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ZOO202

Protochordates / Animal Diversity

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Lesson no 1

Protochordates

The organisms belonging to the Protochordata are generally known as the lower chordates.

Protochordates are an informal category of animals (i.e.: not a proper taxonomic group), named

Mainly for convenience to describe invertebrate animals that are closely related to

Vertebrates. However, they do form a major division of Chordata. They are also known as

Acraniata because they lack a true skull.

Protochordates are members of two deuterostome phyla that are exclusively marine. The

Hemichordata, with solitary enteropneusts and colonial pterobranchs, share a ciliated larva with

Echinoderms and appear to be closely related, but they also have many chordate-like features. The

Invertebrate chordates are composed of the exclusively solitary cephalochordates and the tunicates

With both solitary and colonial forms. The cephalochordates are all free-swimming, but the

Tunicates include both sessile and free-swimming forms

Characteristics of Protochordata (Tunicates & Amphioxus)

Although the amphioxus and the tunicates are quite different, at one time it was believed that the

Amphioxus was a descendant of the tunicate larva. Recent genome analysis has called that view

into question, but there are still many articles which consider both genera together.

Like the remaining subphylum of the chordates, the Vertebrata, the protochordates have a hollow

dorsal nerve cord, gill slits, and a stiff supporting rod, the notochord, the forerunner of the

backbone. The protochordates differ chiefly from the vertebrates in not having a backbone. Recent

protochordates are thought to have evolved from the same ancestral stock as that which gave rise

to the vertebrates.

On the basis of the notochord present, they are divided into three sub-phyla- Hemichordata,

Urochordata and Cephalochordata.

Lesson no 2

Sub-Phylum Hemichordata

Bateson (1885) studied the embryology of some enteropneusts and proposed the

Name Hemichordata to replace Enteropneusta.

Hemichordate, any of a group of wormlike marine invertebrates closely related to both chordates

And echinoderms and usually considered to constitute a phylum, the Hemichordata. The term

Hemichordata—from the Greek hemi, meaning “half,” and chorde, meaning “string,” thus, “half-

Chordate”—was first proposed because the buccal diverticulum, a tubular outgrowth from the

Mouth cavity forward into the proboscis, or “snout,” resembled a rudimentary notochord—the

Dorsal, or back-side, supporting axis of the more primitive vertebrates. This theory has since been

Rejected, however, because it has been determined that the diverticulum bears little resemblance in

Origin and function to the vertebrate notochord. Molecular studies indicate that hemichordates are

More closely related to echinoderms than to chordates. About 90 species have been described.

The phylum Hemichordata includes the acorn worms (class Enteropneusta) and the pterobranchs

(class Pterobranchia). Members of both classes live in or on marine sediments. The Hemichordata

Consist of three classes: Enteropneusta, Pterobranchia, and Planctosphaeroidea. Enteropneusts,

Or acorn worms (about 70 species), are solitary, wormlike, bilaterally symmetrical animals, often

Brilliantly coloured. They are known as acorn worms because of the appearance of the proboscis

And collar. Pterobranchs (about 20 species) are minute, colonial, tube-building forms.

Planctosphaeroidea are known only from a few floating larvae. Enteropneusts are common in the

Intertidal zones from the White Sea and Greenland south to New Zealand and the Cape of Good

Hope; they are found offshore to depths of 400 metres (about 1,300 feet) or more. They vary in

Size from a few centimetres long (*Saccoglossus pygmaeus* of the North Sea) to two metres (about

Seven feet) or more (*Balanoglossus gigas* of Brazilian coastal waters).

Hemichordates are distinguished by a tripartite (threefold) division of the body. At the forward

End of the body is a preoral lobe, behind this is a collar, and last comes a trunk. The name

“hemichordate” means “half chordate,” and hemichordates share some (but not all) of the

Typical chordate characteristics. There are branchial openings, or “gill slits,” that open into the

Pharynx; there is a rudimentary structure in the collar region, the stomochord, that is similar to

A notochord; and there is a dorsal nerve cord, in addition to a smaller ventral nerve cord. However,

Hemichordates are not classified as true chordates, although they are quite closely related. Some

DNA-based studies of evolution suggest that hemichordates are actually closer

To echinoderms than to true chordates. This is supported by the fact that the larvae of at least some

Hemichordates look very much like those of some echinoderms.

Of the three classes of hemichordates, the most familiar living ones are the Enteropneusta, the

Acorn worms. One is pictured at the top right of the page. The triple division of the body is obvious.

Acorn worms also have multiple branchial openings, as many as 200 in some species. They are

Slow burrowers, using the proboscis to burrow through sediment, and may either deposit

Feed (consume sediment and digest the organic matter, rather like earthworms in soil)

Or suspension feed (collect suspended particles from the water). Some of these worms may be

Very large; one species may reach a length of 2.5 meters (almost eight feet), although most are

Much smaller.

The second living class is the Pterobranchia, an obscure group with only about 20 living species.

Pterobranchs are very different from acorn worms; they form colonies in which the individuals are

Interconnected by stems, or stolons. Individuals, or zooids, are often less than 1 millimeter long.

The proboscis is not elongated, as it is in acorn worms, but shield-shaped. The second division of

The body bears a pair of branched tentacles that collect small food particles from the water. There

Is only one branchial opening. Most strikingly, almost all pterobranch species create and live

Within a network of tubes, the coenecium. These tubes are made up of the protein collagen,

Secreted by special glands in the proboscis. Yet similar larvae and a similar tripartite body plan

Unite the enteropneusts and pterobranchs. This diagram shows a colony of pterobranchs in the

Genus *Rhabdopleura*.

What is now considered a third class of hemichordates, the Graptolithina or graptolites, has a

Checkered history. Graptolites are common fossils in Ordovician and Silurian rocks, but for a long

Time no one was sure what kind of animals they were. Most fossil graptolites look like nothing so

Much as tiny sawblades. However, well-preserved graptolites can be seen to be tubular in cross-

Section, with the “teeth of the saw” formed by short open branches from the main tube. Careful

Study of the microscopic structure of the tubes of graptolites showed that they are very similar to

The tubes of pterobranchs.

Unlike their pterobranch kin, which typically live encrusting rocks and shells, most graptolites are

Thought to have been planktonic, floating or slowly sinking through the water. The spiral shape of

Some was probably an adaptation to slow sinking. Other graptolites may have been connected to

Gas-filled sacs, keeping them buoyant.

Characteristics of the phylum Hemichordata include:

1. Marine, deuterostomate animals with a body divided into three regions: proboscis, collar, and

Trunk; coelom divided into three cavities

2. Ciliated pharyngeal slits

3. Open circulatory system

4. Complete digestive tract

5. Dorsal, sometimes tubular, nerve cord

Lesson no 3

Class Enteropneusta

The Class Enteropneusta (acorn-worms) consists of about 75 species of solitary, unsegmented

Worm-like invertebrates. The body is fleshy, cylindrical and divided into three parts: the muscular

Contractile proboscis (prosome), the collar (mesosome) and the non-muscular trunk (metasome),

Each with coelomic compartments. The trunk has many gill slits. Enteropneusts are strictly marine

And benthic (either sessile or sedentary). At least one enteropneust species has been reported

Swarming at the surface of shallow water, feeding on phytoplankton (Brusca and Brusca, 1990) —

Note that this species, *Glandiceps hacksi* (Marion, 1885) does not occur in the North Sea. 

Members of the class Enteropneusta are marine worms that usually range in size between 10 and

40 cm, although some can be as long as 2 m. Zoologists have described about 70 species, and most

Occupy U-shaped burrows in sandy and muddy substrates between the limits of high and low tides.

The common name of the enteropneusts—acorn worms—is derived from the appearance of the

Proboscis, which is a short, conical projection at the worm's anterior end. A ring like collar is

Posterior to the proboscis, and an elongate trunk is the third division of the body (figure 1). A

Ciliated epidermis and gland cells cover acorn worms. A ciliated epidermis and gland cells cover

Acorn worm. The mouth is located ventrally between the proboscis and the collar. A variable

Number of pharyngeal slits are present laterally on the trunk. Their number is from a few to several

Hundred. Pharyngeal slits are openings between pharynx and the outside of the body.

The mouth is located ventrally between the proboscis and the collar. A variable number of

Pharyngeal slits, from a few to several hundred, are positioned laterally on the trunk. Pharyngeal

Slits are openings between the anterior region of the digestive tract, called the pharynx, and the

Outside of the body.

Figure 1. Longitudinal section showing the proboscis, collar, pharyngeal region, and internal structures.

The black arrow shows the path of water through a pharyngeal slit.

Lesson no 4

Enteropneusta: Feeding, Digestion and Nervous system

Cilia and mucus assist acorn worms in feeding. Detritus and other particles adhere to the mucus-

Covered proboscis. Tracts of cilia transport food and mucus posteriorly and ventrally. Ciliary tracts

Converge near the mouth and form a mucoïd string that enters the mouth (Figure 2). Acorn worms

May reject some substances trapped in the mucoïd string by pulling the proboscis against the collar.

Ciliary tracts of the collar and trunk transport rejected material and discard it posteriorly. The

Digestive tract of enteropneusts is a simple tube. Food is digested as diverticula of the gut, called

Hepatic sacs, release enzymes. The worm extends its posterior end out of the burrow during

Defecation. At low tide, coils of fecal material, called castings, lie on the substrate at burrow

Openings.

The nervous system of enteropneusts is ectodermal in origin and lies at the base of the ciliated

Epidermis. It consists of dorsal and ventral nerve tracts and a network of epidermal nerve cells,

Called a nerve plexus. In some species, the dorsal nerve is tubular and usually contains giant nerve

Fibers that rapidly transmit impulses. There are no major ganglia. Sensory receptors are

Unspecialized and widely distributed over the body.

Lesson no. 5

Enteropneusta: Respiration, Circulation and Excretion

Because acorn worms are small, respiratory gases and metabolic waste products (principally

Ammonia) probably are exchanged by diffusion across the body wall. In addition, respiratory gases

Are exchanged at the pharyngeal slits. Cilia associated with pharyngeal slits circulate water into

The mouth and out of the body through the pharyngeal slits. As water passes through the pharyngeal

Slits, gases are exchanged by diffusion between water and blood sinuses surrounding the pharynx.

The circulatory system of acorn worms consists of one dorsal and one ventral contractile vessel.

Blood moves anteriorly in the dorsal vessel and posteriorly in the ventral vessel. Branches from

These vessels lead to open sinuses. All blood flowing anteriorly passes into a series of blood sinuses,

Called the glomerulus, at the base of the proboscis. Excretory wastes may be filtered through the

Glomerulus, into the coelom of the proboscis, and released to the outside through one or two pores

In the wall of the proboscis. The blood of acorn worms is colorless, lacks cellular elements, and

Distributes nutrients and wastes.

Lesson no 6

Enteropneusta: Reproduction and Development

Enteropneusts are dioecious. Two rows of gonads lie in the body wall in the anterior region of the

Trunk, and each gonad opens separately to the outside. Fertilization is external. Spawning by one

Worm induces others in the area to spawn—behavior that suggests the presence of spawning

Pheromones. Ciliated larvae, called tornaria, swim in the plankton for several days to a few weeks.

The larvae settle to the substrate and gradually transform into the adult form (figure 3).

- Enteropneusts normally reproduce sexually via external fertilization, and develop either

Directly or via tornaria larvae.

- The indirect developers, including Balanoglossus and Ptychodera species, are in the

Majority

These species develop from egg to planktonic tornaria larva to adult form.

- The tornaria larvae eventually become sessile, with the burrow-dwellers Developing tails

Behind the anus that they use to anchor themselves in their mucus-lined tunnels.

- Direct developers, on the other hand, hatch into adult animals, by passing the planktonic

Phase.

- An example is Saccoglossus kowalevskii.

Figure 3. Tornaria Larva of an Enteropneust (Balanoglossus). When larval development is

Complete, a tornaria locates a suitable substrate, settles, and begins to burrow and elongate (1 mm).

Lesson no 7

Phylum Chordata

The fossil record of chordates begins in the early Cambrian period, roughly 530 million years ago.

The oldest known chordate fossil was found in China and described in 1995. It is a member of

The species *Yunnanozoon lividum*, within the subphylum Cephalochordata. The

Earliest fossil evidence for members of the vertebrate subphylum also dates back roughly 530

Million years. This is when fossils of the jawless fish first appeared. A timeline showing the order

Of appearance of each of the major chordate groups in the fossil record is shown in Figure below.

The earliest tetrapods (having four legs) are the amphibians, with fossils dating back to the

Devonian period, roughly 363 million years ago. Shortly thereafter, reptile-like tetrapods arose. It

Was some time after the appearance of reptiles, approximately 80 million years, that mammals

Entered the scene. The first mammalian fossils date back to the Triassic period, about 208 million

Years ago. Finally, bird fossils appear 146 million years ago in the Jurassic period.

Traditional metazoan phylogeny classifies the Vertebrata as a subphylum of the phylum Chordata,

Together with two other subphyla, the Urochordata (Tunicata) and the Cephalochordata. The

Chordata, together with the phyla Echinodermata and Hemichordata, comprise a major group, the

Deuterostomia. Chordates invariably possess a notochord and a dorsal neural tube. Although the

Origin and evolution of chordates has been studied for more than a century, few authors have

Intimately discussed taxonomic ranking of the three chordate groups themselves. Accumulating

Evidence shows that echinoderms and hemichordates form a clade (the Ambulacraria), and that

Within the Chordata, cephalochordates diverged first, with tunicates and vertebrates forming a

Sister group. Chordates share tadpole-type larvae containing a notochord and hollow nerve cord,

Whereas ambulacrarians have dipleurula-type larvae containing a hydrocoel. We propose that an

Evolutionary occurrence of tadpole-type larvae is fundamental to understanding mechanisms of

Chordate origin.

Although the phylum Chordata (kor-datah) (L. chorda, cord) does not have an inordinately

Large number of species (about 45,000), its members have been very successful at adapting to

Aquatic and terrestrial environments throughout the world. Sea squirts, members of the subphylum

Urochordata, are briefly described in the “Evolutionary Perspective” that opens this chapter. Other

Chordates include lancelets (subphylum Cephalochordata) and the vertebrates (subphylum

Vertebrata).

Characteristics of the phylum Chordata include 1. Bilaterally symmetrical, deuterostomate

Animals 2. Four unique characteristics present at some stage in development: notochord,

Pharyngeal slits or pouches, dorsal tubular nerve cord, and postanal tail 3. Presence of an endostyle

Or thyroid gland 4. Complete digestive tract 5. Ventral, contractile blood vessel (heart) The four

Characteristics listed in number 2 are unique to chordates and are discussed further in the

Paragraphs that follow (figure 17.6). The phylum is named after the notochord (Gr. Noton, the back

L. chorda, cord), a supportive rod that extends most of the length of

The animal dorsal to the body cavity and into the tail. It consists of a connective-tissue sheath that

Encloses cells, each of which contains a large, fluid-filled vacuole. This arrangement gives the

Notochord some turgidity, which prevents compression along the anteroposterior axis. At the same

Time, the notochord is flexible enough to allow lateral bending, as in the lateral undulations of a

Fish during swimming. In most adult vertebrates, cartilage or bone partly or entirely replaces the

Notochord. Pharyngeal slits are a series of openings in the pharyngeal region between the digestive

Tract and the outside of the body. In some chordates, diverticula from the gut in the pharyngeal

Region never break through to form an open passageway to the outside. These diverticula are then

Called pharyngeal pouches. The earliest chordates used the slits for filter feeding; some living

Chordates still use them for feeding. Other chordates have developed gills in the pharyngeal

Pouches for gas exchange. The pharyngeal slits of terrestrial vertebrates are mainly embryonic

Features and may be incomplete. The tubular nerve cord and its associated structures are largely

Responsible for chordate success. The nerve cord runs along the longitudinal axis of the body, just

Dorsal to the notochord, and usually expands anteriorly as a brain. This central nervous system is

Associated with the development of complex systems for sensory perception, integration, and

Motor responses. The fourth chordate characteristic is a postanal tail. (A postanal tail extends

Posteriorly beyond the anal opening.) Either the notochord or vertebral column supports the tail.

Chordate Body Plan. The development of all chordates involves the formation of a neural tube,

The notochord, pharyngeal slits or pouches, and a postanal tail. Derivatives of all three primary

Germ layers are present. (a) Lateral view. (b) Cross section

Lesson 8

Subphylum Urochordata

Tunicates are mainly found in the subtidal zone of a marine environment. They can

Be found attached to hard surfaces and are about one to twelve centimeters in

Length. Their color ranges from gray to brown to greenish, although some have

Beautiful coloration

About 2,150 species of tunicate exist in the world's oceans, living mostly in shallow water. The

Most numerous group is the ascidians; fewer than 100 species of these are found at depths greater

Than 200 m (660 ft). Some are solitary animals leading a sessile existence attached to the seabed,

But others are colonial and a few are pelagic. Some are supported by a stalk, but most are attached

Directly to a substrate, which may be a rock, shell, coral, seaweed, mangrove root, dock, piling, or

Ship's hull. They are found in a range of solid or translucent colours and may resemble seeds,

Grapes, peaches, barrels, or bottles. One of the largest is a stalked sea tulip, *Pyura pachydermatina*,

Which can grow to be over 1 metre (3.3 ft) tall.

The Tunicata were established by Jean-Baptiste Lamarck in 1816. In 1881, Francis Maitland

Balfour introduced another name for the same group, "Urochorda", to emphasize the affinity of

The group to other chordates. No doubt largely because of his influence, various authors supported

The term, either as such, or as the slightly older "Urochordata", but this usage is invalid because

“Tunicata” has precedence, and grounds for superseding the name never existed. Accordingly, the

Current (formally correct) trend is to abandon the name Urochorda or Urochordata in favour of the

Original Tunicata, and the name Tunicata is almost invariably used in modern scientific works. It

Is accepted as valid by the World Register of Marine Species but not by the Integrated Taxonomic

Information System.

Various common names are used for different species. Sea tulips are tunicates with colourful

Bodies supported on slender stalks. Sea squirts are so named because of their habit of contracting

Their bodies sharply and squirting out water when disturbed. Sea liver and sea pork get their names

From the resemblance of their dead colonies to pieces of meat

A tunicate is a marine invertebrate animal, a member of the subphylum Tunicata. It is part of

The Chordata, a phylum which includes all animals with dorsal nerve cords and notochords. The

Subphylum was at one time called Urochordata, and the term urochordates is still sometimes

Used for these animals. They are the only chordates that have lost their myomeric segmentation,

With the possible exception of the ‘seriation of the gill slits’. Myomere are the blocks of skeletal

Muscle tissue found commonly in chordates. They are commonly zig-zag, “W” or “V”-shaped

Muscle fibers. The myomeres are separated from adjacent myomere by connective tissues and most

Easily seen in larval fishes or in the olm. Myomere counts are sometimes used for identifying

Specimens, since their number corresponds to the number of vertebrae in the adults.

Urochordates have a sparse fossil record. A Precambrian fossil known as Yarnemia has been

Referred to the Urochordata, but this assignment is doubtful. Complete body fossils of tunicates are

Rare, but tunicates in some families generate microscopic spicules that may be preserved as

Microfossils. Such spicules have occasionally been described from Jurassic and later rocks. Few

Paleontologists are familiar with them; tunicate spicules may be mistaken for sponge spicules.

The subphylum Urochordata constitutes a unique group of animals under the, Phylum Chordata.

The members of this subphylum exhibit a high degree of diversity in form, habit and habitat.

The adults are mostly degenerated and un-segmented.

Lesson 9

Introduction to tunicates and their body organization

Members of the subphylum Urochordata (uro-kor-dahtah) (Gr. Uro, tail

L. chorda, cord) are the tunicates or sea squirts. The ascidians

Comprise the largest class of tunicates (see table 17.1). They are sessile as adults and are either

Solitary or colonial.

The appendicularians and thaliaceans are planktonic as adults (figure 17.7). In some localities,

Tunicates occur in large enough numbers to be considered a dominant life-form. Sessile

Urochordates attach their saclike bodies to rocks, pilings, ship hulls, and other solid substrates. The

Unattached end of urochordates contains two siphons that permit seawater to circulate through the

Body. One siphon is the oral siphon, which is the inlet for water circulating through the body and

Is usually directly opposite the attached end of the ascidian (figure 17.8). It also serves as the mouth

Opening. The second siphon, the atrial siphon, is the opening for excurrent water. The body wall

Of most tunicates (L. tunicatus, to wear a tunic or gown) is a connective-tissue-like covering, c

The tunic, that appears gel-like but is often quite tough. Secreted by the epidermis, it is composed

Of proteins, various salts, and cellulose. Some mesodermally derived tissues, including blood

Vessels and blood cells, are incorporated into the tunic. Rootlike extensions of the tunic, called

Stolons, help anchor a tunicate to the substrate and may connect individuals of a colony.

FIGURE 17.7 Subphylum Urochordata. (a) Members of the class Appendicularia are planktonic

And have a tail and notochord that persist into the adult stage. (b) The thaliaceans are barrel-

Shaped, planktonic urochordates. Oral and atrial siphons are at opposite ends of the body, and

Muscles of the body wall contract to create a form of weak jet propulsion.

Tunicates: Body organization

The urochordates or tunicates are a remarkable group of organisms and typically very

Beautiful and photogenic.

Tunicates derive their name from a thick extracellular body covering, called a tunic that is made

Up of cellulose-like, complex sugars. Another interesting feature of tunicates is their circulatory

System. Instead of blood vessels, the heart pumps blood through a number of small pockets

Called sinuses. In addition, the heart periodically changes the direction that it pumps blood.

The adult tunicate body is shaped like a small barrel with two large openings called siphons. The

Inhalent siphon brings water into a saclike, central cavity, called the atrial cavity (distinct from

The coelom), and then through the pharyngeal slits where food is filtered into the digestive system.

The water then exits the cavity through an exhalant siphon. The tunicate coelom is reduced to a

Small compartment surrounding the heart. The majority of the organs lie within a body cavity

Below the atrial cavity called the epicardium, or visceral cavity. The visceral cavity contains the

Digestive tract (except for the pharynx, which is situated in the atrial cavity), the heart, and the

Reproductive organs. The organization of the tunicate body is shown in Figure below.

Longitudinal and circular muscles below the body wall epithelium help to change the shape of the

Adult tunicate. They act against the elasticity of the tunic and the hydrostatic skeleton that seawater

Confined to internal chambers creates. The nervous system of tunicates is largely confined to the

Body wall. It forms a nerve plexus with a single ganglion located on the wall of the pharynx

Between the oral and atrial openings (figure 17.9a). This ganglion is not vital for coordinating 

Bodily functions. Tunicates are sensitive to many kinds of mechanical and chemical stimuli, and

Receptors for these senses are distributed over the body wall, especially around the siphons. There

Are no complex sensory organs.

The organization of an adult tunicate body. The digestive system is outlined in green, the gonad is

In purple, and the circulatory system is in red. Water is brought into the pharynx within the atrial

Cavity and through the pharyngeal slits via the inhalent siphon. Food particles captured by the

Pharyngeal slits are then passed into the remainder of the digestive system, situated in the lower

Cavity called the epicardium. The digestive system ends with an anus that opens back into the atrial

Cavity, and waste exits the body through the exhalent siphon.

Lesson no10

Tunicates: Digestion and Respiration

Most of the larger species of ascidians are solitary and made up of only one zooid, while the

Compound species are colonial and are composed of many zooids. Some colonies may reach sizes

Of one meter or more. The simplest colonies of zooids are spaced apart and connected by stolons.

In most of the colonies that are comprised of specialized zooids, the zooids are completely

Imbedded in the tunic (Barnes and Ruppert, 1994).

Within the tunic each zooid is divided up into three regions: the thoracic (anterior), abdominal,

And postabdominal. The thoracic region contains the pharynx and the abdominal contains the

Digestive tract. The postabdominal region is the most bottom part of the tunicate body and contains

The heart and reproductive organs. Most do not have a postabdomen and some of the larger species

Do not have an abdomen, in this case all of the organs they would contain will be shifted up to one

Side of the pharynx (Barnes and Ruppert, 1994).

Tunicates mainly eat phytoplankton, zooplankton, detritus and other small organisms in the water,

These organisms are filtered through the tunicate. They have cilia in the pharynx and they also

Produce mucus. Their food gets stuck in the mucus and with the help of beating cilia the mucus

Moves toward the digestive system. There are also predatory tunicates, which eat small creatures

That get pulled through their siphon and get stuck on their mucous.

The most obvious internal structures of the urochordates are a very large pharynx and a cavity,

Called the atrium, that surrounds the pharynx laterally and dorsally (figure 17.9b). The pharynx of

Tunicates originates at the oral siphon and is continuous with the remainder of the digestive tract.

The oral margin of the pharynx has tentacles that prevent large objects from entering the pharynx.

Numerous pharyngeal slits called stigmas perforate the pharynx. Cilia associated with the stigmas

Cause water to circulate into the pharynx, through the stigmas, and into the surrounding atrium.

Water leaves the tunicate through the atrial siphon. The digestive tract of adult tunicates continues

From the pharynx and ends at the anus near the atrial siphon. During feeding, cells of a ventral,

Ciliated groove, called the endostyle, form a mucous sheath (figure 17.9b). Cilia move the mucous

Sheet dorsally across the pharynx. Food particles, brought into the oral siphon with incurrent water,

Are trapped in the mucous sheet and passed dorsally. Food is incorporated into a string of mucus

That ciliary action moves into the next region of the gut tract. Digestive enzymes are secreted in

The stomach, and most absorption occurs across the walls of the intestine. Excurrent water carries

Digestive wastes from the anus out of the atrial siphon. In addition to its role in feeding, the pharynx

Also functions in gas exchange. Gases are exchanged as water circulates through the tunicate.

FIGURE 17.9 Internal Structure of a Tunicate. (a) Longitudinal section. Black arrows show the

Path of water. (b) Cross section at the level of the atrial siphon. Small black arrows show

Movement of food trapped in mucus that the endostyle produces.

Lesson 11

Tunicates: Circulation and Excretion

The ascidian tunicate *Corella inflata* is relatively transparent compared to other solitary tunicates

And the circulatory system can be visualized by injecting high molecular weight fluorescein labeled

Dextran into the beating heart or the large vessels at the ends of the heart. In addition, after staining

With neutral red the movement of blood cells can be followed to further define and characterize

The circulatory system. The heart is a gently curved tube with a constriction in the middle and

Extends across the width of the animal. As in other tunicates, pumping is peristaltic and

Periodically reverses direction. During the abvisceral directional phase blood leaves the anterior

End of the heart in two asymmetric vessels that connect to the two sides of the branchial basket (or

Pharynx), in contrast to the direct connection between the heart and the endostyle seen in the

Commonly studied tunicate *Ciona intestinalis*. In *Corella inflata* blood then flows in both transverse

Directions through a complex system of ducts in the branchial basket into large ventral and dorsal

Vessels and then to the visceral organs in the posterior of the animal. During the advisceral phase

Blood leaves the posterior end of the heart in vessels that repeatedly bifurcate to fan into the

Stomach and gonads. Blood speed, determined by following individual cells, is high and pulsatory

Near the heart, but decreases and becomes more constant in peripheral regions. Estimated blood

Flow volume during one directional phase is greater than the total volume of the animal. Circulating

Blood cells are confined to vessels or ducts in the visible parts of the animal and retention of high

Molecular weight dextran in the vessels is comparable to that seen in vertebrates. These flow

Patterns are consistent with a closed circulatory network.

The tunicate heart lies at the base of the pharynx. One vessel from the heart runs anteriorly under

The endostyle, and another runs posteriorly to the digestive organs and gonads. Blood flow through

The heart is not unidirectional. Peristaltic contractions of the heart may propel blood in one

Direction for a few beats; then the direction is reversed. The significance of this reversal is not

Understood. Tunicate blood plasma is colorless and contains various kinds of amoeboid cells.

The body is enclosed in a more-or-less translucent tunic. No special excretory organs appear to be

Present. Nitrogenous waste is excreted as ammonia, which can easily be carried away in

The exhalant flow of water and by diffusion from the general body surface

Ammonia diffuses into water that passes through the pharynx and is excreted. In addition,

Amoeboid cells of the circulatory system accumulate uric acid and sequester it in the intestinal

Loop. Pyloric glands on the outside of the intestine are also thought to have excretory functions.

One clue that tunicates are related to vertebrates is found in the tunicate larva, or tadpole. It even

Looks like a tiny tadpole, and has a nerve cord down its back, similar to the nerve cord found

Inside the vertebrae of all vertebrates.

The tail also has a semi-rigid rod called a notochord, which can be compared to the spine of true

Vertebrates.

Urochordates are monoecious. Gonads are located near the loop of the intestine, and genital ducts

Open near the atrial siphon. Gametes may be shed through the atrial siphon for external

Fertilization, or eggs may be retained in the atrium for fertilization and early development.

Although self-fertilization occurs in some species, cross-fertilization is the rule. Development

Results in the formation of a tadpolelike larva with all four chordate characteristics. Metamorphosis

Begins after a brief free-swimming larval existence, during which the larva does not feed. The

Larva settles to a firm substrate and attaches by adhesive papillae located below the mouth. During

Metamorphosis, the outer epidermis shrinks and pulls the notochord and other tail structures

Internally for reorganization into adult tissues. The internal structures rotate 180°, positioning the

Oral siphon opposite the adhesive papillae and bending the digestive tract into a U shape.

FIGURE 17.8 Tunicate Metamorphosis. Small black arrows show the path of water through the

Body.

Lesson 12

Subphylum Cephalochordata

Cephalochordate, also called acrania, any of more than two dozen species belonging

To the subphylum Cephalochordata of the phylum Chordata. Small, fishlike marine

Invertebrates, they probably are the closest living relatives of the vertebrates.

Cephalochordates and vertebrates have a hollow, dorsal nerve cord, pharyngeal gill slits,

And a notochord. In most vertebrates, the embryonic notochord is eventually replaced by

Bony vertebrae or cartilaginous tissue; among cephalochordates, the notochord is

Retained into adulthood and is never replaced by vertebrae. There are about 20 species in

Two families, each with a single genus. Branchiostoma was formerly called Amphioxus, a

Name that is retained as an informal term. The other genus is Epigonichthys, also

Called Asymmetron. The genus Asymmetron is sometimes retained for some species. The

Cephalochordate fossil record extends back to about 525 million years ago during the early

Part of the Cambrian Period.

Members of the subphylum Cephalochordata (sefa-lo-kordahtah) (Gr. Kephalo, head

L. chorda, cord) are called lancelets. Lancelets clearly

Demonstrate the four chordate characteristics, and for that reason they are often studied

In introductory zoology courses. The cephalochordates consist of two genera,

Branchiostoma (amphioxus) and Asymmetron, and about 45 species. They are distributed

Throughout the world's oceans in shallow waters that have clean sand substrates.

Cephalochordates are small (up to 5 cm long), tadpolelike animals. They are elongate,

Laterally flattened, and nearly transparent. In spite of their streamlined shape,

Cephalochordates are relatively weak swimmers and spend most of their time in a filter

Feeding position_partly to mostly buried with their anterior end sticking out of the sand

(figure 17.10). The notochord of cephalochordates extends from the tail to the head, giving

Them their name. Unlike the notochord of other chordates, most of the cells are muscle

Cells, making the notochord somewhat contractile. Both of these characteristics are

Probably adaptations to burrowing. Contraction of the muscle cells increases the rigidity

Of the notochord by compressing the fluids within, giving additional support when

Pushing into sandy substrates. Relaxation of these muscle cells increases flexibility for

Swimming. Muscle cells on either side of the notochord cause undulations that propel the

Cephalochordate through the water. Longitudinal, ventrolateral folds of the body wall help

Stabilize cephalochordates during swimming, and a median dorsal fin and a caudal fin

Also aid in swimming. An oral hood projects from the anterior end of cephalochordates.

Ciliated, fingerlike projections, called cirri, hang from the ventral aspect of the oral hood

And are used in feeding. The posterior wall of the oral hood bears the mouth opening that

Leads

FIGURE 17.10 Subphylum Cephalochordata. Internal structure of Branchiostoma (amphioxus)

Shown in its partially buried feeding position.

To a large pharynx. Numerous pairs of pharyngeal slits perforate the pharynx and are supported by

Cartilaginous gill bars. Large folds of the body wall extend ventrally around the pharynx and fuse

At the ventral midline of the body, creating the atrium, a chamber that surrounds the pharyngeal

Region of the body. It may protect the delicate, filtering surfaces of the pharynx from bottom

Sediments. The opening from the atrium to the outside is called the atriopore (figure 17.10)

Lesson no 13

Cephalochordates: Feeding and Digestion

Cephalochordates are filter feeders. During feeding, they are partially or mostly buried in sandy

Substrates with their mouths pointed upward. Cilia on the lateral surfaces of gill bars sweep water

Into the mouth. Water passes from the pharynx, through pharyngeal slits to the atrium, and out of

The body through the atriopore. Food is initially sorted at the cirri. Larger materials catch on cilia

Of the cirri. As these larger particles accumulate, contractions of the cirri throw them off. Smaller,

Edible particles are pulled into the mouth with water and are collected by cilia on the gill bars and

In mucus secreted by the endostyle. As in tunicates, the endostyle is a ciliated groove that extends

Longitudinally along the midventral aspect of the pharynx. Cilia move food and mucus dorsally,

Forming a food cord to the gut. A ring of cilia rotates the food cord, dislodging food. Digestion is

Both extracellular and intracellular. A diverticulum off the gut, called the midgut cecum, extends

Anteriorly. It ends blindly along the right side of the pharynx and secretes digestive enzymes. An

Anus is on the left side of the ventral fin.

Lesson no 14

Cephalochordates: Circulation, Excretion, Reproduction and Development

Cephalochordates do not possess a true heart. Contractile waves in the walls of major vessels

Propel blood. Blood contains amoeboid cells and bathes tissues in open spaces. Excretory tubules

Are modified coelomic cells closely associated with blood vessels. This arrangement suggests

Active transport of materials between the blood and excretory tubules. The coelom of

Cephalochordates is reduced, compared to that of most other chordates. It is restricted to canals

Near the gill bars, the endostyle, and the gonads.

The cephalochordates constitute the smallest chordate subphyla and comprise 35 species

Belonging to three genera: Branchiostoma, Epigonichthys and Asymmetron. Most lanceolates are

Gonochores; however, anomalous occurrence of simultaneous hermaphroditic amphioxus

Species is reported. In gonochorics, sex ratio is male-biased, as in *Branchiostomma lanceolatum*.

The two series of symmetric gonads are located ventrolaterally in *Branchiostoma* but

Asymmetron develops gonads on only the right side of the body. The larvae are asymmetrical

With the mouth on the left side and gills on the right side. On metamorphosis, bilateral symmetry

is restored. Captive culture from egg to egg stage has been achieved only in *B. belcheri*. In

Temperate lanceolates, life span ranges from 2-3 years in *B. floridae* and *B. belcheri* to 8 years

in *B. lanceolatu*.

Cephalochordates are dioecious. Gonads bulge into the atrium from the lateral body wall. Gametes

are shed into the atrium and leave the body through the atriopore. External fertilization leads to a

bilaterally symmetrical larva. Larvae are free-swimming, but they eventually settle to the substrate

before metamorphosing into adults.

LESSON NO 15

Phylogenetic Relationships between hemichordates and chordates

Animals in the phyla Hemichordata and Chordata share deuterostome characteristics with

Echinoderms (figure 17.2). Most zoologists, therefore, believe that ancestral representatives of

These phyla were derived from a common, as yet undiscovered, triploblastic ancestor. The

Chordates are characterized by a dorsal tubular nerve cord, a notochord, pharyngeal slits or

Pouches, and a postanal tail. The only characteristics they share with the hemichordates are

Pharyngeal slits and, in some species, a dorsal tubular nerve cord. Therefore, most zoologists agree

That the evolutionary ties between the chordates and hemichordates are closer than those between

Echinoderms and either phylum. Chordates and hemichordates, however, probably diverged from

Widely separated points along the deuterostome lineage. The diverse body forms and lifestyles

Present in these phyla support this generalization.

FIGURE 17.2 Phylogenetic Relationships among the Hemichordata and Chordata. Hemichordates

And chordates (shaded in orange) are distantly related deuterostomes derived from a common, as

Yet undiscovered, diploblastic or triploblastic ancestor.

LESSON NO16

Deuterostomate Phylogeny

The evolutionary relationships between the hemichordates and chordates are difficult to document

With certainty. The dorsal tubular nerve cord and pharyngeal slits of hemichordates are evidence of evolutionary ties between these phyla (figure 17.11). Questions regarding the homologies of these structures, however, remain. Synapomorphies that distinguish chordates from hemichordates include tadpole larvae, a notochord, a postanal tail, and an endostyle. Figure 17.11 also shows evolutionary relationships between members of the three chordate subphyla. As discussed in Chapter 16, the earliest echinoderms were probably sessile filter feeders. The lifestyle of adult Urochordates suggests a similar ancestry (perhaps from a common ancestor with echinoderms) for Chordates. The evolution of motile chordates from attached ancestors may have involved the development of a tadpolelike larva. Increased larval mobility is often adaptive for species with sedentary adults because it promotes dispersal. The evolution of motile adults could have resulted from paedomorphosis, which is the development of sexual maturity in the larval body form. (Paedomorphosis is well documented in the animal kingdom, especially among amphibians.) Paedomorphosis could have led to a small, sexually reproducing, fishlike chordate that could have been the ancestor of higher chordates. The largest and most successful chordates belong to the

Subphylum Vertebrata. Bony or cartilaginous vertebrae that completely or partially replace the

Notochord characterize the vertebrates. The development of the anterior end of the nerve cord into

A brain and the development of specialized sense organs on the head are evidence of a high degree

Of cephalization. The skeleton is modified anteriorly into a skull or cranium. There are eight classes

Of vertebrates (see table 17.1). Because of their cartilaginous and bony endoskeletons, vertebrates

Have left an abundant fossil record. Ancient jawless fishes were common in the Ordovician period,

Approximately 500 million years ago. Over a period of approximately 100 million years, fishes

Became the dominant vertebrates. Near the end of the Devonian period, approximately 400 million

Years ago, terrestrial vertebrates made their appearance. Since that time, vertebrates have radiated

Into most of the earth's habitats. Chapters 18 through 22 give an account of these events.

FIGURE 17.11 One Interpretation of Deuterostomate Phylogeny. The dorsal tubular nerve cord

And pharyngeal slits are possible synapomorphies that link the Hemichordata and the Chordata.

The notochord, postanal tail, and endostyle or thyroid gland are important characteristics that

Distinguish the Hemichordata and Chordata. Some of the synapomorphies that distinguish the

Chordate subphyla are shown.

Fishes

Lesson 17

Characteristics

1. Fishes are aquatic; cold blooded vertebrates
2. Their body is divisible into head, trunk and tail. Neck is absent.
3. It has a spindle shaped body. It is helpful in swimming
4. The body is covered by scales. They are placoid scales, cycloid scales, ctenoid scales,

Ganoid scales etc

5. Respiration is by gills. Gills are the extensions of the pharynx. In the elasmobranches

Fishes, the gills will open separate. In bony fishes the gill slits are covered by operculum

6. On the head a pair of nostrils are present internal nostril are absent. In Dipnoi Internal

Nostrils are present

7. On the head a pair of eyes is present.
8. On the lateral sides of the body LATERAL LINE SENSE organs are present. They detect

The pressure changes of water

9. The body shows paired and unpaired fins. Pelvic and pectoral fins are paired. Dorsal and

Ventral fins are unpaired. They maintain balance in water. They are useful for locomotion

10. The digestive system is well developed. In the intestine of shark scroll valve is present.

The nervous system contains brain and spinal cord. Brain is small & it will not occupy

The entire cranial cavity

11. 10 pairs of cranial nerves are present

12. Kidneys are mesonephric

13. Urinary bladder is absent

14. The skeleton of some fishes is made by cartilage. They are called cartilage fishes. In

Some fishes the skeleton is made by bone. They are called bony fishes

15. In some fresh water fishes accessory respiratory organs are present. They will take up

Aerial respiration

16. Sexes are separate. In male sharks claspers are present

17. Many fishes are oviparous. Some fishes are viviparous.

18. In the development of fishes amnion is not developed. Hence these animals are called

Anamniotes

PHYLOGENETIC RELATIONSHIPS

Fishes are members of the chordate subphylum Vertebrata; thus, they have vertebrae that

Surround their spinal cord and provide the primary axial support. They also have a skull that

Protects the brain (figure 18.1).

Figure 18.1: Fishes. Five hundred million years of evolution have resulted in unsurpassed

Diversity in fishes. The spines of this beautiful marine lionfish (Pterois) are extremely venomous.

Recent cladistic analysis of vertebrate evolution indicates that a group of fishes called hag-fishes

Are the most primitive vertebrates known (living or extinct). Making a connection between this

Lineage and other vertebrates depends on the analysis of two key vertebrate characteristics, the

Brain and bone.

Chinese researchers have recently unearthed the oldest alleged vertebrate fossils a small, lancelet-

Shaped animal that has characteristics that suggest an active, predatory lifestyle. A brain is present

That would have processed sensory information from the pair of eyes that are seen in fossils. Muscle

Blocks along the body wall suggest an active swimming existence. This evidence means that these

530 million-year-old animals located prey by sight and then pursued it through prehistoric seas.

The origin of bone in vertebrates is equally intriguing. A group of ancient eel-like animals, the

Conodonts, are known from fossils that date back about 510 million years (figure 18.2). They have

Been assigned to a variety of phyla, but recent evidence is bringing a growing number of zoologists

To accept them as full-fledged vertebrates. They have two large eyes and a mouth filled with tooth

Like structures made of dentine component found in the vertebrate skeleton. These structures may

Represent the earliest occurrence of bone in vertebrates. Other hypotheses on the origin of bone

Suggest that it may have arisen as denticles in the skin (similar to those of sharks), in association

With certain sensory receptors, or as structures for mineral (especially calcium phosphate) storage.

Regardless of its origin, bone was well developed by 500 million years ago. It was present in the

Bony armor of a group of fishes called ostracoderms. Ostracoderms were relatively inactive filter

Feeders that lived on the bottom of prehistoric lakes and seas. They possessed neither jaws nor

Paired appendages; however, the evolution of fishes resulted in both jaws and paired appendages

As well as many other structures. The results of this adaptive radiation are described in this chapter.

Did ancestral fishes live in freshwater or in the sea? The answer to this question is not simple. The

First vertebrates were probably marine, because ancient stocks of other deuterostome phyla were

All marine. Vertebrates, however, adapted to freshwater very early, and much of the evolution of

Fishes occurred there.

Apparently, early vertebrate evolution involved the movement of fishes back and forth between

Marine and freshwater environments. The majority of the evolutionary history of some fishes took

Place in ancient seas, and most of the evolutionary history of others occurred in freshwater. The

Importance of freshwater in the evolution of fishes is evidenced by the fact that over 41% of all

Fish species are found in freshwater, even though freshwater habitats represent only a small

Percentage (0.0093% by volume) of the earth's water resources.

Lesson 18

Other phylogenetic consideration

Most cladistic and anatomical evidence indicates that the lungfish lineage gave rise to no other

Vertebrate taxa. Two important series of evolutionary events occurred during the evolution of the

Osteichthyes. One of these was an evolutionary explosion that began about 150 million years ago

And resulted in the vast diversity of teleosts living today. The second series of events involves the

Evolution of terrestriality

The presence of functional lungs in modern lungfishes has led to the suggestion that the lungfish

Lineage may have been ancestral to modern terrestrial vertebrates. Another group of

Sarcopterygii, the osteolepiforms, are now believed to be ancestors of terrestrial vertebrates.

These fish probably occupied relatively shallow-water habitats that would have allowed them to

Avoid falling prey to larger predatory fishes. Young osteolepiforms may have inhabited very

Shallow water. In the warm, shallow-water environments, depleted oxygen would have favored the

Evolution of sarcopterygian lungs.

Abundant food, in the form of arthropods and other invertebrates, at the water's edge would have

Favored shallow water and terrestrial feeding, appendages that allowed the fish to wallow at the

Land/water interface, and eye lenses that could function in air.

While millions of years would elapse before any vertebrate could be considered terrestrial, brief

Excursions onto land allowed some vertebrates to exploit resources that for the previous 50 million

Years had only been available to terrestrial arthropods

Lesson 19

Classification of fishes

Lesson 20

Agnathans

Ostracoderms are extinct agnathans that belonged to several classes. Ostracoderms were bottom

Dwellers, often about 15 cm long. Most were probably filter feeders, either filtering suspended

Organic matter from the water or extracting annelids and other animals from muddy sediments.

Some ostracoderms may have used bony plates around the mouth in a jawlike fashion to crack

Gastropod shells or the exoskeletons of arthropods

Class Myxini

Hagfishes are members of the class Myxini. Hagfishes live buried in the sand and mud of marine

Environments, where they feed on soft-bodied invertebrates and scavenge dead and dying fish

(Figure 18.5). When hagfishes find a suitable fish, they enter the fish through the mouth and eat

The contents of the body, leaving only a sack of skin and bones. Most zoologists now consider the

Hagfishes to be the most primitive group of vertebrates.

Lesson 21

Class Cephalaspidomorphi

Lampreys are agnathans in the class. They are common inhabitants of marine and freshwater

Environments in temperate regions. Most adult lampreys prey on other fishes, and the larvae are

Filter feeders. The mouth of an adult is sucker like and surrounded by lips that have sensory and

Attachment functions. Numerous epidermal teeth line the mouth and cover a movable tongue like

Structure (Figure 18.6). Adults attach to prey with their lips and teeth and use their tongues to rasp

Away scales. Lampreys have salivary glands with anticoagulant secretions and feed mainly on the

Blood of their prey. Some lampreys, however, are not predatory.

Members of the genus *Lampetra* are called brook lampreys. The larval stages of brook lampreys

Last for about three years, and the adults neither feed nor leave their stream. They reproduce soon

After metamorphosis and then die. Adult sea lampreys live in the ocean or the Great Lakes. Near

The end of their lives, they migrate—sometimes hundreds of miles—to a spawning bed in a

Freshwater stream. Once lampreys reach their spawning site, usually in relatively shallow water

With swift currents, they begin building a nest by making small depressions in the substrate. When

The nest is prepared, a female usually attaches to a stone with her mouth. A male uses his mouth to

Attach to the female's head and wraps his body around the female. Eggs are shed in small batches

Over a period of several hours, and fertilization is external. The relatively sticky eggs are then

Covered with sand.

Eggs hatch in approximately three weeks into ammocoete larvae. The larvae drift downstream to

Softer substrates, where they bury themselves in sand and mud and filter feed in a fashion similar

To amphioxus. Ammocoete larvae grow from 7 mm to about 17 cm over three years. During later

Developmental stages, the larvae metamorphose to the adult over a period of several months. The

Mouth becomes suckerlike, and the teeth, tongue, and feeding musculature develop. Lampreys

Eventually leave the mud permanently and begin a journey to the sea to begin life as predators.

Adults return only once to the headwaters of their stream to spawn and die.

Lesson 22

GNATHOSTOMES

Two major developments in vertebrate evolution were the appearance of jaws and paired

Appendages. Jaws are used in feeding and are partly responsible for a transition to more active,

Predatory lifestyles. Pectoral fins of fishes are appendages usually just behind the head, and pelvic

Fins are usually located ventrally and posteriorly. Both sets of paired fins give fishes a more precise

Steering mechanism and increase fish agility.

Two classes of gnathostomes still have living members: the cartilaginous fishes (class

Chondrichthyes) and the bony fishes (class Osteichthyes). Another class, the armored fishes, or

Placoderms, contained the earliest jawed fishes. They are now extinct and apparently left no

Descendants. A fourth group of ancient, extinct fishes, the acanthodians, may be more closely

Related to the bony fishes.

Class Chondrichthyes

Members of the class Chondrichthyes include the sharks, skates, rays, and ratfishes (see table

18.1). Most chondrichthians are carnivores or scavengers, and most are marine. In addition to their

Biting mouthparts and paired appendages, chondrichthians possess epidermal placoid scales and

A cartilaginous endoskeleton. The subclass Elasmobranchii (e-lazmo-branke-i) (Gr. Elasmos, plate

Metal branchia, gills), which includes the sharks, skates, and rays, has about seven hundred species

(Figure 18.9). Sharks arose from early jawed fishes midway through the Devonian period, about

375 million years ago. The absence of certain features characteristic of bony fishes (e.g., a swim

Bladder to regulate buoyancy, a gill cover, and a bony skeleton) is sometimes interpreted as

Evidence of the primitiveness of elasmobranchs. This interpretation is mistaken, as these

Characteristics simply resulted from different adaptations in the two groups to similar selection

Pressures. Some of these adaptations are described later in this chapter.

Tough skin with dermal, placoid scales covers sharks (Figure 18.10a). These scales project

Posteriorly and give the skin a tough, sandpaper texture. (In fact, dried shark skin has been used

For sandpaper.) Posteriorly pointed scales also reduce friction with the water as a shark swims.

Shark teeth are actually modified placoid scales. The largest sharks are not predatory but are filter

Feeders. They have pharyngeal-arch modifications that strain plankton. The fiercest and most

Feared sharks are the great white shark (*Carcharodon*) and the mako (*Isurus*). Skates and rays are

Specialized for life on the ocean floor.

Figure 18.10: Scales and Teeth of Sharks. (a) Section of shark skin magnified to show posteriorly

Pointing placoid scales

They usually inhabit shallow water, where they use their blunt teeth to feed on invertebrates. Their

Most obvious modification for life on the ocean floor is a lateral expansion of the pectoral fins into

Wing like appendages. Locomotion results from dorsoventral muscular waves that pass posteriorly

Along the finsThe sting ray (*Dasyatis*) has a tail modified into a defensive lash; the dorsal fin

Persists as a venomous spine. Also included in this group are the electric rays (*Narcine* and

Torpedo) and manta rays (*Manta*) (see figure 18.9b).

A second major group of chondrichthians, in the subclass Holocephali contains about 30 species.

A frequently studied example, *Chimaera*, has a large head with a small mouth surrounded by large

Lips. A narrow, tapering tail has resulted in the common name “ratfish.” Holocephalans div

Figure 18.9: Class Chondrichthyes. (a) A gray reef shark (*Carcharhinus*). (b) A manta ray (*Manta*

Hamiltoni) with two remoras (*Remora remora*) attached to its ventral surface. © A bullseye

Stingray (*Urolophus concentricus*).

Lesson 23

Class Osteichthyes

Members of the class Osteichthyes characterized by having at least some bone in their skeleton

And/or scales, bony operculum covering the gill openings, and lungs or a swim bladder. Any group

That has at least 20,000 species and is a major life-form in most of the earth’s vast aquatic habitats

Must be judged very successful from an evolutionary perspective. The first fossils of bony fishes

Are from late Silurian deposits (approximately 405 million years old). By the Devonian period (350

Million years ago), the two subclasses were in the midst of their adaptive radiations (see table 18.1;

See also figure 18.3). Members of the subclass Sarcopterygii have muscular lobes associated with

Their fins and usually use lungs in gas exchange. One group of sarcoptery gians are the lungfishes.

Only three genera survive today, and all live in regions where seasonal droughts are common.

When freshwater lakes and rivers begin to stagnate and dry, these fishes use lungs to breathe air.

Some (*Neoceratodus*) inhabit the freshwaters of Queensland, Australia. They survive stagnation

By breathing air, but they normally use gills and cannot withstand total drying.

Others are found in freshwater rivers and lakes in tropical Africa (*Protopterus*) and tropical South

America (*Lepidosiren*). They can survive when rivers or lakes are dry by burrowing into the mud.

They keep a narrow air pathway open by bubbling air to the surface. After the substrate dries, the

Only evidence of a lungfish burrow is a small opening in the earth. Lungfishes may remain in

Aestivation for six months or more. (Aestivation is a dormant state that helps an animal withstand

Hot, dry periods.) When rain again fills the lake or riverbed, lungfishes emerge from their burrows

To feed and reproduce.

A second group of sarcopterygians are the coelacanth. The most recent coelacanth fossils are over

70 million years old. It is large—up to 80 kg—and has heavy scales. Ancient coelacanths lived in

Freshwater lakes and rivers; thus, the ancestors of *Latimeria* must have moved from freshwater

Habitats to the deep sea. A third group of sarcopterygians, called osteolepiforms, became extinct

Before the close of the Paleozoic period. They are believed to have been the ancestors of ancient

Amphibians.

The subclass Actinopterygii contains fishes that are sometimes called the ray-finned fishes because

Their fins lack muscular lobes. They usually possess swim bladders, gas-filled sacs along the dorsal

Wall of the body cavity that regulate buoyancy. Zoologists now realize that there have been many

Points of divergence in the evolution of the Actinopterygii. One modern classification system

Divides the Actinopterygii into two infraclasses.

Lesson 24

Chondrosteans

One group of actinopterygians, the chondrosteans, contains many species that lived during the

Permian, Triassic, and Jurassic periods (215 to 120 million years ago), but only 25 species remain

Today. Ancestral chondrosteans had a bony skeleton, but living members, the sturgeons and

Paddlefishes, have cartilaginous skeletons. Chondrosteans also have a tail with a large upper lobe.

Most sturgeons live in the sea and migrate into rivers to breed (figure 18.13a). (Some sturgeons

Live in freshwater but maintain the migratory habits of their marine relatives.) They are large (up

To 1,000 kg), and bony plates cover the anterior portion of the body. Heavy scales cover the tail.

The sturgeon mouth is small, and jaws are weak. Sturgeons feed on invertebrates that they stir up

From the sea or riverbed using their snouts

Paddlefishes are large, freshwater chondrosteans. They have a large, paddlelike rostrum that is

Innervated with sensory organs believed to detect weak electrical fields (figure 18.13b). They swim

Through the water with their large mouths open, filtering crustaceans and small fishes. They are

Found mainly in lakes and large rivers of the Mississippi River basin and are also known from

Western North America and China.

The second group of actinopterygians (Neopterygii) flourished in the Jurassic period and

Succeeded most chondrosteans. Two very primitive genera occur in temperate to warm freshwaters

Of North America. *Lepisosteus*, the garpike, has thick scales and long jaws that it uses to catch

Fishes. *Amia* is commonly referred to as the dogfish or bowfin. Most living fishes are members of

This group and are referred to as teleosts or modern bony fishes. They have a symmetrical caudal

Fin and a swim bladder that has lost its connection to the digestive tract. After their divergence

From ancient marine actinopterygians in the late Triassic period, teleosts experienced a remarkable

Evolutionary diversification and adapted to nearly every available aquatic habitat. The number of

Teleost species exceeds 20,000.

Figure 18.13 Subclass Actinopterygii, the Chondrosteans. (a) Shovelnose sturgeons

(*Scaphirhynchus platyrhynchus*). Sturgeons are covered anteriorly by heavy bony plates and

Posteriorly by scales. (b) The distinctive rostrum of a paddlefish (*Polyodon spathula*) is densely

Innervated with sensory structures that are probably used to detect minute electrical fields. Note

The mouth in its open, filter-feeding position

Lesson 25

LOCOMOTION, NUTRITION AND THE DIGESTIVE SYSTEM

Locomotion

The density of the water makes movement through it difficult and costly. For a fish, however,

Swimming is less energetically costly than running is for a terrestrial organism. The streamlined

Shape of a fish and the mucoid secretions that lubricate its body surface reduce friction between

The fish and the water. Water's buoyant properties also contribute to the efficiency of a fish's

Movement through the water. A fish expends little energy in support against the pull of gravity.

Fishes move through the water using their fins and body wall to push against the incompressible

Surrounding water. Anyone who has eaten a fish filet probably realizes that muscle bundles of

Most fishes are arranged in a pattern. Because these muscles extend posteriorly and anteriorly in a

Zigzag fashion, contraction of each muscle bundle can affect a relatively large portion of the body

Wall. Very efficient, fast-swimming fishes, such as tuna and mackerel, supplement body

Movements with a vertical caudal (tail) fin that is tall and forked. The forked shape of the caudal

Fin reduces surface area that could cause turbulence and interfere with forward movement.

NUTRITION AND THE DIGESTIVE SYSTEM

The earliest fishes were probably filter feeders and scavengers that sifted through the mud of

Ancient seafloors for decaying organic matter, annelids, molluscs, or other bottom dwelling

Invertebrates. Fish nutrition dramatically changed when the evolution of jaws transformed early

Fishes into efficient predators.

Most modern fishes are predators and spend much of their life searching for food. Their prey vary

Tremendously. Some fishes feed on invertebrate animals floating or swimming in the plankton or

Living in or on the substrate. Many feed on other vertebrates. Similarly, the kinds of food that one

Fish eats at different times in its life varies. For example, as a larva, a fish may feed on plankton;

As an adult, it may switch to larger prey, such as annelids or smaller fish. Fishes usually swallow

Prey whole. Teeth capture and hold prey, and some fishes have teeth that are modified for crushing

The shells of molluscs or the exoskeletons of arthropods.

To capture prey, fishes often use the suction that closing the opercula and rapidly opening the

Mouth creates, which develops a negative pressure that sweeps water and prey inside the mouth.

Other feeding strategies have also evolved in fishes. Herring, paddlefishes, and whale sharks are

Filter feeders. Long gill processes, called gill rakers, trap plankton while the fish is swimming

Through the water with its mouth open (see figure 18.13b). Other fishes, such as carp, feed on a

Variety of plants and small animals. A few, such as the lamprey, are external parasites for at least

A portion of their lives. A few are primarily herbivores, feeding on plants. The fish digestive tract

Is similar to that of other vertebrates.

An enlargement, called the stomach, stores large, often infrequent, meals. The small intestine,

However, is the primary site for enzyme secretion and food digestion. Sharks and other

Elasmobranchs have a spiral valve in their intestine, and bony fishes possess outpockets of the

Intestine, called pyloric ceca, which increase absorptive and secretory surfaces.

Lesson 26

Circulation

All vertebrates have a closed circulatory system in which a heart pumps blood, with red blood cells

Containing hemoglobin, through a series of arteries, capillaries, and veins. The evolution of lungs

In fishes was paralleled by changes in vertebrate circulatory systems. These changes are associated

With the loss of gills, delivery of blood to the lungs, and separation of oxygenated and

Un-oxygenated blood in the heart. The vertebrate heart develops from four embryological

Enlargements of a ventral aorta. In fishes, blood flows from the venous system through the sinus

Venosus, the atrium, the ventricle, the conus arteriosus, and into the ventral aorta (figure 18.15a).

Five afferent vessels carry blood to the gills, where the vessels branch into capillaries. Blood is

Collected by efferent vessels, delivered to the dorsal aorta, and distributed to the body. Even though

Lungfishes are not a transitional group, they provide a good example of how lungs alter the

Circulatory pattern.

Circulation to gills continues, but a vessel to the lungs has developed as a branch off aortic arch

VI (figure 18.15b). This vessel is now called the pulmonary artery. Blood from the lungs returns

To the heart through pulmonary veins and enters the left side of the heart. The atrium and ventricle

Of the lungfish heart are partially divided. These partial divisions help keep unoxygenated blood

From the body separate from the oxygenated blood from the lungs. A spiral valve in the conus

Arteriosus helps direct blood from the right side of the heart to the pulmonary artery and blood

From the left side of the heart to the remaining aortic arches.

Thus, the lungfishes show a distinction between a pulmonary circuit and a systemic circuit.

Figure 18.15: Circulatory System of Fishes. Diagrammatic representation of the circulatory

Systems of (a) bony fishes and (b) lungfishes. Hearts are drawn from a ventral view. Major

Branches of arteries carrying blood to and from the gills are called branchial arteries (or

Embryologically, aortic arches) and are numbered with Roman numerals. They begin with II

Because aortic arch I is lost during embryological development.

Lesson 27

Gas Exchange

Fishes live in an environment that contains less than 2.5% of the oxygen present in air. To maintain

Adequate levels of oxygen in their bloodstream, fishes must pass large quantities of water across

Gill surfaces and extract the small amount of oxygen present in the water.

Most fishes have a muscular pumping mechanism to move the water into the mouth and pharynx,

Over the gills, and out of the fish through gill openings. Muscles surrounding the pharynx and the

Opercular cavity, which is between the gills and the operculum, power this pump. Some

Elasmobranchs and open-ocean bony fishes, such as the tuna, maintain water flow by holding their

Mouths open while swimming. This method is called ram ventilation. Elasmobranchs do not have

Opercula to help pump water, and therefore, some sharks must keep moving to survive. Others

Move water over their gills with a pumping mechanism similar to that just described. Rather than

Using an operculum in the pumping process, however, these fishes have gill bars with external

Flaps that close and form a cavity functionally similar to the opercular cavity of other fishes.

Spiracles are modified pharyngeal slits that open just behind the eyes of elasmobranchs and are

Used as an alternate route for water entering the pharynx.

Gas exchange across gill surfaces is very efficient. Gill (visceral) arches support gills. Gill

Filaments extend from each gill arch and include vascular folds of epithelium, called pharyngeal

Lamellae (figure 18.16a,b). Branchial arteries carry blood to the gills and into gill filaments. The

Arteries break into capillary beds in pharyngeal lamellae. Gas exchange occurs as blood and water

Move in opposite directions on either side of the lamellar epithelium. This countercurrent exchange

Mechanism provides very efficient gas exchange by maintaining a concentration gradient between

The blood and the water over the entire length of the capillary bed (figure 18.16c,d).

Figure 18.16: Gas Exchange at the Pharyngeal Lamellae. (a) The gill arches under the operculum

Support two rows of gill filaments. Blood flows into gill filaments through afferent branchial

Arteries, and these arteries break into capillary beds in the pharyngeal lamellae. Water and blood

Flow in opposite directions on either side of the lamellae. (b) Electron micro-graph of the tip of a

Trout gill filament, showing numerous lamellae. (c, d) A comparison of countercurrent and parallel

Exchanges. Water entering the spaces between pharyngeal lamellae is saturated with oxygen in

Both cases. In countercurrent exchange ©, this water encounters blood that is almost completely

Oxygenated, but a diffusion gradient still favors the movement of more oxygen from the water to

The blood. As water continues to move between lamellae, it loses oxygen to the blood because it is

Continually encountering blood with a lower oxygen concentration. Thus, a diffusion gradient is

Maintained along the length of the lamellae. If blood and water moved in parallel fashion (d),

Oxygen would diffuse from water to blood only until the oxygen concentration in blood equaled

The oxygen concentration in water, and the exchange would be much less efficient.

Lesson 28

Swim Bladders and Lungs

The Indian climbing perch spends its life almost entirely on land. These fishes, like most bony

Fishes, have gas chambers called pneumatic sacs. In nonteleost fishes and some teleosts, a

Pneumatic duct connects the pneumatic sacs to the esophagus or another part of the digestive tract.

Swallowed air enters these sacs, and gas exchange occurs across vascular surfaces. Thus, in the

Indian climbing perch, lungfishes, and ancient rhipidistians, pneumatic sacs function(ed) as lungs.

In other bony fishes, pneumatic sacs act as swim bladders.

Most zoologists believe that lungs are more primitive than swim bladders. Much of the early

Evolution of bony fishes occurred in warm, freshwater lakes and streams during the Devonian

Period. These bodies of water frequently became stagnant and periodically dried. Having lungs in

These habitats could have meant the difference between life and death. On the other hand, later

Evolution of modern bony fishes occurred in marine and freshwater environments, where

Stagnation was not a problem. In these environments, the use of pneumatic sacs in buoyancy

Regulation would have been adaptive (figure 18.17).

Buoyancy Regulation

Fishes maintain their vertical position in a column of water in one or more of four ways. One way

Is to incorporate low-density compounds into their tissues. Fishes (especially their livers) are

Saturated with buoyant oils. A second way fishes maintain vertical position is to use fins to provide

Lift. The pectoral fins of a shark are planing devices that help to create lift as the shark moves

Through the water. Also, the large upper lobe of a shark's caudal fin provides upward thrust for the

Posterior end of the body (see figure 18.9a). A third adaptation is the reduction of heavy tissues in

Fishes. The bones of fishes are generally less dense than those of terrestrial vertebrates. One of the

Adaptive features of the elasmobranch cartilaginous skeleton probably results from cartilage being

Only slightly heavier than water. The fourth adaptation is the swim bladder. A fish regulates

Buoyancy by precisely controlling the volume of gas in its swim bladder.

The pneumatic duct connects the swim bladders of garpike, sturgeons, and other primitive bony

Fishes to the esophagus or another part of the digestive tract. These fishes gulp air at the surface to

Force air into their swim bladders.

Most teleosts have swim bladders that have lost a functional connection to the digestive tract. The

Blood secretes gases (various mixtures of nitrogen and oxygen) into the swim bladder using a

Countercurrent exchange mechanism in a vascular network called the rete mirabile ("miraculous

Net"). Gases may be reabsorbed into the blood at the posterior end of the bladder, the ovale (see

Figure 18.17c).

Figure 18.17: Possible Sequence in the Evolution of Pneumatic Sacs. (a) Pneumatic sacs may have originally

Developed from ventral outgrowths of the esophagus. Many ancient fishes probably used pneumatic sacs

As lungs. (b) Primitive lungs developed further during the evolution of vertebrates. Internal compart-

Mentalization increases surface area for gas exchange in land vertebrates. © In most bony fishes,

Pneumatic sacs are called swim bladders, and they are modified for buoyancy regulation. Swim bladders

Are dorsal in position to prevent a tendency for the fish to “belly up” in the water. Pneumatic duct

Connections to the esophagus are frequently lost, and gases transfer from the blood to the swim bladder

Through a countercurrent exchange mechanism called a rete mirabile. The ovale, at the posterior end of

The swim bladder, returns gases to the bloodstream.

Lesson 29

Nervous system and sensory function

The central nervous system of fishes, as in other vertebrates, consists of a brain and a spinal cord.

Sensory receptors are widely distributed over the body. In addition to generally distributed

Receptors for touch and temperature, fishes possess specialized receptors for olfaction, vision,

Hearing, equilibrium and balance, and for detecting water movements. Openings, called external

Nares, in the snouts of fishes lead to olfactory receptors. In most fishes, receptors are in blind-

Ending olfactory sacs. In a few fishes, the external nares open to nasal passages that lead to the

Mouth cavity. Recent research has revealed that some fishes rely heavily on their sense of smell.

For example, salmon and lampreys return to spawn in the streams in which they hatched years

Earlier. Their migrations to these streams often involve distances of hundreds of kilometers, and

The fishes' perception of the characteristic odors of their spawning stream guide them. The eyes of

Fishes are similar in most aspects of structure to those in other vertebrates. They are lidless,

However, and the lenses are round. Focusing requires moving the lens forward or backward in the

Eye. (Most other vertebrates focus by changing the shape of the lens.) Receptors for equilibrium,

Balance, and hearing are in the inner ears of fishes, and their functions are similar to those of other

Vertebrates. Semicircular canals detect rotational movements, and other sensory patches help with

Equilibrium and balance by detecting the direction of the gravitational pull. Fishes lack the outer

And/or middle ear, which conducts sound waves to the inner ear in other vertebrates. Anyone who

Enjoys fishing knows, however, that most fishes can hear. Vibrations may pass from the water

Through the bones of the skull to the middle ear, and a few fishes have chains of bony ossicles

(modifications of vertebrae) that connect the swim bladder to the back of the skull. Vibrations

Strike the fish, are amplified by the swim bladder, and sent through the ossicles to the skull.

Running along each side and branching over the head of most fishes is a lateral-line system. The

Lateral-line system consists of sensory pits in the epidermis of the skin that connect to canals that

Run just below the epidermis. In these pits are receptors that are stimulated by water moving against

Them. Lateral lines are used to detect either water currents, or a predator or a prey that may be

Causing water movements, in the vicinity of the fish. Fishes may also detect low-frequency sounds

With these receptors.

Electric Fishes

A U.S. Navy pilot has just ejected from his troubled aircraft over shark-infested water! What

Measures can the pilot take to ensure survival under these hostile conditions? The Navy has

Considered this scenario. One of the solutions to the problem is a polyvinyl bag suspended from

An inflatable collar. The polyvinyl bag helps conceal the downed flyer from a shark's vision and

Keen sense of smell. But is that all that is required to ensure protection? All organisms produce

Weak electrical fields from the activities of nerves and muscles. Electroreception is the detection

Of electrical fields that the fish or another organism in the environment generates. Electroreception

And/or electrogeneration has been demonstrated in over five hundred species of fishes in seven

Families of Chondrichthyes and Osteichthyes. These fishes use their electroreceptive sense for

Detecting prey and for orienting toward or away from objects in the environment. Nowhere is prey

Detection with this sense better developed than in the rays and sharks. Spiny dogfish sharks, the

Common laboratory specimens, locate prey by electroreception. A shark can find and eat a flounder

That is buried in sand, and it will try to find and eat electrodes that are creating electrical signals

Similar to those that the flounder emits. On the other hand, a shark cannot find a dead flounder

Buried in the sand or a live flounder covered by an insulating polyvinyl sheet.

Some fishes are not only capable of electroreception, but can also generate electrical currents. An

Electric fish (*Gymnarchus niloticus*) lives in freshwater systems of Africa. Muscles near its caudal

Fin are modified into organs that produce a continuous electrical discharge. This current spreads

Between the tail and the head. Porelike perforations near the head contain electroreceptors. The

Electrical waves circulating between the tail and the head are distorted by objects in their field.

This distortion is detected in changing patterns of receptor stimulation.

The electrical sense of *Gymnarchus* is an adaptation to living in murky freshwater habitats where

Eyes are of limited value. The fishes best known for producing strong electrical currents are the

Electric eel (a bony fish) and the electric ray (an elasmobranch). The electric eel (*Electrophorus*)

Occurs in rivers of the Amazon basin in South America. The organs for producing electrical

Currents are in the trunk of the electric eel and can deliver shocks in excess of 500 volts. The

Electric ray (*Narcine*) has electric organs in its fins that are capable of producing pulses of 50

Amperes at about 50 volts. Shocks that these fishes produce are sufficiently strong to stun or kill

Prey, discourage large predators, and teach unwary humans a lesson that will never need to be

Repeated.

Lesson 30 and 31

Excretion and osmoregulation

Fishes, like all animals, must maintain a proper balance of electrolytes (ions) and water in their

Tissues. This osmoregulation is a major function of the kidneys and gills of fishes. Kidneys are

Located near the midline of the body, just dorsal to the peritoneal membrane that lines the body

Cavity. As with all vertebrates, the excretory structures in the kidneys are called nephrons.

Nephrons filter bloodborne nitrogenous wastes, ions, water, and small organic compounds across

A network of capillaries called a glomerulus. The filtrate then passes into a tubule system, where

Essential components may be reabsorbed into the blood. The filtrate remaining in the tubule

System is then excreted. Freshwater fishes live in an environment containing few dissolved

Substances. Osmotic uptake of water across gill, oral, and intestinal surfaces and the loss of

Essential ions by excretion and defecation are constant. To control excess water buildup and ion



Loss, freshwater fishes never drink and only take in water when feeding. Also, the numerous

Nephrons of freshwater fishes frequently possess large glomeruli and relatively short tubule

Systems.

Reabsorption of some ions and organic compounds follows filtration. Because the tubule system

Is relatively short, little water is reabsorbed. Thus, freshwater fishes produce large quantities of

Very dilute urine. Ions are still lost, however, through the urine and by diffusion across gill and

Oral surfaces. Active transport of ions into the blood at the gills compensates for this ion loss. Fresh

Water fishes also get some salts in their food (figure 18.20a).

Marine fishes face the opposite problems. Their environment contains 3.5% ions, and their tissues

Contain approximately 0.65% ions. Marine fishes, therefore, must combat water loss and

Accumulation of excess ions. They drink water and eliminate excess ions by excretion, defecation,

And active transport across gill surfaces. The nephrons of marine fishes frequently possess small

Glomeruli and long tubule systems. Much less blood is filtered than in freshwater fishes, and water

Is efficiently, although not entirely, reabsorbed from the nephron (figure 18.20b). Elasmobranchs

Have a unique osmoregulatory mechanism. They convert some of their nitrogenous wastes into

Urea in the liver. This in itself is somewhat unusual, because most fishes excrete ammonia rather

Than urea. Even more unusual, however, is that urea is sequestered in tissues all over the body.

Enough urea is stored to make body tissues isosmotic with seawater. (That is, the concentration of

Solutes in a shark's tissues is essentially the same as the concentration of ions in seawater.)

Therefore, the problem most marine fishes have of losing water to their environment is much less

Severe for elasmobranchs. Energy that does not have to be devoted to water conservation can now

Be used in other ways.

This adaptation required the development of tolerance to high levels of urea, because urea disrupts

Important enzyme systems in the tissues of most other animals. In spite of this unique adaptation,

Elasmobranchs must still regulate the ion concentrations in their tissues. In addition to having ion-

Absorbing and secreting tissues in their gills and kidneys, elasmobranchs possess a rectal gland

That removes excess sodium chloride from the blood and excretes it into the cloaca. (A cloaca is a

Common opening for excretory, digestive, and reproductive products.) Diadromous fishes migrate

Between freshwater and marine environments. Salmon (e.g., *Oncorhynchus*) and marine lampreys

(*Petromyzon*) migrate from the sea to freshwater to spawn, and the freshwater eel (*Anguilla*)

Migrates from freshwater to marine environments to spawn. Diadromous migrations require gills

Capable of coping with both uptake and secretion of ions. Osmoregulatory powers needed for

Migration between marine and freshwater environments may not be developed in all life-history

Stages. Young salmon, for example, cannot enter the sea until certain cells on the gills develop ion-

Secreting powers. Fishes have few problems getting rid of the nitrogenous by-products of protein

Metabolism. Up to 90% of nitrogenous wastes are eliminated as ammonia by diffusion across gill

Surfaces. Even though ammonia is toxic, aquatic organisms can have it as an excretory product

Because ammonia diffuses in the surrounding water. The remaining 10% of nitrogenous wastes are

Excreted as urea, creatine, or creatinine. These wastes are produced in the liver and are excreted

Via the kidneys.

FIGURE 18.20

Osmoregulation by (a) Freshwater and (b) Marine Fishes. Large arrows indicate passive uptake or

Loss of water or electrolytes (ions) through ingestion and excretion. Small, solid arrows indicate

Active transport processes at gill membranes and kidney tubules. Small, open arrows indicate

Passive uptake or loss by diffusion through permeable surfaces. Insets of kidney nephrons depict

Adaptations within the kidney. Water, ions, and small organic molecules are filtered from the blood

At the glomerulus of the nephron. Essential components of the filtrate can be reabsorbed within the



Lesson 32 and 33

REPRODUCTION AND DEVELOPMENT

Producing overwhelming numbers of eggs, however, is not the only way that fishes increase the

Chances that a few of their will survive. Some fishes show mating behavior that helps ensure

Fertilization, or nesting behavior that protects eggs from predation, sedimentation, and fouling.

Mating may occur in large schools, and one individual releasing eggs or sperm often releases

Spawning pheromones that induce many other adults to spawn. Huge masses of eggs and sperm

Released into the open ocean ensure the fertilization of many eggs. The vast majority of fishes are

Oviparous, meaning that eggs develop outside the female from stored yolk. Some elasmobranchs

Are ovoviviparous, and their embryos develop in a modified oviduct of the female. Nutrients are

Supplied from yolk stored in the egg. Other elasmobranchs, including gray reef sharks and

Hammerheads, are viviparous. A placenta-like outgrowth of a modified oviduct diverts nutrients

From the female to the yolk sacs of developing embryos. Internal development of viviparous bony

Fishes usually occurs in ovarian follicles, rather than in the oviduct. In guppies (*Lebistes*), eggs are

Retained in the ovary, and fertilization and early development occur there. Embryos are then

Released into a cavity within the ovary and development continues, with nourishment coming

Partly from yolk and partly from ovarian secretions.

Some fishes have specialized structures that aid in sperm transfer. Male elasmobranchs, for

Example, have modified pelvic fins called claspers. During copulation, the male inserts a clasper

Into the cloaca of a female. Sperm travel along grooves of the clasper. Fertilization occurs in the

Female's reproductive tract and usually results in a higher proportion of eggs being fertilized than

In external fertilization. Thus, fishes with internal fertilization usually produce fewer eggs.

In many fishes, care of the embryos is limited or nonexistent. Some fishes, however, construct and

Tend nests, and some carry embryos during development. Clusters of embryos may be brooded in

Special pouches attached to some part of the body, or they may be brooded in the mouth. Some of

The best-known brooders include the seahorses (*Hippocampus*) and pipefishes (e.g., *Syngnathus*).

Males of these closely related fishes carry embryos throughout development in ventral pouches.

The male Brazilian catfish (*Loricaria typhys*) broods embryos in an enlarged lower lip. Most fishes

Care little, if at all, for young after hatching. Sunfishes and sticklebacks, however, provide short-

Term care of posthatching young. Male sticklebacks assemble fresh plant material into a mass in

Which the young take refuge. If one offspring wanders too far from the nest, the male snaps it up

In its mouth and spits it back into the nest. Sunfish males do the same for young that wander from

Schools of recently hatched fish. The Cichlidae engage in longer-term care. In some species, young

Are mouth brooded, and other species tend young in a nest. After hatching, the young venture from

The parent's mouth or nest but return quickly when the parent signals danger with a flicking of the

Pelvic fins.

Lesson no 34

General Characteristics of Amphibians

1. Amphibians are cold blooded vertebrates which can live on land and in water.

2. Amphibians show four limbs with which they can swim in water and jump or walk

On the land, (But in apoda limbs are absent.)

3. In Amphibians animals exoskeleton is absent. But in apoda animals small cycloid

Scales are present.

4. In Amphibians the adult animals lungs are present. Gills are absent. But In some

Urodelans the gills are present.

5. Amphibians Skin is a respiratory organ.

6. The Amphibians skull is dicondylic.

7. Amphibians Ribs are absent.

8. In Amphibians The body divisible into head and trunk Tail is present in, urodela

Animals.

9. Amphibians Digestive system is well developed. A well developed liver is present

10. External ear is absent. Middle and inner ears are present, the middle ear columella

Auris is present.

11. Amphibians Heart is 3 chambered with 2 auricles and 1 ventricle The blood

Contains R.B.C. They are nucleated. They contain hemoglobin.

12. Blood vascular system contains hepatic and renal portal systems.

13. Amphibians Kidneys are mesonephric. Urinary bladder is present. It stores urine.

14. Central nervous system is well developed. The brain occupies completely the

Cranial cavity. The brain is divided into fore, mid and hind brains. Brain continuous

As spinal cord.

15. 10 pairs of cranial nerves will arise.

16. Sexes are separate.

17. Male and female can be identified – Sexual dimorphism.

18. In Amphibians the life history a larva stage may be present.

19. Amphibian Eggs are telolecithal, Cleavage is holoblastic unequal.

Lesson no 35

Phylogenetic relationships

During the first 250 million years of vertebrate history, adaptive radiation resulted in vertebrates

Filling most aquatic habitats. Prehistoric waters contained many active, powerful predators. Land,

However, was free of vertebrates and, except for some arthropods, was free of predators. Animals

That moved around the water's edge were not likely to be prey for other animals. With lungs for

Breathing air and muscular fins for scurrying across mud, these animals probably found ample food

In the arthropods that lived there. The major component of the diet of most modern amphibians is

Arthropods.

Adaptive radiation of amphibians resulted in a much greater variety of forms than exists today.

Later convergent and parallel evolution and widespread extinction clouded evolutionary pathways.

No one knows, therefore, what animal was the first amphibian, but the structure of limbs, skulls,

And teeth suggests that Ichthyostega is probably similar to the earliest amphibians (figure 19.2).

Two lineages of early amphibians from the late Devonian and early Carboniferous periods can be

Distinguished by how the roof and the posterior portion of the skull attach to each other. One

Lineage of amphibians became extinct late in the Carboniferous period. An amniotic egg that

Resisted drying evolved in this group. This lineage, called the amniote lineage, left as its

Descendants the reptiles, birds, and mammals (figure 19.3). A second lineage flourished into the

Jurassic period. Most of this lineage became extinct, but not before giving rise to the three orders

Of living amphibians. This lineage is called the nonamniote lineage.

Ichthyostega: An Early Amphibian. Fossils of this early amphibian were discovered in eastern

Greenland in late Devonian deposits. The total length of the restored specimen is about 65 cm.

Terrestrial adaptations are heavy pectoral and pelvic girdles and sturdy limbs that probably helped

Lift the body off the ground. Strong jaws suggest that it was a predator in shallow water, perhaps

Venturing onto shore. Other features include a skull that is similar in structure to ancient

Sarcopterygian fishes and a finlike tail. Note that bony rays dorsal to the spines of the vertebrae



Support the tail fin. This pattern is similar to the structure of the dorsal fins of fishes and is unknown

In any other tetrapod

Evolutionary Relationships among the Amphibians. Earliest amphibians arose during the

Devonian period. A nonamniotic lineage gave rise to three classes of modern amphibians and

Numerous extinct taxa. Some zoologists think that the class Amphibia is a paraphyletic group. If

This is true, the three modern classes should be represented as monophyletic taxa. The amniotic

Lineage of early tetrapods gave rise to reptiles, birds, mammals, and other extinct taxa. Daggers (†)

Indicate extinct taxa. Synapomorphic characters for lower taxonomic groups are not indicated.

Lesson no 36

Classification of Amphibians

Sub class Stegocephali

They are extinct species, Pentadactyl limbs and skin with scales and bony plates

Order Labyrinthodontia

They are primitive amphibians, also known as “Stem Amphibia”. Their teeth large with folded

Dentine same as crossoptergian (fishes) E.g. Eryops (Extinct).

Order Phyllospondyli

They are small Salamander like, notochord and spinal cord housed in common cavity E.g,

Branchiosaurs

Order Lepospondyli

They are Small eel like vertebrae of single piece. Neural arch and centrum is continuous. For

Example Diplocaulus (Extinct)

Subclass Lissamphibia

These are modern Amphibia. No scales are present. Teeth are small and simple

Order Apoda

This order is also known as Gymnophiona. No limbs or limb girdles are present. These are Blind.

Wormlike, legless amphibians with indistinct or even hidden eyes. They have a series of annular

Grooves (annuli) are usually present along the length of the body, heightening the resemblance to

An earthworm. Most caecilians lead a burrowing existence, although members of one

Genus, Typhlonectes, are aquatic.

Some species have the eyes hidden beneath the bones of the skull and probably are blind, but others

At least are able to distinguish movement. A series of annular grooves (annuli) are usually present

Along the length of the body, heightening the resemblance to an earthworm. Most caecilians lead

A burrowing existence, although members of one genus, Typhlonectes, are aquatic. Some species

Have the eyes hidden beneath the bones of the skull and probably are blind, but others at least are

Able to distinguish movement. At larval stages they have teeth, are carnivores and have limbs

During most of their development. Further subdivided into five suborders. Cryptobranchoidea,

Salamandriodea, Ambystomatoidea, Proteidea, Meantes. E.g. Ambystoma, Siren

Order Gymnophiona. A caecilian (*Ichthyophis glutinosus*).

Order caudata

Members of the order Caudata (kawdat-ah) (L. cauda, tail Gr. Ata, to bear) are the salamanders.

They possess a tail throughout life, and both pairs of legs, when present, are relatively

Unspecialized (figure 19.4). Approximately 115 of the 350 described species of salamanders live

In North America. Most terrestrial salamanders live in moist forest-floor litter and have aquatic

Larvae. A number of families live in caves, where constant temperature and moisture conditions

Create a nearly ideal environment. Salamanders in the family Plethodontidae are the most fully

Terrestrial salamanders in that their eggs are laid on land, and the young hatch as miniatures of the

Adult. Members of the family Salamandridae are commonly called newts. They spend most of their

Lives in water and frequently retain caudal fins. Salamanders range in length from only a few

Centimeters to 1.5 m (the Japanese giant salamander, *Andrias japonicus*). The largest North

American salamander is the hellbender (*Cryptobranchus alleganiensis*), which reaches lengths of

About 65 cm. Most salamanders have internal fertilization. Males produce a pyramidal, gelatinous

Spermatophore that is capped with sperm and deposited on the substrate. Females pick up the sperm

Cap with the cloaca and store the sperm in a special pouch, the spermatheca. Eggs are fertilized as

They pass through the cloaca and are usually deposited singly, in clumps, or in strings (figure

19.5a). Larvae are similar to adults but smaller. They often possess external gills, a tail fin, larval

Dentition, and a rudimentary tongue (figure 19.5b). The aquatic larval stage usually metamorphoses

Into a terrestrial adult (figure 19.5c). Many other salamanders undergo incomplete metamorphosis

And are paedomorphic (e.g., *Necturus*); that is, they become sexually mature while still showing

Larval characteristics.

Order Anura (Salientia)

Tail is absent in adult. Eyelids and tympanum present. Skin scaleless and loose. Further divided into

Five suborders; Amphicoela, Opisthocoela, Procoela, Diplasiocela. Examples are Frog and Toad. They

Have Shortened vertebral column (nine or fewer presacral vertebrae). Presence of a urostyle

Formed from developing tail vertebrae. Absence of tail in adults. Hind limb longer than forelimb.

Fusion of radius and ulna into a single element. Fusion of tibia and fibula into a single element.

Lesson no 37

External structure and locomotion

Vertebrate skin protects against infective microorganisms, ultraviolet light, desiccation,

And mechanical injury. As discussed later in this chapter, the skin of amphibians also

Functions in gas exchange, temperature regulation, and absorption and storage of water.

Amphibian skin lacks a covering of scales, feathers, or hair. It is, however, highly

Glandular, and its secretions aid in protection. These glands keep the skin moist to prevent

Drying. They also produce sticky secretions that help a male cling to a female during mating

And produce toxic chemicals that discourage potential predators. The skin of many

Amphibians is smooth, although epidermal thickenings may produce warts, claws, or

Sandpapery textures, which are usually the result of keratin deposits or the formation of

Hard, bony areas. Chromatophores are specialized cells in the epidermis and dermis of the

Skin that are responsible for skin color and color changes. Cryptic coloration, aposematic

Coloration, and mimicry are all common in amphibians.

Support and Movement Water buoys and supports aquatic animals. The skeletons of fishes

Function primarily in protecting internal organs, providing points of attachment for

Muscles, and keeping the body from collapsing during movement. In terrestrial vertebrates,

However, the skeleton is modified to provide support against gravity, and it must be strong

Enough to support the relatively powerful muscles that propel terrestrial vertebrates across

Land. The amphibian skull is flattened, is relatively smaller, and has fewer bony elements

Than the skull of fishes. These changes lighten the skull so it can be supported out of the

Water. Changes in jaw structure and musculature allow terrestrial vertebrates to crush prey

Held in the mouth. The vertebral column of amphibians is modified to provide support and

Flexibility on land (figure 19.8). It acts somewhat like the arch of a suspension bridge by

Supporting the weight of the body between anterior and posterior paired appendages.

Supportive processes called zygapophyses on each vertebra prevent twisting. Unlike fishes,

Amphibians have a neck. The first vertebra is a cervical vertebra, which moves against the

Back of the skull and allows the head to nod vertically. The last trunk vertebra is a sacral

Vertebra. This vertebra anchors the pelvic girdle to the vertebral column to provide

Increased support. A ventral plate of bone, called the sternum, is present in the anterior

Ventral trunk region and supports the forelimbs and protects internal organs. It is reduced

Or absent in the Anura. The origin of the bones of vertebrate appendages is not precisely

Known; however, similarities in the structures of the bones of the amphibian appendages

And the bones of the fins of ancient sarcopterygian fishes suggest possible homologies

(figure 19.9). Joints at the shoulder, hip, elbow, knee, wrist, and ankle allow freedom of

Movement and better contact with the substrate. The pelvic girdle of amphibians consists

Of three bones (the ilium, ischium, and pubis) that firmly attach pelvic appendages to the

Vertebral column. These bones, which are present in all tetrapods, but not fishes, are

Important for support on land.

Skeletons of Amphibians. (a) The salamander skeleton is divided into four regions: cervical,

Trunk, sacral, and caudal. (b) Interlocking processes, called zygapophyses, prevent twisting

Between vertebrae. © A frog skeleton shows adaptations for jumping. Note the long back legs

And the firm attachment of the back legs to the vertebral column through the ilium and urostyle.

Origin of Tetrapod Appendages. A comparison of (a) the fin bones of a rhipidistian and (b) the

Limb bones of a tetrapod suggests that the basic bone arrangements in tetrapod limbs were already

Present in primitive fishes.

Tetrapods depend more on appendages than the body wall for locomotion. Thus, body-wall

Musculature is reduced, and appendicular musculature predominates. (Contrast, for example, what

You eat in a fish dinner as compared to a plate of frog legs.) Salamanders employ a relatively

Unspecialized form of locomotion that is reminiscent of the undulatory waves that pass along the

Body of a fish. Terrestrial salamanders also move by a pattern of limb and body movements in

Which the alternate movement of appendages results from muscle contractions that throw the body

Into a curve to advance the stride of a limb (figure 19.10). Caecilians have an accordion-like

Movement in which adjacent body parts push or pull forward at the same time. The long hindlimbs

And the pelvic girdle of anurans are modified for jumping. The dorsal bone of the pelvis (the ilium)

Extends anteriorly and securely attaches to the vertebral column, and the urostyle extends

Posteriorly and attaches to the pelvis (see figure 19.8). These skeletal modifications stiffen the

Posterior half of the anuran. Long hindlimbs and powerful muscles form an efficient lever system

For jumping. Elastic connective tissues and muscles attach the pectoral girdle to the skull and

Vertebral column, and function as shock absorbers for landing on the forelimbs.

Salamander Locomotion. Pattern of leg movement in salamander locomotion. Blue arrows show

Leg movements.

Lesson no 38

NUTRITION AND THE DIGESTIVE SYSTEM

Most adult amphibians are carnivores that feed on a wide variety of invertebrates. The diets of

Some anurans, however, are more diverse. For example, a bullfrog will prey on small mammals,

Birds, and other anurans. The main factors that determine what amphibians will eat are prey size

And availability. Most larvae are herbivorous and feed on algae and other plant matter. Most

Amphibians locate their prey by sight and simply wait for prey to pass by. Olfaction plays an

Important role in prey detection by aquatic salamanders and caecilians. Many salamanders are

Relatively unspecialized in their feeding methods, using only their jaws to capture prey. Anurans

And plethodontid salamanders, however, use their tongue and jaws in a flip-and-grab feeding

Mechanism (figure 19.11). A true tongue is first seen in amphibians. (The “tongue” of fishes is

Simply a fleshy fold on the floor of the mouth. Fish food is swallowed whole and not manipulated

By the “tongue”.) The amphibian tongue attaches at the anterior margin of the jaw and folds back

Over the floor of the mouth. Mucous and buccal glands on the tip of the tongue exude sticky

Secretions. When prey comes within range, an amphibian lunges forward and flicks out its tongue.

The tongue turns over, and the lower jaw is depressed. The head tilts on its single cervical vertebra,

Which helps aim the strike. The tip of the tongue entraps the prey, and the tongue and prey are

Flicked back inside the mouth. All of this may happen in 0.05 to 0.15 second! The amphibian holds

The prey by pressing it against teeth on the roof of the mouth, and the tongue and other muscles of

The mouth push food toward the esophagus. The eyes sink downward during swallowing and help

Force food toward the esophagus.

Lesson no 39

CIRCULATION, GAS EXCHANGE, AND TEMPERATURE REGULATION

The circulatory system of amphibians shows remarkable adaptations for a life divided between

Aquatic and terrestrial habitats. The separation of pulmonary and systemic circuits is less efficient

In amphibians than in lungfishes (figure 19.12; see also figure 18.15b). The atrium is partially

Divided in urodeles and completely divided in anurans. The ventricle has no septum. A spiral valve

In the conus arteriosus or ventral aorta helps direct blood into pulmonary and systemic circuits. As

Discussed later, gas exchange occurs across the skin of amphibians, as well as in the lungs.

Therefore, blood entering the right side of the heart is nearly as well oxygenated as blood entering

The heart from the lungs! When an amphibian is completely submerged, all gas exchange occurs

Across the skin and other moist surfaces; therefore, blood coming into the right atrium has a higher

Oxygen concentration than blood returning to the left atrium from the lungs.

Circulatory System of Fishes. Diagrammatic representation of the circulatory systems of (a) bony

Fishes and (b) lungfishes. Hearts are drawn from a ventral view. Major branches of arteries carrying

Blood to and from the gills are called branchial arteries (or embryologically, aortic arches) and are

Numbered with Roman numerals. They begin with II because aortic arch I is lost during

Embryological development.

Diagrammatic Representation of an Anuran Circulatory System. (a) The Roman numerals indicate

The various aortic arches. Vessels shown in dashed outline are lost during embryological

Development. (b) A ventral view of the heart

Under these circumstances, blood vessels leading to the lungs constrict, reducing blood flow to the

Lungs and conserving energy. This adaptation is especially valuable for those frogs and

Salamanders that overwinter in the mud at the bottom of a pond. Adult amphibians have fewer

Aortic arches than fishes. After leaving the conus arteriosus, blood may enter the carotid artery

(aortic arch III), which takes blood to the head; the systemic artery (aortic arch IV), which takes

Blood to the body; or the pulmonary artery (aortic arch VI). In addition to a vascular system that

Circulates blood, amphibians have a well-developed lymphatic system of blind-ending vessels that

Returns fluids, proteins, and ions filtered from capillary beds in tissue spaces to the circulatory

System. The lymphatic system also transports water absorbed across the skin. Unlike other

Vertebrates, amphibians have contractile vessels, called lymphatic hearts, that pump fluid through

The lymphatic system. Lymphatic spaces between body-wall muscles and the skin transport and

Store water absorbed across the skin.

Gas Exchange

Terrestrial animals expend much less energy moving air across gas exchange surfaces than do

Aquatic organisms because air contains 20 times more oxygen per unit volume than does water.

On the other hand, exchanges of oxygen and carbon dioxide require moist surfaces, and exposure

Of respiratory surfaces to air may result in rapid water loss. Anyone who has searched pond and

Stream banks for frogs knows that the skin of amphibians is moist. Amphibian skin is also richly

Supplied with capillary beds. These two factors permit the skin to function as a respiratory organ.

Gas exchange across the skin is called cutaneous respiration and can occur either in water or on

Land. This ability allows a frog to spend the winter in the mud at the bottom of a pond. In

Salamanders, 30 to 90% of gas exchange occurs across the skin. Gas exchange also occurs across

The moist surfaces of the mouth and pharynx. This buccopharyngeal respiration accounts for 1 to

7% of total gas exchange. Most amphibians, except for plethodontid salamanders, possess lungs

(figure 19.13a). The lungs of salamanders are relatively simple sacs. The lungs of anurans are

Subdivided, increasing the surface area for gas exchange. Pulmonary (lung) ventilation occurs by

A buccal pump mechanism. Muscles of the mouth and pharynx create a positive pressure to force

Air into the lungs (figure 19.13b–e).

Cutaneous and buccopharyngeal respiration have a disadvantage in that their contribution to total

Gas exchange is relatively constant. The quantity of gas exchanged across these surfaces cannot be

Increased when the metabolic rate increases. Lungs, however, compensate for this shortcoming.

As environmental temperature and activity increase, lungs contribute more to total gas exchange.

At 5° C, approximately 70% of gas exchange occurs across the skin and mouth lining of a frog. At

25° C, the absolute quantity of oxygen exchanged across external body surfaces does not change

Significantly, but because pulmonary respiration increases, exchange across skin and mouth

Surfaces accounts for only about 30% of total oxygen exchange. Amphibian larvae and some adults

Respire using external gills. Cartilaginous rods that form between embryonic pharyngeal slits

Support three pairs of gills. During metamorphosis, the gills are usually reabsorbed, pharyngeal

Slits close, and lungs become functional.

Temperature Regulation

Amphibians are ectothermic. (They depend on external heat sources to maintain body temperature

[see chapter 28.]) Any poorly insulated aquatic animal, regardless of how much metabolic heat it

Produces, loses heat as quickly as it is produced because of powerful heat-absorbing properties of

The water. Therefore, when amphibians are in water, they take on the temperature of their

Environment. On land, however, their body temperatures can differ from that of the environment.

Temperature regulation is mainly behavioral. Some cooling results from evaporative heat loss. In

Addition, many amphibians are nocturnal and remain in cooler burrows or under moist leaf litter

During the hottest part of the day. Amphibians may warm themselves by basking in the sun or on

Warm surfaces. Body temperatures may rise 10° C above the air temperature. Basking after a meal

Is common, because increased body temperature increases the rate of all metabolic reactions—

Including digestive functions, growth, and the fat deposition necessary to survive periods of

Dormancy. Amphibians' daily and seasonal environmental temperatures often fluctuate widely,

And therefore, amphibians have correspondingly wide temperature tolerances. Critical temperature

Extremes for some salamanders lie between

2 and 27°C, and for some anurans between 3 and 41° C.

Lesson no 40

NERVOUS AND SENSORY FUNCTIONS

The nervous system of amphibians is similar to that of other vertebrates. The brain of adult

Vertebrates develops from three embryological subdivisions. In amphibians, the forebrain contains

Olfactory centers and regions that regulate color change and visceral functions. The midbrain

Contains a region called the optic tectum that assimilates sensory information and initiates motor

Responses. The midbrain also processes visual sensory information. The hindbrain functions in

Motor coordination and in regulating heart rate and the mechanics of respiration. Many amphibian

Sensory receptors are widely distributed over the skin. Some of these are simply bare nerve endings

That respond to heat, cold, and pain. The lateral-line system is similar in structure to that found in

Fishes, and it is present in all aquatic larvae, aquatic adult salamanders, and some adult anurans.

Lateral-line organs are distributed singly or in small groups along the lateral and dorsolateral

Surfaces of the body, especially the head. These receptors respond to low-frequency vibrations in

The water and movements of the water relative to the animal. On land, however, lateral-line

Receptors are less important. Chemoreception is an important sense for many amphibians.

Chemoreceptors are in the nasal epithelium and the lining of the mouth, on the tongue, and over

The skin. Olfaction is used in mate recognition, as well as in detecting noxious chemicals and in

Locating food. Vision is one of the most important senses in amphibians because they are primarily



Sight feeders. (Caecilians are an obvious exception.) A number of adaptations allow the eyes of

Amphibians to function in terrestrial environments (figure 19.14). The eyes of some amphibians

(i.e., anurans and some salamanders) and well-developed depth perception necessary for capturing

Prey.

FIGURE 19.14 Amphibian Eye. Longitudinal section of the eye of the leopard frog, *Rana*

pipiens.

Other amphibians with smaller lateral eyes (some salamanders) lack binocular vision. The lower

Eyelid is movable, and cleans and protects the eye. Much of it is transparent and is called the

Nictitating membrane. When the eyeball retracts into the orbit of the skull, the nictitating

Membrane is drawn up over the cornea. In addition, orbital glands lubricate and wash the eye.

Together, eyelids and glands keep the eye free of dust and other debris. The lens is large and nearly

Round. It is set back from the cornea, and a fold of epithelium called the iris surrounds it. The iris

Can dilate or constrict to control the size of the pupil. Focusing, or accommodation, involves

Bending (refracting) light rays to a focal point on the retina. Light waves moving from air across

The cornea are refracted because of the change in density between the two media. The lens provides

Further refraction. Like the eyes of most tetrapods, the amphibian eye focuses on distant objects

When the eye is at rest. To focus on near objects, the protractor lentis muscle must move the lens

Forward (figure 19.14). Receptors called rods and cones are in the retina. Because cones are

Associated with color vision in some other vertebrates, their occurrence suggests that amphibians

Can distinguish between some wavelengths of light. The extent to which color vision is developed

Is unknown. The neuronal interconnections in the retina are complex and allow an amphibian to

Distinguish between flying insect prey, shadows that may warn of an approaching predator, and

Background movements, such as blades of grass moving with the wind. The auditory system of

Amphibians is clearly an evolutionary adaptation to life on land. It transmits both substrateborne

Vibrations and, in anurans, airborne vibrations. The ears of anurans consist of a tympanic

Membrane, a middle ear, and an inner ear. The tympanic membrane is a piece of integument

Stretched over a cartilaginous ring that receives airborne vibrations and transmits them to the

Middle ear, which is a chamber beneath the tympanic membrane. Abutting the tympanic membrane

Is a middle-ear ossicle (bone) called the stapes (columella), which transmits vibrations of the

Tympanic membrane into the inner ear (see figure 24.20). High-frequency (1,000 to 5,000 Hz)

Airborne vibrations are transmitted to the inner ear through the tympanic membrane. Low-

Frequency (100 to 1,000 Hz) substrateborne vibrations are transmitted through the front

Appendages and the pectoral girdle to the inner ear through a second ossicle, called the operculum.

Muscles attached to the operculum and stapes can lock either or both of these ossicles, allowing

An anuran to screen out either high- or low-frequency sounds. This mechanism is adaptive because

Anurans use low- and high-frequency sounds in different situations. Mating calls are high-

Frequency sounds that are of primary importance for only a part of the year (breeding season). At

Other times, low-frequency sounds may warn of approaching predators. Salamanders lack a

Tympanic membrane and middle ear. They live in streams, ponds, caves, and beneath leaf litter.

They have no mating calls, and the only sounds they hear are probably low-frequency vibrations

Transmitted through the substrate and skull to the stapes and inner ear. The sense of equilibrium

And balance is similar to that described for fishes in chapter 18. The inner ear of amphibians has

Semicircular canals that help detect rotational movements and other sensory patches that respond

To gravity and detect linear acceleration and deceleration.

Lesson no 41

Excretion and Osmoregulation

The kidneys of amphibians lie on either side of the dorsal aorta on the dorsal wall of the body

Cavity. A duct leads to the cloaca, and a storage structure, the urinary bladder, is a ventral

Outgrowth of the cloaca. The nitrogenous waste product that amphibians excrete is either ammonia

Or urea. Amphibians that live in freshwater excrete ammonia. It is the immediate end product of

Protein metabolism; therefore, no energy is expended converting it into other products. The toxic

Effects of ammonia are avoided because it rapidly diffuses into the surrounding water. Amphibians

That spend more time on land excrete urea that is produced from ammonia in the liver. Although

Urea is less toxic than ammonia, it still requires relatively large quantities of water for its excretion.

Unlike ammonia, urea can be stored in the urinary bladder. Some amphibians excrete ammonia

When in water and urea when on land. One of the biggest problems that amphibians face is

Osmoregulation. In water, amphibians face the same osmoregulatory problems as freshwater fishes.

They must rid the body of excess water and conserve essential ions. Amphibian kidneys produce



Large quantities of hypotonic urine, and the skin and walls of the urinary bladder transport Na,

Cl

And other ions into the blood. On land, amphibians must conserve water. Adult amphibians do not

Replace water by intentional drinking, nor do they have the impermeable skin characteristic of other

Tetrapods or kidneys capable of producing a hypertonic urine. Instead, amphibians limit water loss

By behavior that reduces exposure to desiccating conditions. Many terrestrial amphibians are

Nocturnal. During daylight hours, they retreat to areas of high humidity, such as under stones, or

In logs, leaf mulch, or burrows. Water lost on nighttime foraging trips must be replaced by water

Uptake across the skin while in the retreat. Diurnal amphibians usually live in areas of high

Humidity and rehydrate themselves by entering the water. Many amphibians reduce evaporative

Water loss by reducing the amount of body surface exposed to air. They may curl their bodies and

Tails into tight coils and tuck their limbs close to their bodies (figure 19.15a). Individuals may form

Closely packed aggregations to reduce overall surface area. Some amphibians have protective

Coverings that reduce water loss. Hardened regions of skin are resistant to water loss and may be

Used to plug entrances to burrows or other retreat openings to maintain high humidity in the retreat.

Other amphibians prevent water loss by forming cocoons that encase the body during long periods

Of dormancy. Cocoons are made from outer layers of the skin that detach and become

Parchmentlike. These cocoons open only at the nares or the mouth and, in experimental situations,

Reduce water loss 20 to 50% over noncocooned individuals (figure 19.15b). Paradoxically, the

Skin—the most important source of water loss—is also the most important structure for 

Rehydration. When an amphibian flattens its body on moist surfaces, the skin, especially in the

Ventral pelvic region, absorbs water. The skin's permeability, vascularization, and epidermal

Sculpturing all promote water reabsorption. Minute channels increase surface area and spread

Water over surfaces not necessarily in direct contact with water. Amphibians can also temporarily

Store water. Water accumulated in the urinary bladder and lymph sacs can be selectively

Reabsorbed to replace evaporative water loss. Amphibians living in very dry environments can

Store volumes of water equivalent to 35% of their total body weight.

Lesson no 42

REPRODUCTION, DEVELOPMENT, AND METAMORPHOSIS

Amphibians are dioecious, and ovaries and testes are located near the dorsal body wall.

Fertilization is usually external, and because the developing eggs lack any resistant coverings,

Development is tied to moist habitats, usually water. A few anurans have terrestrial nests that are

Kept moist by being enveloped in foam or by being located near the water and subjected to flooding.

In a few species, larval stages are passed in the egg membranes, and the immatures hatch into an

Adultlike body. The main exceptions to external fertilization in amphibians are the salamanders.

Only about 10% of all salamanders have external fertilization. All others produce spermatophores,

And fertilization is internal. Eggs may be deposited in soil or water or retained in the oviduct during

Development. All caecilians have internal fertilization, and 75% have internal development.

Amphibian development, which zoologists have studied extensively, usually includes larval stages

Called tadpoles. Amphibian tadpoles often differ from the adults in mode of respiration, form of

Locomotion, and diet. These differences reduce competition between adults and larvae. Interactions

Between internal (largely hormonal) controls and extrinsic factors determine the timing o

Reproductive activities. In temperate regions, temperature seems to be the most important



Environmental factor that induces physiological changes associated with breeding, and breeding

Periods are seasonal, occurring in spring and summer. In tropical regions, amphibian breeding

Correlates with rainy seasons. Courtship behavior helps individuals locate breeding sites and

Identify potential mates. It also prepares individuals for reproduction and ensures that eggs are

Fertilized and deposited in locations that promote successful development. Salamanders rely

Primarily on olfactory and visual cues in courtship and mating, whereas male vocalizations and

Tactile cues are important for anurans. Many species congregate in one location during times of

Intense breeding activity. Male vocalizations are usually species specific and function in the initial

Attraction and contact between mates. After that, tactile cues become more important. The male

Grasps the female—his forelimbs around her waist—so that they are oriented in the same direction,

And the male is dorsal to the female. This positioning is called amplexus and may last from 1 to 24

Hours (figure 19.16). During amplexus, the male releases sperm as the female releases eggs. Little

Is known of caecilian breeding behavior. Males have an intromittent organ that is a modification

Of the cloacal wall, and fertilization is internal.

Vocalization

Sound production is primarily a reproductive function of male anurans. Advertisement calls attract

Females to breeding areas and announce to other males that a given territory is occupied.

Advertisement calls are species specific, and the repertoire of calls for any one species is limited.

The calls may also help induce psychological and physiological readiness to breed. Females

Respond by making reciprocation calls to indicate receptiveness. Release calls inform a partner that

A frog is incapable of reproducing. Unresponsive females give release calls if a male attempts

Amplexus, as do males that have been mistakenly identified as female by another male. Distress

Calls are not associated with reproduction; either sex produces these calls in response to pain or

Being seized by a predator. The calls may be loud enough to cause a predator to release the frog.

The distress call of the South American jungle frog, *Leptodactylus pentadactylus*, is a loud scream

Similar to the call of a cat in distress. The sound-production apparatus of frogs consists of the

Larynx and its vocal cords. This laryngeal apparatus is well developed in males, who also possess

A vocal sac. In the majority of frogs, vocal sacs develop as a diverticulum from the lining of the

Buccal cavity (figure 19.17). Air from the lungs is forced over the vocal cords and cartilages of the

Larynx, causing them to vibrate. Muscles control the tension of the vocal cords and regulate the

Frequency of the sound. Vocal sacs act as resonating structures and increase the volume of the

Sound. The use of sound to attract mates is especially useful in organisms that occupy widely

Dispersed habitats and must come together for breeding. Because many species of frogs often

Converge at the same pond for breeding, finding a mate of the proper species could be chaotic.

Vocalizations help to reduce the chaos.

Lesson no 43

Parental Care

Parental care increases the chances of any one egg developing, but it requires large energy

Expenditures on the part of the parent. The most common form of parental care in amphibians is

Attendance of the egg clutch by either parent. Maternal care occurs in species with internal

Fertilization (predominantly salamanders and caecilians), and paternal care may occur in species

With external fertilization (predominantly anurans). It may involve aeration of aquatic eggs,

Cleaning and/or moistening of terrestrial eggs, protection of eggs from predators, or removal of

Dead and infected eggs. Eggs may be transported when development occurs on land. Females of

The genus *Pipa* carry eggs on their backs. Two species of *Rheobatrachus* were discovered in

Australia within the last 30 years. They have not been observed in the wild since the 1980s and

Are presumed extinct. *Rheobatrachus* females brooded tadpoles in their stomachs, and the young

Emerged from the females' mouths (figure 19.18)! Unfortunately, we will never know whether the

Female swallowed fertilized eggs and all development occurred in her stomach or whether she

Swallowed tadpoles. During brooding, the female's stomach expanded to fill most of her body

Cavity, and the stomach stopped producing digestive secretions. Viviparity and ovoviviparity occur

Primarily in salamanders and caecilians.

Metamorphosis

Metamorphosis is a series of abrupt structural, physiological, and behavioral changes that

Transform a larva into an adult. A variety of environmental conditions, including crowding and

Food availability, influence the time required for metamorphosis. Most directly, however,

Metamorphosis is under the control of neurosecretions of the hypothalamus, hormones of the

Anterior lobe of the pituitary gland (the adenohypophysis), and the thyroid gland. Morphological

Changes associated with the metamorphosis of caecilians and salamanders are relatively minor.

Reproductive structures develop, gills are lost, and a caudal fin (when present) is lost. In the Anura,

However, changes from the tadpole into the small frog are more dramatic (figure 19.19). Limbs

And lungs develop, the tail is reabsorbed, the skin thickens, and marked changes in the head and

Digestive tract (associated with a new mode of nutrition) occur. The mechanics of metamorphosis

Explain paedomorphosis in amphibians. Some salamanders are paedomorphic because cells fail to

Respond to thyroid hormones, whereas others are paedomorphic because they fail to produce the

Hormones associated with metamorphosis. In some salamander families, paedomorphosis is the

Rule. In other families, the occurrence of paedomorphosis is variable and influenced by

Environmental conditions. That amphibians require. Mining, drilling, industrial and agricultural

Operations, and urban sprawl also destroy habitat. Amphibian populations are disappearing,

However, from vast areas of the earth, often in regions where local damage has not occurred. Two

Additional culprits seem to be partly responsible for the decline of amphibian populations—acid

Deposition and ultraviolet radiation (see chapter 6). Amphibian embryos are especially susceptible

To changes in the pH of their watery environment. A pH of 5 or less will kill most embryos. In the

Northern hemisphere, it is estimated that environments are 100 times more acidic than they were

Before the Industrial Revolution. Ultraviolet radiation, especially in the 280 to 320 nm range (UV-

B), also kills amphibian eggs and embryos. Pollutants that contribute to acid deposition and deplete

The ozone shield of the earth may be partly responsible for the alarming reductions in amphibian

Populations. None of these explanations account for all problems with amphibian populations.

Even in remote tropical regions, where none of these problems exist, amphibian populations are

Experiencing similar declines. The causes are unknown. It is imperative that the world's

Governments and funding agencies make funds available to help scientists discover the causes and

Reverse this alarming trend.