Echinoderm and Platyhelminthes (Animal Phylum)

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Echinoderm

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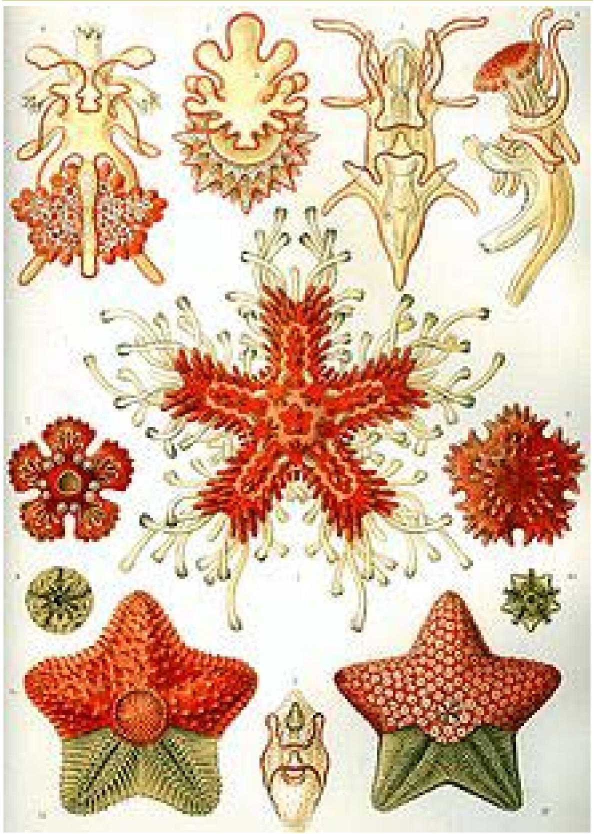
 Haeckel's diagrams of Asteroidea specimens	
Scientific classification	
Kingdom:	Animalia
Subkingdom:	Eumetazoa
Superphylum:	Deuterostomia
Phylum:	**Echinodermata** Klein, 1734

Subphyla & Classes

- Homalozoa † Gill & Caster, 1960

  Homostelea †
  Homoiostelea †
  Stylophora †
  Ctenocystoidea † Robison & Sprinkle, 1969

- Crinozoa

  Crinoidea
  Paracrinoidea † Regnéll, 1945
  Cystoidea † von Buch, 1846

- Asterozoa

  Ophiuroidea
  Asteroidea

- Echinozoa

  Echinoidea
  Holothuroidea
  Ophiocistioidea †
  Helicoplacoidea †
  ?*Arkarua* †

- Pelmatozoa †

  Edrioasteroidea †

- Blastozoa †

  Blastoidea †
  Eocrinoidea †Jaekel, 1899

† = Extinct

Echinoderms (Phylum **Echinodermata**) are a phylum of marine animals. Echinoderms are found at every ocean depth, from the intertidal zone to the abyssal zone. Aside from the problematic *Arkarua*, the first definitive members of the phylum appeared near the start of the Cambrian period.

The phylum contains about 7,000 living species, making it the second-largest grouping of deuterostomes, after the chordates. Echinoderms are also the largest phylum that has no freshwater or terrestrial representatives.

The word is derived from the Greek *ἐχινοδέρματα* (*echinodermata*), plural of *ἐχινόδερμα* (*echinoderma*), "spiny skin" from *ἐχινός* (*echinos*), "sea-urchin", originally "hedgehog," and *δέρμα* (*derma*), "skin".

The echinoderms are important both biologically and geologically: biologically because few other groupings are so abundant in the biotic desert of the deep sea, as well as the shallower oceans, and geologically as their ossified skeletons are major contributors to many limestone formations, and can provide valuable clues as to the geological environment. Further, it is held by some that the radiation of echinoderms was responsible for the Mesozoic revolution of marine life.

Taxonomy

Two main subdivisions of echinoderms are traditionally recognised: the more familiar, motile Eleutherozoa, which encompasses the Asteroidea (starfish), Ophiuroidea (brittle stars), Echinoidea (sea urchins and sand dollars) and Holothuroidea (sea cucumbers); and the sessile Pelmatazoa, which consists of the crinoids and extinct Paracrinoids. Some crinoids, however, namely the feather stars, are also highly motile.

A fifth class of Eleutherozoa consisting of just three species, the Concentricycloidea (sea daisies), were recently merged into the Asteroidea. The fossil record contains a host of other classes which do not appear to fall into any extant crown group.

Anatomy and physiology

Echinoderms evolved from animals with bilateral symmetry. Although adult echinoderms possess pentaradial, or five-sided, symmetry, echinoderm larvae are ciliated, free-swimming organisms that organize in a bilaterally symmetric fashion that makes them look like embryonic chordates. Later, the left side of the body grows at the expense of the right side, which is eventually absorbed. The left side then grows in a pentaradially symmetric fashion, in which the body is arranged in five parts around a central axis.

They exhibit fivefold radial symmetry in portions of their body at some stage of life, even if they have secondary bilateral symmetry. Many crinoids and some seastars exhibit symmetry in multiples of the basic five, with seastars such as *Helicoilaster* known to possess up to 50 arms, and the sea-lily *Comanthina schlegelii* boasting 200.

Skin and skeleton

Echinoderms have a mesodermal skeleton composed of calcareous plates or ossicles. Despite the robustness of the individual skeletal modules, complete echinoderm skeletons are rare in the fossil record. This is because they quickly disarticulate once the encompassing skin rots away, and in the absence of tissue there is nothing to hold the plates together. The modular construction is a result of the growth system employed by echinoderms, which adds new segments at the centre of the radial limbs, pushing the existing plates outwards in the fashion of a trachea. The spines of sea urchins are most readily lost, as each spine can be moved individually and is only loosely attached in life. A walk above a rocky shore will often reveal a large number of spineless but otherwise complete sea urchin skeletons.

Skeletal elements are also deployed in some specialised ways, such as the "Aristotle's lantern" of sea urchins, crinoids' stalks, and the supportive "lime ring" of sea cucumbers.

The epidermis itself consists of cells responsible for the support and maintenance of the skeleton, as well as pigment cells, mechanoreceptor cells, which detect motion on the animal's surface, and sometimes gland cells which secrete sticky fluids or even toxins.

Echinoderms exhibit a wide range of colours

The varied and often vivid colors of echinoderms are produced by the action of skin pigment cells. These may be light sensitive, and as a result many species change appearance completely as night falls. The reaction can happen very quickly — the sea urchin *Centrostephanus longispinus* changes from jet black to grey-brown in just 50 minutes when exposed to light. The colours are produced by a variable combination of coloured pigments, such as the dark melanin, red carotinoids, and carotin proteins, which can be blue, green, or violet.

The water vascular system

Echinoderms possess a unique water vascular or "ambulacral" system. This is a network of fluid-filled canals that function in gas exchange, feeding, and secondarily in locomotion. This system is derived from both the hydrocoel and axocoel. This system may have allowed echinoderms to function without the gill slits found in other deuterostomes.

The system comprises a central ring, the hydrocoel, and radial ambulacra stretching along the body or arms. As well as assisting with the distribution of nutrients through the animal, the system is most obviously expressed in the tube-feet of most echinoderms. These are extensions of the water vascular system which poke through holes in the skeleton and can be extended or contracted by the redistribution of fluid between the foot and internal sac.

In the crinoids, the tube feet waft food particles captured on the radial limbs towards the central mouth; in the asteroids, the same wafting motion is employed to move the animal across the ground. Sea urchins use their feet to prevent the larvae of encrusting organisms from settling on their surfaces; potential settlers are moved to the urchin's mouth and eaten. Some burrowing sea stars poke their tube feet through the surface of the sand or mud above them into the water column and use them to attain oxygen from the water column.

Other organs

Although echinoderms possess a complete digestive gut, it is very simple, often simply leading directly from mouth to anus. It can generally be divided into a pharynx, stomach, intestine and anus or cloaca.

Echinoderms also have a haemal system, and often also a *perihaemal system*. Both are derived from the coelom, and form an open and reduced circulatory system. This usually consists of a central ring and five radial vessels, although there is no true heart, and the blood often lacks any respiratory pigment.

Gaseous exchange occurs by *dermal branchae* or *papulae* in seastars, *peristominal gills* in sea urchins, *genitial bursae* in brittle stars and *cloacal trees* in holothurians. Exchange of gases also takes place through tube feet.

Echinoderms lack specialized excretory organs and so nitrogenous waste, chiefly in the form of ammonia diffuses out through the respiratory surfaces.

They have a simple radial nervous system that consists of a modified nerve net — interconnected neurons with no central brain (although some do possess ganglia). Nerves radiate from central rings around the mouth into each arm or along the body; the branches of these nerves coordinate the movements of the organism.

The gonads occupy the entire body cavities of sea urchins and sea cucumbers, while the less voluminous crinoids, brittle stars, and seastars have two gonads per arm. While the primitive condition is considered to be one genital aperture, many organisms have multiple holes through which eggs or sperm may be released.

Reproduction

Sexual reproduction

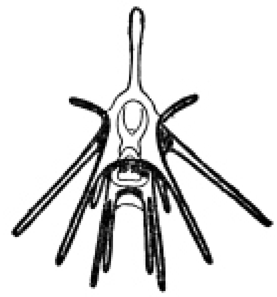
Echinoderms become sexually mature after approximately two to three years, depending on the species and the environmental conditions. The eggs and sperm cells are released into open water, where fertilization takes place. The release of sperm and eggs is coordinated temporally in some species, and spatially in others. Internal fertilization has currently been observed in three species of sea star, three brittle stars and a deep water sea cucumber.

In some species of feather star, the embryos develop in special breeding bags, where the eggs are held until sperm released by a male happen to find them and fertilize the contents. This can also be found among sea urchins and sea cucumbers, where exhibit care for their young can occur, for instance in a few species of sand dollars who carry their young between the pricks of their oral side, and heart urchins possess breeding chambers. With brittle stars, special chambers can be developed near the stomach bags, in which the development of the young takes place. Species of sea cucumbers with specialized care for their offspring may also nurse the young in body cavities or on their surfaces. In rare cases, direct development without passing through a bilateral larval stage can occur in some sea stars and brittle stars. Another strategy that has evolved in some sea stars and brittle stars is the ability to reproduce asexually by dividing in two halves while they are small juveniles, while turning to sexual reproduction when they have reached sexual maturity.

Asexual reproduction

Many echinoderms have remarkable powers of regeneration. Some sea stars are capable of regenerating lost arms. In some cases, lost arms have been observed to regenerate a second complete sea star. Sea cucumbers often discharge parts of their internal organs if they perceive danger. The discharged organs and tissues are quickly regenerated. Sea urchins are constantly losing their spines through damage — all parts are replaceable. Some seastar populations can reproduce entirely asexually purely by the shedding of arms for long periods of time.

Larval development



The "pluteus larva" of a sea urchin

The development of an echinoderm begins with a bilaterally symmetrical embryo, with a coeloblastula developing first. Gastrulation marks the opening of the "second mouth" that places them within the deuterostomes, and the mesoderm, which will host the skeleton, migrates inwards. The secondary body cavity, the coelom, forms by the partitioning of three body cavities.

Upon metamorphosis, each taxon produces a distinct planktonic larva, which varies in shape among the classes. Larval stages with prominent "arms" are often referred to as pluteus larvae (often with a prefix to denote taxon).

The left hand side of the larva develops into the adult organism while the right hand side eventually being absorbed; the left hand side typically becomes the oral plate.

Distribution and habitat

Echinoderms are globally distributed in almost all depths, latitudes and environments in the ocean. They reach highest diversity in reef environments but are also widespread on shallow shores, around the poles — refugia where crinoids are at their most abundant — and throughout the deep ocean, where bottom-dwelling and burrowing sea cucumbers are common — sometimes accounting for up to 90 % of organisms. While almost all echinoderms are benthic — that is, they live on the sea floor — some sea-lilies can swim at great velocity for brief periods of time, and a few deep-sea sea cucumbers are fully floating. Some crinoids are pseudo-planktonic, attaching themselves to floating logs and debris, although this behaviour was exercised most extensively in the Paleozoic, before competition from such organisms as barnacles restricted the extent of the behaviour. Some sea cucumbers employ a similar strategy, hitching lifts by attaching to the sides of fish.

The larvæ of many echinoderms, especially starfish and sea urchins, are pelagic, and with the aid of ocean currents can swim great distances, reinforcing the global distribution of the phylum.

Mode of life

Feeding

The modes of feeding vary greatly between the constituent taxa. Crinoids and some brittle stars tend to be passive filter-feeders, absorbing suspended particles from passing water; sea urchins are grazers, sea cucumbers deposit feeders, and seastars are active hunters.

Crinoids employ a large net-like structure to sieve water as it is swept by currents, and to absorb any particles of matter sinking from the ocean overhead. Once a particle touches the arms of the creature, the tube feet act to swish it to the central mouth of the crinoid, where it is ingested, nutrients removed, and the remains egested through its anus to the underlying water column.

Many sea urchins graze on the surfaces of rocks, scraping off the thin layer of algae covering the surfaces. Other toothless breeds devour smaller organisms, which they may catch with their tube feet, whole. Sand dollars may perform suspension feeding.

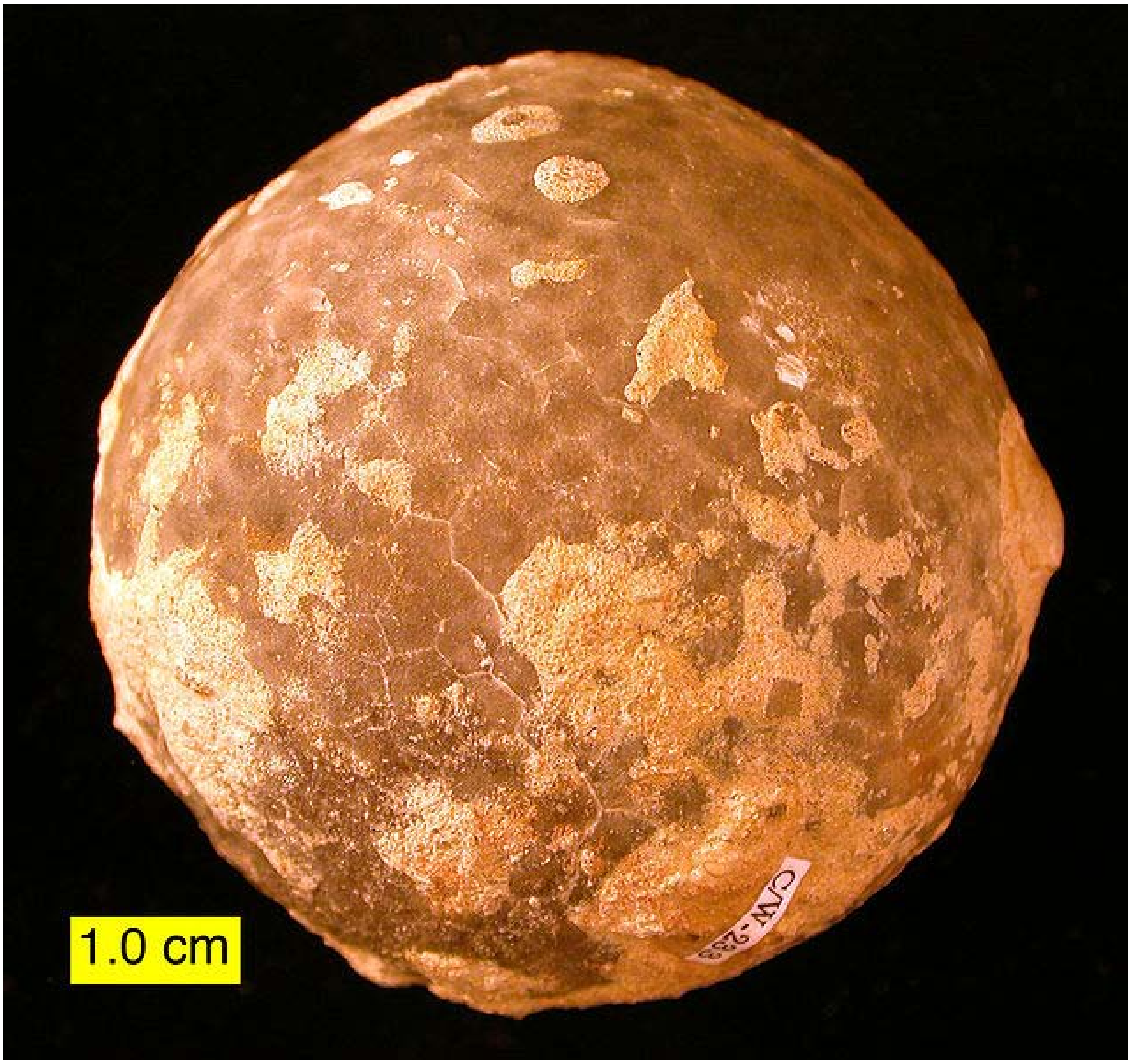
Sea cucumbers may be suspension feeders, sucking vast quantities of sea water through their guts and absorbing any useful matter. Others use their feeding apparatus to actively capture food from the sea floor. Yet others deploy their feeding apparatus as a net, in which smaller organisms become ensnared.

While some sea stars are detritovores, extracting the organic material from mud, and others mimic the crinoids' filter feeding, most are active hunters, attacking other sea stars or shellfish. The latter are seized and held by the tube feet; sea stars then stiffen their legs, expanding the shell. The sea stars can use connective tissue to lock their arms in place and maintain a force on the prey while exerting minimal effort; the unfortunate victim must expend energy resisting the force with its adductor muscle. When the adductor tires, the sea star can insert its stomach through the opening and release gastric juices, digesting the prey alive.

Avoiding predation

Despite their low nutrition value and the abundance of indigestible calcite, many organisms, such as Crabs, sharks, sea birds and larger starfish, make a living by feeding on echinoderms. Defensive strategies employed include the presence of spines, toxins, which can be inherent or delivered through the tube feet, and the discharge of sticky entangling threads by sea cucumbers. Being stabbed by a sea urchin may result in painful injury.

Ecology



The Ordovician cystoid *Echinosphaerites* from northeastern Estonia; approximately 5 cm in diameter

Echinoderms provide a key ecological role in ecosystems. For example, the grazing of sea urchins reduces the rate of colonization of bare rock; the burrowing of sand dollars and sea cucumbers depleted the sea floor of nutrients and encouraged deeper penetration of the sea floor, increasing the depth to which oxygenation occurs and allowing a more complex ecological tiering to develop. Starfish and brittle stars prevent the growth of algal mats on coral reefs, which would obstruct the filter-feeding constituent organisms. Some sea urchins can bore into solid rock; this bioerosion can destabilise rock faces and release nutrients into the ocean.

The echinoderms are also the staple diet of many organisms, most notably the otter; conversely, many sea cucumbers provide a habitat for parasites, including crabs, worms and snails. The extinction of large quantities of echinoderms appears to have caused a subsequent overrunning of ecosystems by seaweed, or the destruction of an entire reef.

Evolution

Fossil crinoid crowns

The first universally accepted echinoderms appear in the Lower Cambrian period (Paul and Smith 1984). Echinoderms left behind an extensive fossil record. Despite this, there are numerous conflicting hypotheses on their phylogeny. Based on their bilateral larvae, many zoologists argue that echinoderm ancestors were bilateral and that their coelom had three pairs of spaces (trimeric).

Some have proposed that radial symmetry arose in a free-moving echinoderm ancestor and that sessile groups were derived several times independently from free-moving ancestors. Unfortunately, this view does not address the significance of radial symmetry as an adaptation for a sessile existence.

The more traditional view is that the first echinoderms were sessile, became radial as an adaptation to that existence, and then gave rise to free-moving groups. This view perceives the evolution of endoskeletal plates with stereom structure and of external ciliary grooves for feeding as early echinoderm developments.

The extinct members of Class Homalozoa, commonly referred to as carpoids, had stereom ossicles but were not radially symmetrical, and the status of their water-vascular system is not known. Further, extinct members of the Class Helicoplacoidea possessed three, true ambulacral grooves, and their mouth was on the side of their body.

Attachment to a substratum would have selected for radial symmetry and may have marked the origin of the Class Crinoidea. Members of Crinoidea, along with the extinct members of Class Cystoidea, were primitively attached to a substratum by an aboral stalk. An ancestor that became free-moving might have given rise to Asteroidea, Ophiuroidia, Holothuroidea, and Echinoidea.

Use by humans

Echinoderms sometimes pose a health threat to humans. The fine structure of the spines of certain species of sea urchins means that if the spine pierces the flesh, it may break off when an attempt is made to remove it. It may require patience — or the assistance of a physician — to fully remove the remaining piece of spine.

Echinoderms are also elements of many cuisines. Around 50,000 tons of sea urchins are captured each year, the gonads of which are consumed particularly in Japan, Peru, and in France. The taste is described as soft and melting, like a mix of seafood and fruit. The quality depends on the color, which can range from light yellow to bright orange.

Sea cucumbers are also considered a delicacy in some countries of south east Asia; particularly popular are the (Pineapple) roller *Thelenota ananas* (*susuhan*) and the red *Halodeima edulis*. They are well known as *bêche de mer* or *Trepang* in China and Indonesia. The sea cucumbers are dried, and the potentially poisonous entrails removed. The strong poisons of the sea cucumbers are often psychoactive, but their effects are not well studied. It does appear that some sea cucumber toxins restrain the growth rate of tumour cells, which has sparked interest from cancer researchers.

The calcareous tests or shells of echinoderms are used as a source of lime by farmers in areas where limestone is unavailable; indeed, 4,000 tons of the animals are used annually for this purpose. This trade is often carried out in conjunction with shellfish farmers, for whom the starfish pose a major irritation by eating their stocks.

Chapter- 2

Crinoid

Crinoids	
Temporal range: Ordovician - Recent	
	
Scientific classification	
Kingdom:	Animalia
Phylum:	Echinodermata
Subphylum:	**Crinozoa**
Class:	**Crinoidea** Miller, 1821
Subclasses	
Articulata (540 species) Cladida (extinct) Flexibilia (extinct) Camerata (extinct) Disparida (extinct)	

Crinoids are marine animals that make up the class **Crinoidea** of the echinoderms (phylum Echinodermata). Crinoidea comes from the Greek word *krinon*, "a lily", and *eidos*, "form". They live both in shallow water and in depths as great as 6,000 meters. **Sea**

lilies refer to the crinoids which, in their adult form, are attached to the sea bottom by a stalk. **Feather stars** or **comatulids** refer to the unstalked forms.

Crinoids are characterized by a mouth on the top surface that is surrounded by feeding arms. They have a U-shaped gut, and their anus is located next to the mouth. Although the basic echinoderm pattern of fivefold symmetry can be recognized, most crinoids have many more than five arms. Crinoids usually have a stem used to attach themselves to a substrate, but many live attached only as juveniles and become free-swimming as adults.

There are only a few hundred known modern forms, but crinoids were much more numerous both in species and numbers in the past. Some thick limestone beds dating to the mid- to late-Paleozoic are almost entirely made up of disarticulated crinoid fragments.

Morphology

A fossil of a typical crinoid, showing (from bottom to top) the stem, calyx, and arms with cirri

Crinoids comprise three basic sections; the stem, the calyx, and the arms. The stem is composed of highly porous ossicles which are connected by ligamentary tissue. The calyx contains the crinoid's digestive and reproductive organs, and the mouth is located at the top of the dorsal cup, while the anus is located peripheral to it. The arms display pentamerism or pentaradial symmetry and comprise smaller ossicles than the stem and are equipped with cirri which facilitate feeding by moving the organic media down the arm and into the mouth.

The majority of living crinoids are free-swimming and have only a vestigial stalk. In those deep-sea species that still retain a stalk, it may reach up to 1 metre (3.3 ft) in length, although it is usually much smaller. The stalk grows out of the *aboral* surface, which forms the upper side of the animal in starfish and sea urchins, so that crinoids are effectively upside-down by comparison with most other echinoderms. The base of the stalk consists of a disc-like sucker, which, in some species, has root-like structures that further increase its grip on the underlying surface. The stalk is often lined by small cirri.

Like other echinoderms, crinoids have pentaradial symmetry. The aboral surface of the body is studded with plates of calcium carbonate, forming an endoskeleton similar to that in starfish and sea urchins. These make the calyx somewhat cup-shaped, and there are few, if any, ossicles in the oral (upper) surface. The upper surface, or *tegmen*, is divided into five *ambulacral areas*, including a deep groove from which the tube feet project, and five *interambulacral areas* between them. The anus, unusually for echinoderms, is found on the same surface as the mouth, at the edge of the tegmen.

The ambulacral grooves extend onto the arms, which thus have tube feet along their inner surfaces. Primitively, crinoids had only five arms, but in most living species these are divided into two, giving ten arms in total. In most living species, especially the free-swimming feather stars, the arms branch several times, producing anything up to two hundred branches in total. The arms are jointed, and lined by smaller feather-like appendages, or *pinnules*, which also include tube feet.

Biology

Feeding

Crinoids feed by filtering small particles of food from the sea water with their feather like arms. The tube feet are covered with a sticky mucus that traps any food that floats past. Once they have caught a particle of food, the tube feet can flick it into the ambulacral groove, where the cilia are able to propel the stream of mucus towards the mouth. Generally speaking, crinoids living in environments with relatively little plankton have longer and more highly branched arms than those living in rich environments.

The mouth descends into a short oesophagus. There is no true stomach, so the oesophagus connects directly to the intestine, which runs in a single loop right around the inside of the calyx. The intestine often includes numerous diverticulae, some of which may be long or branched. The end of the intestine opens into a short muscular rectum.

This ascends towards the anus, which projects from a small conical protuberance at the edge of the tegmen.

Circulatory systems

Like other echinoderms, crinoids possess a water vascular system that maintains hydraulic pressure in the tube feet. This is not connected to external sea water, as in other echinoderms, but only to the body cavity. The body cavity is itself somewhat restricted, being largely replaced by connective tissue, although it is present as narrow canals within the arms and stalk.

Crinoids also possess a separate **haemal system**, consisting of fluid-filled sinuses within the connective tissue. There is a large plexus of sinuses around the oesophagus, with branches extending down to a mass of glandular tissue at the base of the calyx.

These various fluid-filled spaces, in addition to transporting nutrients around the body, also function as both a respiratory and an excretory system. Oxygen is absorbed primarily through the tube feet, which are the most thin-walled parts of the body, while waste is collected by phagocytic **coelomocytes**.

Nervous system

The crinoid nervous system is divided into three parts, with numerous connections between them. The uppermost portion is the only one homologous with the nervous systems of other echinoderms. It consists of a central nerve ring surrounding the mouth, and radial nerves branching into the arms. Below this lies a second nerve ring, giving off two brachial nerves into each arm. Both of these sets of nerves are sensory in nature, with the lower set supplying the pinnules and tube feet.

The third portion of the nervous system lies below the other two, and is responsible for motor action. This is centred on a mass of neural tissue near the base of the calyx, and provides a single nerve to each arm and a number of nerves to the stalk.

Reproduction and life cycle

Crinoids are dioecious, with separate male and female individuals. They have no true gonads, producing their gametes from genital canals found inside some of the pinnules. The pinnules eventually rupture to release the sperm and eggs into the surrounding sea water.

The fertilised eggs hatch to release a free-swimming **vitellaria** larva. The larva is barrel-shaped with rings of cilia running round the body, and a tuft of sensory hairs at the upper pole. In some cases females have been known to temporarily brood the larvae using chambers within the arms. The larva does not feed, and lasts only for a few days before settling to the bottom and attaching itself to the underlying surface using an adhesive gland on its ventral surface. The larva then metamorphoses into a stalked adult. Even the free-swimming feather stars sometimes go through this stage, with the adult eventually breaking away from the stalk.

Within 10 to 16 months the crinoid will be able to reproduce.

Mobility

Most modern crinoids are free-swimming and lack a stem. Examples of fossil crinoids that have been interpreted as free-swimming include *Marsupitsa*, *Saccocoma* and *Uintacrinus*.

In 2005, a stalked crinoid was recorded pulling itself along the sea floor off the Grand Bahama Island. While it has been known that stalked crinoids move, prior to this recording the fastest motion of a crinoid was 0.6 meters/hour (2 ft/h). The 2005 recording showed a crinoid moving at much higher speeds.

Evolution

Origins

Crinoid columnals (*Isocrinus nicoleti*) from the Middle Jurassic Carmel Formation at Mount Carmel Junction, Utah. Scale in mm.

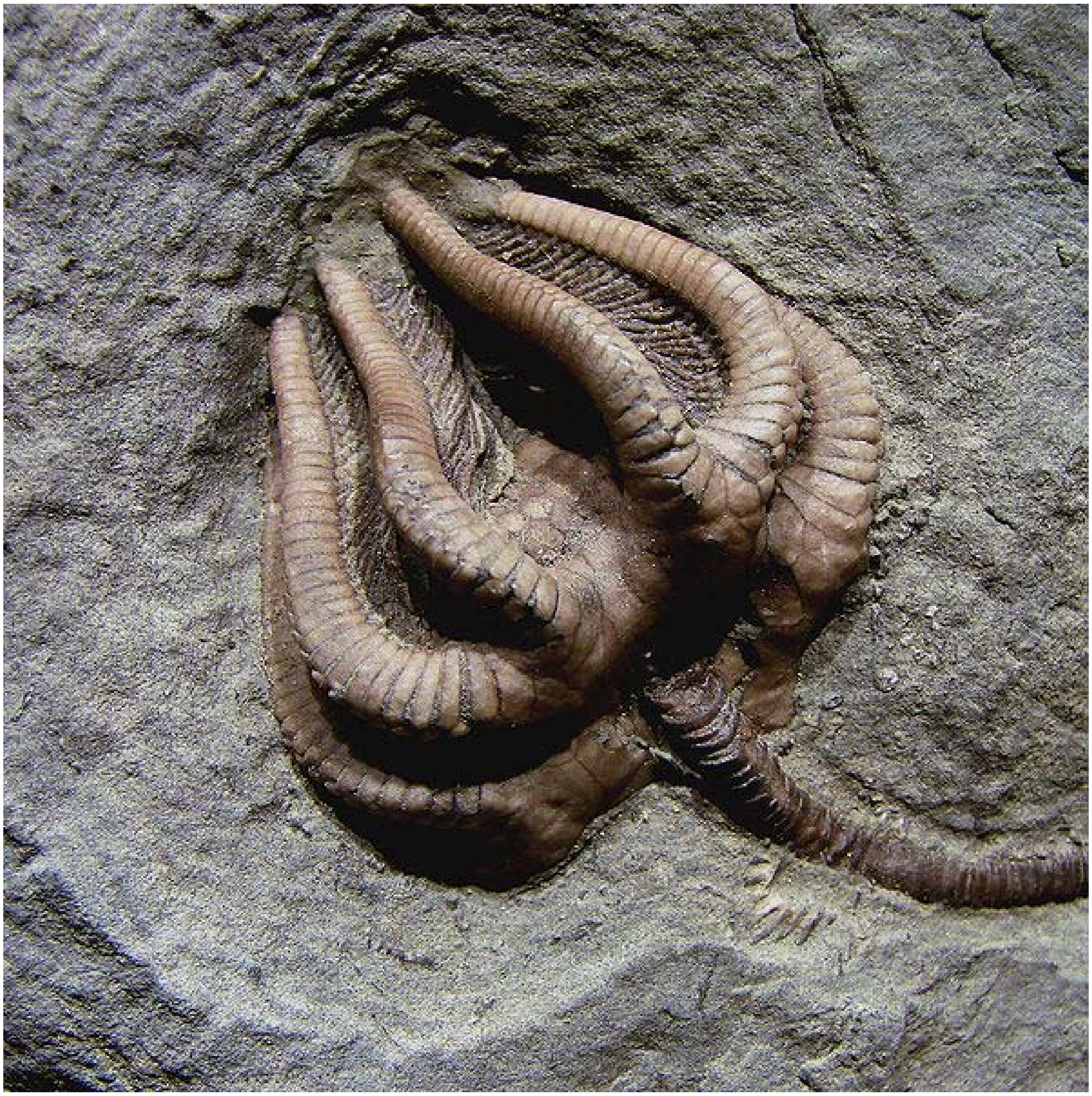
The earliest known crown-group crinoids date to the Ordovician. There are two competing hypotheses pertaining to the origin of the group: the traditional viewpoint holds that crinoids evolved from within the blastozoans (the eocrinoids and their derived descendants the cystoids), whereas the most popular alternative suggests that the crinoids split early from among the edrioasteroids. The debate is difficult to settle, in part because all three candidate ancestors share many characteristics, including radial symmetry, calcareous plates, and stalked or direct attachment to the substrate.

Diversity

The crinoids underwent two periods of abrupt adaptive radiation; the first during the Ordovician, the other after they underwent a selective mass extinction at the end of the Permian period. This Triassic radiation resulted in forms possessing flexible arms becoming widespread; motility, predominantly a response to predation pressure, also became far more prevalent. This radiation occurred somewhat earlier than the Mesozoic marine revolution, possibly because it was mainly prompted by increases in benthic predation, specifically of echinoids. After the end-Permian extinction, crinoids never regained the morphological diversity they enjoyed in the Paleozoic; they occupied a different region of morphospace, employing different ecological strategies from those that had proven so successful in the Paleozoic.

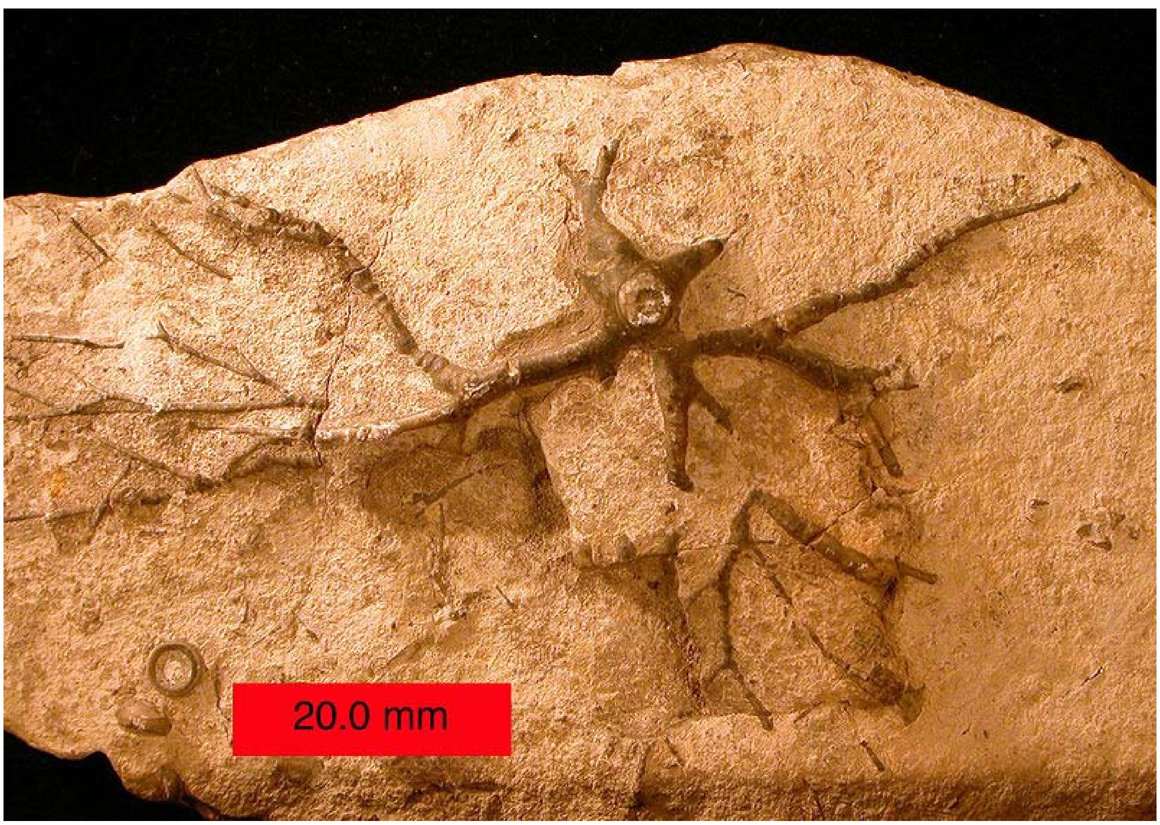
The long and varied geological history of the crinoids demonstrates how well the echinoderms have adapted to filter-feeding. The fossils of other stalked filter-feeding echinoderms, such as blastoids, are also found in the rocks of the Palaeozoic era. These extinct groups can exceed the crinoids in both numbers and variety in certain horizons. However, none of these others survived the crisis at the end of the Permian period.

Fossils of interest



The Carboniferous crinoid, *Agaricocrinus americanus*

Crinoid holdfasts and bryozoans on an Upper Ordovician cobble from northern Kentucky



Root-like crinoid holdfast (Upper Ordovician, southern Ohio)

Some fossil crinoids, such as *Pentacrinites*, seem to have lived attached to floating driftwood and complete colonies are often found. Sometimes this driftwood would become waterlogged and sink to the bottom, taking the attached crinoids with it. The stem of *Pentacrinites* can be several metres long. Modern relatives of *Pentacrinites* live in gentle currents attached to rocks by the end of their stem, which is fairly short. The largest fossil crinoid on record had a stem 40 m (130 ft) in length.

In 2006, geologists isolated complex organic molecules from 350-million-year-old fossils of crinoids—the oldest such molecules yet found. Christina O'Malley, a doctoral student in earth sciences at The Ohio State University, found orange and yellow organic molecules inside the fossilized remains of several species of crinoids dating back to the Mississippian period.

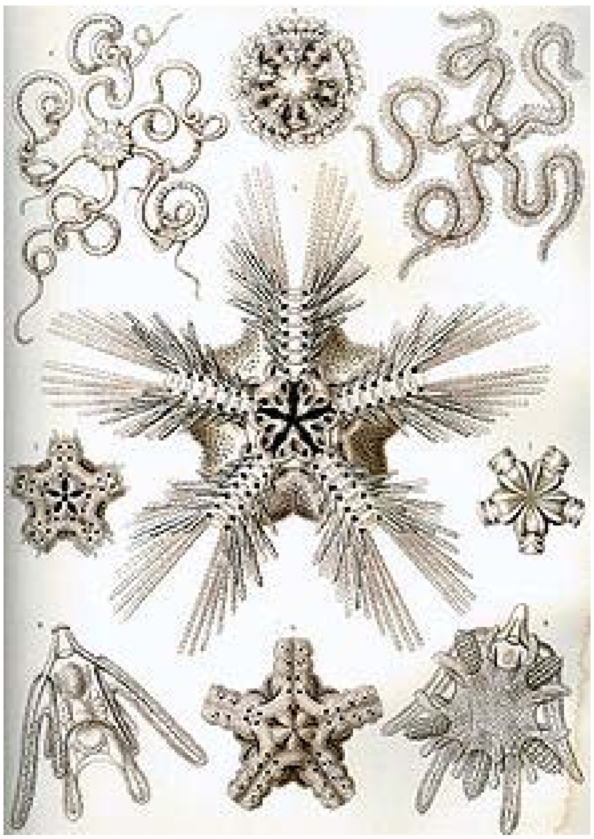
Crinoid uses

- Fossilised crinoid columnals extracted from limestone quarried on Lindisfarne, or found washed up along the foreshore, which were threaded into necklaces or rosaries, became known as St. Cuthbert's beads.
- In the Midwestern United States, fossilized segments of columnal crinoids are sometimes known as Indian beads.
- Crinoids are the state fossil of Missouri.

Chapter- 3

Brittle Star

Brittle Star **Temporal range: 488.2–0 Ma** **Ordovician to Holocene**	



"Ophiodea" from Ernst Haeckel's *Kunstformen der Natur*, 1904

Scientific classification	
Kingdom:	Animalia
Phylum:	Echinodermata
Subphylum:	Asterozoa

Class:	**Ophiuroidea** Gray, 1840

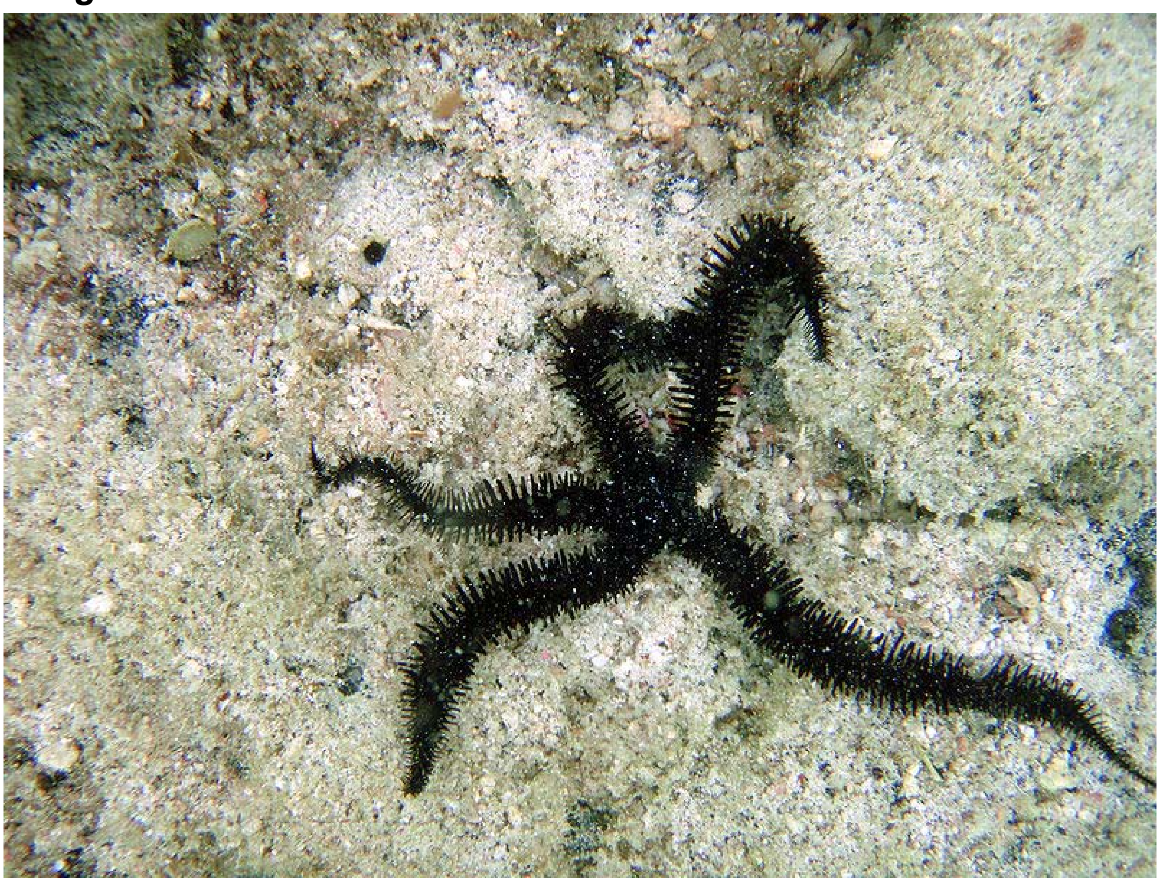
Orders
Oegophiurida Ophiurida Phrynophiurida

Brittle stars, or **ophiuroids**, are echinoderms, closely related to starfish. They crawl across the seafloor using their flexible arms for locomotion. The ophiuroids generally have five long slender, whip-like arms which may reach up to 60 centimetres (24 in) in length on the largest specimens. They are also known as serpent stars.

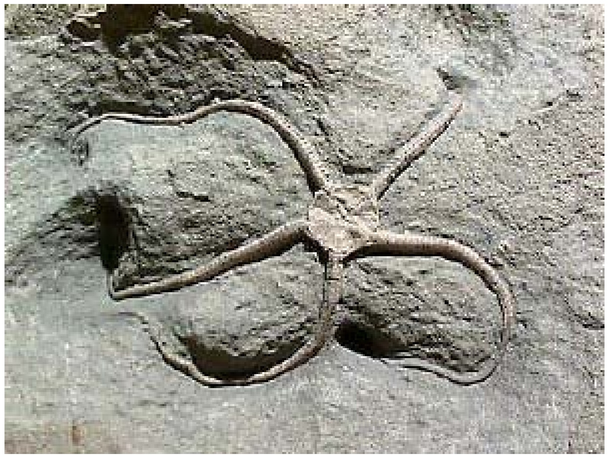
Ophiuroidea contains two large clades, Ophiurida (brittle stars) and Euryalida (basket stars). Many of the ophiuroids are rarely encountered in the relatively shallow depths normally visited by humans, but they are a diverse group.

There are some 1,500 species of brittle stars living today, and they are largely found in deep waters more than 500 metres (1,650 feet) down.

Range



Brittle star in Kona, Hawaii



Fossil brittle star *Palaeocoma egertoni* from the Jurassic of England

The ophiuroids diverged in the Early Ordovician, about 500 million years ago. Ophiuroids can be found today in all of the major marine provinces, from the poles to the tropics. In fact, crinoids, holothurians, and ophiuroids live at depths from 16–35 m, all over the world. Basket stars are usually confined to the deeper parts of this range. Ophiuroids are known even from abyssal (>6000 m) depths. However brittle stars are also common, if cryptic, members of reef communities, where they hide under rocks and even within other living organisms. A few ophiuroid species can even tolerate brackish water, an ability otherwise almost unknown among echinoderms. A brittle star's skeleton is made up of embedded ossicles.

Taxonomy

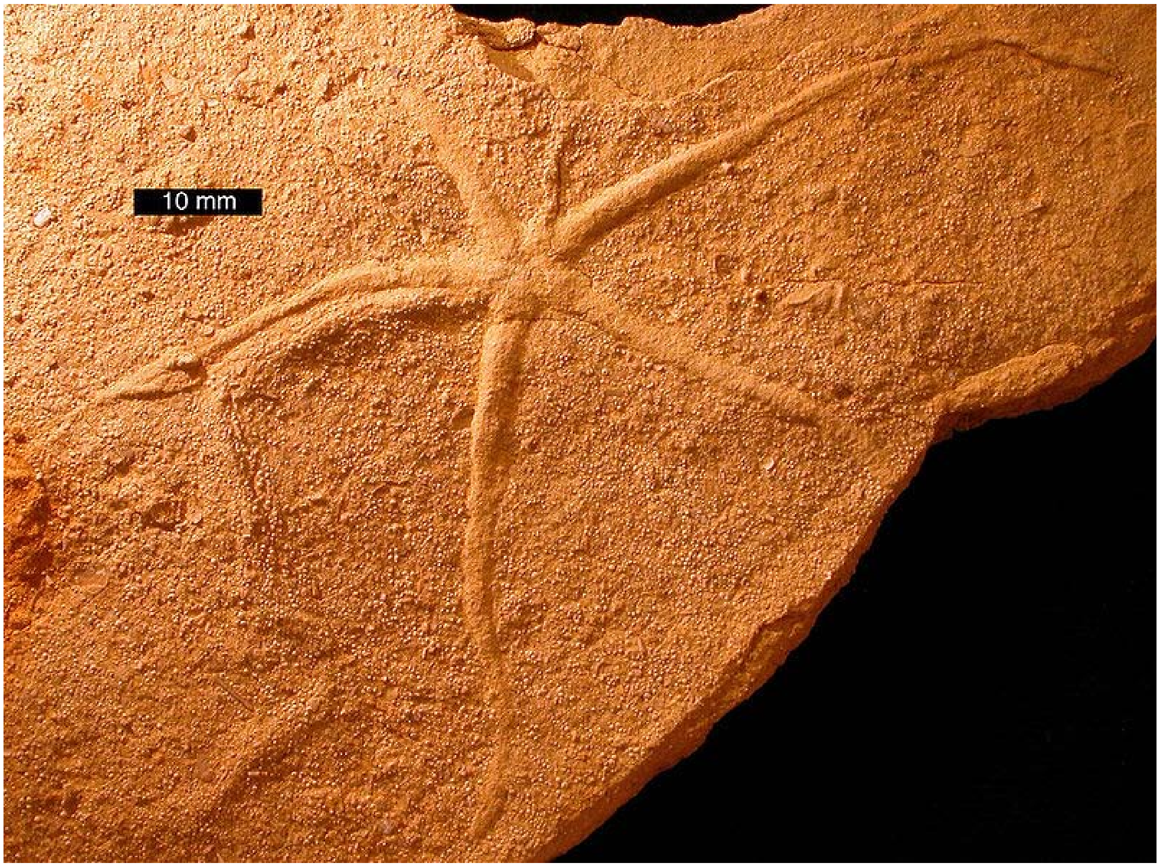
There are roughly 1900 extant species in 230 genera, grouped in the three orders currently living: Oegophiurida, Phrynophiurida, and Ophiurida. There is also a Paleozoic order, the Stenurida.

The relationships among ophiuroids, asteroids, and all other echinoderms provide an enduring problem in invertebrate evolution. Developmental and other studies based on modern organisms imply that asteroids and ophiuroids are not closely related within the echinoderms. Stenurid morphology, in contrast, suggests a close common ancestry for the two; the nature of the ambulacral plates is important, but even their general form is transitional.

Stenurida (extinct)

This is a Paleozoic (Ordovician–Devonian) order, bearing a double row of plates (ambulacra) that abut across the arm axis either directly opposite one another or slightly offset. In contrast, modern ophiuroids have a single series of axial arm plates termed vertebrae. In stenurids, as in modern ophiuroids, lateral plates are present at the sides of ambulacrals, and prominent lateral spines are typical. Stenurids lack the dorsal and ventral arm shields that are found in most ophiuroids. Proximal ambulacral pairs can be partially separated, forming a buccal slit, an expansion of the mouth frame. The arms of some stenurids are slender and flexible, but those of others are broad and comparatively stiff. The central disk varies from little larger than the juncture of the arms to an expansion that extends most of the length of the arms. The content of the order is poorly established, and fewer than 10 genera are known.

Anatomy



Asteriacites, a trace fossil of an ophiuroid; Carmel Formation, near Gunlock, Utah; scale bar is 10 mm

Of all echinoderms, the Ophiuroidea may have the strongest tendency toward 5-segment radial (pentaradial) symmetry. The body outline is similar to that of starfish, in that ophiuroids have five arms joined to central body disk. However, in ophiuroids the central body disk is sharply marked off from the arms.

The disk contains all of the viscera. That is, the internal organs of digestion and reproduction never enter the arms, as they do in the Asteroidea. The underside of the disc contains the mouth, which has five toothed jaws formed from skeletal plates. The madreporite is usually located within one of the jaw plates, and not on the upper side of the animal as it is in starfish.

Green brittle star - *Ophiarachna incrassata*

Water-vascular system

The vessels of the water vascular system end in tube feet. The water vascular system generally has one madreporite. Others, such as certain Euryalina, have one per arm on the aboral surface. Still other forms have no madreporite at all. Suckers and ampullae are absent from the tube feet.

Nervous system

The nervous system consists of a main nerve ring which runs around the central disk. At the base of each arm, the ring attaches to a radial nerve which runs to the end of the limb. The nerves in each limb run through a canal at the base of the vertebral ossicles.

Ophiuroids have no eyes, or other specialised sense organs. However, they have several types of sensitive nerve ending in their epidermis, and are able to sense chemicals in the water, touch, and even the presence or absence of light. Moreover, tube feet may sense light as well as odors. These are especially found at the ends of their arms, detecting light and retreating into crevices.

Digestion

The mouth is rimmed with five jaws, and serves as an anus (egestion) as well as a mouth (ingestion). Behind the jaws is a short esophagus and a large, blind stomach cavity which occupies much of the dorsal half of the disk. Ophiuroids have neither a head nor an anus. Digestion occurs within 10 pouches or infolds of the stomach, which are essentially ceca, but unlike in sea stars, almost never extend into the arms. The stomach wall contains glandular hepatic cells.

Ophiuroids are generally scavengers or detritivores. Small organic particles are moved into the mouth by the tube feet. Ophiuroids may also prey on small crustaceans or worms. Basket stars in particular may be capable of suspension feeding, using the mucus coating on their arms to trap plankton and bacteria. They extend one arm out and use the other four as anchors. Brittle stars will eat small suspended organisms if available. In large, crowded areas, brittle stars eat suspended matter from prevailing seafloor currents.

In basket stars the arms are used to rhythmically sweep food to the mouth. *Pectinura* will consume beech pollen in the New Zealand fjords (since those trees hang over the water). *Eurylina* clings to coral branches to browse on the polyps.

Respiration

Gas exchange and excretion occur through cilia-lined sacs called bursae; each opens between the arm bases on the underside of the disc. Typically there are ten bursae, and each fits between two stomach digestive pouches. Water flows through the bursae by means of cilia or muscular contraction. Oxygen is transported through the body via the **hemal system**, a series of sinuses and vessels distinct from the water vascular system.

The bursae are probably also the main organs of excretion, with phagocytic "coelomocytes" collecting waste products in the body cavity and then migrating to the bursae for expulsion from the body.

Musculo-skeletal system

Like all echinoderms, the Ophiuroidea possess a skeleton of calcium carbonate in the form of calcite. In ophiuroids, the calcite ossicles are fused to form armor plates which are known collectively as the *test*. The plates are covered by the epidermis, which consists of a smooth syncytium. In most species, the joints between the ossicles and superficial plates allow the arm to bend to the side, but not to bend upwards. However, in the basket stars, the arms are flexible in all directions.

Both the Ophiurida and Euryalida (the basket stars) have five long, slender, flexible whip-like arms, up to 60 centimeters in length. They are supported by an internal skeleton of calcium carbonate plates that are referred to as vertebral ossicles. These "vertebrae" articulate by means of ball-in-socket joints, and are controlled by muscles. They are essentially fused plates which correspond to the parallel ambulacral plates in sea stars and

5 Paleozoic families of ophiuroids. In modern forms the vertebrae are along the median of the arm.

The ossicles are surrounded by a relatively thin ring of soft tissue, and then by four series of jointed plates, one each on the upper, lower, and the lateral surfaces of the arm. The two lateral plates often have a number of elongated spines projecting outwards; these help to provide traction against the substrate while the animal is moving. The spines, in ophiuroids, compose a rigid border to the arm edges, whereas in euryalids they are transformed into downward-facing clubs or hooklets. Euryalids are similar to ophiurids, if larger, but their arms are forked and branched. Ophiuroid podia generally function as sensory organs. They are not usually used for feeding, as in Asteroidea. In the Paleozoic era brittle stars had open ambicular grooves but in modern forms these are turned inward.

In living ophiuroids the vertebrates are linked by well-structured longitudinal muscles. Ophiuroida move horizontally, and *Euryalina* move vertically. The latter have bigger vertebrae and smaller muscles. They are less spasmodic, but can coil their arms around objects, holding even after death. These movement patterns are distinct to the taxa, separating them. Ophiuroida move quickly when disturbed. One arm presses ahead, whereas the other four act as two pairs of opposite levers, thrusting the body in a series of rapid jerks. Although adults do not use their tube feet for locomotion, very young stages use them as stilts and even serve as an adhesive structure.

Reproduction

The sexes are separate in most species, though a few are hermaphroditic or protandric. The gonads are located in the disc, and open into pouches in between the arms, called genital bursae. Fertilisation is external in most species, with the gametes being shed into the surrounding water through the bursal sacs. An exception is the Ophiocanopidae, in which the gonads do not open into bursae and are instead paired in a chain along the basal arm joints.

Many species brood developing larvae in the bursae, effectively giving birth to live young. A few, such as *Amphipholus squamata* are truly viviparous, with the embryo receiving nourishment from the mother through the wall of the bursa. However, there are some species that do not brood their young, instead having a free-swimming larval stage. Referred to as an **ophiopluteus**, these larvae have four pairs of rigid arms lined with cilia. They develop directly into an adult, without the attachment stage found in most starfish larvae. The number of species exhibiting ophiopluteus larvae are fewer than those that diretly develop.

In a few species the female carries a dwarf male, clinging to it with the mouth.

Life Span

Brittle stars generally sexually mature in 2 years, become full grown in 3 to 4 years, and live up to 5 years. Euryalina, such as *Gorgonocephalus*, may well live much longer.

Regeneration

Ophiuroids can readily regenerate lost arms or arm segments unless all arms are lost. Ophiuroids use this ability to escape predators, similar to lizards deliberately shedding (autotomy) the distal part of their tails to confuse pursuers. Moreover, the Amphiuridae can regenerate gut and gonad fragments lost along with the arms. The six-armed Ophiactidae generally exhibit transverse fission, which yields three large arms and three small arms. No discarded arms have shown ability to regenerate.

The ophiuroid coelom is strongly reduced, particularly in comparison to other echinoderms.

Micro brittle starfish and *Caulerpa racemosa*

Locomotion

Brittle stars use their arms for locomotion. They do not, like sea stars, depend on tube feet, which are mere sensory tentacles without suction. Brittle stars move fairly rapidly by wriggling their arms which are highly flexible and enable the animals to make either snake-like or rowing movements. However, they tend to attach themselves to the seafloor or to sponges or cnidarians, such as coral. Their movement has some similarities with animals with bilateral symmetry.

Ecology

Brittle stars live in areas from the low-tide level downwards. Six families live at least 2 meters deep; the genera *Ophiura*, *Amphiophiura*, and *Ophiacantha* range below 4 meters. Shallow species live among sponges, stones, or coral, or under the sand or mud, with only their arms protruding. Two of the best-known shallow species are the green brittle star (*Ophioderma brevispina*), found from Massachusetts to Brazil, and the common European brittle star (*Ophiothrix fragilis*). Deep-water species tend to live in or on the sea floor or adhere to coral or urchins. The most widespread species is the long-armed brittle star (*Amphipholis squamata*), a grayish or bluish species that is strongly luminescent.

Parasites

The main parasite to enter the digestive tract or genitals are *Protozoa*. Crustaceans, nematodes, trematodes, and polychaete annelids, also serve as parasites. Algal parasites like *Coccomyxa ophiurae* cause spinal malformation. Unlike sea stars and sea urchins, annelids are not a typical parasite.

Human relations

Brittle stars are not used as food, even though they are non-toxic.

Aquaria

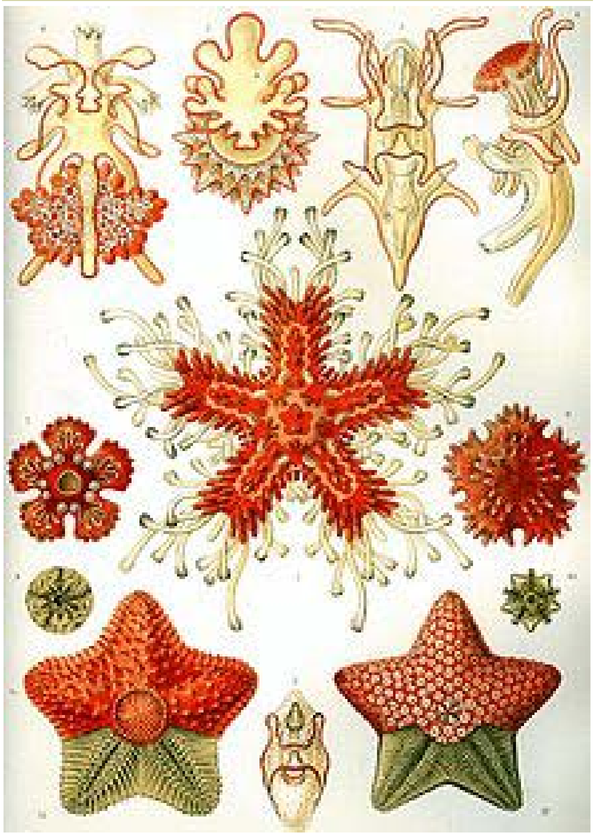
Brittle stars are a moderately popular invertebrate in fishkeeping. They can easily thrive in marine tanks, in fact the micro brittle star is a common "hitchhiker" that will propagate and become common in almost any saltwater tank, if one happens to come along on some live rock.

Larger brittle stars are popular because, unlike asteriodae, they are not generally seen as a threat to coral, and are also faster-moving and more active than their more archetypical cousins.

Chapter- 4

Starfish

Sea Stars Temporal range: Ordovician–Recent	



"**Asteroidea**" from Ernst Haeckel's *Kunstformen der Natur*, 1904

Scientific classification	
Kingdom:	Animalia
Phylum:	Echinodermata
Subphylum:	Asterozoa
Class:	**Asteroidea**

De Blainville, 1830

Orders
Brisingida (100 species) Forcipulatida (300 species) Paxillosida (255 species) Notomyotida (75 species) Spinulosida (120 species) Valvatida (695 species) Velatida (203 species)

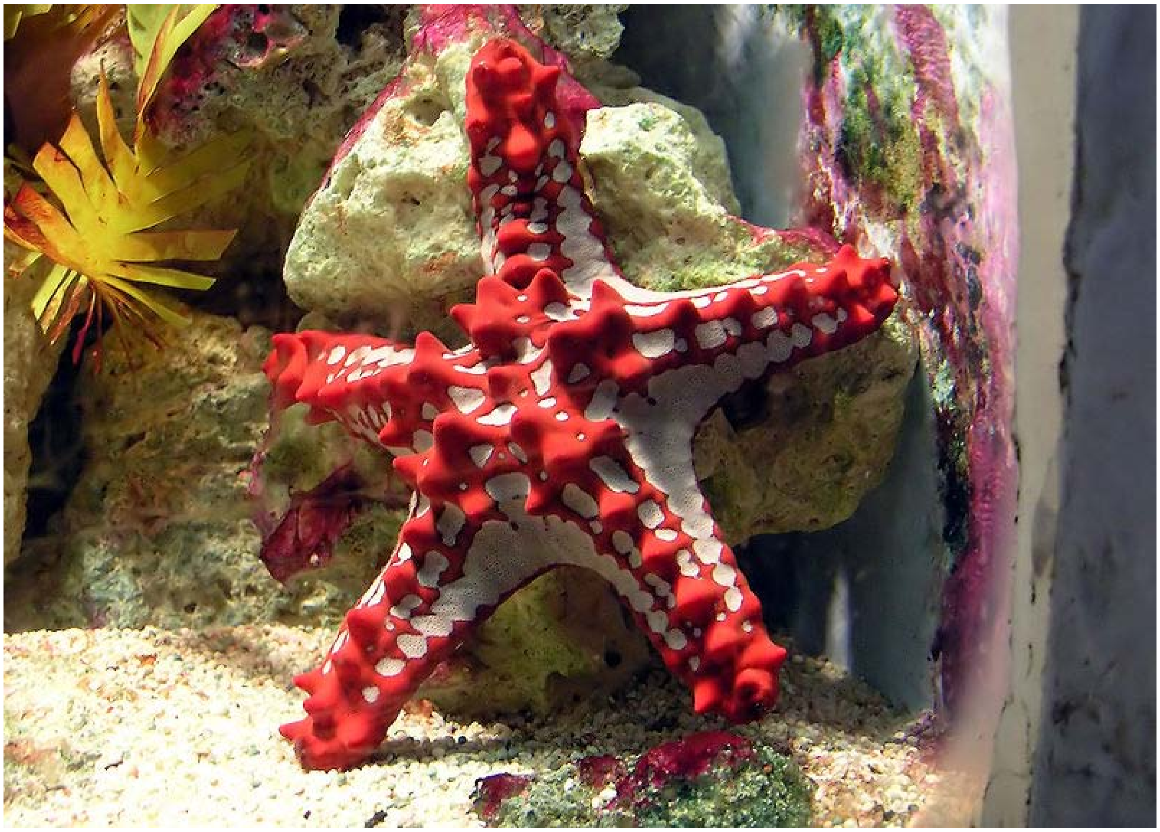
Starfish or **sea stars** are echinoderms belonging to the class **Asteroidea**. The names "starfish" and "sea star" essentially refer to members of the Class Asteroidea. However, common usage frequently finds "starfish" and "sea star" also applied to ophiuroids which are correctly referred to as "brittle stars" or "basket stars".

There are 2,000 living species of starfish that occur in all the world's oceans, including the Atlantic, Pacific, Indian as well as in the Arctic and the Southern Ocean (i.e., Antarctic) regions. Starfish occur across a broad depth range from the intertidal to abyssal depths (>6000 m).

Starfish are among the most familiar of marine animals and possess a number of widely known traits, such as regeneration and feeding on mussels. Starfish possess a wide diversity of body forms and feeding methods. The extent that Asteroidea can regenerate varies with individual species. Broadly speaking, starfish are opportunistic feeders, with several species having specialized feeding behavior, including suspension feeding and specialized predation on specific prey.

The Asteroidea occupy several important roles throughout ecology and biology. Sea stars, such as the Ochre sea star (*Pisaster ochraceus*) have become widely known as the example of the keystone species concept in ecology. The tropical Crown of Thorns starfish (*Acanthaster planci*) are voracious predators of coral throughout the Indo-Pacific region. Other starfish, such as members of the Asterinidae are frequently used in developmental biology.

Appearance



Red-knobbed starfish *Protoreaster linckii*, a sea star from the Indian Ocean

Schmedelian pin-cushion sea star (*Culcita schmideliana*) on Meedhupparu house reef in the Maldives

Closeup of the top surface of a starfish

Starfish express pentamerism or pentaradial symmetry as adults. However, the evolutionary ancestors of echinoderms are believed to have had bilateral symmetry. Starfish, as well as other echinoderms, do exhibit bilateral symmetry, but only as larval forms.

Most starfish typically have five rays or arms, which radiate from a central disk. However, several species frequently have six or more arms. Several asteroid groups, such as the Solasteridae, have 10-15 arms whereas some species, such as the Antarctic *Labidiaster annulatus* can have up to 50. It is not unusual for species that typically have five-rays to exceptionally possess six or more rays due to developmental abnormalities.

The bodies of starfish are composed of calcium carbonate components, known as ossicles. These form the endoskeleton, which takes on a variety of forms that are externally expressed as a variety of structures, such as spines and granules. The architecture and individual shape/form of these plates which often occur in specific patterns or series, as well as their location are the source of morphological data used to classify the different groups within the Asteroidea. Terminology referring to body location in sea stars is usually based in reference to the mouth to avoid incorrect assumptions of homology with the dorsal and ventral surfaces in other bilateral animals. The bottom surface is often referred to as the oral or actinal surface whereas the top surface is referred to as the aboral or abactinal side.

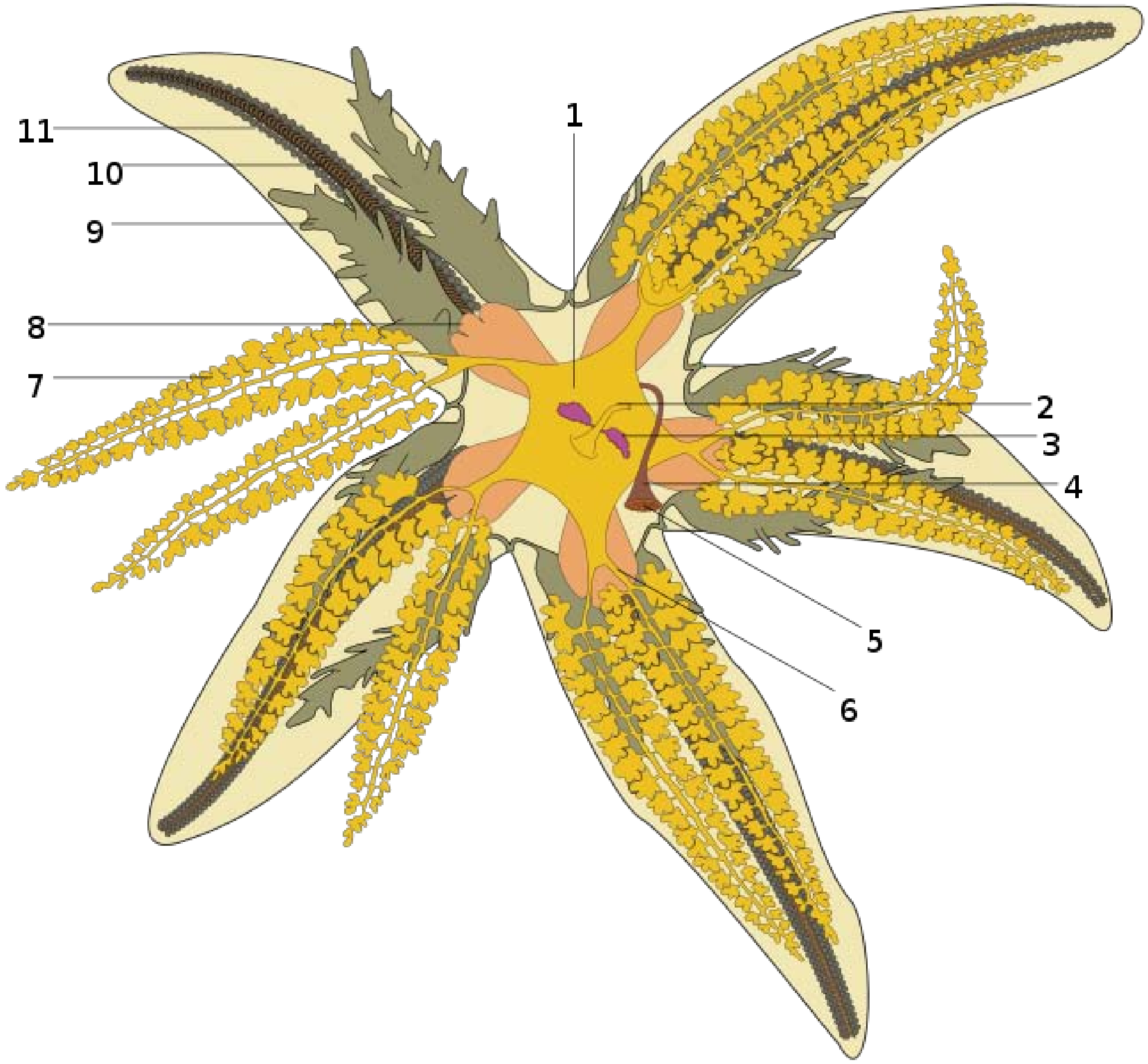
The body surface of sea stars often has several structures that comprise the basic anatomy of the animal and can sometimes assist in its identification.

The **madreporite** can be easily identified as the light-colored circle, located slightly off center on the central disk. This is a porous plate which is connected via a calcified channel to the animal's water vascular system in the disk. Its function is, at least in part, to provide additional water for the animal's needs, including replenishing water to the water vascular system.

Several groups of asteroids, including the Valvatacea but especially the Forcipulatacea possess small bear-trap or valve-like structures known as pedicellariae. These can occur widely over the body surface. In forcipulate asteroids, such as *Asterias* or *Pisaster*, pedicellariae occur in pom-pom like tufts at the base of each spine, whereas in goniasterids, such as Hippasteria, pedicellariae are scattered over the body surface. Although the full range of function for these structures is unknown, some are thought to act as defense where others have been observed to aid in feeding. The Antarctic *Labidiaster annulatus* uses its large, pedicellariae to capture active krill prey. The North Pacific *Stylasterias* has been observed to capture small fish with its pedicellariae.

Other types of structures vary by taxon. For example, Porcellanasteridae employ additional cribriform organs which occur among their lateral plate series, which are thought to generate current in the burrows made by these infaunal sea star.

Internal anatomy



Dissection of *Asterias rubens*
1 - Pyloric stomach 2 - Intestine and anus 3 - Rectal sac 4 - Stone canal 5 - Madreporite 6 - Pyloric caecum 7 - Digestive glands 8 - Cardiac stomach 9 - Gonad 10 - Radial canal 11 - Tube feet

As echinoderms, starfish possess a hydraulic water vascular system that aids in locomotion. The water vascular system has many projections called tube feet on the ventral face of the sea star's arms which function in locomotion and aid with feeding. Tube feet emerge through openings in the endoskeleton and are externally expressed through the open grooves present along the bottom of each arm.

The body cavity not only contains the water vascular system that operates the tube feet, but also the circulatory system, called the **hemal system**. Hemal channels form rings around the mouth (the oral hemal ring), closer to the top of the sea star and around the digestive system (the gastric hemal ring). A portion of the body cavity called the axial sinus connects the three rings. Each ray also has hemal channels running next to the gonads.

On the end of each arm or ray there is a microscopic eye (ocellus), which allows the sea star to see, although it only allows it to see light and dark, which is useful to see movement. Only part of the cells are pigmented (thus a red or black color) and there is no cornea or iris. This eye is known as a pigment spot ocellus.

Several types of toxins and secondary metabolites have been extracted from several species of sea star. Research into the efficacy of these compounds for possible pharmacological or industrial use occurs worldwide.

Digestive system

The mouth of a starfish is located on the underside of the body, and opens through a short esophagus into firstly a cardiac stomach, and then, a second, pyloric stomach. Each arm also contains two pyloric caeca, long hollow tubes branching outwards from the pyloric stomach. Each pyloric caecum is lined by a series of digestive glands, which secrete digestive enzymes and absorb nutrients from the food. A short intestine runs from the upper surface of the pyloric stomach to open at an anus in the center of the upper body.

Many sea stars, such as *Astropecten* and *Luidia* swallow their prey whole, and start to digest it in the stomachs before passing it into the pyloric caeca. However, in a great many species, the cardiac stomach can be everted out of the organism's body to engulf and digest food. In these species, the cardiac stomach fetches the prey then passes it to the pyloric stomach, which always remains internal.

Some species are able to use their water vascular systems to force open the shells of bivalve molluscs such as clams and mussels by injecting their stomachs into the shells. With the stomach inserted inside the shell, the sea star is able to digest the mollusc in place. The cardiac stomach is then brought back inside the body, and the partially digested food is moved to the pyloric stomach. Further digestion occurs in the intestine. Waste is excreted through the anus on the aboral side of the body.

Because of this ability to digest food outside of its body, the sea star is able to hunt prey that are much larger than its mouth would otherwise allow, such as clams and oysters, arthropods, small fish, and molluscs. However, some species are not pure carnivores, and may supplement their diet with algae or organic detritus. Some of these species are grazers, but others trap food particles from the water in sticky mucus strands that can be swept towards the mouth along ciliated grooves.

Some echinoderms can live for several weeks without food under artificial conditions. Scientists believe that they may receive some nutrients from organic material dissolved in seawater.

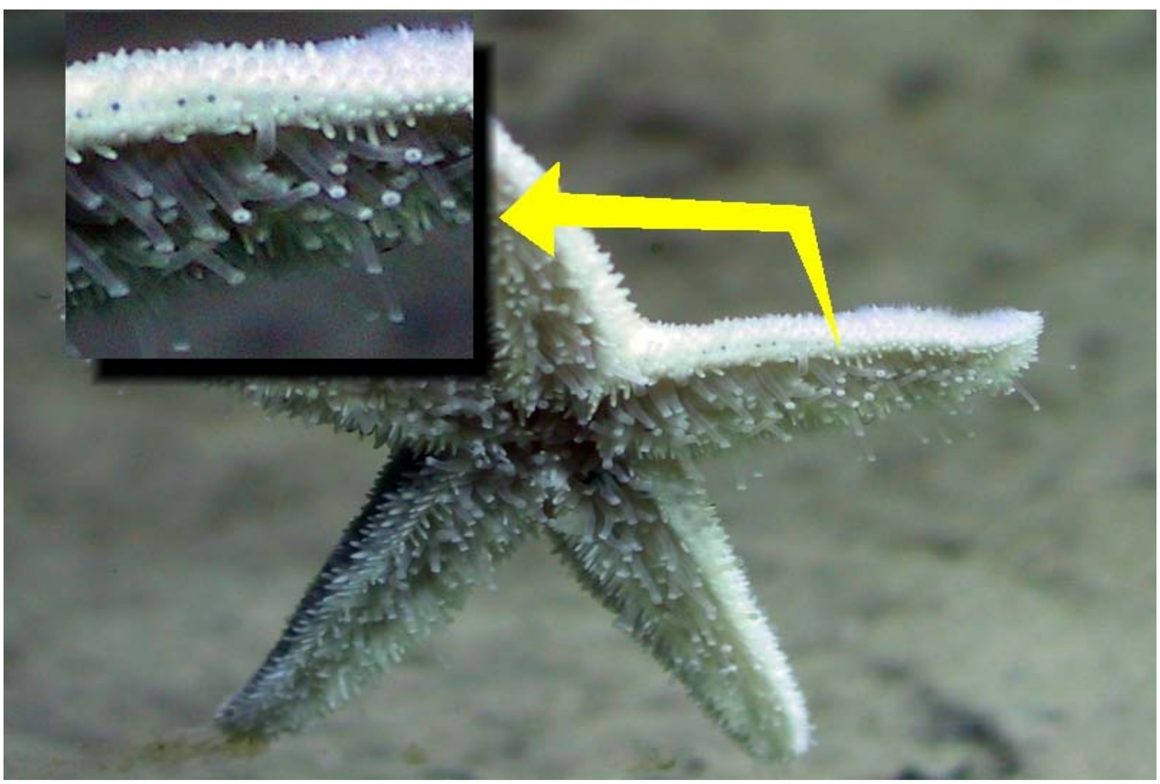
Nervous system

Echinoderms have rather complex nervous systems, but lack a true centralized brain. All echinoderms have a network of interlacing nerves called a nerve plexus which lies within, as well as below, the skin. The esophagus is also surrounded by a central nerve ring which sends radial nerves into each of the arms, often parallel with the branches of the water vascular system. The ring nerves and radial nerves coordinate the sea star's balance and directional systems.

Although the echinoderms do not have many well-defined sensory inputs, they are sensitive to touch, light, temperature, orientation, and the status of water around them. The tube feet, spines, and pedicellariae found on sea stars are sensitive to touch, while eyespots on the ends of the rays are light-sensitive. The tube feet, especially those at the tips of the rays, are also sensitive to chemicals and this sensitivity is used in locating odor sources, such as food.

The eyespots each consist of a mass of ocelli, consisting of pigmented epithelial cells that respond to light and narrow sensory cells lying between them. Each ocellus is covered by a thick, transparent, cuticle that both protects them and acts as a lens. Many starfish also possess individual photoreceptor cells across their body and are able to respond to light even when their eyespots are covered.

Locomotion

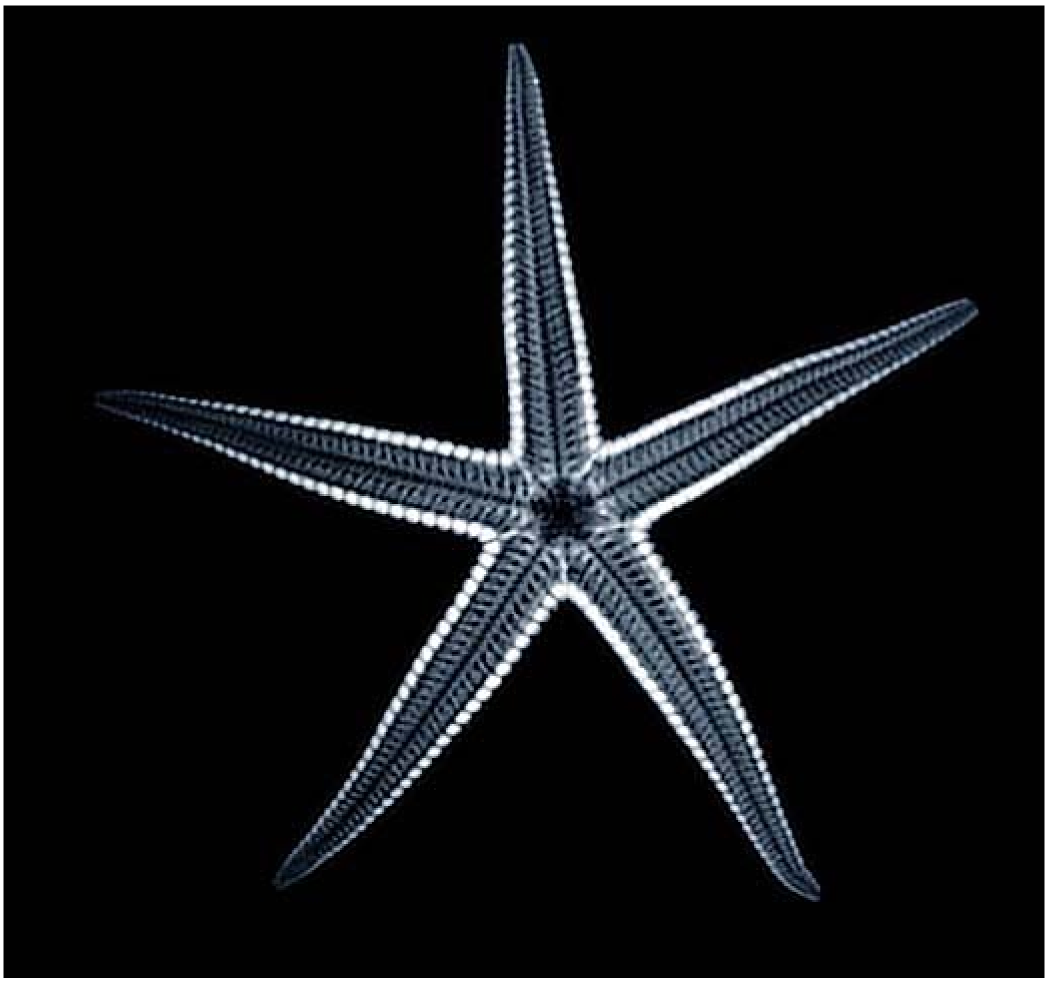


The underside of a sea star. The inset shows a magnified view of the tube feet.

Sea stars move using a water vascular system. Water comes into the system via the madreporite. It is then circulated from the stone canal to the ring canal and into the radial canals. The radial canals carry water to the ampulla portion of tube feet.

Tube feet consist of internal ampulla and external podium, or "foot". The ampulla squeezes forcing water into podium, which expands to contact substrate. Although the podium resembles a suction cup, gripping action is a function of adhesive chemicals rather than suction. De-adhesive chemicals and podial contraction allow for the release off of substrate.

The tube feet latch on to surfaces and move in a wave, with one body section attaching to the surfaces as another releases. Most sea stars cannot move quickly. However, some burrowing species from the genera *Astropecten* and *Luidia* are capable of rapid, creeping motion: "gliding" across the ocean floor. This motion results from their pointed tubefeet adapted specially for excavating patches of sand.



Sea-star endoskeleton

Endoskeleton

Sea stars, like other echinoderms have mesodermal endoskeletons consisting of small calcareous ossicles (bony plates).

Respiration and excretion

Respiration occurs mainly through the tube feet, and through tiny structures called **papullae** that dot the body surface. These papullae are thin-walled projections of the body cavity, reaching through the muscular body wall and into the surrounding water. Oxygen from the water is distributed through the body mainly by the fluid in the main body cavity; the hemal system may also play a minor role.

Excretion of nitrogenous waste is also performed through the tube feet and papullae, and there are no distinct excretory organs. The body fluid contains phagocytic cells called **coelomocytes**, which are also found within the hemal and water vascular systems. These cells engulf waste material, and eventually migrate to the tips of the papullae where they are ejected into the surrounding water. Some waste may also be excreted by the pyloric glands and voided with the faeces.

Starfish do not appear to have any mechanisms for osmoregulation, and keep their body fluids at the same salt concentration as the surrounding water. Although some species can tolerate relatively low salinity, the lack of osmoregulation likely explains why starfish are not found in fresh water, or even in estuarine environments.

Life cycle

Starfish are capable of both sexual and asexual reproduction. Most species are dioecious, with separate male and female individuals, but some are hermaphrodites. For example, the common species *Asterina gibbosa* is protandric, with individuals being born male, but later changing into females.

Male and female sea stars are not distinguishable from the outside; one needs to see the gonads or be lucky enough to catch them spawning. Each arm contains two gonads, which release gametes through openings called gonoducts, located on the central body between the arms.

Reproduction

An eleven-armed sea star

Fertilization takes place externally, both male and female releasing their gametes into the environment. The resulting fertilized embryos form part of the zooplankton in most species. However, some species brood their eggs, either by simply sitting over them, or using specialised brooding baskets on their aboral surface. In at least one species (*Leptasterias tenera*), the eggs are actually brooded inside the pyloric stomach. In these brooding species, the eggs are relatively large, and supplied with yolk, and they generally develop directly into miniature starfish, without a larval stage. Brooding is especially common in polar and deep-sea species, environments less favourable for larvae.

Sea stars commonly reproduce by free-spawning: releasing their gametes into the water where they are fertilized by gametes from the opposite sex. To increase their chances of fertilization, sea stars probably gather in groups when they are ready to spawn, use environmental signals to coordinate timing (day length to indicate the correct time of the year, dawn or dusk to indicate the correct time of day), and may use chemical signals to indicate their readiness to each other.

Some species of sea star also reproduce asexually by fragmentation, often with part of an arm becoming detached and eventually developing into an independent individual sea star. This has led to some notoriety. Sea stars can be pests to fishermen who make their living on the capture of clams and other mollusks at sea as sea stars prey on these. The fishermen would think they had killed the sea stars by chopping them up and disposing of them at sea, but each fragment would regenerate into a complete adult, ultimately leading to their increased numbers until the issue was better understood. A sea-star arm can only regenerate into a whole new organism if some of the central disk of the sea star is part of the chopped off arm. A starfish which is regenerating from a severed arm, with one full-sized arm and the other arms small, is sometimes called a **comet starfish**.

Larval development

Like all echinoderms, starfish are developmentally (embryologically) deuterostomes; a feature they share with chordates (including vertebrates), but not with most other invertebrates. Their embryo initially develops bilateral symmetry, again reflecting their likely common ancestry with chordates. Later development takes a very different path, however, as the developing star fish settles out of the zooplankton and develops the characteristic radial symmetry. As the organism grows, one side of the body grows more than the other, and eventually absorbs the smaller side. After that, the body is formed into five parts around a central axis. Then the echinoderm has radial symmetry.

The larvae of echinoderms are ciliated, free-swimming organisms. Fertilized eggs grow into bipinnaria and (in most cases) later into brachiolaria larvae, which either grow using a yolk or by catching and eating other plankton. In either case, they live as plankton, suspended in the water and swimming by using beating cilia. The larvae are bilaterally symmetric — unlike adults, they have a distinct left and right side. Eventually, they undergo a complete metamorphosis, settle to the bottom, and grow into adults.

Lifespan

The lifespan of starfish varies considerably between species, generally being longer in larger species. For example, *Leptasterias hexactis* (adult weight 2 grams) reaches sexual maturity in two years, and lives for about ten years in total, while *Pisaster ochraceus* (adult weight 80 grams) reaches maturity in five years, and may live to the age of 34.

Diet

Sea star *Pisaster ochraceus* consuming a mussel in Central California

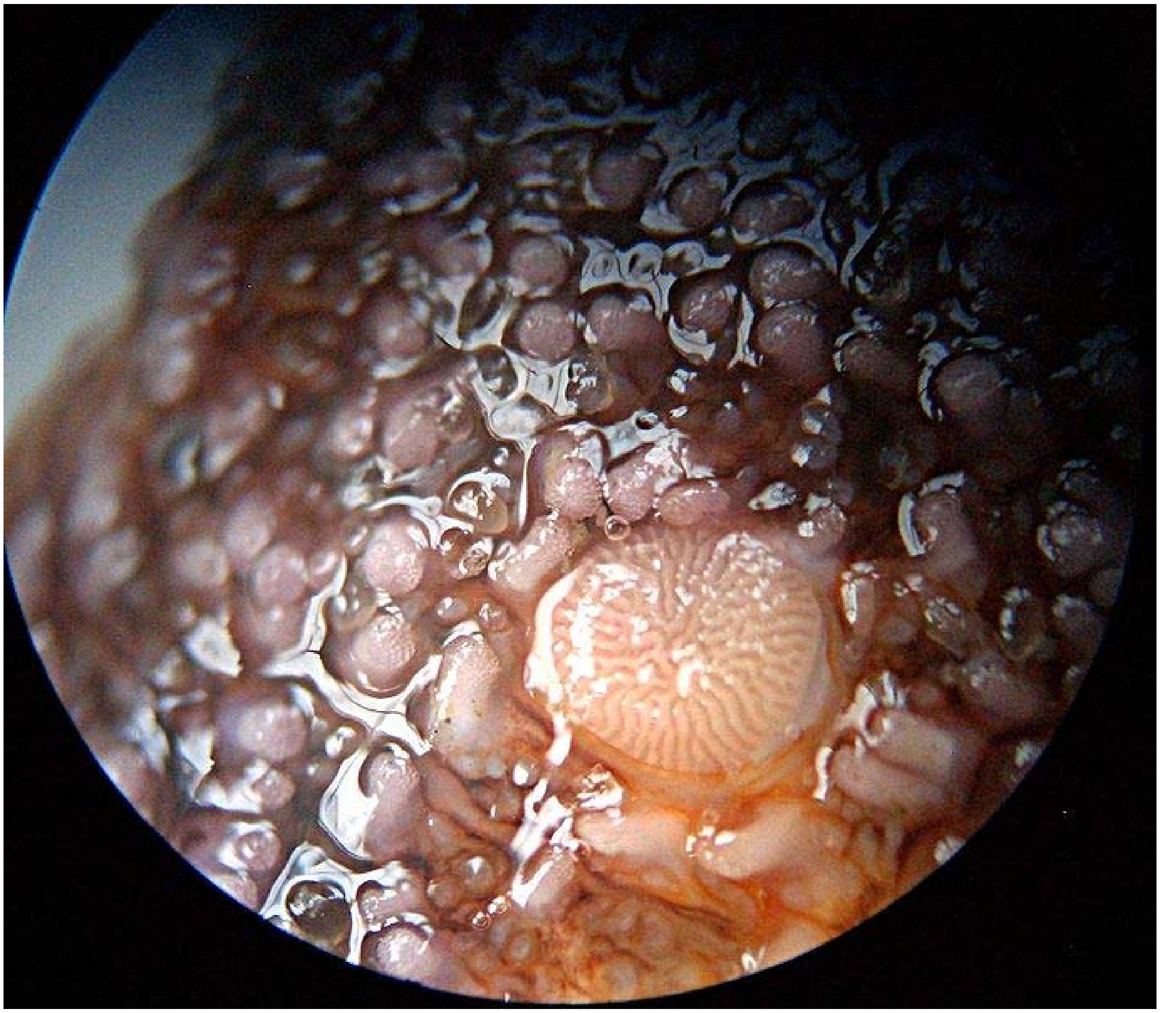
Most species are generalist predators, eating mollusks such as clams, oysters, some snails, or any other animal too slow to evade the attack (e.g. other echinoderms, or dying fish). Some species are detritivores, eating decomposed animal and plant material or organic films attached to substrate. Others may consume coral polyps (the best-known example for this is the infamous Crown-of-thorns starfish), sponges or even suspended particles and plankton (such as sea stars of the Order Brisingida). The processes of feeding and capture may be aided by special parts; *Pisaster brevispinus* or short-spined pisaster from the West Coast of America may use a set of specialized tube feet to extend itself deep into the soft substrata to extract prey (usually clams). Grasping the shellfish, the sea star slowly pries open the shell by wearing out the adductor muscle and then inserts (also called evisceration) its stomach into an opening to devour the organism.

Distribution

There are about 1,800 known living species of sea star, and they occur in all of the Earth's oceans. The greatest variety of sea stars is found in the tropical Indo-Pacific. Areas known for their great diversity include the tropical-temperate regions around Australia, the tropical East Pacific, and the cold-temperate water of the North Pacific (California to

Alaska). *Asterias* is a common genus found in European waters and on the eastern coast of the United States; *Pisaster*, along with *Dermasterias* ("leather star"), are usually found on the western coast. Habitats range from tropical coral reefs, kelp forests to deep-sea floor, although none of them live within the water column; all species of sea star found are living as benthos. Echinoderms need a delicate internal balance in their body; no sea stars are found in freshwater environments.

Diversity



Sea stars move using a water vascular system. Water comes into the system via the madreporite.

As mentioned above there are over 1800 species; with many species awaiting discovery. Some of the better known sea stars include:

- Bat star
- Blue sea star
- Carpet sea star
- Comb sea star

- Common starfish
- Crown-of-thorns sea star
- Eleven-armed sea star
- Japanese sea star
- Ochre sea star
- Pincushion sea star
- Pink sea star

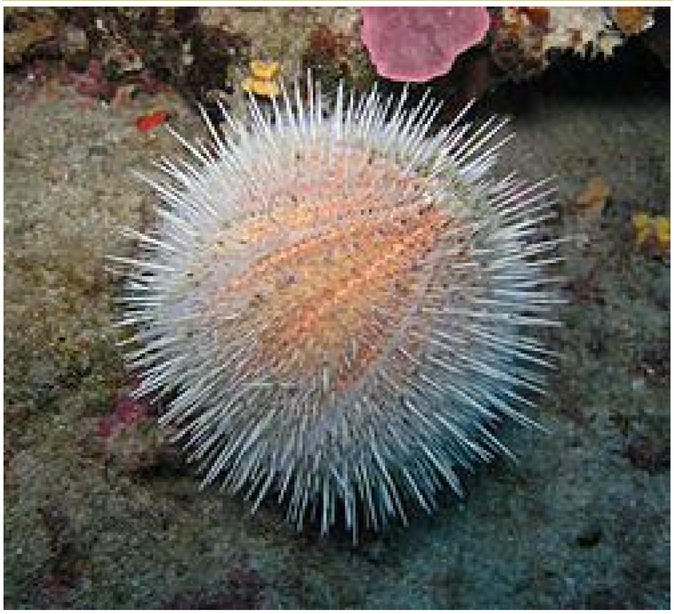
The Northern Pacific sea star (*Asterias amurensis*) known as *gohongaze* is considered an edible delicacy.

Threats

Due to the nature of the water vascular system, sea stars and other echinoderms have little to no ability to filter pollutants and toxins out of the water they inhabit, since it is literally pumped directly into their bodies. This makes them highly susceptible to damage from pollution and contaminants. Oil pollution, such as the Deepwater Horizon spill, may have a serious and very negative impact on echinoderm populations in the affected areas.

Chapter- 5

Sea Urchin

Sea Urchin Temporal range: Ordovician–Recent	
	
The 'Water melon' sea urchin (*Echinus melo*) in North west of Sardinia	
Scientific classification	
Kingdom:	Animalia
Phylum:	Echinodermata
Subphylum:	Echinozoa
Class:	**Echinoidea** Leske, 1778
Subclasses	

- Subclass Perischoechinoidea
  - Order Cidaroida (pencil urchins)
- Subclass Euechinoidea
  - Superorder Atelostomata

        - Order Cassiduloida
        - Order Spatangoida (heart urchins)
    - Superorder Diadematacea
        - Order Diadematoida
        - Order Echinothurioida
        - Order Pedinoida
    - Superorder Echinacea
        - Order Arbacioida
        - Order Echinoida
        - Order Phymosomatoida
        - Order Salenioida
        - Order Temnopleuroida
    - Superorder Gnathostomata
        - Order Clypeasteroida (sand dollars)
        - Order Holectypoida

Sea urchins or **urchins** are small, spiny, globular animals which, with their close kin, such as sand dollars, constitute the class **Echinoidea** of the echinoderm phylum. They inhabit all oceans. Their shell, or "test", is round and spiny, typically from 3 to 10 centimetres (1.2 to 3.9 in) across. Common colors include black and dull shades of green, olive, brown, purple, and red. They move slowly, feeding mostly on algae. Sea otters, wolf eels, triggerfish, and other predators feed on them. Humans harvest them and serve their roe as a delicacy.

The name *urchin* is an old name for the round spiny hedgehogs that sea urchins resemble.

Taxonomy

Sea urchins are members of the phylum Echinodermata, which also includes sea stars, sea cucumbers, brittle stars, and crinoids. Like other echinoderms they have fivefold symmetry (called pentamerism) and move by means of hundreds of tiny, transparent, adhesive "tube feet". The symmetry is not obvious in the living animal, but is easily visible in the dried test. "Echinodermate" means "spiny skin" in Greek.

Specifically, the term "sea urchin" refers to the "regular echinoids," which are symmetrical and globular. The term includes several different taxonomic groups: the order Echinoida, the order Cidaroida or "slate-pencil urchins", which have very thick, blunt spines, and others. Besides sea urchins, the class Echinoidea also includes three groups of "irregular" echinoids: flattened sand dollars, sea biscuits, and heart urchins.

Together with sea cucumbers (Holothuroidea), they make up the subphylum Echinozoa, which is characterized by a globoid shape without arms or projecting rays. Sea cucumbers and the irregular echinoids have secondarily evolved diverse shapes.

Although many sea cucumbers have branched tentacles surrounding the oral opening, these have originated from modified tube feet and are not homologous to the arms of the crinoids, sea stars, and brittle stars.

Anatomy

Urchins typically range in size from 6 to 12 centimetres (2.4 to 4.7 in), although the largest species can reach up to 36 centimetres (14 in).

Five-fold symmetry

Like other echinoderms, sea urchins are bilaterans. Their early larvae have bilateral symmetry but they develop fivefold symmetry as they mature. This is most apparent in the "regular" sea urchins, which have roughly spherical bodies, with five equally-sized parts radiating out from the central axis. Several sea urchins, however, including the sand dollars, are oval in shape, with distinct front and rear ends, giving them a degree of bilateral symmetry. In these urchins, the upper surface of the body is slightly domed, but the underside is flat, while the sides are devoid of tube feet. This "irregular" body form has evolved to allow the animals to burrow through sand or other soft material.

Organs and test

The lower half of a sea urchin's body is referred to as the *oral surface*, because it contains the mouth, while the upper half is the *aboral surface*. The internal organs are enclosed in a hard **test** composed of fused plates of calcium carbonate covered by a thin dermis and epidermis. The test is rigid, and divides into five *ambulacral areas* separated by five *inter-ambulacral areas*. Each of these areas consists of two rows of plates, so that the test includes twenty rows in total. The plates are covered in rounded tubercles, to which the spines are attached. The inner surface of the test is lined by peritoneum.

Feet

Urchins have tube feet, which arise from the five ambulacral areas. (The tube feet are moved by the water vascular system.)

Mouth/anus

The mouth lies in the center of the oral surface in regular urchins, or towards one end of irregular urchins. It is surrounded by lips of softer tissue, with numerous small bony pieces embedded in it. This area, called the *peristome*, also includes five pairs of modified tube feet and, in many species, five pairs of gills. On the upper surface, opposite the mouth, is a region termed the *periproct*, which surrounds the anus. The periproct contains a variable number of hard plates, depending on species, one of which contains the madreporite.

Endoskeleton

The sea urchin builds its spicules, the sharp crystalline "bones" that constitute the animal's endoskeleton, in the larval stage. The fully formed spicule is composed of a single crystal with an unusual morphology. It has no facets and within 48 hours of fertilization assumes a shape that looks very much like the Mercedes-Benz logo.

In other echinoderms, the endoskeleton is associated with a layer of muscle that allows the animal to move its arms or other body parts. This is entirely absent in sea urchins, which are unable to move in this way.

Spines

The spines, long and sharp in some species, protect the urchin from predators. The spines inflict a painful wound when they penetrate human skin, but are not dangerous. It is not clear if the spines are venomous (unlike the pedicellariae between the spines, which are venomous).

Typical sea urchins have spines that are 1 to 3 centimetres (0.39 to 1.2 in) in length, 1 to 2 millimetres (0.039 to 0.079 in) thick, and not terribly sharp. *Diadema antillarum*, familiar in the Caribbean, has thin, potentially dangerous spines that can reach 10 to 30 centimetres (3.9 to 12 in) long.

Reproductive organs

Sea urchins are dioecious, having separate male and female sexes, although there is generally no easy way to distinguish the two. Regular sea urchins have five gonads, lying underneath the interambulacral regions of the test, while the irregular forms have only four, with the hindmost gonad being absent. Each gonad has a single duct, rising from the upper pole to open at a gonopore lying in one of the genital plates surrounding the anus. The gonads are lined with muscles underneath the peritoneum, and these allow the animal to squeeze its gametes through the duct and into the surrounding sea water, where fertilization takes place.

Physiology

Digestion

The mouth of most sea urchins is made up of five calcium carbonate teeth or jaws, with a fleshy tongue-like structure within. The entire chewing organ is known as *Aristotle's lantern* (image), from Aristotle's description in his *History of Animals*:

…the urchin has what we mainly call its head and mouth down below,and a place for the issue of the residuum up above. The urchin has, also, five hollow teeth inside, and in the middle of these teeth a fleshy substance serving the office of a tongue. Next to this comes the esophagus, and then the stomach, divided into five parts, and filled with excretion, all the five parts uniting at the anal vent, where the shell is perforated for an outlet... In reality the mouth-apparatus of the urchin is continuous from one end to the other, but to outward appearance it is not so, but looks like a horn lantern with the panes of horn left out. (Tr. D'Arcy Thompson)

Recent research has shown that the sea urchin's teeth are self-sharpening; it can chew through stone.

Heart urchins are unusual in not having a lantern. Instead, the mouth is surrounded by cilia that pull strings of mucus containing food particles towards a series of grooves around the mouth.

The lantern, where present, surrounds both the mouth cavity and the pharynx. At the top of the lantern, the pharynx opens into the esophagus, which runs back down the outside of the lantern, to join the small intestine and a single caecum. The small intestine runs in a full circle around the inside of the test, before joining the large intestine, which completes another circuit in the opposite direction. From the large intestine, a rectum ascends towards the anus. Despite the names, the small and large intestine of sea urchins are in no way homologous to the similarly named structures in vertebrates.

Digestion occurs in the intestine, with the caecum producing further digestive enzymes. An additional tube, called the *siphon*, runs beside much of the intestine, opening into it at both ends. It may be involved in resorption of water from food.

Circulation

Sea urchins possess both a water vascular system and a *hemal system*, the latter containing blood. However, the main circulatory fluid fills the general body cavity, or coelom. This fluid contains phagocytic *coelomocytes* which move through the vascular and hemal systems. The coelomocytes are an essential part of blood clotting, but also collect waste products and actively remove them from the body through the gills and tube feet.

Respiration

Most sea urchins possess five pairs of external gills, located around the mouth. These are thin-walled projections of the body cavity, and are the main organs of respiration in those urchins that possess them. Fluid can be pumped through the gills' interior by muscles associated with the lantern, but this is not continuous, and occurs only when the animal is low on oxygen. Tube feet can also act as respiratory organs, and are the primary sites of gas exchange in heart urchins and sand dollars, both of which lack gills.

Nervous system

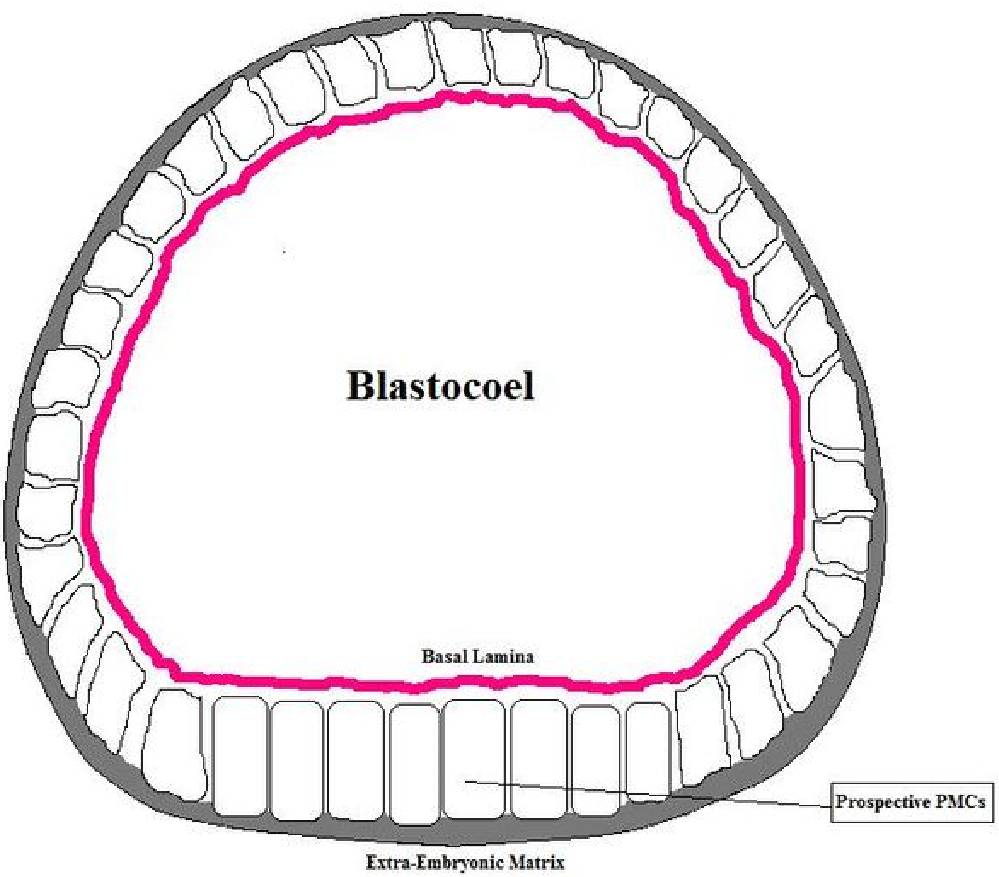
The nervous system of sea urchins has a relatively simple layout. There is no true brain. The center is a large nerve ring encircling the mouth just inside the lantern. From the nerve ring, five nerves radiate underneath the radial canals of the water vascular system, and branch into numerous finer nerves to innervate the tube feet, spines, and pedicellariae.

Senses

Sea urchins are sensitive to touch, light, and chemicals. Although they do not have eyes or eye spots, recent research suggests that their entire body might function as one compound eye. They also have statocysts, called *spheridia*, that are located within the ambulacral plates and help the animal remain upright.

Development

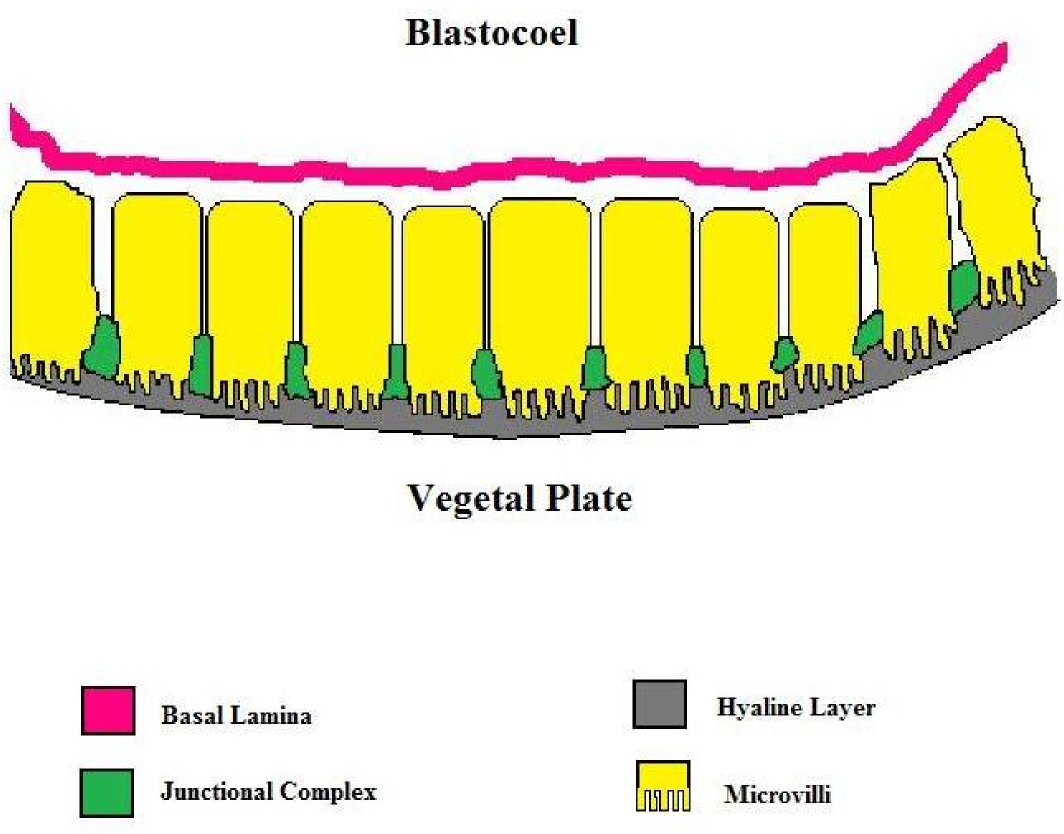
Ingression of primary mesenchyme cells



Sea Urchin Blastula

During early development, the sea urchin embryo undergoes ten cycles of cell division resulting in a single epithelial layer enveloping a blastocoel. The embryo must then begin gastrulation, a multipart process which involves the dramatic rearrangement and invagination of cells to produce the three germ layers.

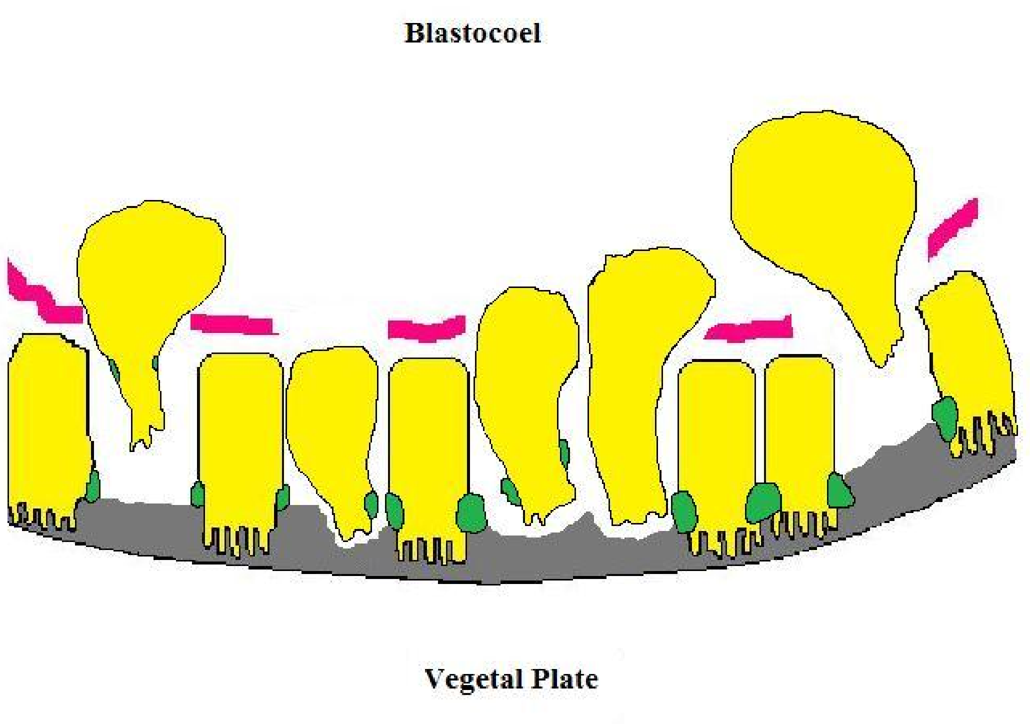
The first step of gastrulation is the epithelial to mesenchymal transition and ingression of primary mesenchyme cells into the blastocoel. Primary mesenchyme cells, or PMCs, are cells located in the vegetal plate that are specified to become mesoderm. Prior to ingression, PMCs exhibit all the features of other epithelial cells that comprise the embryo. Cells of the epithelium are bound basally to a laminal matrix and apically to an extra-embryonic matrix. The apical microvilli of these cells reach into the hyaline layer, a component of the extra-embryonic matrix. Neighboring epithelial cells are also connected to each other through apical junctions, protein complexes containing adhesion molecules such as cadherins linked to catenins.



Prospective PMCs at Vegetal Plate

As PMCs begin to undergo an epithelial to mesenchymal transition, the lamina which binds them dissolves to begin the mechanical release of the cells. Expression of the membrane protein that binds laminin, integrin, also becomes irregular at the beginning of ingression. The microvilli which secure PMCs to the hyaline layer shorten, as the cells reduce their affinity for the extra-embryonic matrix. These cells concurrently increase their affinity for other components of the basal matrix, such as fibronectin, in part driving the movement of cells inward. The apical junctions which bind PMCs to their neighboring epithelial cells become disrupted during this transition, and are absent in cells that have fully ingressed into the blastocoel. Because staining for cadherins and catenins in ingressing cells decreases and develops as intracellular accumulations, apical junctions are thought to be cleared by endocytosis during ingression.

Once the PMCs disrupt all attachment to their former location, the cells themselves change their morphology by contracting their apical surface, apical constriction, and enlarging their basal surface; acquiring a "bottle cell" phenotype. Cytoskeletal rearrangements mediate the shape changes of PMCs; and though the cytoskeleton assists in the mechanics of ingression, other mechanisms drive the process. Experimentally disrupting microtubule dynamics in the species Strongylocentrotus pupuratus by applying colchicine stalls the ingression of PMCs but does not inhibit it. Similarly, experimentally disrupting actin-myosin contraction using inhibitors slows down ingression, but does not arrest the process.



Epithelial-to-Mesenchymal Transition and Ingression of PMCs

The morphogenetic movements of the PMCs are an autonomous cellular behavior. Experimentally grafting PMCs into heterotopic tissue does not prevent the cells from ingressing. In studies where PMCs are cultured in insolation, the cells were observed to gain affinity for fibronectin and simultaneously lose affinity for extra-embryonic matrix independent of the embryonic environment.

Life history

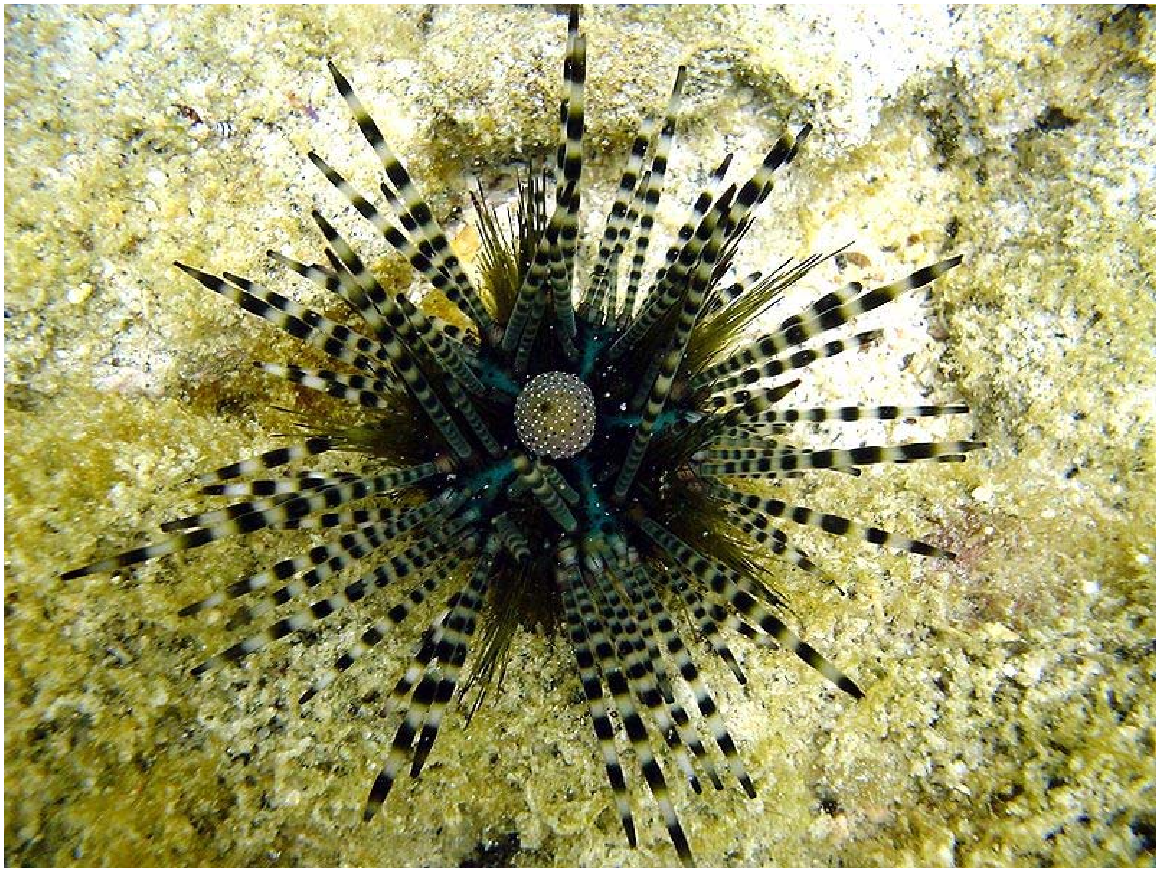
At first glance, sea urchins often appear sessile, i.e., incapable of moving. Sometimes the most visible life sign is the spines, which attach to ball-and-socket joints and can point in any direction. In most urchins, touch elicits a prompt reaction from the spines, which converge toward the touch point. Sea urchins have no visible eyes, legs, or means of propulsion, but can move freely over hard surfaces using adhesive tube feet, working in conjunction with the spines.

Reproduction

In most cases, the eggs float freely in the sea, but some species hold onto them with their spines, affording them a greater degree of protection. The fertilized egg develops into a free-swimming blastula embryo in as little as twelve hours. Initially a simple ball of cells, the blastula soon transforms into a cone-shaped **echinopluteus** larva. In most species, this larva has twelve elongated arms, but in a few it contains supplies of nutrient yolk and lacks arms, since it has no need to feed. The arms are lined with bands of cilia that capture food particles and transport them to the mouth.

It may take several months for the larva to complete its development, which begins with the formation of the test plates around the mouth and anus. Soon the larva sinks to the bottom and metamorphoses into adult form in as little as one hour. In some species, adults reach their maximum size in about five years.

Ecology



Echinothrix calamaris, a species of sea urchin. The sphere in the middle of a sea urchin is its anus.

Sea urchins feed mainly on algae, but can also feed on sea cucumbers, and a wide range of invertebrates such as mussels, polychaetes, sponges, brittle stars and crinoids. Population density varies by habitat with more dense populations being found in barren areas as compared to kelp stands. Even in these barren areas, greatest densities are also found in shallow water. Populations are also generally found in deeper water if waves action is present. Density also decrease in winter when storms cause them to seek protection in cracks and around larger underwater structures.

Sea urchin is one of the favorite foods of sea otters and is also the main source of nutrition for wolf eels. Left unchecked, urchins devastate their environment, creating what biologists call an urchin barren, devoid of macroalgae and associated fauna. Sea otters have re-entered British Columbia, dramatically improving coastal ecosystem health.

Evolutionary history

Fossil heart urchin *Lovenia woodsi* from the Pliocene of Australia

The earliest echinoid fossils date to the upper part of the Ordovician period (*c* 450 MYA), and the species has survived to the present day, where they are a successful and diverse group of organisms. Spines may be present in well-preserved specimens, but usually only the test remains. Isolated spines are common as fossils. Some echinoids (such as *Tylocidaris clavigera*, from the Cretaceous period's English Chalk Formation) had very heavy club-shaped spines that would be difficult for an attacking predator to break through and make the echinoid awkward to handle. Such spines simplify walking on the soft sea-floor.

Cretaceous heart urchins from Castle Hayne quarry, North Carolina, USA

Most of the fossil echinoids from the Paleozoic era are incomplete, consisting of isolated spines and small clusters of scattered plates from crushed individuals. Most specimens occur in Devonian and Carboniferous rocks. The shallow water limestones from the Ordovician and Silurian periods of Estonia are famous for echinoids. Paleozoic echinoids probably inhabited relatively quiet waters. Because of their thin test, they would certainly not have survived in the wave-battered coastal waters inhabited by many modern echinoids. During the upper part of the Carboniferous period, there was a marked decline in echinoid diversity, and this trend continued to the Permian period. They neared extinction at the end of the Paleozoic era, with just six species known from the Permian period. Only two lineages survived this period's massive extinction of and into the Triassic: the genus *Miocidaris*, which gave rise to modern cidaroida (pencil urchins), and the ancestor that gave rise to the euechinoids. By the upper part of the Triassic period, their numbers began to increase again. Cidaroids have changed very little since the Late Triassic and are today considered to be living fossils.

Two Saddle Wrasses, *Thalassoma duperrey* feeding on a sea urchin

The euechinoids, on the other hand, diversified into new lineages throughout the Jurassic period and into the Cretaceous period, and from them emerged the first irregular echinoids (superorder Atelostomata) during the early Jurassic, and later the other superorder (Gnathostomata) of irregular urchins which evolved independently. These two superorders are today representing 47% of all extant species of echinoids thanks to their adaptive breakthroughs, which allowed them to exploit habitats and food sources unavailable to regular echinoids. During the Mesozoic and Cenozoic eras the echinoids flourished. Most echinoid fossils are often abundant in the restricted localities and formations where they occur. An example of this is *Enallaster*, which exists by the thousands in certain outcrops of limestone from the Cretaceous period in Texas. Many fossils of the Late Jurassic *Plesiocidaris* still have the spines attached.

Some echinoids, such as *Micraster* which is found in the Cretaceous period Chalk Formation of England and France, serve as zone or index fossils. Because they evolved rapidly, they aid geologists in dating the surrounding rocks. However, most echinoids are not abundant enough and are of too limited range to serve as zone fossils.

In the early Tertiary (*c* 65 to 1.8 MYA), sand dollars (order Clypeasteroida) arose. Their distinctive flattened test and tiny spines were adapted to life on or under loose sand. They form the newest branch on the echinoid tree.

Chapter- 6

Sea Cucumber

Sea cucumber	
	
A sea cucumber	
Scientific classification	
Kingdom:	Animalia
Phylum:	Echinodermata
Subphylum:	Echinozoa
Class:	**Holothuroidea** de Blainville, 1834
Orders	

- Subclass Apodacea
    - Apodida
    - Molpadiida
- Subclass Aspidochirotacea
    - Aspidochirotida
    - Elasipodida
- Subclass Dendrochirotacea
    - Dactylochirotida
    - Dendrochirotida

Sea cucumbers are echinoderms from the class *Holothuroidea*. They are marine animals with a leathery skin and an elongated body containing a single, branched gonad. Sea cucumbers are found on the sea floor worldwide. There are a number of **holothurian** species and genera, many of which are targeted for human consumption. The harvested product is variously referred to as *trepang*, *bêche-de-mer* or *balate*.

Like all echinoderms, sea cucumbers have an endoskeleton just below the skin, calcified structures that are usually reduced to isolated microscopic ossicles (or sclerietes) joined by connective tissue. In some species these can sometimes be enlarged to flattened plates, forming an armour. In pelagic species such as *Pelagothuria natatrix* (Order Elasipodida, family Pelagothuriidae), the skeleton and a calcareous ring are absent.

Overview

Sea cucumbers communicate with each other by sending hormone signals through the water.

A remarkable feature of these animals is the catch collagen that forms their body wall. This can be loosened and tightened at will, and if the animal wants to squeeze through a small gap, it can essentially liquefy its body and pour into the space. To keep itself safe in these crevices and cracks, the sea cucumber hooks up all its collagen fibres to make its body firm again.

A sea cucumber in Mahé, Seychelles ejects sticky filaments from the anus in self-defence

Some species of coral-reef sea cucumbers within the order Aspidochirotida can defend themselves by expelling their sticky cuvierian tubules (enlargements of the respiratory tree that float freely in the coelom) to entangle potential predators. When startled, these cucumbers may expel some of them through a tear in the wall of the cloaca in an autotomic process known as evisceration. Replacement tubules grow back in one-and-a-half to five weeks, depending on the species. The release of these tubules can also be accompanied by the discharge of a toxic chemical known as holothurin, which has similar properties to soap. This chemical can kill any animal in the vicinity and is one more way in which these sedentary animals can defend themselves.

They can be found in great numbers on the deep sea floor, where they often make up the majority of the animal biomass. At depths deeper than 5.5 mi (8.8 km), sea cucumbers comprise 90% of the total mass of the macrofauna. Sea cucumbers form large herds that move across the bathygraphic features of the ocean, hunting food. The body of some deep water holothurians is made of a tough gelatinous tissue with unique properties that makes the animals able to control their own buoyancy, making it possible for them to either live on the ocean floor or to float over it to move to new locations with a minimum of energy, for instance *Enypniastes eximia*, *Peniagone leander* and *Paelopatides confundens*.

In more shallow waters, sea cucumbers can form dense populations. The strawberry sea cucumber (*Squamocnus brevidentis*) of New Zealand lives on rocky walls around the southern coast of the South Island where populations sometimes reach densities of 1,000 animals per square metre. For this reason, one such area in Fiordland is simply called the strawberry fields.

Emperor shrimp *Periclimenes imperator* on a *Bohadschia argus* sea cucumber

A variety of fish, most commonly pearl fish, have evolved a commensalistic symbiotic relationship with sea cucumbers in which the pearl fish will live in sea cucumber's cloaca using it for protection from predation, a source of food (the nutrients passing in and out of the anus from the water), and to develop into their adult stage of life. Many polychaete worms and crabs have also specialized to use the cloacal respiratory trees for protection by living inside the sea cucumber.

The largest American species is *Holothuria floridana*, which abounds just below low-water mark on the Florida reefs.

Visitors to the Mariana Islands often encounter the local variation, called **balate**, which litters the sea floor all around the island, including in water as shallow as 3 feet (91 cm). These jet black sea cucumbers are normally 10 to 12 inches (25 to 30 cm) long, 1.5 to 2.0 inches (3.8 to 5.1 cm) in diameter and are often curled up, partially covered with sand from the sea floor.

The most common way to separate the subclasses is by looking at their oral tentacles. Subclass Dendrochirotacea has 8-30 oral tentacles, subclass Aspidochirotacea has 10-30 leaflike or shieldlike oral tentacles, while subclass Apodacea may have up to 25 simple or pinnate oral tentacles and is also characterized by reduced or absent tube feet, as in the order Apodida.

Anatomy

Conspicuous Sea Cucumber, Coconut Island, Hawaii

Sea cucumbers are typically 10 to 30 centimetres (3.9 to 12 in) in length, although the smallest known species is just 3 millimetres (0.12 in) long, and the largest can reach 1 metre (3.3 ft). The body ranges from almost spherical to worm-like, and lacks the arms found in many other echinoderms, such as starfishes. The anterior end of the animal, containing the mouth, corresponds to the oral pole of other echinoderms (which, in most cases, is the underside), while the posterior end, containing the anus, corresponds to the aboral pole. Thus, compared with other echinoderms, sea cucumbers can be said to be lying on their side.

Diet and digestive system

A sea cucumber feeding while on gravel

Holothuroidea are generally scavengers, feeding on debris in the benthic zone of the ocean. Exceptions include pelagic cucumbers and the species *Rynkatropa pawsoni*, which has a commensal relationship with deep-sea anglerfish. The diet of most cucumbers consists of plankton and decaying organic matter found in the sea. Some sea cucumbers position themselves in currents and catch food that flows by with their open tentacles. They also sift through the bottom sediments using their tentacles.

A pharynx lies behind the mouth and is surrounded by a ring of ten calcareous plates. In most sea cucumbers, this is the only substantial part of the skeleton, and it forms the point of attachment for muscles that can retract the tentacles into the body for safety as for the main muscles of the body wall. Many species possess an oesophagus and stomach, but in some the pharynx opens directly into the intestine. The intestine is typically long and coiled, and loops through the body three times before terminating in a cloacal chamber, or directly as the anus.

Nervous system

Sea cucumbers have no true brain. A ring of neural tissue surrounds the oral cavity, and sends nerves to the tentacles and the pharynx. The animal is, however, quite capable of functioning and moving about if the nerve ring is surgically removed, demonstrating that it does not have a central role in nervous coordination. In addition, five major nerves run from the nerve ring down length of the body beneath each of the ambulacral areas.

Most sea cucumbers have no distinct sensory organs, although there are various nerve endings scattered through the skin giving the animal a sense of touch and a sensitivity to the presence of light. There are, however, a few exceptions; members of the Apodida order are known to possess statocysts, while some species possess small eye-spots near the bases of their tentacles.

Respiratory system

Sea cucumbers extract oxygen from water in a pair of 'respiratory trees' that branch off the cloaca just inside the anus, so that they 'breathe' by drawing water in through the anus and then expelling it. The trees consist of a series of narrow tubules branching from a common duct, and lie on either side of the digestive tract. Gas exchange occurs across the thin walls of the tubules, to and from the fluid of the main body cavity.

Together with the intestine, the respiratory trees also act as excretory organs, with nitrogenous waste diffusing across the tubule walls in the form of ammonia and phagocytic coelomocytes depositing particulate waste.

Circulatory systems

Like all echinoderms, sea cucumbers possess both a water vascular system that provides hydraulic pressure to the tentacles and tube feet, allowing them to move, and a *haemal system*. The latter is more complex than that in other echinoderms, and consists of well-developed vessels as well as open sinuses.

A central haemal ring surrounds the pharynx next to the ring canal of the water vascular system, and sends off additional vessels along the radial canals beneah the ambulacral areas. In the larger species, additional vessels run above and below the intestine and are connected by over a hundred small muscular ampullae, acting as miniature hearts to pump blood around the haemal system. Additional vessels surround the respiratory trees, although they contact them only indirectly, via the coelomic fluid.

Indeed, the blood itself is essentially identical with the coelomic fluid that bathes the organs directly, and also fills the water vascular system. Phagocytic coelomocytes, somewhat similar in function to the white blood cells of vertebrates, are formed within the haemal vessels, and travel throughout the body cavity as well as both circulatory systems. An additional form of coelomocyte, not found in other echinoderms, has a flattened discoid shape, and contains haemoglobin. As a result, in many (though not all) species, both the blood and the coelomic fluid are red in colour.

Vanadium has been reported in high concentrations in holothurian blood, however researchers have been unable to reproduce these results.

Locomotion and exoskeleton

Like all echinoderms, sea cucumbers possess pentaradial symmetry. However, because of their posture, they have secondarily evolved a degree of bilateral symmetry. For example, because one side of the body is typically pressed against the substratum, and the other is not, there is usually some difference between the two surfaces. Like sea urchins, most sea cucumbers have five strip-like ambulacral areas running along the length of the body from the mouth to the anus. The three on the lower surface have numerous tube feet, often with suckers, that allow the animal to crawl along. The two on the upper surface have under-developed or vestigial tube feet, and, in some species, lack tube feet altogether.

In some species, the ambulacral areas can no longer be distinguished, with tube feet spread over a much wider area of the body. Those of the subclass Apodacea have no tube feet or ambulacral areas at all, and burrow through sediment with muscular contractions of their body.

However, even in those sea cucumbers that lack regular tube feet, those immediately around the mouth are always present. These are highly modified into retractile tentacles, much larger than the regular tube feet. Sea cucumbers have between ten and thirty such tentacles, depending on the species.

Echinoderms typically possess an internal skeleton composed of plates of calcium carbonate. In most sea cucumbers, however, these have become reduced to microscopic ossicles embedded beneath the skin. A few genera, such as *Sphaerothuria*, retain relatively large plates, giving them a scaly armour.

Reproduction and life cycle

Most sea cucumbers reproduce by releasing sperm and ova into the ocean water. Depending on conditions, one organism can produce thousands of gametes. Sea cucumbers are typically dioecious, with separate male and female individuals, but some species are protandric. The reproductive system consists of a single gonad, consisting of a cluster of tubules emptying into a single duct that opens on the upper surface of the animal, close to the tentacles.

At least 30 species, including the red-chested sea cucumber (*Pseudocnella insolens*), fertilise their eggs internally and then pick up the fertilised zygote with one of their feeding tentacles. The egg is then inserted into a pouch on the adult's body, where it develops and eventually hatches from the pouch as a juvenile sea cucumber. A few species are known to brood their young inside the body cavity, giving birth through a small rupture in the body wall close to the anus.

In all other species, the egg develops into a free-swimming larva, typically after around three days of development. The first stage of larval development is known as an **auricularia**, and is only around 1 millimetre (0.039 in) in length. This larva swims by means of a long band of cilia wrapped around its body, and somewhat resembles the bipinnaria larva of starfish. As the larva grows it transforms into the **doliolaria**, with a barrel-shaped body and three to five separate rings of cilia. The tentacles are usually the first adult features to appear, before the regular tube feet.

Holothurians as food and medicine

Dried sea cucumbers in a Japanese pharmacy

To supply the markets of Southern China, Macassan trepangers traded with the Indigenous Australians of Arnhem Land. This Macassan contact with Australia is the first recorded example of trade between the inhabitants of the Australian continent and their Asian neighbours.

There are many commercially important species of sea cucumber that are harvested and dried for export for use in Chinese cuisine as *Hoi sam*. Some of the more commonly found species in markets include:

- *Holothuria scabra*
- *Holothuria fuscogilva*
- *Actinopyga mauritiana*
- *Stichius japonicus*
- *Parastichopus californicus*
- *Thelenota ananas*
- *Acaudina molpadioides*
- *Isostichopus fuscus*

Some varieties of sea cucumber (known as *gamat* in Malaysia or *teripang* in Indonesia) are said to have excellent healing properties. There are pharmaceutical companies being built based on gamat. Extracts are prepared and made into oil, cream, or cosmetics. Some products are intended to be taken internally. A single study conducted on an unreported number of mice found intraperitoneal injection of sea cucumber extract to be somewhat effective in high doses (100 mg/kg) against internal pain, but ineffective against externally induced pain. Another study suggested that the sea cucumber contains all the fatty acids necessary to play a potential active role in tissue repair.

On December 21, 2007, a study published in PLoS Pathogens found that a lectin from *Cucumaria echinata* impaired the development of the malaria parasite when produced by transgenic mosquitoes.

Commercial harvest

In recent years, the sea cucumber industry in Alaska has increased due to increased export of the skins and muscles to China.

In China, many commercial sea cucumbers are farmed in artificial ponds. These ponds can be as large as 1,000 acres (4.0 km^2), and satisfy much of the local demand. Wild sea cucumbers are caught by divers and these wild Alaskan sea cucumbers have higher nutritional value and are larger than farmed Chinese sea cucumbers. Larger size and higher nutritional value has allowed the Alaskan fisheries to continue to compete for market shares, despite the increase in local, Chinese sea cucumber farming.

Chapter- 7

Flatworm

Platyhelminth worms Temporal range: 40–0 Ma	
	
Bedford's flatworm, *Pseudobiceros bedfordi*	
Scientific classification	
Kingdom:	Animalia
(unranked):	Protostomia
(unranked):	Spiralia
(unranked):	Platyzoa
Phylum:	**Platyhelminthes** Gegenbaur, 1859
Classes	
Cestoda Monogenea Trematoda Turbellaria	

The **flatworms**, known in scientific literature as **Platyhelminthes** or **Plathelminthes** (from the Greek πλατύ, *platy*, meaning "flat" and ἕλμινς (root: ἑλμινθ-), *helminth-*, meaning worm) are a phylum of relatively simple bilaterian, unsegmented, soft-bodied invertebrate animals. Unlike other bilaterians, they have no body cavity, and no specialized circulatory and respiratory organs, which restricts them to flattened shapes that allow oxygen and nutrients to pass through their bodies by diffusion.

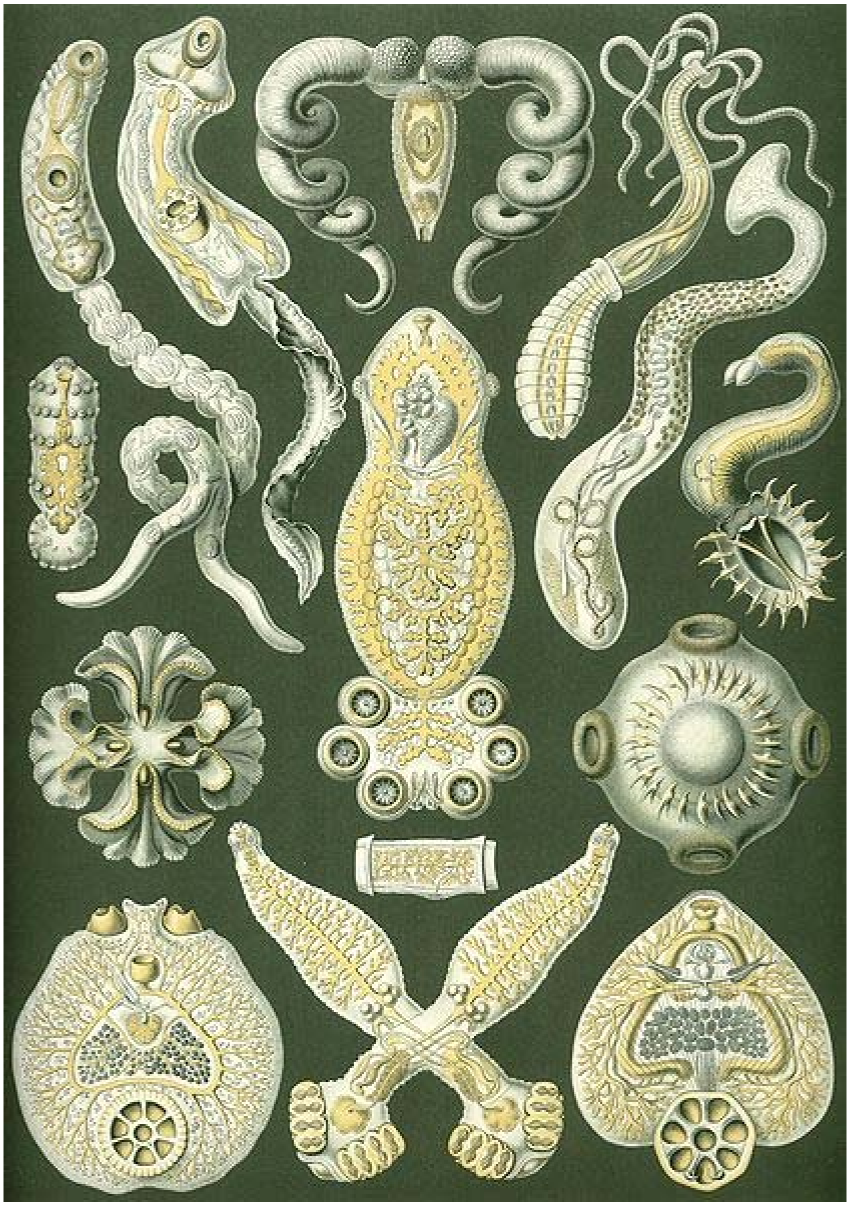
In traditional zoology texts Platyhelminthes are divided into Turbellaria, which are mostly non-parasitic animals such as planarians, and three entirely parasitic groups: Cestoda, Trematoda and Monogenea. Turbellarians are mostly predators, and live in water or in shaded, humid terrestrial environments such as leaf litter. Cestodes (tapeworms) and trematodes (flukes) have complex life-cycles, with mature stages that live as parasites in the digestive systems of fish or land vertebrates, and intermediate stages that infest secondary hosts. The eggs of trematodes are excreted from their main hosts, whereas adult cestodes generate vast numbers of hermaphroditic, segment-like proglottids which detach when mature, are excreted and then release eggs. Unlike the other parasitic groups, the monogeneans are external parasites infesting aquatic animals, and their larvae metamorphose into the adult form after attaching to a suitable host.

Because they do not have internal body cavities, for over a century Platyhelminthes were regarded as a primitive stage in the evolution of bilaterians (animals with bilateral symmetry and hence with distinct front and rear ends). However, analyses since the mid-1980s have separated out one sub-group, the Acoelomorpha, as basal bilaterians, in other words closer to the original bilaterians than to any other modern groups. The remaining Platyhelminthes form a monophyletic group, in other words one that contains all and only descendants of a common ancestor that is itself a member of the group. The redefined Platyhelminthes is part of the Lophotrochozoa, one of the three main groups of more complex bilaterians. These analyses have also concluded that the redefined Platyhelminthes, excluding Acoelomorpha, consists of two monophyletic sub-groups, Catenulida and Rhabditophora, and that Cestoda, Trematoda and Monogenea form a monophyletic sub-group within one branch of the Rhabditophora. Hence the traditional platyhelminth sub-group "Turbellaria" is now regarded as paraphyletic since it excludes the wholly-parasitic groups although these are descended from one group of "turbellarians".

Over half of all known flatworm species are parasitic, and some do enormous harm to humans and their livestock. Schistosomiasis, caused by one genus of trematodes, is the second most devastating of all human diseases caused by parasites, surpassed only by malaria. Neurocysticercosis, which arises when larvae of the pork tapeworm *Taenia solium* penetrate the central nervous system, is the major cause of acquired epilepsy worldwide. The threat of platyhelminth parasites to humans in developed countries is rising because of organic farming, the popularity of raw or lightly cooked foods, and imports of food from high-risk areas. In less developed countries, people often cannot afford the fuel required to cook food thoroughly, and poorly-designed water-supply and irrigation projects increase the dangers presented by poor sanitation and unhygienic farming.

Two planarian species have been used successfully in the Philippines, Indonesia, Hawaii, New Guinea and Guam to control populations of the imported giant African snail *Achatina fulica*, which was displacing native snails. However, there is now concern that these planarians may themselves become a serious threat to native snails. In North-west Europe there are concerns about the spread of the New Zealand planarian *Arthurdendyus triangulatus*, which preys on earthworms.

Description



Varied flatworm species from *Kunstformen der Natur (1904), plate 75*

Distinguishing features

Platyhelminthes are bilaterally symmetrical animals, in other words their left and right sides are mirror images of each other; this also implies that they have distinct top and bottom surfaces and distinct head and tail ends. Like other bilaterians they have three main cell layers, while the radially symmetrical cnidarians and ctenophores "(comb jellies)" have only two cell layers. Beyond that, they are "defined more by what they do not have than by any particular series of bodily specializations." Unlike other bilaterians, platyhelminthes have no internal body cavity and are therefore described as acoelomates. They also lack specialized circulatory and respiratory organs. Their bodies are soft and unsegmented.

	Cnidarians and Ctenophores	Platyhelminthes	More "advanced" bilaterians
Bilateral symmetry	No	Yes	
Number of main cell layers	Two, with jelly-like layer between them	Three	
Distinct brain	No	Yes	
Specialized digestive system	No	Yes	
Specialized excretory system	No	Yes	
Body cavity containing internal organs	No		Yes
Specialized circulatory and respiratory organs	No		Yes

Features common to all sub-groups

The lack of circulatory and respiratory organs limits platyhelminths to sizes and shapes that enable oxygen to reach and carbon dioxide to leave all parts of their bodies by simple diffusion. Hence many are microscopic and the large species have flat ribbon-like or leaf-like shapes. The guts of large species have many branches, so that nutrients can diffuse to all parts of the body. Respiration through the whole surface of the body makes platyhelminthes vulnerable to fluid loss, and restricts them to environments where dehydration is unlikely: sea and freshwater; moist terrestrial environments such as leaf litter or between grains of soil; and as parasites within other animals.

The space between the skin and gut is filled with mesenchyme, a connective tissue that is made of cells and reinforced by collagen fibers that act as a type of skeleton, providing attachment points for muscles. The mesenchyme contains all the internal organs and allows the passage of oxygen, nutrients and waste products. It consists of two main types of cell: fixed cells, some of which have fluid-filled vacuoles; and stem cells, which can transform into any other type of cell, and are used in regenerating tissues after injury or asexual reproduction.

Most platyhelminths have no anus and regurgitate undigested material through the mouth. However, some long species have an anus and some with complex branched guts have more than one anus, since excretion only through the mouth would be difficult for them. The gut is lined with a single layer of endodermal cells which absorb and digest food.

Some species break up and soften food first by secreting enzymes in the gut or pharynx (throat).

All animals need to keep the concentration of dissolved substances in their body fluids at a fairly constant level. Internal parasites and free-living marine animals live in environments that have high concentrations of dissolved material, and generally let their tissues have the same level of concentration as the environment, while freshwater animals need to prevent their body fluids from becoming too dilute. Despite this difference in environments, most platyhelminths use the same system to control the concentration of their body fluids. Flame cells, so called because the beating of their flagella looks like a flickering candle flame, extract from the mesenchyme water that contains wastes and some re-usable material, and drive it into networks of tube cells which are lined with flagella and microvilli. The tube cells' flagella drive the water towards exits called nephridiopores, while their microvilli re-absorb re-usable materials and as much water as is needed to keep the body fluids at the right concentration. These combinations of flame cells and tube cells are called protonephredia.

In all platyhelminths the nervous system is concentrated at the head end. This is least marked in the acoels, which have nerve nets rather like those of cnidarians and ctenophores, but densest around the head. Other platyhelminths have rings of ganglia in the head and main nerve trunks running along their bodies.

Major sub-groups

Early classification divided the flatworms into four groups: Turbellaria, Trematoda, Monogenea and Cestoda. It had long been recognized that this classification was artificial, and in 1985 Ehlers proposed a phylogenetically more correct classification where the massively polyphyletic "Turbellaria" was split into a dozen orders, and Trematoda, Monogenea and Cestoda were joined in the new order Neodermata. However, the classification presented here is the early, traditional, classification, as it still is the one used everywhere except in scientific articles.

Turbellaria

The turbellarian *Pseudoceros dimidiatus*

Two turbellarians mating by penis fencing. Each has two penises, the white spikes on the undersides of their heads.

These have about 4,500 species, are mostly free-living, and range from 1 mm (0.039 in) to 600 mm (24 in) in length. Most are predators or scavengers, and terrestrial species are mostly nocturnal and live in shaded humid locations such as leaf litter or rotting wood. However, some are symbiotes of other animals such as crustaceans, and some are parasites. Free-living turbellarians are mostly black, brown or gray, but some larger ones are brightly colored. The Acoela and Nemertodermatida were traditionally regarded as turbellarians, but are now regarded as members of a separate phylum, the Acoelomorpha, or as two separate phyla. *Xenoturbella*, a genus of very simple animals, has also been re-classified as a separate phylum.

Turbellarians have no cuticle (external layer of organic but non-cellular material). In a few species the skin is a syncitium, a collection of cells with multiple nuclei and a single shared external membrane. However the skins of most species consist of a single layer of cells, each of which generally has multiple cilia (small mobile "hairs"), although in some large species the upper surface has no cilia. These skins are also covered with microvilli between the cilia. They have many glands, usually submerged in the muscle layers below the skin and connect to the surface by pores through which they secrete mucus, adhesives and other substances.

Small aquatic species use the cilia for locomotion, while larger ones use muscular movements of the whole body or of a specialized sole to creep or swim. Some are capable of burrowing, anchoring their rear ends at the bottom of the burrow and then stretching the head up to feed and then pulling it back down for safety. Some terrestrial species throw a thread of mucus which they use as a rope to climb from one leaf to another.

The acoel *Convoluta roscoffensis* swallows cells of the green alga *Tetraselmis* and does not feed as an adult, presumably relying on the alge to provide nourishment as endosymbionts. In other acoels the gut is lined by a syncitium. These and some other turbellarians have a simple pharynx lined with cilia and generally feed by using cilia to sweep food particles and small prey into their mouths, which are usually in the middle of the underside. Most other turbellarians have a pharynx that is eversible, in other words can be extended by being turned inside-out, and the mouths of different species can be anywhere along the underside. The freshwater species *Microstomum caudatum* can open its mouth almost as wide as its body is long, to swallow prey about as large as itself.

Most turbellarians have pigment-cup ocelli ("little eyes"), one pair in most species but two or even three pairs in some. A few large species have many eyes in clusters over the brain, mounted on tentacles, or spaced uniformly round the edge of the body. The ocelli can only distinguish the direction from which light is coming and enable the animals to avoid it. A few groups – mainly catenulids, acoelomorphs and seriates – have statocysts, fluid-filled chambers containing a small solid particle or, in a few groups, two. These statocysts are thought to be balance and acceleration sensors, as that is the function they perform in cnidarian medusae and in ctenophores. However, turbellarian statocysts have no sensory cilia, and it is unknown how they sense the movements and positions of the solid particles. On the other hand most have ciliated touch-sensor cells scattered over their bodies, especially on tentacles and around the edges. Specialized cells in pits or grooves on the head are probably smell-sensors.

Planaria, a sub-group of seriates, are famous for their ability to regenerate if divided by cuts across their bodies. Experiments show that, in fragments that do not already have a head, a new head grows most quickly on those that were closest to the original head. This suggests that the growth of a head is controlled by a chemical whose concentration diminishes from head to tail. Many turbellarians clone themselves by transverse or longitudinal division, and others, especially acoels, reproduce by budding.

All turbellarians are hermaphrodites, in other words have both female and male reproductive cells, and fertilize eggs internally by copulation. Some of the larger aquatic species mate by penis fencing, a duel in which each tries to impregnate the other, and the loser adopts the female role of developing the eggs. In most species "miniature adults" emerge when the eggs hatch, but a few large species produce plankton-like larvae.

Trematoda

These parasites' name refers to the cavity in their holdfasts (Greek τρῆμα, hole), which resemble suckers and anchor them within their hosts. The skin of all species is a syncitium, a layer of cells that shares a single external membrane. Trematodes are divided into two groups, Digenea and Aspidogastrea (also known as Aspodibothrea).

Digenea

These are often called flukes as most have flat rhomboid shapes like that of a flounder (Old English *flóc*). They have about 11,000 species, more than all other platyhelminthes combined, and second only to roundworms among parasites on metazoans. Adults usually have two holdfasts, a ring round the mouth and a larger sucker midway along what would be the underside in a free-living flatworm. Although the name "Digeneans" means "two generations", most have very complex lifecycles with up to seven stages, depending on what combinations of environments the early stages encounter – most importantly whether the eggs are deposited on land or in water. The intermediate stages transfer the parasites from one host to another. The definitive host in which adults develop is a land vertebrate, the earliest host of juvenile stages is usually a snail that may live on land or in water, and in many cases a fish or arthropod is the second host. For example, the adjoining illustration shows the life cycle of the intestinal fluke metagonimus, which hatches in the intestine of a snail; moves to a fish where it penetrates the body and encysts in the flesh; then moves to the small intestine of a land animal that eats the fish raw; and then generates eggs that are excreted and ingested by snails, thereby completing the cycle. Schistosomes, which cause the devastating tropical disease bilharzia, belong to this group.

Adults range between 0.2 mm (0.0079 in) and 6 mm (0.24 in) in length. Individual adult digeneans are of a single sex, and in some species slender females live in enclosed grooves that run along the bodies of the males, and partially emerge to lay eggs. In all species the adults have complex reproductive systems and can produce between 10,000 and 100,000 times as many eggs as a free-living flatworm. In addition the intermediate stages that live in snails reproduce asexually.

Adults of different species infest different parts of the definitive host, for example the intestine, lungs, large blood vessels, and liver. The adults use a relatively large, muscular pharynx to ingest cells, cell fragments, mucus, body fluids or blood. In both the adults and the stages that life in snails, the external syncytium absorbs dissolved nutrients from the host. Adult digeneans can live without oxygen for long periods.

Aspidogastrea

Members of this small group have either a single divided sucker or a row of suckers that cover the underside. They infest the guts of bony or cartilaginous fish and of turtles, and the body cavities of marine and freshwater bivalves and gastropods. Their eggs produce ciliated swimming larvae, and the life-cycle has one or two hosts.

Cercomeromorpha

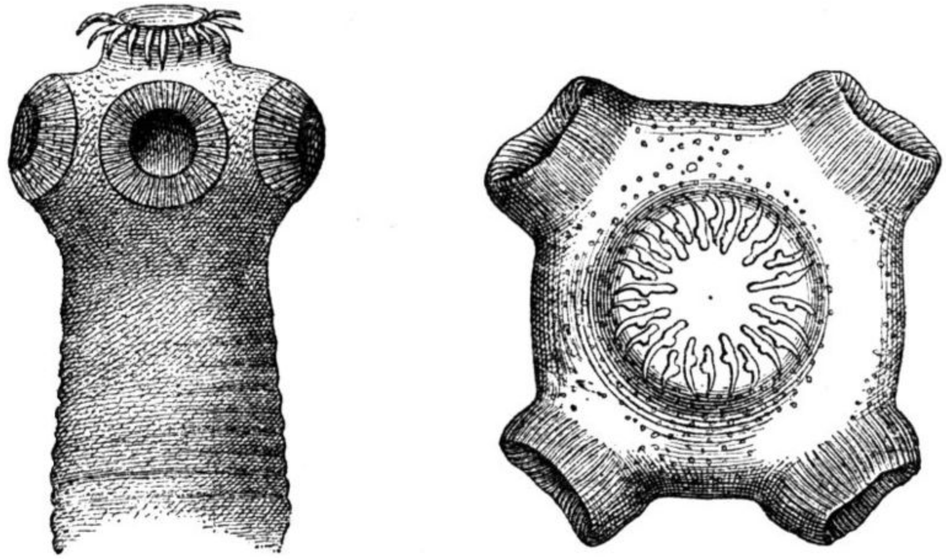
This group of parasites attach themselves to the host by means of disks that bear crescent-shaped hooks. They are divided into Monogea and Cestoda.

Monogenea

There are about 1,100 species of monogeans. Most are external parasites that require particular host species, mainly fish but in some cases amphibians or aquatic reptiles. However, some are internal parasites. Adult monogeans have large attachment organs at the rear, haptors (Greek ἅπτειν, haptein, means "catch"), which have suckers and hooks. To minimize water-resistance they have flattened bodies. In some species the pharynx secretes enzymes that digest the host's skin, allowing the parasite to feed on blood and cellular debris. Others graze externally on mucus and flakes of the host's skin. The name "Monogenea" is based on the fact that these parasites have only one non-larval generation.

Cestoda

These are often called tapeworms because of their flat, slender but very long bodies – the name "cestode" is derived from the Latin word *cestus*, which means "tape". The adults of all 3,400 cestode species are internal parasites in the organs of vertebrates, including fish, cats, dogs and humans. The head is generally tiny compared to the size of the whole animal, and forms a scolex that attaches the parasite to the lining of the host's gut. The commonest type of scolex has four suckers round the sides and a disk equipped with hooks at the end. However, some species have more complex arrangements, for example *Myzophyllobothrium*'s scolex looks rather like a part-peeled banana, with four sucker-like flaps on the sides and a group of four small suckers on short stalks at the end.



Scolex of the pork tapeworm *Taenia solium*: left from side, right from above

Cestodes have no mouths or guts, and the syncitial skin absorbs nutrients – mainly carbohydrates and amino acids – from the host, and also disguises it chemically to avoid attacks by the host's immune system. Shortage of carbohydrates in the host's diet stunts the growth of the parasites and kills some. Their metabolisms generally use simple but inefficient chemical processes, and the parasites compensate by consuming large amounts of food relative to their size.

In the majority of species, known as eucestodes ("true tapeworms"), the neck produces a chain of segments called proglottids by a process known as strobilation. Hence the most mature proglottids are furthest from the scolex. Adults of *Taenia saginata*, which infests humans, can form proglottid chains over 20 metres (66 ft) long, although 4 metres (13 ft) is more typical. Each proglottid has both male and female reproductive organs. If the host's gut contains two or more adults of the same cestode species, they generally fertilize each other; but proglottids of the same worm can fertilize each other and even fertilize themselves. When the eggs are fully developed, the proglottids separate and are excreted by the host. The eucestode life-cycle is less complex than that of digeneans, but varies depending on the species. For example:

- Adults of *Diphyllobothrium* infest fish, and the juveniles use copepod crustaceans as intermediate hosts. Excreted proglottids release their eggs into the water, and the eggs hatch into ciliated swimming larvae. If a larva is swallowed by a copepod, it sheds the cilia and the skin becomes a syncitium and the larvae makes its way into the copepod's hemocoel (internal cavity that is the main part of the circulatory system) and attached itself with three small hooks. If the copepod is eaten by a fish, the larva metamorphoses into a small, unsegmented tapeworm, drills through to the gut and becomes an adult.
- Various species of *Taenia* infest the guts of humans, cats and dogs. The juveniles use herbivores – for example pigs, cattle and rabbits – as intermediate hosts.

> Excreted proglottids release eggs that stick to grass leaves and hatch after being swallowed by a herbivore. The larva makes its way to the herbivore's muscles and metamorphoses into an oval worm about 10 millimetres (0.39 in) long, with a scolex that is kept inside. When the definitive host eats infested and raw or undercooked meat from an intermediate host, the worm's scolex pops out and attaches itself to the gut, and the adult tapeworm develops.

A smaller group, known as Cestodaria, have no scolex, do not produce proglottids, and have body shapes like those of diageneans. Cestodarians parasitize fish and turtles.

Classification and evolutionary relationships

The oldest known platyhelminth specimen is a fossil preserved in Eocene age baltic amber and placed in the monotypic species *Palaeosoma balticus*, while the oldest subfossil specimens are schistosome eggs discovered in ancient Egyptian mummies. The Platyhelminthes have very few synapomorphies, distinguishing features that all Platyhelminthes and no other animals have. This makes it difficult to work out both their relationships with other groups of animals and the relationships between different groups that are described as members of the Platyhelminthes.

The "traditional" view before the 1990s was that Platyhelminthes formed the sister group to all the other bilaterians, which include for example arthropods, molluscs, annelids and chordates. Since then molecular phylogenetics, which aims to work out evolutionary "family trees" by comparing different organisms' biochemicals such as DNA, RNA and proteins, has radically changed scientists' view of evolutionary relationships between animals. Detailed morphological analyses of anatomical features in the mid-1980s and molecular phylogenetics analyses since 2000 using different sections of DNA agree that Acoelomorpha, consisting of Acoela (traditionally regarded as very simple "turbellarians") and Nemertodermatida (another small group previously classified as "turbellarians") are the sister group to all other bilaterians, including the rest of the "Platyhelminthes". However a study in 2007 concluded that Acoela and Nemertodermatida were two distinct groups of bilaterians, although it agreed that both are more closely related to cnidarians (jellyfish, etc.) than other bilaterians are.

Xenoturbella, a bilaterian with whose only well-defined organ is a statocyst, was originally classified as a "primitive turbellarian". However it has recently been re-classified as a deuterostome.

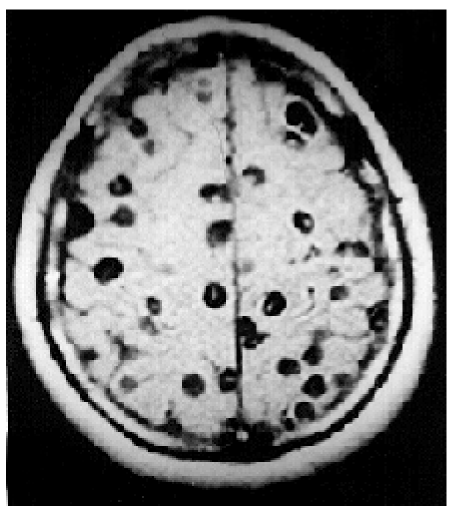
The "Platyhelminthes" excluding "Acoelomorpha" contain two main groups, Catenulida and Rhabditophora, and it is generally agreed that both are monophyletic, in other words each contains all and only the descendants of an ancestor which is a member of the same group. Early molecular phylogenetics analyses of the Catenulida and Rhabditophora left uncertainties about whether these could be combined in a single monophyletic group, but a study in 2008 concluded that they could, and therefore that "Platyhelminthes" could be redefined as Catenulida plus Rhabditophora, excluding the "Acoelomorpha".

Other molecular phylogenetics analyses agree that the redefined "Platyhelminthes" are most closely related to Gastrotricha and that both are part of a grouping known as Platyzoa. It is generally agreed that the Platyzoa are at least closely related to the Lophotrochozoa, a super-phylum that includes molluscs and annelid worms. The majority view is that Platyzoa are part of Lophotrochozoa, but a significant minority of researchers regard Platyzoa as a sister group of Lophotrochozoa.

It has been agreed since 1985 that each of the wholly parasitic platyhelminth groups (Cestoda, Monogenea and Trematoda) is monophyletic, and that together these form a larger monophyletic grouping, the Neodermata, in which the adults of all members have syncitial skins. However there is debate about whether the Cestoda and Monogenea can be combined as an intermediate monophyletic group, the Cercomeromorpha, within the Neodermata. It is generally agreed that the Neodermata are a sub-group a few levels down in the "family tree" of the Rhabditophora. Hence the traditional sub-phylum "Turbellaria" is paraphyletic, since it does not include the Neodermata although these are descendants of a sub-group of "turbellarians".

Interaction with humans

Parasitism



Magnetic resonance image of a patient with neurocysticercosis demonstrating multiple cysticerci within the brain

Cestodes (tapeworms) and digeneans (flukes) cause important diseases in humans and their livestock, and monogeneans can cause serious losses of stocks in fish farms. Schistosomiasis, also known as bilharzia or snail fever, is the second most devastating parasitic disease in tropical countries, behind malaria. The Carter Center estimates that 200 million people in 74 countries are infected with the disease, and half the victims live in Africa. The condition has a low mortality rate, but often is a chronic illness that can damage internal organs. It can impair the growth and cognitive development of children, and increase the risk of bladder cancer in adults. The disease is caused by several flukes of the genus *Schistosoma*, which can bore through human skin. The people most at risk are those who use infected bodies of water for recreation or laundry.

In 2000 an estimated 45 million people were infected with the beef tapeworm *Taenia saginata* and 3 million with the pork tapeworm *Taenia solium*. Infection of the digestive system by adult tapeworms causes abdominal symptoms that are unpleasant but not disabling or life-threatening. However neurocysticercosis resulting from penetration of *T. solium* larvae into the central nervous system is the major cause of acquired epilepsy worldwide. In 2000 about 39 million people were infected with trematodes (flukes) that naturally parasitize fish and crustaceans but can pass to humans who eat raw or lightly cooked sea food. Infection of humans by the broad fish tapeworm *Diphyllobothrium latum*, occasionally causes vitamin B12 deficiency and, in severe cases, megaloblastic anemia.

The threat to humans in developed countries is rising as a result of social trends: the increase in organic farming, which uses manure and sewage sludge rather than artificial fertilizers, and spreads parasites both directly and via the droppings of seagulls which feed on manure and sludge; the increasing popularity of raw or lightly cooked foods; imports of meat, sea food and salad vegetables from high-risk areas; and, as an underlying cause, reduced awareness of parasites compared with other public health issues such as pollution. In less developed countries inadequate sanitation and the use of human feces (night soil) as fertilizer and to enrich fish farm ponds continues to spread parasitic platyhelminthes, and poorly-designed water-supply and irrigation projects have provided additional channels for their spread. People in these countries often cannot afford the cost of fuel required to cook food thoroughly enough to kill parasites. Controlling parasites that infect humans and livestock has become more difficult as many species have become resistant to drugs that used to be effective, mainly for killing juveniles in meat.

Pests

There is concern about the proliferation in North-west Europe, including the British Isles, of the New Zealand planarian *Arthurdendyus triangulatus*, which preys on earthworms. *A. triangulatus* is thought to have reached Europe in containers of plants imported by botanical gardens.

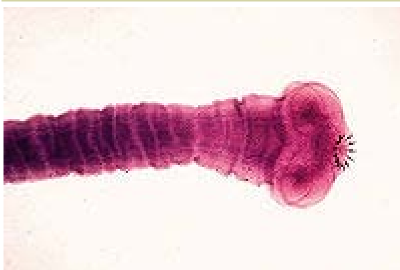
Benefits

In Hawaii the planarian *Endeavouria septemlineata* has been used to control the imported giant African snail *Achatina fulica*, which was displacing native snails, and *Platydemus manokwari*, another planarian, has been used for the same purpose in Philippines, Indonesia, New Guinea and Guam. Although *A. fulica* has declined sharply in Hawaii, there are doubts about how much *E. septemlineata* contributed to this. On the other hand *P. manokwari* is given credit for severely reducing and in places exterminating *A. fulica* – achieving much greater success than most biological pest control programs, which generally aim for a low, stable population of the pest species. The ability of planarians to take different kinds of prey and to resist starvation may account for its ability to decimate *A. fulica*. However these abilities have raised concerns that planarians may themselves become a serious threat to native snails.

Chapter- 8

Cestoda

Cestoda



Scolex of *Taenia solium*

Scientific classification	
Kingdom:	Animalia
Phylum:	Platyhelminthes
Class:	**Cestoda**

Subclasses and orders

Cestodaria
Amphilinidea
Gyrocotylidea
Eucestoda
Aporidea
Caryophyllidea
Cyclophyllidea
Diphyllidea
Lecanicephalidea
Litobothridea
Nippotaeniidea
Proteocephalidea
Pseudophyllidea
Spathebothriidea
Tetraphyllidea
Trypanorhyncha

Cestoda (**Cestoidea**) is the name given to a class of parasitic flatworms, commonly called **tapeworms**, of the phylum Platyhelminthes. Its members live in the digestive tract of vertebrates as adults, and often in the bodies of various animals as juveniles. Over a thousand species have been described, and all vertebrate species can be parasitised by at least one species of tapeworm. Several species parasitise humans after being consumed in underprepared meat such as pork (*T. solium*), beef (*T. saginata*), fish (*Diphyllobothrium* spp.), in food prepared in conditions of poor hygiene (*Hymenolepis* spp. or *Echinococcus* spp.).

T. saginata, the beef tapeworm, can grow up to 12 m (40 ft); other species may grow to over 30 m (100 ft).

Anatomy

Scolex

The worm's *scolex* ("head") attaches to the intestine of the definitive host. In some species, the scolex is dominated by bothria (tentacles), which are sometimes called "sucking grooves", and function like suction cups. Other species have hooks and suckers that aid in attachment. Cyclophyllid cestodes can be identified by the presence of four suckers on their scolex.

While the scolex is often the most distinctive part of an adult tapeworm, it is often unnoticed in a clinical setting as it is inside the patient. Thus, identifying eggs and proglottids in feces is important.

Body systems

The main nerve centre of a cestode is a cerebral ganglion in its scolex. Motor and sensory innervation depends on the number and complexity of the scolex. Smaller nerves emanate from the commissures to supply the general body muscular and sensory ending. The cirrus and vagina are innervated, and sensory endings around the genital pore are more plentiful than other areas. Sensory function includes both tactoreception and chemoreception. Some nerves are only temporary. These are in the proglottids, and stop working with a detach.

Proglottids

The body is composed of successive segments (*proglottids*). The sum of the proglottids is called a strobila, which is thin, and resembles a strip of tape. From this is derived the common name "tapeworm". Like some other flatworms, cestodes use flame cells (protonephridia), located in the proglottids, for excretion. Mature proglottids are released from the tapeworm's posterior end and leave the host in feces.

Because each proglottid contains the male and female reproductive structures, they can reproduce independently. Some biologists have suggested that each should be considered a single organism, and that the tapeworm is actually a colony of proglottids.

The layout of proglottids comes in two forms, craspedote, meaning proglottids are overlapped by the previous proglottid, and acraspedote which indicates a non-overlapping conjoined proglottid.

Once anchored to the host's intestinal wall, the tapeworm absorbs nutrients through its skin as the food being digested by the host flows past it and it begins to grow a long tail, with each segment containing an independent digestive system and reproductive tract. Older segments are pushed toward the tip of the tail as new segments are produced by the neckpiece. By the time a segment has reached the end of the tail, only the reproductive tract is left. It then drops off, carrying the tapeworm eggs to the next host.

Reproduction and life cycle

True tapeworms are exclusively hermaphrodites; they have both male and female reproductive systems in their bodies. The reproductive system includes one or many testes, cirrus, vas deferens and seminal vesicle as male organs, and a single lobed or unlobed ovary with the connecting oviduct and uterus as female organs. There is a common external opening for both male and female reproductive systems, known as genital pore, which is situated at the surface opening of the cup-shaped atrium. Even though they are sexually hermaphroditic, self-fertilization is a rare phenomenon. In order to permit hybridization, cross-fertilization between two individuals is often practiced for reproduction. During copulation, the cirrus of one individual connects with that of the other through the genital pore, and then exchange their spermatozoa.

The life cycle of tapeworms is simple in the sense that there are no asexual phases as in other flatworms, but complicated in that at least one intermediate host is required as well as the definitive host. This life cycle pattern has been a crucial criterion for assessing evolution among Platyhelminthes. Many tapeworms have a two-phase life cycle with two types of host. The adult *Taenia saginata* lives in the gut of a primate such as a human. Proglottids leave the body through the anus and fall onto the ground, where they may be eaten with grass by animals such as cows. In the cow's body, the juvenile form migrates and establishes as a cyst in body tissues such as muscles, rather than the gut; they cause more damage to this host than the intestinal form to its host. The parasite completes its life cycle when the grass-eater is eaten by a compatible carnivore—possibly a human with a preference for raw meat—in whose gut the adult *Taenia* establishes itself.

Chapter- 9

Monogenea and Trematoda

Monogenea

Monogenea	

Dermophthirius, a microbothriidmonogenean parasitic on elasmobranchs

Scientific classification	
Kingdom:	Animalia
Phylum:	Platyhelminthes
Class:	**Monogenea** Carus, 1863
Subclasses	

Monopisthocotylea
Polyopisthocotylea

Monogenea (adj. monogenean) are a group of largely ectoparasitic members of the flatworm phylum Platyhelminthes, class **Monogenea**.

Characteristics

Monogenea are small parasitic flatworms mainly found on skin or gills of fish. They are rarely longer than about 2 cm. A few species infecting certain marine fish are larger and marine forms are generally larger than those found on fresh water hosts. Monogeneans lack respiratory, skeletal and circulatory systems and have no or weakly-developed oral suckers.. Monogenea attach to hosts using hooks, clamps and a variety of other specialized structures. They are often capable of dramatically elongating and shortening as they move. Biologists need to ensure that specimens are completely relaxed before measurements are taken.

Like all ectoparasites monogeneans have well developed attachment structures. The anterior structures are collectively termed the **prohaptor**, while the posterior ones are collectively termed the **opisthaptor**. The posterior opishaptor with its hooks, anchors, clamps etc. is typically the major attachment organ.

Like other flatworms, Monogenea have no true body cavity (coelom). They have a simple digestive system consisting of a mouth opening with a muscular pharynx and an intestine with no terminal opening (anus). Generally, they also are hermaphroditic with functional reproductive organs of both sexes occurring in one individual. Most species are oviparous but a few are viviparous. Monogenea are Platyhelminthes and therefore are among the lowest invertebrates to possess three embryonic germ layers—endoderm, mesoderm, and ectoderm. In addition, they have a head region that contains concentrated sense organs and nervous tissue (brain).

Systematics and Evolution

The ancestors of Monogenea were probably free-living flatworms similar to modern Turbellaria. According to the more widely accepted view, "rhabdocoel turbellarians gave rise to monogeneans; these, in turn, gave rise to digeneans, from which the cestodes were derived. Another view is that the rhabdocoel ancestor gave rise to two lines; one gave rise to monogeneans, who gave rise to digeneans, and the other line gave rise to cestodes".

There are about 50 families and thousands of described species.

Some parasitologists divide Monogenea into two (or three) subclasses based on the complexity of their haptor: Monopisthocotylea have one main part to the haptor, often with hooks or a large attachment disc, whereas Polyopisthocotylea have multiple parts to the haptor, typically clamps. These groups are also known as Polyonchoinea and Heteronchoinea, respectively. Polyopisthocotyleans are almost exclusively gill-dwelling blood feeders, whereas Monopisthocotyleans may live on the gills, skin and fins.

Monopistocotylea include:

- Genus *Gyrodactylus,* which has no eyespots and is viviparous.
- Genus *Dactylogyrus,* which has four eyespots and is oviparous. This is one of the largest metazoan genera, with at least 970 species.
- Genus *Neobenedenia,* which is much larger and lives on the skin of many tropical marine species, causing problematic infections in marine aquaria.

All of which can cause epizootics in freshwater fish when raised in aquaculture.

Polyopisthocotylea include:

- Genus *Diclidophora,* which is primarily found in marine fish and primitive freshwater fish like sturgeons and paddlefish.

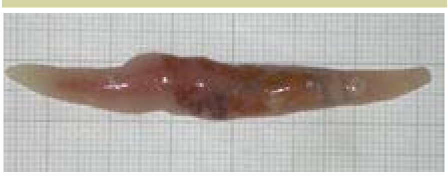
- Genus *Protopolystoma,* found in aquatic clawed toads (*Xenopus* species).

Ecology and life cycle

Monogeneans possess the simplest life cycle among the parasitic platyhelminths. They have no intermediate hosts and are ectoparasitic on fish (seldom in the urinary bladder and rectum of cold-blooded vertebrates). Although they are hermaphrodites, the male reproductive system becomes functional before the female part. The eggs hatch releasing a heavily ciliated larval stage known as an *oncomiracidium*. The *oncomiracidium* has numerous posterior hooks and is generally the life stage responsible for transmission from host to host.
No known monogeneans infect birds, but one (*Oculotrema hippopotami*) infects mammals, parasitizing the eye of the hippopotamus.

Trematoda

Trematoda



Botulus microporus, a giant digenean parasite from the intestine of a lancetfish

Scientific classification

Kingdom:	Animalia
Phylum:	Platyhelminthes
Class:	**Trematoda** Rudolphi, 1808

Subclasses
Aspidogastrea
Digenea

Trematoda is a class within the phylum Platyhelminthes that contains two groups of parasitic flatworms, commonly referred to as "flukes".

Taxonomy and biodiversity

The trematodes or flukes are estimated to include 18,000 to 24,000 species, and are divided into two subclasses. Nearly all trematodes are parasites of mollusks and vertebrates. The smaller Aspidogastrea, comprising about 100 species, are obligate parasites of mollusks and may also infect turtles and fish, including cartilaginous fish. The Digenea, which constitute the majority of trematode diversity, are obligate parasites of both mollusks and vertebrates, but rarely occur in cartilaginous fish.

Formerly the Monogenea were included in Trematoda on the basis that these worms are also vermiform parasites, but modern phylogenetic studies have raised this group to the status of a sister class within the Platyhelminthes, along with the Cestoda.

Anatomy

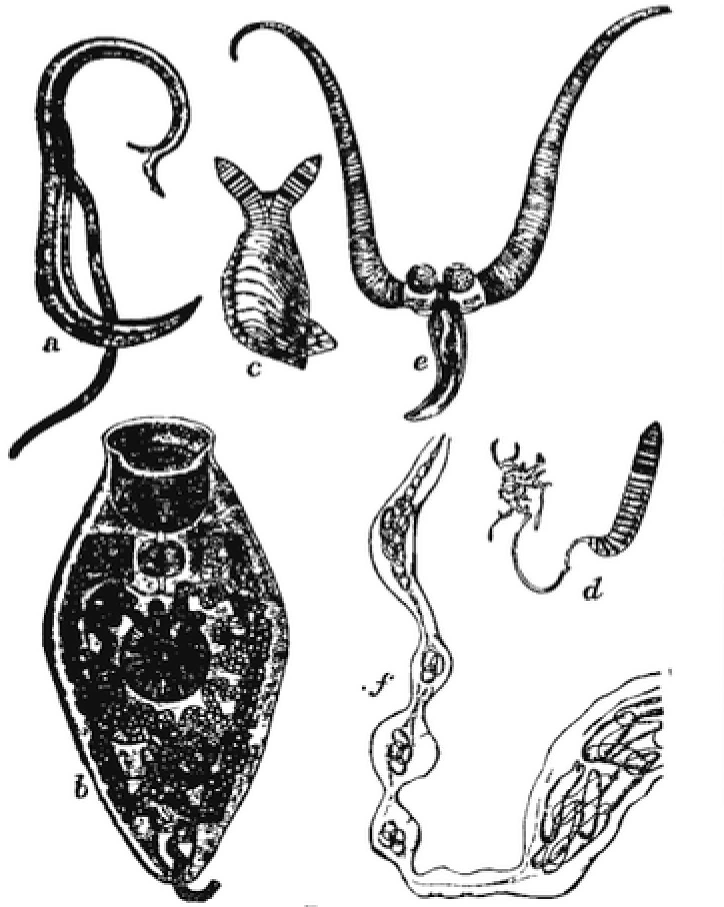


FIG. 9.

A, *Schistostomum (Bilharzia) haematobium*, the thin female in the gynaecophoric canal of the stouter male. (after Leuckart).
B, *Distomum macrostomum*, showing the digestive and the greater part of the genital apparatus with the cirrus protruded.
C, Snail (*Succinea*), the tentacles deformed by *Leucochloridium* (Natural size)
D, *Leucochloridium* removed from the tentacle (Natural size, after Zeller)
E, *Bucephalus polymorphus*. (Highly magnified; after Ziegler)
F, Portion of a sporocyst containing *Bucephali* in process of development. (× about 50 after Lacaze Duthiers)

Varied trematodes

Trematodes are flattened oval or worm-like animals, usually no more than a few centimetres in length, although species as small as 1 millimetre (0.039 in) and as large as 7 metres (23 ft) are known. Their most distinctive external feature is the presence of two suckers, one close to the mouth, and the other on the underside of the animal.

The body surface of trematodes comprises a tough syncitial tegument, which helps protect against digestive enzymes in those species that inhabit the gut of larger animals. It is also the surface of gas exchange; there are no respiratory organs.

The mouth is located at the forward end of the animal, and opens into a muscular, pumping pharynx. The pharynx connects, via a short oesophagus, to one or two blind-ending caeca, which occupy most of the length of the body. In some species, the caeca are themselves branched. As in other flatworms, there is no anus, and waste material must be egested through the mouth.

Although the excretion of nitrogenous waste occurs mostly through the tegument, trematodes do possess an excretory system, which is instead mainly concerned with osmoregulation. This consists of two or more protonephridia, with those on each side of the body opening into a collecting duct. The two collecting ducts typically meet up at a single bladder, opening to the exterior through one or two pores near the posterior end of the animal.

The brain consists of a pair of ganglia in the head region, from which two or three pairs of nerve cords run down the length of the body. The nerve cords running along the ventral surface are always the largest, while the dorsal cords are present only in the Aspidogastrea. Trematodes generally lack any specialised sense organs, although some ectoparasitic species do possess one or two pairs of simple ocelli.

Reproductive system

Most trematodes are simultaneous hermaphrodites, having both male and female organs. There are usually two testes, with sperm ducts that join together on the underside of the front half of the animal. This final part of the male system varies considerably in structure between species, but may include sperm storage sacs and accessory glands, in addition to the copulatory organ, which is either eversible, and termed a *cirrus*, or non-eversible, and termed a penis.

There is usually only a single ovary, which is connected, via a pair of ducts to a number of *vitelline glands* on either side of the body, that produce yolk cells. Eggs pass from the ovary into a glandular receptacle called the *ootype* or *Mehlis' gland*, where fertilization occurs. This opens into an elongated uterus that opens to the exterior close to the male opening. The ovary is often also associated with a storage sac for sperm, and a copulatory duct termed *Laurer's canal*.

Life cycles

Almost all trematodes infect mollusks as the first host in the life cycle, and most have a complex life cycle involving other hosts. Most trematodes are monoecious and alternately reproduce sexually and asexually. The two main exceptions to this are the Aspidogastrea, which have no asexual reproduction, and the schistosomes, which are dioecious.

In the definitive host, in which sexual reproduction occurs, eggs are commonly shed along with host feces. Eggs shed in water release free-swimming larval forms that are infective to the intermediate host, in which asexual reproduction occurs.

A species that exemplifies the remarkable life history of the trematodes is the bird fluke, *Leucochloridium paradoxum*. The definitive hosts, in which the parasite multiplies, are various woodland birds, while the hosts in which the parasite grows (intermediate host) are various species of snail. The adult parasite in the bird's gut produces eggs and these eventually end up on the ground in the bird's faeces. Some very fortunate eggs get swallowed by a snail and here they hatch into tiny, transparent larva (miracidium). These larvae grow and take on a sac-like appearance. This stage is known as the sporocyst and it forms a central body in the snail's digestive gland that extends into a brood sac in the snail's head, muscular foot and eye-stalks. It is in the central body of the sporocyst where the parasite replicates itself, producing lots of tiny embryos (redia). These embryos move to the brood sac and mature into cercaria.

Infections

Human infections are most common in Asia, Africa, South America, or the Middle East. However, trematodes can be found anywhere that human waste is used as fertilizer.

Etymology

Trematodes are commonly referred to as *flukes*. This term can be traced back to the Old English name for flounder, and refers to the flattened, rhomboidal shape of the worms.

The flukes can be classified into two groups, on the basis of the system which they infect in the vertebrate host.

- **Tissue flukes** infect the bile ducts, lungs, or other biological tissues. This group includes the lung fluke, *Paragonimus westermani*, and the liver flukes, *Clonorchis sinensis* and *Fasciola hepatica*.
- **Blood flukes** inhabit the blood in some stages of their life cycle. *Blood flukes include species of the genus* Schistosoma*.*

They may also be classified according to the environment in which they are found. For instance, **pond flukes** infect fish in ponds.

Chapter- 10

Turbellaria

Turbellaria	
	
A marine species *Pseudobiceros bedfordi* (Bedford's Flatworm), a member of the Polycladida	
Scientific classification	
Kingdom:	Animalia
Phylum:	Platyhelminthes
Class:	**Turbellaria** Ehrenberg, 1831
Orders	
Catenulida Haplopharyngida Lecithoepitheliata Macrostomida Nemertodermata Polycladida Prolecithophora Rhabdocoela Seriata Temnocephalida Tricladida	

The **Turbellaria** are one of the traditional sub-divisions of the phylum Platyhelminthes (flatworms), and include all the sub-groups that are not exclusively parasitic. There are about 4,500 species, which range from 1 mm (0.039 in) to 600 mm (24 in) in length. All the larger forms are flat with ribbon-like or leaf-like shapes, since their lack of respiratory and circulatory systems means that they have to rely on diffusion for internal transport of metabolites. However, many of the smaller forms are round in cross section. Most are predators, and all live in water or in moist terrestrial environments. Most forms reproduce sexually and with few exceptions all are simultaneous hermaphrodites.

The Acoelomorpha and the genus *Xenoturbella* were formerly included in the Turbellaria, but are no longer regarded as Platyhelminthes. All the exclusively parasitic Platyhelminthes form a monophyletic group Neodermata, and it is agreed that these are descended from one small sub-group within the free-living Platyhelminthes. Hence the "Turbellaria" as traditionally defined are paraphyletic.

Description

Traditional classifications divide the Platyhelminthes into four groups: Turbellaria and the wholly parasitic Trematoda, Monogenea and Cestoda. In this classification the Turbellaria include the Acoelomorpha (Acoela and Nemertodermatida). The name "Turbellaria" refers to the "whirlpools" of microscopic particles created close the skins of aquatic species by the movement of their cilia.

Features common to all Platyhelminthes

Platyhelminthes are bilaterally symmetrical animals, in other words their left and right sides are mirror images of each other; this also implies that they have distinct top and bottom surfaces and distinct head and tail ends. Like other bilaterians they have three main cell layers (it is triploblastic), while the radially symmetrical cnidarians and ctenophore have only two cell layers. Unlike most other bilaterians, platyhelminthes have no internal body cavity and are therefore described as acoelomates. They also lack specialized circulatory and respiratory organs

The lack of circulatory and respiratory organs limits platyhelminths to sizes and shapes that enable oxygen to reach and carbon dioxide to leave all parts of their bodies by simple diffusion. Hence many are microscopic and the large species have flat ribbon-like or leaf-like shapes. The guts of large species have many branches, so that nutrients can diffuse to all parts of the body. Respiration through the whole surface of the body makes platyhelminthes vulnerable to fluid loss, and restricts them to environments where dehydration is unlikely: sea and freshwater; moist terrestrial environments such as leaf litter or between grains of soil; and as parasites within other animals.

The space between the skin and gut is filled with mesenchyme, a connective tissue that is made of cells and reinforced by collagen fibers that act as a type of skeleton, providing attachment points for muscles. The mesenchyme contains all the internal organs and allows the passage of oxygen, nutrients and waste products. It consists of two main types of cell: fixed cells, some of which have fluid-filled vacuoles; and stem cells, which can transform into any other type of cell, and are used in regenerating tissues after injury or asexual reproduction.

Most platyhelminths have no anus and regurgitate undigested material through the mouth. However some long species have an anus and some with complex branched guts have more than one anus, since excretion only through the mouth would be difficult for them. The gut is lined with a single layer of endodermal cells which absorb and digest food. Some species break up and soften food first by secreting enzymes in the gut or the pharynx (throat).

All animals need to keep the concentration of dissolved substances in their body fluids at a fairly constant level. Internal parasites and free-living marine animals live in environments that have high concentrations of dissolved material, and generally let their tissues have the same level of concentration as the environment, while freshwater animals need to prevent their body fluids from becoming too dilute. Despite this difference in environments, most platyhelminths use the same system to control the level of concentration in their body fluids. Flame cells, so called because the beating of their flagella looks like a flickering candle flame, extract from the mesenchyme water that contains wastes and some re-usable material, and drive it into networks of tube cells which are lined with flagella and microvilli. The tube cells' flagella drive the water towards exits called nephridiopores, while their microvilli re-absorb re-usable materials and as much water as is needed to keep the body fluids at the right level of concentration. These combinations of flame cells and tubule cells are called protonephredia.

In all platyhelminths the nervous system is concentrated at the head end. Most species have rings of ganglia in the head and main nerve trunks running along their bodies.

Planarians are famous for their ability to regenerate if divided by cuts across their bodies. Experiments show that, in fragments that do not already have a head, a new head grows most quickly on those that were closest to the original head. This suggests that the growth of a head is controlled by a chemical whose concentration diminishes from head to tail.

Features specific to Turbelleria

The turbellarian *Pseudoceros dimidiatus*

Two turbellarians mating by penis fencing. Each has two penises, the white spikes on the undersides of their heads.

These have about 4,500 species, are mostly free-living, and range from 1 mm (0.039 in) to 600 mm (24 in) in length. Most are predators or scavengers, and terrestrial species are mostly nocturnal and live in shaded humid locations such as leaf litter or rotting wood. However some are symbiotes of other animals such as crustaceans, and some are parasites. Free-living turbellarians are mostly black, brown or gray, but some larger ones are brightly colored.

Turbellarians have no cuticle (external layer of organic but non-cellular material). In a few species the skin is a syncitium, a collection of cells with multiple nuclei and a single shared external membrane. However the skins of most species consist of a single layer of cells, each of which generally has multiple cilia (small mobile "hairs"), although in some large species the upper surface has no cilia. These skins are also covered with microvilli between the cilia. They have many glands, usually submerged in the muscle layers below the skin and connect to the surface by pores through which they secrete mucus, adhesives and other substances.

Small aquatic species use the cilia for locomotion, while larger ones use muscular movements of the whole body or of a specialized sole to creep or swim. Some are capable of burrowing, anchoring their rear ends at the bottom of the burrow and then stretching the head up to feed and then pulling it back down for safety. Some terrestrial species throw a thread of mucus which they use as a rope to climb from one leaf to another.

Some Turbelleria have spicular skeletons, giving the appearance of annulations.

Diet and digestion

The acoel *Convoluta roscoffensis* swallows cells of the green alga *Tetraselmis* and does not feed as an adult, presumably relying on the alge to provide nourishment as endosymbionts. In other acoels the gut is lined by a syncitium. These and some other turbellarians have a simple pharynx lined with cilia and generally feed by using cilia to sweep food particles and small prey into their mouths, which are usually in the middle of the underside.

Most other turbellarians are carnivorous, either preying on small invertebrates or protozoans, or scavenging on dead animals. A few feed on larger animals, including oysters and barnacles, which some, such as *Bdelloura*, are commensal on the gills of horseshoe crabs. These turbellarians usually have an eversible pharynx, in other words, one that can be extended by being turned inside-out, and the mouths of different species can be anywhere along the underside. The freshwater species *Microstomum caudatum* can open its mouth almost as wide as its body is long, to swallow prey as large as itself.

The intestine is lined by phagocytic cells which capture food particles that have already been partially digested by enzymes in the gut. Digestion is then completed within the phagocytic cells and the nutrients diffuse through the body.

Nervous system

Concentration of nervous tissue in the head region is least marked in the acoels, which have nerve nets rather like those of cnidarians and ctenophores, but densest around the head. In other turbellarians, a distinct brain is present, albeit relatively simple in structure. From the brain one to four pairs of nerve cords run along the length the body, with numerous smaller nerves branching off. The ventral pair of nerve cords are typically the largest, and, in many species, are the only ones present. Unlike more complex animals, such as annelids, there are no ganglia on the nerve cords, other than those forming the brain.

Most turbellarians have pigment-cup ocelli ("little eyes"), one pair in most species, but two or even three pairs in some. A few large species have many eyes in clusters over the brain, mounted on tentacles, or spaced uniformly round the edge of the body. The ocelli can only distinguish the direction from which light is coming and enable the animals to avoid it.

A few groups – mainly catenulids, acoelomorphs and seriates – have statocysts, fluid-filled chambers containing a small solid particle or, in a few groups, two. These statocysts are thought to be balance and acceleration sensors, as that is the function they perform in cnidarian medusae and in ctenophores. However turbellarian statocysts have no sensory cilia, and it is unknown how they sense the movements and positions of the solid particles.

Most species have ciliated touch-sensor cells scattered over their bodies, especially on tentacles and around the edges. Specialized cells in pits or grooves on the head are probably smell-sensors.

Reproduction

Many turbellarians clone themselves by tranverse or longitudinal division, and others, especially acoels, reproduce by budding. The planarian *Dugesia* is a well-known representative of class Turbellaria.

All turbellarians are simultaneous hermaphrodites, having both female and male reproductive cells, and fertilize eggs internally by copulation. Some of the larger aquatic species mate by penis fencing, a duel in which each tries to impregnate the other, and the loser adopts the female role of developing the eggs.

Although the acoels have no distinct gonads at all, in other turbellarians there are one or more pairs of both testes and ovaries. Sperm ducts run from the testes, through bulb-like seminal vesicles, to the muscular penis. In many species, this basic plan is considerably complicated by the addition of accessory glands or other structures. The penis lies inside a cavity, and can be everted through an opening on the posterior underside of the animal. It often, although not always, possesses a sharp stylet. Unusually among animals, in most species, the sperm cells have two tails, rather than one.

In most platyhelminths, the ovaries are divided into two regions, one producing the ova, and the other producing specialised yolk cells to nourish the developing embryo. While many turbellarians have this arrangement, some are apparently more primitive. In these latter species, the ovaries are undivided, and the egg cells contain yolk within their own cytoplasm, as is the case in most other animals. In either arrangement, the ovaries possess oviducts that run to a bursa for storing sperm. The bursa is in turn connected to the vagina, which opens in front of the penis. In some cases, there also be other structures for sperm storage, in addition to the bursa, or even a uterus for storage of ripe eggs.

In most species "miniature adults" emerge when the eggs hatch, but a few large species produce plankton-like larvae.

Classification and evolutionary relationships

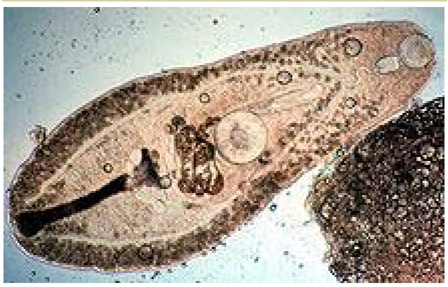
Detailed morphological analyses of anatomical features in the mid-1980s and molecular phylogenetics analyses since 2000 using different sections of DNA agree that Acoelomorpha, consisting of Acoela (traditionally regarded as very simple "turbellarians") and Nemertodermatida (another small group previously classified as "turbellarians") are the sister group to all other bilaterians, including the rest of the "Platyhelminthes".

The "Platyhelminthes" excluding "Acoelomorpha" contain two main groups, Catenulida and Rhabditophora, and it is generally agreed that both are monophyletic, in other words each contains all and only the descendants of an ancestor which is a member of the same group. Early molecular phylogenetics analyses of the Catenulida and Rhabditophora left uncertainties about whether these could be combined in a single monophyletic group, but a study in 2008 concluded that they could, and therefore that "Platyhelminthes" could be redefined as Catenulida plus Rhabditophora, excluding the "Acoelomorpha".

It has been agreed since 1985 that each of the wholly parasitic platyhelminth groups (Cestoda, Monogenea and Trematoda) is monophyletic, and that together these form a larger monophyletic grouping, the Neodermata, in which the adults of all members have syncitial skins. It is also generally agreed that the Neodermata are a relatively small sub-group a few levels down in the "family tree" of the Rhabditophora. Hence the traditional sub-phylum "Turbellaria" is paraphyletic, since it does not include the Neodermata although these are descendants of a sub-group of "turbellarians".

Chapter- 11

Digenea

Digenea	
	
Helicometra sp. (Plagiorchiida: Opecoelidae) from the intestine of a Flame Cardinal fish	
Scientific classification	
Kingdom:	Animalia
Phylum:	Platyhelminthes
Class:	Trematoda
Subclass:	**Digenea** Carus, 1863
Orders	
Azygiida Echinostomida Opisthorchiida Plagiorchiida Strigeidida	

Digenea (Gr. *Dis* - double, *Genos* - race) is a subclass within the Platyhelminthes consisting of parasitic flatworms with a syncytial tegument and, usually, two suckers, one ventral and one oral. Adults are particularly common in the digestive tract, but occur throughout the organ systems of all classes of vertebrates. Once thought to be related to the Monogenea, it is now recognised that they are closest to the Aspidogastrea and that the Monogenea are more closely allied with the Cestoda. Around 6,000 species have been described to date.

Morphology

Key features

Characteristic features of the digenea include a syncitial tegument; that is, a tegument where the junctions between cells are broken down and a single continuous cytoplasm surrounds the entire animal. A similar tegument is found in other members of the Neodermata; a group of platyhelminths comprising the Digenea, Aspidogastrea, Monogenea and Cestoda. Digeneans possess a vermiform, unsegmented body-plan and have a solid parenchyma with no body cavity, as in all platyhelminths.

There are typically two suckers, an anterior oral sucker surrounding the mouth, and a ventral sucker sometimes termed the *acetabulum*, on the ventral surface. The oral sucker surrounds the mouth, while the ventral sucker is a blind muscular organ with no connection to any internal structure.

Monostome is a term used to describe worms with one sucker (oral). Flukes with an oral sucker and an acetabulum at the posterior end of the body are called *Amphistomes*. *Distomes* are flukes with an oral sucker and a ventral sucker, but the ventral sucker if somewhere other than posterior. These terms are common in older literature, when they were thought to reflect systematic relationships within the groups. They have fallen out of use in modern digenean taxonomy.

Reproductive system

The vast majority of digeneans is hermaphroditic. This is likely to be an adaptation to low abundance within hosts, allowing the life cycle to continue when only one individual successfully infects the final host. Fertilisation is internal, with sperm being transferred via the cirrus to the Laurer's Canal or genital aperture. A key group of digeneans which are dioecious are the schistosomes. Asexual reproduction in the first larval stage is ubiquitous.

While the sexual formation of the digenean eggs and asexual reproduction in the first larval stage (miracidium) is widely reported, the developmental biology of the asexual stages remains a problem. Electron microscopic studies have shown that the light microscopically visible germ balls consist of mitotically dividing cells which give rise to embryos and to a line of new germ cells that become included in these embryonic stages. Since the absence of meiotic processes is not proven, the exact definition remains doubtful.

Male organs

Protandry is the general rule among the Digenea. Usually two testes are present, but some flukes can have more than 100. Also present are vasa efferentia, a vas deferens, seminal vesicle, ejaculatory duct and a cirrus (analogous to a penis) usually (but not always) enclosed in a cirrus sac. The cirrus may or may not be covered in proteinaceous spines. The exact conformation of these organs within the male terminal genitalia is taxonomically important at the familial and generic levels.

Female organs

Usually there is a single ovary with an oviduct, a seminal receptacle, a pair of vitelline glands (involved in yolk and egg-shell production) with ducts, the ootype (a chamber where eggs are formed), a complex collection of glands cells called *Mehlis' gland*, which is believed to lubricate the uterus for egg passage.

In addition, some digeneans possess a canal called Laurer's Canal, which leads from the oviduct to the dorsal surface of the body. The function of this canal is debated, but it may be used for insemination in some species or for disposal of waste products from reproduction in other species. Most trematodes possess an ovicapt, an enlarged portion of the oviduct where it joins the ovary. It probably controls the release of ova and spaces out their descent down the uterus.

The uterus typically opens into a common genital atrium that also received the distal male copulatory organ (cirrus) before immediately opening onto the outer surface of the worm. The distal part of the uterus may be expanded into a metraterm, set off from the proximal uterus by a muscular sphincter, or it may be lined with spines, as in the Monorchiidae and some other families.

Digestive system

As adults, most digeneans possess a terminal or subterminal mouth, a muscular pharynx that provides the force for ingesting food, and a forked, blind digestive system consisting of two tubular sacs called caeca (sing. caecum). In some species the two gut caeca join posteriorly to make a ring-shaped gut or cyclocoel. In others the caeca may fuse with the body wall posteriorly to make one or more anuses, or with the excretory vesicle to form a uroproct. Digeneans are also capable of direct nutrient uptake through the tegument by pinocytosis and phagocytosis by the syncitium. Most adult digeneans occur in the vertebrate alimentary canal or its associated organs, where they most often graze on contents of the lumen (e.g., food ingested by the host, bile, mucus), but they may also feed across the mucosal wall (e.g., submucosa, host blood). The blood flukes, such as schistosomes, spirorchiids and sanguinicolids, feed exclusively on blood. Asexual stages in mollusc intermediate hosts feed mostly by direct absorption, although the redia stage found in some groups does have a mouth, pharynx and simple gut and may actively consume host tissue or even other parasites. Encysted metacercarial stages and free-living cercarial stages do not feed.

Nervous system

Paired ganglia at the anterior end of the body serve as the brain. From this nerves extend anteriorly and posteriorly. Sensory receptors are, for the most part, lacking among the adults, although they do have tangoreceptor cells. Larval stages have many kinds of sensory receptors, including light receptors and chemoreceptors. Chemoreception plays an important role in the free-living miracidial larva recognising and locating its host.

Life cycles

There is a bewildering array of variation on the complex digenean life cycle, and plasticity in this trait is probably a key to the group's success. In general, the life cycles may have two, three, or four obligate (necessary) hosts, sometimes with transport or paratenic hosts in between. The three-host life cycle is probably the most common. In almost all species, the first host in the life cycle is a mollusc. This has led to the inference that the ancestral digenean was a mollusc parasite and that vertebrate hosts were added subsequently.

The alternation of sexual and asexual generations is an important feature of digeneans. This phenomenon involves the presence of several discrete generations in one life-cycle.

A typical digenean trematode life cycle is as follows. Eggs leave the vertebrate host in faeces and use various strategies to infect the first intermediate host, in which sexual reproduction does not occur. Digeneans may infect the first intermediate host (usually a snail) by either passive or active means. The eggs of some digeneans, for example, are (passively) eaten by snails (or, rarely, by an annelid worm), in which they proceed to hatch. Alternatively, eggs may hatch in water to release an actively swimming, ciliated larva, the miracidium, which must locate and penetrate the body wall of the snail host.

After post-ingestion hatching or penetration of the snail, the miracidium metamorphoses into a simple, sac-like *mother sporocyst*. The mother sporocyst undergoes a round of internal asexual reproduction, giving rise to either *rediae* (sing. redia) or *daughter sporocysts*. The second generation is thus the daughter parthenita sequence. These in turn undergo further asexual reproduction, ultimately yielding large numbers of the second free-living stage, the *cercaria* (pl. cercariae).

Free-swimming cercariae leave the snail host and move through the aquatic or marine environment, often using a whip-like tail, though a tremendous diversity of tail morphology is seen. Cercariae are infective to the second host in the life cycle, and infection may occur passively (e.g., a fish consumes a cercaria) or actively (the cercaria penetrates the fish).

The life cycles of some digeneans include only two hosts, the second being a vertebrate. In these groups, sexual maturity occurs after the cercaria penetrates the second host, which is in this case also the definitive host. Two host life-cycles can be primary (there never was a third host) as in the Bivesiculidae, or secondary (there was at one time in evolutionary history a third host but it has been lost).

In three-host life cycles, cercariae develop in the second intermediate host into a resting stage, the *metacercaria*, which is usually encysted in a cyst of host and parasite origin, or encapsulated in a layer of tissue derived from the host only. This stage is infective to the definitive host. Transmission occurs when the definitive host preys upon an infected second intermediate host. Metacercariae excyst in the definitive host's gut in response to a variety of physical and chemical signals, such as gut pH levels, digestive enzymes, temperature, etc. Once excysted, adult digeneans migrate to more or less specific sites in the definitive host and the life cycle repeats.

Evolution

The evolutionary origins of the Digenea have been debated for some time, but there appears general agreement that the proto-digenean was a parasite of a mollusc, possibly of the mantle cavity. Evidence for this comes from the ubiquity of molluscs as first intermediate hosts for digeneans, and the fact that most aspidogastreans (the sister group to the Digenea) also have mollusc associations. It is thought that the early trematodes (the collective name for digeneans and aspidogastreans) likely evolved from rhabdocoel turbellarians that colonised the open mantle cavity of early molluscs.

It is likely that more complex life cycles evolved through a process of terminal addition, whereby digeneans survived predation of their mollusc host, probably by a fish. Other hosts were added by until the modern bewildering diversity of life cycle patterns developed.

Important families

The Digenea includes at least 50 families. Below is a list of the more commonly encountered ones.

Acanthocolpidae	Derogenidae	Haplosplanchnidae	Paramphistomidae
Accacoeliidae	Dicrocoeliidae	Hemiuridae	Paragonimidae
Allocreadiidae	Didymozoidae	Heronomidae	Philophthalmidae
Angiodictyidae	Diplostomidae	Heterophyidae	Plagiorchiidae
Apocreadiidae	Echinostomatidae	Lecithasteridae	Sanguinicolidae
Atractotrematidae	Enenteridae	Lepocreadiidae	Schistosomatidae
Azygiidae	Fasciolidae	Microphallidae	Sclerodistomidae
Bivesiculidae	Faustulidae	Monorchiidae	Strigeidae

Bucephalidae	Fellodstomidae	Nasitrematidae	Syncoeliidae
Campulidae	Gorgoderidae	Notocotylidae	Tandanicolidae
Cryptogonimidae	Gyliauchenidae	Opecoelidae	Transversotrematidae
Cyclocoelidae	Haploporidae	Opisthorchiidae	Zoogonidae

There are some digenean families that are either basal to or *incertae sedis* among the orders listed above:

- Acanthocollaritrematidae
- Echinoporidae
- Gekkonotrematidae
- Gyliauchenidae
- Jubilariidae
- Meristocotylidae
- Mesotretidae

Human digenean infections

Only about 12 of the 6,000 known species are infectious to humans, but some of these species are important diseases afflicting over 200 million people. The species that infect humans can be divided into groups, the schistosomes and the non-schistosomes.

Schistosomes

The Schistosomes occur in the circulatory system of the definitive host. Humans become infected after free-swimming cercaria liberated from infected snails penetrate the skin. These dioecious worms are long and thin, ranging in size from 10 to 30 mm in length to 0.2 to 1.0 mm in diameter. Adult males are shorter and thicker than females, and have a long groove along one side of the body in which the female is clasped. Females reach sexual maturity after they have been united with a male. After mating the two remain locked together for the rest of their lives. They can live for several years and produce many thousands of eggs.

The four species of schistosomes that infect humans are members of the genus *Schistosoma*.

Human Schistosomes		
Scientific Name	**First Intermediate Host**	**Endemic Area**
Schistosoma mansoni	*Biomphalaria* spp.	Africa, South America, Caribbean, Middle East
Schistosoma haematobium	*Bulinus* spp.	Africa, Middle East
Schistosoma japonicum	*Oncomelania* spp.	China, East Asia, Philippines
Schistosoma intercalatum	*Bulinus* spp.	Africa

Non-schistosomes

There seven major species of non-schistosomes that infect humans are listed below. People become infected after ingesting metacercarial cysts on plants or in undercooked animal flesh. Most species inhabit the human gastrontestinal tract, where they shed eggs along with host feces. *Paragonimus westermani*, which colonizes the lungs, can also pass its eggs in saliva. These flukes generally cause mild pathology in humans, but more serious effects may also occur.

Human non-Schistosomes			
Scientific Name	**First Intermediate Host**	**Mode of Human Infection**	**Endemic Area**
Fasciolopsis buski	*Segmentina* sp.	Plants	Asia, India
Heterophyes heterophyes	*Pirinella*	Mullet, Tilapia	Asia, Eastern Europe, Egypt, Middle East
Metagonimus yokogawaii	*Semisulcospira* sp.	Carp, Trout	Siberia
Gastrodiscoides hominis	*Helicorbis* sp.	Plants	India, Vietnam, Philippines
Clonorchis sinensis	*Bulinus* sp.	Fish	East Asia, North America
Fasciola hepatica	*Galba truncatula*	Plants	Central America, North America, South America

Paragonimus westermani	*Oncomelania* sp.	Crabs, crayfish	Asia

Chapter- 12

Aspidogastrea

Aspidogastrea	

Lobatostoma manteri, an Aspidogastrean parasite of Australian fishes.

Scientific classification	
Kingdom:	Animalia
Phylum:	Platyhelminthes
Class:	Trematoda
Subclass:	**Aspidogastrea**

Families

Aspidogastridae
Multicalycidae
Rugogastridae
Stichocotylidae

The **Aspidogastrea** (Ancient Greek: ἀσπίς *aspis* “shield”, γαστήρ *gaster* “stomach/pouch”) is a small group of flukes comprising about 80 species. It is a subclass of the trematoda, and sister group to the Digenea. Species range in length from approximately one millimeter to several centimeters. They are parasites of freshwater and marine molluscs and vertebrates (cartilaginous and bony fishes and turtles). Maturation may occur in the mollusc or vertebrate host. None of the species has any economic importance, but the group is of very great interest to biologists because it has several characters which appear to be archaic.

Morphology

Shared characteristics

Shared characteristics of the group are a large ventral disc with a large number of small alveoli ("suckerlets") or a row of suckers and a tegument with short protrusions, so-called "microtubercles".

Larval physiology

Larvae of some species have ciliated patches. Those of *Multicotyle purvisi* have four patches on the anterior side of the posterior sucker and six at the posterior side, those of *Cotylogaster occidentalis* have an anterior ring of eight and a posterior ring of six, while larvae of *Aspidogaster conchicola*, *Lobatostoma manteri*, *Rugogaster hydrolagi* lack cilia altogether. Larvae of some species hatch from eggs, others do not.

Excretory system

Like most platyhelminthes, aspidogastreans use flame cells as an excretory mechanism. The two excretory bladders are located dorsally, on the anterior side of the posterior sucker, connected to ducts, and three flame cell "bulbs" on each side of the body; the ducts contain cilia to aid the flow of excreta.

Nervous system

Aspidogastreans have a nervous system of extraordinary complexity, greater than that of related free-living forms, and a great number of sensory receptors of many different types. The nervous system is of great complexity, consisting of a great number of longitudinal nerves (connectives) connected by circular commissures. The brain (cerebral commissure) is located dorsally, in the anterior part of the body, the eyes dorsally attached to it. A nerve from the main connective enters the pharynx and also supplies the intestine. Posteriorly, the main connective enters the sucker.

Sensory receptors are scattered over the ventral and dorsal surface, the largest numbers occurring on the ventral surface, at the anterior end and on the posterior sucker. Electron-microscopic studies revealed 13 types of receptors.

Life cycles

Their life cycle is much simpler than that of digenean trematodes, including a mollusc and a facultative or compulsory vertebrate host. There are no multiplicative larval stages in the mollusc host, as known from all digeneans.

Host specificity of most aspidogastreans is very low, i.e., a single species of aspidogastrean can infect a wide range of host species, whereas a typical digenean trematode is restricted to few species (at least of molluscs). For example, *Aspidogaster conchicola* infects many species of freshwater bivalves belonging to several families, as well as snails, many species of freshwater fishes of several families, and freshwater tortoises.

Life cycles have been elucidated for a number of species. *Lobatostoma manteri* is an example of a species which has obligate vertebrate hosts. Adult worms live in the small intestine of the snubnosed dart, *Trachinotus blochi* (Teleostei, Carangidae), on the Great Barrier Reef. They produce large numbers of eggs which are shed in the faeces. If eaten by various prosobranch snails, larvae hatch in the stomach, and—depending on the species of snail—stay there or migrate to the digestive gland where they grow up to the preadult stage which has all the characteristics of the adult including a testis and ovary.

Evolutionary relationships

Digenean trematodes have been cultured in various, complex, media. However, their parasitic stages die soon in water. Aspidogastreans may survive for many days or even weeks outside a host in simple physiological saline solution). For example, adult *A. conchicola* survived in water for a fortnight, and in a mixture of water and saline solution for up to five weeks. *L. manteri* extracted from fish could be kept alive for up to 13 days in dilute sea water in which they laid eggs containing larvae infective to snails. This has led to the suggestions that aspidogastreans are archaic trematodes, not yet well adapted to specific hosts, which have given rise to the more "advanced" digenean trematodes, and that the complex life cycles of digenean trematodes have evolved from the simple ones of aspidogastreans.

Synapomorphies of the trematodes are presence of a *Laurer's Canal*, a posterior sucker (transformed to an adhesive disc in the Aspidogastrea), and life cycles involving molluscs and vertebrates. DNA studies have consistently supported this sister group relationship. The question of whether vertebrates or molluscs are the original hosts of the trematodes, has not been resolved.

This view is supported by the evolutionary relationships of the hosts which these two subclasses utilise. The hosts of aspidogastreans include chondrichthyan fishes (sharks, rays and chimaeras), a group that is 450 million years old, whereas the digeneans, are known from teleost fishes (210 million years old) as well as from various "higher" vertebrates; very few species have invaded chondrichthyans secondarily.

Families within the Aspidogastrea

Rohde (2001) distinguish four families of Aspidogastrea:

- The **Rugogastridae** include a single genus, *Rugogaster*, with two species from the rectal glands of holocephalan fishes. It is characterised by a single row of rugae (transverse thickenings of the body surface), numerous testes, and two caeca. Species of all other families have a single caecum and either one or two testes.

- The **Stichocotylidae** include the single species *Stichocotyle nephropis* from the intestine of elasmobranchs. It has a single ventral row of well separated suckers.
- The **Multicalycidae** include the single genus *Multicalyx* from the intestine of holocephalans and elasmobranchs. It is characterised by a single ventral row of alveoli.
- The **Aspidogastridae** includes species infecting molluscs, teleosts and turtles. The ventral adhesive disc bears either three or four rows of alveoli. Rohde distinguishes three subfamilies of Aspidogastridae, the *Rohdellinae*, *Cotylaspidinae* and *Aspidogastrinae*.

Gibson further recognized two orders, the **Aspidogastrida** with the single family Aspidogastridae, and the **Stichocotylida** including the Stichocotylidae, Multicalycidae and Rugogastridae. However, similarities between species of these two orders are so great that distinction at the level of orders does not seem justified.