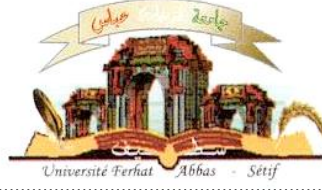


الجمهورية الجزائرية الديمقراطية الشعبية
وزارة التعليم العالي و البحث العلمي

Université Ferhat Abbas Sétif 1
Faculté des Sciences de la
Nature et de la Vie



جامعة فرحات عباس، سطيف 1
كلية علوم الطبيعة و الحياة

DEPARTEMENT OF BASIC STUDIES

POLYCOPIED

COURS « ZOOLOGY »

(2^{ME} YEAR BIOLOGY LICENSE LMD)

(BASIC STUDIES)

Presented by :

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Academic Year: 2024/2025

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Introduction :

The science of biology encompasses the sum of human knowledge concerning organisms. The branch of biology dealing with animals is known as zoology; that dealing with plants, as botany. Zoology can be defined as the body of facts and doctrines derived from the scientific study of animals.

A scientific study requires precise and meticulous observation with a definite goal in mind; the scientific study of zoology attempts to understand the structure and activities of animals. It is concerned not only with animals themselves, but also with their relationships to the organic and inorganic elements of the world.

This handout aims to observe animals in their ecosystems, analyze their relationships with the environment, their behaviors, and their nutrition. It contributes to projects for the protection of one or more species, potentially alerting public authorities to the danger of animal extinction.

Therefore, this handout aims to provide students, whether they are destined for research or biodiversity management, with the necessary foundations of phylogeny, biology, and morphological identification of the main animal groups.

I. Presentation of the Animal Kingdom

1. Definition

Zoology (Zoo = animal, logos = study)

Zoology is the science that studies the animal kingdom. It is a science that utilizes the findings of several disciplines: general anatomy, comparative anatomy, histology, physiology, embryology, paleontology, ecology, and genetics.

Taxonomy (or taxinomy): Is the science of biological classification and the development of its laws, based on systematic knowledge. It includes the classification, nomenclature, and identification of specimens.

Systematics: Is the arrangement of organisms into groups or taxa according to their similarity or evolutionary relationship, in a coherent system.

Nomenclature: Is the branch of taxonomy concerned with assigning names to taxonomic units, according to strict rules (International Code).

Identification (or determination): Is the practical application of taxonomy to find the identity of a biological sample and recognize its belonging to an already described taxon.

Individual: An individual is a functional biological system that can be unicellular or composed of numerous cells, which can be grouped into tissues and organs..

Species : A species is a group of individuals differentiated from others by a characteristic property, called the "specific difference," which distinguishes the multiple species within the same genus.

Genus : Is a set constituted of sets united by a common property. The elements of the genus are the species..

2. Bases of classification

The animal kingdom includes a multitude of living beings of different appearance (morphology) and constitution (internal anatomy, histology, biochemistry, ...). In the 16th century, each of these forms is called by a long phrase describing its external appearance. The first foundations of taxonomy or taxinomy (taxis = rule; science that studies the classification or systematics of living beings) were laid by Carl Von Linné (Swedish naturalist, 1707-1778). He is

also the initiator of the binomial nomenclature. The current classification of the animal kingdom is based mainly on research in embryology and paleontology.

3. Zoological nomenclature

3.1. Zoological unit (Species)

Definition: The species is a set of related individuals, of the same hereditary morphology, of the same physiological characters, of a common way of life and occupying a definable geographical area.

A species is recognized by 4 criteria:

- Internal (intraspecific) fertility and external (interspecific) sterility;
- Internal and external morphology;
- Physiology: biochemical (odors, secretions, ...) and biophysical (reaction to environmental conditions);
- Ecology and distribution.

3.2. Categories higher than the species

The set of species with common characters form a category higher than the species called genus. Thus, each set of categories (taxa) corresponds to a higher level (Σ species = genus, Σ genera = family, Σ families = order, Σ orders = class, Σ classes = phylum, Σ phyla = kingdom). The phylum is the level that corresponds to the different stages of evolution. Depending on the degree of complexity of a taxon, there may be intermediate values (subclass, subfamily, group, tribe, ...).

3.3. Binomial nomenclature (binomial denomination)

In the binomial nomenclature, this species is often accompanied by its genus, or the name of the genus begins with a capital letter and the name of the species with a lowercase letter, so the binomial name of the golden beetle is *Carabus auratus*.

This nomenclature can be followed by the name of the discoverer and the year of discovery. Thus, our golden beetle can take the name *Carabus auratus*. Linné, 1761

To classify these species, phylogenetic classification is based on certain principles. One of the first principles is the economy of hypotheses, also called the principle of parsimony, in order to better link the species, the kinship link must be probable. The principle of parsimony lies in

the fact that hypotheses of convergence must be limited to the strict minimum and hypotheses of homology maximized. Each hypothesis of convergence is symbolized by a node in the phylogenetic tree. At the end of the classification, only the tree with the fewest nodes will be the most probable. A second resides in the fact that a taxon must be a unique evolutionary lineage. Each level of the hierarchy is called a taxon. Each taxon is defined by the main traits shared by the species that constitute it. When all the members of a taxon have evolved from a common ancestor, we speak of a monophyletic group.

A third lies in homology, phylogeny is based on acquired morphological characters. If two species have a character in common, they have a kinship link. Finally, to develop a good classification, it is necessary to use plans of organizations, these plans of organizations describe an ideal model of an animal corresponding to a taxon. This plan of organization is refined as we descend in the classification.

Taxonomy is therefore the science that arranges organisms into taxa, taxa that are chosen arbitrarily. Systematics seeks to recognize and identify these taxa. In all, there are considered to be 8 main classification units:

- The species • The genus • The family • The order • The class • The phylum • The kingdom • The domain.

EXAMPLE: CLASSIFICATION OF THE BEE.

The scientific name is written: *Apis mellifica* or *Apis mellifica*

Kingdom: Animal

Sub-kingdom : Metazoa

Division : Eumetazoa

Subdivision : Bilateria

Phylum : Arthropoda

Sub-phylum : Tracheata

Class : Insecta

Superorder : Hymenopteroidea

Order : Hymenoptera

Suborder : Aculeata

Superfamily : Apoidea

Family : Apidae

Subfamily : Apinae

Genus : Apis

Species : Apis mellifica

Subspecies : Apis mellifica ligustica

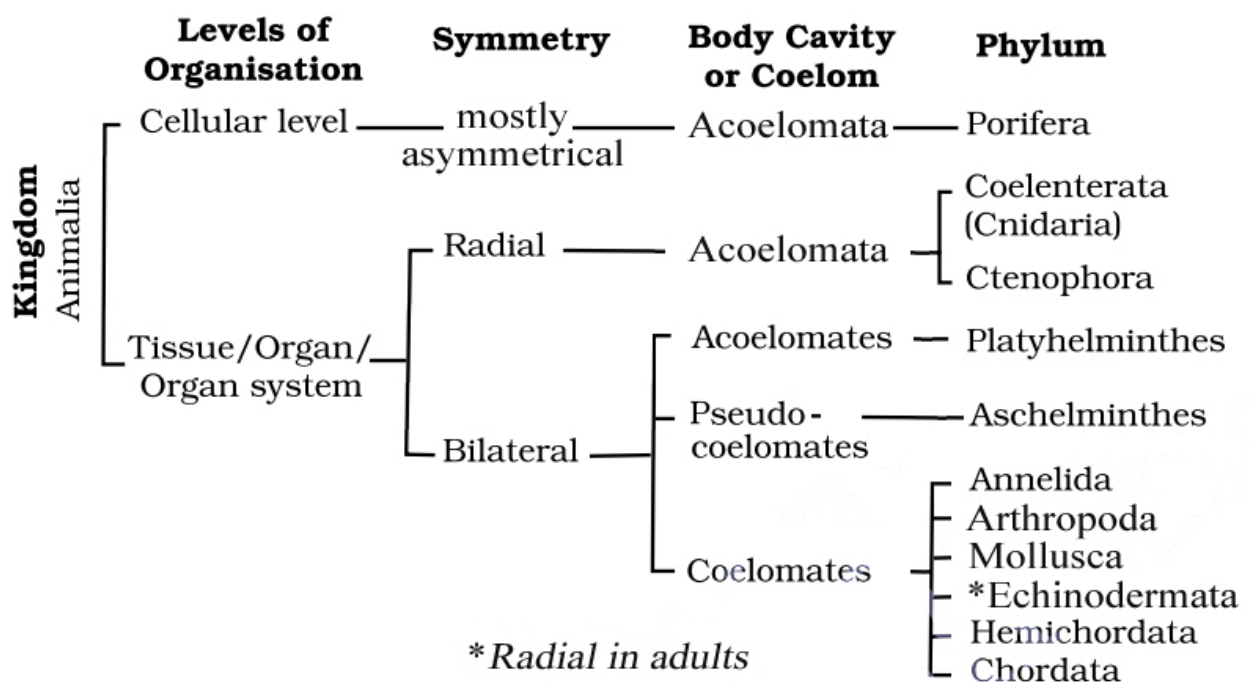


Figure 1 : classification of Animals.

4. Biology and phylogeny of the animal kingdom

The animal kingdom is divided into 2 subkingdoms :

4.1. Protozoa (protos = first or primitive) : It is extremely difficult to define the group of organisms commonly called protozoa. They are generally defined as unicellular animals. Their nucleus contains chromatin of variable density depending on the physiological state in which they find themselves. Their cytoplasm generally contains organelles and food vacuoles.

More than 64,000 species of protozoa are now identified. These animals, half of which are made up of fossils, are found in all environments where life is present.



Figure 2 : Exemple of Protozoa

4.2. Metazoa (Meta = several or advanced): A metazoan is an animal belonging to the kingdom Metazoa, as opposed to protozoa, metazoans have several cells, are mobile and must necessarily feed on pre-existing organic matter, this is what is called heterotrophy.

Metazoans must therefore take their food from other organisms, living or dead. They can even feed on the remains of other organisms, for example dead leaves, used hair or feathers, molts, etc.



Figure 3 : Metazoa

4.3. Distinction between Protozoa and Metazoa

A protozoan organism possesses all the basic characteristics of a metazoan cell, to which are added the locomotor organelles. Some protozoa organize themselves into colonies (clusters of similar cells resulting from the asexual multiplication of an individual). Others go through a multicellular stage during their development cycle. Some zoologists prefer to define protozoa as acellular (organisms not subdivided into cells).

II. Subkingdom of Protozoa

1. General information on protozoa

Protozoa (from the Greek protos = first; zoôn = animal) are unicellular organisms, which can associate in colonies (some cnidosporidia), which appear to form multicellular beings, but in which the anatomical elements are all similar. Protozoa live exclusively in water or at least in damp soil; as soon as the humidity runs out, they become encysted until the conditions become favorable for life again. They play an important role in nature. They destroy, to feed on them, a multitude of pathogenic bacteria and especially putrefaction agents, at the same time as some are the agents of diseases that can be very devastating (malaria, in particular, which is due to a Sporozoan, Plasmodium). Let us add further that the accumulated shells of many species of Protozoa, especially of fossil Foraminifera, have great technical importance in constituting diatomaceous earth, dynamite earth, etc. The Cretaceous rocks of the island of Rügen (Germany), England, Greece, etc., are almost entirely made up of these accumulations of shells, and it is the very whiteness of these immense deposits that has given rise to the names Albion, Albania, Crete, etc.

Protozoa are generally microscopic beings, sometimes difficult to distinguish from lower plants. Thus the spores of certain Algae present at a certain stage of their development such a similarity, not to say identity, with species of Protozoa, that it would be impossible to distinguish them without studying the later phases of development, and even so? To resolve this difficulty, Bory de Saint-Vincent proposed, in 1824, to create the intermediate kingdom of Psychodians. Haeckel took up this idea and created the kingdom of Protists, which contains not only unicellular, sometimes colonial, beings with an animal or plant character, Protozoa, Bacteria, Diatoms. But also some multicellular organisms, the Fungi. The Protozoa thus form the animal component of the kingdom of Protists, whose plant component takes the name of Protophytes.

As eukaryotic Protists, the Protozoa are opposed to the Metazoans. They are anatomically simple organisms, since they appear to be reduced to a single cell, but from a biological point of view one can say that a multitude of functions are assigned to them.

A classification of Protozoa.

The many species that make up this group - more than 30,000 - can be divided into three classes, the Infusoria (Ciliates and Flagellates), the Sporozoans and the Rhizopods.

Table 1 : Classification of Protozoa.

Infusoria Protoplasmic body surrounded by a membrane locomotor organs.	
Ciliates Body covered with vibrating cilia	Holotrichs
	Acinetians.
	Peritrichs
	Spirotrichs
Flagellates Moving with the help of flagella	Protomonads
	Metamonads
	Opalines
Sporozoans Generally parasitic, devoid of locomotor organs immobile or with slow movements, reproducing by spores.	
Gregarinomorphs	Gregarines
Coccidiomorphs	Aconoidasids
	Coccidia
	Sarcosporidia
	Cnidosporidia
Rhizopods Protoplasm not surrounded by a membrane emission of pseudopods	
Actinopods	Radiolarians
	Heliozoans
	Acantharians
Foraminifera	Monothalams
	Polythalams
Amibas	Gymnamoebians
	Thecamoebians

2. Nutrition

In the thickness of the ectoplasmic walls, we see a contractile vacuole forming in many Protozoa, especially in Rhizopods, which is considered an organ of excretion and respiration. This is the first perceptible sign of differentiation in this group; a second is the formation of a special opening, the cytostome, intended to serve as a mouth for the Infusoria, and that of the suction organ (fasciculated sucker) of the Acinetians. In species provided with a mouth, there is generally also a distinct anus, the cytoproct.

Solid food particles are often received in vacuoles, called digestive, with acid secretion, a kind of temporary stomachs, carried in a slow movement of cyclosis with the entire endoplasm; evacuation takes place at any point of the body, if there is no cytoproct. In ciliates such as *Didinium*, *Monodinium*, *Balantidium* (*Paramecia*), etc., the protoplasm tends to become channeled for the passage of food in a certain direction; this is the first indication of the formation of an intestine.

3. Locomotion.

The ectoplasm of the Protozoa can contain contractile fibers (*Stentors*, *Spirostomes*), true nematocysts, others very varied serve for locomotion. In *Amoebas*, various other *Rhizopods*, etc., movement is by the emission of pseudopods; thus the body can, thanks to the contractility of the ectoderm, emit finger-like expansions, into which the entire mass of the individual rushes; in *Foraminifera*, we see protoplasmic filaments coming out through the openings of the test, the contraction of which determines the movement of the whole body. It is not always possible to clearly understand the mechanism that presides over the movements of certain Protozoa. Thus the *Gregarines* generally offer a displacement as a whole without contraction of the body, and which can be compared to that of certain *Diatoms*. In the higher groups, *Infusoria*, for example, we find already well-differentiated organs. Thus, in *Flagellates* there are long flexible, contractile appendages, in the thickness of which a striation has been observed that recalls that of the muscle fibers; these filaments (flagella) are constantly undulating (*Noctiluca*, *Cercomonas*, etc.). The *Ciliates* present, as their name indicates, vibrating cilia, numerous and short, covering the entire surface of the body (*Rolophrya*); or distributed in fringes (*Calceolus*); or they are cirri (*Aspidisca*, *Euplotes*), or rigid bristles, or finally undulating membranes that seem to be formed by the coalescence of the cilia between them and are near the oral orifice (*Onychodromus*); a few species, such as *Paramaecium*, *Cyrtostomum*, present what has been called trichocysts.

The Trichocysts are small "fusiform organs, capable of elongating at the slightest contact, transforming into so many small venomous needles that immobilize and can kill the prey" (Aubert).

4. Reproduction.

A typical protozoan is a unicellular organism, i.e., composed of a nucleated protoplasmic element surrounded by a more or less differentiated peripheral layer. These animals rarely lack a nucleus, and if it is not visible as one or several small condensed masses, then at least the nuclein or nuclear substance is dispersed throughout the protoplasm in the form of granules. The nucleus generally serves, as in all cells, to primarily ensure the functions of multiplication and reproduction. Reproduction occurs through binary fission (bipartition preceded by nuclear division, mitosis), budding (separation of a small nucleated mass from the parent organism), and sporulation (division of the protoplasmic mass into numerous nucleated fragments, each forming a spore).

5. Phylum: Sarcomastigophora

5.1. Subphylum: Flagellates

Flagellates, or Zooflagellates, are characterized by the presence of one or more flagella and the absence of cilia. Certain species of flagellates are parasites in humans, where they are the determining cause of specific diseases, particularly sleeping sickness. These are the ones we will study first.

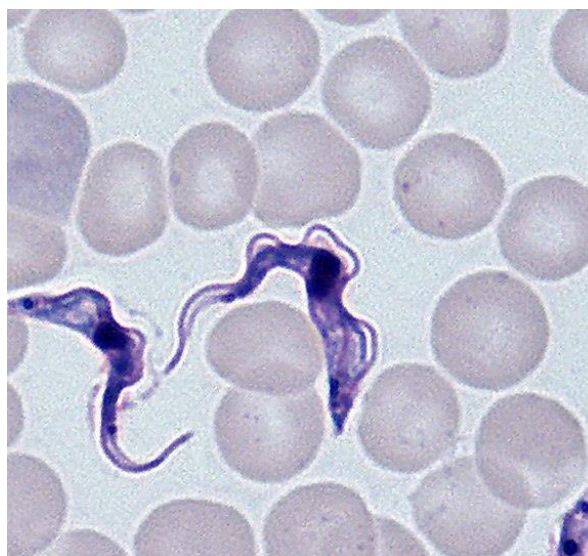


Figure 4 : Example of Flagellates

A. Trypanosomes.

Trypanosomes mostly inhabit the blood of many vertebrates and the digestive tract of certain invertebrates. In Asia, Africa, and America, they cause severe epizootics among domestic animals such as cattle, horses, donkeys, and sheep.

B. Reproduction of Trypanosomes.

Reproduction occurs by binary fission as follows: the protoplasm enlarges, the nucleus and the blepharoplast (kinetoplast) approach each other and divide into two, as does the flagellum, which starts dividing at its base (stages 2, 3, and 4 in Figure 4)

A small portion of the protoplasm then constricts at the base of the new flagellum, forming a smaller daughter trypanosome. Its posterior protoplasmic part is not yet separated from the parent trypanosome's protoplasm (stage 5). The parent trypanosome continues to produce successive daughter trypanosomes through the same process. These daughters remain attached to the parent by their protoplasm while their flagella are free, forming a rosette-like structure (stage 7). Eventually, the protoplasmic mass constricts into as many segments as there are nuclei (stage 8), each segment becoming a new independent trypanosome (stage 9).

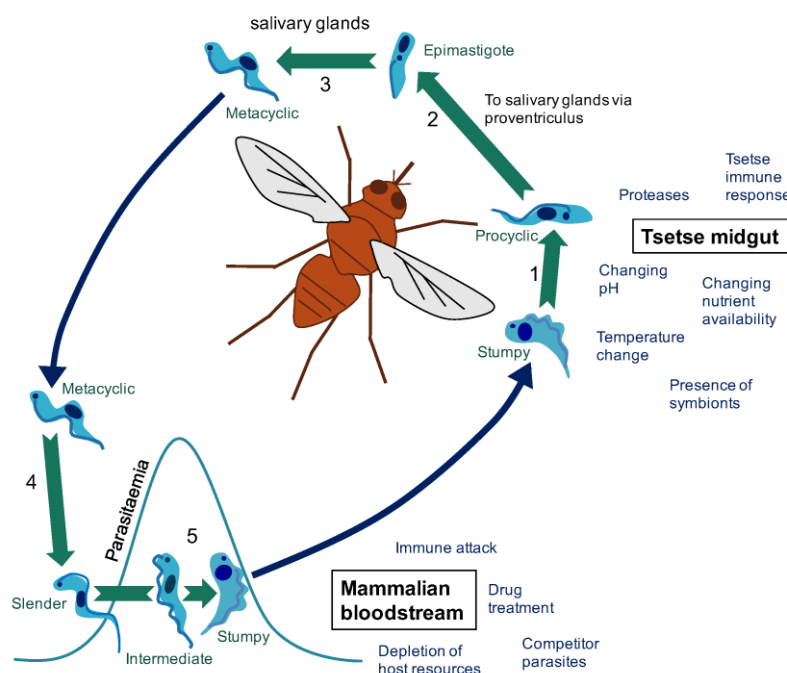


Figure 5 : Stages of Trypanosome Reproduction

5.2. Reproduction of Flagellates.

Reproduction occurs either by simple division, by spores, or, in some species, by conjugation. Division is the most common form of reproduction; it is a simple longitudinal binary fission. If the species has a mouth and a flagellum, it develops a second mouth and a second flagellum before dividing.

Spore formation occurs under unfavorable conditions: the flagellum retracts, and the body encysts itself into a resistant membrane. Inside this cyst, it divides into several zoospores, which are released later when nutritional conditions become favorable again.

6. Phylum: Ciliophora

The fundamental characteristic of species in this group is the presence of cilia covering all or part of the body surface. These ciliates are the most advanced organisms in terms of organization among the Infusoria. These forms are common in ponds and water bodies rich in organic matter, where bacteria—that serve as their primary food source—abound. They thrive in herbal infusions and water containing decomposing plant matter. They are also abundant in the rumen of ruminants, the rectum and bladder of amphibians, the digestive tract of certain worms, etc.

Several species have also been found in the human digestive tract. Among them, *Paramoecium coli* or *Balantidium coli* causes a specific type of dysentery called balantidial dysentery, as opposed to amoebic dysentery. This organism normally lives in the cecum and colon of pigs and can accidentally infect humans through contaminated water or undercooked pork

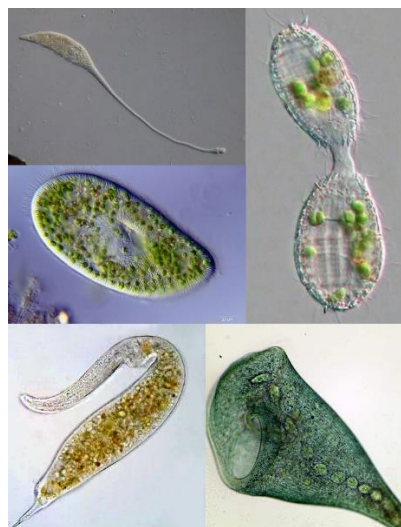


Figure 6 : Ciliophoras

6.1. Reproduction.

Reproduction in ciliates occurs through division. In fixed species, the division is longitudinal, while in free-living forms, the division is transverse. The main nucleus (macronucleus) is not the only structure to divide; the small mass of chromatin, called the micronucleus or paraneucleus, also divides into $2n$ chromosomes, with half going to the nucleus of each new cell.

The multiplication of *Paramecia*, which has been observed over long periods in nutrient liquids, occurs very rapidly, with two to five divisions every twenty-four hours.

7. Phylum: Apicomplexa (Sporozoa)

The general characteristics of this group include the presence of a membrane. Their extremely simple organization is the result of degradation caused by their parasitic lifestyle, common to all animals in this group. They parasitize certain animals, occupying epithelial cells or tissues to which they remain attached. As a result, they completely lack locomotor structures, such as flagella and cilia.

The name "Sporozoa" comes from their mode of reproduction by sporulation, common to all members, although the specifics are highly diverse, making this group an artificial construct. Here, we adopt a classification that recognizes two main subdivisions: Gregarines and Coccidomorphs (including Hemospora, Piroplasms, Coccidia, Sarcosporidia, and Cnidosporidia).

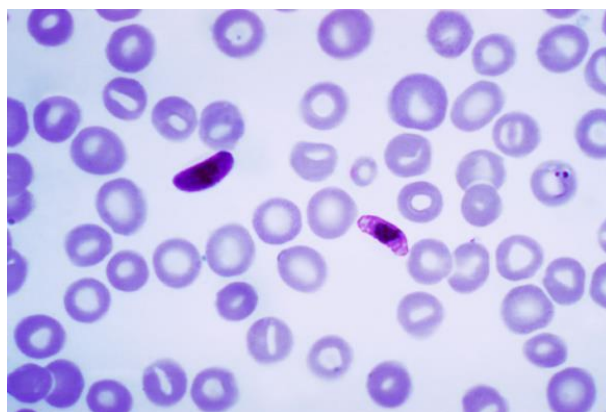


Figure 7 : Apicomplexa

8. Classification

8.1. Gregarines

Gregarines, or Gregarinians, often reach 1 mm in size and are the most complex sporozoans. In their adult stage, they exhibit a free phase that occurs in the intestines or deep cavities of worms and arthropods. Their motility is limited to a form of gliding or alternating flexions due to weak body contractions.

The protoplasm is divided into two zones: the endoplasm and the ectoplasm. The endoplasm is a granular, viscous, and weakly contractile mass containing a transparent, round, or oval nucleus. It also includes numerous oily droplets and starch-like grains called xoamylon. The ectoplasm is hyaline in appearance and interacts with the outer membrane or cuticle.

8.2 Les Coccidomorphs

This group includes the Hemospora, Piroplasms, and the organisms formerly referred to as Psorospermia. By regrouping Myxosporidia and Microsporidia into "Cnidosporidia," we arrive at a classification closer to modern systems.

8.3. Hemosporidia.

Hemosporidia, also known as blood amoebas, have the same structure as amoebas and parasitize the red blood cells of vertebrates, including humans. Among the species, we describe the Plasmodium, responsible for different febrile illnesses known as malaria.

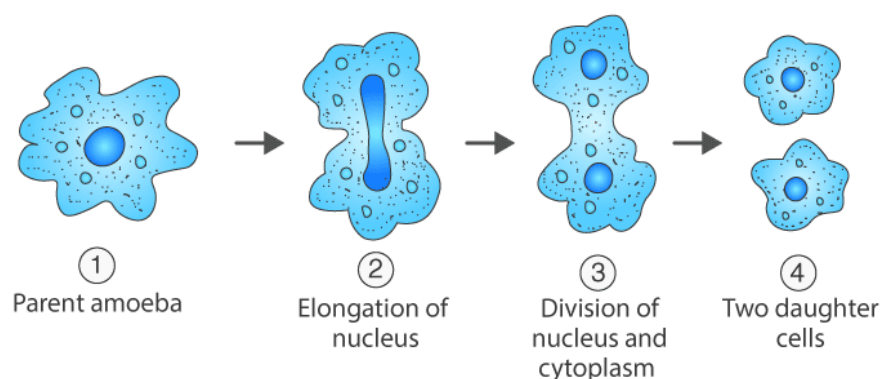


Figure 8 : Asexual Multiplication of Amoebas in Human Blood (from Verdun and Mandoul, Précis de Parasitologie). - 1, young amoeba entering a blood cell. - 2 to 5, its growth. - 6 and 7, formation of spores or merozoites (rosette-shaped bodies). - 8, their release.

9. Phylum Cnidosporidia

Parasitic protozoa of the intestine and muscles of invertebrates and fish. Their developmental cycle begins with an amoeboid germ (sporoplasm) which grows to give large multinucleated sacs (plasmodia) containing complex spores at the origin of tumors in the host.

1° Myxosporidia.

Myxosporidia, or fish Psorospermia, consist of a plasmic mass capable of amoeboid movements with a homogeneous ectoplasm and yellow or brown endoplasm, rich in fat globules and containing several nuclei which are the starting point of sporulation. The spores are complex in structure and vary in shape and volume with each fish; each spore is composed of a solid envelope, formed of two valves and a protoplasmic content; at the anterior part of the spore, between the plasma and the envelope, are two thick-walled vesicles (polar globules), containing a spiral filament which unwinds and exits under certain conditions; these are stinging organs comparable to the nematocysts of Coelenterates. At maturity, the two valves separate by the action of an elastic ribbon which occupies the suture line, and the content, a sarcodic globule, emerges to form... [The text cuts off here mid-sentence]

These parasites are found in fish, in the skin, gills, spleen, kidney, swim bladder, and ovary, and can cause, by their prodigious multiplication, great devastation, especially among young fish..

2° Microsporidia.

Microsporidia, or insect Psorospermia, are shiny, oval corpuscles, formed of an amoeboid protoplasmic mass, in which numerous ovoid spores appear which become free by the destruction of the plasmic mass; these spores have a shiny, very resistant membrane, which, when ruptured, releases a small amoeboid mass, which penetrates the tissues (especially connective tissues), grows and reproduces the Microsporidia. Pébrine, a disease of silkworms, is caused by a Microsporidia (*Nosema bombyci*); the tissues of the chrysalis, the butterfly, and the eggs laid by it are infected, and thus the disease is transmitted from generation to generation.

III. Subkingdom Metazoa

1. Phylum Porifera

- Also called sponges

- Metazoa called "parazoa", i.e., "next to" true Metazoa, because they do not have true embryonic layers (ectoderm, mesoderm, endoderm), which we will begin to discuss with Cnidarians.

- Absence of true organs
- Presence of flagellated cells, the choanocytes, circulating the aquatic environment through channels open to the outside
- Poorly or uncoordinated cell function
- Sexual reproduction (most often hermaphroditism and cross-fertilization) and asexual reproduction (budding)
- Marine or freshwater
- Solitary or colonial
- Approximately 5500 described species
- Fixed to a support

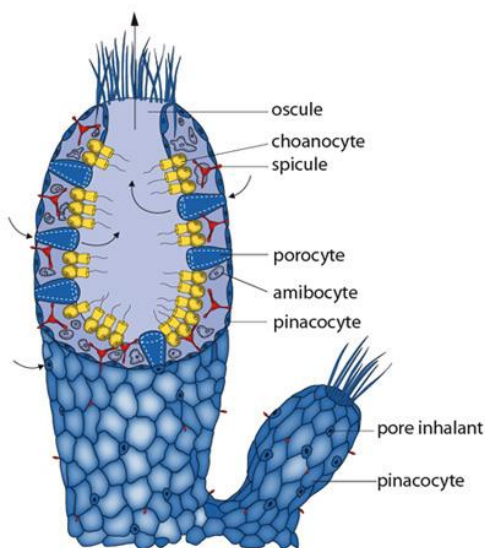


Figure 10 : General appearance of sponges



Figure 9: Sponges

Sponges represent a transition from unicellular to multicellular life. Multicellularity allows for increased individual size and the development of varied complex structures. However, this evolutionary experiment appears to have been a dead end; sponges haven't given rise to any other lineages. To emphasize this, some zoologists classify them in the Parazoa kingdom, distinct from other Metazoa.

1.1. External Examination:

- The fundamental form is a double-walled tube ("ascon" type): ectomesenchyme and endoderm.
- Inhalant pores, or ostia, are tiny orifices covering the surface.
- The central cavity opens at the top through the osculum, or exhalant pore.
- A continuous water current flows through the sponge, entering through the inhalant pores and exiting through the osculum.

1.2. Internal Examination:

A. Cell Types

The outer body wall is the ectomesenchyme, composed of :

- Pinacocytes: Flat cells forming the sponge's outer covering, not resting on a basal lamina, so not a true epithelium. Each inhalant pore is formed within a contractile porocyte. The osculum's diameter can also vary, controlling water flow speed and sometimes stopping it completely. In some sponges, this control is facilitated by specialized cells called myocytes, which resemble smooth muscle cells.
- Mesenchyme: Includes the mesoglea (a gelatinous protein matrix beneath the pinacocytes), skeletal material (collagen, spongin, spicules), and various cell types. These include totipotent cells (archaeocytes) that can differentiate into all cell types, amoebocytes (which digest filtered food particles), and cells producing mesoglea or skeletal material. These cells are highly mobile and constantly move within the sponge.

The inner body wall is the endoderm, composed of choanocytes lining the central cavity. Each choanocyte has a flagellum surrounded by a collar of closely packed microvilli. The flagella's beating generates the water current through the sponge. Choanocytes also participate in digestion and reproduction.

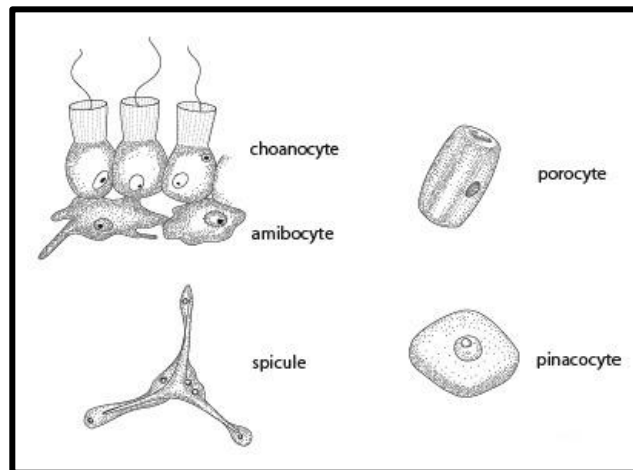


Figure 11 : Cell types of sponges

1.3 Digestive System

Sponges are filter-feeding microphages, consuming small organic particles that enter through the inhalant pores. Choanocytes capture food particles as water passes through their microvilli collars. The particles are then phagocytosed. Intracellular digestion occurs either within the choanocyte or in an amoebocyte, to which the choanocyte transfers the contents of its food vacuole. Amoebocytes store and distribute digested nutrients among the different cell types.

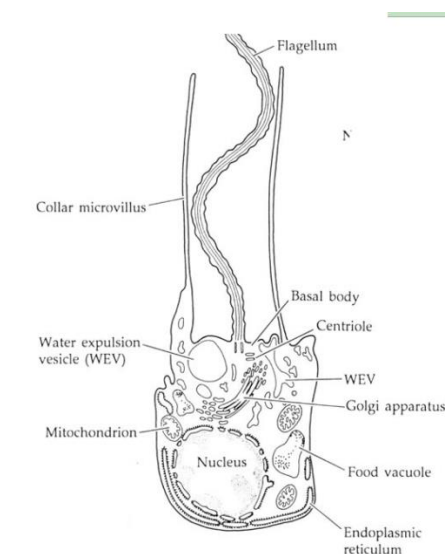


Figure 12 : Structure of a Choanocyte

1.4 Respiratory, Circulatory, and Excretory Systems

Most sponge cells are in direct contact with the surrounding aquatic environment. Many exchanges occur by simple diffusion, facilitated by the water current:

- Elimination of indigestible residues

- Excretion of nitrogenous waste (NH₃)
- Respiratory gas exchange (O₂ and CO₂)

Freshwater sponges have contractile vacuoles that act as an osmoregulatory system, storing and regularly expelling excess water accumulating in the cells..

1.5. Nervous System

Sponges lack a nervous system. Coordination occurs through the diffusion of chemical messages and cell movement.

1.6 Reproductive System

A. Sexual Reproduction

Sperm are thought to originate from choanocytes that migrate into the mesoglea, dedifferentiate (losing their flagellum and collar), and then differentiate into spermatogonia. In other species, spermatogonia differentiate directly from archaeocytes. Spermatogonia multiply, undergo meiosis, and then spermiogenesis. Sperm leave the parent sponge with the exhalant current.

Eggs originate from archaeocytes, which differentiate and accumulate reserves. Eggs remain in the mesoglea.

Fertilization is unique: a sperm enters with the inhalant current and is captured by a choanocyte, which acts as a transport cell within the mesoglea. Near an egg, the choanocyte transfers the sperm.

Zygote development occurs within the sponge. Several embryo types exist, including:

Parenchymula

Covered with an outer layer of flagellated cells, containing most adult cell types except choanocytes.

Amphiblastula

A hollow embryo with one hemisphere of small flagellated cells and the other of large non-flagellated cells.

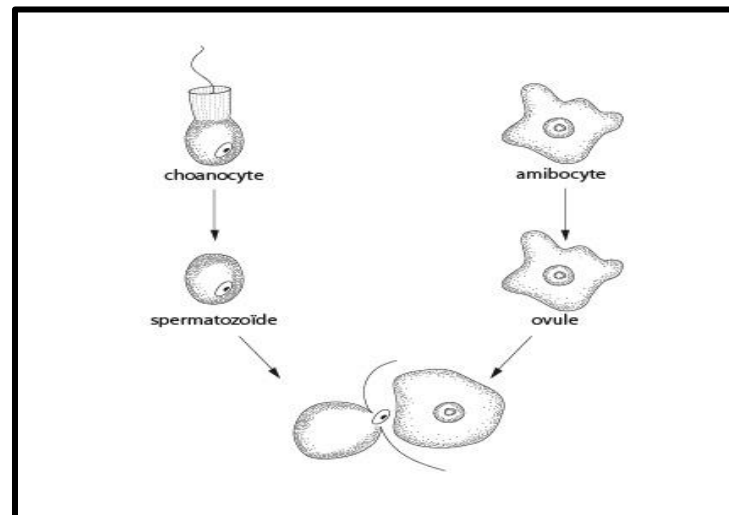


Figure 13 : Sexual reproduction

These embryos leave the parent sponge and briefly exist freely. After attaching to a substrate, they reorganize. In parenchymula, the outer flagellated cells lose their flagella, move inward, and differentiate into choanocytes. In amphiblastula, the small flagellated cells invaginate, and the large cells eventually surround them.

B. Reproduction asexuée

Gemmules

Gemmules

Cell clusters resistant to unfavorable conditions, especially in freshwater sponges. Archaeocytes filled with nutrients are surrounded by layers of spongin separated by spicules. These clusters develop into adult sponges when conditions permit.

Buds

After individual growth is complete, growth continues through budding. Buds may become separate individuals, remain attached, or become integrated to varying degrees, forming colonies that can function as higher-order individuals.

Regeneration

A sponge can regenerate a missing fragment. This property is exploited in bath sponge cultivation. Dissociated sponge cells can reaggregate into a functional sponge under appropriate conditions. This model is used in basic biology to study cell interactions.

1.6 Classification :

Given the limited morphological characters in sponges, molecular methods, including gene sequencing, are used for classification. Four distinct groups have been identified :

- Calcarea (Calcisponges): Calcareous skeletons (e.g., Grantia).
- Hexactinellida: Six-pointed spicules forming complex, lightweight structures, a choanosyncytium rather than a choanoderm, and no continuous pinacoderm (e.g., Euplectella).
- Demospongiae: Leuconoid structure, siliceous spicules in a collagen matrix (e.g., Halichondria, Haliclona).
- Homoscleromorpha: Recently identified, represented by the family Plakinidae.

These monophyletic groups are further studied in practical work.

2. Phylum Cnidaria

- Metazoa
- Diploblastic
- Gastrovascular cavity with a single opening (mouth)
- Primarily radial symmetry around the oral-aboral axis
- Differentiated cells
- Presence of organs
- Nerve net
- Marine or freshwater
- Attached (polyp) or free-swimming (medusa)

Cnidarians include corals, jellies, and hydras. They have a diploblastic, radially symmetrical body plan with a gastrovascular cavity and a single opening serving as both mouth and anus. One of the oldest lineages is Cnidaria. Cnidarians have diversified into a wide range of sessile and mobile forms. Most still exhibit the diploblastic.



Figure 14 : Cnidaria

The basic body plan of a cnidarian consists of a sac-like structure with a digestive compartment, known as the gastrovascular cavity. A single opening to this cavity serves as both the mouth and the anus.

There are two variations of this body plan: the sessile polyp and the mobile medusa. Polyps have a cylindrical shape and attach to a substrate by the aboral end of their body (the end opposite to the mouth), extending their tentacles to capture prey. Examples of polyp forms include hydras and sea anemones. A medusa (plural: medusae) resembles a flattened, mouth-down version of the polyp. It moves freely in water through a combination of passive drifting and contractions of its bell-shaped body. Medusae include free-swimming jellyfish. The tentacles of a jellyfish hang from the oral surface, which faces downward. Some cnidarians exist only as polyps, others only as medusae, and some undergo both polyp and medusa stages in their life cycle.

Cnidarians are carnivorous and often use tentacles arranged in a ring around their mouth to capture prey and push food into their gastrovascular cavity, where digestion begins. Enzymes are secreted into the cavity, breaking down prey into a nutrient-rich broth.

Cells lining the cavity then absorb these nutrients and complete digestion, while undigested remains are expelled through the mouth/anus..

2.1. External Examination

- Flat oral surface with a crown of tentacles
- Elongated slit-like mouth

- Short and thick trunk
- Aboral surface with a muscular adhesive disc

The mouth extends into a muscular pharynx, which descends into the gastrovascular cavity. A pair of ciliated and glandular grooves, called the siphonoglyphs, run along the pharynx. Vertical partitions, known as septa, divide the gastrovascular cavity into compartments

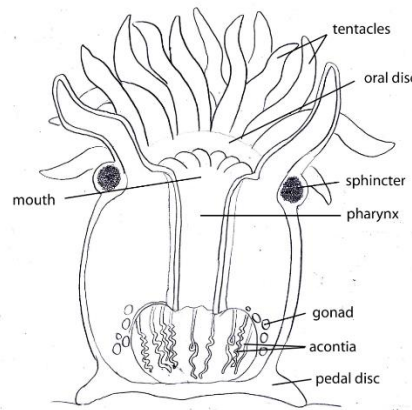


Figure 15 : Longitudinal Section of Actinia Showing the Arrangement of Septa and Pharynx

The development of septa in hexacorallian anthozoans occurs as follows:

- 6 pairs in a young anemone (primary septa)
- Later, 6 new pairs develop (secondary septa) between the primary ones
- Additional septa continue to appear, always forming between existing pairs
- This pattern of septa development is called cyclomeric growth

2.2. Internal Examination

Tegument

The internal organization of *Actinia equina* is visible in a cross-section of the trunk, which can be labeled in practical work. The main section is surrounded by smaller sections oriented in different ways within the tentacles. These sections appear circular or elongated, depending on whether they are cut transversely or obliquely. At the tentacle level, three layers can be distinguished:

1. Ectodermal sheet
2. Mesogleal layer

3. Endodermal sheet surrounding the central lumen, which extends from the gastrovascular cavity

The circular section of the trunk shows compartmentalization. The outer boundary is formed by the polyp's wall, which is connected to the actinopharynx (central tube) by septa. These septa divide the intermediate zone, the gastrovascular cavity, into small chambers. The walls of both the trunk and actinopharynx consist of ecto-endodermal layers. Under a microscope, these two tissues are seen to be separated by a thin layer of mesoglea. The septa consist of a double endodermal sheet supported by an intercalary layer of mesoglea. The endoderm and mesoglea of the septa are continuous with those of the body walls.

The ectodermal and endodermal layers can be unistratified or pseudostratified (formed by very tall, convoluted cells). They feature localized specializations due to the presence of abundant specialized cells.

The histological structure of the ectoderm and endoderm is similar to that of other cnidarians, but with a more regular cell arrangement. For example:

Endodermal muscle fibers are localized along mesenteries, where they form retractor muscles

Along the septa edges, rows of flagellated epithelial-muscular cells surround rows of glandular cells

This grouping of cells in specific locations represents the early formation of organ structures

.2.3 Excretory System

Cnidarians lack a respiratory and excretory system. Instead, they rely on diffusion for respiration and excretion. The thin body wall and circulation within the gastrovascular cavity allow direct exchanges between all cells and the surrounding aquatic environment.

2.4 Nervous System

The nervous system will be examined in the medusa *Aurelia aurita*.

2.5 Reproductive System and Life Cycle

A. Sexual Reproduction

- **Sea anemones are dioecious** (either male or female)

- **Eggs and sperm develop on the septa** and are expelled from the gastrovascular cavity through the mouth
- **Fertilization occurs in the surrounding water**
- The zygote develops into a **ciliated, free-swimming planula larva**
- The **planula settles** and develops into a **polyp**

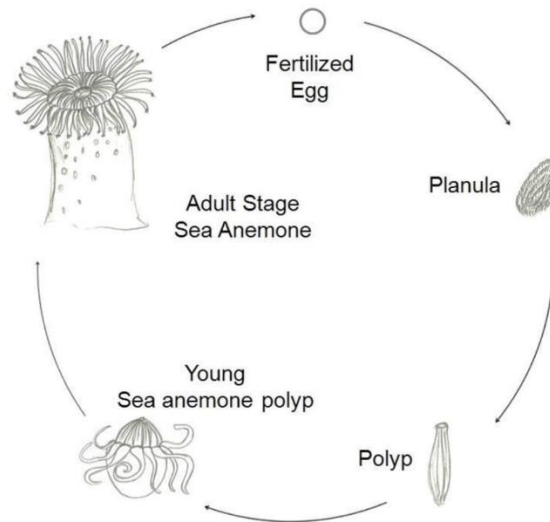


Figure 16 : Life Cycle of a Sea Anemone

B. Asexual Reproduction

- **By fission:** The animal splits longitudinally into two, and each half regenerates the missing parts

- **By budding**

C. Development

- **Egg segmentation**
- **Blastula stage:** Hollow sphere containing a cavity (**blastocoel**)
- **Gastrula stage:** Two-layered embryo formed by **cell migration into the blastocoel**
- **Planula:** Free-swimming larva, which eventually **settles and develops** into...
- **Polyp:** Tentacles, mouth, and gastrovascular cavity form

2.5 Classification

A. Subphylum: Medusozoa

- **Class Hydrozoa (Hydrozoans):** Represented by Hydroids, which exhibit an alternation of polyp and medusa generations. Also includes Siphonophores, which are free-floating colonial forms
- **Class Scyphozoa (Scyphozoans):** Free-swimming true jellyfish, typically with 8 tentacles. Their body mass consists of about 95% water
- **Class Cubozoa (Cubozoans) :** Cube-shaped jellyfish with potent stinging cells, some species (e.g., *Chironex* sp.) can be lethal to humans. Tentacles are arranged in groups of 4 or multiples of 4

B. Subphylum: Anthozoa (Anthozoans)

- **Class Hexacorallia (Hexacorallians):**
 - Includes **corals, sea anemones, and cerianthids**
 - Characterized by **polyp structures with 6 tentacles or multiples of 6**
 - The most widespread **Hexacorallian corals** are **stony corals (Madreporarians)**
- **Class Octocorallia (Octocorallians):**
 - Includes **gorgonians and soft corals**
 - Characterized by **8-tentacled polyps**, such as **red coral (*Corallium rubrum*)**, **blue corals**, and **soft corals (Alcyonarians)**

3. Phylum Ctenophora

Also called ctenophores, from the Greek ctenos meaning "comb" and phoros meaning "bearer," ctenophores are exclusively marine animals, sometimes benthic.

These planktonic organisms move using locomotor cilia and can be capable of bioluminescence. They also have a remarkable regenerative ability: half of their body can be torn apart and fully regenerated into two different individuals.

3.1 Classification

This phylum includes 150 species. Ctenophores are diploblastic animals belonging to the Eumetazoa. They were previously classified among jellyfish due to their morphological

resemblance but were later removed from this group because they lack cnidocytes, unlike cnidarians.

There is very little data available on ctenophores, and their classification remains uncertain. However, they are known to be more closely related to bilaterians than to cnidarians. This is due to their bilateral symmetry, true muscle tissue, and sperm with a single acrosome.

The phylum Ctenophora is divided into two classes based on the presence or absence of tentacles:

- Class Tentaculata: Possesses two retractable tentacles.
- Class Nuda: Lacks tentacles.

The order Platyctenida, which includes 35 species, consists of benthic ctenophores.

3.2 Anatomy and Morphology

Ctenophores exhibit biradial symmetry and are organized along an oral-aboral axis (extending from the mouth to the opposite end). They possess eight rows of cilia arranged in comb-like structures that diffract light, giving them an iridescent appearance.

These animals are gelatinous, transparent, and fragile. Some have tentacles that contain colloblasts, specialized adhesive cells used for prey capture. Unlike cnidarians, most ctenophores lack an anus, although some species have two small pores on the aboral surface, along with an apical organ.

This apical organ contains a statocyst, a small balancing structure with a statolith, which helps the animal orient itself in the water. Ctenophores lack a respiratory system, and gas exchange occurs directly through the body surface.

Ctenophores display great morphological diversity. They can range in size from a few centimeters to over a meter and come in various shapes, such as spherical, oval, ribbon-like, or flattened (Platyctenida resemble flatworms).

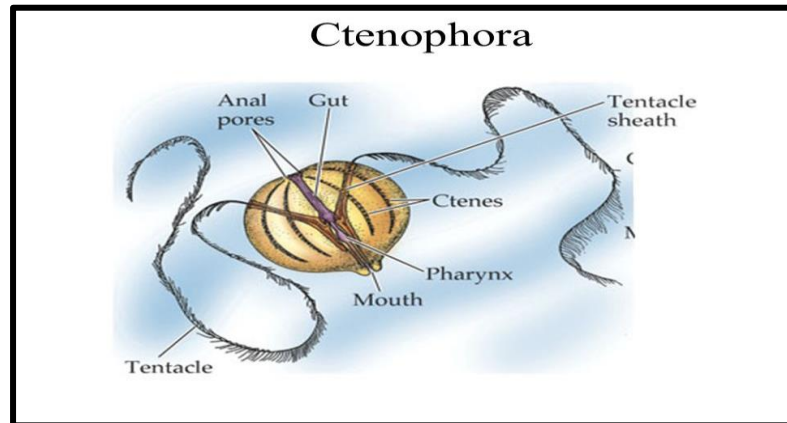


Figure 17 : Anatomy of Ctenophores

3.3 Nutrition

Ctenophores are carnivorous predators. Their tentacles capture prey and retract toward the mouth. Digestion begins in the esophagus with enzymatic breakdown, followed by hydrolysis in the stomach.

Their diet includes plankton, larvae, worms, crustaceans, cnidarians, other ctenophores, and sometimes small fish.

3.4 Reproduction

Most ctenophores are hermaphroditic, possessing both male and female reproductive organs. Reproduction is generally sexual, except in rare cases.

External fertilization: Gametes are released into the water, where fertilization occurs.

The fertilized egg undergoes multiple divisions, developing into a free-swimming larva, which later metamorphoses into an adult.

In some species, this metamorphosis is minimal, as the larva closely resembles the adult form.

3.5 Predators and Ecological Relationships

Ctenophores have **few known predators**, but they can be preyed upon by:

- Some cnidarians
- Turtles
- Fish
- Seabirds

- Other ctenophores

They can also occasionally be parasitized by crustaceans.

4. Phylum Platyhelminthes

Vers plats (y compris les ténias, les planaires, et douves) ont une symétrie bilatérale et un système nerveux central qui traite les informations provenant des structures sensorielles. Ils n'ont pas de cavité corporelle ni d'organes pour la circulation

- Metazoans, triploblastic, acoelomates
- Bilateral symmetry
- Protostomes
- Flattened body, with an anterior part (head) enriched with nervous and sensory structures
- Gastrovascular cavity open to the exterior through the mouth, serving digestive and circulatory functions, absent in some parasitic forms
- Differentiated excretory system with protonephridia
- Nervous system composed of a double ventral cord, with more developed parts (cerebral ganglia) in the anterior region
- Sexual and asexual reproduction (fission, budding)
- Hermaphrodites, with complex reproductive systems
- Marine, freshwater, or terrestrial
- Free-living or parasitic

Diversity and Animal Evolution: Invertebrates

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- Marine, freshwater, or terrestrial
- Free-living or parasitic

4.1 Group Overview

The four classes of Platyhelminthes exhibit remarkable adaptation to both free-living and increasingly advanced parasitism. We will study the planarian, a free-living and aquatic flatworm, precisely identifying the cytological derivatives of the three embryonic layers of this first triploblastic metazoan. We will then analyze the characteristics of two parasitic species representing two other clades of Platyhelminthes..

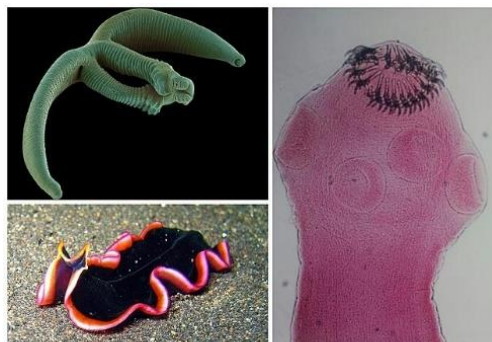


Figure 18: Plathelminthes

4.2 External Examination

- Size: 1–2 cm
- Color: Whitish
- Anterior part widened: head, with two dorsal eyes and two lateral lobes
- Dorsal side: pairs of excretory openings

- Ventral side: mouth located in the posterior third, with the genital opening slightly behind

4.3 Internal Examination

General Triploblastic Structure:

Three cellular layers: ectoderm, endoderm, and mesoderm.

This cross-section clearly demonstrates the triploblastic body structure. Platyhelminthes are acoelomates, meaning no coelomic cavity is present within the mesoderm.

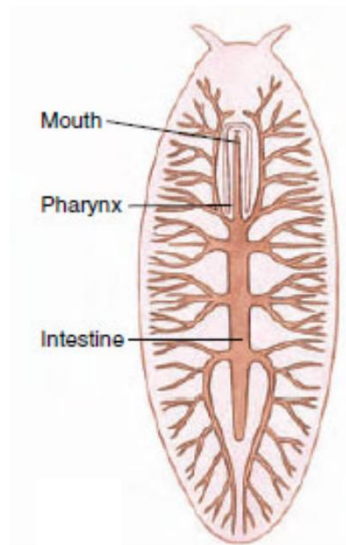


Figure 19 : External appearance of Platyhelminthes

Simple epidermis resting on a basal membrane, with:

- **Ciliated cells** (locomotion)
- **Glandular cells**: mucus, sticky substances (lubrication, attachment), toxic substances (protection)
- **Sensory cells** (stimulus perception)

4.4 Musculature

Successive layers beneath the ectoderm include circular, longitudinal, and oblique muscle fibers.

4.5 Locomotor System

The planarian primarily moves by gliding, using ciliated cells covering its ventral surface. The mucus secreted by glandular cells on this surface provides lubrication, facilitating movement. It also uses muscle contractions to alter its body shape and change direction.

4.6 Digestive System

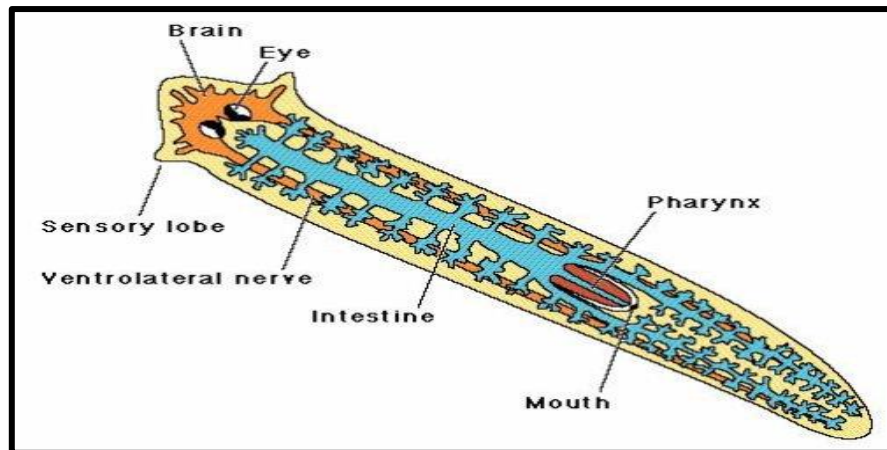


Figure 20 : The digestive system of the planarian

The mouth extends into a muscular, eversible pharynx. This pharynx is a hollow tube lined with ectodermal tissue, retracting into a sheath when not in use. It serves for prey capture. The pharynx leads to the gastrovascular cavity, lined with endoderm, which consists of an anterior branch and two posterior branches.

The endoderm consists of:

- Glandular cells, which secrete digestive enzymes
- Absorptive cells, which phagocytize food particles and complete digestion within the cytoplasm (via lysosomes)

4.7 Respiratory System

- No specialized respiratory organs
- Oxygen absorption and carbon dioxide release occur via diffusion

4.8 Excretory System

Two lateral canals communicate with the exterior through a series of excretory pores. These canals branch into the mesenchyme and terminate in protonephridia. Water and possibly some waste products are transferred from the interstitial fluid into the protonephridium. The beating of flagella generates a current that propels the liquid through the tubule.

Thus, the primary role of the protonephridium is osmoregulation (as freshwater continuously enters the body, it must be expelled). Additionally, it plays a role in the excretion of certain toxins.

4.9 Reproductive System

The planarian is hermaphroditic.

A. Male Reproductive System

- Numerous testicular masses dispersed throughout the mesenchyme
- Two sperm ducts
- The two sperm ducts converge at the midline into a seminal vesicle, connected to the penis, which is housed in the genital atrium

B. Female Reproductive System

- Two ovaries located in the anterior region
- Oviducts merging into a single duct that opens into the genital atrium
- Vitelline glands branching along the entire length of the oviducts
- One uterus, a large sac opening into the genital atrium

4.10. Sexual Reproduction and Development

Although these animals are hermaphrodites, they engage in copulation, leading to cross-fertilization.

Sperm cells are deposited by one individual's penis into the genital atrium of its partner. They travel up the oviducts, where fertilization occurs. Eggs descend through the oviducts, becoming surrounded by vitelline cells produced by the vitelline glands, and then enter the genital atrium, where they are enclosed in a substance secreted by the uterus. This substance hardens, forming rigid cocoons. The cocoons are laid through the genital pore.

Inside the cocoon, the eggs develop into juvenile worms resembling their parents within 2–3 weeks.

A. Asexual Reproduction

Occurs through spontaneous constriction behind the pharynx, splitting into two complete individuals.

B. Regeneration

Definition: A series of processes resulting in the partial or complete restoration of a lost body part or organ. This occurs in response to trauma, whether accidental or experimental.

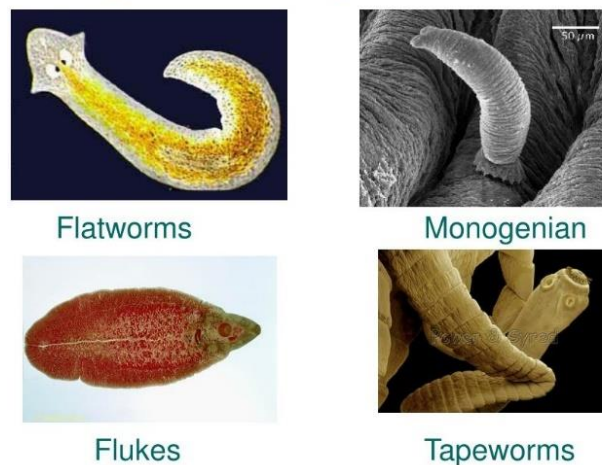


Figure 21 : Some Platyhelminthes

5. Phylum Nematelminthes (Roundworms)

- Metazoans, triploblastic, acoelomate organisms with a cylindrical, thread-like body and bilateral symmetry.
- Unsegmented, non-metamorphic body with a circular cross-section, covered by a thick cuticle (growth occurs through molting) into which muscle bundles are inserted.
- No respiratory or circulatory system. No cilia, locomotor organs, or sensory organs.
- Excretory system can be glandular (large cells near the esophagus that phagocytose waste) or tubular (H-shaped lateral canals).
- Dioecious (sexes are generally separate), with some species showing marked sexual dimorphism.
- Nematelminthes can be free-living or parasitic in plants and animals.

5.1 Morphology

Nematodes have bilateral symmetry, with a cylindrical or thread-like body that is unsegmented.

5.2 Anatomy

a) Tegument and Myoepithelial Cells

- The tegument consists of a thick cuticle made of collagen and keratin, covering a syncytial epidermis (hypodermis).
- No circular muscles; instead, myoepithelial cells are arranged in four longitudinal muscle fields.

b) Viscera (Perivisceral Cavity)

- Pseudocoelomates: The digestive and reproductive organs float in the pseudocoelomic cavity.

c) Digestive System

- A simple, tubular digestive tract running along the body.
- Consists of a mouth, a muscular pharynx, an intestine, and an anus opening into a cloaca.

d) Genital System

- Sexes are separate (dioecious).
- Males: A single testis that joins the digestive tract at the cloaca. Males have a pair of cuticular spicules, which aid in copulation. Sperm cells lack flagella.
- Females: A pair of tubular ovaries, curved and meeting at a common medioventral genital opening.

e) Reproductive System

- Most nematodes reproduce through amphimixis (fusion of haploid male and female pronuclei).
- High fecundity: Eggs are produced in large numbers.

- Some species are viviparous, while others carry eggs and embryos attached to their cuticle.
- The life cycle includes multiple larval stages, separated by molts.

f) Excretory System

- No flame cells (protonephridia) like in Platyhelminthes.
- Instead, two lateral excretory canals act as tubules, each contained within a single giant cell.
- The excretory opening is ventral.

g) Nervous System and Sensory Receptors

- Simple nervous system, with few peripheral fibers.
- Myoepithelial cells are directly connected to longitudinal nerve cords.
- Tactile receptors and chemoreceptors are located in the anterior part of the body.
- Many nematodes exhibit cellular constancy (each species has a fixed number of cells).

6. Phylum of Annelids

Annelids, or segmented worms, are distinguished from other worms by the segmentation of their bodies. Earthworms are the most familiar annelids, but the phylum mainly consists of marine and freshwater species.

6.1 Evolutionary Origin of Annelids

Why was metamerism so important? To answer this question, we must first examine the living conditions at the time of the annelids' emergence. The ancestor of annelids was a flatworm that could move similarly to a planarian, either by undulating or crawling using cilia. Annelids developed three important adaptations:

- The appearance of a true coelom,
- Metamerism (segmentation), and
- The development of a circulatory system

6.2 Some Annelid Architectures

Some of the most primitive annelids live in marine sediments, where they burrow more or less deeply. Some sedentary worms live in tubes that protect them and use their tentacles to

capture food on the sediment surface, while others, more specialized, feed by filtering water that circulates through their burrows. Some errant polychaetes have completely abandoned their burrows and can swim using their parapodia as paddles to enhance the efficiency of body undulations for locomotion. In these wandering worms, the right and left sides of each metamere are partitioned, increasing locomotion efficiency. Why?

Earthworms illustrate well the adaptations of annelid architecture to terrestrial life. Their impact on soils is as significant as that of polychaetes on marine sediments. Earthworms enrich the soil by accelerating the recycling of nutrients in terrestrial environments. In these worms, there is no partition between the left and right sides of the coelom, as they move by burrowing straight through the substrate.

The leech is an atypical annelid. Its coelom is reduced to a series of sinuses surrounding the internal organs and circulatory system.

The Earthworm, *Lumbricus terrestris*

The classic example used to describe annelids, particularly oligochaetes, is the common earthworm, *Lumbricus terrestris*.

This well-known cosmopolitan terrestrial species inhabits soils that do not dry out, are not too acidic, and are rich in organic matter. The tunnels are dug partly by compacting the soil on either side and partly by ingesting it; their surface is covered with defecated soil, which acts as a cement. They sometimes extend more than two meters deep.

6.3 External Anatomy

The body has a cylindrical, pointed anterior end and a flattened posterior end. The dorsal surface is identifiable by its darker pigmentation and the dark median line of the dorsal blood vessel, visible through the body wall. Examine the external features and gently touch the body surface to locate the setae. The setae can retract into grooves and require a dissecting microscope at low magnification to be seen. They are present on all segments except the first and last. Identify their position and number.

The head consists of a prostomium and a peristomium. The mouth is located at the base of the first segment, the peristomium, which surrounds the oral opening. The prostomium, which is immediately anterior, is not considered a true segment. Locate the anus at the posterior end.

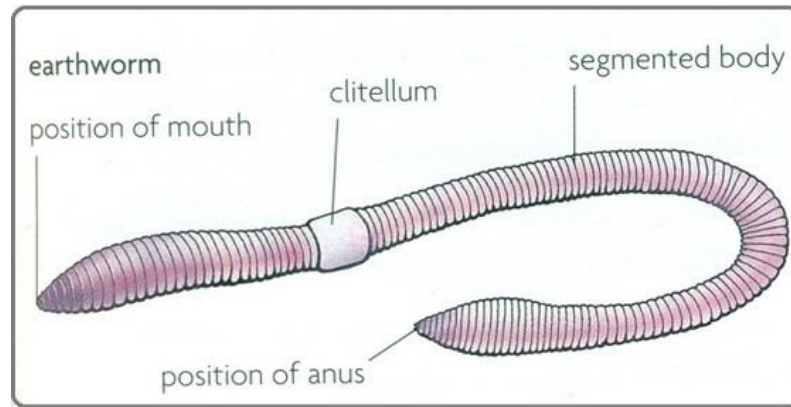


Figure 22: External appearance of Annelids

6.4 Digestive System

Segments 1-3 at the anterior end of the alimentary canal form the oral region, leading (in segments 4 and 5) to the pharynx, which has a thick wall. The pharynx is connected to the body wall by its musculature. The esophagus, with a thin wall, extends from segment 6 to segment 13 or 14. In segments 14 or 15 to 16 lies the crop, while segments 17 to 19 contain the muscular gizzard, which grinds food using small stones. The intestine runs through the rest of the body and appears yellow beneath its loose envelope of chloragogen tissue. These modified peritoneal cells function like a liver, synthesizing and storing fats and glycogen.

Remove a section of the intestine, open it ventrally, rinse out its contents, and note the typhlosole, a dorsal longitudinal fold that increases the absorption surface.

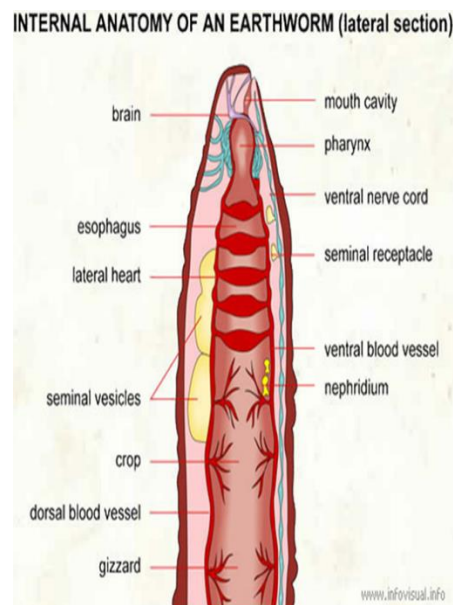


Figure 23: Internal anatomy of an earthworm

6.5 Excretory System

There are no specialized respiratory organs. Respiration occurs through simple diffusion across the skin. However, the blood contains a respiratory pigment, hemoglobin, which aids in oxygen transport.

6.6 Excretory System

The excretory system consists of a pair of metanephridia in each segment except the first three and the last three. Carefully remove a metanephridium along with the anterior septum's middle section. Place it on a slide in a drop of water without a coverslip. Examine it under a microscope. The small nephrostome, attached to the anterior face of the septum, is a funnel with a fringe of cilia. It leads through the septum to a coiled, ciliated tube in the following segment, which opens externally through the nephridiopore in the same segment.

6.7 Reproductive System

The most noticeable characteristic of the reproductive system is the presence of three large seminal vesicles, part of the male system, which store sperm before release. Sperm is released from two small testes located on the septa between the 9th and 10th segments and between the 10th and 11th segments, inside the seminal vesicles. Once the sperm matures, it passes through ciliated ducts, then the vas deferens, and exits through the male genital openings. Much of this is not observable in a preserved specimen.

The internal female reproductive system is simple but difficult to observe. Identify segment 13, then push aside the esophagus and seminal vesicles. Using a dissecting microscope, try to locate the tiny ovary hanging from the anterior septum near the mid-ventral line. Eggs are released from the ovary, pass into the ducts on adjacent septa, and travel through the oviduct to the female genital opening. Finally, identify the two pairs of seminal receptacles located in segments 9 and 10.

6.8 Classification

Thus, the annelid phylum presents a vast number of variations, leading to the distinction of three classes:

A. Hirudinea (Leeches) or Discophora

Leeches have a condensed embryogenesis, making it difficult to establish genetic relationships. These animals generally have an elongated, flattened body without appendages. The rings are short and sometimes difficult to see. External rings, marked by folds in the skin, do not always correspond to the fewer internal segments. Typically, three to five external rings correspond to one internal segment. The anterior rings are not differentiated. Both ends of the body end in a sucker, with the larger, posterior sucker serving as the primary attachment organ.

The mouth is very close to the anterior pole and always ventral. The buccal cavity contains teeth, whose arrangement is important for taxonomy, or an extendable proboscis. The intestine runs the full length of the body and opens near the posterior sucker. Leeches also have a visceral nervous system. Their best-known sensory organs are eyes, which are usually present.

B. Chaetopoda (Setae-Bearing Worms)

Chaetopods are a superclass of annelids that include free-living worms with paired setae, implanted either in crypts or on rudimentary feet, often with a distinct head featuring tentacles or cirri.

Chaetopods are mainly marine worms, though some live in freshwater, and others, like earthworms, in moist soil. Some exhibit unique reproductive and metamorphic phenomena. This group is divided into two classes:

C. Oligochaetes (Earthworms, Compost Worms)

D. Polychaetes (*Nereis*, *Sabelle*, *Serpula*)

7. Phylum Mollusca

- Triploblastic coelomate metazoans
- Body cavity of the hemocoel type, with a significant reduction of the coelom
- Primarily bilateral symmetry, which may become asymmetrical secondarily
- Absent or reduced segmentation
- Adult body structure consists of three main regions: a muscular ventral foot, a dorsal visceral mass, and a mantle that secretes a shell (internal or external) or calcareous spicules

- Complete digestive system with specialized regions, a pair of ventral nerve cords, an open circulatory system (except for cephalopods) with a heart, and a complex excretory system (nephridia)
- Sexual reproduction (mostly hermaphroditic with cross-fertilization)
- Trochophore larva + veliger larva
- Holoblastic spiral cleavage
- Terrestrial, marine, or freshwater habitats

7.1 External Examination

Despite their apparent diversity, mollusks share a common body plan, which can be illustrated using a hypothetical ancestral mollusk.

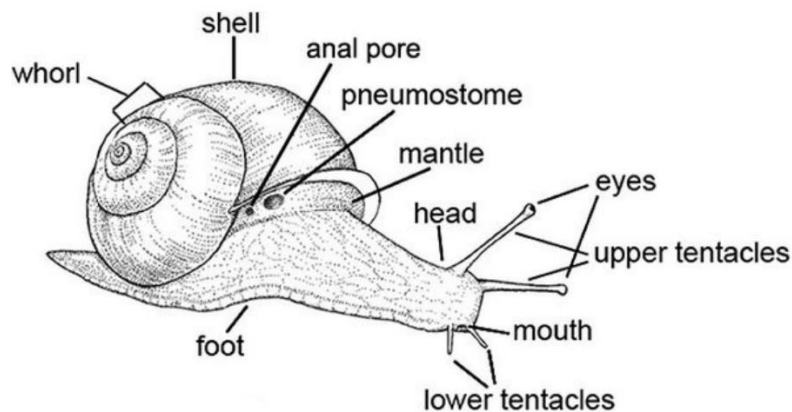


Figure 24 : External structure of a hypothetical ancestral mollusk (longitudinal section)

7.2 External Structure

This mollusk consists of three regions: the head, the foot, and the visceral mass. The entire body is covered by the mantle, which secretes the shell. The pallial cavity is the space between the body and the mantle. These elements are present in all mollusks. The ancestral form exhibits bilateral symmetry. Its shell would have been little more than a simple cuticle.

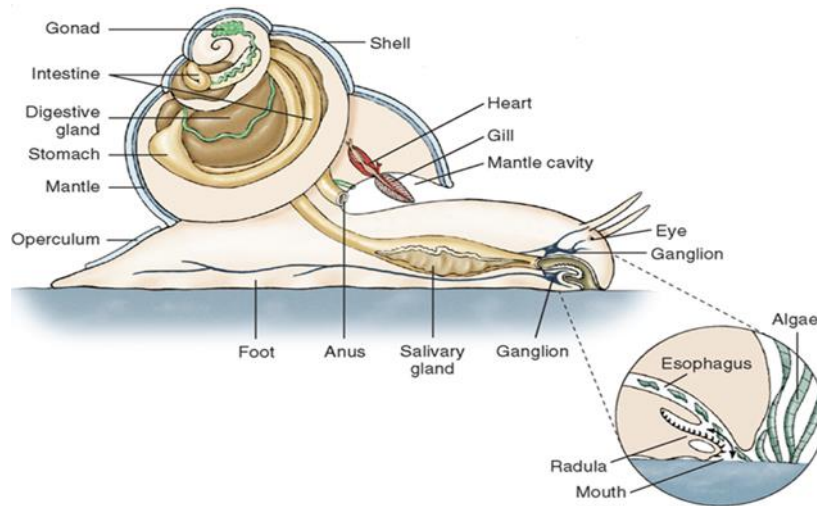


Figure 25 : Digestive system of the ancestral mollusk

7.3 Digestive System

Salivary glands open into the buccal cavity. Food passes from the buccal cavity through a tubular esophagus into the stomach. A pair of digestive glands is associated with the stomach, where digestion occurs intracellularly. In many modern species, extracellular digestion also takes place via enzymes secreted into the stomach cavity, but this advancement likely did not exist in the ancestral mollusk. The intestine follows the stomach, with the anus opening posteriorly into the pallial cavity.

7.4 Circulatory and Respiratory Systems

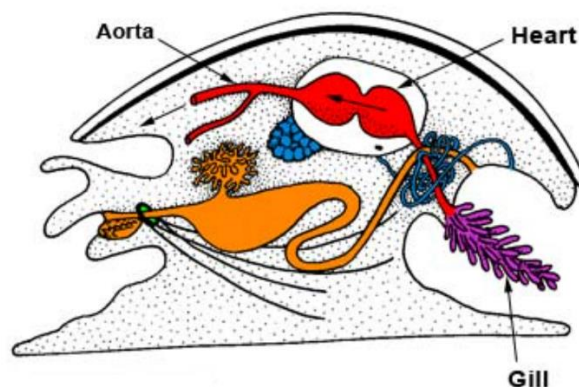


Figure 26 : Circulatory and respiratory systems of the ancestral mollusk

A coelomic cavity is located in the dorsal region, surrounding the heart and part of the intestine, making it a pericardial and perivisceral coelom. The heart consists of a pair of posterior auricles and a single anterior ventricle.

The auricles collect oxygenated blood from the gills, which is then pumped into the ventricle and distributed through the aorta. The aorta branches into smaller vessels that open into sinuses, allowing direct blood contact with tissues—this is an open circulatory system. The blood contains a respiratory pigment called hemocyanin, similar to hemoglobin but containing copper instead of iron, giving it a blue color.

The ancestral mollusk's gills consist of lamellae attached to a central axis. They are richly vascularized, innervated, and mobile due to muscle control. Located in the pallial cavity, they are symmetrically arranged on both sides of the body. Osphradia, sensory organs located above the gills, detect water quality entering the pallial cavity.

7.5 Excretory System

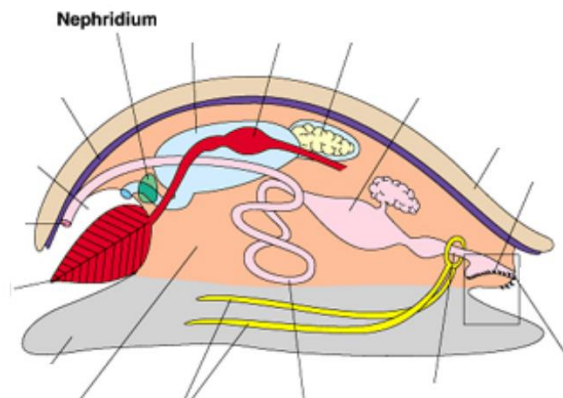


Figure 27 : Excretory system of the ancestral mollusk

The excretory organs of the ancestral mollusk likely consisted of a pair of kidneys, known as nephridia.

These nephridia open into the coelom through two nephrostomes and expel waste externally via nephropores into the pallial cavity.

The pericardial coelom receives waste from two sources:

- The heart releases a blood filtrate, as the blood is "filtered" through the heart wall.
- Certain pericardial glandular cells produce additional waste.

7.6 Nervous System

The nervous system of the primitive mollusk consists of a nerve ring surrounding the esophagus, from which two pairs of nerve cords extend toward the rear of the body.

- The ventral pair innervates the foot muscles (pedal nerve cords).
- The dorsal pair innervates the mantle and visceral organs (visceral nerve cords).

Many modern species possess eyes and statocysts, which function as balance organs.

7.7 Reproductive System

A pair of gonads is located beneath the anterior coelomic wall. At maturity, eggs or sperm are released into the coelomic cavities and transported outside through ducts. Fertilization is external.

7.8 Classification:

A. Subphyla :

- **Aculifera:** Lacking a shell but possessing calcareous spicules; primitive marine organisms.
- **Conchifera:** Possessing a calcareous shell secreted by the mantle and a locomotory foot; includes five classes, two of which—bivalves and gastropods—are found in freshwater.

A.1 Class Bivalvia (Lamellibranchs or Pelecypods)

- Headless animals with bilateral symmetry.
- The body is enclosed within the mantle and protected by a two-valved shell. The valves are hinged together by a ligament, often with interlocking teeth to ensure alignment.
- The opening and closing of the shell are controlled by strong adductor muscles.

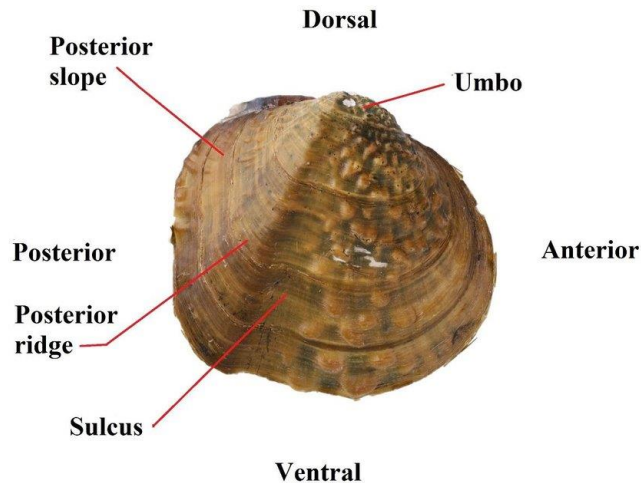


Figure 28 : External examination of a mussel

A.2 Class Gastropoda

- Characterized by a 180° forward torsion of the visceral mass.
- Possess a spirally coiled shell and a well-differentiated head with a radula (chitinous tongue-like organ with teeth) and jaw.

Based on their nervous system, gastropods are divided into two subclasses:

- **Prosobranchs (Streptoneura)**: Have an operculum covering the shell opening. Freshwater species breathe through a single gill.
- **Pulmonates (Euthyneura)**: Lack an operculum; their pallial cavity is gill-less but highly vascularized, functioning as a lung. Some species also breathe cutaneously.

Pulmonates are further categorized based on eye placement:

- **Stylommatophoran Pulmonates**: Terrestrial, with eyes at the tentacle tips.
- **Basommatophoran Pulmonates**: Aquatic, with eyes at the tentacle base.

A.3 Class Cephalopoda

- Bilateral symmetry, with a foot modified into a ring of tentacles.

Decapods

- Stalked suckers
- 10 arms, including two long retractable ones

- Calcareous shell and lateral fins

Octopods

- Sessile suckers
- 8 arms
- No shell or fins

Example: *Octopus vulgaris*

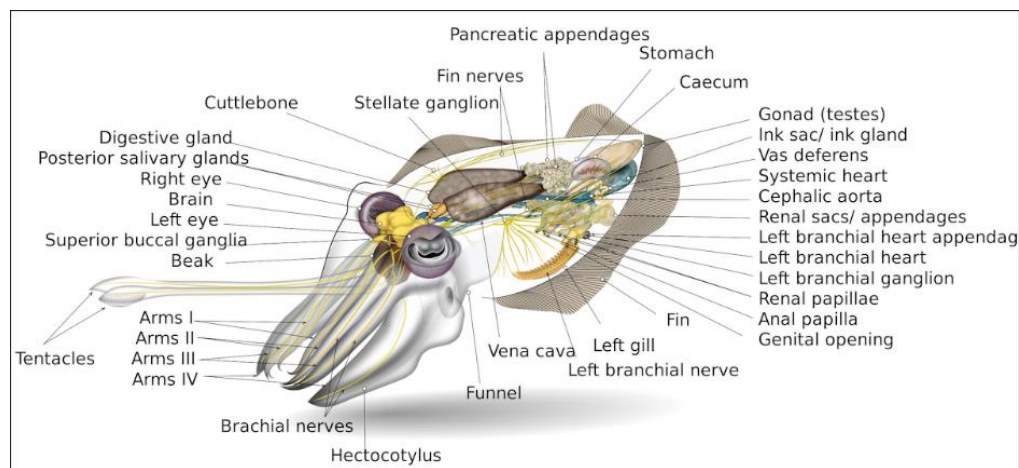


Figure 29 : Internal Examination of the Cuttlefish

8. Phylum Arthropoda

Arthropods (arthros: joint / pode = foot)

- Jointed legs are always present in adults but may be absent in larvae.
- They move through coordinated movements of their locomotor organs (i.e., their jointed legs).
- This is the largest and most diverse phylum, as at least 80% of all described species are arthropods.
- They are found in all environments and exhibit diverse forms, yet despite their apparent diversity, all arthropods share a consistent body plan and classification based on the structure and arrangement of appendages.

8.1 General Characteristics

- Triploblastic and coelomate animals
- Ventral nervous system (hyponeurians)

- Segmented body (metameric animals)
- Ecdysozoans: They possess an exoskeleton (cuticle), a rigid layer secreted by epidermal cells.
- Coelom: General cavity or hemocoel (where hemolymph circulates). Organs are bathed in hemolymph, which is not entirely confined within vessels.
- Hemolymph contains blood cells (hemocytes).

8.2 Circulatory System

- Open circulatory system.
- Consists of a dorsal heart (a long contractile tube through which blood moves from the rear to the front).
- Blood (hemolymph) is released into sinuses where organs are immersed and later returns to the heart via the pericardial sinus.

8.3 Respiratory System

- Terrestrial forms: Have book lungs or tracheal systems.
- Aquatic forms: Respire either through cutaneous respiration or using gills.

8.4 Digestive System

- Composed of three main sections: stomodeum, mesenteron, and proctodeum.
- The stomodeum and proctodeum have mechanical functions, while the **mesenteron** (midgut) is responsible for digestion.

8.5 Excretory System

- No true excretory organ.
- Most invertebrates have nephridia, but arthropods have specialized structures like:
 - Coxal glands (in spiders)
 - Malpighian tubules (bathed in hemolymph, filtering nitrogenous waste)

8.6 Nervous System

- Hyponeurial organization (as opposed to dorsal nervous systems, called epineurians).
- Composed of:

- Anterior part ("brain"): Large cerebral ganglia.
- Ventral nerve cord: A chain of paired ganglia (one per segment).
- Neuroendocrine system: Regulates various physiological functions like vitellogenesis (egg maturation) and molting

8.7 Reproductive System

Mostly dioecious (separate sexes), though hermaphroditism occurs in some species.

8.8 Classification of Arthropods:

Arthropods belong to:

- Metazoans: Multicellular animals.
- Eumetazoans: Animals with true tissues.
- Bilaterians: Organisms with bilateral symmetry.
- Protostomes: Mouth develops before the anus during embryonic development.
- Cuticulates: Animals with a two-layered cuticle.
- Ecdysozoans: Grow through successive molts.

8.8.1 Evolutionary Classification

- Latreille (1825) grouped these organisms into Cephalidians, later divided into Crustaceans, Arachnids, and Insects, forming Condylopes (jointed animals).
- The term Arthropoda, introduced 20 years later, became widely accepted.

8.8.2 Distinctive Features of Arthropods

1. Exoskeleton (cuticle)
2. Tagmatization (body segmentation into functional units)
3. Jointed appendages
4. Adaptation to terrestrial life

A. Subphylum Trilobitomorpha

- Extinct marine arthropods with a calcareous exoskeleton.
- Extremely abundant during the Cambrian and Ordovician periods, but went extinct at the end of the Paleozoic era.

- Had a flattened oval body divided into:
 - Cephalon (head) with antennae, compound eyes, and biramous appendages.
 - Thorax with paired biramous limbs.
 - Pygidium (tail section).
- Named after their three longitudinal lobes: central axial lobe and two pleural lobes.



Figure 30 : Trilobites

B. Subphylum Crustacea

B.1 Characteristics:

- Gills for respiration
- Two pairs of antennae
- Segmented body, each bearing a pair of jointed appendages
- Chitinous exoskeleton reinforced with calcium carbonate

B.2 Classification

1/ Malacostraca :

- Largest class, includes crabs, lobsters, and shrimp.
- 20 segments (5 cephalic, 8 thoracic, 7 abdominal).

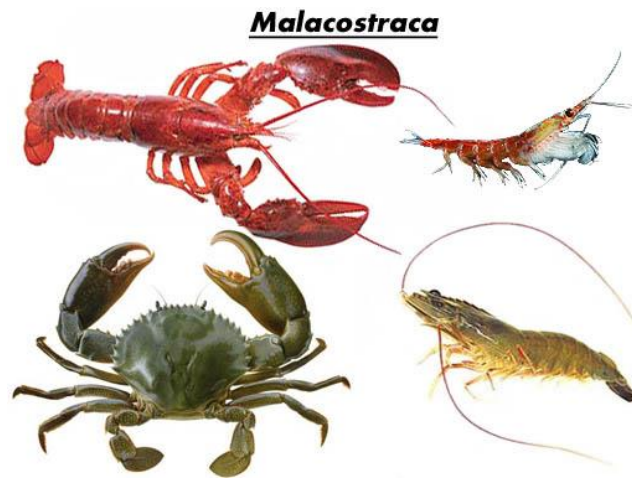


Figure 31 : Some species of Malacostraca

2/ Branchiopoda: Small, freshwater crustaceans (e.g., fairy shrimp).



Figure 32 : Some species of Branchiopoda

3/ Ostracoda: Small crustaceans enclosed in a bivalve shell, resemble mollusks..

C. Subphylum Arachnida

- **Body divided into two regions:**
 - **Prosoma (cephalothorax):** Bears simple eyes and six pairs of appendages.
 - **Opisthosoma (abdomen).**
- **Appendages:**
 1. **Chelicerae (first pair, for feeding).**
 2. **Pedipalps (second pair, sensory or predatory).**
 3. **Four pairs of walking legs.**



Figure 33 : Some Arachnids

D. Subphylum Myriapoda

- Terrestrial arthropods with numerous legs.
- Diplopody: Metameres grouped in pairs (diplosomites).
- Divided into two main classes:
 1. Chilopoda (centipedes):
 - Flattened body.
 - One pair of legs per segment.
 - Carnivorous, with venomous fangs.
 2. Diplopoda (millipedes):
 - Cylindrical body.
 - Two pairs of legs per segment.
 - Herbivorous, can roll into a ball (Glomeris).

E. Subphylum Hexapoda (Insects)

- Body divided into three parts:
 - Head: One pair of antennae, compound eyes.
 - Thorax: Three segments (prothorax, mesothorax, metathorax), each with a pair of jointed legs.
 - Abdomen: 11 segments, no appendages.
- Classification is primarily based on the presence and structure of wings.

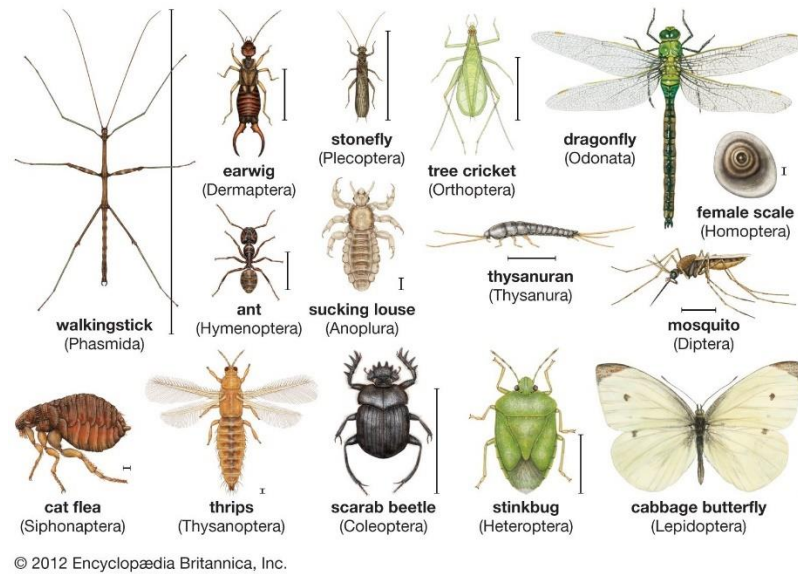


Figure 34 : Some insects

9. Phylum Echinodermata

Echinoderms are exclusively marine, benthic animals found in all seas, from coastal waters to deep oceans. There are approximately 7,000 known species today, ranging in size from a few centimeters to over a meter. The major phenotypic characteristic of echinoderms is their radial symmetry of "order 5" or pentaradial symmetry, which is present at least during development.

9.1 General Characteristics

- Multicellular animals (Metazoans), triploblastic, coelomates
- Deuterostomes
- Enterocoely (coelom formation)
- Pentaradial symmetry, sometimes secondarily modified to bilateral symmetry
- Locomotion via a water vascular system, also called the ambulacral system
- Larval stage of the Pluteus type
- Complete digestive system with specialized regions
- Differentiated excretory system with metanephridia
- Open circulatory system
- Epithelial nervous system with nerve cords
- Sexual reproduction with external fertilization
- Highly developed regeneration ability
- Exclusively marine, benthic, and free-living

9.2 Classification

Holothuroidea (Sea Cucumbers)

- Vermiform (worm-like) body elongated along the symmetry axis
- The nerve groove is internal
- The anterior end has a mouth surrounded by 10 buccal tentacles used to collect food particles (microphagous feeding)

Asteroidea (Sea Stars or Starfish)

- Flattened body along the symmetry axis
- A star-shaped body with five arms, attached broadly at their base, with no clear separation from a central pentagonal disc
- Open nerve grooves
- Pentaradial symmetry

Ophiuroidea (Brittle Stars)

- Also flattened along the symmetry axis like Asteroidea
- Distinguished by a well-defined central disc with five long, slender, and highly mobile arms that move in a snake-like motion (hence the name "Ophiuroidea")
- Arms lack ventral grooves

Echinoidea (Sea Urchins)

- Globular or hemispherical body covered in spines (hence the name "Echinoidea")
- Protected by a rigid, calcareous test made of fused plates
- The oral side is the dominant side of the animal
- The mouth has five movable jaws

Crinoidea (Feather Stars & Sea Lilies)

- Cup-shaped body protected by calcareous plates, supported by a long stalk (at least in the larval stage)
- The calyx has five long, usually branched arms
- No madreporite, spines, or pedicellariae

- Most Crinoids are stalked in their larval stage, but many species (e.g., feather stars) lose their stalk as adults and attach temporarily using cirri



Figure 35: Some Examples of Echinoderms

10. Phylum Chordata

Chordates are triploblastic, coelomate deuterostomes characterized by:

- A dorsal notochord (or "chorde dorsale")
- A dorsal hollow nerve cord
- Pharyngeal gill slits
- A post-anal tail
- A closed circulatory system
- Segmented muscles in the form of myotomes

All vertebrates, including humans, belong to this phylum. Some non-vertebrate groups, Urochordates and Cephalochordates, share the presence of a notochord at some stage of their life cycle, making them part of the Chordata. They serve as evolutionary links between invertebrates and vertebrates.

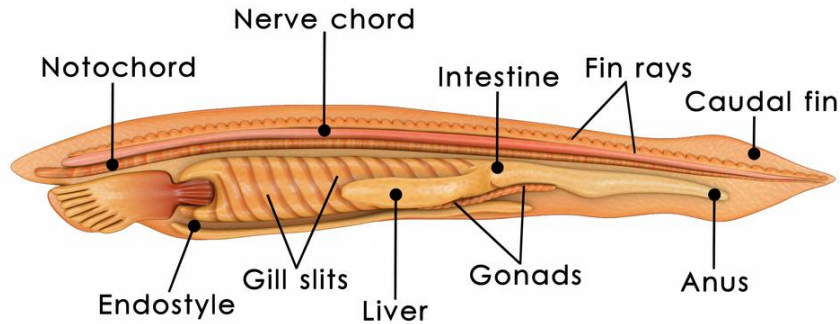


Figure 36: General structure of Chordata

10.1 Classification

A. Urochordates (Tunicates)

- Marine animals with bilateral symmetry
- Adult body is sac-like or barrel-shaped, covered by a gelatinous or cartilaginous tunic made of tunicin (similar to cellulose)
- Two openings: an anterior opening for water and food intake, and a posterior opening for waste and water expulsion
- Gill-based respiration; water enters through a ciliated canal called the endostyle
- Digestive system consists of a ciliated esophagus, a stomach, and an intestinal tube that opens into a cloacal chamber or directly outside

Classification of Tunicates:

Originally grouped with mollusks as "Molluscoïdes", later studies of their larvae led to their classification with *Amphioxus* under "Protochordates". Today, tunicates are a subphylum of Chordata, alongside Cephalochordates and Vertebrates. They are divided into three classes:

- Appendicularia
- Ascidiacea
- Thaliacea

A.1. Cephalochordates (*Amphioxus*)

Cephalochordates, such as *Amphioxus*, have a dorsal notochord running the entire length of their body.

Digestive, Respiratory, and Circulatory Systems

- The buccal cavity functions in both respiration and digestion
- Mouth is located at the anterior end, shaped like a slit, surrounded by cartilaginous structures but lacking jaws
- Circulatory system is similar to some annelids, with a ventral blood vessel but no centralized heart

Reproductive System

- Both males and females have 22-24 pairs of closed reproductive sacs along the branchial chamber
- Fertilization occurs externally after gametes are released into the environment

B. Vertebrates

- Vertebrates have a double nervous system, consisting of:
 1. Central nervous system (CNS): brain (olfactory lobes, cerebrum, optic lobes, cerebellum) and spinal cord
 2. Autonomic nervous system: a double sympathetic nerve chain
- The defining feature is the vertebral column, replacing the notochord
- Respiration occurs through lungs (mammals, birds, reptiles) or gills (fish, amphibian larvae)
- Complete digestive system with separate mouth and anus

Major Divisions of Vertebrates

1. Agnathans (Jawless Vertebrates)

- Lack lower jaws, feed by suction
- Includes lampreys and hagfish

2. Gnathostomes (Jawed Vertebrates)

- Divided into:
 - Tetrapods (land vertebrates), including:
 - Mammals
 - Birds
 - Reptiles

- Amphibians (Batrachians)
- Fishes, divided into:
 - Chondrichthyans (cartilaginous fish like sharks)
 - Osteichthyans (bony fish)

B.1 Fish

1. Cyclostomes

Cyclostomes are jawless fish, including hagfish and lampreys.

2. Chondrichthyans

Chondrichthyans, also known as cartilaginous fish, are an ancient group of marine vertebrates. Although they are not as numerous and diverse as bony fish, their morphological adaptations, specialized musculature for swimming, sensory organs, powerful jaws, and feeding habits have secured their survival in their environment.

In addition to descending from skeletal ancestors, chondrichthyans have minimal ossification in their skeleton, which is made primarily of cartilage—this is their defining characteristic. Examples include **sharks**.

There are two main types of cartilaginous fish, each with distinct characteristics:

Elasmobranchs (Sharks and Rays)

This group includes sharks and rays. Some are carnivores that locate prey through olfactory organs, as their vision is poorly developed. Currently, there are **8 orders of sharks with 400 species** and **4 orders of rays with 500 species**.

Characteristics of Sharks:

- **Body:**
 - Streamlined, fusiform body with a pointed snout and ventral mouth.
 - A heterocercal tail with two differently shaped and structured lobes, one containing the end of the vertebral column.
 - Paired pectoral and pelvic fins, two dorsal fins.

- Males have **claspers (myxopterygia, pterygopodia)** on their pelvic fins for copulation.
- **Vision, Skin, and Sensory Organs:**
 - Equal-sized, ventral nostrils in front of the mouth.
 - Eyes lack eyelids, though some species have **nictitating membranes** and spiracles behind each eye.
 - Rough skin, sometimes resembling sandpaper, covered in **placoid scales (dermal denticles)** that reduce turbulence.
 - Sensory organs (**neuromasts**) along the body detect vibrations and water currents.
 - Special electroreceptors (**ampullae of Lorenzini**) on the head detect electric fields emitted by prey.
- **Teeth:**
 - Not fused to the jaw, arranged in two rows where the back row replaces missing front teeth.
 - Depending on the species, teeth can be **serrated** for cutting, **sharp** for gripping, or **flat** for scraping surfaces (as seen in rays).
- **Skeleton and Swimming:**
 - Cartilaginous skeleton instead of bone.
 - No swim bladder, requiring continuous movement or resting on the seabed to avoid sinking.
 - Large liver rich in **squalene (lipids)** helps with buoyancy.

Holocephalans (Chimaeras)

This group includes **47 species**, combining features of both elasmobranchs and bony fish.

- **Body:**
 - Elongated body with a **prominent head and whip-like tail**.
 - Males have **claspers** to hold females during copulation.
 - Rabbit-like snout.
- **Jaws and Teeth:**
 - No separate teeth, but **flat, plate-like structures**.
 - Upper jaw is completely fused to the skull (unlike sharks).
 - Name meaning: *Holo* = whole / *cephale* = head.

- **Size:**
 - Can grow up to **2 meters** in length.
- **Defense:**
 - A venomous spine on the dorsal fin.
- **Diet:**
 - Feeds on **crustaceans, mollusks, echinoderms, small fish, and algae** by crushing food.

Reproduction of Chondrichthyans

Cartilaginous fish exhibit **internal fertilization** and various reproductive strategies:

- **Oviparous:**
 - Lay yolk-filled eggs immediately after fertilization.
 - Many sharks and rays enclose eggs in a **horny capsule** with tendrils to attach to surfaces.
 - Embryonic development lasts **6 months to 2 years**.
 - Found in small and **benthic species**, which can lay up to **100 eggs**.
- **Viviparous:**
 - Develop a **placenta** to nourish the embryo.
 - This adaptation has contributed to their evolutionary success.
 - **60% of chondrichthyans** use this method, mostly **large active species**.
- **Ovoviviparous:**
 - Embryos develop inside the **oviduct**, nourished by their **yolk sac** until birth.
 - Variations in embryo nutrition include:
 - **Histotrophy:** Embryo feeds on **uterine secretions**.
 - **Oophagy:** Embryo **consumes unfertilized eggs** in the uterus.
 - **Adelphophagy (intrauterine cannibalism):** Strongest embryo **eats siblings** before or after hatching.

Once hatched, **no parental care** is provided.

Classification of Cartilaginous Fish

Chondrichthyans (*Chondro* = cartilage / *ichthys* = fish) belong to two subclasses:

- **Elasmobranchs (Sharks and Rays)**
- **Holocephalans (Chimaeras)**

In total, there are over **900 species**, mainly marine, though some inhabit **freshwater or euryhaline (variable salinity) environments**.

Examples of Sharks

Sharks are divided into **8 orders**, each with distinct representatives:

1. **Heterodontiformes** (Bullhead sharks):
 - Small, warm-water sharks like *Heterodontus francisci* (horn shark).
 - Found in the **Indian and western Pacific Oceans** (absent in the Atlantic).
2. **Squaliformes** (Dogfish sharks):
 - Lack **nictitating membranes** and **anal fins**.
 - Some species have **venomous dorsal fin spines**, like *Squalus acanthias* (spiny dogfish).
 - Inhabit **deep Atlantic waters**.
3. **Pristiophoriformes** (Sawsharks):
 - Possess an **elongated, serrated snout** to sift through sediment for food.
 - Feed on **squid, shrimp, and small fish**.
 - Example: *Pristiophorus japonicus* (Japanese sawshark).
4. **Squatiformes** (Angel sharks):
 - Flattened body with **large pectoral fins**, resembling rays.
 - Example: *Squatina squatina* (angel shark).
 - Found in the **Atlantic Ocean, Mediterranean Sea, and North Sea**.
5. **Hexanchiformes** (Primitive sharks):
 - Represent ancient sharks still in existence.
 - Example: *Hexanchus nakamurai* (bigeye sixgill shark).
 - Despite their appearance, they **feed on invertebrates** and are harmless to humans.
6. **Orectolobiformes** (Carpet sharks):
 - Warm-water sharks with a **short snout and small mouth**.
 - Found worldwide in all oceans.
 - Includes the **largest shark**, *Rhincodon typus* (whale shark).
 - Whale sharks are **filter feeders**, similar to baleen whales.

7. **Carcharhiniformes** (Ground sharks):

- Most diverse order, found in **tropical, temperate, and deep waters** worldwide.
- Characterized by a **long snout, large mouth, and nictitating membrane**.
- Example: *Galeocerdo cuvier* (tiger shark), named for its **striped pattern**.

8. **Lamniformes** (Mackerel sharks):

- Includes well-known species like *Carcharodon carcharias* (great white shark).
- Found in **warm and temperate waters** globally.
- Notorious for **frequent attacks on humans**.

This classification showcases the **diversity and evolutionary success** of cartilaginous fish, highlighting their essential role in marine ecosystems.



Figure 37: Shark

Exemples of rays

Rays are classified into **4 orders**:

- **Rajiformes (True Rays)**: Found worldwide, from the **Arctic to the Antarctic**. Includes *Potamotrygon motoro*, a **freshwater stingray from South America**, known for its **venomous tail spine**.
- **Pristiformes (Sawfish)**: Have **elongated, saw-like snouts**. Example: *Pristis pectinata*, found in tropical and subtropical waters. **Hunts at night** and is often mistaken for saw sharks.
- **Torpediniformes (Electric Rays)**: Capable of **generating electric shocks** to stun prey and predators. Example: *Torpedo torpedo*, found in the **Mediterranean and Atlantic**.

- **Myliobatiformes (Eagle Rays and Manta Rays):** The **largest rays**, closely related to Rajiformes. Includes *Mobula birostris*, which lacks a tail spine and inhabits **temperate waters worldwide**.

This classification highlights the **diversity of cartilaginous fish**, demonstrating their **unique adaptations** in marine ecosystems.



Figure 38: Ray

3. Actinopterygians (Ray-Finned Fish)

Bony fish, or **Osteichthyans**, are a large group of animals that, alongside **cartilaginous fish (Chondrichthyans)** and **jawless fish**, form the group commonly referred to as "fish." Bony fish are **gnathostome vertebrates** whose skeleton is primarily made of fully calcified bone, with some cartilaginous parts.

These fish are known as **gnathostome vertebrates** because they possess **articulated jaws**. Before their emergence, the few vertebrate animals that existed lacked this feature and were **jawless vertebrates (Agnathans)**—animals with a skeleton but without a jaw.

The development of articulated jaws marked a significant evolutionary advancement for these animals. By increasing the musculature of the mouth, their **suction capability** improved, providing an advantage in predation. Additionally, **true bony teeth** and **paired fins** appeared, enhancing their movement capabilities.

Classification of Bony Fish

The oldest known fossil remains of **bony fish** date back to the **Devonian period**. Osteichthyans are divided into two classes:

Actinopterygians (Ray-Finned Fish)

Actinopterygians are characterized by **fins covered with skin and supported by bony rays**. From an evolutionary perspective, they are divided into three groups:

- **Chondrosteans**: Today, only a few species remain, such as **sturgeons and bichirs**. They are characterized by a **body covered in bony plates and a cartilaginous skeleton**.
- **Holosteans**: This group includes species such as **Lepisosteiformes (garfish)**, which still survive today.
- **Teleosteans**: This group represents the **vast majority of modern fish species**.

Sarcopterygians (Lobe-Finned Fish)

Sarcopterygians are the most significant group in terms of **the evolution of terrestrial vertebrates**. They are characterized by **lobed, fleshy fins**. This class is divided into two groups:

- **Actinistians (Coelacanth)**: Fossil records date back to the **Devonian period**, but they were largely replaced by **Actinopterygians** by the end of the **Paleozoic era**. They are the **closest bony fish relatives to terrestrial vertebrates** and have a **three-lobed caudal fin**.
- **Dipnoans (Lungfish)**: These fish are **adapted to life in shallow waters, ponds, and rivers**. In addition to **gills**, they also have **lungs**, which is why they are often referred to as "**lungfish**." This group includes the genera **Neoceratodus, Protopterus, and Lepidosiren**.



Figure 39 : Round sardinella

Characteristics of Bony Fish

So far, we have explored some of the main characteristics of **bony fish (Osteichthyans)**. These animals form a highly diverse group, yet they share many common features that define them as a distinct category.

As their name suggests, **Osteichthyans** are primarily characterized by a **skeleton composed of calcified bones**. Additionally, the **head** of these fish consists of two parts:

- The **cranial box**, which protects the brain.
- The **planchocranium**, which forms the articulated jaw.

This **jaw** contains two crucial bones:

- **Quadrate bone**: Later evolved into the hammer (malleus) of the mammalian middle ear.
- **Articular bone**: Later evolved into the anvil (incus) of the mammalian middle ear.

Another distinguishing feature of bony fish is their **skin**, composed of an **epidermis** containing **mucous glands** and a **dermis**, which gives rise to **scales**. These **scales** originate from a thin **bony layer** that evolved from an ancient group of fish known as **ostracoderms**. In some species, **mucous glands** can develop **toxic proteins**, turning into **venomous glands**.

Photophores in Bony Fish

Some bony fish, particularly those living in **deep-sea environments**, may possess an organ called a **photophore**. A **photophore** is a **light-emitting organ** that can be simple or as complex as a human eye, containing **lenses, shutters, color filters, and reflectors**. The light may be

produced through **metabolic reactions** or through **symbiotic bacteria** living inside the photophore. Photophores play a crucial role in the identification of **benthic fish**, and they are used either to **attract prey** or **confuse predators**.

Fins of Bony Fish

Bony fish possess **distinct fins**:

- **Unpaired fins**: Dorsal, caudal (tail), and anal fins, aligned along the **sagittal plane** of the body.
 - **Paired fins**: Pectoral and pelvic fins.
-

Swim Bladder of Bony Fish

Bony fish have a **buoyancy organ** called the **swim bladder**. This is a **flexible-walled gas-filled sac** located **dorsally**, beneath the **vertebral column** and above the **digestive tract**. The swim bladder controls buoyancy through **gas exchange** with the bloodstream, allowing the fish to **ascend or descend** in the water without muscular effort.

The swim bladder can be classified into two types:

1. **Physostomous Swim Bladder**: Connected to the digestive tract via a **pneumatic duct**, allowing gas to be released into the gut.
2. **Physoclistous Swim Bladder**: **No connection** to the digestive system; gases are **released through the circulatory system**.

In both cases, the swim bladder is **highly vascularized** for efficient gas exchange.

Circulatory System of Bony Fish

Bony fish have a **simple circulatory system**, where **blood passes through the heart only once per cycle**. The heart is **tubular** and consists of:

- A **venous sinus**, which collects deoxygenated blood.

- An **atrium**, which receives the blood.
- A **ventricle**, which pumps the blood.

The **oxygen-depleted blood** arrives from the **body veins** and is pumped by the **ventricle** to the **gills**, where **oxygenation** occurs. The **oxygenated blood** is then distributed throughout the body via **arteries**, and returns to the heart through **veins**.

Bony fish have **closed, single, and incomplete circulation**, meaning:

- There is only **one circuit** for blood flow.
 - **Oxygenated and deoxygenated blood may mix**.
-

Sensory Organs of Bony Fish

Bony fish possess specialized **sensory organs** known as **lateral lines**. These are **canals running along the sides of the head and body**, connected to the external environment via **small pores**.

The **primary function** of the lateral line is to **detect low-frequency vibrations**. In some species, it can also detect **weak electric fields**, aiding in navigation and prey detection.

Habitat of Bony Fish

Bony fish are **aquatic animals** that rely on water for **hydration, respiration, and other vital functions**.

They have **colonized all aquatic environments**, including:

- **Freshwater**: Rivers, lakes, and lagoons.
- **Saltwater**: Seas and oceans, where they can live at **various depths**, from **shallow** to **deep-sea** environments.

This group includes both **freshwater bony fish** and **marine bony fish**.

Diet of Bony Fish

Due to their vast diversity, **bony fish exhibit a wide range of feeding behaviors:**

- **Herbivores:** Feed on **algae**.
- **Filter feeders:** Extract **tiny food particles** from the water.
- **Predators:** Actively hunt prey, such as **tuna**.

Bony fish have a **highly developed sense of taste**, with **chemoreceptors (taste buds)** scattered along their **skin and inside their mouths**.

Each **taste bud** consists of:

- **Support cells**
- **Basal cells**
- **Sensory receptor cells** (with microvilli for detecting food stimuli).

Taste buds are also **connected to nerve fibers**, transmitting **taste information** to the brain.

Reproduction of Bony Fish

In **Osteichthyans**, **male and female reproductive organs do not differ significantly**.

- **Most species** have **external fertilization** and are **oviparous**.
- **Males and females release gametes** into the water, where fertilization occurs externally.
- Typically, the **female lays unfertilized eggs** in a **protected area**, and the **male fertilizes them** by releasing sperm over them.

In **rare cases**, **internal fertilization** occurs. When this happens, **males** possess a specialized **organ called a gonopodium**, used to **anchor and transfer sperm** to the female.

Examples of Bony Fish

Here are some of the most **representative species of bony fish**:

- **European Sturgeon** (*Acipenser sturio*)
- **Paddlefish** (*Polyodon spathula*)
- **Reedfish** (*Erpetoichthys calabaricus*)
- **Alligator Gar** (*Atractosteus spatula*)
- **Nelma (Sheefish)** (*Stenodus nelma*)
- **Danube Salmon** (*Hucho hucho*)
- **Lusitanian Toadfish** (*Halobatrachus didactylus*)
- **Mackerel** (*Scomber scombrus*)
- **Gilt-Head Bream** (*Sparus aurata*)
- **European Hake** (*Merluccius merluccius*)
- **Three-Banded Clownfish** (*Amphiprion ocellaris*)
- **Blue Tang** (*Paracanthurus hepatus*)
- **Lord Howe Butterflyfish** (*Amphichaetodon howensis*)
- **Ocean Sunfish** (*Mola mola*)
- **Greater Amberjack** (*Seriola dumerili*)
- **Greater Weever** (*Trachinus draco*)
- **Striped Marlin** (*Kajikia audax*)
- **Angelfish** (*Pterophyllum scalare*)
- **Guppy** (*Poecilia reticulata*)
- **Neon Tetra** (*Paracheirodon innesi*)

These species demonstrate the incredible **diversity and adaptability** of bony fish across various aquatic habitats.

B.2 Amphibians (Batrachians)

Under the name Batrachians (from the Greek *batrakhos* = frog), but more commonly referred to as Amphibians, we designate a class of cold-blooded vertebrates with usually bare skin, pulmonary and transient or persistent branchial respiration, double and incomplete circulation, two occipital condyles, and a life cycle that includes metamorphosis. Their embryos lack an amnion and allantois. This class mainly includes frogs, toads, and salamanders, all of

which, as a fundamental characteristic, invariably undergo metamorphosis. Several amphibians also secrete venom.

Classification of Amphibians

In general, the classification of animals is not absolute or unchanging. Thanks to scientific advancements, new discoveries lead to modifications in the taxonomic placement of groups and species. Below, we present both the traditional Linnaean classification and the more modern cladistic classification of living amphibians.

Regarding amphibian classification, there are not many major disagreements, and a general consensus exists regarding their taxonomy. Depending on whether one follows the Linnaean system or the cladistic approach, terms such as order or clade, respectively, are used. Amphibians are classified as follows:

- **Gymnophiona:** Caecilians
- **Caudata (Urodela):** Salamanders and newts
- **Anura (Salientia):** Frogs and toads

Physical Characteristics of Amphibians

The essential physical characteristics of amphibians are:

- A predominantly bony skeleton, with variable vertebrae and, in some cases, ribs.
- A variable body shape. Some have a well-differentiated head, neck, trunk, and limbs, while others have a compact body with a fused head and trunk, lacking a distinct neck.
- Some lack limbs entirely (*apodans*), while others have four distinct limbs, though in some cases, the forelimbs are smaller than the hind limbs. Some species have two pairs of small, non-functional limbs.
- Their feet are usually webbed and lack true claws. Depending on the group, they may have five, four, or fewer toes.
- They possess chromatophores, which give them a variety of colors, as well as various glands, some of which are venomous.
- Their skin is smooth, moist, and almost entirely devoid of scales, except in some cases where scales are embedded within the skin.

- They have a mouth, typically large, with teeth on both jaws or sometimes only on the upper jaw.

Reproduction of Amphibians

Amphibians have separate sexes, and fertilization can be internal or external. In salamanders and caecilians, fertilization is typically internal, whereas in frogs and toads, it is usually external. Most amphibians reproduce oviparously, although some species are ovoviviparous or viviparous.

A common characteristic among almost all amphibians is their metamorphic development, meaning there is a significant transformation between larval and adult forms. However, some exceptions exist, such as certain salamander species that retain larval traits in adulthood, a phenomenon known as *neoteny*. Additionally, some terrestrial salamanders undergo direct development, meaning that upon hatching, they closely resemble adults.

Most amphibians, even if they do not require a body of water to lay eggs, need humid environments to deposit their eggs. Some species lay eggs in water-filled leaves, burrow into the soil where temperature and humidity levels are suitable, and some frogs even lay eggs on land and hydrate them with water to keep them moist.

Diet of Amphibians

Amphibians are primarily carnivorous, although larval forms usually consume plant matter.

Habitat of Amphibians

Amphibians are widely distributed across the planet. As an intermediate group between fish and reptiles, most species require aquatic or at least highly humid environments. Some amphibians spend their entire lives in water, while others transition between aquatic and terrestrial habitats. Some remain underground near water sources.

Examples of Amphibians

Here are some of the most well-known amphibian species:

- **Common salamander** (*Salamandra salamandra*)

- **Alpine newt** (*Ichthyosaura alpestris*)
- **Axolotl** (*Ambystoma mexicanum*)
- **Greater siren** (*Siren lacertina*)
- **Ringed caecilian** (*Siphonops annulatus*)
- **Common toad** (*Bufo bufo*)
- **Colombian golden poison frog** (*Phyllobates terribilis*)
- **Tomato frog** (*Dyscophus antongilii*)

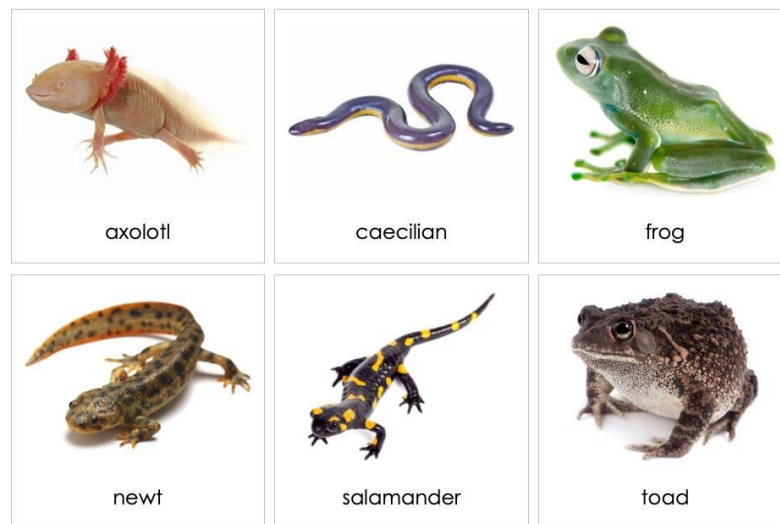


Figure 40: Exemple of Amphibians

B.3 Reptiles

Reptiles are cold-blooded vertebrates, typically oviparous, with pulmonary respiration. They have separate sexes; their embryos develop within an amnion and an allantoic membrane, enclosed in a more or less cylindrical egg with a membranous or parchment-like shell. Reptiles are much more complex than fish in all aspects of their organization, which is primarily terrestrial. None of them are fully aquatic: crocodiles, like lizards and snakes, breathe through lungs and must periodically surface to inhale air.

Classification of Reptiles

According to the Linnaean classification, reptiles are divided into the following orders:

- **Order Testudines** (turtles)
- **Order Squamata** (snakes, amphisbaenians, and lizards)

- **Order Sphenodontia** (tuataras)
- **Order Crocodilia** (crocodiles)

Cladistic classification, based on evolutionary relationships, no longer uses the term "reptiles" to group these animals. Instead, they are classified as follows:

- **Lepidosaurs:** Tuataras (*Sphenodon*) and squamates (lizards, amphisbaenians, and snakes)
- **Archosaurs:** Crocodiles and birds
- **Testudines:** Turtles

Physical Characteristics of Reptiles

The most notable physical characteristics of this group of animals include:

- A variable body shape, compact in some species and elongated in others.
- A covering of keratinous scales; in some groups, epidermal bony plates and very few glands are present.
- Limbs usually have five toes and are adapted for running, climbing, or swimming, though some reptiles lack limbs altogether.
- A well-defined and developed skeletal structure, including a sternum (with some exceptions) and a ribcage.
- The presence of chromatophores, allowing for a variety of colors.
- A well-developed jaw with teeth capable of exerting significant pressure.

Reproduction of Reptiles

Reptiles have separate sexes and internal fertilization. Males possess paired testes that produce sperm, which travel through the deferent ducts to the cloacal wall, forming the copulatory organ.

Females have paired ovaries, and their oviducts provide nutrients for the embryo and produce a protective eggshell. Reptiles have evolved to lay their eggs on land, where the shell and internal membranes offer protection and nutrition, allowing the eggs to develop in dry environments.

Hatchlings are born with lungs, meaning they do not undergo a larval stage requiring water. Some reptiles are viviparous, having developed modifications similar to a placenta.

Diet of Reptiles

Reptiles can be either herbivorous or carnivorous. Iguanas belong to the herbivorous group, while crocodiles are carnivorous.

Habitat of Reptiles

Reptiles have a widespread global distribution. Many thrive in terrestrial habitats, though some have arboreal habits. Others, while breathing at the surface, frequently inhabit aquatic environments.

Examples of Reptiles

Notable species include:

- **Green sea turtle** (*Chelonia mydas*)
- **Hermann's tortoise** (*Testudo hermanni*)
- **Indian cobra** (*Naja naja*)
- **Green anaconda** (*Eunectes murinus*)
- **Tuatara** (*Sphenodon punctatus*)
- **Green iguana** (*Iguana iguana*)
- **Mexican blind lizard** (*Anelytropsis papillosus*)
- **Flying dragon** (*Draco spilonotus*)
- **Komodo dragon** (*Varanus komodoensis*)
- **Orinoco crocodile** (*Crocodylus intermedius*)

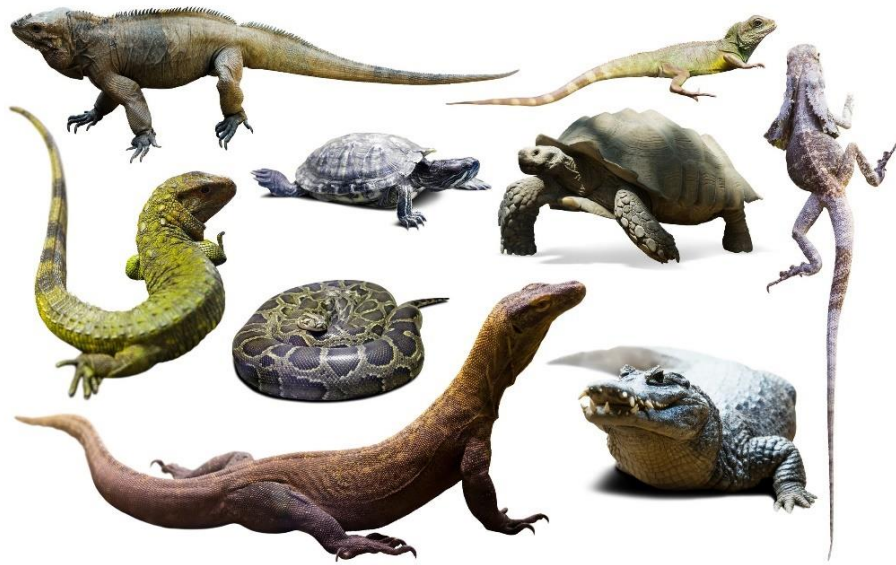


Figure 41 : Reptiles

B.4 Birds

(Borrowed from Latin *aucellus*; from *avis*, meaning the same) Birds form a class of animals within the vertebrate phylum. They are characterized by warm-blooded circulation with a constant body temperature, primarily oviparous reproduction, and thoracic limbs modified into wings, which generally allow them to fly. They are covered in feathers. There are approximately 10,000 bird species worldwide. Nearly all aspects of their anatomy have been modified for adaptation to flight.

The digestive system is not as developed as in mammals. The absence of a true stomach is compensated by the presence of a crop, a proventriculus, and a gizzard—each forming successive, unequal swellings along the intestinal tract. These structures function to soften and grind food before it is processed in the intestine. The upper portion (midgut) is connected to a liver and pancreas, while the lower portion, known as the cecal intestine, leads to the cloaca, from which the rectum follows.

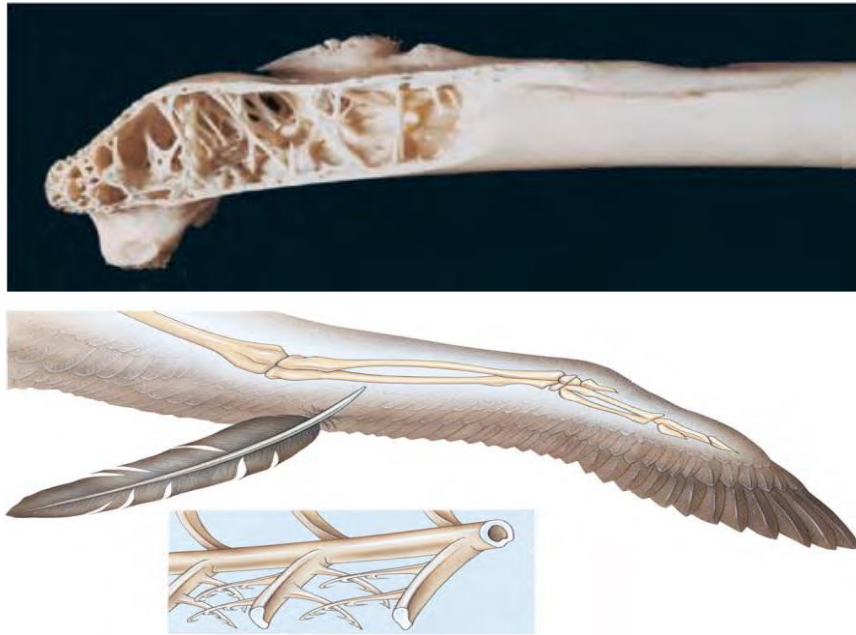


Figure 42 : Wing and feather

Adaptations for Flight

One of the most evident adaptations of birds for flight is their wings and feathers. Feathers are made of beta-keratin, a protein also found in the scales of other reptiles. The shape and arrangement of feathers create an aerodynamic wing profile, following similar principles of aerodynamics as airplane wings.

The power to flap wings comes from the contraction of large pectoral (chest) muscles anchored to a keel on the sternum (breastbone). Some birds, such as eagles and falcons, have wings adapted for soaring on air currents, flapping only occasionally. Others, like hummingbirds, must continuously beat their wings to stay airborne. Among the fastest birds are swifts, which can reach speeds of up to 170 km/h (105 mph).

Flight offers numerous advantages. It enhances hunting and scavenging abilities, as many birds feed on flying insects, a highly abundant and nutritious food source. Flight also provides an easy escape from terrestrial predators and allows some birds to migrate over long distances, taking advantage of different food resources and seasonal breeding areas.

Metabolism and Respiration

Flight demands a significant energy expenditure, requiring an active metabolism. Birds are **endothermic**, meaning they generate their own metabolic heat to maintain a high and constant body temperature. Feathers, along with fat layers in some species, provide insulation, helping birds retain body heat.

Their respiratory system is highly efficient. Tiny air tubes in the lungs connect to elastic air sacs, ensuring continuous airflow and maximizing oxygen intake. This efficient respiratory system, combined with a circulatory system featuring a four-chambered heart, supplies oxygen and nutrients to tissues, supporting a high metabolic rate. Flight also requires keen vision and fine muscle control.

Birds have color vision and excellent eyesight. The visual and motor areas of their brain are well-developed, and their brain is proportionally larger than that of amphibians and non-avian reptiles.

Reproduction in Birds

Birds typically exhibit complex behaviors, especially during the breeding season, when they perform courtship displays. Since bird eggs have hard shells when laid, fertilization must be internal. Mating generally involves direct contact between the cloacal openings of both partners.

Once eggs are laid, the avian embryo must be kept warm through **incubation**, which can be performed by the mother, father, or both, depending on the species.

The Bird Beak: A Key Adaptation

Birds have distinct features that set them apart in the animal kingdom. One of these is their **horned beak**, which forms the external part of their mouth. Unlike other vertebrates, birds have **no teeth**. Their beak is one of many adaptations that have allowed them to colonize a wide variety of environments.

The shape and structure of the beak are highly adapted to their feeding habits. The size, shape, and strength of a bird's beak directly affect its diet. Additionally, the beak, along with leg length and other body characteristics, allows birds to explore different environments and access

diverse food sources. In some species, beak shape plays a role in attracting mates, such as in toucans.

Structurally, a bird's beak consists of an **upper mandible** (culmen) and a **lower mandible**, both covered by a keratinized sheath called the **rhamphotheca**. This external structure is supported by an internal framework.

Types of Bird Beaks

Beak size and shape vary significantly among species. Some common types include:

- **Short, strong, and hooked beaks** (birds of prey and raptors)
- **Spear-shaped beaks** (found in some fish-eating water birds)
- **Long, thin beaks** (common in certain wading birds and insectivores)
- **Thick, short beaks** (typical of granivorous birds)

Additionally, some birds are **generalists**, meaning their beaks are not highly specialized, allowing them to consume a variety of foods. In contrast, **specialist birds** have beaks adapted to specific diets, sometimes with extremely specialized structures—such as those of certain hummingbirds.



Figure 43 : Some common types of beaks

B.5. Mammals:

Mammals form a class of warm-blooded vertebrates with skin covered in hair. However, among mammals, cetaceans have very few hairs. They almost always give birth to live young, and females have specialized glands called mammary glands, which secrete milk to nourish their offspring. This last characteristic, which has no exceptions, is what gives the class its name.

The other common characteristics of all mammals include those of vertebrates. Their digestive system is complete, with a mouth equipped with teeth, an esophagus, a stomach, intestines, a liver, and a pancreas. Their blood is red and warm, and their heart has four chambers—two ventricles and two atria. Their respiration is pulmonary. All mammals, except for a few marine mammals, have four limbs used for locomotion.

Within this class, there are vast differences in size, from tiny bats weighing just over 4 grams to massive animals like the blue whale, which can weigh over 150 tons and measure around 30 meters in length. Some species can fly, others are aquatic, and some live underground. Mammals inhabit all regions of the world, from oceans and polar areas to high mountains and arid deserts.

Subclasses of Mammals:

A. Subclass Prototheria:

Most mammals, including humans, reproduce sexually, requiring male and female reproductive cells for fertilization and development. However, some mammals lay eggs. These belong to the order Monotremata, which includes mammals with reptilian characteristics and an oviparous mode of reproduction. They lay eggs through a cloaca, an opening that serves digestive, urinary, and reproductive functions.

Despite their reptilian traits, monotremes also share characteristics with other mammals:

- They are homeothermic (can regulate their body temperature).
- Their skin is covered in hair.
- They nurse their young with milk produced by mammary glands.
- They have a diaphragm.
- Their heart has four chambers.

- These unique features make monotremes a mix of different animal groups, making them truly exceptional.

The Platypus

The platypus (*Ornithorhynchus anatinus*) has a peculiar appearance, as if made from different animal parts: it has a duck-like bill, webbed otter-like feet, a beaver-like tail, and dense fur. Interestingly, the platypus is venomous—males have a spur on their hind legs to defend against predators. Its thick brown fur, with gray or yellow patches, keeps it warm in the water, where it spends most of its time. Most specimens are about 60 cm long and weigh around 3 kg.

The platypus is native to eastern Australia and lives in burrows near rivers. It feeds on insects and invertebrates, which it catches using electrolocation—detecting the weak electrical signals produced by other animals when they move.

For reproduction, female platypuses lay eggs formed in the uterus and incubate them for about 10 days. They usually lay one to three eggs, with two being most common. Once hatched, the young feed on milk secreted through the mother's skin, as platypuses do not have nipples.



Figure 44 : Platypus

The Echidna

The echidna, scientifically named Tachyglossidae, is the other egg-laying mammal. It has a robust body covered in long spines (about 7 cm long) and short fur. It lacks a tail and looks similar to a hedgehog.

To defend itself, the echidna burrows into the ground, exposing only its spiny back. There are two species: the short-beaked and long-beaked echidna. It is found only in New Guinea and Australia, is nocturnal, and hides in rocks, tree roots, and bushes during the day. It is a good swimmer and mainly feeds on insects, using its keen sense of smell and sticky 20 cm-long

tongue to catch prey. Lacking teeth, it grinds food with keratinized spikes on the roof of its mouth.

Like the platypus, the echidna lays eggs but nurses its young with milk from mammary glands.



Figure 45 : Echidnas

B. Subclass Theria

This subclass is divided into two infraclasses:

B.1 Infraclass Metatheria (Marsupials)

Among Australia's most distinctive mammals are the marsupials, including kangaroos, koalas, and quokkas. They have thick fur that protects them from high temperatures and frequent wildfires. Unlike other mammals, marsupial young are born underdeveloped and continue to grow inside an external pouch that functions similarly to a placenta.



Figure 46 : kangaroos

Kangaroos are well-known marsupials that raise their young in their pouch until they are strong enough to survive outside.

B.2 Infraclass Eutheria (Placentals)

This infraclass includes the placental mammals, which make up the most diverse group of mammals. Eutherians include all placental mammals as well as marsupials.

Classification of Placental Mammals:

Placental mammals are classified into 18 orders, each with distinct characteristics:

- **Xenarthra** (29 species) – Found only in the Americas, includes anteaters (*Tamandua mexicana*), sloths (*Choloepus didactylus*), and armadillos.
- **Pholidota** (7 species) – Includes pangolins (*Manis crassicaudata*), known for their large body scales and long, sticky tongues to eat termites.
- **Lagomorpha** (80 species) – Includes hares and rabbits, which have continuously growing incisors.
- **Rodentia** (2024 species) – The largest order, including rats, mice, and squirrels, found worldwide.
- **Macroscelidea** (15 species) – Includes elephant shrews (*Elephantulus brachyrhynchus*), small African mammals with long snouts.
- **Primates** (236 species) – Includes monkeys, lemurs, apes, and humans (*Homo sapiens*).
- **Scandentia** (19 species) – Tree shrews, small mammals adapted to arboreal life in Southeast Asia.
- **Dermoptera** (2 species) – Flying lemurs (*Colugos*), which glide between trees.
- **Chiroptera** (928 species) – Bats, the only mammals capable of true flight.
- **Carnivora** (271 species) – Includes bears, lions, wolves, otters, and seals.
- **Insectivora** (429 species) – Includes shrews, hedgehogs, and moles.
- **Artiodactyla** (220 species) – Hoofed mammals with an even number of toes, such as deer, cattle, and giraffes.
- **Cetacea** (78 species) – Fully aquatic mammals including whales, dolphins, and porpoises.
- **Tubulidentata** (1 species) – The armadillo (*Orycteropus afer*), which feeds on termites.
- **Perissodactyla** (18 species) – Hoofed mammals with an odd number of toes, including horses, rhinos, and tapirs.
- **Hyracoidea** (6 species) – Hyraxes, which resemble rodents but are related to elephants.

- Proboscidea (2 species) – Elephants, distinguished by their trunks.
- **Sirenia** (5 species) – Fully aquatic herbivores, including manatees and dugongs.

Placental mammals are the most diverse and widespread group of mammals, found in almost every environment on Earth.

This overview highlights the incredible diversity of mammals, from tiny bats to massive whales, and from egg-laying monotremes to highly evolved primates. Their adaptability has allowed them to thrive in nearly every habitat on the planet.



Figure 46 : Orders of Eutheria (Placentals)

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