
Aquatic Animals
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Fish

Fish
Fossil range: Ordovician–Neogene

A giant grouper at the Georgia Aquarium, seen swimming among schools of other fish

The ornate lionfish as seen from a head-on view

Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
(unranked)	Craniata

Included groups
Jawless fish
†Armoured fish
Cartilaginous fish
Ray-finned fish
Lobe-finned fishes

Excluded groups
Tetrapods

A **fish** is any aquatic vertebrate animal that is covered with scales, and equipped with two sets of paired fins and several unpaired fins. Most fish are "cold-blooded", or ectothermic, allowing their body temperatures to vary as ambient temperatures change. Fish are abundant in most bodies of water. They can be found in nearly all aquatic environments, from high mountain streams (e.g., char and gudgeon) to the abyssal and even hadal depths of the deepest oceans (e.g., gulpers and anglerfish). At 31,900 species, fish exhibit greater species diversity than any other class of vertebrates.

Food prepared from animals classified as fish is also referred to as fish, and is an important human food source. Commercial and subsistence fishers hunt fish in wild fisheries or farm them in ponds or in cages in the ocean. They are also caught by recreational fishers and raised by fishkeepers, and are exhibited in public aquaria. Fish have had a role in culture through the ages, serving as deities, religious symbols, and as the subjects of art, books and movies.

Diversity of fish

The term "fish" most precisely describes any non-tetrapod craniate (i.e. an animal with a skull and in most cases a backbone) that has gills throughout life and whose limbs, if any, are in the shape of fins. Unlike groupings such as birds or mammals, fish are not a single clade but a paraphyletic collection of taxa, including hagfishes, lampreys, sharks and rays, ray-finned fish, coelacanths, and lungfish. Indeed, lungfish and coelacanths are closer relatives of tetrapods (such as mammals, birds, amphibians, etc.) than of other fish such as ray-finned fish or sharks, so the last common ancestor of all fish is also an ancestor to tetrapods. As paraphyletic groups are no longer recognised in modern systematic biology, the use of the term "fish" as a biological group must be avoided.

Many types of aquatic animals commonly referred to as "fish" are not fish in the sense given above; examples include shellfish, cuttlefish, starfish, crayfish and jellyfish. In earlier times, even biologists did not make a distinction – sixteenth century natural historians classified also seals, whales, amphibians, crocodiles, even hippopotamuses, as well as a host of aquatic invertebrates, as fish. However, according the definition above, all mammals, including Cetaceans like Whales and Dolphins, are not fish. In some contexts, especially in aquaculture, the true fish are referred to as **finfish** (or **fin fish**) to distinguish them from these other animals.

A typical fish is ectothermic, has a streamlined body for rapid swimming, extracts oxygen from water using gills or uses an accessory breathing organ to breathe atmospheric oxygen, has two sets of paired fins, usually one or two (rarely three) dorsal fins, an anal fin, and a tail fin, has jaws, has skin that is usually covered with scales, and lays eggs.

Fish come in many shapes and sizes. This is a sea dragon, a close relative of the seahorse. Their leaf-like appendages enable them to blend in with floating seaweed.

Each criterion has exceptions. Tuna, swordfish, and some species of sharks show some warm-blooded adaptations—they can heat their bodies significantly above ambient water temperature. Streamlining and swimming performance varies from fish such as tuna, salmon, and jacks that can cover 10–20 body-lengths per second to species such as eels and rays that swim no more than 0.5 body-lengths per second. Many groups of freshwater fish extract oxygen from the air as well as from the water using a variety of different structures. Lungfish have paired lungs similar to those of tetrapods, gouramis have a structure called the labyrinth organ that performs a similar function, while many catfish, such as *Corydoras* extract oxygen via the intestine or stomach. Body shape and the arrangement of the fins is highly variable, covering such seemingly un-fishlike forms as seahorses, pufferfish, anglerfish, and gulpers. Similarly, the surface of the skin may be naked (as in moray eels), or covered with scales of a variety of different types usually defined as placoid (typical of sharks and rays), cosmoid (fossil lungfish and coelacanths), ganoid (various fossil fish but also living gars and bichirs), cycloid, and ctenoid (these last two are found on most bony fish). There are even fish that live mostly on land. Mudskippers feed and interact with one another on mudflats and go underwater to hide in their burrows. The catfish *Phreatobius cisternarum* lives in underground, phreatic habitats, and a relative lives in waterlogged leaf litter.

Fish range in size from the huge 16-metre (52 ft) whale shark to the tiny 8-millimetre (0.3 in) stout infantfish.

Taxonomy

Fish are a paraphyletic group: that is, any clade containing all fish also contains the tetrapods, which are not fish. For this reason, groups such as the "Class Pisces" seen in older reference works are no longer used in formal classifications.

Fish are classified into the following major groups:

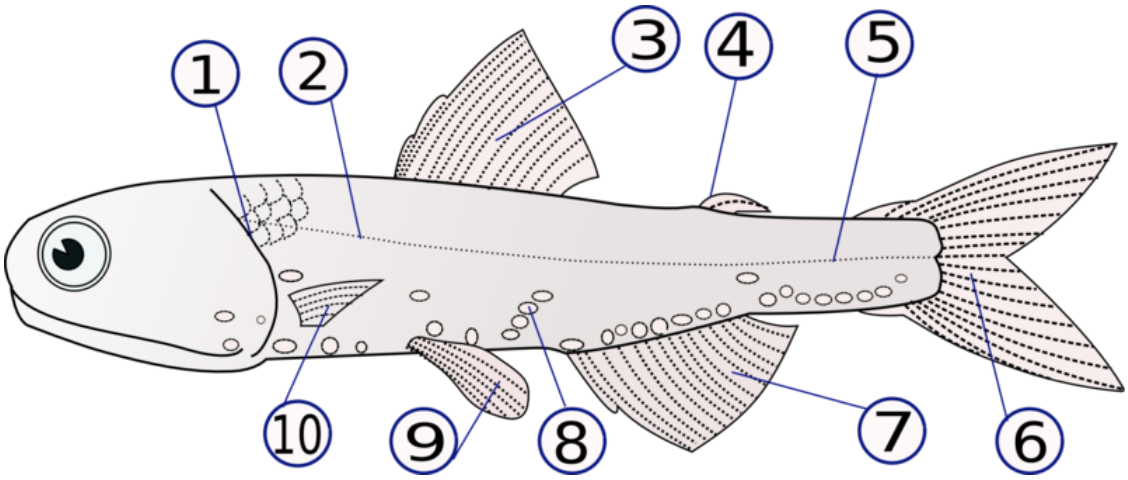
- Class Myxini (hagfish)
- Class Pteraspidomorphi (early jawless fish)
- Class Thelodonti
- Class Anaspida
- Class Petromyzontida or Hyperoartia
    - Petromyzontidae (lampreys)
- Class Conodonta (conodonts)
- Class Cephalaspidomorphi (early jawless fish)
    - (unranked) Galeaspida
    - (unranked) Pituriaspida
    - (unranked) Osteostraci
- Infraphylum Gnathostomata (jawed vertebrates)
    - Class Placodermi (armoured fish, extinct)
    - Class Chondrichthyes (cartilaginous fish)
    - Class Acanthodii (spiny sharks, extinct)
    - Superclass Osteichthyes (bony fish)
        - Class Actinopterygii (ray-finned fish)
            - Subclass Chondrostei
                - Order Acipenseriformes (sturgeons and paddlefishes)
                - Order Polypteriformes (reedfishes and bichirs).
            - Subclass Neopterygii
                - Infraclass Holostei (gars and bowfins)
                - Infraclass Teleostei (many orders of common fish)
        - Class Sarcopterygii (lobe-finned fish)
            - Subclass Coelacanthimorpha (coelacanths)
            - Subclass Dipnoi (lungfish)

Some palaeontologists contend that because Conodonta are chordates, they are primitive fish.

The position of hagfish in the phylum chordata is not settled. Phylogenetic research in 1998 and 1999 supported the idea that the hagfish and the lampreys form a natural group, the Cyclostomata, that is a sister group of the Gnathostomata.

The various fish groups account for more than half of vertebrate species. There are almost 28,000 known extant species, of which almost 27,000 are bony fish, with 970 sharks, rays, and chimeras and about 108 hagfish and lampreys. A third of these species fall within the nine largest families; from largest to smallest, these families are Cyprinidae, Gobiidae, Cichlidae, Characidae, Loricariidae, Balitoridae, Serranidae, Labridae, and Scorpaenidae. About 64 families are monotypic, containing only one species. The final total of extant species may grow to exceed 32,500.

Anatomy



The anatomy of *Lampanyctodes hectoris*
(1) – operculum (gill cover), (2) – lateral line, (3) – dorsal fin, (4) – fat fin, (5) – caudal peduncle, (6) – caudal fin, (7) – anal fin, (8) – photophores, (9) – pelvic fins (paired), (10) – pectoral fins (paired)

Respiration

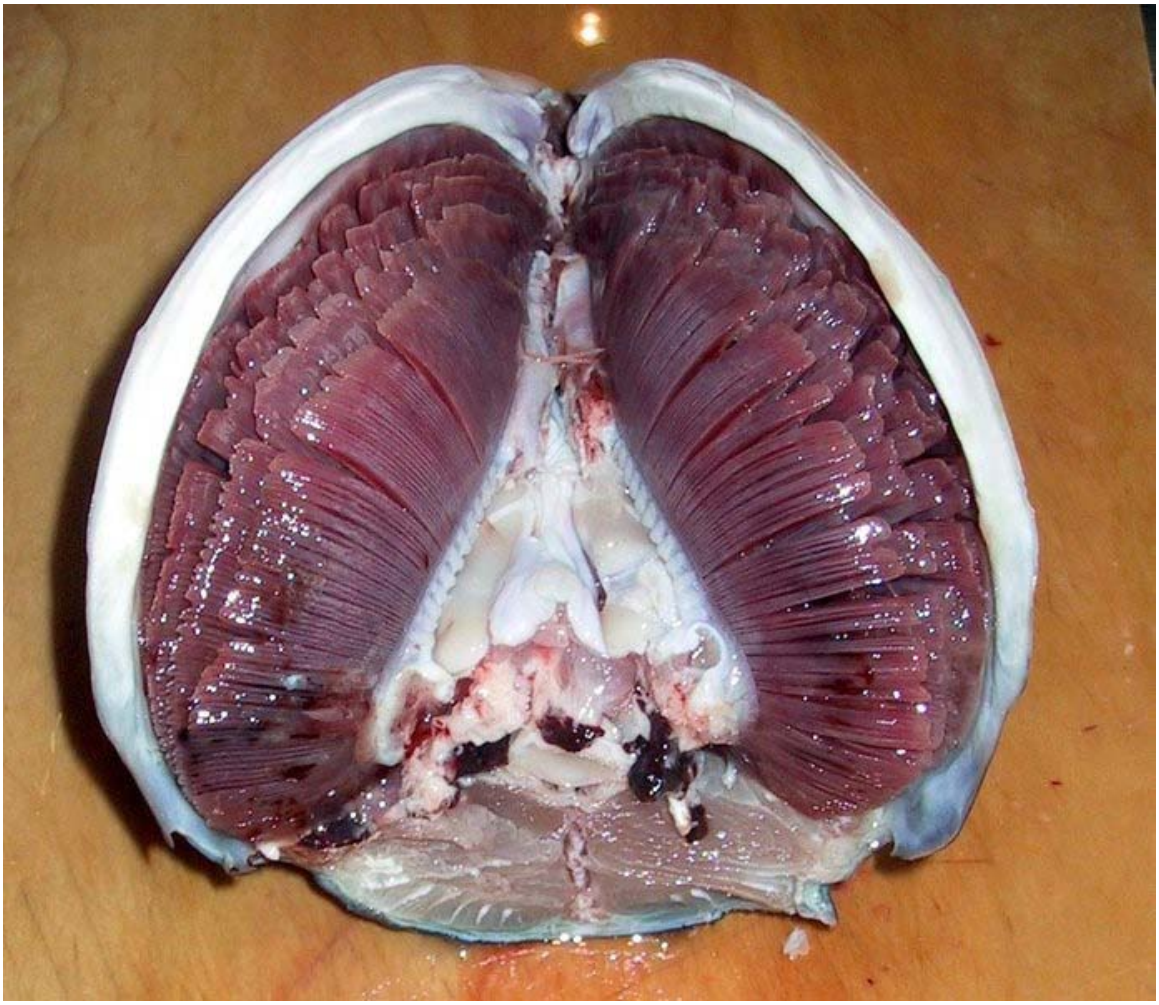
Most fish exchange gases using gills on either side of the pharynx. Gills consist of threadlike structures called filaments. Each filament contains a capillary network that provides a large surface area for exchanging oxygen and carbon dioxide. Fish exchange gases by pulling oxygen-rich water through their mouths and pumping it over their gills. In some fish, capillary blood flows in the opposite direction to the water, causing counter current exchange. The gills push the oxygen-poor water out through openings in the sides of the pharynx. Some fish, like sharks and lampreys, possess multiple gill openings. However, most fish have a single gill opening on each side. This opening is hidden beneath a protective bony cover called an operculum.

Juvenile bichirs have external gills, a very primitive feature that they share with larval amphibians.

Swim bladder of a Rudd (Scardinius erythrophthalmus)

Many fish can breathe air via a variety of mechanisms. The skin of anguillid eels may absorb oxygen. The buccal cavity of the electric eel may breathe air. Catfish of the families Loricariidae, Callichthyidae, and Scoloplacidae absorb air through their digestive tracts. Lungfish, with the exception of the Australian lungfish, and bichirs have paired lungs similar to those of tetrapods and must surface to gulp fresh air through the mouth and pass spent air out through the gills. Gar and bowfin have a vascularized swim bladder that functions in the same way. Loaches, trahiras, and many catfish breathe by passing air through the gut. Mudskippers breathe by absorbing oxygen across the skin (similar to frogs). A number of fish have evolved so-called **accessory breathing organs** that extract oxygen from the air. Labyrinth fish (such as gouramis and bettas) have a labyrinth organ above the gills that performs this function. A few other fish have structures resembling labyrinth organs in form and function, most notably snakeheads, pikeheads, and the Clariidae catfish family.

Breathing air is primarily of use to fish that inhabit shallow, seasonally variable waters where the water's oxygen concentration may seasonally decline. Fish dependent solely on dissolved oxygen, such as perch and cichlids, quickly suffocate, while air-breathers survive for much longer, in some cases in water that is little more than wet mud. At the most extreme, some air-breathing fish are able to survive in damp burrows for weeks without water, entering a state of aestivation (summertime hibernation) until water returns.



Tuna gills inside of the head. The fish head is oriented snout-downwards, with the view looking towards the mouth.

Fish can be divided into **obligate air breathers** and **facultative air breathers**. Obligate air breathers, such as the African lungfish, *must* breathe air periodically or they suffocate. Facultative air breathers, such as the catfish *Hypostomus plecostomus*, only breathe air if they need to and will otherwise rely on their gills for oxygen. Most air breathing fish are facultative air breathers that avoid the energetic cost of rising to the surface and the fitness cost of exposure to surface predators.

Circulation

Fish have a closed-loop circulatory system. The heart pumps the blood in a single loop throughout the body. In most fish, the heart consists of four parts, including two chambers and an entrance and exit. The first part is the sinus venosus, a thin-walled sac that collects blood from the fish's veins before allowing it to flow to the second part, the atrium, which is a large muscular chamber. The atrium serves as a one-way antechamber, sends blood to the third part, ventricle. The ventricle is another thick-walled, muscular

chamber and it pumps the blood, first to the fourth part, bulbous arteriosus, a large tube, and then out of the heart. The bulbus arteriosus connects to the aorta, through which blood flows to the gills for oxygenation.

Digestion

Jaws allow fish to eat a wide variety of food, including plants and other organisms. Fish ingest food through the mouth and break it down in the esophagus. In the stomach, food is further digested and, in many fish, processed in finger-shaped pouches called pyloric caeca, which secrete digestive enzymes and absorb nutrients. Organs such as the liver and pancreas add enzymes and various chemicals as the food moves through the digestive tract. The intestine completes the process of digestion and nutrient absorption.

Excretion

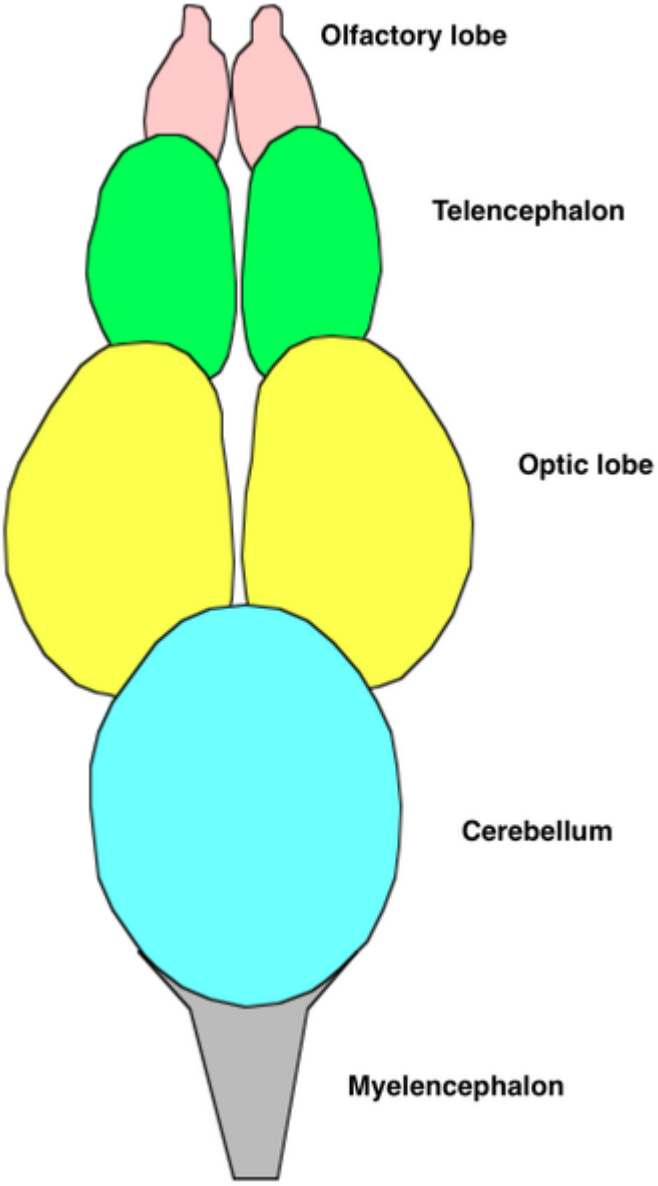
As with many aquatic animals, most fish release their nitrogenous wastes as ammonia. Some of the wastes diffuse through the gills. Blood wastes are filtered by the kidneys.

Saltwater fish tend to lose water because of osmosis. Their kidneys return water to the body. The reverse happens in freshwater fish: they tend to gain water osmotically. Their kidneys produce dilute urine for excretion. Some fish have specially adapted kidneys that vary in function, allowing them to move from freshwater to saltwater.

Scales

The scales of fish originate from the mesoderm (skin); they may be similar in structure to teeth.

Sensory and nervous system



Dorsal view of the brain of the rainbow trout

Central nervous system

Fish typically have quite small brains relative to body size compared with other vertebrates, typically one-fifteenth the brain mass of a similarly sized bird or mammal. However, some fish have relatively large brains, most notably mormyrids and sharks, which have brains about as massive relative to body weight as birds and marsupials.

Fish brains are divided into several regions. At the front are the olfactory lobes, a pair of structures that receive and process signals from the nostrils via the two olfactory nerves.

The olfactory lobes are very large in fish that hunt primarily by smell, such as hagfish, sharks, and catfish. Behind the olfactory lobes is the two-lobed telencephalon, the structural equivalent to the cerebrum in higher vertebrates. In fish the telencephalon is concerned mostly with olfaction. Together these structures form the **forebrain**.

Connecting the forebrain to the **midbrain** is the diencephalon (in the diagram, this structure is below the optic lobes and consequently not visible). The diencephalon performs functions associated with hormones and homeostasis. The pineal body lies just above the diencephalon. This structure detects light, maintains circadian rhythms, and controls color changes.

The midbrain or mesencephalon contains the two optic lobes. These are very large in species that hunt by sight, such as rainbow trout and cichlids.

The **hindbrain** or metencephalon is particularly involved in swimming and balance. The cerebellum is a single-lobed structure that is typically the biggest part of the brain. Hagfish and lampreys have relatively small cerebellae, while the mormyrid cerebellum is massive and apparently involved in their electrical sense.

The **brain stem** or myelencephalon is the brain's posterior. As well as controlling some muscles and body organs, in bony fish at least, the brain stem governs respiration and osmoregulation.

Sense organs

Most fish possess highly developed sense organs. Nearly all daylight fish have color vision that is at least as good as a human's. Many fish also have chemoreceptors that are responsible for extraordinary senses of taste and smell. Although they have ears, many fish may not hear very well. Most fish have sensitive receptors that form the lateral line system, which detects gentle currents and vibrations, and senses the motion of nearby fish and prey. Some fish, such as catfish and sharks, have organs that detect low-level electric current. Other fish, like the electric eel, can produce electric current.

Fish orient themselves using landmarks and may use mental maps based on multiple landmarks or symbols. Fish behavior in mazes reveals that they possess spatial memory and visual discrimination.

Capacity for pain

Experiments done by William Tavolga provide evidence that fish have pain and fear responses. For instance, in Tavolga’s experiments, toadfish grunted when electrically shocked and over time they came to grunt at the mere sight of an electrode.

In 2003, Scottish scientists at the University of Edinburgh and the Roslin Institute concluded that rainbow trout exhibit behaviors often associated with pain in other animals. Bee venom and acetic acid injected into the lips resulted in fish rocking their

bodies and rubbing their lips along the sides and floors of their tanks, which the researchers concluded were attempts to relieve pain, similar to what mammals would do. Neurons fired in a pattern resembling human neuronal patterns.

Professor James D. Rose of the University of Wyoming claimed the study was flawed since it did not provide proof that fish possess "conscious awareness, particularly a kind of awareness that is meaningfully like ours". Rose argues that since fish brains are so different from human brains, fish are probably not conscious in the manner humans are, so that reactions similar to human reactions to pain instead have other causes. Rose had published a study a year earlier arguing that fish cannot feel pain because their brains lack a neocortex. However, animal behaviorist Temple Grandin argues that fish could still have consciousness without a neocortex because "different species can use different brain structures and systems to handle the same functions."

Animal welfare advocates raise concerns about the possible suffering of fish caused by angling. Some countries, such as Germany have banned specific types of fishing, and the British RSPCA now formally prosecutes individuals who are cruel to fish.

Muscular system

Most fish move by alternately contracting paired sets of muscles on either side of the backbone. These contractions form S-shaped curves that move down the body. As each curve reaches the back fin, backward force is applied to the water, and in conjunction with the fins, moves the fish forward. The fish's fins function like an airplane's flaps. Fins also increase the tail's surface area, increasing speed. The streamlined body of the fish decreases the amount of friction from the water. Since body tissue is denser than water, fish must compensate for the difference or they will sink. Many bony fish have an internal organ called a swim bladder that adjusts their buoyancy through manipulation of gases.

Homeothermy

A 3-tonne (3.0 LT; 3.3 ST) great white shark off Isla Guadalupe

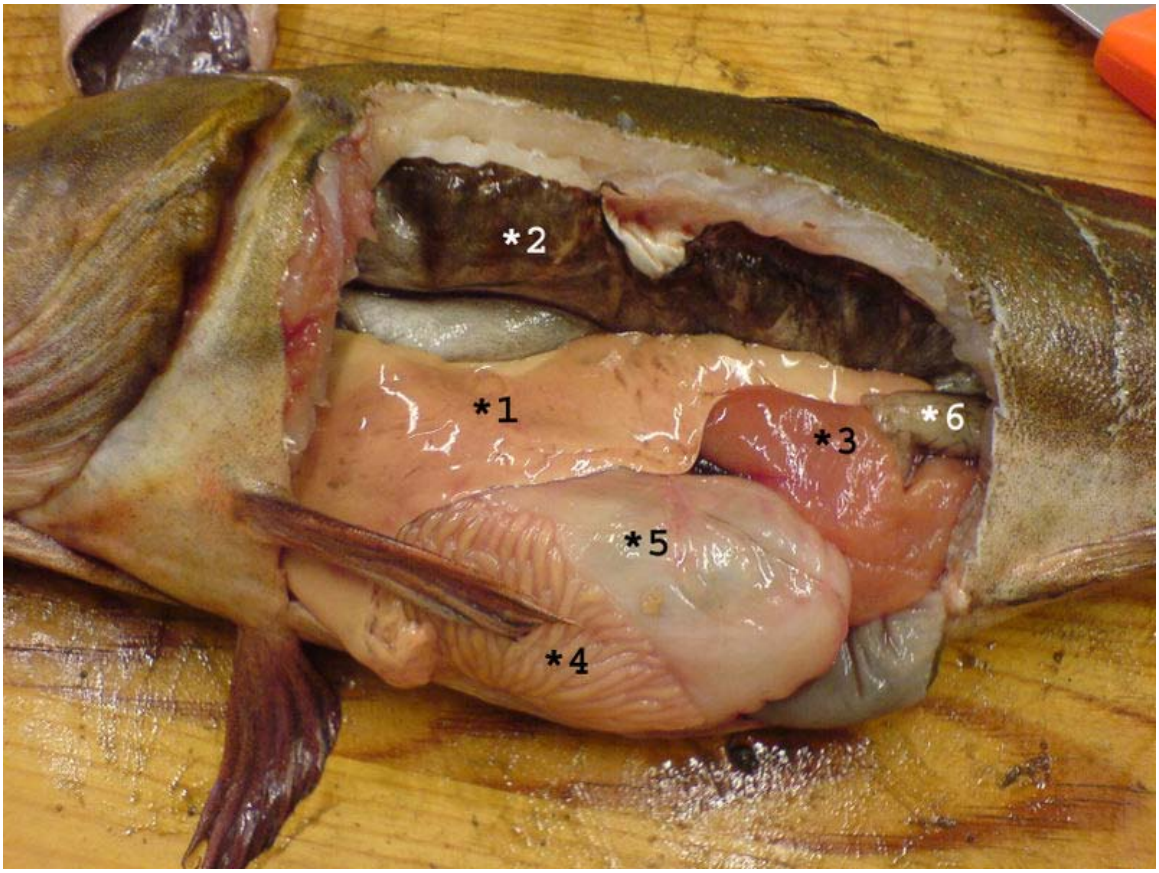
Although most fish are exclusively aquatic and ectothermic, there are exceptions to both cases.

Fish from multiple groups can live out of the water for extended time periods. Amphibious fish such as the mudskipper can live and move about on land for up to several days.

Certain species of fish maintain elevated body temperatures. Endothermic teleosts (bony fish) are all in the suborder Scombroidei and include the billfishes, tunas, and one species of "primitive" mackerel (*Gasterochisma melampus*). All sharks in the family Lamnidae – shortfin mako, long fin mako, white, porbeagle, and salmon shark – are endothermic, and evidence suggests the trait exists in family Alopiidae (thresher sharks). The degree of endothermy varies from the billfish, which warm only their eyes and brain, to bluefin tuna and porbeagle sharks who maintain body temperatures elevated in excess of 20 °C above ambient water temperatures. Endothermy, though metabolically costly, is thought to provide advantages such as increased muscle strength, higher rates of central nervous system processing, and higher rates of digestion.

Reproductive system

Organs



Organs: 1. Liver, 2. Gas bladder, 3. Roe, 4. Pyloric caeca, 5. Stomach, 6. Intestine

Fish reproductive organs include testes and ovaries. In most species, gonads are paired organs of similar size, which can be partially or totally fused. There may also be a range of secondary organs that increase reproductive fitness.

In terms of spermatogonia distribution, the structure of teleosts testes has two types: in the most common, spermatogonia occur all along the seminiferous tubules, while in Atherinomorph fish they are confined to the distal portion of these structures. Fish can present cystic or semi-cystic spermatogenesis in relation to the release phase of germ cells in cysts to the seminiferous tubules lumen.

Fish ovaries may be of three types: gymnovarian, secondary gymnovarian or cystovarian. In the first type, the oocytes are released directly into the coelomic cavity and then enter the ostium, then through the oviduct and are eliminated. Secondary gymnovarian ovaries shed ova into the coelom from which they go directly into the oviduct. In the third type, the oocytes are conveyed to the exterior through the oviduct. Gymnovaries are the primitive condition found in lungfish, sturgeon, and bowfin. Cystovaries characterize

most teleosts, where the ovary lumen has continuity with the oviduct. Secondary gymnovaries are found in salmonids and a few other teleosts.

Oogonia development in teleosts fish varies according to the group, and the determination of oogenesis dynamics allows the understanding of maturation and fertilization processes. Changes in the nucleus, ooplasm, and the surrounding layers characterize the oocyte maturation process.

Postovulatory follicles are structures formed after oocyte release; they do not have endocrine function, present a wide irregular lumen, and are rapidly reabsorbed in a process involving the apoptosis of follicular cells. A degenerative process called follicular atresia reabsorbs vitellogenic oocytes not spawned. This process can also occur, but less frequently, in oocytes in other development stages.

Some fish are hermaphrodites, having both testes and ovaries either at different phases in their life cycle or, as in hamlets, have them simultaneously.

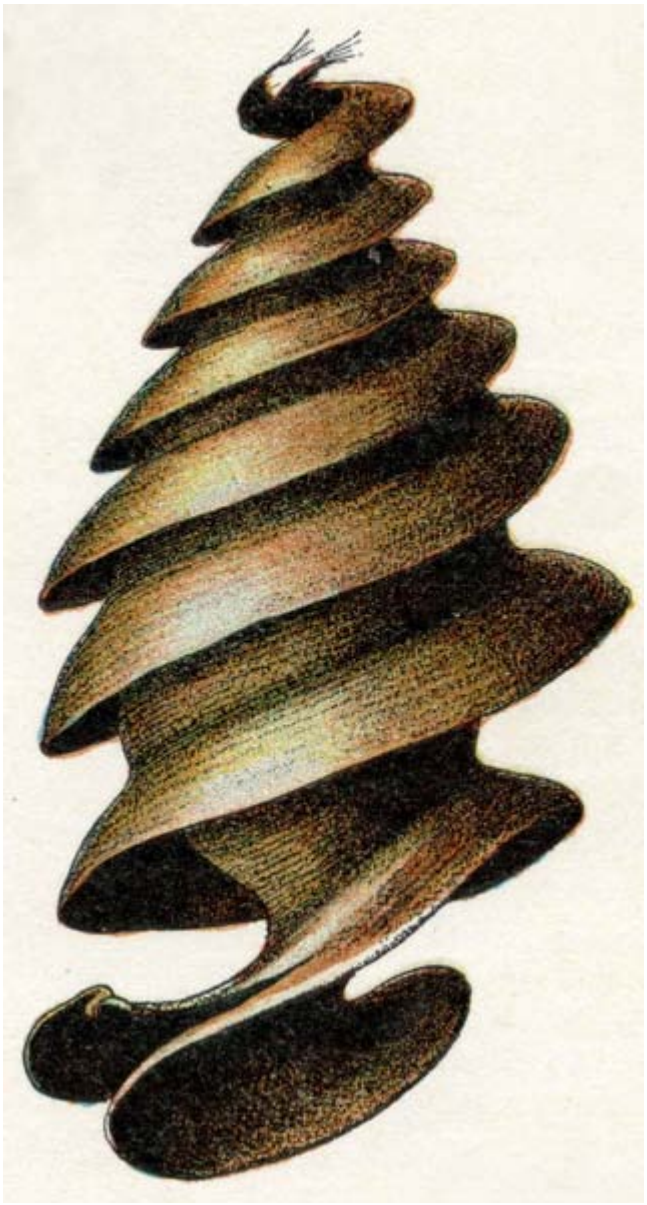
Reproductive method

Over 97% of all known fish are oviparous, that is, the eggs develop outside the mother's body. Examples of oviparous fish include salmon, goldfish, cichlids, tuna, and eels. In the majority of these species, fertilisation takes place outside the mother's body, with the male and female fish shedding their gametes into the surrounding water. However, a few oviparous fish practice internal fertilization, with the male using some sort of intromittent organ to deliver sperm into the genital opening of the female, most notably the oviparous sharks, such as the horn shark, and oviparous rays, such as skates. In these cases, the male is equipped with a pair of modified pelvic fins known as claspers.

Marine fish can produce high numbers of eggs which are often released into the open water column. The eggs have an average diameter of 1 millimetre (0.039 in).

Egg of lamprey

Egg of catshark (mermaids' purse)



Egg of bullhead shark

Egg of chimaera

The newly hatched young of oviparous fish are called larvae. They are usually poorly formed, carry a large yolk sac (for nourishment) and are very different in appearance from juvenile and adult specimens. The larval period in oviparous fish is relatively short (usually only several weeks), and larvae rapidly grow and change appearance and structure (a process termed metamorphosis) to become juveniles. During this transition larvae must switch from their yolk sac to feeding on zooplankton prey, a process which depends on typically inadequate zooplankton density, starving many larvae.

In ovoviviparous fish the eggs develop inside the mother's body after internal fertilization but receive little or no nourishment directly from the mother, depending instead on the

yolk. Each embryo develops in its own egg. Familiar examples of ovoviviparous fish include guppies, angel sharks, and coelacanths.

Some species of fish are viviparous. In such species the mother retains the eggs and nourishes the embryos. Typically, viviparous fish have a structure analogous to the placenta seen in mammals connecting the mother's blood supply with that of the embryo. Examples of viviparous fish include the surf-perches, splitfins, and lemon shark. Some viviparous fish exhibit oophagy, in which the developing embryos eat other eggs produced by the mother. This has been observed primarily among sharks, such as the shortfin mako and porbeagle, but is known for a few bony fish as well, such as the halfbeak *Nomorhamphus ebrardtii*. Intrauterine cannibalism is an even more unusual mode of vivipary, in which the largest embryos eat weaker and smaller siblings. This behavior is also most commonly found among sharks, such as the grey nurse shark, but has also been reported for *Nomorhamphus ebrardtii*.

Aquarists commonly refer to ovoviviparous and viviparous fish as livebearers.

Immune system

Immune organs vary by type of fish. In the jawless fish (lampreys and hagfish), true lymphoid organs are absent. These fish rely on regions of lymphoid tissue within other organs to produce immune cells. For example, erythrocytes, macrophages and plasma cells are produced in the anterior kidney (or pronephros) and some areas of the gut (where granulocytes mature.) They resemble primitive bone marrow in hagfish. Cartilaginous fish (sharks and rays) have a more advanced immune system. They have three specialized organs that are unique to chondrichthyes; the epigonal organs (lymphoid tissue similar to mammalian bone) that surround the gonads, the Leydig's organ within the walls of their esophagus, and a spiral valve in their intestine. These organs house typical immune cells (granulocytes, lymphocytes and plasma cells). They also possess an identifiable thymus and a well-developed spleen (their most important immune organ) where various lymphocytes, plasma cells and macrophages develop and are stored. Chondrostean fish (sturgeons, paddlefish and bichirs) possess a major site for the production of granulocytes within a mass that is associated with the meninges (membranes surrounding the central nervous system.) Their heart is frequently covered with tissue that contains lymphocytes, reticular cells and a small number of macrophages. The chondrostean kidney is an important hemopoietic organ; where erythrocytes, granulocytes, lymphocytes and macrophages develop.

Like chondrostean fish, the major immune tissues of bony fish (or teleostei) include the kidney (especially the anterior kidney), which houses many different immune cells. In addition, teleost fish possess a thymus, spleen and scattered immune areas within mucosal tissues (e.g. in the skin, gills, gut and gonads). Much like the mammalian immune system, teleost erythrocytes, neutrophils and granulocytes are believed to reside in the spleen whereas lymphocytes are the major cell type found in the thymus. In 2006, a lymphatic system similar to that in mammals was described in one species of teleost fish,

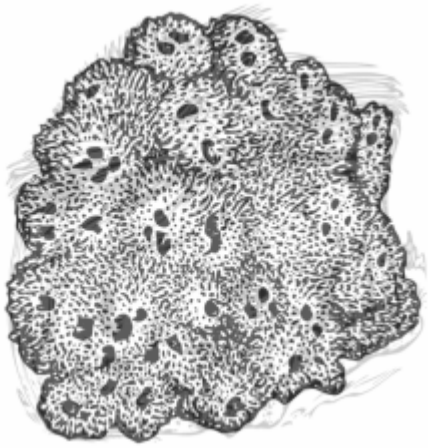
the zebrafish. Although not confirmed as yet, this system presumably will be where naive (unstimulated) T cells accumulate while waiting to encounter an antigen.

Diseases

Like other animals, fish suffer from diseases and parasites. To prevent disease they have a variety of defenses. *Non-specific* defenses include the skin and scales, as well as the mucus layer secreted by the epidermis that traps and inhibits the growth of microorganisms. If pathogens breach these defenses, fish can develop an inflammatory response that increases blood flow to the infected region and delivers white blood cells that attempt to destroy pathogens. Specific defenses respond to particular pathogens recognised by the fish's body, i.e., an immune response. In recent years, vaccines have become widely used in aquaculture and also with ornamental fish, for example furunculosis vaccines in farmed salmon and koi herpes virus in koi.

Some species use cleaner fish to remove external parasites. The best known of these are the Bluestreak cleaner wrasses of the genus *Labroides* found on coral reefs in the Indian and Pacific Oceans. These small fish maintain so-called "cleaning stations" where other fish congregate and perform specific movements to attract the attention of the cleaners. Cleaning behaviors have been observed in a number of fish groups, including an interesting case between two cichlids of the same genus, *Etroplus maculatus*, the cleaner, and the much larger *Etroplus suratensis*.

Evolution



Outdated evolutionary view of continual gradation

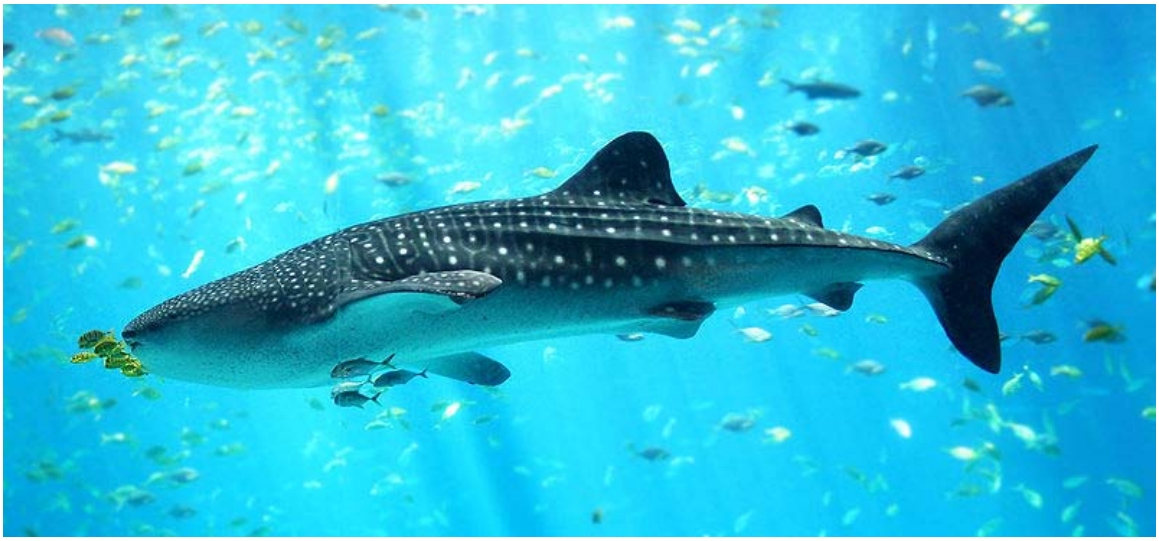
Dunkleosteus was a gigantic, 10 meter (33 ft) long prehistoric fish.

Fish do not represent a monophyletic group, and therefore the "evolution of fish" is not studied as a single event.

Proliferation of fish was apparently due to the hinged jaw, because jawless fish left very few descendants. Lampreys may approximate pre-jawed fish. The first jaws are found in Placodermi fossils. It is unclear if the advantage of a hinged jaw is greater biting force, improved respiration, or a combination of factors.

Fish may have evolved from a creature similar to a coral-like Sea squirt, whose larvae resemble primitive fish in important ways. The first ancestors of fish may have kept the larval form into adulthood (as some sea squirts do today), although perhaps the reverse is the case.

Conservation



A Whale shark, the world's largest fish, is classified as Vulnerable.

The 2006 IUCN Red List names 1,173 fish species that are threatened with extinction. Included are species such as Atlantic cod, Devil's Hole pupfish, coelacanths, and great white sharks. Because fish live underwater they are more difficult to study than terrestrial animals and plants, and information about fish populations is often lacking. However, freshwater fish seem particularly threatened because they often live in relatively small water bodies. For example, the Devil's Hole pupfish occupies only a single 3 by 6 metres (10 by 20 ft) pool.

Overfishing

Overfishing is a major threat to edible fish such as cod and tuna. Overfishing eventually causes population (known as stock) collapse because the survivors cannot produce enough young to replace those removed. Such **commercial extinction** does not mean that the species is extinct, merely that it can no longer sustain a fishery.

One well-studied example of fishery collapse is the Pacific sardine *Sadinops sagax caerulues* fishery off the California coast. From a 1937 peak of 790,000 long tons (800,000 t) the catch steadily declined to only 24,000 long tons (24,000 t) in 1968, after which the fishery was no longer economically viable.

The main tension between fisheries science and the fishing industry is that the two groups have different views on the resiliency of fisheries to intensive fishing. In places such as Scotland, Newfoundland, and Alaska the fishing industry is a major employer, so governments are predisposed to support it. On the other hand, scientists and conservationists push for stringent protection, warning that many stocks could be wiped out within fifty years.

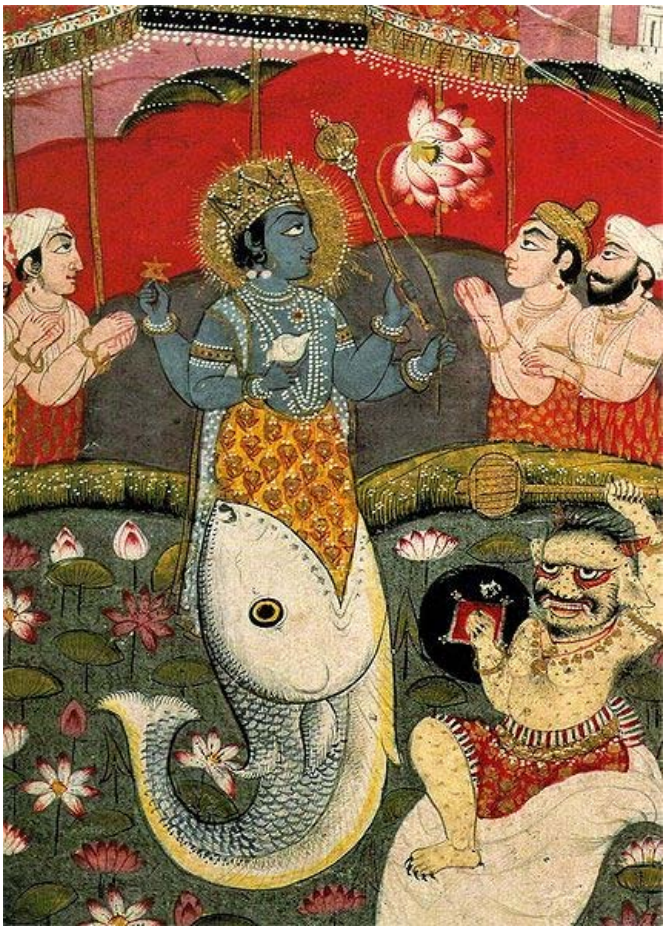
Habitat destruction

A key stress on both freshwater and marine ecosystems is habitat degradation including water pollution, the building of dams, removal of water for use by humans, and the introduction of exotic species. An example of a fish that has become endangered because of habitat change is the pallid sturgeon, a North American freshwater fish that lives in rivers damaged by human activity.

Exotic species

Introduction of non-native species has occurred in many habitats. One of the best studied examples is the introduction of Nile perch into Lake Victoria in the 1960s. Nile perch gradually exterminated the lake's 500 endemic cichlid species. Some of them survive now in captive breeding programmes, but others are probably extinct. Carp, snakeheads, tilapia, European perch, brown trout, rainbow trout, and sea lampreys are other examples of fish that have caused problems by being introduced into a lien environments.

Culture



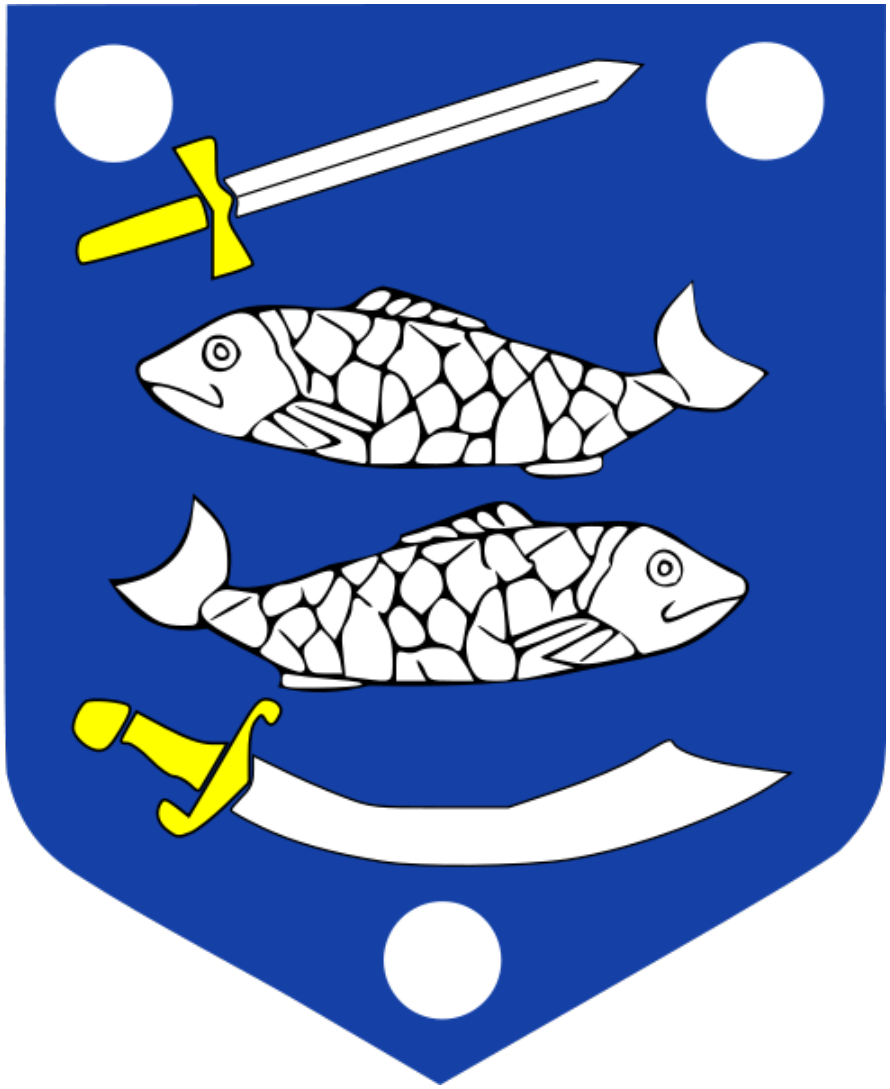
Incarnation of Vishnu as a Merman

In the Book of Jonah a "great fish" swallowed Jonah the Prophet. Legends of half-human, half-fish mermaids have featured in stories like those of Hans Christian Andersen and movies like *Splash*.

Among the deities said to take the form of a fish are Ika-Roa of the Polynesians, Dagon of various ancient Semitic peoples, the shark-gods of Hawai'i and Matsya of the Dravidas of India. The astrological symbol Pisces is based on a constellation of the same name, but there is also a second fish constellation in the night sky, Piscis Austrinus.

Fish have been used figuratively in many different ways, for example the ichthys used by early Christians to identify themselves, through to the fish as a symbol of fertility among Bengalis.

Coat of arms of Comacchio, Italy



coat of arms of Narva, Estonia

Fish feature prominently in art and literature, in movies such as *Finding Nemo* and books such as *The Old Man and the Sea*. Large fish, particularly sharks, have frequently been the subject of horror movies and thrillers, most notably the novel *Jaws*, which spawned a series of films of the same name that in turn inspired similar films or parodies such as *Shark Tale*, *Snakehead Terror*, and *Piranha*.

In the semiotic of Ashtamangala (buddhist symbolism) the golden fish (Sanskrit: Matsya), represents the state of fearless suspension in samsara, perceived as the harmless ocean, referred to as 'buddha-eyes' or 'rigpa-sight'. The fish symbolizes the auspiciousness of all living beings in a state of fearlessness without danger of drowning in the Samsaric Ocean of Suffering, and migrating from teaching to teaching freely and spontaneously just as fish swim.

Fish riders in a 1920s poster of the Republic of China.

They have religious significance in Hindu, Jain and Buddhist traditions but also in Christianity who is first signified by the sign of the fish, and especially referring to feeding the multitude in the desert. In the dhamma of Buddha the fish symbolize happiness as they have complete freedom of movement in the water. They represent fertility and abundance. Often drawn in the form of carp which are regarded in the Orient as sacred on account of their elegant beauty, size and life-span.

The name of the Canadian city of Coquitlam, British Columbia is derived from *Kwikwetlem*, which is said to be derived from a Coast Salish term meaning "little red fish".

Terminology

Fish or fishes?

Though often used interchangeably, these words have different meanings. ***Fish*** is used either as singular noun or to describe a group of specimens from a single species. ***Fishes*** describes a group of different species.

Shoal or school

These goldband fusiliers are schooling because their swimming is synchronised

A random assemblage of fish merely using some localised resource such as food or nesting sites is known simply as an ***aggregation***. When fish come together in an interactive, social grouping, then they may be forming either a *shoal* or a *school* depending on the degree of organisation. A ***shoal*** is a loosely organised group where each fish swims and forages independently but is attracted to other members of the group and adjusts its behaviour, such as swimming speed, so that it remains close to the other members of the group. ***Schools*** of fish are much more tightly organised, synchronising their swimming so that all fish move at the same speed and in the same direction. Shoaling and schooling behaviour is believed to provide a variety of advantages.

Examples:

- Cichlids congregating at lekking sites form an *aggregation*.
- Many minnows and characins form *shoals*.
- Anchovies, herrings and silversides are classic examples of *schooling* fish.

While school and shoal have different meanings within biology, they are often treated as synonyms by non-specialists, with speakers of British English using "shoal" to describe

any grouping of fish, while speakers of American English often using "school" just as loosely.

Chapter- 2

Sea Snake

Sea snake

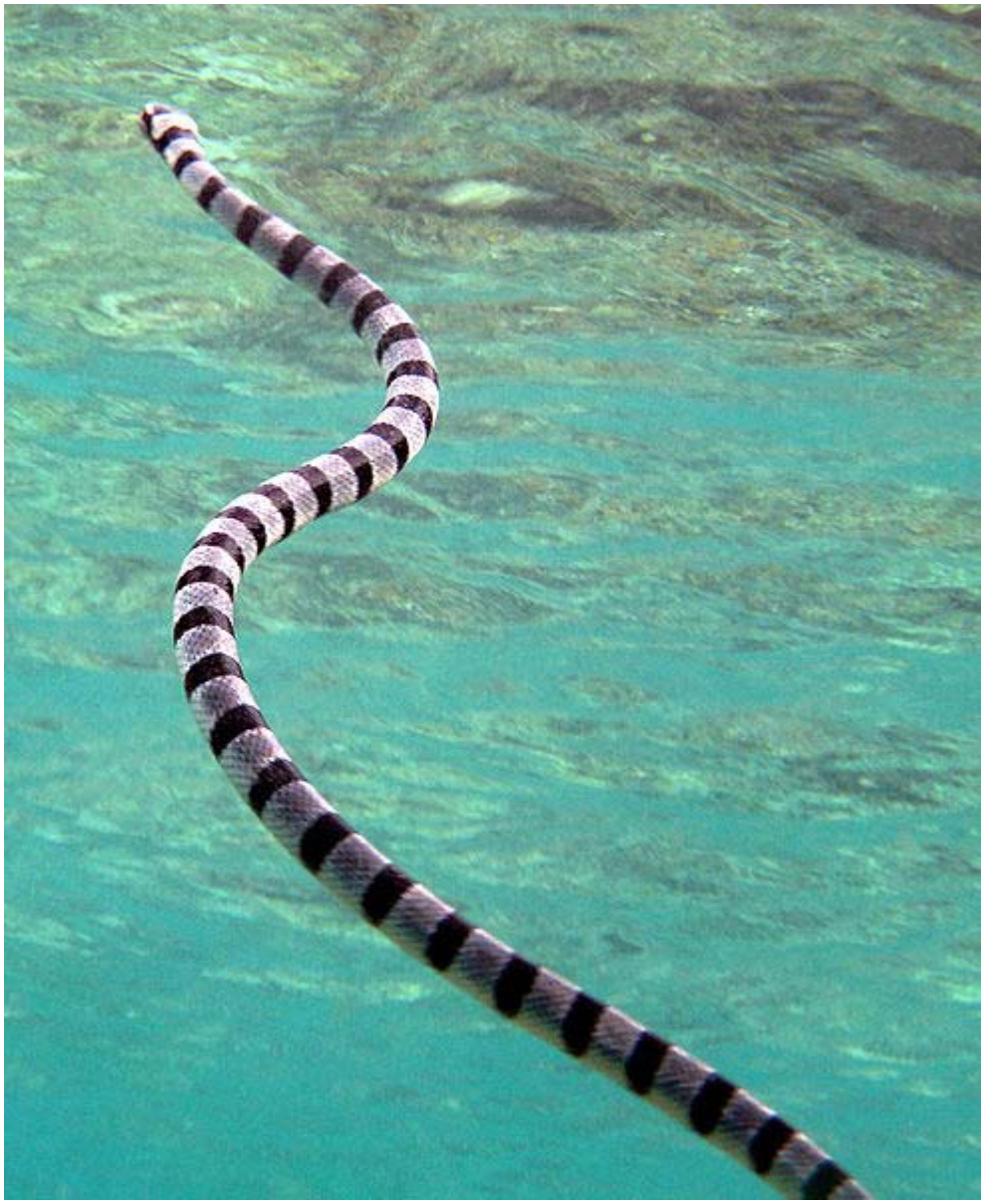
Yellow-bellied sea snake, *Pelamis platurus*
Scientific classification
Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Class: Reptilia
Order: Squamata
Suborder: Serpentes
Family: **Hydrophiidae** Boie, 1827

Sea snakes are venomous elapid snakes that inhabit marine environments for most or all of their lives. Though they evolved from terrestrial ancestors, most are extensively adapted to a fully aquatic life and are unable to even move on land, except for the genus *Laticauda*, which retain ancestral characteristics which allow limited land movement. They are found in warm coastal waters from the Indian Ocean to the Pacific. All have paddle-like tails and many have laterally compressed bodies that give them an eel-like appearance. Unlike fish, they do not have gills and must surface regularly to breathe. They are among the most completely aquatic of all air-breathing vertebrates. Among this group are species with some of the most potent venoms of all snakes. Some have gentle

dispositions and bite only when provoked, but others are much more aggressive. Currently, 17 genera are described as sea snakes, comprising 62 species.

Description

Adults of most species grow to between 120–150 cm (3.9–4.9 ft) in length, with the largest, *Hydrophis spiralis*, reaching a maximum of 3 m (9.8 ft). Their eyes are relatively small with a round pupil and most have nostrils that are located dorsally. The skulls do not differ significantly from terrestrial elapids, although the dentition is relatively primitive with short fangs and (with the exception of *Emydocephalus*) as many as 18 smaller teeth behind them on the maxilla.



Yellow-lipped sea krait, *Laticauda colubrina*.

Most sea snakes are completely aquatic and have adapted to their environment in many ways, the most characteristic of which is a paddle-like tail that has increased their swimming ability. To a varying degree, the bodies of many species are laterally compressed, especially in the pelagic species. This has often caused the ventral scales to become reduced in size, even difficult to distinguish from the adjoining scales. Their lack of ventral scales means that they have become virtually helpless on land, but as they live out their entire life cycle at sea, they have no need to leave the water.

The only genus that has retained the enlarged ventral scales is the sea kraits, *Laticauda*, with only five species. These snakes are considered to be more primitive, as they still spend much of their time on land, where their ventral scales afford them the necessary grip. *Laticauda* are also the only sea snakes with internasal scales, i.e., their nostrils are not located dorsally.

As it is easier for a snake's tongue to fulfill its olfactory function under water, its action is short compared to that of terrestrial snake species. Only the forked tips protrude from the mouth through a divided notch in the middle of the rostral scale. The nostrils have valves consisting of a specialized spongy tissue to exclude water, and the windpipe can be drawn up to where the short nasal passage opens into the roof of the mouth. This an important adaptation for an animal that must surface to breathe, but may have its head partially submerged when doing so. The lung has become very large and extends almost the entire length of the body, although it is thought that the rear portion developed to aid buoyancy rather than to exchange gas. It is also possible that the extended lung serves to store air for dives.

Most sea snakes are able to respire through their skin. This is unusual for reptiles, because their skin is thick and scaly, but experiments with the black-and-yellow sea snake, *Pelamis platurus* (a pelagic species), have shown that this species can satisfy about 20% of its oxygen requirements in this manner, which allows for prolonged dives.

Blue-lipped sea krait, *Laticauda laticaudata*.

Like other land animals that have adapted to life in a marine environment, sea snakes ingest considerably more salt than their terrestrial relatives through their diet and when sea water is inadvertently swallowed. This meant that they had to evolve a more effective means of regulating the salt concentration of their blood. Mammals have the advantage of being able to pass salt in solution, mostly in the urine, but kidney function in birds and reptiles is too weak to remove salt in sufficient amounts. In birds, such as penguins, salt is removed through nasal glands, just as with the marine iguanas of the Galapagos Islands. Sea turtles have lacrimal glands that allow them to produce very salty tears. In sea snakes, the posterior sublingual glands, located under and around the tongue sheath, evolved to allow them to expel salt with their tongue action.

Scalation among sea snakes is highly variable. As opposed to terrestrial snake species that have imbricate scales to protect against abrasion, the scales of most pelagic sea snakes do not overlap. Reef dwelling species, such as *Aypisurus*, do have imbricate scales to protect against the sharp coral. The scales themselves may be smooth, keeled, spiny or granular, the latter often looking like warts. *Pelamis* has body scales that are "peg-like", while those on its tail are juxtaposed hexagonal plates.

Aipysurus laevis has been found to have photoreceptors in the skin of its tail, allowing it to detect light and presumably aiding it to remain hidden inside coral holes during the day. While other species have not been tested, it is possible that *A. laevis* is not unique among sea snakes in this respect.

Distribution and habitat

Sea snakes are mostly confined to the warm tropical waters of the Indian Ocean and the western Pacific Ocean, with a few species found well out into Oceania. The geographic range of one species, *Pelamis platurus*, is wider than that of any other reptile species, save for a few species of sea turtles. It extends from the east coast of Africa, from Djibouti in the north to Cape Town in the south, across the Indian Ocean, the Pacific, south as far as the northern coast of New Zealand, all the way to the western coast of the Americas, where it occurs from northern Peru in the south (including the Galápagos Islands) to the Gulf of California in the north. Isolated specimens have been found as far north as San Clemente in the United States.

Sea snakes do not occur in the Atlantic Ocean. It is thought that *Pelamis* would be found there were it not for the cold currents off Namibia and western South Africa that keep it from crossing into the eastern South Atlantic, or south of 5° latitude along the South American west coast. Sea snakes do not occur in the Red Sea*, believed to be due to its increased salinity, so there is no danger of them crossing through the Suez Canal. Salinity, or rather a lack thereof, is also thought to be the reason why *Pelamis* has not crossed into the Caribbean via the Panama Canal.

Despite their marine adaptations, most sea snakes prefer shallow waters near land, around islands, and especially waters that are somewhat sheltered, as well as near estuaries. They may swim up rivers and have been reported as far as 160 km (99 mi) from the sea. Others, such as *Pelamis platurus*, are pelagic and are found in drift lines; slicks of floating debris brought together by surface currents. Some sea snakes inhabit mangrove swamps and similar brackish water habitats and there are two landlocked fresh water forms: *Hydrophis semperi* occurs in Lake Taal in the Philippines, and *Laticauda crockeri* in Lake Te Nggano on Rennell Island in the Solomon Islands.

Behavior

Stidworthy (1974) describes all sea snake species as being reluctant to bite, and Fichter (1982) adds that they are quite docile. Spawls and Branch (1994) also claims they are mainly non-aggressive. The US Navy describes sea snakes as generally mild tempered, although there is variation among species and individuals. Mehrtens (1987) suggests that species such as *Pelamis platurus*, that feed by simply gulping down their prey, are more likely to bite when provoked because they seem to use their venom more for defence. This is in contrast to others, such as *Laticauda*, that use their venom for prey immobilization; these snakes are frequently handled with impunity by local fishermen. Species that have been reported as much more aggressive include *Aipysurus laevis*, *Astrotia stokesii*, *Enhydrina schistosa* and *Hydrophis ornatus*.

Olive sea snake, *Aipysurus laevis*.

Ditmars (1933) mentions that when they are taken out of the water, their movements become very erratic. They crawl awkwardly in these situations and can become quite aggressive, striking wildly at anything that moves. Yet they are frequently caught in nets by fishermen, who unravel and throw them back barehanded, usually suffering no harm. On land, sea snakes are unable to coil and strike like terrestrial snakes.

Observations suggest that sea snakes are active both day and night. In the morning, and sometimes late in the afternoon, they can be seen at the surface basking in the sunlight. When disturbed, they dive below. Sea snakes have been reported swimming at depths of over 90 m (300 ft). They can remain submerged for as long as a few hours, possibly depending on temperature and degree of activity.

Huge aggregations of sea snakes have been reported. For example, in 1932 millions of *Astrotia stokesii*, a relative of *Pelamis*, were seen from a steamer in the Strait of Malacca, off the coast of Malaysia, and formed a line of snakes 3 m (9.8 ft) wide and 100 km (62 mi) long. The cause of this phenomenon is unknown, although it likely has to do with reproduction. Ditmars (1933) mentions that, in that same area, sea snakes can sometimes be seen swimming in schools of several dozen, and that after typhoons many dead specimens can be found on the beaches.

Feeding

Most sea snake species prey on fish, especially eels. The latter, when bitten, stiffen and die within seconds. One species prefers molluscs and crustaceans, such as prawns, while a few others feed only on fish eggs, which is unusual for a venomous snake. Some reef dwelling species have small heads and thin necks, making it possible for them to extract small eels from the soft bottom where they hide. Stidworthy (1974) states that sea snakes will sometimes take bait from a fishing line.

Reproduction

Except for a single genus, all sea snakes are ovoviviparous; the young are born alive in the water where they live their entire life cycle. In some species, the young are quite large: up to half as long as the mother. The one exception is the genus *Laticauda*, which is oviparous; its five species all lay their eggs on land.

Venom

Like their cousins in the Elapidae family, the majority of sea snakes are highly venomous; however, when bites occur, it is rare for much venom to be injected, so that envenomation symptoms usually seem non-existent or trivial. For example, *Pelamis platurus* has a venom more potent than any other terrestrial snake species in Costa Rica, but despite its abundance in the waters off its western coast, few human fatalities have been reported. Nevertheless, all sea snakes should be handled with great caution.

Bites in which envenomation does occur are usually painless and may not even be noticed when contact is made. Teeth may remain in the wound. There is usually little or no swelling, and it is rare for any nearby lymph nodes to be affected. The most important symptoms are rhabdomyolysis (rapid breakdown of skeletal muscle tissue) and paralysis. Early symptoms include headache, a thick-feeling tongue, thirst, sweating, and vomiting. Symptoms that can occur after 30 minutes to several hours post-bite include generalized aching, stiffness, and tenderness of muscles all over the body. Passive stretching of the muscles is also painful, and trismus, which is similar to tetanus, is common. This is followed later on by symptoms typical of other elapid envenomations: a progressive flaccid paralysis, starting with ptosis and paralysis of voluntary muscles. Paralysis of muscles involved in swallowing and respiration can be fatal. After 3–8 hours, myoglobin as a result of muscle breakdown may start to show up in the blood plasma, which can cause the urine to turn a dark reddish, brown, or black color, and eventually lead to acute renal failure. After 6 to 12 hours, severe hyperkalemia, also the result of muscle breakdown, can lead to cardiac arrest.

Taxonomy

Sea snakes were at first regarded as a unified and separate family, the Hydrophiidae, that later came to comprise two subfamilies: the Hydrophiinae, or true/aquatic sea snakes

(now 16 genera with 57 species), and the more primitive Laticaudinae, or sea kraits (1 genus, *Laticauda*, with 5 species). Eventually, as it became clear just how closely related the sea snakes are to the elapids, the taxonomic situation became less well-defined. Some taxonomists responded by moving the sea snakes to the Elapidae, thereby creating the subfamilies Elapinae, Hydrophiinae and Laticaudinae, although the latter may be omitted if *Laticauda* is included in the Hydrophiinae. No one has yet been able to convincingly work out the phylogenetic relationships between the various elapid subgroups, and the situation is still unclear. Therefore, others opted to either continue to work with the older traditional arrangements, if only for practical reasons, or to lump all of the genera together in the Elapidae, with no taxonomic subdivisions, to reflect the work that remains to be done.

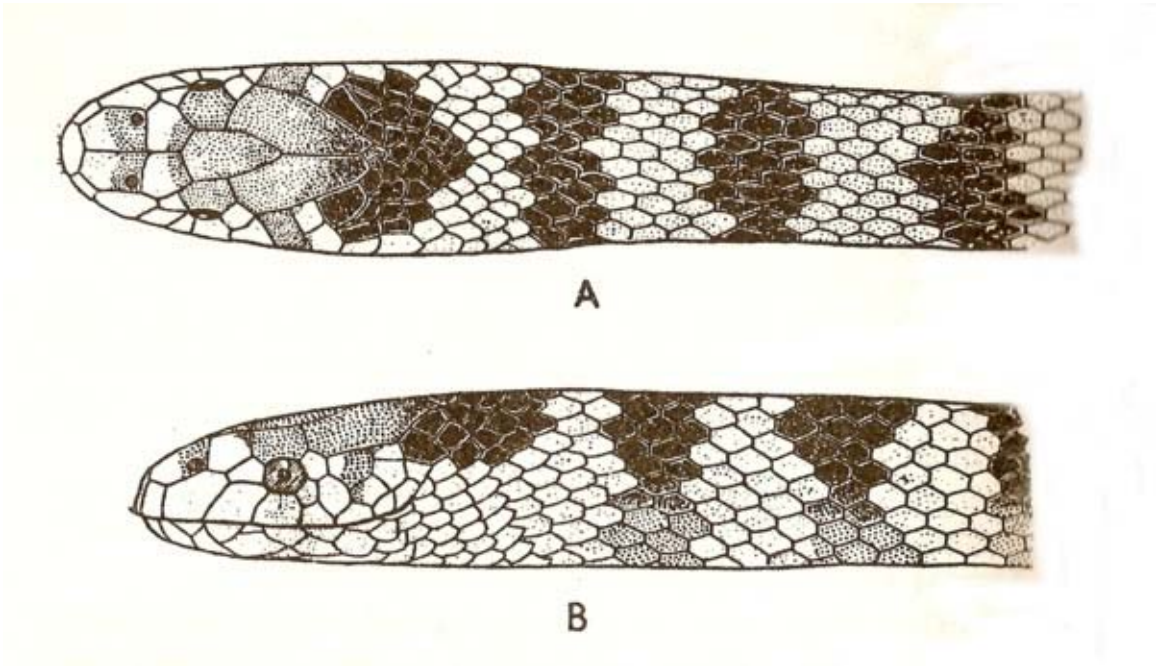
Genus	Taxon author	Species	Subsp.*	Common name	Geographic range
Acalyptophis	Boulenger, 1869	1	0	Spiny-headed Sea Snake or Horned Sea Snake	Gulf of Thailand, South China Sea, the Strait of Taiwan, and the coasts of Guangdong, Indonesia, Philippines, New Guinea, New Caledonia, Australia (Northern Territory, Queensland, Western Australia)
Aipysurus	Lacépède, 1804	7	1	Olive sea snakes	Timor Sea, South China Sea, Gulf of Thailand, and coasts of Australia (North Territory, Queensland, West Australia), New Caledonia, Loyalty Islands, southern New Guinea, Indonesia, western Malaysia and Vietnam.
Astrotia	Fischer, 1855	1	0	Stoke's sea snake	Coastal areas from west India and Sri Lanka through Gulf of Thailand to China Sea, west Malaysia, Indonesia east to New Guinea, north and east coasts of Australia, Philippines
Emydocephalus	Krefft, 1869	2	0	Turtlehead sea snakes	The coasts of Timor (Indonesian sea), New Caledonia, Australia (North Territory, Queensland, West Australia), and in the Southeast Asian Sea along the coasts of China, Taiwan,

					Japan, and the Ryukyu Island.
Enhydrina	Gray, 1849	2	0	Beaked sea snakes	In the Persian Gulf (Oman, United Arab Emirates, etc.), south to the Seychelles and Madagascar, SE Asian Sea (Pakistan, India, Bangladesh, Myanmar, Thailand, Vietnam), Australia (North Territory, Queensland), New Guinea and Papua New Guinea.
Ephalophis	M.A. Smith, 1931	1	0	Grey's mudsnake	North-western Australia
Hydrelaps	Boulenger, 1896	1	0	Port Darwin mudsnake	Northern Australia, southern New Guinea
Hydrophis	Latreille *In* Sonnini & Latreille, 1801	34	3	Sea snakes	Indoaustralian and Southeast Asian waters.
Kerilia	Gray, 1849	1	0	Jerdon's sea snake	Southeast Asian waters.
Kolpophis	M.A. Smith, 1926	1	0	Bighead sea snake	Indian Ocean.
Lapemis	Gray, 1835	2	0	Spine-bellied Sea Snake, Shaw's Sea Snake	Persian Gulf to Indian Ocean, South China Sea, Indo-Australian archipelago and the western Pacific.
Laticauda	Laurenti, 1768	5	0	Sea kraits	Southeast Asian and Indoaustralian waters.
Parahydrophis	Burger & Natsuno, 1974	1	0	Northern mangrove sea snake	Northern Australia, southern New Guinea
Parapistocalamus	Roux, 1934	1	0	Hediger's snake	Bougainville Island, Solomons
Pelamis	Daudin, 1803	1	0	Yellow bellied sea	Indian and Pacific Oceans

				snake	
Praescutata	Wall, 1921	1	0		From the Persian Gulf to the Indian Ocean, the South Chinese Sea, and northeast to the coastal region of Fujian and Strait of Taiwan.
Thalassophis	P. Schmidt, 1852	1	0	Anomalous sea snake	South Chinese Sea (Malaysia, Gulf of Thailand), Indian Ocean (Sumatra, Java, Borneo)

**) Not including the nominate subspecies.*

Captivity



Hydrophis cyanocinctus

At best, these snakes make difficult captives. Ditmars (1933) described them as nervous and delicate captives that usually refuse to eat, preferring only to hide in the darkest corner of the tank. Over 50 years later, Mehrtens (1987) wrote that although they were rarely displayed in western zoological parks, some species were regularly on display in Japanese aquariums. Available food supply is one factor that limits the number of species that can be kept in captivity, since some have diets that are too specialized. Another is that some species appear too intolerant to handling, or even being removed from the water. Regarding their facilities, the *Laticauda* species need to be able to exit the water somewhere and bask, while the other strictly aquatic genera do not, basically requiring only a tank of filtered (synthetic) sea water maintained at about 29°C, along with a

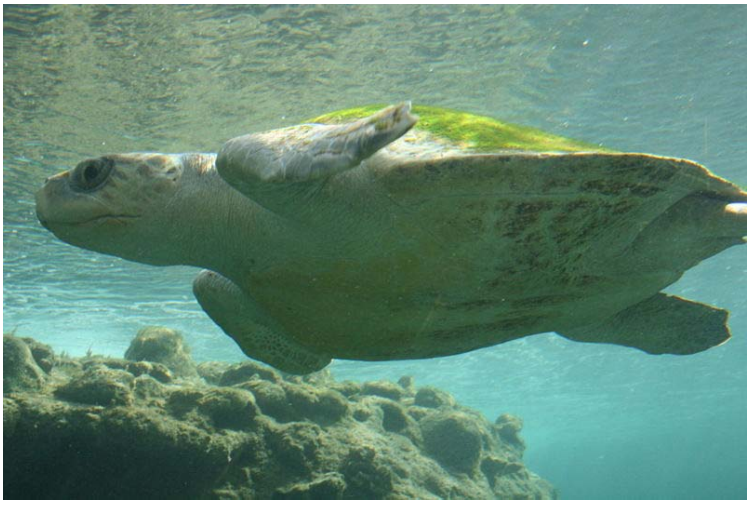
submerged shelter. Species that have done relatively well in captivity include the ringed sea snake, *Hydrophis cyanocinctus*, which feed on fish and eels in particular. *Pelamis platurus* has done especially well in captivity, accepting small fish, including goldfish. However, care has to be taken to house them in round or oval tanks, or in rectangular tanks with corners that are well-rounded, to prevent the snakes from damaging their snouts by swimming into the sides.

Conservation status

Most sea snakes are not on the CITES protection lists. Only one species, *Laticauda crockeri*, is classified as vulnerable (VU) according to the IUCN Red List of Threatened Species.

Chapter- 3

Sea Turtle

Sea turtles

An olive ridley sea turtle
Conservation status

Endangered (IUCN 3.1)
Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Reptilia
Order:	Testudines
Suborder:	Cryptodira
Superfamily:	**Chelonioidea** Bauer, 1893

Genera

- Family **Cheloniidae** (Oppel, 1811)
  - *Caretta*
  - *Chelonia*
  - *Eretmochelys*
  - *Lepidochelys*
  - *Natator*
- Family Dermochelyidae
  - *Dermochelys*
- Family Protostegidae (extinct)
- Family Toxochelyidae (extinct)
- Family Thalassemyidae (extinct)

Sea turtles (superfamily **Chelonioidea**) are marine reptiles that inhabit all of the world's oceans except the Arctic.

Distribution

The superfamily Chelonioidea has a world-wide distribution; sea turtles can be found in all oceans except for the polar regions. Some species travel between oceans. The flatback sea turtle is found solely on the northern coast of Australia.

Biology

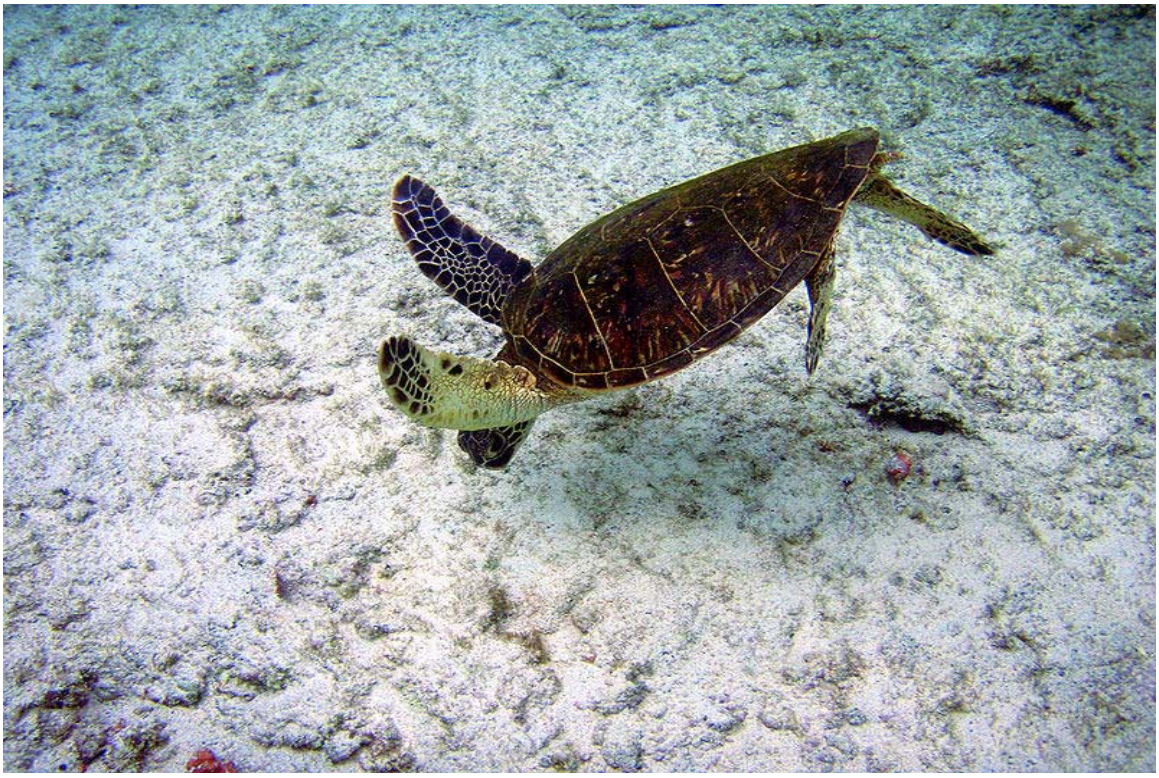
Respiration

A Green sea turtle breaks the surface to breathe.

Sea turtles are almost always submerged in water, and, therefore, have developed an anaerobic system of respiration. Although all sea turtles breathe air, under dire circumstances they may divert to anaerobic respiration for long periods of time. When surfacing to breathe, a sea turtle can quickly refill its lungs with a single explosive exhalation and rapid inhalation. Their large lungs have adapted to permit rapid exchange of oxygen and to avoid trapping gases during deep dives. However, sea turtles must emerge while breeding, given the extra level of activity.

Life history

Hawksbill sea turtle swims at Black Hills, Honduras



A feeding green sea turtle, *Chelonia mydas*

According to SeaWorld Parks & Entertainment, a lifespan of 80 years is feasible for sea turtles.

It takes decades for sea turtles to reach sexual maturity. After mating at sea, adult female sea turtles return to land to nest at night. Different species of sea turtles exhibit various levels of philopatry. In the extreme case, females return to the beach where they hatched. This can take place every two to four years in maturity. They make from one to eight nests per season.

The mature nesting female hauls herself onto the beach, nearly always at night, and finds suitable sand on which to create a nest. Using her hind flippers, she digs a circular hole 40 to 50 centimetres (16 to 20 in) deep. After the hole is dug, the female then starts filling the nest with a clutch of soft-shelled eggs one by one until she has deposited around 50 to 200 eggs, depending on the species. Some species have been reported to lay 250 eggs, such as the hawksbill. After laying, she re-fills the nest with sand, re-sculpting and smoothing the surface until it is relatively undetectable visually. The whole process takes thirty to sixty minutes. She then returns to the ocean, leaving the eggs untended.

The hatchling's gender depends on the sand temperature. Lighter sands maintain higher temperatures, which decreases incubation time and results in more female hatchlings.

Incubation takes about two months. The eggs in one nest hatch together over a very short period of time. When ready, hatchlings tear their shells apart with their snout and dig

through the sand. Again, this usually takes place at night, when predators such as seagulls cannot fly. Once they reach the surface, they instinctively head towards the sea. If, as happens on rare occasions, hatching takes place during daylight, only a very small proportion of each hatch (usually 0.01%) succeed, because local opportunist predators, such as the common seagull, gorge on the new sea turtles. Thus there is an obvious evolutionary drive to hatch at night, when survival rates on the beach are much higher.

The hatchlings then proceed into the ocean, where a variety of marine predators await them. In 1987, Carr discovered that the young of *Chelonia mydas* and *Caretta caretta* spent a great deal of their pelagic lives in floating sargassum beds, where there are thick mats of unanchored seaweed. Within these beds, they found ample shelter and food. In the absence of sargassum beds, sea turtle young feed in the vicinity of upwelling "fronts". In 2007, Reich determined that green sea turtle hatchlings spend the first three to five years of their lives in pelagic waters. In the open ocean, pre-juveniles of this particular species were found to feed on zooplankton and smaller nekton before they are recruited into inshore seagrass meadows as obligate herbivores.

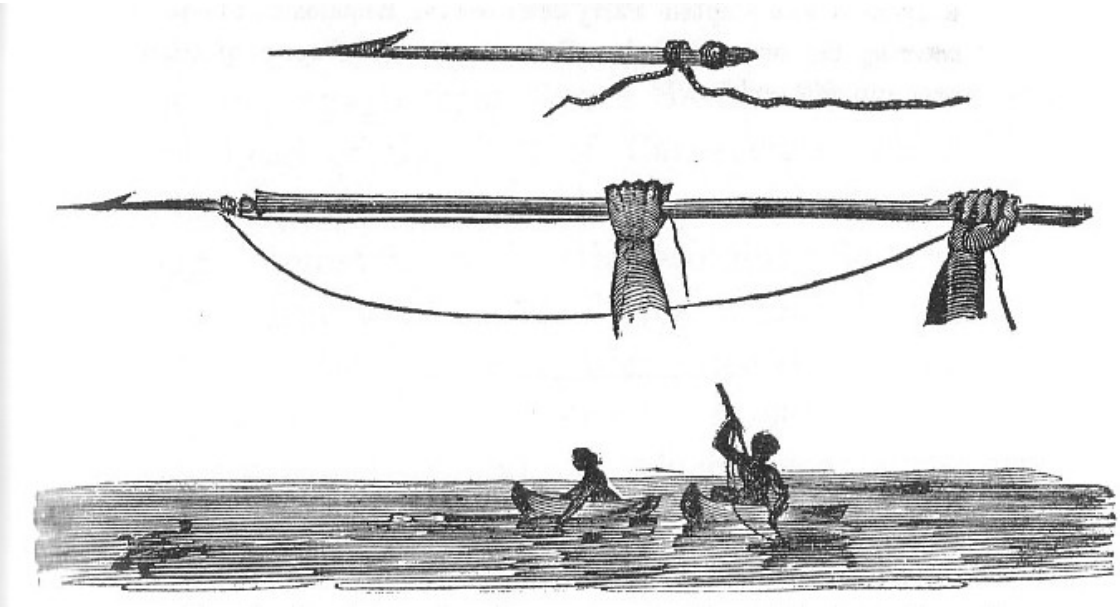
Instead of nesting individually like the other species, Ridley sea turtles come ashore en masse, known as an "arribada" (arrival). With the Kemp's ridley sea turtles this occurs during the day.

Salt gland

Sea turtles possess a salt excretory gland at the corner of the eye, in the nostrils, or in the tongue, depending on the species; chelonian salt glands are found in the corner of the eyes in leatherback sea turtles. Due to the iso-osmotic makeup of jellyfish and the other gelatinous prey upon which sea turtles subsist, sea turtle diets are high in salt; chelonian salt gland excretions are almost entirely composed of sodium chloride 1500-1800 mosmoll-1 (Marshall and Cooper, 1988; Nicolson and Lutz, 1989; Reina and Cooper, 2000).

Importance to humans

Moche Sea Turtle. 200 A.D. Larco Museum Collection, Lima, Peru



"Manner in which Natives of the East Coast strike turtle". Near Cooktown, Australia. From Phillip Parker King's Survey. 1818.

Marine sea turtles are caught worldwide, although it is illegal to hunt most species in many countries. A great deal of intentional marine sea turtle harvests worldwide are for food.

Many parts of the world have long considered sea turtles to be fine dining. Ancient Chinese texts dating to the fifth century B.C. describe sea turtles as exotic delicacies. Many coastal communities around the world depend on sea turtles as a source of protein, often harvesting several sea turtles at once and keeping them alive on their backs until needed. Coastal peoples gather sea turtle eggs for consumption.

Sea turtles are popular in Mexico as boot material and food.

To a much lesser extent, specific species of marine sea turtles are targeted not for their flesh, but for their shells. Tortoiseshell, a traditional decorative ornamental material used in Japan and China, comes from the carapace scutes of the hawksbill sea turtle. Ancient Greeks and ancient Romans processed sea turtle scutes (primarily from the hawksbill) for various articles and ornaments used by their elites, such as combs and brushes. The skin of the flippers are prized for use as shoes and assorted leather goods.

The Moche people of ancient Peru worshipped the sea and its animals. They often depicted sea turtles in their art.

Sea turtles enjoy immunity from the sting of the deadly box jellyfish and regularly eat them, helping keep tropical beaches safe for humans.

Sea turtles, especially green sea turtles, are one of the few animals that eat sea grass. Sea grass needs to be constantly cut short to help it grow across the sea floor. Sea turtles act as grazing animals that cut the grass short and help maintain the health of the sea grass beds. Sea grass beds provide breeding and developmental grounds for numerous species of fish, shellfish and crustaceans. Without sea grass beds, many marine species humans harvest would be lost, as would the lower levels of the food chain. The reactions could result in many more marine species eventually becoming endangered or extinct.

Beaches and dune systems do not get many nutrients. Sea turtles use beaches and the lower dunes to nest and lay their eggs. Sea turtles lay around 100 eggs in a nest and lay between 3 and 7 nests during the summer nesting season. Along a 20-mile stretch of beach on the east coast of Florida sea turtles lay over 150,000 lbs of eggs in the sand. Dune vegetation is able to grow and become stronger with the presence of nutrients from sea turtle eggs, unhatched nests, eggs and trapped hatchlings. As the dune vegetation grows stronger and healthier, the health of the entire beach/dune ecosystem becomes better. Stronger vegetation and root systems helps to hold the sand in the dunes and helps protect the beach from erosion.

Beach towns, such as Tortuguero, Costa Rica, have transitioned from a tourism industry that made profits from selling sea turtle meat and shells to an ecotourism-based economy. Tortuguero is considered to be the founding location of sea turtle conservation. In the 1960s the cultural demand for sea turtle meat, shells, and eggs were quickly killing once abundant sea turtle populations that nested on the beach. The Caribbean Conservation Corporation began working with villagers to promote ecotourism as a permanent substitute to sea turtle hunting. Sea turtle nesting grounds became sustainable. Since the creation of a sea turtle, ecotourism-based economy, Tortugero annually houses thousands of tourists who visit the protected 22-mile beach that hosts sea turtle walks and nesting grounds.

Conservation

All species of sea turtles are listed as threatened or endangered. The leatherback, Kemp's Ridley, and hawksbill sea turtles are critically endangered. The Olive Ridley and green sea turtles are endangered, and the loggerhead is threatened. The flatback's conservation status is unclear due to lack of data.

One of the most significant threats now comes from bycatch due to imprecise fishing methods. Long-lining has been identified as a major cause of accidental sea turtle death. There is also black-market demand for tortoiseshell for both decoration and supposed health benefits.

Sea turtles must surface to breathe. Caught in a fisherman's net, they are unable to surface and thus suffocate. In early 2007, almost a thousand sea turtles were killed inadvertently in the Bay of Bengal over the course of a few months after netting.

However, some relatively inexpensive changes to fishing techniques, such as slightly larger hooks and traps from which sea turtles can escape, can dramatically cut the mortality rate. Turtle Excluder Devices (TEDs) have reduced sea turtle bycatch in shrimp nets by 97 percent. Another danger comes from marine debris, especially from abandoned fishing nets in which they can become entangled.

Beach development is another area which threatens sea turtles. Since many sea turtles return to the same beach each time to nest, development can disrupt the cycle. There has been a movement to protect these areas, in some cases by special police. In some areas, such as the east coast of Florida, conservationists dig up sea turtle eggs and relocate them to fenced nurseries to protect them from beach traffic.

Since hatchlings find their way to the ocean by crawling towards the brightest horizon, they can become disoriented on developed stretches of coastline. Lighting restrictions can prevent lights from shining on the beach and confusing hatchlings. Sea turtle-safe lighting uses red or amber LED light, invisible to sea turtles, in place of white light.

Another major threat to sea turtles is black-market trade in eggs and meat. This is a problem throughout the world, but especially a concern in the Philippines, India, Indonesia and the coastal nations of Latin America. Estimates reach as high as 35,000 sea turtles killed a year in Mexico and the same number in Nicaragua. Conservationists in Mexico and the United States have launched "Don't Eat Sea Turtle" campaigns in order to reduce this trade in sea turtle products. These campaigns have involved figures such as Dorismar, Los Tigres del Norte and Maná. Sea turtles are often consumed during the Catholic season of Lent, even though they are reptiles, not fish. Consequently, conservation organizations have written letters to the Pope asking that he declare sea turtles meat.

Loggerhead sea turtle exits from fishing net through a turtle excluder device (TED)

Climate change may also cause a threat to sea turtles. Since sand temperature at nesting beaches defines the sex of a sea turtle while developing in the egg, there is concern that rising temperatures may produce too many females. However, more research is needed to understand how climate change might affect sea turtle gender distribution and what other possible threats it may pose.

Fibropapillomatosis disease causes tumors in sea turtles.

Injured sea turtles are sometimes rescued and rehabilitated by professional organizations, such as the Mote Marine Laboratory in Sarasota, Florida, the Marine Mammal Center in Northern California, the ClearWater Marine Aquarium in Clearwater, Florida, and the Sea Turtle Inc. organization in South Padre Island, Texas. One such sea turtle, named Nickel for the coin that was found lodged in her throat, lives at the Shedd Aquarium in Chicago.

In the Caribbean, researchers are having some success in assisting a comeback. In September 2007, Corpus Christi, Texas, wildlife officials found 128 Kemp's ridley sea turtle nests on Texas beaches, a record number, including 81 on North Padre Island (Padre Island National Seashore) and four on Mustang Island. Wildlife officials released 10,594 Kemp's ridleys hatchlings along the Texas coast this year.

Also in 2007, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service issued a determination that the leatherback, the hawksbill and the Kemp's Ridley populations were endangered while that of green sea turtles and olive ridleys were threatened.

In Southeast Asia, the Philippines has had several initiatives dealing with the issue of sea turtle conservation. In 2007, the province of Batangas in the Philippines declared the catching and eating of Pawikans illegal. However, the law seems to have had little effect as Pawikan eggs are still in demand in Batangan markets. In September 2007, several Chinese poachers were apprehended off the Turtle Islands in the country's southernmost province of Tawi-Tawi. The poachers had collected more than a hundred sea turtles, along with 10,000 sea turtle eggs.

Sea turtles are very vulnerable to oil pollution, both because of their tendency to linger on the water's surface, and because oil can effect them at every stage of their life cycle. Oil can poison the sea turtles upon entering their digestive system,

Fragile ecosystems

Sea turtles on a beach in Hawaii

Sea turtles play key roles in two ecosystem types that are critical to them as well as to humans—oceans and beaches/dunes. In the oceans, for example, sea turtles, especially green sea turtles, are one of very few creatures (manatees are another) that eat the sea grass that grows on the sea floor. Sea grass must be kept short to remain healthy, and beds of healthy sea grass are essential breeding and development areas for many species of fish and other marine life. A decline or loss of sea grass beds would damage these populations, triggering a chain reaction and negatively impacting marine and human life.

Beaches and dunes form a fragile ecosystem that depends on vegetation to protect against erosion. Eggs, hatched or unhatched, and hatchlings that fail to make it into the ocean are nutrient sources for dune vegetation. Every year, sea turtles lay countless eggs on beaches. Along one twenty-mile (32 km) stretch of beach in Florida alone, for example, more than 150,000 pounds of eggs are laid each year.

Taxonomy and evolution

Immature Hawaiian Green sea turtle in shallow waters

Eurysternum wagneri fossil at the Museum für Naturkunde, Berlin

Sea turtles, along with other turtles and tortoises, are part of the order Testudines.

The seven living species of sea turtles are: flatback sea turtle, green sea turtle, hawksbill sea turtle, Kemp's ridley sea turtle, leatherback sea turtle, loggerhead sea turtle and olive ridley sea turtle. All species except the leatherback are in the family Cheloniidae. The leatherback belongs to the family Dermochelyidae and is its only member.

The species are primarily distinguished by their anatomy: for instance, the prefrontal scales on the head, the number of and shape of scutes on the carapace, and the type of inframarginal scutes on the plastron. The leatherback is the only sea turtle that does not have a hard shell; instead, it bears a mosaic of bony plates beneath its leathery skin. It is the largest sea turtle, measuring 6 to 7 feet (1.8 to 2.1 m) in length at maturity, and 3 to 5 feet (0.91 to 1.5 m) in width, weighing up to 1,300 pounds (590 kg). Other species are smaller, being mostly 2 to 4 feet (0.61 to 1.2 m) and proportionally narrower.

Sea turtles constitute a single radiation that became distinct from all other turtles at least 110 million years ago.

From *SWOT Report*, vol. 1:

- **Family Cheloniida**
  - *Chelonia mydas* or green sea turtle

    - *Eretmochelys imbricata* or hawksbill sea turtle
    - *Natator depressus* or flatback sea turtle
    - *Caretta caretta* or Loggerhead sea turtle
    - *Lepidochelys kempii* or Kemp's ridley sea turtle
    - *Lepidochelys olivacea* or olive ridley sea turtle
- **Family Dermochelyidae**
    - *Dermochelys coriacea* or leatherback sea turtle

Chapter- 4

Cetacea

Cetaceans Temporal range: 55–0 Ma Early Eocene - Present

Humpback Whale breaching
Scientific classification
Kingdom: Animalia
Phylum: Chordata
Class: Mammalia
Infraclass: Laurasiatheria
(unranked): Cetartiodactyla
Order: **Cetacea** Brisson, 1762
Suborders
Mysticeti Odontoceti †Archaeoceti

The order **Cetacea** includes the marine mammals commonly known as whales, dolphins, and porpoises. *Cetus* is Latin and is used in biological names to mean "whale"; its original meaning, "large sea animal", was more general. It comes from Ancient Greek κῆτος (*kētos*), meaning "whale" or "any huge fish or sea monster". In Greek mythology the monster Perseus defeated was called Ceto, which is depicted by the constellation of Cetus. Cetology is the branch of marine science associated with the study of cetaceans.

Cetaceans are the mammals best adapted to aquatic life. Their body is fusiform (spindle-shaped). The forelimbs are modified into flippers. The tiny hindlimbs are vestigial; they do not attach to the backbone and are hidden within the body. The tail has horizontal flukes. Cetaceans are nearly hairless, and are insulated from the cooler water they inhabit by a thick layer of blubber. Some species are noted for their high intelligence.

Respiration

A dolphin in the Strait of Gibraltar

Cetaceans breathe air. They surface periodically to exhale carbon dioxide and inhale a fresh supply of oxygen. During diving, a muscular action closes the blowholes (nostrils), which remain closed until the cetacean next breaks the surface; when it surfaces, the muscles open the blowholes and warm air is exhaled.

Cetaceans' blowholes have evolved to a position at the top of the head, simplifying breathing in sometimes rough seas. When the stale air, warmed from the lungs, is exhaled, it condenses as it meets colder external air. As with a terrestrial mammal breathing out on a cold day, a small cloud of 'steam' appears. This is called the 'blow' or 'spout' and varies by species in terms of shape, angle and height. Species can be identified at a distance using this characteristic.

Cetaceans can remain under water for much longer periods than other mammals, (approximately 7–30 minutes, varying by species) due to large physiological differences. Two studied advantages of cetacean physiology let this order (and other marine mammals) forage underwater for extended periods without breathing:

- Mammalian myoglobin concentrations in skeletal muscle have much variation. New Zealand white rabbits have 0.08 grams (0.0028 oz) +/- 0.6 grams (0.021 oz) myoglobin in 100 grams (3.5 oz) of wet muscle, whereas a Northern Bottlenose Whale has 6.34 grams (0.224 oz). Myoglobin, by nature, has a higher oxygen affinity than hemoglobin. The higher the myoglobin concentration in skeletal muscle, the longer the animal can stay underwater.

- Increased body size also increases maximum dive duration. Greater body size implies increased muscle mass and increased oxygen stores. Cetaceans also obey Kleiber's law, which states that mass and metabolic rate are inversely related. I.e., larger animals consume less oxygen than smaller animals per unit mass.

Vision, hearing and echolocation

Cetacean eyes are set on the side rather than the front of the head. This means that only cetaceans with pointed 'beaks' (such as dolphins) have good binocular vision forward and downward. Tear glands secrete greasy tears, which protect the eyes from the salt in the water. The lens is almost spherical, which is most efficient at focusing the minimal light that reaches deep water. Cetaceans make up for their generally poor vision (with the exception of the dolphin) with excellent hearing.

As with the eyes, cetacean ears are also small. Life in the sea accounts for the cetacean's loss of its external ears, whose function is to collect and focus airborne sound waves. However, water conducts sound better than air, so the external ear is unneeded: it is a tiny hole in the skin, just behind the eye. The highly developed inner ear can detect sounds from dozens of miles away and discern from which direction the sound comes.

Odontoceti are generally capable of echolocation. From this, Odontoceti can discern the size, shape, surface characteristics, distance and movement of an object. With this ability cetaceans can search for, chase and catch fast-swimming prey in total darkness. Echolocation is so advanced in most Odontoceti that they can distinguish between prey and non-prey (such as humans or boats); captive Odontoceti can be trained to distinguish between, for example, balls of different sizes or shapes. Mysticeti have little need of

echolocation, because they prey upon tiny fish such as krill that are impractical to locate with echolocation.

Cetaceans also use sound to communicate, whether it be groans, moans, whistles, clicks or the complex 'singing' of the Humpback Whale.

Feeding

The toothed whales such as the sperm whale, beluga, dolphins and porpoises, have teeth that they use for catching fish, squid or other marine life. They do not chew but swallow prey whole. When they catch large prey, such as when the orca (*Orcinus orca*) catches a seal, they bite off and swallow one chunk at a time.

Mysticeti instead have baleen plates made of keratin (the same substance as human fingernails) which hang from the upper jaw. These plates filter small animals (such as krill and fish) from the seawater. Cetaceans included in this group include the Blue, Humpback, Bowhead and Minke whales.

Not all Mysticeti feed on plankton: the larger species eat small shoaling fish, such as herring and sardine, called micronecton. The gray whale (*Eschrichtius robustus*), is a benthic feeder, primarily eating sea floor crustaceans.

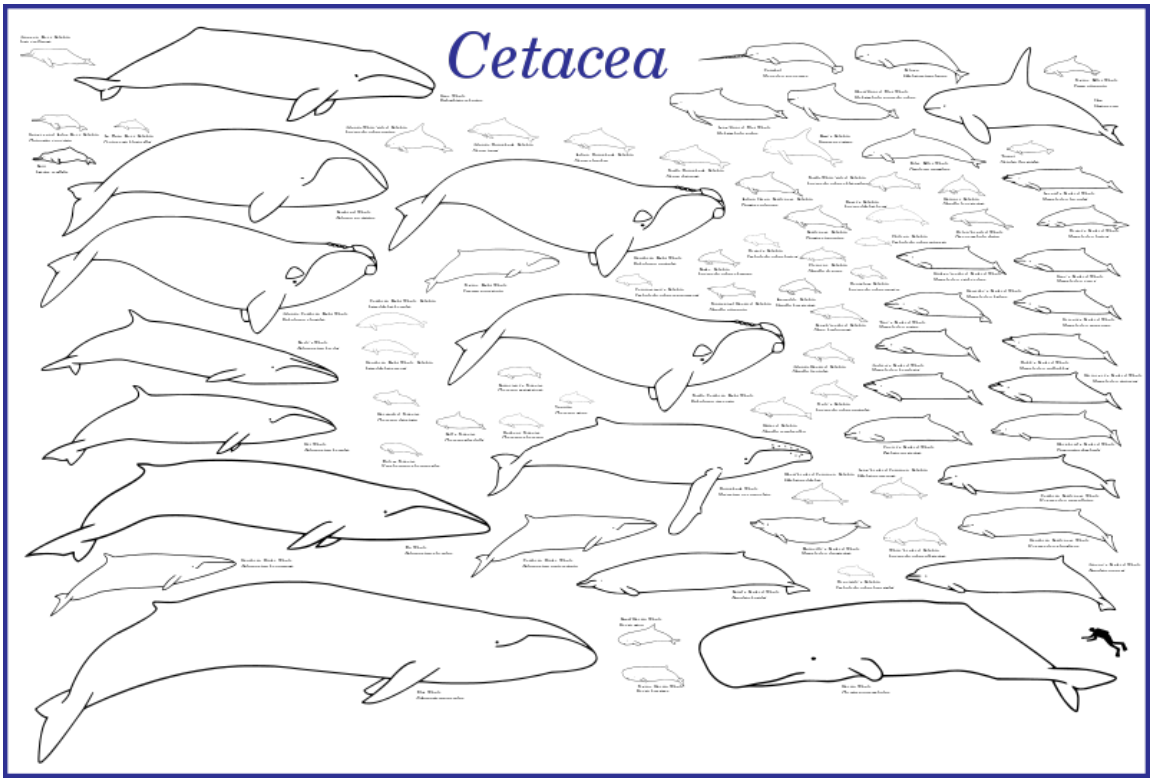
Mammalian nature

Cetaceans are mammals, that is, members of the class Mammalia. The closest living relatives of cetaceans are the even-toed ungulates, such as the hippopotamus and deer.

Mammalian characteristics include warm-bloodedness, breathing air through their lungs, and suckling their young, and growing hair, although very little of it.

Another way of distinguishing a cetacean from a fish is by the shape of the tail. Fish tails are vertical and move from side to side when the fish swims. Cetacea tails—called a fluke—are horizontal and move up and down, because cetacea spines bend in the same manner as a human spine.

Taxonomy



Size comparison of all known extant cetacean species. Note the human diver at lower right for scale.

The order Cetacea contains about ninety species, all marine except for four species of freshwater dolphins. The order contains two suborders, Mysticeti (baleen whales) and Odontoceti (toothed whales, which includes dolphins and porpoises). The species range in size from Commerson's Dolphin, smaller than a human, to the Blue Whale, the largest animal ever known to have lived.

Mysticeti vs Odontoceti

Fossils indicate that before evolving baleen, Mysticeti also had teeth, so defining the Odontoceti via teeth alone is problematic, and paleontologists have instead identified other features uniting fossil and modern odontocetes that are not shared by Mysticetes.

Characteristic	**Odontoceti**	**Mysticeti**
Feeding	Echolocation, fast	Filter feeder, not fast
Size	Smaller (except Sperm whale)	Larger
Blowhole	One	Two
Dentition	Teeth	Baleen plates
Melon	Ovoid, in anterior facial	Vestigial or none

	region	
Skull and facial tissue	Dorsally asymmetric	Symmetric
Sexual dimorphism	Some species have larger males	Females always larger
Mandible	Symphyseal	Nonsymphyseal
Pan bone of lower jaw	Yes	No
Maxillae projection	Outward over expanded supraorbital processes	Under eye orbit, with bony protuberance anterior to eye orbit
Tympanic bulla and periotic bone	Fused, equal sized	Larger, separate tympanic

Tree

The classification here closely follows Dale W. Rice, *Marine Mammals of the World: Systematics and Distribution* (1998), which has become the standard taxonomy reference in the field. There is very close agreement between this classification and that of *Mammal Species of the World: 3rd Edition* (Wilson and Reeder eds., 2005). Any differences are noted using the abbreviations "Rice" and "MSW3" respectively. Further differences due to recent discoveries are also noted.

Discussion of synonyms and subspecies are relegated to the relevant genus and species articles.

- **ORDER CETACEA**
  - **Suborder Mysticeti**: Baleen whales
    - Family Balaenidae: Right whales and Bowhead Whale
      - Genus *Balaena*
        - Bowhead Whale, *Balaena mysticetus*
      - Genus *Eubalaena*
        - North Atlantic Right Whale, *Eubalaena glacialis*
        - North Pacific Right Whale, *Eubalaena japonica*
        - Southern Right Whale, *Eubalaena australis*
    - Family Balaenopteridae: Rorquals
      - Subfamily Balaenopterinae
        - Genus *Balaenoptera*
          - Common Minke Whale, *Balaenoptera acutorostrata*
          - Antarctic Minke Whale, *Balaenoptera bonaerensis*
          - Sei Whale, *Balaenoptera borealis*
          - Bryde's Whale, *Balaenoptera brydei*
          - Eden's Whale *Balaenoptera edeni* - Rice lists this as a separate species, MSW3 does not

            - *Balaenoptera omurai* - MSW3 lists this is a synonym of Bryde's Whale but suggests this may be temporary.
            - Blue Whale, *Balaenoptera musculus*
            - Fin Whale, *Balaenoptera physalus*
        - Subfamily Megapterinae
            - Genus *Megaptera*
                - Humpback Whale, *Megaptera novaeangliae*
    - Family Eschrichtiidae
        - Genus *Eschrichtius*
            - Gray Whale, *Eschrichtius robustus*
    - Family Neobalaenidae: Pygmy Right Whale
        - Genus *Caperea*
            - Pygmy Right Whale, *Caperea marginata*
- **Suborder Odontoceti**: toothed whales
    - Family Delphinidae: Dolphin
        - Genus *Cephalorhynchus*
            - Commerson's Dolphin, *Cephalorhyncus commersonii*
            - Chilean Dolphin, *Cephalorhyncus eutropia*
            - Heaviside's Dolphin, *Cephalorhyncus heavisidii*
            - Hector's Dolphin, *Cephalorhyncus hectori*
        - Genus *Delphinus*
            - Long-beaked Common Dolphin, *Delphinus capensis*
            - Short-beaked Common Dolphin, *Delphinus delphis*
            - Arabian Common Dolphin, *Delphinus tropicalis*. Rice recognises this as a separate species. MSW3 does not.
        - Genus *Feresa*
            - Pygmy Killer Whale, *Feresa attenuata*
        - Genus *Globicephala*
            - Short-finned Pilot Whale, *Globicephala macrorhyncus*
            - Long-finned Pilot Whale, *Globicephala melas*
        - Genus *Grampus*
            - Risso's Dolphin, *Grampus griseus*
        - Genus *Lagenodelphis*
            - Fraser's Dolphin, *Lagenodelphis hosei*
        - Genus *Lagenorhynchus*
            - Atlantic White-sided Dolphin, *Lagenorhynchus acutus*
            - White-beaked Dolphin, *Lagenorhynchus albirostris*
            - Peale's Dolphin, *Lagenorhynchus australis*
            - Hourglass Dolphin, *Lagenorhynchus cruciger*

        - Pacific White-sided Dolphin, *Lagenorhynchus obliquidens*
        - Dusky Dolphin, *Lagenorhynchus obscurus*
    - Genus *Lissodelphis*
        - Northern Right Whale Dolphin, *Lissodelphis borealis*
        - Southern Right Whale Dolphin, *Lissodelphis peronii*
    - Genus *Orcaella*
        - Irrawaddy Dolphin, *Orcaella brevirostris*
            - Australian Snubfin Dolphin, *Orcaella heinsohni*. 2005 discovery, thus not recognized by Rice or MSW3 and subject to revision.
    - Genus *Orcinus*
        - Killer Whale, *Orcinus orca*
    - Genus *Peponocephala*
        - Melon-headed Whale, *Peponocephala electra*
    - Genus *Pseudorca*
        - False Killer Whale, *Pseudorca crassidens*
    - Genus *Sotalia*
        - Tucuxi, *Sotalia fluviatilis*
        - Costero, *Sotalia guianensis*
    - Genus *Sousa*
        - Pacific Humpback Dolphin, *Sousa chinensis*
        - Indian Humpback Dolphin, *Sousa plumbea*
        - Atlantic Humpback Dolphin, *Sousa teuszii*
    - Genus *Stenella*
        - Pantropical Spotted Dolphin, *Stenella attenuata*
        - Clymene Dolphin, *Stenella clymene*
        - Striped Dolphin, *Stenella coeruleoalba*
        - Atlantic Spotted Dolphin, *Stenella frontalis*
        - Spinner Dolphin, *Stenella longirostris*
    - Genus *Steno*
        - Rough-toothed Dolphin, *Steno bredanensis*
    - Genus *Tursiops*
        - Indian Ocean Bottlenose Dolphin, *Tursiops aduncus*
        - Common Bottlenose Dolphin, *Tursiops truncatus*
- Family Monodontidae
    - Genus *Delphinapterus*
        - Beluga, *Delphinapterus leucas*
    - Genus *Monodon*
        - Narwhal, *Monodon monoceros*
- Family Phocoenidae: Porpoises
    - Genus *Neophocaena*
        - Finless Porpoise, *Neophocaena phocaenoides*

        - Genus *Phocoena*
            - Spectacled Porpoise, *Phocoena dioptrica*
            - Harbour Porpoise, *Phocoena phocaena*
            - Vaquita, *Phocoena sinus*
            - Burmeister's Porpoise, *Phocoena spinipinnis*
        - Genus *Phocoenoides*
            - Dall's Porpoise, *Phocoenoides dalli*
    - Family Physeteridae: Sperm Whale family
        - Genus *Physeter*
            - Sperm Whale, *Physeter catodon* (syn. *P. macrocephalus*)
    - Family Kogiidae - MSW3 treats *Kogia* as a member of Physeteridae
        - Genus *Kogia*
            - Pygmy Sperm Whale, *Kogia breviceps*
            - Dwarf Sperm Whale, *Kogia sima*
    - **Superfamily Platanistoidea**: River dolphins
        - Family Iniidae
            - Genus *Inia*
                - Amazon River Dolphin, *Inia geoffrensis*
                    - Bolivian River Dolphin, *Inia boliviensis*
        - † Family Lipotidae - MSW3 treats *Lipotes* as a member of *Iniidae*
            - † Genus *Lipotes*
                - † Baiji, *Lipotes vexillifer*
        - Family Pontoporiidae - MSW3 treats *Pontoporia* as a member of *Iniidae*
            - Genus *Pontoporia*
                - La Plata Dolphin, *Pontoporia blainvillei*
        - Family Platanistidae
            - Genus *Platanista*
                - Ganges and Indus River Dolphin, *Platanista gangetica*. MSW3 treats *Platanista minor* as a separate species, with common names Ganges River Dolphin and Indus River Dolphin, respectively.
    - Family Ziphidae, Beaked whales
        - Genus *Berardius*
            - Arnoux's Beaked Whale, *Berardius arnuxii*
            - Baird's Beaked Whale (North Pacific Bottlenose Whale), *Berardius bairdii*
        - Subfamily Hyperoodontidae
            - Genus *Hyperoodon*
                - Northern Bottlenose Whale, *Hyperoodon ampullatus*

        - Southern Bottlenose Whale, *Hyperoodon planifrons*
    - Genus *Indopacetus*
        - Indo-Pacific Beaked Whale (Longman's Beaked Whale), *Indopacetus pacificus*
    - Genus *Mesoplodon*, Mesoplodont Whale
        - Sowerby's Beaked Whale, *Mesoplodon bidens*
        - Andrews' Beaked Whale, *Mesoplodon bowdoini*
        - Hubbs' Beaked Whale, *Mesoplodon carlhubbsi*
        - Blainville's Beaked Whale, *Mesoplodon densirostris*
        - Gervais' Beaked Whale, *Mesoplodon europaeus*
        - Ginkgo-toothed Beaked Whale, *Mesoplodon ginkgodens*
        - Gray's Beaked Whale, *Mesoplodon grayi*
        - Hector's Beaked Whale, *Mesoplodon hectori*
        - Layard's Beaked Whale, *Mesoplodon layardii*
        - True's Beaked Whale, *Mesoplodon mirus*
        - Perrin's Beaked Whale, *Mesoplodon perrini*. This species was recognised in 2002 and as such is listed by MSW3 but not Rice.
        - Pygmy Beaked Whale, *Mesoplodon peruvianus*
        - Stejneger's Beaked Whale, *Mesoplodon stejnegeri*
        - Spade Toothed Whale, *Mesoplodon traversii*
- Genus *Tasmacetus*
    - Tasman Beaked Whale (Shepherd's Beaked Whale), *Tasmacetus shepherdi*
- Genus *Ziphius*
    - Cuvier's Beaked Whale, *Ziphius cavirostris*

Chapter- 5

Freshwater Snail

Bithynia tentaculata, a small freshwater gastropod in the family Bithyniidae

Pomacea insularum, an apple snail

Planorbella trivolvis, and air-breathing ramshorn snail

A **freshwater snail** is one kind of freshwater mollusc, the other kind being freshwater clams and mussels, i.e. freshwater bivalves. Specifically a freshwater snail is a gastropod that lives in a non-marine or freshwater habitat. The majority of freshwater gastropods have a shell, with very few exceptions. Some groups of snails that live in freshwater respire using gills, other groups need to come up to the surface of the water in order to take in air to breathe.

The total number of Recent species of freshwater gastropods is about 4,000 (3,795-3,972).

Taxonomy

2005 taxonomy

The following cladogram is an overview of the main clades of gastropods based on the taxonomy of Bouchet & Rocroi (2005), with families that contain freshwater species marked in **boldface**: (Some of these highlighted families consist entirely of freshwater species, but some of them also contain, or even mainly consist of, marine species.)

Neritimorpha

Note: The numbers of species quoted in this overview refer to extant species only, in other words, extinct fossil species are not counted here.

- Neritiliidae, 5 freshwater species
- Neritidae, largely confined to the tropics, also the rivers of Europe, family includes the marine "nerites". There are about 110 freshwater species.

Family Neritidae, shells of *Theodoxus fluviatilis*.

Family Neritidae, *Neritina natalensis*

Caenogastropoda

These are freshwater snails with a gill and an operculum. In freshwater habitats there are ten major families, as well as other families of lesser importance:

Architaenioglossa

- Ampullariidae, an exclusively freshwater family that is largely tropical and includes the large "apple snails" kept in aquaria. 105-170 species.
- Viviparidae, medium to large snails, live-bearing, commonly referred to as "mystery snails". World wide except South America, and everywhere confined to fresh waters. 125-150 species.

Family Ampullariidae, *Pomacea bridgesii*.

Family Viviparidae, *Viviparus viviparus*.

Sorbeoconcha

- Melanopsidae, family native to rivers draining to the Mediterranean, also Middle East, and some South Pacific islands. About 25-50 species.
- Pachychilidae - 165-225 species. native to South and Central America. Formerly included with the Pleuroceridae by many authors.
- Paludomidae - about 100 species in south Asia, diverse in African Lakes, and Sri Lanka. Formerly classified with the Pleuroceridae by some authors.
- Pleuroceridae, abundant and diverse in eastern North America, largely high-spired snails of small to large size. About 200 species
- Semisulcospiridae, - primarily eastern Asia, Japan, also the *Juga* snails of northwestern North America. Formerly included with the Pleuroceridae.
- Thiaridae, high-spired parthenogenic snails of the tropics, includes those referred to as "trumpet snails" in aquaria. 135 species.

Family Pleuroceridae, *Io fluvialis*.

Family Semisulcospiridae, *Semisulcospira kurodai*.

Family Thiaridae, *Melanoides tuberculatus*.

Littorinimorpha

- Littorinidae - 2 species in the genus *Cremnoconchus* are freshwater living in waterfalls. Other species are marine.
- Amnicolidae - about 200 species.
- Assimineidae - about 20 freshwater species, other are marine
- Bithyniidae, small snails, native to Eastern Hemisphere. About 130 species.
- Cochliopidae - 246 species.
- Helicostoidae, the only species *Helicostoa sinensis* lives in China.
- Hydrobiidae, small to very small snails found world wide. About 1250 freshwater species other are marine.
- Lithoglyphidae - about 100 species.
- Moitessieriidae - 55 species.
- Pomatiopsidae, small amphibious snails scattered worldwide, most diverse in eastern and Southeast Asia. About 170 species.
- Stenothyridae - about 60 freshwater species, others are marine.

Clea helena, family Buccinidae.

Neogastropoda

- Buccinidae - 8-10 freshwater species in the genus *Clea*,native to Southeast Asia. Other Buccinidae are marine.
- Marginellidae - 2 freshwater species in the genus *Rivomarginella*, native to Southeast Asia. Other Marginellidae are marine.

Heterobranchia

Family Valvatidae, shells of *Valvata sibirica*, scale is in mm

Lower Heterobranchia

- Glacidorbidae - 20 species.

- Valvatidae, small low-spired snails referred to as "valve snails". 71 species.

Acochlidium fijiiensis is one of very few freshwater gastropods without a shell.
Acochlidiacea

- Acochlidiidae (including synonym Strubelliidae) - 5 shell-less species: *Acochlidium amboinense*, *Acochlidium bayerfehlmanni*, *Acochlidium fijiiensis*, *Palliohedyle sutteri* and *Strubellia paradoxa*
- Tantulidae - there is only one species which is shell-less *Tantulum elegans*.

Pulmonata, Basommatophora

Basommatophorans are pulmonate or air-breathing aquatic snails, characterized by having their eyes located at the base of their tentacles, rather than at the tips, as in the true land snails Stylommatophora. The majority of basommatophorans have shells that are thin, translucent, and relatively colorless, and all five freshwater basommatophoran families lack an operculum.

- Chilinidae, small to medium-sized snails confined to temperate and cold South America. About 15 species.
- Latiidae, small limpet-like snails confined to New Zealand. One or three species.
- Acroloxidae - about 40 species.
- Lymnaeidae, found worldwide, but are most numerous in temperate and northern regions. These are the dextral (right-handed) pond snails. About 100 species.
- Planorbidae, "rams horn" snails, with a worldwide distribution. About 250 species.
- Physidae, left-handed (sinistral) "pouch snails", native to Europe, Asia, North America. About 80 species.

Family Lymnaeidae, *Lymnaea stagnalis*.

Family Physidae, *Physella acuta*.

Family Planorbidae, *Planorbarius corneus*.

As human food

A dish of cooked freshwater nerites from the Rajang River, Sarawak, Malaysia

A dish of cooked freshwater snails, ampullariids and viviparids from Poipet, Cambodia

Several different snail species are eaten in Asian cuisine, including freshwater species.

Archaeological investigations in Guatemala have revealed that the diet of the Maya of the Classic Period (AD 250-900) included freshwater snails.

Aquarium snails

In the developed world, people encounter freshwater snails most commonly in aquaria along with tropical fish. Species available vary in different parts of the world. In the United States, commonly available species include ramshorn snails such as *Planorbella duryi*, apple snails such as *Pomacea bridgesii* and the high-spired thiarid malaysian trumpet snail *Melanoides tuberculata*.

Parasitology

Freshwater snails are widely known to be hosts in the lifecycles of a variety of human and animal parasites, particularly trematodes or "flukes". Some of these relations for prosobranch snails include *Oncomelania* in the family Pomatiopsidae as hosts of *Schistosoma*, and *Bithynia*, *Parafossarulus* and *Amnicola* as hosts of *Opisthorchis*. *Thiara* and *Semisulcospira* may host *Paragonimus*, and *Goniobasis* (older term including

Elimia, *Juga* and other small high-spired pleurocerid snails) may host *Nanophyetus salmincola*. Basommatophoran snails are even more widely infected, with many *Biomphalaria* (Planorbidae) serving as hosts for *Schistosoma mansoni*, *Fasciolopsis* and other parasitic groups. The tiny *Bulinus* snails are hosts for *Schistosoma haematobium*. Lymnaeid snails (Lymnaeidae) serve as hosts for *Fasciola* and the cerceriae causing swimmer's itch.

it is worth pointing out that snail-vectored parasites of humans can also be considered to be human-borne parasites of snails; humans are much more likely to carry and spread exotic diseases over long distances than snails are.

Chapter- 6

Cnidaria

Cnidaria **Temporal range: 580–0 Ma** **Ediacaran–Recent**

Pacific sea nettles, *Chrysaora fuscescens*
Scientific classification
Domain: Eukaryota
Kingdom: Animalia
Phylum: **Cnidaria** Hatschek, 1888
Subphylum/Classes
Anthozoa—corals and sea anemones Medusozoa—jellyfish: Cubozoa—box jellyfish, sea wasps Hydrozoa—hydroids, hydra-like animals Scyphozoa—true jellyfish Staurozoa—stalked jellyfish

Unranked, may not be scyphozoans
Myxozoa—parasites
Polypodiozoa—parasites

Cnidaria is a phylum containing over 9,000 species of animals found exclusively in aquatic and mostly marine environments. Their distinguishing feature is cnidocytes, specialized cells that they use mainly for capturing prey. Their bodies consist of mesoglea, a non-living jelly-like substance, sandwiched between two layers of epithelium that are mostly one cell thick. They have two basic body forms: swimming medusae and sessile polyps, both of which are radially symmetrical with mouths surrounded by tentacles that bear cnidocytes. Both forms have a single orifice and body cavity that are used for digestion and respiration. Many cnidarian species produce colonies that are single organisms composed of medusa-like or polyp-like zooids, or both. Cnidarians' activities are coordinated by a decentralized nerve net and simple receptors. Several free-swimming Cubozoa and Scyphozoa possess balance-sensing statocysts, and some have simple eyes. Not all cnidarians reproduce sexually. Many have complex lifecycles with asexual polyp stages and sexual medusae, but some omit either the polyp or the medusa stage.

Cnidarians were for a long time grouped with Ctenophores in the phylum Coelenterata, but increasing awareness of their differences caused them to be placed in separate phyla. Cnidarians are classified into four main groups: sessile Anthozoa (sea anemones, corals, and sea pens (sea anemones are not sessile but only move 3-4 inces an hour); swimming Scyphozoa (jellyfish); Cubozoa (box jellies); and Hydrozoa, a diverse group that includes all the freshwater cnidarians as well as many marine forms, and has both sessile members such as *Hydra* and colonial swimmers such as the Portuguese Man o' War. Staurozoa have recently been recognised as a class in their own right rather than a sub-group of Scyphozoa, and there is debate about whether Myxozoa and Polypodiozoa are cnidarians or closer to bilaterians (more complex animals).

Most cnidarians prey on organisms ranging in size from plankton to animals several times larger than themselves, but many obtain much of their nutrition from endosymbiotic algae, and a few are parasites. Many are preyed upon by other animals including starfish, sea slugs, fish and turtles. Coral reefs, whose polyps are rich in endosymbiotic algae, support some of the world's most productive ecosystems, and protect vegetation in tidal zones and on shorelines from strong currents and tides. While corals are almost entirely restricted to warm, shallow marine waters, other cnidarians live in the depths, in polar seas and in freshwater.

Fossil cnidarians have been found in rocks formed about 580 million years ago, and other fossils show that corals may have been present shortly before 490 million years ago and diversified a few million years later. Fossils of cnidarians that do not build mineralized structures are very rare. Scientists currently think that cnidarians, ctenophores and bilaterians are more closely related to calcareous sponges than these are to other sponges, and that anthozoans are the evolutionary "aunts" or "sisters" of other cnidarians, and the

most closely related to bilaterians. Recent analyses have concluded that cnidarians, although considered more "primitive" than bilaterians, have a wider range of genes.

Jellyfish stings killed several hundred people in the 20th century, and cubozoans are particularly dangerous. On the other hand, some large jellyfish are considered a delicacy in eastern and southern Asia. Coral reefs have long been economically important as providers of fishing grounds, protectors of shore buildings against currents and tides, and more recently as centers of tourism. However, they are vulnerable to over-fishing, mining for construction materials, pollution, and damage caused by tourism.

Classification

Cnidarians were for a long time grouped with Ctenophores in the phylum Coelenterata, but increasing awareness of their differences caused them to be placed in separate phyla. Cnidarians are classified into four main groups: sessile Anthozoa (sea anemones, corals, sea pens); swimming Scyphozoa (jellyfish); Cubozoa (box jellies); and Hydrozoa, a diverse group that includes all the freshwater cnidarians as well as many marine forms, and has both sessile members such as *Hydra* and colonial swimmers such as the Portuguese Man o' War. Staurozoa have recently been recognised as a class in their own right rather than a sub-group of Scyphozoa, and there is debate about whether Myxozoa and Polypodiozoa are cnidarians or closer to bilaterians.

Modern cnidarians are generally classified into four classes:

	Hydrozoa	Scyphozoa	Cubozoa	Anthozoa
Number of species	2,700	200	20	6,000
Examples	*Hydra*, siphonophores	Jellyfish	Box jellies	Sea anemones, corals, sea pens
Cells found in mesoglea	No	Yes	Yes	Yes
Nematocysts in exodermis	No	Yes	Yes	Yes
Medusa phase in life cycle	In some species	Yes, except for Stauromedusae if they are scyphozoans	Yes	No
Number of medusae produced per polyp	Many	Many	One	(not applicable)

Stauromedusae, small sessile cnidarians with stalks and no medusa stage, have traditionally been classified as members of the Scyphozoa, but recent research suggests they should be regarded as a separate class, Staurozoa.

The Myxozoa, microscopic parasites, were first classified as protozoans, but recently as heavily modified cnidarians, and more closely related to Hydrozoa and Scyphozoa than

to Anthozoa. However other recent research suggests that *Polypodium hydriforme*, a parasite *within* the egg cells of sturgeon, is closely related to the Myxozoa and that both *Polypodium* and the Myxozoa are intermediate between cnidarians and bilaterian animals.

Some researchers classify the extinct conulariids as cnidarians, while others propose that they form a completely separate phylum.

Ecology

Coral reefs support rich ecosystems

Many cnidarians are limited to shallow waters because they depend on endosymbiotic algae for much of their nutrients. The life cycles of most have polyp stages, which are limited to locations that offer stable substrates. Nevertheless major cnidarian groups contain species that have escaped these limitations. Hydrozoans have a worldwide range: some, such as *Hydra*, live in freshwater; *Obelia* appears in the coastal waters of all the oceans; and *Liriope* can form large shoals near the surface in mid-ocean. Among anthozoans, a few scleractinian corals, sea pens and sea fans live in deep, cold waters, and some sea anemones inhabit polar seabeds while others live near hydrothermal vents over 10 kilometres (6.2 mi) below sea-level. Reef-building corals are limited to tropical seas between 30°N and 30°S with a maximum depth of 46 metres (151 ft), temperatures between 20°C and 28°C, high salinity and low carbon dioxide levels. Stauromedusae,

although usually classified as jellyfish, are stalked, sessile animals that live in cool to Arctic waters. Cnidarians range in size from *Hydra*, 5–20 millimetres (0.20–0.79 in) long, to the Lion's mane jellyfish, which may exceed 2 metres (6.6 ft) in diameter and 75 metres (246 ft) in length.

Prey of cnidarians ranges from plankton to animals several times larger than themselves. Some cnidarians are parasites, mainly on jellyfish but a few are major pests of fish. Others obtain most of their nourishment from endosymbiotic algae or dissolved nutrients. Predators of cnidarians include: sea slugs, which can incorporate nematocysts into their own bodies for self-defense; starfish, notably the crown of thorns starfish, which can devastate corals; butterfly fish and parrot fish, which eat corals; and marine turtles, which eat jellyfish. Some sea anemones and jellyfish have a symbiotic relationship with some fish; for example clown fish live among the tentacles of sea anemones, and each partner protects the other against predators.

Coral reefs form some of the world's most productive ecosystems. Common coral reef cnidarians include both Anthozoans (hard corals, octocorals, anemones) and Hydrozoans (fire corals, lace corals) The endosymbiotic algae of many cnidarian species are very effective primary producers, in other words converters of inorganic chemicals into organic ones that other organisms can use, and their coral hosts use these organic chemicals very efficiently. In addition reefs provide complex and varied habitats that support a wide range of other organisms. "Fringing" reefs just below low-tide level also have a mutually beneficial relationship with mangrove forests at high-tide level and sea grass meadows in between: the reefs protect the mangroves and seagrass from strong currents and waves that would damage them or erode the sediments in which they are rooted, while the mangroves and seagrass protect the coral from large influxes of silt, fresh water and pollutants. This additional level of variety in the environment is beneficial to many types of coral reef animals, which for example may feed in the sea grass and use the reefs for protection or breeding.

History

Fossil cnidarians have been found in rocks formed about 580 million years ago, and other fossils show that corals may have been present shortly before 490 million years ago and diversified a few million years later. Fossils of cnidarians that do not build mineralized structures are very rare. Scientists currently think that cnidarians, ctenophores and bilaterians are more closely related to calcareous sponges than these are to other sponges, and that anthozoans are the evolutionary "aunts" or "sisters" of other cnidarians, and the most closely related to bilaterians. Recent analyses have concluded that cnidarians, although considered more "primitive" than bilaterians, have a wider range of genes.

Distinguishing features

Cnidarians form an animal phylum that is more complex than sponges, about as complex as ctenophores (comb jellies), and less complex than bilaterians, which include almost all other animals. However, both cnidarians and ctenophores are more complex than sponges

as they have: cells bound by inter-cell connections and carpet-like basement membranes; muscles; nervous systems; and **some** have sensory organs. Cnidarians are distinguished from all other animals by having cnidocytes that fire like harpoons and are used mainly to capture prey but also as anchors in some species.

Like sponges and ctenophores, cnidarians have two main layers of cells that sandwich a middle layer of jelly-like material, which is called the mesoglea in cnidarians; more complex animals have three main cell layers and no intermediate jelly-like layer. Hence, cnidarians and ctenophores have traditionally been labelled diploblastic, along with sponges. However, both cnidarians and ctenophores have a type of muscle that, in more complex animals, arises from the middle cell layer. As a result some recent text books classify ctenophores as triploblastic, and it has been suggested that cnidarians evolved from triploblastic ancestors.

	Sponges	**Cnidarians**	**Ctenophores**	**Bilateria**
Cnidocytes	No	Yes	No	
Colloblasts	No		Yes	No
Digestive and circulatory organs	No			Yes
Number of main cell layers	Two, with jelly-like layer between them		Two or Three	Three
Cells in each layer bound together	No, except that Homoscleromorpha have basement membranes.	Yes: inter-cell connections; basement membranes		
Sensory organs	No	Yes		
Number of cells in middle "jelly" layer	Many	Few		(Not applicable)
Cells in outer layers can move inwards and change functions	Yes	No		(Not applicable)
Nervous system	No	Yes, simple		Simple to complex
Muscles	None	Mostly epitheliomuscular	Mostly myoepithelial	Mostly myocytes

Description

Main cell layers

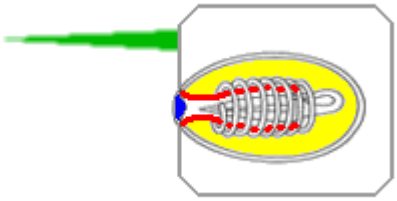
Cnidaria are diploblastic animals, in other words they have two main cell layers, while more complex animals are triploblasts having three main layers. The two main cell layers of cnidarians form epithelia that are mostly one cell thick, and are attached to a fibrous basement membrane, which they secrete. They also secrete the jelly-like mesoglea that separates the layers. The layer that faces outwards, known as the ectoderm ("outside skin"), generally contains the following types of cells:

- Epitheliomuscular cells whose bodies form part of the epithelium but whose bases extend to form muscle fibers in parallel rows. The fibers of the outward-facing cell layer generally run at right angles to the fibers of the inward-facing one. In Anthozoa (anemones, corals, etc.) and Scyphozoa (jellyfish), the mesoglea also contains some muscle cells.
- Cnidocytes, the harpoon-like "nettle cells" that give the phylum Cnidaria its name. These appear between or sometimes on top of the muscle cells.
- Nerve cells. Sensory cells appear between or sometimes on top of the muscle cells, and communicate via synapses (gaps across which chemical signals flow) with motor nerve cells, which lie mostly between the bases of the muscle cells.
- Interstitial cells, which are unspecialized and can replace lost or damaged cells by transforming into the appropriate types. These are found between the bases of muscle cells.

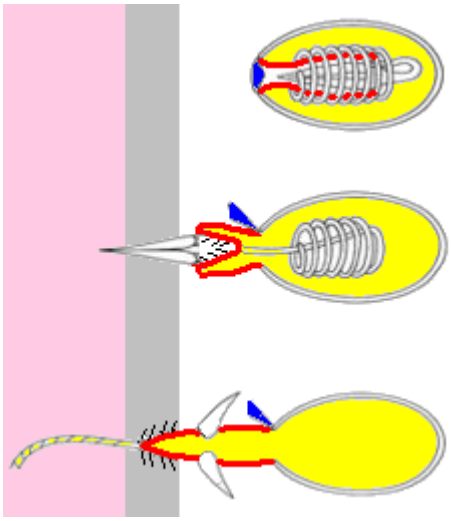
In addition to epitheliomuscular, nerve and interstitial cells, the inward-facing gastroderm ("stomach skin") contains gland cells that secrete digestive enzymes. In some species it also contains low concentrations of cnidocytes, which are used to subdue prey that is still struggling.

The mesoglea contains small numbers of amoeba-like cells, and muscle cells in some species. However the number of middle-layer cells and types are much lower than in sponges.

Cnidocytes



A hydra's nematocyst, before firing.
"trigger" cilium



Firing sequence of the cnida in a hydra's nematocyst
Operculum (lid)
"Finger" that turns inside out
/ / / Barbs
Venom
Victim's skin
Victim's tissues

These "nettle cells" function as harpoons, since their payloads remain connected to the bodies of the cells by threads. Three types of cnidocytes are known:

- Nematocysts inject venom into prey, and usually have barbs to keep them embedded in the victims. Most species have nematocysts.
- Spirocysts do not penetrate the victim or inject venom, but entangle it by means of small sticky hairs on the thread. Only members of the class Anthozoa (sea anemones and corals) have spirocysts.
- Ptychocysts are not used for prey capture — instead the threads of discharged ptychocysts are used for building protective tubes in which their owners live. Ptychocysts are found only in the order Cerianthria, tube anemones.

The main components of a cnidocyte are:

- A cilium (fine hair) which projects above the surface and acts as a trigger. Spirocysts do not have cilia.
- A tough capsule, the cnida, which houses the thread, its payload and a mixture of chemicals which may include venom or adhesives or both. ("cnida" is derived from the Greek word κνίδη, which means "nettle")
- A tube-like extension of the wall of the cnida that points into the cnida, like the finger of a rubber glove pushed inwards. When a cnidocyte fires, the finger pops out. If the cell is a venomous nematocyte, the "finger"'s tip reveals a set of barbs that anchor it in the prey.

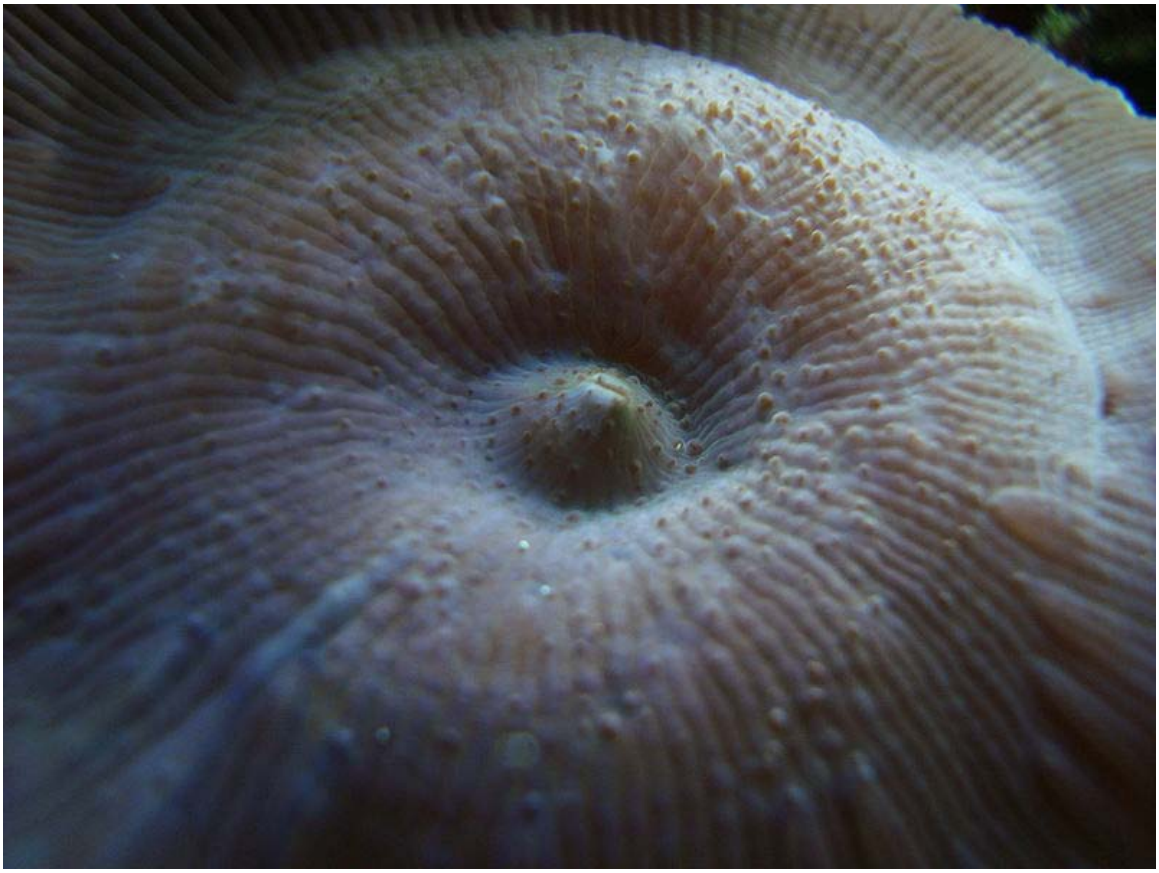
- The thread, which is an extension of the "finger" and coils round it until the cnidocyte fires. The thread is usually hollow and delivers chemicals from the cnida to the target.
- An operculum (lid) over the end of the cnida. The lid may be a single hinged flap or three flaps arranged like slices of pie.
- The cell body which produces all the other parts.

It is difficult to study the firing mechanisms of cnidocytes as these structures are small but very complex. At least four hypotheses have been proposed:

- Rapid contraction of fibers round the cnida may increase its internal pressure.
- The thread may be like a coiled spring that extends rapidly when released.
- In the case of *Chironex* (the "sea wasp"), chemical changes in the cnida's contents may cause them to expand rapidly by polymerization.
- Chemical changes in the liquid in the cnida make it a much more concentrated solution, so that osmotic pressure forces water in very rapidly to dilute it. This mechanism has been observed in nematocysts of the class Hydrozoa, sometimes producing pressures as high as 140 atmospheres, similar to that of scuba air tanks, and fully extending the thread in as little as 2 milliseconds (0.002 second).

Cnidocytes can only fire once, and about 25% of a hydra's nematocysts are lost from its tentacles when capturing a brine shrimp. Used cnidocytes have to be replaced, which takes about 48 hours. To minimise wasteful firing, two types of stimulus are generally required to trigger cnidocytes: their cilia detect contact, and nearby sensory cells "smell" chemicals in the water. This combination prevents them from firing at distant or non-living objects. Groups of cnidocytes are usually connected by nerves and, if one fires, the rest of the group requires a weaker minimum stimulus than the cells that fire first.

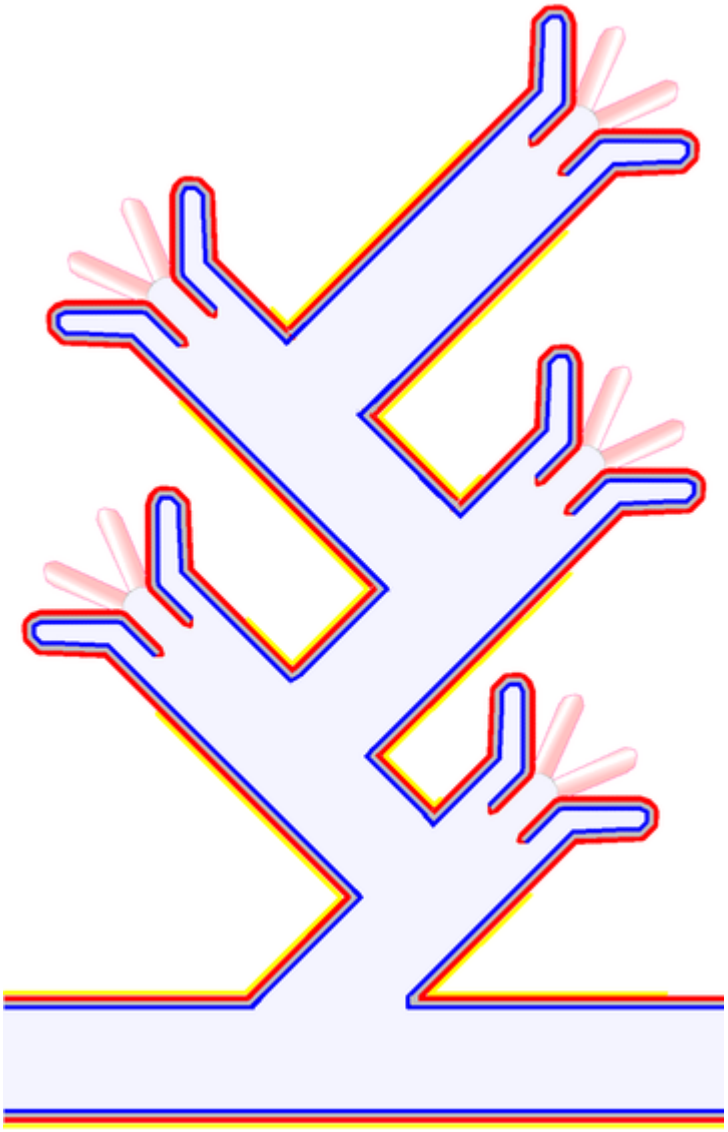
Basic body forms



Oral end of actinodiscus polyp, with close-up of the mouth

Adult cnidarians appear as either swimming medusae or sessile polyps. Both are radially symmetrical, like a wheel and a tube respectively. Since these animals have no heads, their ends are described as "oral" (nearest the mouth) and "aboral" (furthest from the mouth). Most have fringes of tentacles equipped with cnidocytes around their edges, and medusae generally have an inner ring of tentacles around the mouth. The mesoglea of polyps is usually thin and often soft, but that of medusae is usually thick and springy, so that it returns to its original shape after muscles around the edge have contracted to squeeze water out, enabling medusae to swim by a sort of jet propulsion.

Colonial forms



Tree-like polyp colony

Cnidaria produce a variety of colonial forms, each of which is one organism but consists of polyp-like zooids. The simplest is a connecting tunnel that runs over the substrate (rock or seabed) and from which single zooids sprout. In some cases the tunnels form visible webs, and in others they are enclosed in a fleshy mat. More complex forms are also based on connecting tunnels but produce "tree-like" groups of zooids. The "trees" may be formed either by a central zooid that functions as a "trunk" with later zooids growing to the sides as "branches", or in a zig-zag shape as a succession of zooids, each of which grows to full size and then produces a single bud at an angle to itself. In many cases the connecting tunnels and the "stems" are covered in periderm, a protective layer

of chitin. Some colonial forms have other specialized types of zooid, for example, to pump water through their tunnels.

Siphonophores form complex colonies that consist of: an upside-down polyp that forms a central stem with a gas-filled float at the top; one or more sets of medusa-like zooids that provide propulsion; leaf-like bracts that give some protection to other parts; sets of tentacles that bear nematocytes that capture prey; other tentacles that act as sensors; near the base of each set of tentacles, a polyp-like zooid that acts as a stomach for the colony; medusa-like zooids that serve as gonads. Although some of these zooids resemble polyps or medusae in shape, they lack features that are not relevant to their specific functions, for example the swimming "medusae" have no digestive, sensory or reproductive cells. The best-known siphonophore is the Portuguese Man o' War (*Physalia physalis*).

Skeletons

In medusae the only supporting structure is the mesoglea. *Hydra* and most sea anemones close their mouths when they are not feeding, and the water in the digestive cavity then acts as a hydrostatic skeleton, rather like a water-filled balloon. Other polyps such as *Tubularia* use columns of water-filled cells for support. Sea pens stiffen the mesoglea with calcium carbonate spicules and tough fibrous proteins, rather like sponges.

In some colonial polyps a chitinous periderm gives support and some protection to the connecting sections and to the lower parts of individual polyps. Stony corals secrete massive calcium carbonate exoskeletons. A few polyps collect materials such as sand grains and shell fragments, which they attach to their outsides. Some colonial sea anemones stiffen the mesoglea with sediment particles.

Locomotion

Chrysaora quinquecirrha ("sea nettle") swimming

Medusae swim by a form of jet propulsion: muscles, especially inside the rim of the bell, squeeze water out of the cavity inside the bell, and the springiness of the mesoglea powers the recovery stroke. Since the tissue layers are very thin, they provide too little power to swim against currents and just enough to control movement within currents.

Hydras and some sea anemones can move slowly over rocks and sea or stream beds by various means: creeping like snails, crawling like inchworms, or by somersaulting. A few can swim clumsily by waggling their bases.

Nervous system and senses

Cnidaria have no brains or even central nervous systems. Instead they have decentralized nerve nets consisting of : sensory neurons that generate signals in response to various types of stimulus, such as odors; motor neurons that tell muscles to contract; all connected by "cobwebs" of intermediate neurons. As well as forming the "signal cables", intermediate neurons also form ganglia that act as local coordination centers. The cilia of the cnidocytes detect physical contact. Nerves inform cnidocytes when odors from prey or attackers are detected and when neighbouring cnidocytes fire. Most of the

communications between nerve cells are via chemical synapses, small gaps across which chemicals flow. As this process is too slow to ensure that the muscles round the rim of a medusa's bell contract simultaneously in swimming the neurons which control this communicate by much faster electrical signals across gap junctions.

Medusae and complex swimming colonies such as siphonophores and chondrophores sense tilt and acceleration by means of statocysts, chambers lined with hairs which detect the movements of internal mineral grains called statoliths. If the body tilts in the wrong direction, the animal rights itself by increasing the strength of the swimming movements on the side that is too low. They also have ocelli ("little eyes"), which can detect the direction from which light is coming. Box jellies have camera eyes, although these probably do not form images, and their lenses simply produce a clearer indication of the direction from which light is coming.

Feeding and excretion

Cnidarians feed in several ways: predation, absorbing dissolved organic chemicals, filtering food particles out of the water, and obtaining nutrients from symbiotic algae within their cells. Most obtain the majority of their food from predation but some, including the corals *Hetroxenia* and *Leptogorgia*, depend almost completely on their endosymbionts and on absorbing dissolved nutrients. Cnidaria give their symbiotic algae carbon dioxide, some nutrients and a place in the sun.

Predatory species use their cnidocytes to poison or entangle prey, and those with venomous nematocysts may start digestion by injecting digestive enzymes. The "smell" of fluids from wounded prey makes the tentacles fold inwards and wipe the prey off into the mouth. In medusae the tentacles round the edge of the bell are often short and most of the prey capture is done by "oral arms", which are extensions of the edge of the mouth and are often frilled and sometimes branched to increase their surface area. Medusae often trap prey or suspended food particles by swimming upwards, spreading their tentacles and oral arms and then sinking. In species for which suspended food particles are important, the tentacles and oral arms often have rows of cilia whose beating creates currents that flow towards the mouth, and some produce nets of mucus to trap particles.

Once the food is in the digestive cavity, gland cells in the gastroderm release enzymes that reduce the prey to slurry, usually within a few hours. This circulates through the digestive cavity and, in colonial cnidarians, through the connecting tunnels, so that gastroderm cells can absorb the nutrients. Absorption may take a few hours, and digestion within the cells may take a few days. The circulation of nutrients is driven by water currents produced by cilia in the gastroderm or by muscular movements or both, so that nutrients reach all parts of the digestive cavity. Nutrients reach the outer cell layer by diffusion or, for animals or zooids such as medusae which have thick mesogleas, are transported by mobile cells in the mesoglea.

Indigestible remains of prey are expelled through the mouth. The main waste product of cells' internal processes is ammonia, which is removed by the external and internal water currents.

Respiration

There are no respiratory organs, and both cell layers absorb oxygen from and expel carbon dioxide into the surrounding water. When the water in the digestive cavity becomes stale it must be replaced, and nutrients that have not been absorbed will be expelled with it. Some Anthozoa have ciliated grooves on their tentacles, allowing them to pump water out of and into the digestive cavity without opening the mouth. This improves respiration after feeding and allows these animals, which use the cavity as a hydrostatic skeleton, to control the water pressure in the cavity without expelling undigested food.

Cnidaria that carry photosynthetic symbionts may have the opposite problem, an excess of oxygen, which may prove toxic. The animals produce large quantities of antioxidants to neutralize the excess oxygen.

Regeneration

All cnidarians can regenerate, allowing them to recover from injury and to reproduce asexually. Medusae have limited ability to regenerate, but polyps can do so from small pieces or even collections of separated cells. This enables corals to recover even after apparently being destroyed by predators.

Reproduction

Sexual

In the Cnidaria sexual reproduction often involves a complex life cycle with both polyp and medusa stages. For example in Scyphozoa (jellyfish) and Cubozoa (box jellies) a larva swims until it finds a good site, and then becomes a polyp. This grows normally but then absorbs its tentacles and splits horizontally into a series of disks that become juvenile medusae, a process called strobilation. The juveniles swim off and slowly grow to maturity, while the polyp re-grows and may continue strobilating periodically. The adults have gonads in the gastroderm, and these release ova and sperm into the water in the breeding season.

Shortened forms of this life cycle are common, for example some oceanic scyphozoans omit the polyp stage completely, and cubozoan polyps produce only one medusa. Hydrozoa have a variety of life cycles. Some have no polyp stages and some (e.g. *hydra*) have no medusae. In some species the medusae remain attached to the polyp and are responsible for sexual reproduction; in extreme cases these reproductive zooids may not look much like medusae. Anthozoa have no medusa stage at all and the polyps are responsible for sexual reproduction.

Spawning is generally driven by environmental factors such as changes in the water temperature, and their release is triggered by lighting conditions such as sunrise, sunset or the phase of the moon. Many species of Cnidaria may spawn simultaneously in the same location, so that there are too many ova and sperm for predators to eat more than a tiny percentage — one famous example is the Great Barrier Reef, where at least 110 corals and a few non-cnidarian invertebrates produce enough to turn the water cloudy. These mass spawnings may produce hybrids, some of which can settle and form polyps, but it is not known how long these can survive. In some species the ova release chemicals that attract sperm of the same species.

The fertilized eggs develop into larvae by dividing until there are enough cells to form a hollow sphere (blastula) and then a depression forms at one end (gastrulation) and eventually become the digestive cavity. However in cnidarians the depression forms at the end further from the yolk (at the animal pole), while in bilaterians it forms at the other end (vegetal pole). The larvae, called planulae, swim or crawl by means of cilia. They are cigar-shaped but slightly broader at the "front" end, which is the aboral, vegetal-pole end and eventually attaches to a substrate if the species has a polyp stage.

Anthozoan larvae either have large yolks or are capable of feeding on plankton, and some already have endosymbiotic algae that help to feed them. Since the parents are immobile, these feeding capabilities extend the larvae's range and avoid overcrowding of sites. Scyphozoan and hydrozoan larvae have little yolk and most lack endosymbiotic algae, and therefore have to settle quickly and metamorphose into polyps. Instead these species rely on their medusae to extend their ranges.

Asexual

All known cnidaria can reproduce asexually by various means, in addition to regenerating after being fragmented. Hydrozoan polyps only bud, while the medusae of some hydrozoans can divide down the middle. Scyphozoan polyps can both bud and split down the middle. In addition to both of these methods, Anthozoa can split horizontally just above the base.

Evolutionary history

Fossil record

The fossil coral *Cladocora* from Pliocene rocks in Cyprus

The earliest widely accepted animal fossils are rather modern-looking cnidarians, possibly from around 580 million years ago, although fossils from the Doushantuo Formation can only be dated approximately. The identification of some of these as embryos of animals has been contested, but other fossils from these rocks strongly resemble tubes and other mineralized structures made by corals. Their presence implies that the cnidarian and bilaterian lineages had already diverged. Although the Ediacaran fossil *Charnia* used to be classified as a jellyfish or sea pen, more recent study of growth patterns in *Charnia* and modern cnidarians has cast doubt on this hypothesis, and there are now no bona-fide cnidarian body fossils in the Ediacaran. Few fossils of cnidarians without mineralized skeletons are known from more recent rocks, except in lagerstätten that preserved soft-bodied animals.

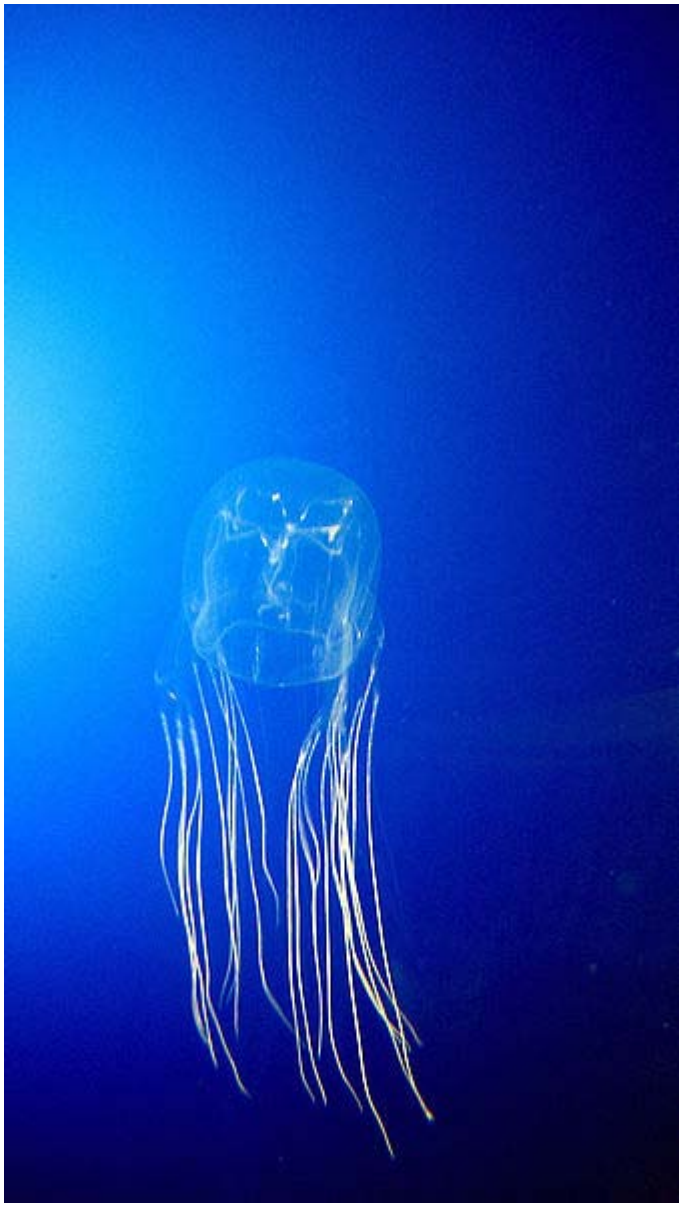
A few mineralized fossils that resemble corals have been found in rocks from the Cambrian period, and corals diversified in the Early Ordovician. These corals, which were wiped out in the Permian-Triassic extinction about 251 million years ago, did not dominate reef construction since sponges and algae also played a major part. During the Mesozoic era rudist bivalves were the main reef-builders, but they were wiped out in the

Cretaceous-Tertiary extinction 65 million years ago, and since then the main reef-builders have been scleractinian corals.

Interaction with humans

Jellyfish stings killed about 1,500 people in the 20th century, and cubozoans are particularly dangerous. On the other hand, some large jellyfish are considered a delicacy in eastern and southern Asia. Coral reefs have long been economically important as providers of fishing grounds, protectors of shore buildings against currents and tides, and more recently as centers of tourism. However, they are vulnerable to over-fishing, mining for construction materials, pollution, and damage caused by tourism.

Beaches protected from tides and storms by coral reefs are often the best places for housing in tropical countries. Reefs are an important food source for low-technology fishing, both on the reefs themselves and in the adjacent seas. However despite their great productivity reefs are vulnerable to over-fishing, because much of the organic carbon they produce is exhaled as carbon dioxide by organisms at the middle levels of the food chain and never reaches the larger species that are of interest to fishermen. Tourism centered on reefs provides much of the income of some tropical islands, attracting photographers, divers and sports fishermen. However human activities damage reefs in several ways: mining for construction materials; pollution, including large influxes of fresh water from storm drains; commercial fishing, including the use of dynamite to stun fish and the capture of young fish for aquariums; and tourist damage caused by boat anchors and the cumulative effect of walking on the reefs. Coral, mainly from the Pacific Ocean has long been used in jewellery, and demand rose sharply in the 1980s.



The dangerous "sea wasp" *Chironex fleckeri*

Some large jellyfish species have been used in Chinese cuisine at least since 200 AD, and are now fished in the seas around most of South East Asia. Japan is the largest single consumer of edible jellyfish, importing at first only from China but now from all of South East Asia as prices rose in the 1970s. This fishing industry is restricted to daylight hours and calm conditions in two short seasons, from March to May and August to November. The commercial value of jellyfish food products depends on the skill with which they are prepared, and "Jellyfish Masters" guard their trade secrets carefully. Jellyfish is very low in cholesterol and sugars, but cheap preparation can introduce undesirable amounts of heavy metals.

The "sea wasp" *Chironex fleckeri* has been described as the world's most venomous animal and is held responsible for 67 deaths, although it is difficult to identify the animal as it is almost transparent. Most stingings by *C. fleckeri* cause only mild symptoms. Seven other box jellies can cause a set of symptoms called Irukandji syndrome, which takes about 30 minutes to develop, and from a few hours to two weeks to disappear. Hospital treatment is usually required, and there have been a few deaths.

Chapter- 7

Mollusca

Mollusca **Temporal range: Cambrian–Recent**	
	
Tonicella lineata, a polyplacophoran or chiton, anterior end towards the right	
Scientific classification	
Kingdom:	Animalia
Superphylum:	Lophotrochozoa
Phylum:	**Mollusca** Linnaeus, 1758
Diversity	
85,000 recognized living species	

The **Mollusca**, common name **molluscs** or **mollusks**, is a large phylum of invertebrate animals. There are around 85,000 recognized extant species of molluscs. This is the largest marine phylum, comprising about 23% of all the named marine organisms. Numerous molluscs also live in freshwater and terrestrial habitats. Molluscs are highly diverse, not only in size and in anatomical structure, but also in behaviour and in habitat.

The phylum Mollusca is typically divided into nine or ten taxonomic classes, of which two are extinct. The gastropods (snails and slugs) include by far the most classified species, accounting for 80% of the total. Cephalopod molluscs such as squid, cuttlefish and octopus are among the most neurologically advanced invertebrates. Either the giant squid or the colossal squid is the largest known species of animal without a backbone.

The two most universal features of the body structure of molluscs are a mantle with a significant cavity used for breathing and excretion, and the organization of the nervous system. Because of the great range of anatomical diversity, many textbooks base their descriptions on a hypothetical "generalized mollusc", with features common to many but not all classes within the Mollusca.

There is good evidence for the appearance of gastropods, cephalopods and bivalves in the Cambrian period 542 to 488.3 million years ago. However, the evolutionary history both of the emergence of molluscs from the ancestral group Lophotrochozoa, and of their diversification into the well-known living and fossil forms, is still vigorously debated. The most abundant metallic element in molluscs is calcium.

Molluscs have for many centuries been the source of important luxury goods, notably pearls, mother of pearl, Tyrian purple dye, and sea silk. Their shells have also been used as money in some pre-industrial societies.

There is a risk of food poisoning from toxins that accumulate in molluscs under certain conditions, and many countries have regulations that aim to minimize this risk. Blue-ringed octopus bites are often fatal, and the bite of *Octopus rubescens* can cause necrosis that lasts longer than one month if untreated, and headaches and weakness persisting for up to a week even if treated. Stings from a few species of large tropical cone shells can also kill. However, the sophisticated venoms of these cone snails have become important tools in neurological research and show promise as sources of new medications.

Schistosomiasis (also known as bilharzia, bilharziosis or snail fever) is transmitted to humans via water snail hosts, and affects about 200 million people. A few species of snails and slugs are serious agricultural pests, and in addition, accidental or deliberate introduction of various snail species into new territory has resulted in serious damage to some natural ecosystems.

Taxonomy

The phylum Mollusca is monophyletic and is typically divided into nine or ten taxonomic classes, of which two are extinct. The gastropods (snails and slugs) include by far the most classified species, accounting for 80% of the total. Cephalopod molluscs such as squid, cuttlefish and octopus are among the most neurologically advanced invertebrates. Either the giant squid or the colossal squid is the largest known species of animal without a backbone.

Opinions vary about the number of classes of molluscs—for example the table below shows eight living classes, and two extinct ones. However some authors combine the Caudofoveata and solenogasters into one class, the Aplacophora. Two of the commonly recognized classes are known only from fossils

Synonymy has been a great problem. The phylum Mollusca is certainly the marine group where the number of names, given in the last 250 years, and number of valid names of species are most at odds with each other. The great number of scientific journals and publications, most of which can only be consulted on payment, makes it difficult for the taxonomist to know whether or not a newly described species has actually been described before in the relevant literature. This causes many synonymies to remain unrecognized for decades. It is currently believed that synonyms represent at most 10-20% of the 1,635 new marine species (many of which are mollusks) that are on average being described each year.

Class	Major organisms	Described living species	Distribution
Caudofoveata	worm-like organisms	120	seabed 200–3,000 metres (660–9,800 ft)
Aplacophora	solenogasters, worm-like organisms	200	seabed 200–3,000 metres (660–9,800 ft)
Polyplacophora	chitons	1,000	rocky tidal zone and seabed
Monoplacophora	An ancient lineage of molluscs with cap-like shells	31	seabed 1,800–7,000 metres (5,900–23,000 ft); one species 200 metres (660 ft)
Gastropoda	All the snails and slugs including abalone, limpets, conch, nudibranchs, sea hares, sea butterfly	70,000	marine, freshwater, land
Cephalopoda	squid, octopus, cuttlefish, nautilus	900	marine
Bivalvia	clams, oysters, scallops, geoducks, mussels	20,000	marine, freshwater
Scaphopoda	tusk shells	500	marine 6–7,000 metres (20–23,000 ft)
Rostroconchia †	fossils; probable ancestors of bivalves	extinct	marine
Helcionelloida †	fossils; snail-like organisms such as *Latouchella*	extinct	marine

Distinguishing features

The two most universal features of the body structure of molluscs are a mantle with a significant cavity used for breathing and excretion, and the organization of the nervous system. Because of the great range of anatomical diversity, many textbooks base their descriptions on a hypothetical "generalized mollusc", with features common to many but not all classes within the Mollusca.

Diversity

About 80% of all known mollusc species are gastropods (snails and slugs), including the cowry (a sea snail) pictured here.

Estimates of accepted described living species of molluscs vary from 50,000 to a maximum of 120,000 species. In 2009 Chapman estimated the number of described living species at 85,000. Haszprunar in 2001 estimated about 93,000 named species, which include 23% of all named marine organisms. Molluscs are second only to arthropods in numbers of living animal species—far behind the arthropods' 1,113,000 but well ahead of chordates' 52,000. It has been estimated that there are about 200,000 living species in total, and 70,000 fossil species, although the total number of mollusc species that ever existed, whether or not preserved, must be many times greater than the number alive today.

Molluscs have more varied forms than any other animal phylum. They include snails, slugs and other gastropods; clams and other bivalves; squids and other cephalopods; and other lesser-known but similarly distinctive sub-groups. The majority of species still live in the oceans, from the seashores to the abyssal zone, but some form a significant part of the freshwater fauna and the terrestrial ecosystems. Molluscs are extremely diverse in tropical and temperate regions but can be found at all latitudes. About 80% of all known mollusc species are gastropods. Cephalopoda such as squid, cuttlefish and octopus are among the neurologically most advanced of all invertebrates. The giant squid, which until recently had not been observed alive in its adult form, is one of the largest invertebrates.

However a recently caught specimen of the colossal squid, 10 metres (33 ft) long and weighing 500 kilograms (0.49 LT; 0.55 ST), may have overtaken it.

Freshwater and terrestrial molluscs appear exceptionally vulnerable to extinction. Estimates of the numbers of non-marine molluscs vary widely, partly because many regions have not been thoroughly surveyed. There is also a shortage of specialists who can identify all the animals in any one area to species. However, in 2004 the IUCN Red List of Threatened Species included nearly 2,000 endangered non-marine molluscs. For comparison, the great majority of molluscs species are marine but only 41 of these appeared on the 2004 Red List. 42% of recorded extinctions since the year 1500 are of molluscs, almost entirely non-marine species.

Definition

The words *mollusc* and mollusk are both derived from the French *mollusque*, which originated from the Latin *molluscus*, from *mollis*, soft. *Molluscus* was itself an adaptation of Aristotle's τὰ μαλάκια, "the soft things", which he applied to cuttlefish. The scientific study of molluscs is known as malacology.

Molluscs have developed such a varied range of body structures that it is difficult to find synapomorphies (defining characteristics) that apply to all modern groups. The most general characteristic of molluscs is that they are unsegmented and bilaterally symmetrical. The following are present in all modern molluscs:

- The dorsal part of the body wall is a mantle (or pallium) which secretes calcareous spicules, plates or shells. It overlaps the body with enough spare room to form a mantle cavity.
- The anus and genitals open into the mantle cavity.
- There are two pairs of main nerve cords.

Other characteristics that commonly appear in textbooks have significant exceptions:

	Class						
Characteristic	**Aplacophora**	**Polyplacophora**	**Monoplacophora**	**Gastropoda**	**Cephalopoda**	**Bivalvia**	**Scaphopoda**
Radula, a rasping "tongue" with chitinous teeth	Absent in 20% of Neomeniomorpha	Yes	Yes	Yes	Yes	No	Internal, cannot extend beyond body
Broad, muscular foot	Reduced or absent	Yes	Yes	Yes	Modified into arms	Yes	Small, only at "front" end

Dorsal concentration of internal organs (visceral mass)	Not obvious	Yes	Yes	Yes	Yes	Yes	Yes
Large digestive ceca	No ceca in some aplacophora	Yes	Yes	Yes	Yes	Yes	No
Large complex metanephridia ("kidneys")	None	Yes	Yes	Yes	Yes	Yes	Small, simple

A "generalized mollusc"

Because of the enormous variations between groups of molluscs, many text books start the subject by describing a "generalized mollusc", which some suggest *may* resemble very early molluscs and which is rather similar to modern monoplacophorans.

The generalized mollusc has a single, "limpet-like" shell on top. The shell is secreted by a mantle that covers the upper surface. The underside consists of a single muscular "foot". The visceral mass, or visceropallium, is the soft, non-muscular metabolic region of the mollusc. It contains the body organs.

Mantle and mantle cavity

The mantle cavity is a fold in the mantle that encloses a significant amount of space. It is lined with epidermis. It is exposed, according to habitat, to sea, fresh water or air. The cavity was at the rear in the earliest molluscs but its position now varies from group to group. The anus, a pair of osphradia (chemical sensors) in the incoming "lane", the hindmost pair of gills and the exit openings of the nephridia ("kidneys") and gonads (reproductive organs) are in the mantle cavity. The whole soft body of bivalves lies within an enlarged mantle cavity.

Shell

The mantle edge secretes a shell (secondarily absent in a number of taxonomic groups, such as the nudibranchs) that consists of mainly chitin and conchiolin (a protein) hardened with calcium carbonate), except that the outermost layer in almost all cases is all conchiolin. Molluscs never use phosphate to construct their hard parts, with the questionable exception of *Cobcrephora*. While most mollusc shells are composed mainly of aragonite, those gastropods that lay eggs with a hard shell use calcite (sometimes with traces of aragonite) to construct the eggshells.

The shell consists of three layers : the outer layer (the periostracum) made of organic matter, a middle layer made of columnar calcite and an inner layer consisting of laminated calcite, that is often nacreous.

Foot

The underside consists of a muscular foot, which has adapted to different purposes in different classes. The foot carries a pair of statocysts, which act as balance sensors. In gastropods, it secretes mucus as a lubricant to aid movement. In forms that have only a top shell, such as limpets, the foot acts as a sucker attaching the animal to a hard surface, and the vertical muscles clamp the shell down over it; in other molluscs, the vertical muscles pull the foot and other exposed soft parts into the shell. In bivalves, the foot is adapted for burrowing into the sediment;[:4] in cephalopods it is used for jet propulsion,[:4] and the tentacles and arms are derived from the foot.

Multiple functions of organs

Molluscs organs are used for multiple functions. For example: the heart and nephridia ("kidneys") are important parts of the reproductive system as well as the circulatory and excretory systems; in bivalves, the gills both "breathe" and produce a water current in the mantle cavity, which serves both excretion and reproduction.

Circulation

Molluscs' circulatory systems are mainly open. Although molluscs are coelomates, their coeloms are reduced to fairly small spaces enclosing the heart and gonads. The main body cavity is a hemocoel through which blood and coelomic fluid circulate and which encloses most of the other internal organs. These hemocoelic spaces act as an efficient hydrostatic skeleton. The blood contains the respiratory pigment hemocyanin as an oxygen-carrier. The heart consists of one or more pairs of atria (auricles), which receive oxygenated blood from the gills and pump it to the ventricle, which pumps it into the aorta (main artery), which is fairly short and opens into the hemocoel.

The atria of the heart also function as part of the excretory system by filtering waste products out of the blood and dumping it into the coleom as urine. A pair of nephridia ("little kidneys") to the rear of and connected to the coelom extracts any re-usable materials from the urine and dumps additional waste products into it, and then ejects it via tubes that discharge into the mantle cavity.

Respiration

Most molluscs have only one pair of gills, or even only one gill. Generally the gills are rather like feathers in shape, although some species have gills with filaments on only one side. They divide the mantle cavity so that water enters near the bottom and exits near the top. Their filaments have three kinds of cilia, one of which drives the water current through the mantle cavity, while the other two help to keep the gills clean. If the

osphradia detect noxious chemicals or possibly sediment entering the mantle cavity, the gills' cilia may stop beating until the unwelcome intrusions have ceased. Each gill has an incoming blood vessel connected to the hemocoel and an outgoing one to the heart.

Eating, digestion, and excretion

Most molluscs have muscular mouths with radulae, "tongues" bearing many rows of chitinous teeth, which are replaced from the rear as they wear out. The radula primarily functions to scrape bacteria and algae off rocks. This radula is associated with the odontophore, a cartilaginous supporting organ

Molluscs mouths also contain glands that secrete slimy mucus, to which the food sticks. Beating cilia (tiny "hairs") drive the mucus towards the stomach, so that the mucus forms a long string.

At the tapered rear end of the stomach and projecting slightly into the hindgut is the prostyle, a backward-pointing cone of feces and mucus, which is rotated by further cilia so that it acts as a bobbin, winding the mucus string onto itself. Before the mucus string reaches the prostyle, the acidity of the stomach makes the mucus less sticky and frees particles from it.

The particles are sorted by yet another group of cilia, which send the smaller particles, mainly minerals, to the prostyle so that eventually they are excreted, while the larger ones, mainly food, are sent to the stomach's cecum (a pouch with no other exit) to be digested. The sorting process is by no means perfect.

Periodically, circular muscles at the hindgut's entrance pinch off and excrete a piece of the prostyle, preventing the prostyle from growing too large. The anus is in the part of the mantle cavity that is swept by the outgoing "lane" of the current created by the gills. Carnivorous molluscs usually have simpler digestive systems.

As the head has largely disappeared in bivalves, their mouth has been equipped with labial palps (two on each side of the mouth) to collect the detritus from its mucus.

Nervous system

Molluscs have two pairs of main nerve cords (three in bivalves) the visceral cords serving the internal organs and the pedal ones serving the foot. Both pairs run below the level of the gut, and include ganglia as local control centers in important parts of the body. Most pairs of corresponding ganglia on both sides of the body are linked by commissures (relatively large bundles of nerves). The only ganglia above the gut are the cerebral ganglia, which sit above the esophagus (gullet) and handle "messages" from and to the eyes. The pedal ganglia, which control the foot, are just below the esophagus and their commissure and connections to the cerebral ganglia encircle the esophagus in a nerve ring.

The brain, in species that have one, encircles the esophagus. Most molluscs have a head with eyes, and all have a pair of sensor-containing tentacles, also on the head, that detect chemicals, vibrations and touch.

Reproduction

The simplest molluscan reproductive system relies on external fertilization, but there are more complex variations. All produce eggs, from which may emerge trochophore larvae, more complex veliger larvae, or miniature adults. Two gonads sit next to the coelom, a small cavity that surrounds the heart and shed ova or sperm into the coloem, from which the nephridia extract them and emit them into the mantle cavity. Molluscs that use such a system remain of one sex all their lives and rely on external fertilization. Some molluscs use internal fertilization and/or are hermaphrodites, functioning as both sexes; both of these methods require more complex reproductive systems.

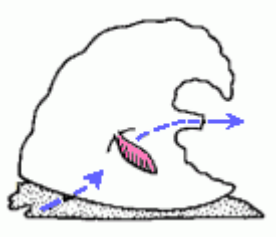
The most basic molluscan larva is a trochophore, which is planktonic and feeds on floating food particles by using the two bands of cilia round its "equator" to sweep food into the mouth, which uses more cilia to drive them into the stomach, which uses further cilia to expel undigested remains through the anus. New tissue grows in the bands of mesoderm in the interior, so that the apical tuft and anus are pushed further apart as the animal grows. The trochophore stage is often succeeded by a veliger stage in which the prototroch, the "equatorial" band of cilia nearest the apical tuft, develops into the velum ("veil"), a pair of cilia-bearing lobes with which the larva swims. Eventually the larva sinks to the seafloor and metamorphoses into the adult form. Whilst metamorphosis is the usual state in molluscs, the cephalopods differ in exhibiting direct development: the hatchling is a 'miniaturized' form of the adult.

Evolution

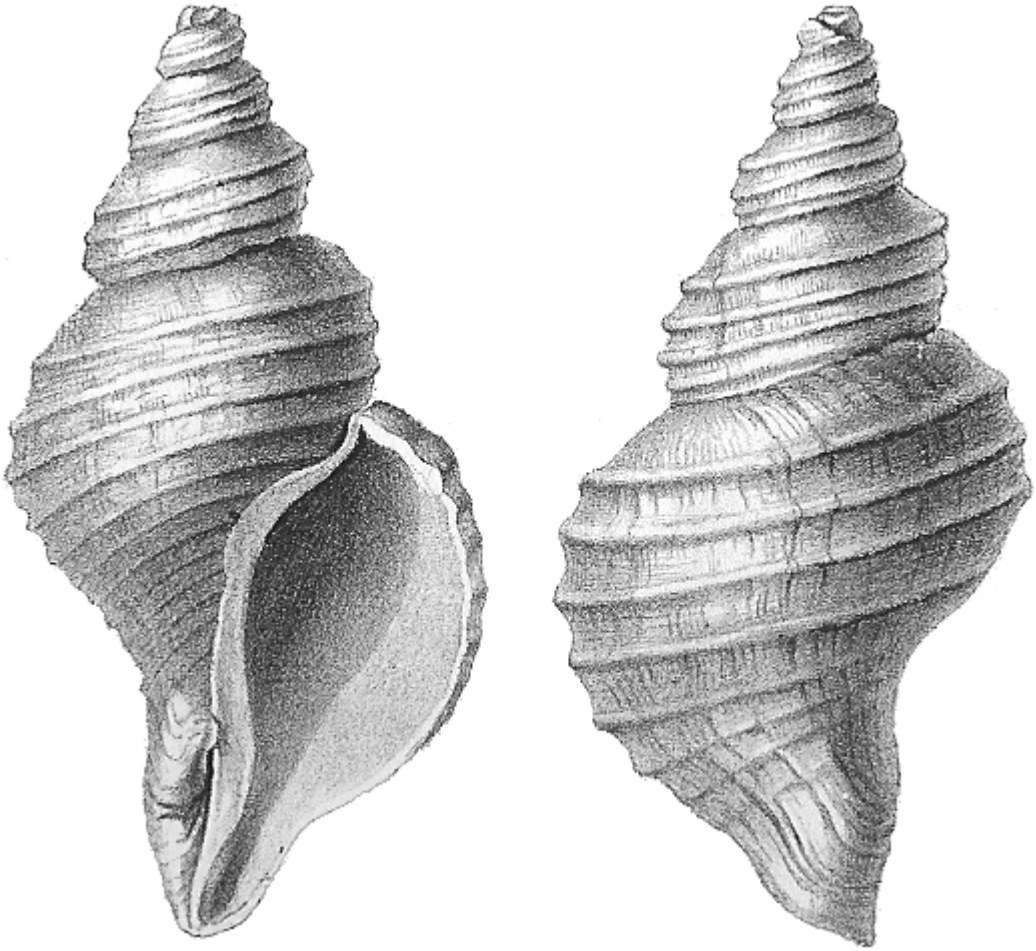
Fossil record

There is good evidence for the appearance of gastropods, cephalopods and bivalves in the Cambrian period 542 to 488.3 million years ago. However, the evolutionary history both of the emergence of molluscs from the ancestral group Lophotrochozoa, and of their diversification into the well-known living and fossil forms, is still vigorously debated.

There is debate about whether some Ediacaran and Early Cambrian fossils really are molluscs. *Kimberella*, from about 555 million years ago, has been described as "mollusc-like", but others are unwilling to go further than "probable bilaterian". There is an even sharper debate about whether *Wiwaxia*, from about 505 million years ago, was a mollusc, and much of this centers on whether its feeding apparatus was a type of radula or more similar to that of some polychaete worms. Nicholas Butterfield, who opposes the idea that *Wiwaxia* was a mollusc, has written that earlier microfossils from 515 to 510 million years ago are fragments of a genuinely mollusc-like radula.



The tiny Helcionellid fossil *Yochelcionella* is thought to be an early mollusk



Spirally coiled shells appear in many gastropods

However, the Helcionellids, which first appear over 540 million years ago in Early Cambrian rocks from Siberia and China, are thought to be early molluscs with rather snail-like shells. Shelled molluscs therefore predate the earliest trilobites. Although most helcionellid fossils are only a few millimeters long, specimens a few centimeters long have also been found, most with more limpet-like shapes. There have been suggestions that the tiny specimens were juveniles and the larger ones adults.

Some analyses of helcionellids concluded that these were the earliest gastropods. However other scientists are not convinced that Early Cambrian fossils show clear signs of the torsion that identifies modern gastropods twists the internal organs so that the anus lies above the head.

For a long time it was thought that *Volborthella*, some fossils of which pre-date 530 million years ago, was a cephalopod. However discoveries of more detailed fossils showed that *Volborthella*'s shell was not secreted but built from grains of the mineral silicon dioxide (silica), and that it was not divided into a series of compartments by septa as those of fossil shelled cephalopods and the living *Nautilus* are. *Volborthella*'s classification is uncertain. The Late Cambrian fossil *Plectronoceras* is now thought to be the earliest clearly cephalopod fossil, as its shell had septa and a siphuncle, a strand of tissue that *Nautilus* uses to remove water from compartments that it has vacated as it grows, and which is also visible in fossil ammonite shells. However, *Plectronoceras* and other early cephalopods crept along the seafloor instead of swimming, as their shells contained a "ballast" of stony deposits on what is thought to be the underside and had stripes and blotches on what is thought to be the upper surface. All cephalopods with external shells except the nautiloids became extinct by the end of the Cretaceous period 65 million years ago. However, the shell-less Coleoidea (squid, octopus, cuttlefish) are abundant today.

The Early Cambrian fossils *Fordilla* and *Pojetaia* are regarded as bivalves. "Modern-looking" bivalves appeared in the Ordovician period, 488 to 443 million years ago. One bivalve group, the rudists, became major reef-builders in the Cretaceous, but became extinct in the Cretaceous-Tertiary extinction. Even so, bivalves remain abundant and diverse.

The Hyolitha is a class of extinct animals with a shell and operculum that may be molluscs. Authors who suggest that they deserve their own phylum do not comment on the position of this phylum in the tree of life

Phylogeny

A possible "family tree" of molluscs (2007). Does not include annelid worms as the analysis concentrated on fossilizable "hard" features.

The phylogeny (evolutionary "family tree") of molluscs is a controversial subject. In addition to the debates about whether *Kimberella* and any of the "halwaxiids" were molluscs or closely related to molluscs, there are debates about the relationships between the classes of living molluscs. In fact some groups traditionally classifed as molluscs may have to be redefined as distinct but related.

Molluscs are generally regarded members of the Lophotrochozoa, a group defined by having trochophore larvae and, in the case of living Lophophorata, a feeding structure called a lophophore. The other members of the Lophotrochozoa are the annelid worms and seven marine phyla. The diagram on the right summarizes a phylogeny presented in 2007.

Because the relationships between the members of the family tree are uncertain, it difficult to identify the features inherited from the last common ancestor of all molluscs. For example, it is uncertain whether the ancestral mollusc was metameric (composed of repeating units)—if it was, that would suggest an origin from an annelid-like worm. Scientists disagree about this: Giribet and colleagues concluded in 2006 that the repetition of gills and of the foot's retractor muscles were later developments, while in 2007 Sigwart concluded that the ancestral mollusc was metameric, and that it had a foot used for creeping and a "shell" that was mineralized. In one particular one branch of the family tree, the shell of conchiferans is thought to have evolved from the spicules (small spines) of aplacophorans; however this is difficult to reconcile with the embryological origins of spicules.

The molluscan shell appears to have originated from a mucus coating, which eventually stiffened into a cuticle. This would have been impermeable and thus forced the development of more sophisticated respiratory apparatus in the form of gills. Eventually, the cuticle would have become mineralized, using the same genetic machinery (*engrailed*) as most other bilaterian skeletons. The first mollusc shell almost certainly was reinforced with the mineral aragonite.

The evolutionary relationships *within* the molluscs are also debated, and the diagrams below show two widely supported reconstructions:

Morphological analyses tend to recover a conchiferan clade that receives less support from molecular analyses, although these results also lead to unexpected paraphylies, for instance scattering the bivalves throughout all other mollusc groups.

However, an analysis in 2009 that used both morphological and molecular phylogenetics comparisons concluded that the molluscs are not monophyletic; in particular, that Scaphopoda and Bivalvia are both separate, monophyletic lineages unrelated to the remaining molluscan classes—in other words that the traditional phylum Mollusca is polyphyletic, and that it can only be made monophyletic if scaphopods and bivalves are excluded. A 2010 analysis managed to recover the traditional conchiferan and seriala groups, but similarly concluded that the molluscs are not monophyletic, this time suggesting that solenogastres are more closely related to the non-molluscan taxa used as an outgroup than to other molluscs. Current molecular data is insufficient to constrain the molluscan phylogeny, and since the methods used to determine the confidence in clades are prone to over-estimation, it is risky to place too much emphasis even on the areas that different studies agree.

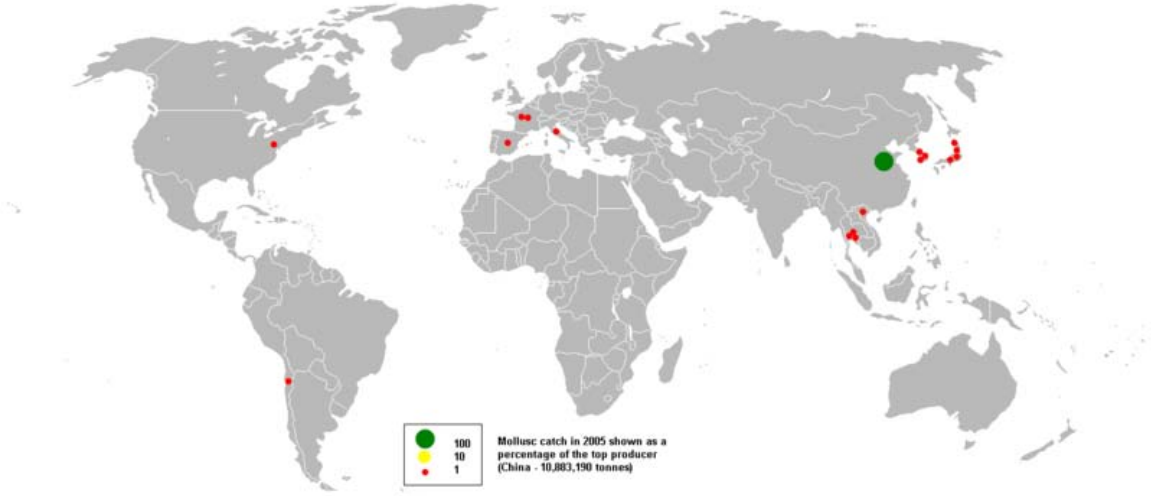
Human interaction

Molluscs have for many centuries been the source of important luxury goods, notably pearls, mother of pearl, Tyrian purple dye, and sea silk. Their shells have also been used as money in some pre-industrial societies.

There is a risk of food poisoning from toxins that accumulate in molluscs under certain conditions, and many countries have regulations that aim to minimize this risk. Blue-ringed octopus bites are often fatal, and the bite of *Octopus rubescens* can cause necrosis that lasts longer than one month if untreated, and headaches and weakness persisting for up to a week even if treated. Stings from a few species of large tropical cone shells can also kill. However, the sophisticated venoms of these cone snails have become important tools in neurological research and show promise as sources of new medications.

Schistosomiasis (also known as bilharzia, bilharziosis or snail fever) is transmitted to humans via water snail hosts, and affects about 200 million people. A few species of snails and slugs are serious agricultural pests, and in addition, accidental or deliberate introduction of various snail species into new territory has resulted in serious damage to some natural ecosystems.

Uses by humans



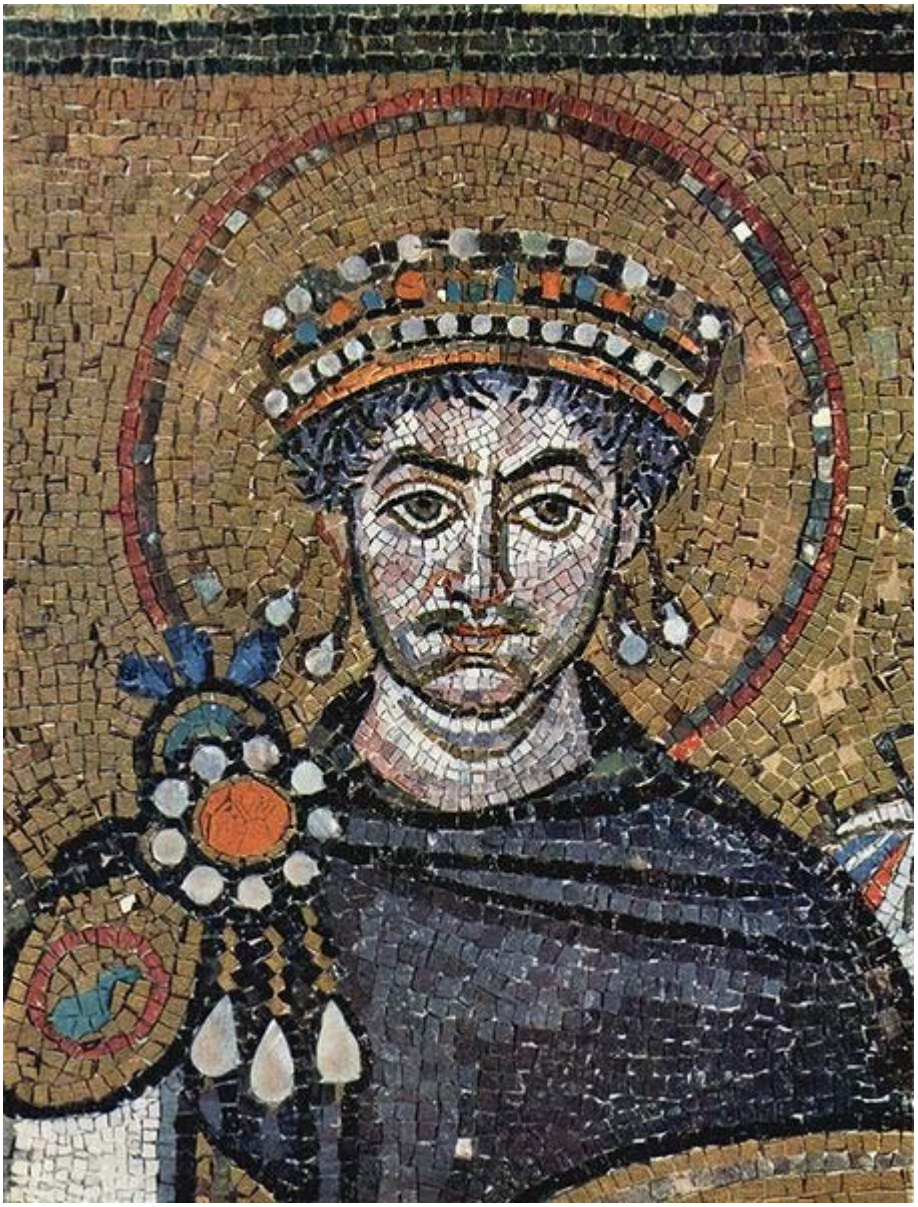
Mollusc output in 2005

Molluscs, especially bivalves such as clams and mussels, have been an important food source since at least the advent of anatomically modern humans—and this has often resulted in over-fishing. Other commonly eaten molluscs include octopuses and squids, whelks, oysters, and scallops. In 2005, China accounted for 80% of the global mollusc catch, netting almost 11,000,000 tonnes (11,000,000 LT; 12,000,000 ST). Within Europe, France remained the industry leader. Some countries regulate importation and handling of molluscs and other seafood, mainly to minimize the poison risk from toxins that accumulate in the animals.

Saltwater pearl oyster farm in Seram, Indonesia

Most molluscs that have shells can produce pearls, but only the pearls of bivalves and some gastropods whose shells are lined with nacre are valuable. The best natural pearls are produced by pearl oyster.s *Pinctada margaritifera* and *Pinctada mertensi*, which live in the tropical and sub-tropical waters of the Pacific Ocean. Natural pearls form when a small foreign object gets stuck between the mantle and shell.

There are two methods of culturing pearls, by inserting either "seeds" or beads into oysters. The "seed" method uses grains of ground shell from freshwater mussels, and over-harvesting for this purpose has endangered several freshwater mussel species in the southeastern USA. The pearl industry is so important in some areas that significant sums of money are spent on monitoring the health of farmed molluscs.



Byzantine Emperor Justinian I clad in Tyrian purple

Other luxury and high-status products were made from molluscs. Tyrian purple, made from the ink glands of murex shells, "... fetched its weight in silver" in the fourth-century BC, according to Theopompus. The discovery of large numbers of Murex shells on Crete suggests that the Minoans may have pioneered the extraction of "Imperial purple" during the Middle Minoan period in the 20th–18th century BC, centuries before the Tyrians. Sea silk is a fine, rare and valuable fabric produced from the long silky threads (byssus) secreted by several bivalve molluscs, particularly *Pinna nobilis*, to attach themselves to the sea bed. Procopius, writing on the Persian wars circa 550 CE, "stated that the five hereditary satraps (governors) of Armenia who received their insignia from the Roman Emperor were given chlamys (or cloaks) made from *lana pinna* (Pinna "wool," or byssus). Apparently only the ruling classes were allowed to wear these chlamys."

Mollusc shells, including those of cowries, were used as a kind of money in several pre-industrial societies. However these "currencies" generally differed in important ways from the standardized government-backed and -controlled money familiar to industrial societies. Some shell "currencies" were not used for commercial transactions but mainly as social status displays at important occasions such as weddings. When used for commercial transactions they functioned as commodity money, in other words as a tradable commodity whose value differed from place to place, often as a result of difficulties in transport, and which was vulnerable to incurable inflation if more efficient transport or "goldrush" behavior appeared.

Stings and bites

The blue-ringed octopus's rings are a warning signal—this octopus is alarmed, and its bite can kill.

When handled alive, a few species of molluscs can sting or bite and, with some species, this can present a serious risk to the human handling the animal. To put this into perspective however, deaths from mollusc venoms are less than 10% of the number of deaths from jellyfish stings.

All octopuses are venomous but only a few species pose a significant threat to humans. Blue-ringed octopuses in the genus *Hapalochlaena*, which live around Australia and New Guinea, bite humans only if severely provoked, but their venom kills 25% of human victims. Another tropical species, *Octopus apollyon*, causes severe inflammation that can last for over a month even if treated correctly.

Live cone snails can be dangerous to shell-collectors but are useful to neurology researchers

All species of cone snails are venomous and can sting when handled, although many species are too small to pose much of a risk to humans. These are carnivorous gastropods that feed on marine invertebrates (and in the case of larger species on fish). Their venom is based on a huge array of toxins, some fast-acting and others slower but deadlier—they can afford to do this because their toxins require less time and energy to be produced compared with those of snakes or spiders. Many painful stings have been reported, and a few fatalities, although some of the reported fatalities may be exaggerations. Only the few larger species of cone snail that can capture and kill fish are likely to be seriously dangerous to humans. The effects of individual cone shell toxins on victims' nervous

systems are so precise that they are useful tools for research in neurology, and the small size of their molecules makes it easy to synthesize them.

The traditional belief that a giant clam can trap the leg of a person between its valves, thus drowning them, is a myth.

Pests

Skin vesicles created by the penetration of *Schistosoma*. Source: Centers for Disease Control and Prevention

Schistosomiasis (also known as bilharzia, bilharziosis or snail fever) is "second only to malaria as the most devastating parasitic disease in tropical countries. An estimated 200 million people in 74 countries are infected with the disease — 100 million in Africa alone." The parasite has 13 known species, of which two infect humans. The parasite itself is not a mollusc, but all the species have freshwater snails as intermediate hosts.

Some species of molluscs, particularly certain snails and slugs, can be serious crop pests, and when introduced into new environments can unbalance local ecosystems. One such pest, the giant African snail *Achatina fulica*, has been introduced to many parts of Asia, as well as to many islands in the Indian Ocean and Pacific Ocean. In the 1990s this species reached the West Indies. Attempts to control it by introducing the predatory snail *Euglandina rosea* proved disastrous, as the predator ignored *Achatina fulica* and went on to extirpate several native snail species instead.