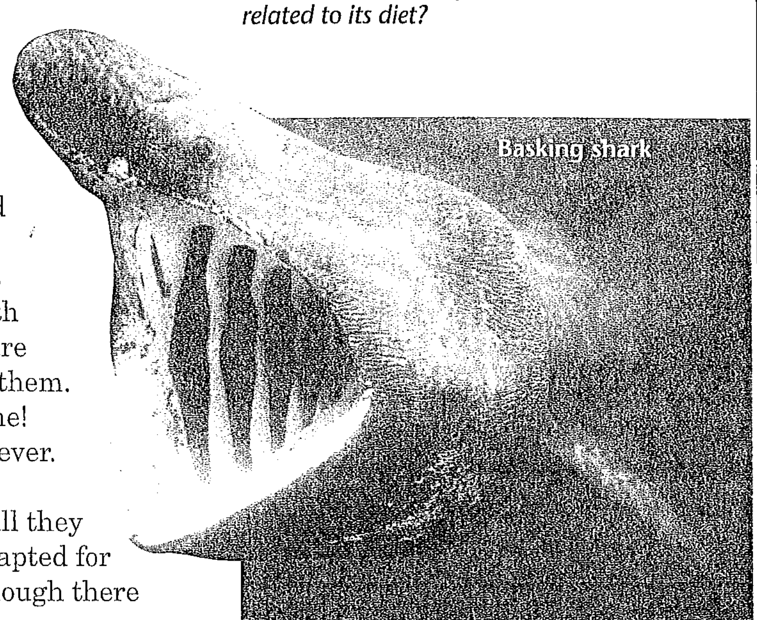
Sharks and Their Relatives The class Chondrichthyes (kahn-DRIK-theez) contains sharks, rays, skates, and a few uncommon fishes such as sawfishes and chimaeras. Some chondrichthyes are shown in **Figure 30–18.** *Chondros* is the Greek word for cartilage, so the name of this class tells you that the skeletons of these fishes are built entirely of cartilage, not bone. The cartilage of these animals is similar to the flexible tissue that supports your nose and your external ears. Most cartilaginous fishes also have toothlike scales covering their skin. These scales make shark skin so rough that it can be used as sandpaper.

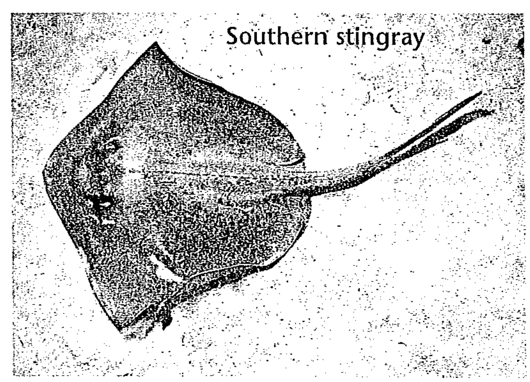
Most of the 350 or so living shark species have large curved tails, torpedo-shaped bodies, and pointed snouts with the mouth underneath. One of the most noticeable characteristics of sharks is their enormous number of teeth. Many sharks have thousands of teeth arranged in several rows. As teeth in the front rows are worn out or lost, new teeth are continually replacing them. A shark goes through about 20,000 teeth in its lifetime!

Not all sharks have such fierce-looking teeth, however. Some, like the basking shark, are filter feeders with specialized feeding structures. Their teeth are so small they are virtually useless. Other sharks have flat teeth adapted for crushing the shells of mollusks and crustaceans. Although there are a number of carnivorous sharks large enough to prey on humans, most sharks do not attack people.

Skates and rays are even more diverse in their feeding habits than their shark relatives. Some feed on bottom-dwelling invertebrates by using their mouths as powerful vacuums. However, the largest rays, like the largest sharks, are filter feeders that eat floating plankton. Skates and rays often glide through the sea with flapping motions of their large, winglike pectoral fins. When they are not feeding or swimming, many skates and rays cover themselves with a thin layer of sand and spend hours resting on the ocean floor.

▼ **Figure 30–18** Sharks and rays have skeletons that are made of cartilage. The large jaws and teeth of many sharks make them top predators in the world's oceans. **Applying Concepts** *How is the structure of a basking shark's mouth related to its diet?*





Silky shark

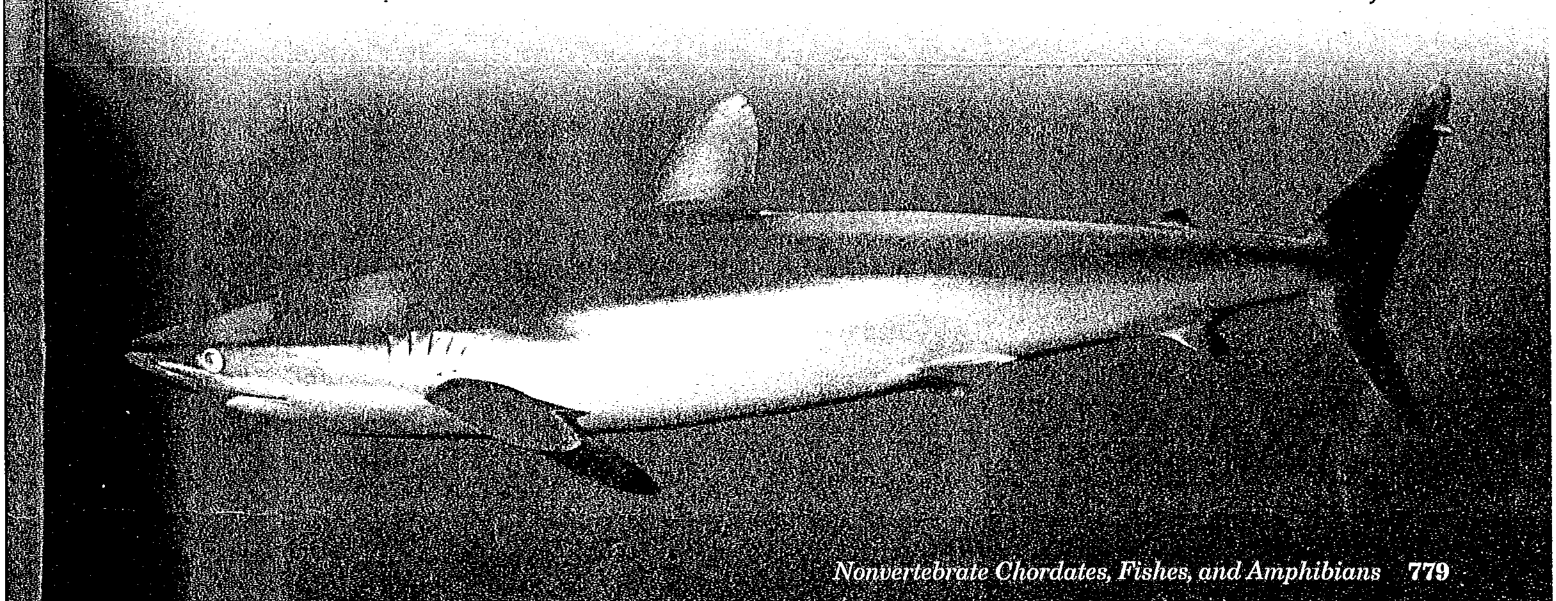
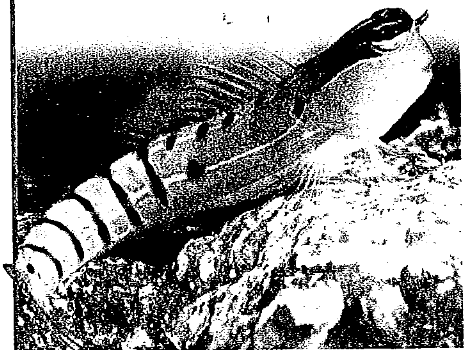
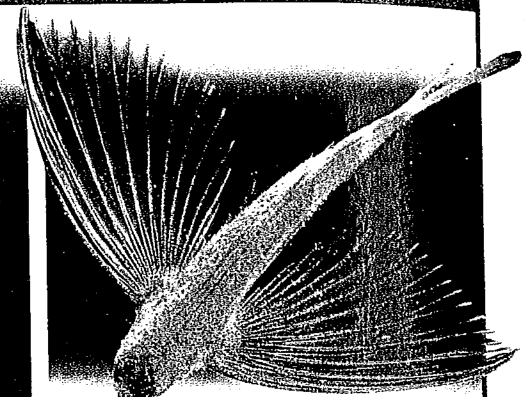


Figure 30–19 Diversity of Ray-finned Fishes



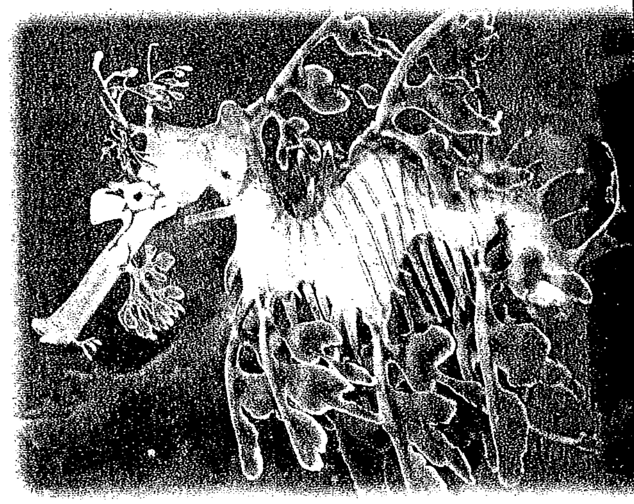
Combtooth Blenny

Emperor Angelfish



Flying Fish

Peacock Flounder



Leafy Sea Dragon

Nearly all bony fishes belong to an enormous and diverse group called ray-finned fishes. These fishes have thin, bony spines that form the fins. **Observing** *What unusual adaptations do you see in each of these fishes?*

Bony Fishes Bony fishes make up the class Osteichthyes (ahs-tee-IK-theez). The skeletons of these fishes are made of hard, calcified tissue called bone. Almost all living bony fishes belong to a huge group called ray-finned fishes, some of which are shown in **Figure 30–19.** The name "ray-finned" refers to the slender bony spines, or rays, that are connected by a thin layer of skin to form the fins. The fin rays support the skin much as the thin rods in a handheld folding fan hold together the webbing of the fan.

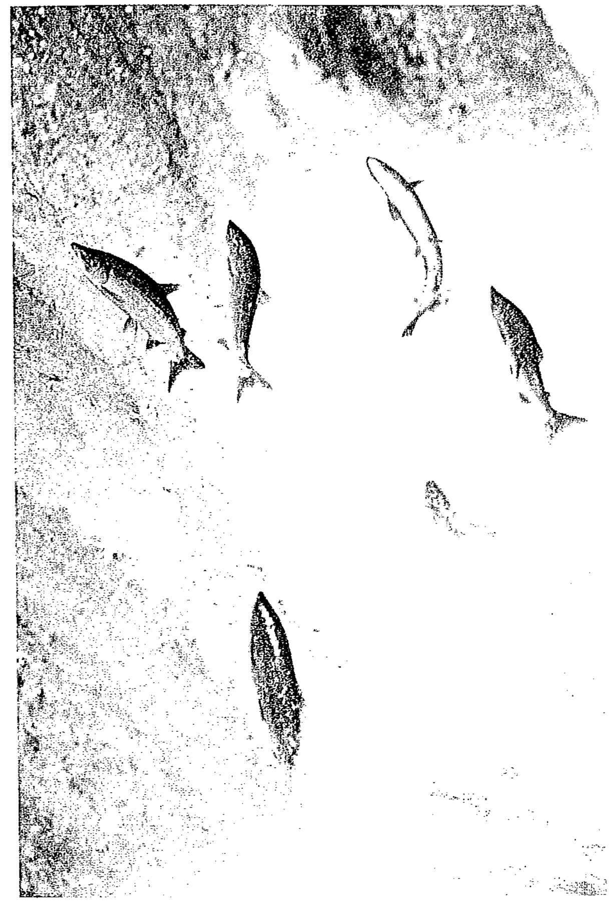
Only seven living species of bony fishes are not classified as ray-finned fishes. These are the lobe-finned fishes, a subclass that includes lungfishes and the coelacanth (SEE-luh-kanth). Lungfishes live in fresh water, but the coelacanth lives in salt water. The fleshy fins of lobe-finned fishes have support bones that are more substantial than the rays of ray-finned fishes. Some of these bones are jointed, like the arms and legs of land vertebrates.

Ecology of Fishes

Most fishes spend all their lives either in fresh water or in the ocean. Most freshwater fishes cannot tolerate the high salt concentration in saltwater ecosystems, because their kidneys cannot maintain internal water balance in this environment. Since freshwater fishes cannot maintain homeostasis in salt water, they cannot survive in the ocean. In contrast, ocean fishes cannot tolerate the low salt concentration in freshwater ecosystems.

However, some fish species can move from saltwater ecosystems to fresh water, and vice versa. Lampreys, sturgeons, and salmon, for example, spend most of their lives in the ocean but migrate to fresh water to breed. Fishes with this type of behavior are called anadromous (uh-NAH-druh-mus). Salmon, for example, begin their lives in rivers or streams but soon migrate to the sea. After one to four years at sea, mature salmon return to the place of their birth to reproduce. This trip can take several months, covering as much as 3200 kilometers, and can involve incredible feats of strength, as shown in **Figure 30–20.** The adult salmon recognize their home stream using their sense of smell.

In contrast to anadromous fishes, some fishes live their lives in fresh water but migrate to the ocean to breed. These fishes are said to be catadromous (kuh-TAD-ruh-mus). European eels, for instance, live and feed in the rivers of North America and Europe. They travel up to 4800 kilometers to lay their eggs in the Sargasso Sea, in the North Atlantic Ocean. The eggs are carried by currents to shallow coastal waters. As they grow into young fish, the eels find their way to fresh water and migrate upstream.



▲ **Figure 30–20** Adult salmon return from the sea to reproduce in the stream or river in which they were born. Their journey is often long and strenuous. The salmon must swim upstream against the current and may even leap up waterfalls! **Applying Concepts** *What sense do the salmon use to find their home stream?*

30–2 Section Assessment

1. **Key Concept** Identify the main characteristics of fishes.
2. **Key Concept** What adaptive advantages do jaws and fins provide for fishes?
3. **Key Concept** List four specific ways in which fishes are adapted for aquatic life.
4. **Key Concept** Name the three main groups of fishes and give an example for each group.
5. **Critical Thinking Applying Concepts** For fishes to survive in an aquarium, the water must be kept clean and well oxygenated. Explain why water quality is so important to a fish's survival.

Focus on the BIG Idea

Structure and Function
In Chapter 27, you learned about the circulatory system of annelids. Create a Venn diagram comparing the circulatory system of an annelid with that of a fish. How are the two circulatory systems similar and different?

30–3 Amphibians

Guide for Reading

Key Concepts
- What is an amphibian?
- How are amphibians adapted for life on land?
- What are the main groups of living amphibians?

Vocabulary
cloaca
nictitating membrane
tympanic membrane

Reading Strategy: Making Comparisons
As you read, write down similarities and differences between fishes and amphibians. Consider such characteristics as body structure, habitat, and method of reproduction.

Amphibians have survived for hundreds of millions of years, typically living in places where fresh water is plentiful. With over 4000 living species, amphibians are the only modern descendants of an ancient group that gave rise to all other land vertebrates.

What Is an Amphibian?

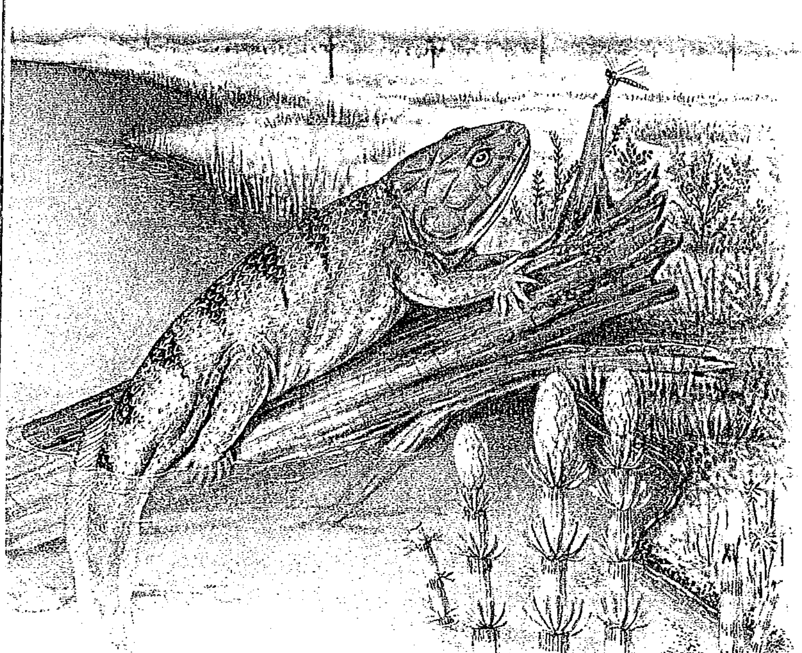
The word *amphibian* means "double life," emphasizing that these animals live both in water and on land. The larvae are fishlike aquatic animals that respire using gills. In contrast, the adults of most species of amphibians are terrestrial animals that respire using lungs and skin.

An amphibian is a vertebrate that, with some exceptions, lives in water as a larva and on land as an adult, breathes with lungs as an adult, has moist skin that contains mucous glands, and lacks scales and claws. In a sense, amphibians are to the animal kingdom what mosses and ferns are to the plant kingdom: They are descendants of ancestral organisms that evolved some—but not all—of the adaptations necessary for living entirely on land.

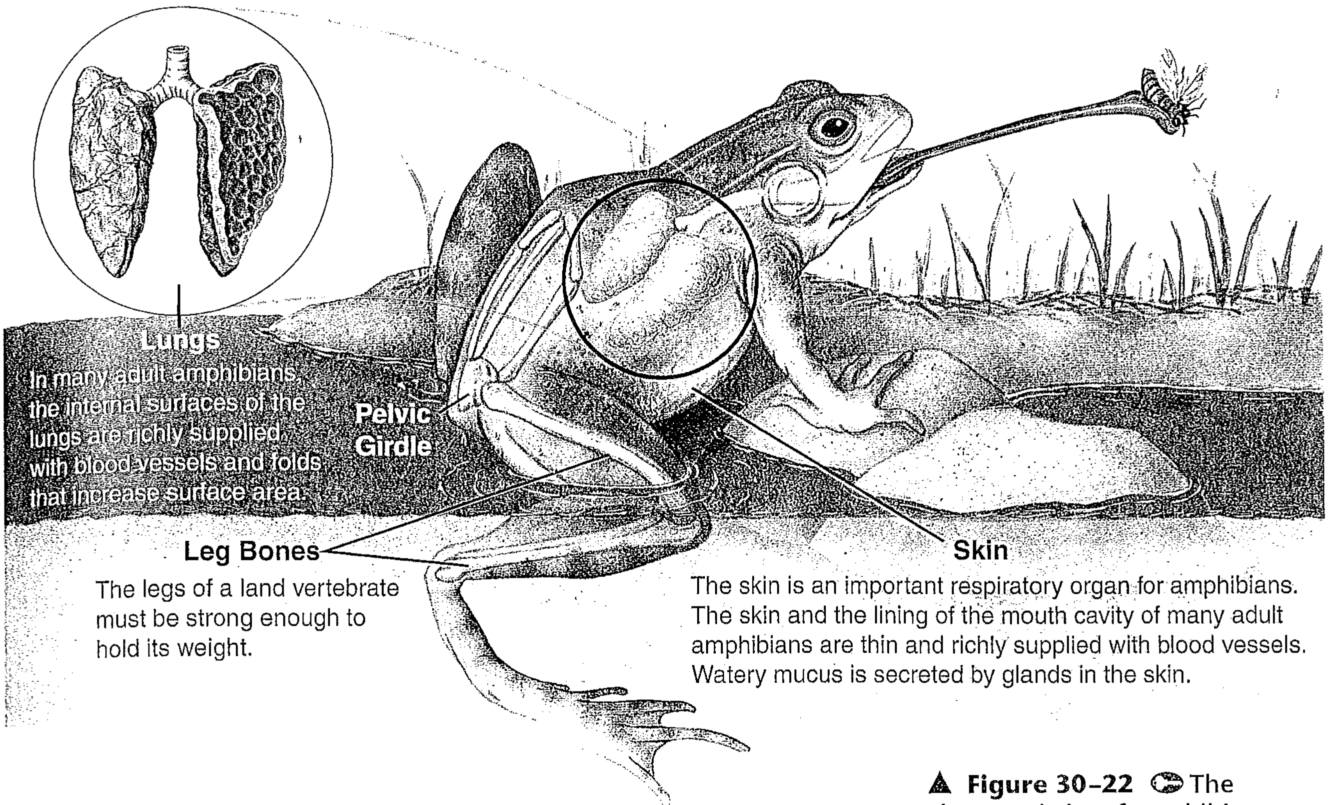
Evolution of Amphibians

The first amphibians to climb onto land probably resembled lobe-finned fishes similar to the modern coelacanth. However, the amphibians had legs, as in **Figure 30–21.** They appeared in the late Devonian Period, about 360 million years ago.

The transition from water to land involved more than just having legs and clambering out of the water. Vertebrates colonizing land habitats faced the same challenges that had to be overcome by invertebrates. Terrestrial vertebrates have to breathe air, protect themselves and their eggs from drying out, and support themselves against the pull of gravity.



◀ **Figure 30–21** Evolving in the swamplike tropical ecosystems of the Devonian Period, amphibians were the first chordates to live at least part of their lives on land. **Most amphibians live in water as larvae and on land as adults.**



▲ **Figure 30–22** **The characteristics of amphibians include adaptations for living partially on land.** For example, lungs enable adult amphibians to obtain oxygen from air.

Early amphibians evolved several adaptations that helped them live at least part of their lives out of water. Bones in the limbs and limb girdles of amphibians became stronger, permitting more efficient movement. Lungs and breathing tubes enabled amphibians to breathe air. The sternum, or breastbone, formed a bony shield to support and protect internal organs, especially the lungs. Some of these adaptations are shown in **Figure 30–22.**

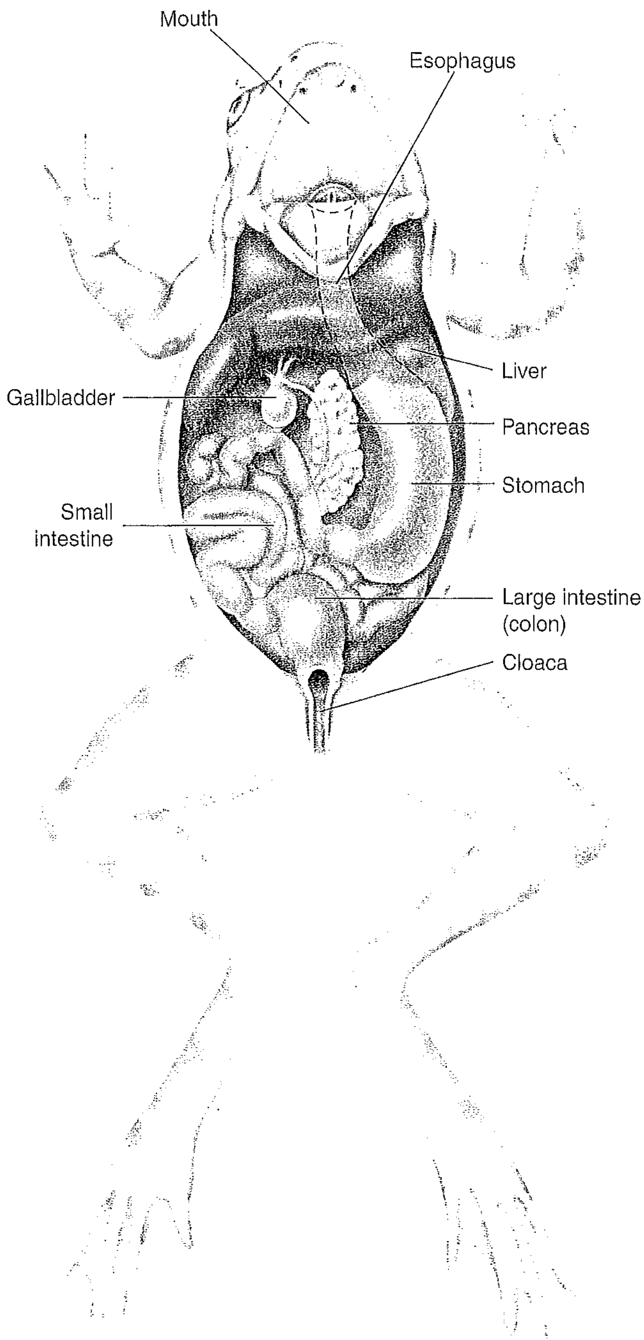
Soon after they first appeared, amphibians underwent a major adaptive radiation. Some of these ancient amphibians were huge. One early amphibian, *Eogyrinus,* is thought to have been about 5 meters long. Amphibians became the dominant form of animal life in the warm, swampy fern forests of the Carboniferous Period, about 360 to 290 million years ago. In fact, they were so numerous that the Carboniferous Period is sometimes called the Age of Amphibians. These animals gave rise to the ancestors of living amphibians and of vertebrates that live completely on land.

The great success of amphibians didn't last, however. Climate changes caused many of their low, swampy habitats to disappear. Most amphibian groups became extinct by the end of the Permian Period, about 245 million years ago. Only three orders of small amphibians survive today—frogs and toads, salamanders, and caecilians (see-SIL-ee-unz).

✓CHECKPOINT *Which geological period is called the Age of Amphibians?*

Word Origins

Carboniferous is a combination of two root words—*carbone* and *fer. Carbone* is a French word for coal; *fer* is a Latin suffix meaning "bearing or producing." *Carboniferous* is an adjective describing the coal-making period of the Paleozoic Era. **If *cone* refers to a reproductive structure of a tree, what do you think the word *coniferous* means?**



▲ **Figure 30–23** This illustration shows the organs of a frog's digestive system. **Comparing and Contrasting** *Which digestive organs are found in both frogs and fishes?*

Form and Function in Amphibians

Although the class Amphibia is relatively small, it is diverse enough to make it difficult to identify a typical species. As you examine essential life functions in amphibians, you will focus on the structures found in frogs.

Feeding The double lives of amphibians are reflected in the feeding habits of frogs. Tadpoles are typically filter feeders or herbivores that graze on algae. Like other herbivores, the tadpoles eat almost constantly. Their intestines, whose long, coiled structure helps break down hard-to-digest plant material, are usually filled with food. However, when tadpoles change into adults, their feeding apparatus and digestive tract are transformed to strictly meat-eating structures, complete with a much shorter intestine.

Adult amphibians are almost entirely carnivorous. They will eat practically anything they can catch and swallow. Legless amphibians can only snap their jaws open and shut to catch prey. In contrast, many salamanders and frogs have long, sticky tongues specialized to capture insects.

Trace the path of food in a frog's digestive system in **Figure 30–23.** From the mouth, food slides down the esophagus into the stomach. The breakdown of food begins in the stomach and continues in the small intestine, where digestive enzymes are manufactured and food is absorbed. Tubes connect the intestine with organs such as the liver, pancreas, and gallbladder that secrete substances that aid in digestion. The small intestine leads to the large intestine, or colon. At the end of the large intestine is a muscular cavity called the **cloaca** (kloh-AY-kuh), through which digestive wastes, urine, and eggs or sperm leave the body.

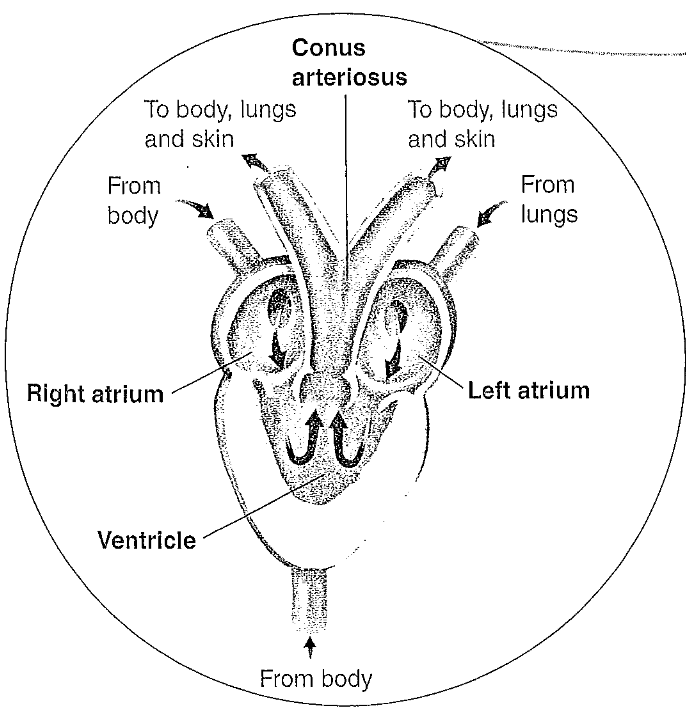
Respiration In most larval amphibians, gas exchange occurs through the skin as well as the gills. Lungs typically replace gills when an amphibian becomes an adult, although some gas exchange continues through the skin and the lining of the mouth cavity. In frogs, toads, and many other adult amphibians, the lungs are reasonably well developed. In other amphibians, such as salamanders, the lungs are not as well developed. In fact, many terrestrial salamanders have no lungs at all! Lungless salamanders exchange gases through the thin lining of the mouth cavity as well as through the skin.

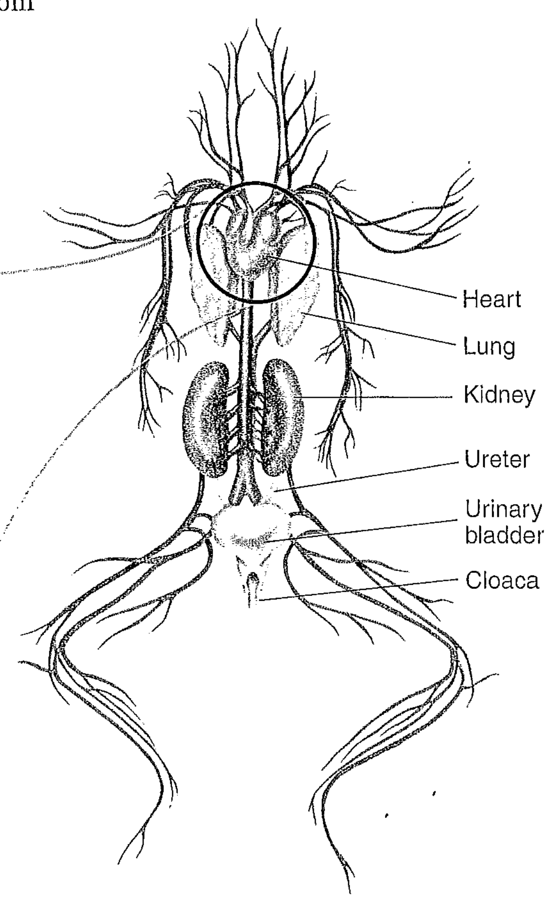
Circulation In frogs and other adult amphibians, the circulatory system forms what is known as a double loop. The first loop carries oxygen-poor blood from the heart to the lungs and skin, and takes oxygen-rich blood from the lungs and skin back to the heart. The second loop transports oxygen-rich blood from the heart to the rest of the body and then carries oxygen-poor blood from the body back to the heart.

The amphibian heart, shown in **Figure 30–24,** has three separate chambers: left atrium, right atrium, and ventricle. Oxygen-poor blood circulates from the body into the right atrium. At the same time, oxygen-rich blood from the lungs and skin enters the left atrium. When the atria contract, they empty their blood into the ventricle. The ventricle then contracts, pumping blood out to a single, large blood vessel that divides and branches off into smaller blood vessels. Because of the pattern in which the blood vessels branch, most oxygen-poor blood goes to the lungs, and most oxygen-rich blood goes to the rest of the body. However, there is some mixing of oxygen-rich and oxygen-poor blood.

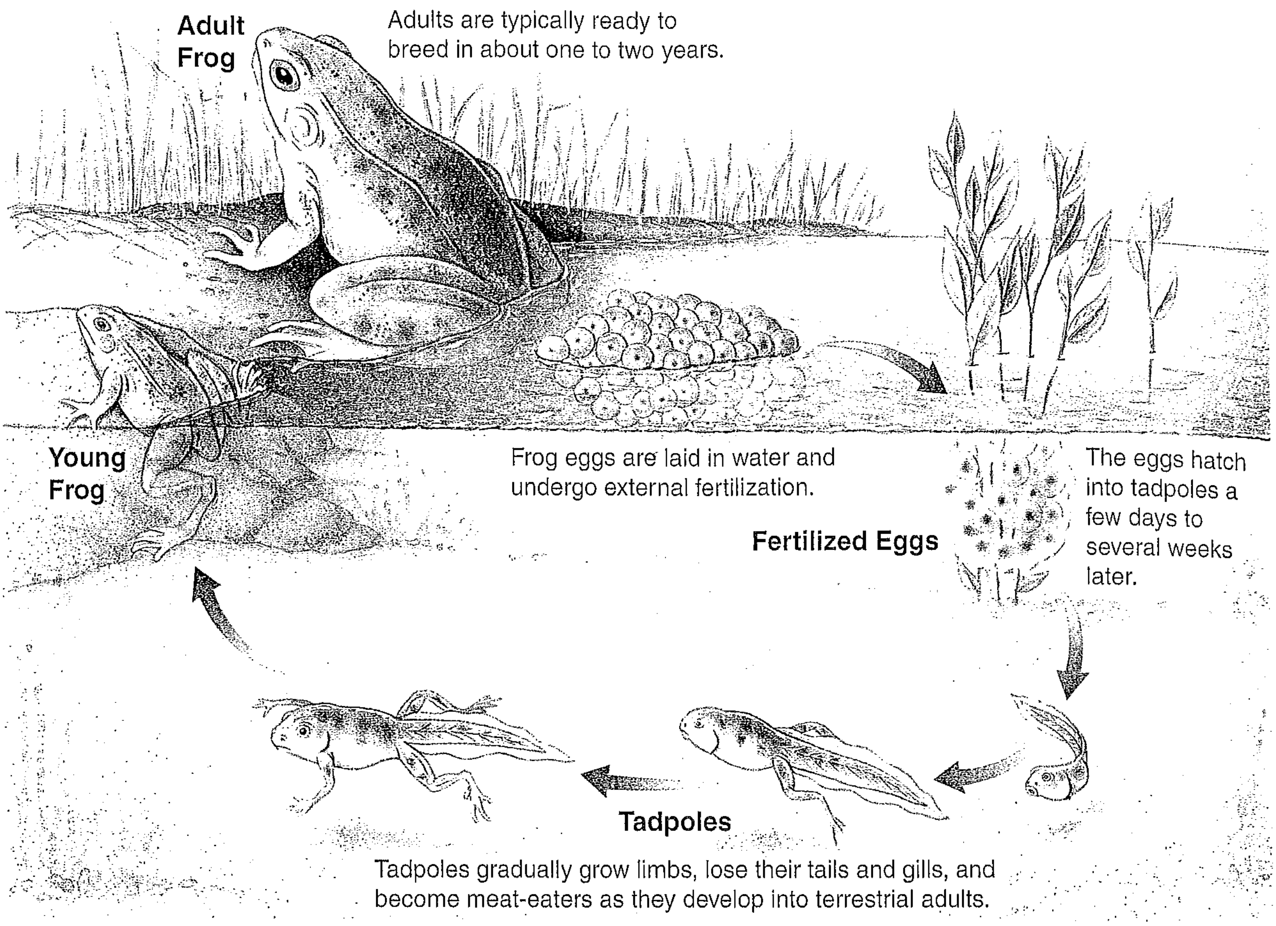
CHECKPOINT *How many chambers are in an amphibian's heart?*

Excretion Amphibians have kidneys that filter wastes from the blood. The excretory product of the kidneys—urine—travels through tubes called ureters into the cloaca. From there, urine can be passed directly to the outside, or it may be temporarily stored in a small urinary bladder just above the cloaca.





▼ **Figure 30–24** Like all vertebrates, amphibians have a circulatory system and an excretory system. An amphibian's heart has three chambers—two atria and one ventricle. Although some wastes diffuse across the skin, kidneys remove most wastes from the bloodstream. **Applying Concepts** *What excretory product do the kidneys produce?*



▲ **Figure 30–25** An amphibian typically begins its life in the water, then moves onto land as an adult. This diagram shows the process of metamorphosis in a frog. **Comparing and Contrasting** *How are tadpoles similar to fish? How are they different?*

Reproduction Amphibian eggs do not have shells and tend to dry out if they are not kept moist. Thus, in most species of amphibians, the female lays eggs in water, then the male fertilizes them externally. In a few species, including most salamanders, eggs are fertilized internally.

When frogs reproduce, the male climbs onto the female's back and squeezes. In response to this stimulus, the female releases as many as 200 eggs that the male then fertilizes. Frog eggs are encased in a sticky, transparent jelly that attaches the egg mass to underwater plants and makes the eggs difficult for predators to grasp. The yolk of the egg nourishes the developing embryos until they hatch into larvae that are commonly called tadpoles. **Figure 30–25** shows the metamorphosis of tadpoles into frogs.

Most amphibians, including common frogs, abandon their eggs after they lay them. A few take great care of both eggs and young. Some amphibians incubate their young in highly unusual places, such as in the mouth, on the back, or even in the stomach! Male midwife toads wrap sticky strings of fertilized eggs around their hind legs and carry them about until the eggs are ready to hatch.

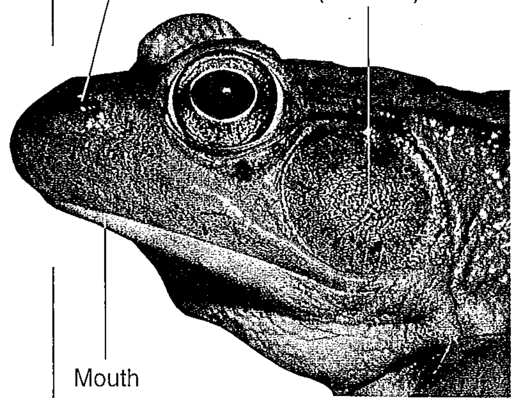
✓CHECKPOINT *What is the function of the jelly surrounding frog eggs?*

Movement Amphibian larvae often move very much like fishes, by wiggling their bodies and using a flattened tail for propulsion. Most adult amphibians, like other four-limbed vertebrates, use their front and back legs to move in a variety of ways. Adult salamanders have legs that stick out sideways. These animals walk—or, in some cases, run—by throwing their bodies into S-shaped curves and using their legs to push backward against the ground. Other amphibians, including frogs and toads, have well-developed hind limbs that enable them to jump long distances. Some amphibians, such as tree frogs, have disks on their toes that serve as suction cups for climbing.

Response The brain of an amphibian has the same basic parts as that of a fish. Like fishes, amphibians have well-developed nervous and sensory systems. **Figure 30–26** points out some sense organs in a typical frog. An amphibian's eyes are large and can move around in their sockets. The surface of the eye is protected from damage under water and kept moist on land by a transparent **nictitating** (NIK-tuh-tayt-ing) **membrane.** This movable membrane is located inside the regular eyelid, which can also be closed over the eye. Frogs have keen vision that enables them to spot and respond to moving insects. However, frogs probably do not see color as well as fishes do.

Amphibians hear through **tympanic** (tim-PAN-ik) **membranes,** or eardrums, located on each side of the head. In response to the external stimulus of sound, a tympanic membrane vibrates, sending sound waves deeper within the skull to the middle and inner ear. Many amphibian larvae and adults also have lateral line systems, like those of fishes, that detect water movement.

▼ **Figure 30–26** A frog's eyes and ears are among its most important sensory organs. Transparent eyelids called nictitating membranes protect the eyes underwater and keep them moist in air. Tympanic membranes receive sound vibrations from air as well as water. **Inferring** *What functions does hearing serve in frogs?*



Analyzing Data

Amphibian Population Trends

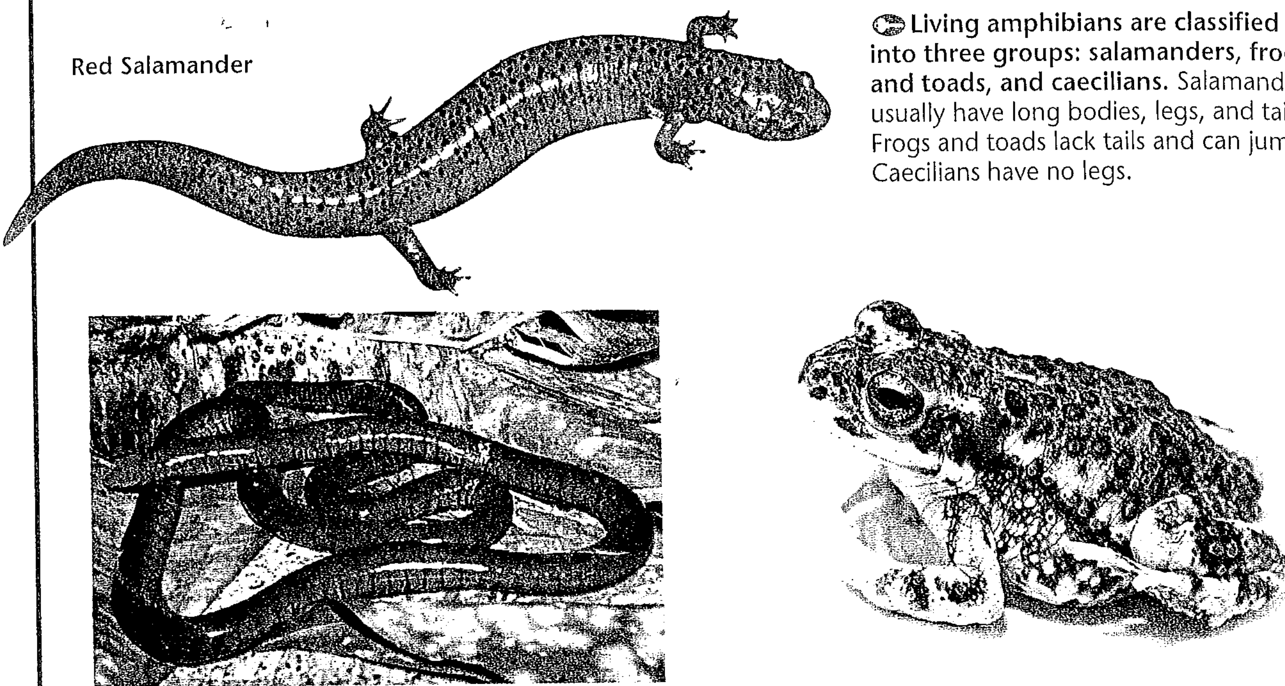
Over the past several decades, scientists have reported changes in amphibian populations worldwide. In 2000, a team of researchers analyzed data sets contributed by various amphibian population studies conducted in 37 different countries. The results of this analysis are shown in the table. Study the data table and answer the questions.

Numbers of Amphibian Populations

Region	Declining	Increasing	No Trend
Western Europe	309	248	29
North America	130	96	14
South America	31	19	1
Australia/NZ	17	6	1
Asia	10	10	1
Eastern Europe	4	5	0
Africa/Middle East	2	2	1

1. **Using Tables and Graphs** How many amphibian populations were studied?
2. **Predicting** If the trends presented in the data table continue, how do you expect amphibian populations in North America to change in the next two decades?
3. **Calculating** What percentage of worldwide amphibian populations is decreasing?
4. **Evaluating** Do you think that regional population data can be used to predict global population trends? Explain your answer.

Figure 30–27 Diversity of Amphibians



Living amphibians are classified into three groups: salamanders, frogs and toads, and caecilians. Salamanders usually have long bodies, legs, and tails. Frogs and toads lack tails and can jump. Caecilians have no legs.

Red Salamander

Caecilian

Chilean Red-Spotted Toad

Groups of Amphibians

Modern amphibians can be classified into three categories. **The three groups of amphibians alive today are salamanders, frogs and toads, and caecilians.** Representative members are shown in **Figure 30–27.**

Salamanders Members of the order Urodela (yoor-oh-DEE-luh), including salamanders and newts, have long bodies and tails. Most also have four legs. Both adults and larvae are carnivores. The adults usually live in moist woods, where they tunnel under rocks and rotting logs. Some salamanders, such as the mud puppy, keep their gills and live in water all their lives.

Frogs and Toads The most obvious feature that members of the order Anura (uh-NOOR-uh) share is their ability to jump. Frogs tend to have long legs and make lengthy jumps, whereas the relatively short legs of toads limit them to short hops. Frogs are generally more closely tied to water—including ponds and streams—than toads, which often live in moist woods and even in deserts. Adult frogs and toads lack tails.

Caecilians The least known of the amphibians are the caecilians, members of the order Apoda (ay-POH-duh). Caecilians are legless animals that live in water or burrow in moist soil or sediment, feeding on small invertebrates such as termites. Many have fishlike scales embedded in their skin—which demonstrates that some amphibians don't fit the general definition.

Ecology of Amphibians

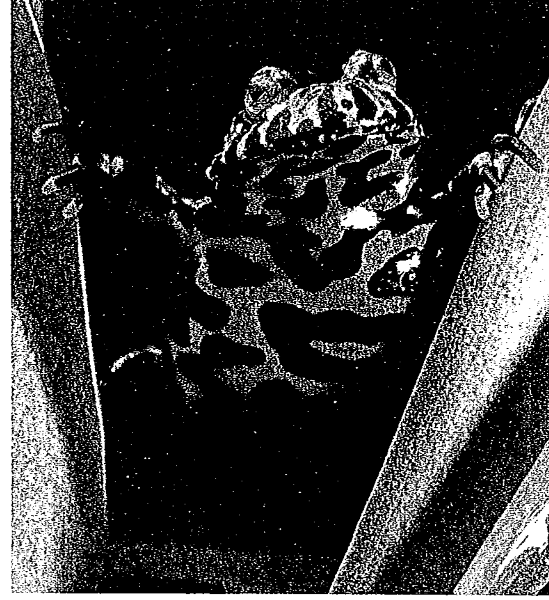
Amphibians must live near water, and they are common in moist, warm places such as tropical rain forest biomes. In contrast, because most amphibians cannot tolerate dry conditions, comparatively few live in desert biomes. Desert amphibians have adaptations that enable them to take advantage of water when it is available. For example, some toads stay inactive in sealed burrows for months, then emerge when a heavy rain falls.

Many amphibians make an ideal meal for predators such as birds and mammals. However, amphibians have adaptations that protect them from predators. For example, many species have skin colors and markings that enable them to blend in with their surroundings. Most adult amphibians, such as the toad in **Figure 30–28,** have skin glands that ooze an unpleasant-tasting and poisonous substance, or toxin.

Recently, scientists have noticed an alarming trend in amphibian populations worldwide. For the past several decades, the numbers of living species have been decreasing. The golden toad of Costa Rica, for example, seems to be extinct. In North America, the numbers of boreal toads have dwindled. Even the leopard frog and its relatives, once common worldwide, are getting harder to find.

Scientists do not yet know what is causing the global amphibian population to decline. It is possible that amphibians are susceptible to a wide variety of environmental threats, such as decreasing habitat, depletion of the ozone layer, acid rain, water pollution, fungal infections, introduced aquatic predators, and an increasing human population.

To better understand this phenomenon, biologists worldwide have been focusing their efforts and sharing data about amphibian populations. In the late 1990s, a group of scientists set up monitoring programs that cover the entire area of North America. One such program relies mostly on the efforts of volunteers, who are trained to recognize the specific call of various species such as cricket frogs, bullfrogs, or spring peepers.



▲ **Figure 30–28** Some amphibians that release toxins, such as this European fire-bellied toad, have bodies that are brightly colored and have bold patterns. The colors and patterns serve as a warning to potential predators. **Using Analogies** *How is the underside of this frog comparable to a dog showing its teeth?*

30–3 Section Assessment

1. **Key Concept** List the characteristics of amphibians.
2. **Key Concept** What adaptations helped amphibians evolve into land animals?
3. **Key Concept** List the three groups of amphibians.
4. What characteristics usually restrict amphibian reproduction to moist environments?
5. How are scientists attempting to deal with the problem of declining amphibian populations?
6. **Critical Thinking Formulating Hypotheses** Most caecilian species are totally blind as adults. How do you think this characteristic has evolved?

Thinking Visually

Cycle Diagrams
Construct a cycle diagram that identifies and describes the stages in the life cycle of a typical amphibian. For information about cycle diagrams, see Appendix A at the back of the book.

Chapter 30 Study Guide

30–1 The Chordates

Key Concepts

- A chordate is an animal that has, for at least some stage of its life, a dorsal, hollow nerve cord; a notochord; pharyngeal pouches; and a tail that extends beyond the anus.
- The two groups of nonvertebrate chordates are tunicates and lancelets.

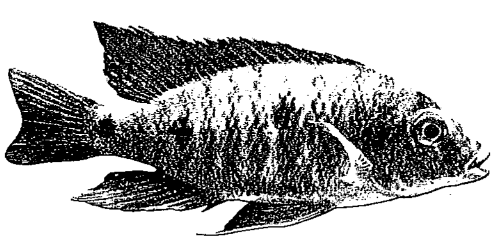
Vocabulary
chordate, p. 767
notochord, p. 767
pharyngeal pouch, p. 767
vertebra, p. 768

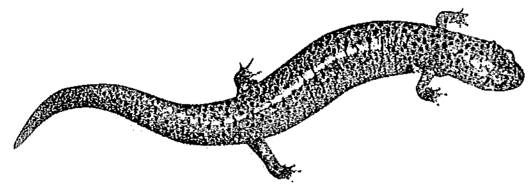
30–2 Fishes

Key Concepts

- Fishes are aquatic vertebrates; most fishes have paired fins, scales, and gills.
- The evolution of jaws and the evolution of paired fins were important developments during the rise of fishes.
- Fishes' adaptations to aquatic life include various modes of feeding, specialized structures for gas exchange, and paired fins for locomotion.
- On the basis of their basic internal structure, all living fishes can be classified into three groups: jawless fishes, cartilaginous fishes, and bony fishes.

Vocabulary
cartilage, p. 773
atrium, p. 776
ventricle, p. 776
cerebrum, p. 777
cerebellum, p. 777
medulla oblongata, p. 777
lateral line system, p. 777
swim bladder, p. 777
oviparous, p. 778
ovoviviparous, p. 778
viviparous, p. 778





30–3 Amphibians

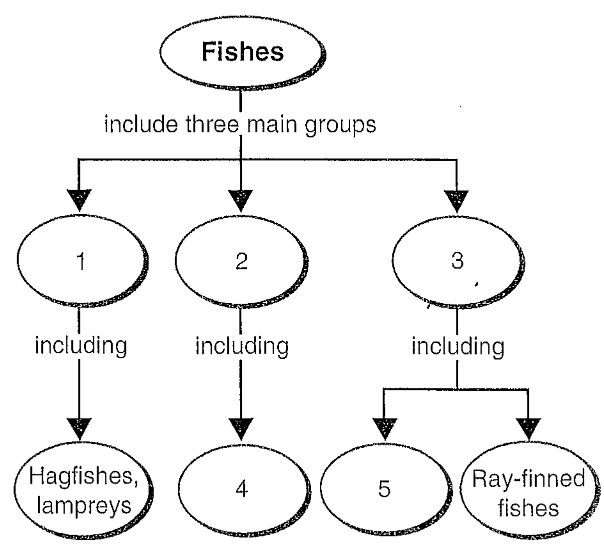
Key Concepts

- An amphibian is a vertebrate that, with some exceptions, lives in water as a larva and on land as an adult, breathes with lungs as an adult, has moist skin that contains mucous glands, and lacks scales and claws.
- Early amphibians evolved several adaptations that helped them live at least part of their lives out of water. Bones in the limbs and limb girdles of amphibians became stronger, permitting more-efficient movement. A set of lungs and breathing tubes enabled them to breathe air. Their sternum formed a bony shield that supports and protects the internal organs, especially the lungs.
- The three groups of living amphibians are salamanders, frogs and toads, and caecilians.

Vocabulary
cloaca, p. 784
nictitating membrane, p. 787
tympanic membrane, p. 787

Thinking Visually

Using information from this chapter, complete the following concept map:



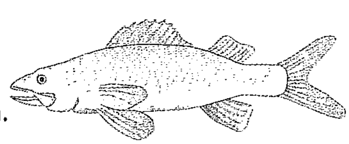
Chapter 30 Assessment

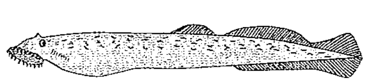
Interactive textbook with assessment at PHSchool.com

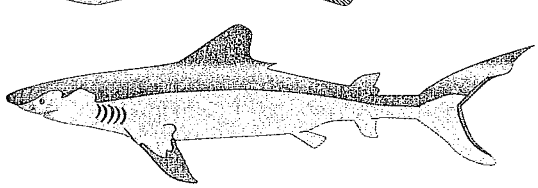
Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. Which of the following is NOT characteristic of all chordates?
   a. hollow nerve cord c. fins
   b. pharyngeal pouches d. notochord
2. The term LEAST closely related to the others is
   a. chordate. c. invertebrate.
   b. cerebrum. d. lancelet.
3. The evolution of jaws and paired fins was an important development during the rise of
   a. tunicates. c. fishes.
   b. lancelets. d. amphibians.
4. Most fishes exchange gases by pumping water from their mouths
   a. over the gill filaments.
   b. through the pyloric ceca.
   c. over the atrium.
   d. through the esophagus.
5. In fishes, the part of the brain that coordinates body movements is the
   a. olfactory lobe. c. cerebrum.
   b. optic lobe. d. cerebellum.
6. A species that lays eggs that develop outside of the mother's body is
   a. oviparous. c. ovoviviparous.
   b. viviparous. d. nonviparous.
7. Examine the diagrams below. Which of these is a jawed cartilaginous fish?

a. 

b. 

c. 

d. 

8. At the end of the large intestine of a frog is a muscular cavity called the
   a. cloaca. c. gallbladder.
   b. pancreas. d. esophagus.
9. An adult amphibian's heart typically has
   a. one chamber.
   b. two chambers.
   c. three chambers.
   d. four chambers.
10. Each of the following serves as an organ of gas exchange in frogs, toads, and many salamanders EXCEPT the
    a. skin. c. lungs.
    b. mouth cavity. d. nictitating membrane.

Understanding Concepts

11. Describe what happens to the notochord in most developing vertebrates.
12. How does a lancelet obtain food?
13. Which two major groups of fishes evolved from the early jawed fishes and still survive today?
14. Identify three feeding modes that are observed in fishes.
15. Describe the flow of blood through the heart of a typical fish, naming the four structures.
16. In what form is nitrogenous waste excreted from the bodies of most fishes?
17. What is a lateral line system? What does it enable a fish to do?
18. What is the function of a fish's swim bladder?
19. How do a fish's muscles function in swimming?
20. How are lampreys and sharks similar? How are they different?
21. List some of the challenges that early vertebrates faced as they moved from water to land habitats during the course of evolution.
22. How are tadpoles and adult frogs adapted for their specific feeding behaviors?
23. What adaptation do many adult amphibians have to carry out respiration?
24. Discuss how blood flows through the heart of an adult frog.
25. Many amphibians have specialized structures that aid in movement. Describe two of these structures.
26. Why are most amphibians unable to tolerate living in desert biomes?

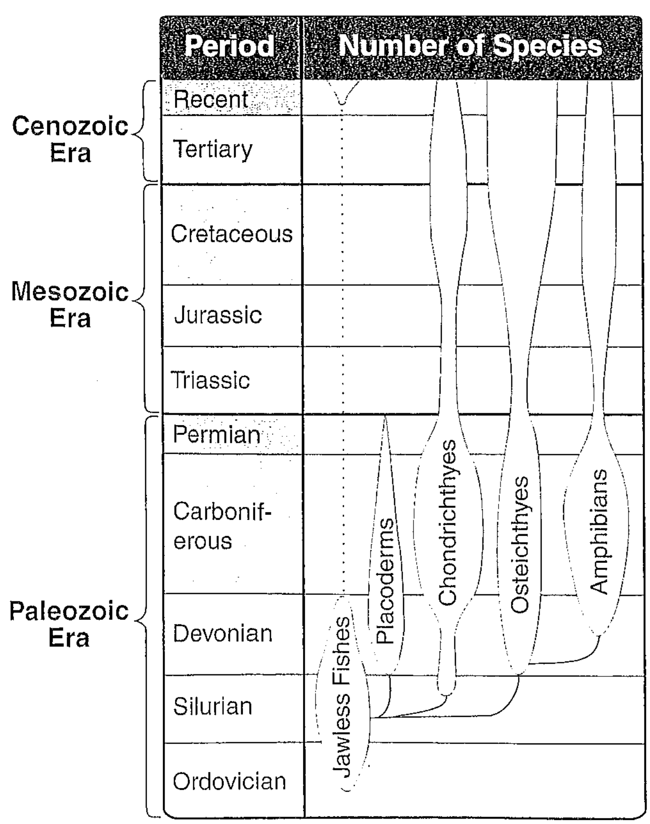
Critical Thinking

27. **Applying Concepts** The kidneys of saltwater fishes are adapted to meet the needs of a marine environment. Why would it be impossible for a saltwater fish to survive in fresh water?

28. **Inferring** How might dams across rivers affect the reproduction of salmon?

29. **Inferring** The skin of amphibians is thin and moist. Amphibian eggs have no shell and must be kept moist. How might the worldwide decline of amphibian populations be related to these two characteristics?

30. **Interpreting Graphics** The chart below shows changes in five groups of vertebrates over the past 500 million years. The thickness of each band indicates changes in the relative number of species over geologic time. Use this chart to answer the questions.
    a. During which period did amphibians evolve?
    b. Did the amphibians evolve from early jawless fishes or from early bony fishes (Osteichthyes)? Explain your answer.
    c. In which groups of fishes have the number of species increased during recent times?
    d. Which group of fishes is extinct?



31. **Designing Experiments** Design an experiment to determine the effect of diet on the development of tadpoles. Define the variables you would need to control.

32. **Applying Concepts** Which anatomical characteristics of nonvertebrate chordates suggest that, in terms of phylogeny (evolutionary relationships), these animals are more closely related to vertebrates than to other groups of animals?

Focus on the BIG Idea

Evolution In Chapter 15, you learned about Darwin's theory of evolution by natural selection. How might natural selection have contributed to the great diversity of fishes that exists today? (*Hint*: Think of the many different kinds of aquatic environments that fishes inhabit.)

Writing in Science

Write a paragraph comparing and contrasting the characteristics of the three major groups of amphibians. Be sure to say how they are similar as well as how they are different. (*Hint:* To prepare to write, construct a compare-contrast table that compares the three groups. Characteristics for comparison might include shape of body, number of legs, and habitat.)

Performance-Based Assessment

Modeling Structure and Function Using modeling clay, paper, or other suitable materials, make a three-dimensional model of a fish or an amphibian. Identify each of the external structures described in the chapter. Attach flags or markers that describe how each of these structures is adapted to the habitat and behavior of the animal you have modeled.

Go Online
PHSchool.com
For: An interactive self-test
Visit: PHSchool.com
Web Code: cba-9300

Standardized Test Prep

Test-Taking Tip If a test question seems confusing, try rephrasing it in your own words. Rephrasing a question will often allow you to better understand it.

Directions: Choose the letter that best answers the question or completes the statement.

1. Which of the following is NEVER true of oviparous fishes?
   (A) Their eggs are fertilized externally.
   (B) Their eggs hatch outside the mother's body.
   (C) They have paired fins.
   (D) The embryos receive nourishment directly from the mother's body.
   (E) Their skeletons are made of bone.

2. Which of the following indicates how amphibian larvae typically feed?
   I. Filter feeders
   II. Carnivores
   III. Herbivores
   (A) I only
   (B) III only
   (C) I and II only
   (D) I and III only
   (E) I, II, and III

3. Into which of the following groups can nonvertebrate chordates be classified?
   I. Lancelets
   II. Tunicates
   III. Fishes
   (A) I only
   (B) I and II only
   (C) I and III only
   (D) II and III only
   (E) I, II, and III

4. A fish is UNLIKE an amphibian in that a fish
   (A) is a nonvertebrate chordate.
   (B) has a heart with one atrium.
   (C) has moist skin.
   (D) has a nictitating membrane.
   (E) lacks a dorsal nerve cord.

5. Which of the following is in the order Apoda?
   (A) shark
   (B) frog
   (C) snake
   (D) caecilian
   (E) lancelet

Questions 6–8 Each of the lettered choices below refers to the following numbered statements. Select the best lettered choice. A choice may be used once, more than once, or not at all.

(A) Tunicates
(B) Lancelets
(C) Fishes
(D) Salamanders
(E) Caecilians

6. Legless amphibians
7. Organisms that feed through a mouth with no jaws, are thin enough to breathe through their body surface, and do not have a true heart
8. Members of the subphylum Cephalochordata
9. Aquatic vertebrates with fins, scales, and gills

Questions 10–11

An ecologist collected data about the number of frogs that inhabit a certain pond each year. In addition, he collected data about the total amount of rainfall in that area each spring. The data are shown in the table.

Rainfall and Frog Population in Pond

Year	Amount of Rainfall (centimeters)	Number of Frogs
1995	13	45
1996	20	61
1997	8	33
1998	5	20
1999	23	63

10. In what year were the most frogs observed?
    (A) 1995
    (B) 1996
    (C) 1997
    (D) 1998
    (E) 1999

11. Which statement is best supported by the data?
    (A) The number of frogs increased each year.
    (B) The number of frogs decreased each year.
    (C) The number of frogs increased or decreased based on whether it is an odd or even numbered year.
    (D) The number of frogs in the pond increased as the amount of rainfall increased.
    (E) The number of frogs in the pond decreased as the amount of rainfall increased.