Annelida, Chordata, Echinoderm and Platyhelminthes

(Animal Phylum)

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Class Clitellata

Oligochaeta – earthworms, etc.
Branchiobdellida
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The **annelids** (also called "ringed worms"), formally called **Annelida** (from French *annelés* "ringed ones", ultimately from Latin *anellus* "little ring"), are a large phylum of segmented worms, with over 17,000 modern species including ragworms, earthworms and leeches. They are found in marine environments from tidal zones to hydrothermal vents, in freshwater, and in moist terrestrial environments. Although most textbooks still use the traditional division into polychaetes (almost all marine), oligochaetes (which include earthworms) and leech-like species, research since 1997 has radically changed this scheme, viewing leeches as a sub-group of oligochaetes and oligochaetes as a sub-group of polychaetes. In addition, the Pogonophora, Echiura and Sipuncula, previously regarded as separate phyla, are now regarded as sub-groups of polychaetes. Annelids are considered members of the Lophotrochozoa, a "super-phylum" of protostomes that also includes molluscs, brachiopods, flatworms and nemerteans.

The basic annelid form consists of multiple segments, each of which has the same sets of organs and, in most polychaetes, a pair of parapodia that many species use for locomotion. Septa separate the segments of many species, but are poorly-defined or absent in some, and Echiura and Sipuncula show no obvious signs of segmentation. In species with well-developed septa, the blood circulates entirely within blood vessels, and the vessels in segments near the front ends of these species are often built up with muscles to act as hearts. The septa of these species also enable them to change the shapes of individual segments, which facilitates movement by peristalsis ("ripples" that pass along the body) or by undulations that improve the effectiveness of the parapodia. In species with incomplete septa or none, the blood circulates through the main body cavity without any kind of pump, and there is a wide range of locomotory techniques – some burrowing species turn their pharynges inside out to drag themselves through the sediment.

Although many species can reproduce asexually and use similar mechanisms to regenerate after severe injuries, sexual reproduction is the normal method in species whose reproduction has been studied. The minority of living polychaetes whose reproduction and lifecycles are known produce trochophore larvae, which live as plankton and then sink and metamorphose into miniature adults. Oligochaetes are full hermaphrodites and produce a ring-like cocoon round their bodies, in which the eggs and hatchlings are nourished until they are ready to emerge.

Earthworms support terrestrial food chains both as prey and by aerating and enriching soil. The burrowing of marine polychaetes, which may constitute up to a third of all species in near-shore environments, encourages the development of ecosystems by enabling water and oxygen to penetrate the sea floor. In addition to improving soil fertility, annelids serve humans as food and as bait. Scientists observe annelids to monitor the quality of marine and fresh water. Although blood-letting is no longer in favor with doctors, some leech species are regarded as endangered species because they have been over-harvested for this purpose in the last few centuries. Ragworms' jaws are now being studied by engineers as they offer an exceptional combination of lightness and strength.

Since annelids are soft-bodied, their fossils are rare – mostly jaws and the mineralized tubes that some of the species secreted. Although some late Ediacaran fossils may represent annelids, the oldest known fossil that is identified with confidence comes from about 518 million years ago in the early Cambrian period. Fossils of most modern mobile polychaete groups appeared by the end of the Carboniferous, about 299 million years ago. Scientists disagree about whether some body fossils from the mid Ordovician, about 472 to 461 million years ago, are the remains of oligochaetes, and the earliest certain fossils of the group appear in the Tertiary period, which began 65 million years ago.

Classification and diversity

There are over 17,000 living annelid species, ranging in size from microscopic to the Australian giant Gippsland earthworm, which can grow up to 3 metres (9.8 ft) long. Although research since 1997 has radically changed scientists' views about the evolutionary family tree of the annelids, most textbooks use the traditional classification into the following sub-groups:

- **Polychaetes** (about 12,000 species). As their name suggests, they have multiple chetae ("hairs") per segment. Polychaetes have parapodia that function as limbs, and nuchal organs ("nuchal" means "on the neck") that are thought to be chemosensors. Most are marine animals, although a few species live in fresh water and even fewer on land.

An earthworm's clitellum

- **Clitellates** (about 5,000 species). These have few or no chetae per segment, and no nuchal organs or parapodia. However, they have a unique reproductive organ, the ring-shaped clitellum ("pack saddle") round their bodies, which produces a cocoon that stores and nourishes fertilized eggs until they hatch. The clitellates are sub-divided into:
    - **Oligochaetes** ("with few hairs"), which includes earthworms. Oligochaetes have a sticky pad in the roof of the mouth. Most are burrowers that feed on wholly or partly decomposed organic materials.
    - **Hirudinea**, whose name means "leech-shaped" and whose best known members are leeches. Marine species are mostly blood-sucking parasites, mainly on fish, while most freshwater species are predators. They have suckers at both ends of their bodies, and use these to move rather like inchworms.

The Archiannelida, minute annelids that live in the spaces between grains of sediment, were treated as a separate class because of their simple body structure, but are now regarded as polychaetes. Some other groups of animals have been classified in various ways, but are now widely regarded as annelids:

- Pogonophora / Siboglinidae were first discovered in 1914, and their lack of a recognizable gut made it difficult to classify them. They have been classified as a separate phylum, Pogonophora, or as two phyla, Pogonophora and Vestimentifera. More recently they have been re-classified as a family, Siboglinidae, within the polychaetes.
- The Echiura have a checkered taxonomic history: in the 19th century they were assigned to the phylum "Gephyrea", which is now empty as its members have been assigned to other phyla; the Echiura were next regarded as annelids until the 1940s, when they were classified as a phylum in their own right; but a molecular phylogenetics analysis in 1997 concluded that Echiurans are annelids.
- Myzostomida live on crinoids and other echinoderms, mainly as parasites. In the past they have been regarded as close relatives of the trematode flatworms or of the tardigrades, but in 1998 it was suggested that they are a sub-group of polychaetes. However, another analysis in 2002 suggested that myzostomids are more closely related to flatworms or to rotifers and acanthocephales.

Distinguishing features

No single feature distinguishes Annelids from other invertebrate phyla, but they have a distinctive combination of features. Their bodies are long, with segments that are divided externally by shallow ring-like constrictions called annuli and internally by septa ("partitions") at the same points, although in some species the septa are incomplete and in a few cases missing. Most of the segments contain the same sets of organs, although sharing a common gut, circulatory system and nervous system makes them inter-dependent. Their bodies are covered by a cuticle (outer covering) that does not contain cells but is secreted by cells in the skin underneath, is made of tough but flexible collagen and does not molt – on the other hand arthropods' cuticles are made of the more rigid α-chitin, and molt until the arthropods reach their full size. Most annelids have closed circulatory systems, where the blood makes its entire circuit via blood vessels.

Summary of distinguishing features

	Annelida	Recently merged into Annelida		Closely-related	Similar-looking phyla	
		Echiura	**Sipuncula**	**Nemertea**	**Arthropoda**	**Onychophora**
External segmentation	Yes	no	no	Only in a few species	Yes, except in mites	no
Repetition of internal organs	Yes	no	no	Yes	In primitive forms	Yes
Septa between segments	In most species	no	no	No	No	No
Cuticle material	collagen	collagen	collagen	none	α-chitin	α-chitin
Molting	Generally no; but some polychaetes molt their jaws, and leeches molt their skins	no	no	no	Yes	Yes
Body cavity	Coelom; but this is reduced or missing in many leeches and some small polychaetes	2 coeloms, main and in proboscis	2 coeloms, main and in tentacles	Coelom only in proboscis	Hemocoel	Hemocoel
Circulatory system	Closed in most species	Open outflow, return via branched vein	Open	Closed	Open	Open

Description

Most of an annelid's body consists of segments that are practically identical, having the same sets of internal organs and external chaetae (Greek χαιτη, meaning "hair") and, in some species, appendages. However, the frontmost and rearmost sections are not regarded as true segments as they do not contain the standard sets of organs and do not develop in the same way as the true segments. The frontmost section, called the prostomium (Greek προ- meaning "in front of" and στομα meaning "mouth") contains the brain and sense organs, while the rearmost, called the pygidium (Greek πυγιδιον, meaning "little tail") contains the anus, generally on the underside. The first section behind the prostomium, called the peristomium (Greek περι- meaning "around" and στομα meaning "mouth"), is regarded by some zoologists as not a true segment, but in some polychaetes the peristomium has chetae and appendages like those of other segments.

The segments develop one at a time from a growth zone just ahead of the pygidium, so that an annelid's youngest segment is just in front of the growth zone while the peristomium is the oldest. This pattern is called teloblastic growth. Some groups of annelids, including all leeches, have fixed maximum numbers of segments, while others add segments throughout their lives.

The phylum's name is derived from the Latin word *annelus*, meaning "little ring".

Body wall, chetae and parapodia

Annelids' cuticles are made of collagen fibers, usually in layers that spiral in alternating directions so that the fibers cross each other. These are secreted by the one-cell deep epidermis (outermost skin layer). A few marine annelids that live in tubes lack cuticles, but their tubes have a similar structure, and mucus-secreting glands in the epidermis protect their skins. Under the epidermis is the dermis, which is made of connective tissue, in other words a combination of cells and non-cellular materials such as collagen. Below this are two layers of muscles, which develop from the lining of the coelom (body cavity): circular muscles make a segment longer and slimmer when they contract, while under them are longitudinal muscles, usually four distinct strips, whose contractions make the segment shorter and fatter. Some annelids also have oblique internal muscles that connect the underside of the body to each side.

The chetae ("hairs") of annelids project out from the epidermis to provide traction and other capabilities. The simplest are unjointed and form paired bundles near the top and bottom of each side of each segment. The parapodia ("limbs") of annelids that have them often bear more complex chetae at their tips – for example jointed, comb-like or hooked. Chetae are made of moderately flexible β-chitin and are formed by follicles, each of which has a chaetoblast ("hair-forming") cell at the bottom and muscles that can extend or retract the cheta. The chetoblasts produce chetae by forming microvilli, fine hair-like extensions that increase the area available for secreting the cheta. When the cheta is complete, the microvilli withdraw into the chetoblast, leaving parallel tunnels that run almost the full length of the cheta. Hence annelids' chetae are structurally different from the setae ("bristles") of arthropods, which are made of the more rigid α-chitin, have a single internal cavity, and are mounted on flexible joints in shallow pits in the cuticle.

Nearly all polychaetes have parapodia that function as limbs, while other major annelid groups lack them. Parapodia are unjointed paired extensions of the body wall, and their muscles are derived from the circular muscles of the body. They are often supported internally by one or more large, thick chetae. The parapodia of burrowing and tube-dwelling polychaetes are often just ridges whose tips bear hooked chetae. In active crawlers and swimmers the parapodia are often divided into large upper and lower paddles on a very short trunk, and the paddles are generally fringed with chetae and sometimes with cirri (fused bundles of cilia) and gills.

Nervous system and senses

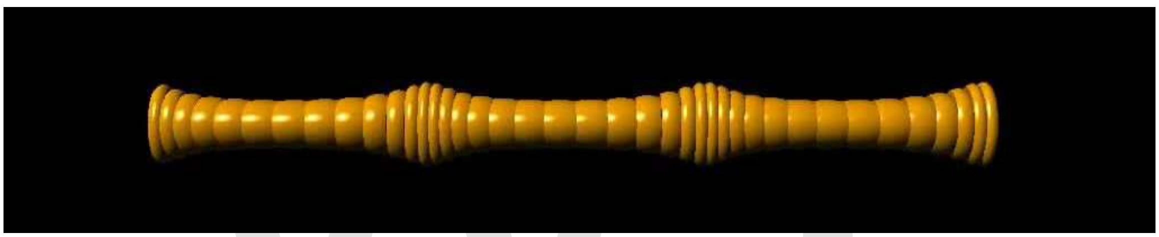
The brain generally forms a ring round the pharynx (throat), consisting of a pair of ganglia (local control centers) above and in front of the pharynx, linked by nerve cords either side of the pharynx to another pair of ganglia just below and behind it. The brains of polychaetes are generally in the prostomium, while those of clitellates are in the peristomium or sometimes the first segment behind the peristomium. In some very mobile and active polychaetes the brain is enlarged and more complex, with visible hindbrain, midbrain and forebrain sections. The rest of the central nervous system is generally "ladder-like", consisting of a pair of nerve cords that run through the bottom part of the body and have in each segment paired ganglia linked by a transverse connection. From each segmental ganglion a branching system of local nerves runs into the body wall and then encircles the body. However, in most polychaetes the two main nerve cords are fused, and in the tube-dwelling genus *Owenia* the single nerve chord has no ganglia and is located in the epidermis.

As in arthropods, each muscle fiber (cell) is controlled by more than one neuron, and the speed and power of the fiber's contractions depends on the combined effects of all its neurons. Vertebrates have a different system, in which one neuron controls a group of muscle fibers. Most annelids' longitudinal nerve trunks include giant axons (the output signal lines of nerve cells). Their large diameter decreases their resistance, which allows them to transmit signals exceptionally fast. This enables these worms to withdraw rapidly from danger by shortening their bodies. Experiments have shown that cutting the giant axons prevents this escape response but does not affect normal movement.

The sensors are primarily single cells that detect light, chemicals, pressure waves and contact, and are present on the head, appendages (if any) and other parts of the body. Nuchal ("on the neck") organs are paired, ciliated structures found only in polychaetes, and are thought to be chemosensors. Some polychaetes also have various combinations of ocelli ("little eyes") that detect the direction from which light is coming and camera eyes or compound eyes that can probably form images. The compound eyes probably evolved independently of arthropods' eyes. Some tube-worms use ocelli widely spread over their bodies to detect the shadows of fish, so that they can quickly withraw into their tubes. Some burrowing and tube-dwelling polychaetes have statocysts (tilt and balance sensors) that tell them which way is down. A few polychaete genera have on the undersides of their heads palps that are used both in feeding and as "feelers", and some of these also have antennae that are structurally similar but probably are used mainly as "feelers".

Coelom, locomotion and circulatory system

Most annelids have a pair of coeloms (body cavities) in each segment, separated from other segments by septa and from each other by vertical mesenteries. Each septum forms a sandwich with connective tissue in the middle and mesothelium (membrane that serves as a lining) from the preceding and following segments on either side. Each mesentery is similar except that the mesothelium is the lining of each of the pair of coeloms, and the blood vessels and, in polychaetes, the main nerve cords are embedded in it. The mesothelium is made of modified epitheliomuscular cells, in other words their bodies form part of the epithelium but their bases extend to form muscle fibers in the body wall. The mesothelium may also form radial and circular muscles on the septa, and circular muscles around the blood vessels and gut. Parts of the mesothelium, especially on the outside of the gut, may also form chloragogen cells that perform similar functions to the livers of vertebrates: producing and storing glycogen and fat; producing the oxygen-carrier hemoglobin; breaking down proteins; and turning nitrogenous waste products into ammonia and urea to be excreted.



Peristalsis moves this "worm" to the right

Many annelids move by peristalsis (waves of contraction and expansion that sweep along the body), or flex the body while using parapodia to crawl or swim. In these animals the septa enable the circular and longitudinal muscles to change the shape of individual segments, by making each segment a separate fluid-filled "balloon". However, the septa are often incomplete in annelids that are semi-sessile or that do not move by peristalsis or by movements of parapodia – for example some move by whipping movements of the body, some small marine species move by means of cilia (fine muscle-powered hairs) and some burrowers turn their pharynges (throats) inside out to penetrate the sea-floor and drag themselves into it.

The fluid in the coeloms contains coelomocyte cells that defend the animals against parasites and infections. In some species coelomocytes may also contain a respiratory pigment – red hemoglobin in some species, green chlorocruorin in others – and provide oxygen transport within their segments. Respiratory pigment is also dissolved in the blood plasma. Species with well-developed septa generally also have blood vessels running all long their bodies above and below the gut, the upper one carrying blood forwards while the lower one carries it backwards. Networks of capillaries (fine blood vessels) in the body wall and around the gut transfer blood between the main blood vessels and to parts of the segment that need oxygen and nutrients. Both of the major vessels, especially the upper one, can pump blood by contracting. In some annelids the forward end of the upper blood vessel is enlarged with muscles to form a heart, while in the forward ends of many earthworms some of the vessels that connect the upper and lower main vessels function as hearts. Species with poorly-developed or no septa generally have no blood vessels and rely on the circulation within the coelom for delivering nutrients and oxygen.

However, leeches and their closest relatives have a body structure that is very uniform within the group but significantly different from that of other annelids, including other members of the Clitellata. In leeches there are no septa, the connective tissue layer of the body wall is so thick that it occupies much of the body, and the two coeloms are widely separated and run the length of the body. They function as the main blood vessels, although they are side-by-side rather than upper and lower. However, they are lined with mesothelium, like the coeloms and unlike the blood vessels of other annelids. Leeches generally use suckers at their front and rear ends to move like inchworms. The anus is on the upper surface of the pygidium.

Respiration

In some annelids, including earthworms, all respiration is via the skin. However, many polychaetes and some clitellates (the group to which earthworms belong) have gills associated with most segments, often as extensions of the parapodia in polychaetes. The gills of tube-dwellers and burrowers usually cluster around whichever end has the stronger water flow.

Feeding and excretion

Feeding structures in the mouth region vary widely, and have little correlation with the animals' diets. Many polychaetes have a muscular pharynx that can be everted (turned inside out to extend it). In these animals the foremost few segments often lack septa so that, when the muscles in these segments contract, the sharp increase in fluid pressure from all these segments everts the pharynx very quickly. Two families, the Eunicidae and Phyllodocidae, have evolved jaws, which can be used for seizing prey, biting off pieces of vegetation, or grasping dead and decaying matter. On the other hand some predatory polychaetes have neither jaws nor eversible pharynges. Selective deposit feeders generally live in tubes on the sea-floor and use palps to find food particles in the sediment and then wipe them into their mouths. Filter feeders use "crowns" of palps covered in cilia that wash food particles towards their mouths. Non-selective deposit feeders ingest soil or marine sediments via mouths that are generally unspecialized. Some clitellates have sticky pads in the roofs of their mouths, and some of these can evert the pads to capture prey. Leeches often have an eversible proboscis, or a muscular pharynx with two or three teeth.

The gut is generally an almost straight tube supported by the mesenteries (vertical partitions within segments), and ends with the anus on the underside of the pygidium. However, in members of the tube-dwelling family Siboglinidae the gut is blocked by a swollen lining that houses symbiotic bacteria, which can make up 15% of the worms' total weight. The bacteria convert inorganic matter – such as hydrogen sulfide and carbon dioxide from hydrothermal vents, or methane from seeps – to organic matter that feeds themselves and their hosts, while the worms extend their palps into the gas flows to absorb the gases needed by the bacteria.

Annelids with blood vessels use metanephridia to remove soluble waste products, while those without use protonephridia. Both of these systems use a two-stage filtration process, in which fluid and waste products are first extracted and these are filtered again to re-absorb any re-usable materials while dumping toxic and spent materials as urine. The difference is that protonephridia combine both filtration stages in the same organ, while metanephridia perform only the second filtration and rely on other mechanisms for the first – in annelids special filter cells in the walls of the blood vessels let fluids and other small molecules pass into the coelomic fluid, where it circulates to the metanephridia. In annelids the points at which fluid enters the protonephridia or metanephridia are on the forward side of a septum while the second-stage filter and the nephridiopore (exit opening in the body wall) are in the following segment. As a result the hindmost segment (before the growth zone and pygidium) has no structure that extracts its wastes, as there is no following segment to filter and discharge them, while the first segment contains an extraction structure that passes wastes to the second, but does not contain the structures that re-filter and discharge urine.

Reproduction and life cycle

Asexual reproduction

This sabellid tubeworm is budding

Polychaetes can reproduce asexually, by dividing into two or more pieces or by budding off a new individual while the parent remains a complete organism. Some oligochaetes, such as *Aulophorus furcatus*, seem to reproduce entirely asexually, while others reproduce asexually in summer and sexually in autumn. Asexual reproduction in oligochaetes is always by dividing into two or more pieces, rather than by budding. However, leeches have never been seen reproducing asexually.

Most polychaetes and oligochaetes also use similar mechanisms to regenerate after suffering damage. Two polychaete genera, *Chaetopterus* and *Dodecaceria*, can regenerate from a single segment, and others can regenerate even if their heads are removed. Annelids are the most complex animals that can regenerate after such severe damage. On the other hand leeches cannot regenerate.

Sexual reproduction

It is thought that annelids were originally animals with two separate sexes, which released ova and sperm into the water via their nephridia. The fertilized eggs develop into trochophore larvae, which live as plankton. Later they sink to the sea-floor and metamorphose into miniature adults: the part of the trochophore between the apical tuft and the prototroch becomes the prostomium (head); a small area round the trochophore's anus becomes the pygidium (tail-piece); a narrow band immediately in front of that becomes the growth zone that produces new segments; and the rest of the trochophore becomes the peristomium (the segment that contains the mouth).

However, the lifecycles of most living polychaetes, which are almost all marine animals, are unknown, and only about 25% of the 300+ species whose lifecycles are known follow this pattern. About 14% use a similar external fertilization but produce yolk-rich eggs, which reduce the time the larva needs to spend among the plankton, or eggs from which miniature adults emerge rather than larvae. The rest care for the fertilized eggs until they hatch – some by producing jelly-covered masses of eggs which they tend, some by attaching the eggs to their bodies and a few species by keeping the eggs within their bodies until they hatch. These species use a variety of methods for sperm transfer; for example, in some the females collect sperm released into the water, while in others the males have penes that inject sperm into the female. There is no guarantee that this is a representative sample of polychaetes' reproductive patterns, and it simply reflects scientists' current knowledge.

Some polychaetes breed only once in their lives, while others breed almost continuously or through several breeding seasons. While most polychaetes remain of one sex all their lives, a significant percentage of species are full hermaphrodites or change sex during their lives. Most polychaetes whose reproduction has been studied lack permanent gonads, and it is uncertain how they produce ova and sperm. In a few species the rear of the body splits off and becomes a separate individual that lives just long enough to swim to a suitable environment, usually near the surface, and spawn.

Most mature clitellates (the group that includes earthworms and leeches) are full hermaphrodites, although in a few leech species younger adults function as males and become female at maturity. All have well-developed gonads, and all copulate. Earthworms store their partners' sperm in spermathecae ("sperm stores") and then the clitellum produces a cocoon that collects ova from the ovaries and then sperm from the spermathecae. Fertilization and development of earthworm eggs takes place in the cocoon. Leeches' eggs are fertilized in the ovaries, and then transferred to the cocoon. In all clitellates the cocoon also either produces yolk when the eggs are fertilized or nutrients while they are developing. All clitellates hatch as miniature adults rather than larvae.

Ecological significance

Charles Darwin's book *The Formation of Vegetable Mould through the Action of Worms* (1881) presented the first scientific analysis of earthworms' contributions to soil fertility. Some burrow while others live entirely on the surface, generally in moist leaf litter. The burrowers loosen the soil so that oxygen and water can penetrate it, and both surface and burrowing worms help to produce soil by mixing organic and mineral matter, by accelerating the decomposition of organic matter and thus making it more quickly available to other organisms, and by concentrating minerals and converting them to forms that plants can use more easily. Earthworms are also important prey for birds ranging in size from robins to storks, and for mammals ranging from shrews to badgers, and in some cases conserving earthworms may be essential for conserving endangered birds.

Marine annelids may account for over one-third of bottom-dwelling animal species round coral reefs and in tidal zones. Burrowing species increase the penetration of water and oxygen and water into the sea-floor sediment, which encourages the growth of populations of bacteria and small animals alongside their burrows.

Although blood-sucking leeches do little direct harm to their victims, some transmit flagellates that can be very dangerous to their hosts. Some small tube-dwelling oligochaetes transmit myxosporean parasites that cause whirling disease in fish.

Interaction with humans

Earthworms make a significant contribution to soil fertility. The rear end of the Palolo worm, a marine polychaete that tunnels through coral, detaches in order to spawn at the surface, and the people of Samoa regard these spawning modules as a delicacy. Anglers sometimes find that worms are more effective bait than artificial flies, and worms can be kept for several days in a tin lined with damp moss. Ragworms are commercially important as bait and as food sources for aquaculture, and there have been proposals to farm them in order to reduce over-fishing of their natural populations. Some marine polychaetes' predation on molluscs causes serious losses to fishery and aquaculture operations.

Scientists study aquatic annelids to monitor the oxygen content, salinity and pollution levels in fresh and marine water.

Accounts of the use of leeches for the medically dubious practise of blood-letting have come from China around 30 AD, India around 200 AD, ancient Rome around 50 AD and later throughout Europe. In the 19th century medical demand for leeches was so high that some areas' stocks were exhausted and other regions imposed restrictions or bans on exports, and *Hirudo medicinalis* is treated as an endangered species by both IUCN and CITES. More recently leeches have been used to assist in microsurgery, and their saliva has provided anti-inflammatory compounds and several important anticoagulants, one of which also prevents tumors from spreading.

Ragworms' jaws are strong but much lighter than the hard parts of many other organisms, which are biomineralized with calcium salts. These advantages have attracted the attention of engineers. Investigations showed that ragworm jaws are made of unusual proteins that bind strongly to zinc.

Evolutionary history

Fossil record

Since annelids are soft-bodied, their fossils are rare. Polychaetes' fossil record consists mainly of the jaws that some species had and the mineralized tubes that some secreted. Some Ediacaran fossils such as *Dickinsonia* in some ways resemble polychaetes, but the similarities are too vague for these fossils to be classified with confidence. The small shelly fossil *Cloudina*, from 549 to 542 million years ago, has been classified by some authors as an annelid, but by others as a cnidarian (i.e. in the phylum to which jellyfish and sea anemones belong). Until 2008 the earliest fossils widely accepted as annelids were the polychaetes *Canadia* and *Burgessochaeta*, both from Canada's Burgess Shale, formed about 505 million years ago in the early Cambrian. *Myoscolex*, found in Australia and a little older than the Burgess Shale, was possibly an annelid. However, it lacks some typical annelid features and has features which are not usually found in annelids and some of which are associated with other phyla. Then Simon Conway Morris and John Peel reported *Phragmochaeta* from Sirius Passet, about 518 million years old, and concluded that it was the oldest annelid known to date. There has been vigorous debate about whether the Burgess Shale fossil *Wiwaxia* was a mollusc or an annelid. Polychaetes diversified in the early Ordovician, about 488 to 474 million years ago. It is not until the early Ordovician that the first annelid jaws are found, thus the crown-group cannot have appeared before this date and probably appeared somewhat later. By the end of the Carboniferous, about 299 million years ago, fossils of most of the modern mobile polychaete groups had appeared. Many fossil tubes look like those made by modern sessile polychaetes, but the first tubes clearly produced by polychaetes date from the Jurassic, less than 199 million years ago.

The earliest good evidence for oligochaetes occurs in the Tertiary period, which began 65 million years ago, and it has been suggested that these animals evolved around the same time as flowering plants in the early Cretaceous, from 130 to 90 million years ago. A trace fossil consisting of a convoluted burrow partly filled with small fecal pellets may be evidence that earthworms were present in the early Triassic period from 251 to 245 million years ago. Body fossils going back to the mid Ordovician, from 472 to 461 million years ago, have been tentatively classified as oligochaetes, but these identifications are uncertain and some have been disputed.

Family tree

Traditionally the annelids have been divided into two major groups, the polychaetes and clitellates. In turn the clitellates were divided into oligochaetes, which include earthworms, and hirudinomorphs, whose best-known members are leeches. For many years there was no clear arrangement of the approximately 80 polychaete families into higher-level groups. In 1997 Greg Rouse and Kristian Fauchald attempted a "first heuristic step in terms of bringing polychaete systematics to an acceptable level of rigour", based on anatomical structures, and divided polychaetes into:

- Scolecida, less than 1,000 burrowing species that look rather like earthworms.
- Palpata, the great majority of polychaetes, divided into:
  - Canalipalpata, which are distinguished by having long grooved palps that they use for feeding, and most of which live in tubes.
  - Aciculata, the most active polychaetes, which have parapodia reinforced by internal spines (aciculae).

Also in 1997 Damhnait McHugh, using molecular phylogenetics to compare similarities and differences in one gene, presented a very different view, in which: the clitellates were an off-shoot of one branch of the polychaete family tree; the pogonophorans and echiurans, which for a few decades had been regarded as a separate phyla, were placed on other branches of the polychaete tree. Subsequent molecular phylogenetics analyses on a similar scale presented similar conclusions.

In 2007 Torsten Struck and colleagues compared 3 genes in 81 taxa, of which 9 were outgroups, in other words not considered closely related to annelids but included to give an indication of where the organisms under study are placed on the larger tree of life. For a cross-check the study used an analysis of 11 genes (including the original 3) in 10 taxa. This analysis agreed that clitellates, pogonophorans and echiurans were on various branches of the polychaete family tree. It also concluded that the classification of polychaetes into Scolecida, Canalipalpata and Aciculata was useless, as the members of these alleged groups were scattered all over the family tree derived from comparing the 81 taxa. In addition, it also placed sipunculans, generally regarded at the time as a separate phylum, on another branch of the polychaete tree, and concluded that leeches were a sub-group of oligochaetes rather than their sister-group among the clitellates. Rouse accepted the analyses based on molecular phylogenetics, and their main conclusions are now the scientific consensus, although the details of the annelid family tree remain uncertain.

In addition to re-writing the classification of annelids and 3 previously independent phyla, the molecular phylogenetics analyses undermine the emphasis that decades of previous writings placed on the importance of segmentation in the classification of invertebrates. Polychaetes, which these analyses found to be the parent group, have completely segmented bodies, while polychaetes' echiurans and sipunculan offshoots are not segmented and pogonophores are segmented only in the rear parts of their bodies. It now seems that segmentation can appear and disappear much more easily in the course of evolution than was previously thought. The 2007 study also noted that the ladder-like nervous system, which is associated with segmentation, is less universal than previously thought in both annelids and arthropods.

Annelids are members of the protostomes, one of the two major superphyla of bilaterian animals – the other is the deuterostomes, which includes vertebrates. Within the protostomes, annelids used to be grouped with arthropods under the super-group Articulata ("jointed animals"), as segmentation is obvious in most members of both phyla. However, the genes that drive segmentation in arthropods do not appear to do the same in annelids. Arthropods and annelids both have close relatives that are unsegmented. It is at least as easy to assume that they evolved segmented bodies independently as it is to assume that the ancestral protostome or bilaterian was segmented and that segmentation disappeared in many descendant phyla. The current view is that annelids are grouped with molluscs, brachiopods and several other phyla that have lophophores (fan-like feeding structures) and/or trochophore larvae as members of Lophotrochozoa. Bryzoa may be the most basal phylum (the one that first became distinctive) within the Lophotrochozoa, and the relationships between the other members are not yet known. Arthropods are now regarded as members of the Ecdysozoa ("animals that molt"), along with some phyla that are unsegmented.

The "Lophotrochozoa" hypothesis is also supported by the fact that many phyla within this group, including annelids, molluscs, nemerteans and flatworms, follow a similar pattern in the fertilized egg's development. When their cells divide after the 4-cell stage, descendants of these 4 cells form a spiral pattern. In these phyla the "fates" of the embryo's cells, in other words the roles their descendants will play in the adult animal, are the same and can be predicted from a very early stage. Hence this development pattern is often described as "spiral determinate cleavage".

Chapter- 2

Polychaete

Polychaetes Temporal range: 530–0 Ma Cambrian (or earlier?) - present	
	
"A variety of marine worms": plate from *Das Meer* by M. J. Schleiden (1804–1881).	
Scientific classification	
Kingdom:	Animalia
Phylum:	Annelida
Class:	**Polychaeta** Grube, 1850
Subclasses	

Palpata
Scolecida

The **Polychaeta** or **polychaetes** are a class of annelid worms, generally marine. Each body segment has a pair of fleshy protrusions called parapodia that bear many bristles, called chaetae, which are made of chitin. Indeed, polychaetes are sometimes referred to as **bristle worms**. More than 10,000 species are described in this class. Common representatives include the lugworm (*Arenicola marina*) and the sandworm or clam worm *Nereis*.

Polychaetes as a class are robust and widespread, with species that live in the coldest ocean temperatures of the abyssal plain, to forms which tolerate the extreme high temperatures near hydrothermal vents. Polychaetes occur throughout the Earth's oceans at all depths, from forms that live as plankton near the surface, to a 2–3 cm specimen (still unclassified) observed by the robot ocean probe Nereus at the bottom of the Challenger Deep, the deepest spot in the Earth's oceans.

Description

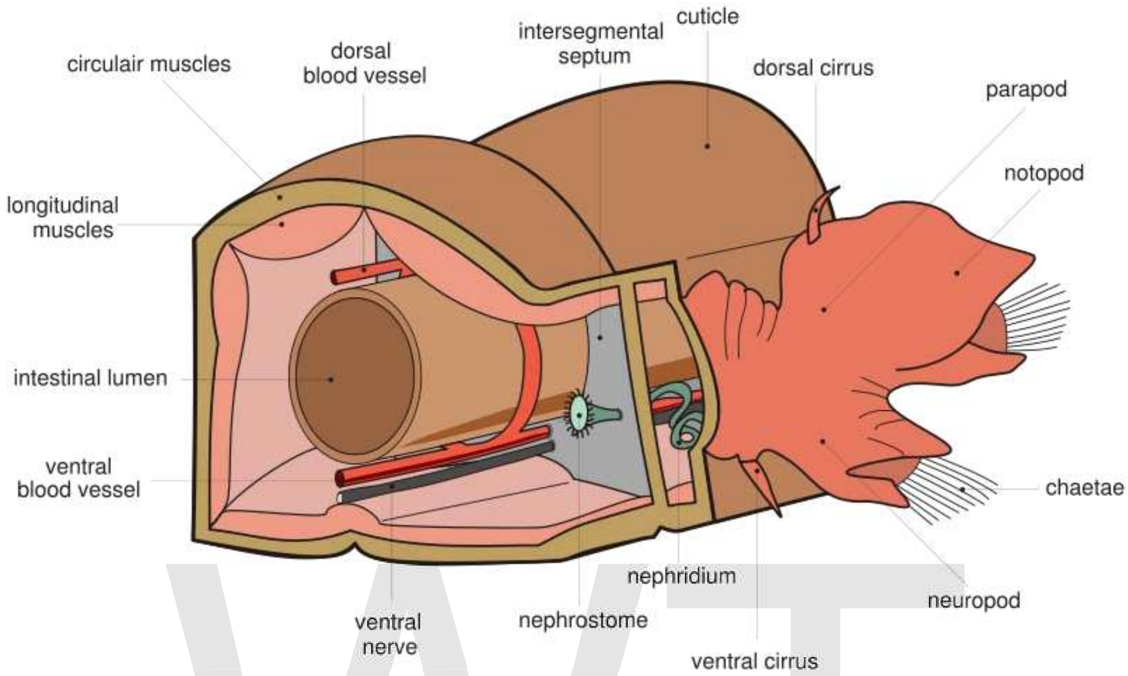
Polychaetes are segmented worms, generally less than 10 centimetres (3.9 in) in length, although ranging at the extremes from 1 millimetre (0.039 in) to 3 metres (9.8 ft). They are often brightly coloured, and may be iridescent or even luminescent. Each segment bears a pair of paddle-like and highly vascularized parapodia, which are used for movement and, in many species, act as the worm's primary respiratory surfaces. Bundles of bristles, called setae, project from the parapodia.

However, polychaetes vary widely from this generalised pattern, and can display a range of different body forms. The most generalised polychaetes are those that crawl along the bottom, but others have adapted to many different ecological niches, including burrowing, pelagic life, tube-dwelling or boring, commensalism, and parasitism, requiring various modifications to their body structure.

The head, or prostomium, is relatively well developed, compared with other annelids. It projects forward over the mouth, which therefore lies on the animal's underside. The head normally includes two to four pair of eyes, although there are some blind species. These are typically fairly simple structures, capable of distinguishing only light and dark, although some species have large eyes with lenses that may be capable of more sophisticated vision.

The head also includes a pair of antennae, tentacle-like palps, and a pair of pits lined with cilia, known as "nuchal organs". These latter appear to be chemoreceptors, and help the worm to seek out food.

Internal anatomy and physiology



General anatomy of a polychaete

The outer surface of the body wall consists of a simple columnar epithelium covered by a thin cuticle. Underneath this, in order, are a thin layer of connective tissue, a layer of circular muscle, a layer of longitudinal muscle, and a peritoneum surrounding the body cavity. Additional oblique muscles move the parapodia. In most species, the body cavity is divided into separate compartments by sheets of peritoneum between each segment, but in some species, it is more continuous.

The mouth of polychaetes varies in form depending on their diet, since the group includes predators, herbivores, filter feeders, scavengers, and parasites. In general, however, it possesses a pair of jaws and a pharynx that can be rapidly everted, allowing the worm to grab food and pull it into the mouth. In some species, the pharynx is modified into a lengthy proboscis. The digestive tract is a simple tube, usually with a stomach part way along.

The smallest species, and those adapted to burrowing, lack gills, breathing only through their body surface. Most other species, however, have external gills, generally, although not always, associated with the parapodia.

There is usually a well-developed, if simple, circulatory system. There are two main blood vessels, with smaller vessels to supply the parapodia and the gut. Blood flows forward in the dorsal vessel, above the gut, and returns back down the body in the ventral vessel, beneath the gut. The blood vessels themselves are contractile, helping to push the blood along, so most species have no need of a heart. In a few cases, however, muscular pumps analogous to a heart are found in various parts of the system. Conversely, some species have little or no circulatory system at all, transporting oxygen in the coelomic fluid that fills their body cavity.

The blood itself may be colourless, or have any of three different respiratory pigments. The most common of these is haemoglobin, but some groups have haemerythrin or the green-coloured chlorocruorin instead.

The nervous system consists of a single or double ventral nerve cord running the length of the body, with ganglia and a series of small nerves in each segment. The brain is relatively large, compared with that of other annelids, and lies in the upper part of the head. An endocrine gland is attached to the ventral posterior surface of the brain, and appears to be involved in reproductive activity. In addition to the sensory organs on the head, there may also photosensitive eye-spots on the body, statocysts, and numerous additional sensory nerve endings, most likely in involved with the sense of touch.

Polychaetes have a varying number of protonephridia or metanephridia for excreting waste, which in some cases can be relatively complex in structure. The body also contains greenish "chloragogen" tissue, similar to that found in oligochaetes, which appears to function in metabolism, in a similar fashion to that of the vertebrate liver.

Their cuticle is constructed from cross-linked fibres of collagen and may be 200 nm to 13mm thick. Their jaws are formed from sclerotised collagen, and their setae from sclerotised chitin.

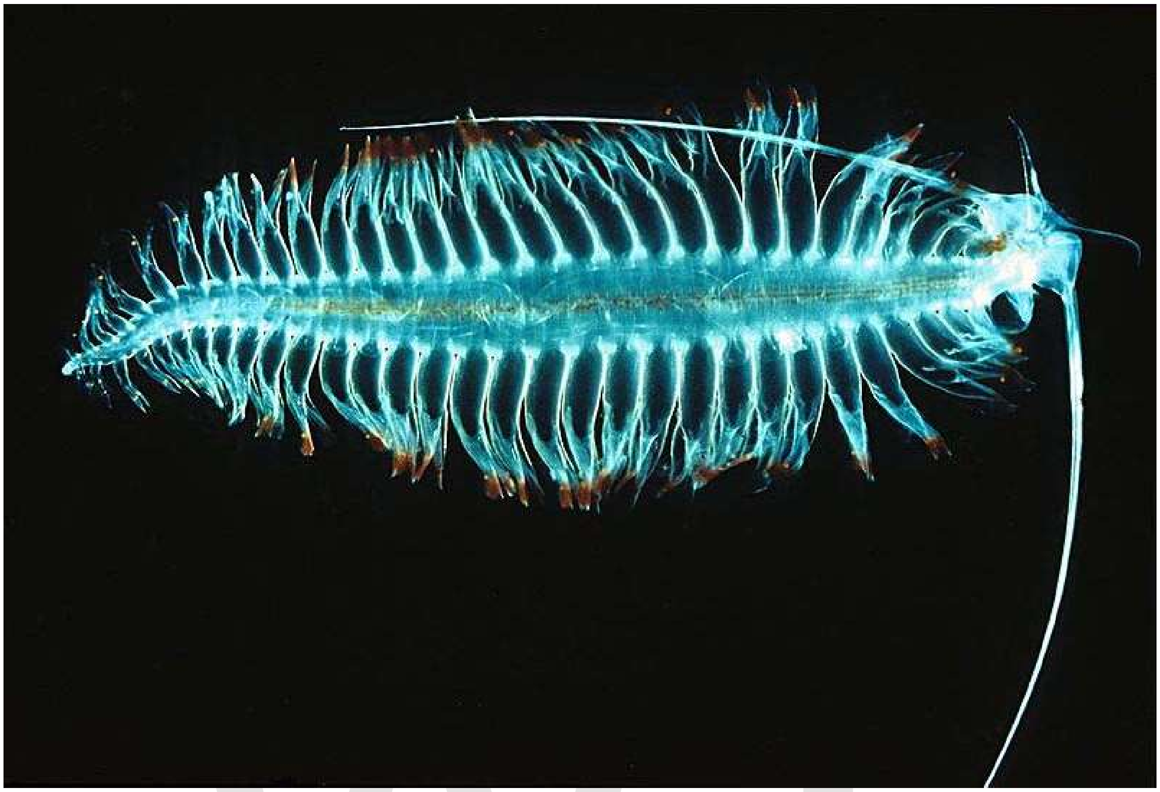
Ecology

Christmas tree worms (*Spirobranchus giganteus*) from East Timor

Polychaetes are extremely variable in both form and lifestyle and include a few taxa that swim among the plankton. Most burrow or build tubes in the sediment, and some live as commensals. A few are parasitic. The mobile forms (Errantia) tend to have well-developed sense organs and jaws, while the stationary forms (Sedentaria) lack them but may have specialized gills or tentacles used for respiration and deposit or filter feeding, e.g., fanworms.

A few groups have evolved to live in terrestrial environments, like Namanereidinae with many terrestrial species, but are restricted to humid areas. Some have even evolved cutaneous invaginations for aerial gas exchange.

Sabellastarte indica



Tomopteris from plankton

Notable polychaetes

- One notable polychaete, the Pompeii worm (*Alvinella pompejana*) is endemic to the hydrothermal vents of the Pacific Ocean. Pompeii worms are among the most heat-tolerant complex animals known.
- A recently discovered genus, *Osedax*, includes a species nicknamed the "bone-eating snot flower".
- Another remarkable polychaete is *Hesiocaeca methanicola*, which lives on methane clathrate deposits.
- *Lamellibrachia luymesi* is a cold seep tube worm that reaches lengths of over 3 meters and may be the most long-lived animal at over 250 years old.
- A still unclassified multi-legged predatory polychaete worm was identified only by observation from the underwater vehicle Nareus at the bottom of the Challenger Deep, the greatest depth in the oceans, near 10,902 m (35,768 ft) depth. It was about an inch long visually, but the probe failed to capture it, so it could not be studied in detail.

Reproduction

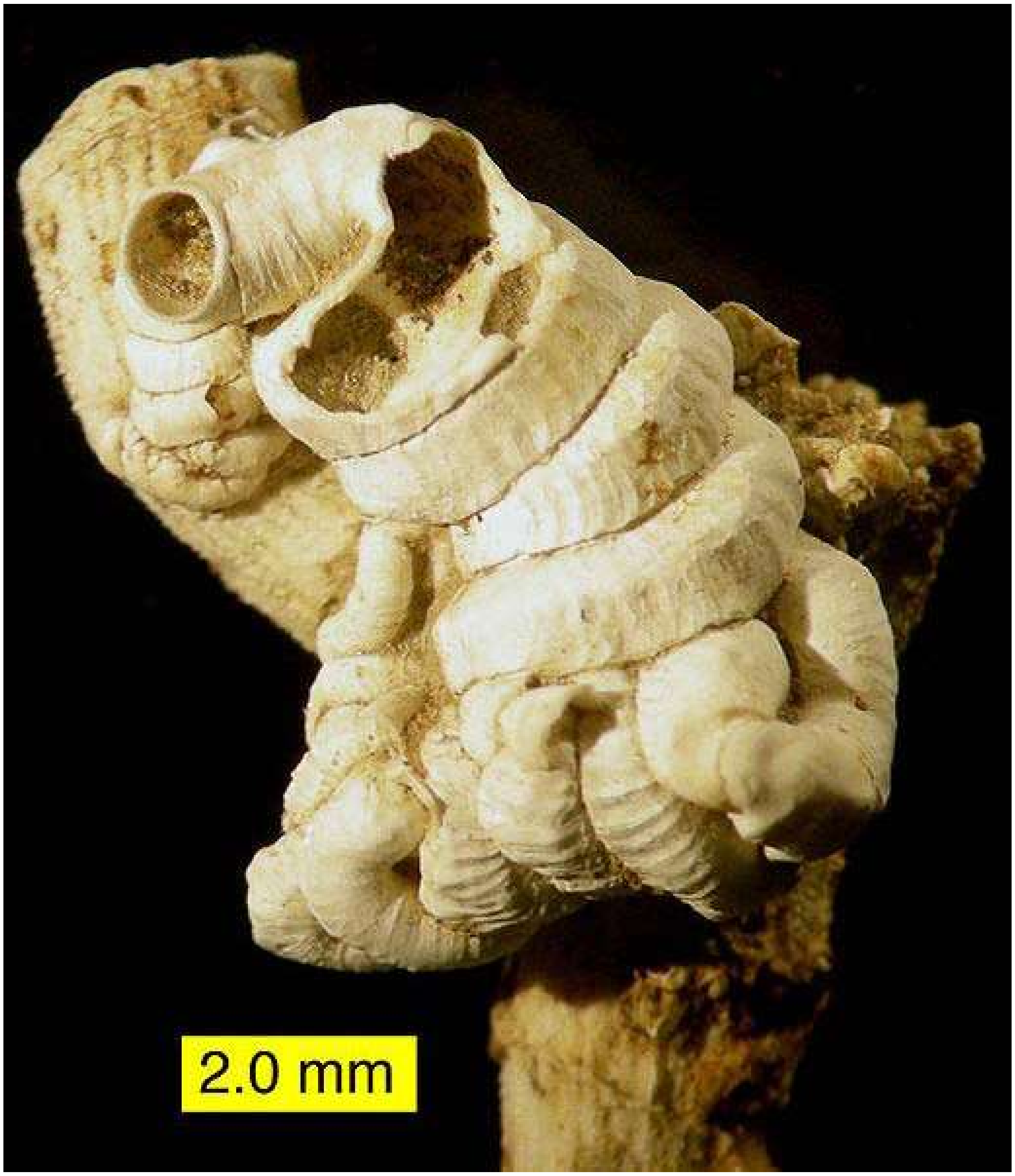
Most polychaetes have separate sexes, rather than being hermaphroditic. The most primitive species have a pair of gonads in every segment, but, in most species, there has been some degree of specialisation. The gonads shed immature gametes directly into the body cavity, where they complete their development. Once mature, the gametes are shed into the surrounding water through ducts or openings that vary between species, or in some cases by the complete rupture of the body wall (and subsequent death of the adult). A few species copulate, but most fertilise the eggs externally.

The fertilised eggs typically hatch into trochophore larvae, which float among the plankton, and eventually metamorphose into the adult form by adding segments. A few species have no larval form, with the egg hatching into a form resembling the adult, and in many that do have larvae, the trochophore never feeds, surviving off the yolk that remains from the egg.

Some of the polychaetes exhibit remarkable reproductive strategies. Some species in the genus *Eunicie* reproduce by a process called epitoky. For much of the year, these worms look like any other burrow-dwelling polychaete, but as the breeding season approaches the worm undergoes a remarkable transformation as new, specialized segments begin to grow from its rear end until the worm can be clearly divided into two halves. The front half, the atoke, is asexual. The new rear half is responsible for breeding and is known as the epitoke.

Each of the epitoke segments is packed with eggs and sperm and features a single eyespot on its surface. The beginning of the last lunar quarter is the cue for these animals to breed and the epitokes break free from the atokes and float to the surface. The eye spots sense when the epitoke reaches the surface and the segments from millions of worms burst, releasing their eggs and sperm into the water.

Fossil record



Tube of a serpulid worm attached to a branch of the coral *Cladocora* from the Pliocene of Cyprus.

The oldest crown-group polychaete fossils come from the Sirius Passet Lagerstatte, a rich, sedimentary deposit in Greenland tentatively dated to the late Atdabanian (early Cambrian). Many of the more famous Burgess Shale organisms, such as *Canadia* and *Wiwaxia*, may also have polychaete affinites. An even older fossil, *Cloudina*, dates to the terminal Ediacaran period; this has been interpreted as an early polychaete, although consensus is absent.

Being soft bodied, the fossil record of polychaetes is dominated by their fossilized jaws, known as scolecodonts, and the mineralized tubes that some of them secrete. However, their cuticle does have some preservation potential; it tends to survive for at least 30 days after a polychaete's death. Although biomineralisation is usually necessary to preserve soft tissue after this time, the presence of polychaete muscle in the non-mineralised Burgess shale shows that this need not always be the case. Their preservation potential is similar to that of jellyfish.

Taxonomy and systematics

Taxonomically, polychaetes are thought to be paraphyletic, meaning that the group contains its most recent common ancestor, but does not contain all descendants of that ancestor. Groups that may be descended from the polychaetes include the earthworms, leeches, sipunculans, and echiurans. The Pogonophora and Vestimentifera were once considered separate phyla, but are now classified in the polychaete family Siboglinidae.

Much of the classification below matches Rouse & Fauchald, 1998, although that paper does not apply ranks above family.

Older classifications recognize many more (sub)orders than the layout presented here. As comparatively few polychaete taxa have been subject to cladistic analysis, some groups which are usually considered invalid today may eventually be reinstated.

Subclass Palpata
Order Aciculata

- Basal or *incertae sedis*
    - Family Aberrantidae
    - Family Nerillidae
    - Family Spintheridae
- Suborder Eunicida
    - Family Amphinomidae
    - Family Diurodrilidae
    - Family Dorvilleidae
    - Family Eunicidae
    - Family Euphrosinidae
    - Family Hartmaniellidae
    - Family Histriobdellidae
    - Family Lumbrineridae
    - Family Oenonidae
    - Family Onuphidae

Suborder Phyllodocida

- Family Acoetidae
- Family Alciopidae

- Family Aphroditidae
- Family Chrysopetalidae
- Family Eulepethidae
- Family Glyceridae
- Family Goniadidae
- Family Hesionidae
- Family Ichthyotomidae
- Family Iospilidae

- Family Lacydoniidae
- Family Lopadorhynchidae
- Family Myzostomatidae
- Family Nautillienellidae
- Family Nephtyidae
- Family Nereididae
- Family Paralacydoniidae
- Family Pholoidae
- Family Phyllodocidae
- Family Pilargidae
- Family Pisionidae
- Family Polynoidae
- Family Pontodoridae
- Family Sphaeodoridae
- Family Syllidae
- Family Typhloscolecidae

Order Canalipalpata

- Basal or *incertae sedis*
  - Family Polygordiidae
  - Family Protodrilidae
  - Family Protodriloididae
  - Family Saccocirridae
- Suborder Sabellida
  - Family Oweniidae
  - Family Siboglinidae (formerly the phyla Pogonophora & Vestimentifera)

- Family Serpulidae
- Family Sabellidae
- Family Sabellariidae

Suborder Spionida

- Family Apistobranchidae
- Family Chaetopteridae
- Family Longosomatidae
- Family Magelonidae

- Family Poecilochaetidae
- Family Spionidae
- Family Trochochaetidae
- Family Uncispionidae

Suborder Terebellida

- Family Acrocirridae (sometimes placed in Spionida)
- Family Alvinellidae
- Family Ampharetidae
- Family Cirratulidae (sometimes placed in Spionida)
- Family Ctenodrilidae (sometimes own suborder Ctenodrilida)
- Family Fauveliopsidae (sometimes own suborder Fauveliopsida)
- Family Flabelligeridae (sometimes suborder Flabelligerida)
- Family Flotidae (sometimes included in Flabelligeridae)
- Family Pectinariidae
- Family Poeobiidae (sometimes own suborder Poeobiida or included in Flabelligerida)
- Family Sternaspidae (sometimes own suborder Sternaspida)
- Family Terebellidae
- Family Trichobranchidae

- **Subclass Scolecida**

  - Family Aeolosomatidae
  - Family Arenicolidae
  - Family Capitellidae
  - Family Cossunidae
  - Family Maldanidae
  - Family Opheliidae
  - Family Orbiniidae
  - Family Paraonidae
  - Family Parergodrilidae
  - Family Potamodrilidae
  - Family Psammodrilidae
  - Family Questidae
  - Family Scalibregmatidae

Chapter- 3

Clitellata and Oligochaeta

Clitellata

Clitellata	

Earthworm

Scientific classification	
Kingdom:	Animalia
Phylum:	Annelida
Class:	**Clitellata**

Subclasses

Branchiobdellae
Hirudinea
"Oligochaeta" (paraphyletic)

Clitellata is a class of Annelid worms, characterized by having a clitellum - the 'collar' that forms a reproductive cocoon during part of their life cycle. The **clitellates** comprise around 8,000 species. Unlike the class of Polychaeta, they do not have parapodia and their heads are less developed.

Habitats

Most clitellates live on land, in freshwater and in the ocean.

Reproduction

All clitellata are hermaphrodites. During reproduction, the clitellum secretes a coat which hardens. The worm then creeps out backward from the coat and deposits either fertilized zygotes or both ovae and sperms into the coat, which is then packed into a cocoon. The zygotes then evolve further directly in the cocoon without passing through a larva stadium (as opposed to other annelids, e.g. polychaeta.) This mechanism is considered to be apomorphic (newer in evolution).

Systematics

- Branchiobdella - formerly in Hirudinea
- Hirudinea (leeches)
- Oligochaeta (earthworms - aquatic microdriles + terrestrial megadriles)

The Acanthobdellidea are sometimes moved out of the Hirudinea as a distinct subclass too. Overall. clitellate phylogeny is not well resolved.

Namely, the Acanthobdellidea, Branchiobdella and Hirudinea are monophyletic but actually embedded among the "Oligochaeta", which are actually an evolutionary grade of lineages that are outwardly similar but not actually very close relatives. In particular, the leeches and earthworms appear to be very close relatives. Two approaches are possible:

- abolish Oligochaeta as traditionally delimited in favor of a number of smaller monophyletic lineages
- treat Oligochaeta and Clitellata as synonymous while splitting up the traditional "oligochaetes" into monophyletic lineages.

Oligochaeta

Oligochaeta	
	
Earthworm (*Lumbricus terrestris*)	
Scientific classification	
Kingdom:	Animalia
Phylum:	Annelida
Class:	Clitellata
Subclass:	**Oligochaeta**
Orders	
Haplotaxida Lumbriculida Moniligastrida	

Oligochaeta is a subclass of animals in the biological phylum Annelida, which is made up of many types of aquatic and terrestrial worms, and this includes all of the various earthworms. Specifically, it contains the terrestrial megadrile earthworms (some of which are semi- or fully aquatic), and freshwater or semi-terrestrial microdrile forms including the tubificids, pot worms and ice worms (Enchytraeidae), blackworms (Lumbriculidae) and several interstitial marine worms.

With around 10,000 known species the Oligochaeta make up about one half of the phylum Annelida.

These worms usually have few setae (chaetae) or "bristles" on the outer body surface, and lack parapodia, unlike polychaeta.

Common characteristics

Oligochaetes are well-segmented worms and most have a spacious body cavity (coelom) that is used as a hydroskeleton. They range in length from less than 0.5 millimetres (0.020 in) up to 2 to 3 metres (6.6 to 9.8 ft) in the 'giant' species such as the giant Gippsland earthworm and the Mekong Worm *Amynthas mekongianus* (Cognetti, 1922).

The first segment, or prostomium, of oligochaetes is usually a smooth lobe or cone without sensory organs, although it is sometimes extended to form a tentacle. The remaining segments have no appendages, but they do have a small number of bristles, or setae. These tend to be longer in aquatic forms than in the burrowing earthworms, and can have a variety of shapes. Oligochaetes are able to reproduce via insertion of a penis into an orifice called a vagina.

Each segment has four bundles of setae, with two igloos on the underside, and the others on the sides. The bundles can contain anything from one to twenty-five setae, and include muscles to pull them in and out of the body. This enables the worm to gain a grip on the soil or mud as it burrows into the substrate. When burrowing, the body moves peristaltically, alternately contracting and stretching to push itself forward.

A number of segments in the forward part of the body are modified by the presence of numerous secretory glands. Together, they form the clitellum, which is important in reproduction.

Internal anatomy

Most Oligochaetes are detritus feeders, although some genera are predaceous, such as *Agriodrilus* and *Phagodrilus*. The digestive tract is essentially a tube running the length of the body, but has a powerful muscular pharynx immediately behind the mouth cavity. In many species, the pharynx simply helps the worm suck in food, but in many aquatic species, it can be turned inside out and placed over food like a suction cup before being pulled back in.

The remainder of the digestive tract may include a crop for storage of food, and a gizzard for grinding it up, although these are not present in all species. The oesophagus includes "calciferous glands" that maintain calcium balance by excreting indigestible calcium carbonate into the gut. A number of yellowish "chloragogen cells" surround the intestine and the dorsal blood vessel, forming a tissue that functions in a similar fashion to the vertebrate liver. Some of these cells also float freely in the body cavity, where they are referred to as "eleocytes".

Most oligochaetes have no gills or similar structures, and simply breathe through their moist skin. The few exceptions generally have simple, filamentous gills. Excretion is through small ducts known as metanephridia. Terrestrial oligochaetes secrete urea, but the aquatic forms typically secrete ammonia, which dissolves rapidly into the water.

The vascular system consists of two main vessels connected by lateral vessels in each segment. Blood is carried forward in the dorsal vessel (in the upper part of the body) and back through the ventral vessel (underneath), before passing into a sinus surrounding the intestine. Some of the smaller vessels are muscular, effectively forming hearts; from one to five pairs of such hearts is typical. The blood of oligochaetes contains haemoglobin in all but the smallest of species, which have no need of respiratory pigments.

The nervous system consists of two ventral nerve cords, which are usually fused into a single structure, and three to four pairs of smaller nerves per body segment. Only a few aquatic oligochaetes have eyes, and even then they are only simply ocelli. Nonetheless, their skin has several individual photoreceptors, allowing the worm to sense the presence of light, and burrow away from it. Oligochaetes can taste their surroundings using chemoreceptors located in tubercles across their body, and their skin is also supplied with numerous free nerve endings that presumably contribute to their sense of touch.

Life cycle

Earthworms are hermaphrodites, which means that each animal has both male and female reproductive organs. They have external fertilization (except for some members of the African family Eudrilidae), but copulate and store sperm in a receptacle called a spermatheca. When two earthworms mate, both worms typically fertilize each other. Like leeches, they have a clitellum which secretes a "cocoon" or capsule into which both eggs and sperm are deposited and acts as an incubator for the embryonic worms. The cocoon is deposited in the soil. On hatching, the young worms resemble small adults and grow continually until they reach maturity. They lack a trochophore larval stage.

Habitat

Earthworms typically live in various types of soil or mud, as well as organic matter such as compost or even feces. They are found on every continent except Antarctica. Native earthworm species are often eradicated from natural areas as people clear native vegetation and introduced species become more dominant in these disturbed habitats. Introduced earthworms are most common in disturbed environments such as suburban gardens and farmland paddocks.

Families

The following list of Oligochaeta families follows ICZN conventionn so that family-group name (ending in -idae) is followed by authorship and date.

Oligochaete worm

- Randiellidae (Erséus & Strehlow, 1986)
- Tubificidae (Vejdovsky, 1884 (including Naidinae Ehrenberg, 1831))
- Narapidae (Righi, 1983)
- Opistocystidae (Cernosvitov, 1936)
- Dorydrilidae (Cook, 1971)
- Parvidrilidae (Erséus, 1999)
- Phreodrilidae (Beddard, 1891)
- Propappidae (Coates, 1986)
- Haplotaxidae (Michaelsen, 1900)
- Tiguassuidae (Brinkhurst, 1988)
- Lumbriculidae (Vejdovsky, 1884)
- Enchytraeidae (Vejdovsky, 1879)
- Moniligastridae (Claus, 1880)
- Alluroididae (Michaelsen, 1900)
- Syngenodrilidae (Smith and Green, 1919)
- Glossoscolecidae (Michaelsen, 1900)
- Tumakidae (Righi, 1995)
- Ailoscolecidae (Bouché, 1969) (including Komarekionidae Gates, 1974)
- Sparganophilidae (Michaelsen, 1918)

- Microchaetidae (Michaelsen, 1900)
- Lumbricidae Claus, 1876 (including Diporodrilinae Bouché, 1970; Eiseniinae Omodeo, 1956; Spermophorodrilinae Omodeo & Rota, 1989; Postandrilinae Qiu & Bouché, 1998; Allolobophorinae Kvavadze, 2000 and Helodrilinae Kvavadze, 2000)
- Kynotidae - Brinkhurst & Jamieson, 1971
- Hormogastridae Michaelsen, 1900 (including Vignysinae Bouché, 1970 and Xaninae Diaz Cosin *et al.*, 1989)
- Lutodrilidae McMahan, 1978
- Criodrilidae Vejdovsky, 1884 (including Biwadrilidae Brinkhurst & Jamieson, 1971)
- Almidae Duboscq, 1902
- Ocnerodrilidae Beddard, 1891 (including Malabariinae Gates, 1966)
- Acanthodrilidae Claus, 1880 (including Diplocardiinae Michaelsen, 1900)
- Octochaetidae Michaelsen, 1900 (including Benhamiinae Michaelsen, 1895/7)
- Exxidae Blakemore, 2000
- Megascolecidae Rosa, 1891 (including Pontodrilinae Vejdovsky, 1884; Plutellinae Vejdovsky, 1884 and Argilophilinae Fender & McKey-Fender, 1990)
- Eudrilidae Claus, 1880.

Chapter- 4

Leech

Leech	
	
Hirudo medicinalis	
Scientific classification	
Kingdom:	Animalia
Phylum:	Annelida
Class:	Nasteh
Subclass:	**Hirudinea** Lamarck, 1818
Infraclasses	
Acanthobdellidea Euhirudinea	

Leeches are annelids comprising the subclass **Hirudinea**. There are freshwater, terrestrial, and marine leeches. Like the Oligochaeta, they share the presence of a clitellum. Like earthworms, leeches are hermaphrodites. Some, but not all, leeches are hematophagous.

The European medical leech, *Hirudo medicinalis*, and some congeners, as well as some other species, have been used for clinical bloodletting for thousands of years, although most leeches do not feed on human blood, but instead prey on small invertebrates, which they eat whole.

Haemophagic leeches attach to their hosts and remain there until they become full, at which point they fall off to digest. A leech's body is composed of 34 segments. They all have an anterior (oral) sucker formed from the first six segments of their body, which is used to connect to a host for feeding, and also release an anesthetic to prevent the host from feeling the leech. They use a combination of mucus and suction (caused by concentric muscles in those six segments) to stay attached and secrete an anti-clotting enzyme, hirudin, into the host's blood stream.

Some species of leech will nurture their young, while providing food, transport, and protection, which is unusual behavior amongst annelids.

Systematics and taxonomy

Leeches are presumed to have evolved from certain Oligochaeta, most of which feed on detritus. However, some species in the Lumbriculidae are predatory and have similar adaptations as found in leeches. Consequently, the systematics and taxonomy of leeches is in need of review. While leeches form a clade, the remaining oligochetes are not their sister taxon but a diverse paraphyletic group containing some lineages that are closely related to leeches, and others that are far more distant.

There is some dispute as to whether Hirudinea should be a class itself, or a subclass of the Clitellata. The resolution mainly depends on the eventual fate of the oligochaetes, which as noted above do not form a natural group as traditionally circumscribed. Another possibility would be to include the leeches in the taxon Oligochaeta, which would then be ranked as a class and contain most of the clitellates. The Branchiobdellida are leechlike clitellates which were formerly included in the Hirudinea but are apparently just really close relatives.

Leech climbing a door by Lake Leake, Tasmania

The more primitive Acanthobdellidea are often included with the leeches, but some authors treat them as a separate clitellate group. True leeches of the infraclass Euhirudinea have both anterior and posterior suckers. They are divided into two groups: Arhynchobdellida and Rhynchobdellida

- Rhynchobdellida): "Jawless" leeches, armed with a muscular straw-like proboscis puncturing organ in a retractable sheath. The Rhynchobdellae consist of two families:
  - Glossiphoniidae: Flattened leeches with a poorly defined anterior sucker
  - Piscicolida: have cylindrical bodies and a usually well-marked, bell-shaped, anterior sucker. The Glossiphoniidae live in fresh-water habitats; the Pisciolidae are found in seawater habitats.

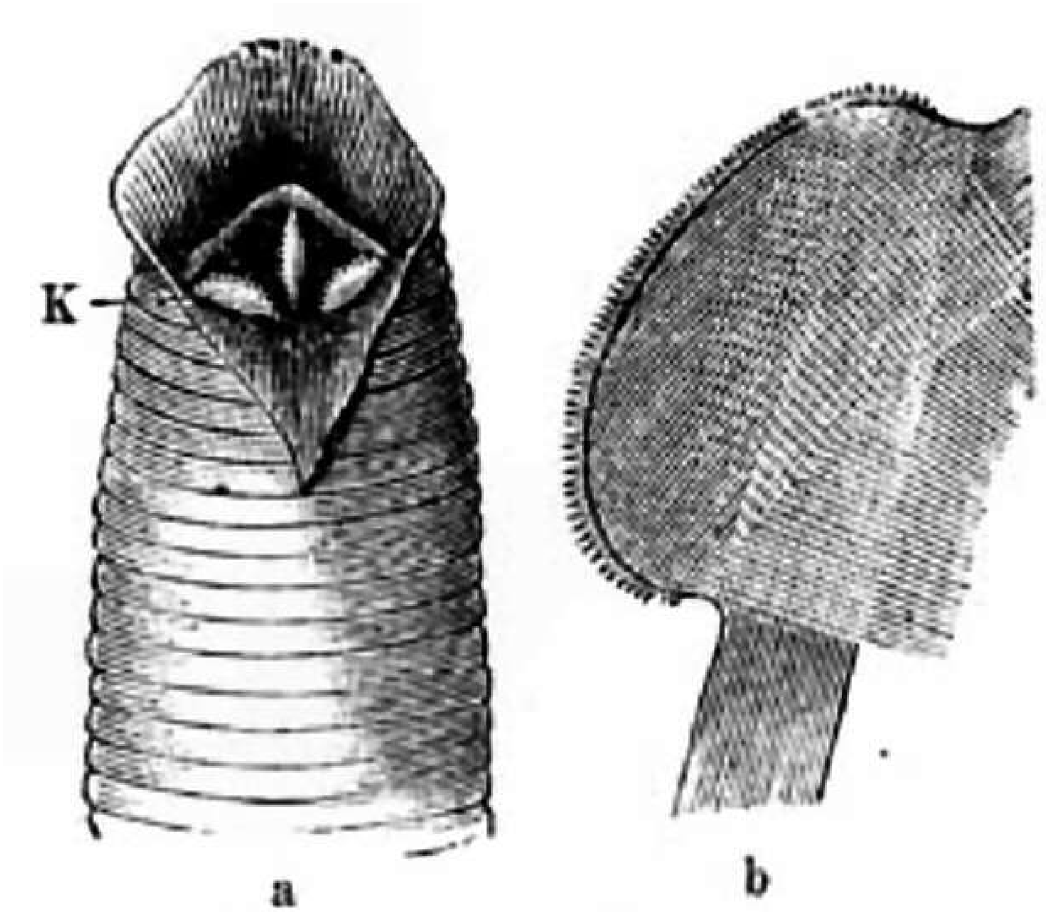
- Arhynchobdellida: Leeches which lack a proboscis and which may or may not have jaws armed with teeth. Arhynchobellids are divided into two orders:
  - Gnathobdela: In this order of "jawed" leeches, armed with teeth, is found the quintessential leech: the European medical (bloodsucking) leech, *Hirudo medicinalis*. It has a tripartite-jaw filled with hundreds of tiny sharp teeth. The incision mark left on the skin by the European medical leech is an inverted Y inside a circle. Its North American counterpart is *Macrobdela decora*, a much less efficient medical leech. Within this order, the family Hirudidae is characterized by aquatic leeches and the family Haemadipsidae by terrestrial leeches. In the latter are *Haemadipsa sylvestris*, the Indian leech and *Haemadipsa zeylanica* (yamabiru), the Japanese mountain or land leech.
  - Pharyngobdella: These so called worm-leeches consist of freshwater or amphibious leeches that have lost the ability to penetrate a host's tissue and suck blood. They are carnivorous and equipped with a relatively large, toothless, mouth to ingest worms or insect larvae, which are swallowed whole.
    The Pharyngobdella have six to eight pairs of eyes, as compared with five pairs in Gnathobdelliform leeches, and include three related families. The Erpobdellidae are some species from freshwater habitats.

Reproduction

Leeches are hermaphrodites, meaning each one of them has both female and male reproductive organs (ovaries and testes respectively). Leeches reproduce by reciprocal fertilization, and sperm transfer occurs during copulation. Similarly to the earthworms, leeches also use a clitellum to hold their eggs and secrete the cocoon.

During reproduction leeches utilize hyperdermic injection of their sperm. They use a spermatophore, which is a structure containing the sperm. Once next to another leech, the two will line up with their anterior side opposite the other's posterior. The leech then shoots the spermatophore into the clitellur region of the opposing leech where its sperm will make its way to the female reproductive parts.

Nutrition



Mouthparts and sucker

A leech swollen with blood

Leech attacking a slug

On haematophagous leeches, the digestive system starts with the jaw which is located ventrally on the anterior side of the body. It is attached to the pharynx, then the esophagus extending to the crop,then to the gizzard, which leads to the intestinum, where it ends at the posterior sucker. The crop is a type of stomach that works like an expandable storage compartment. The crop allows a leech to store blood up to five times its body size; and because the leech produces an anti-coagulant, the stored blood remains in a liquid state; because of this ability to hold blood without the blood decaying, due to bacteria living inside the crop, medicinal leeches only need to feed two times a year.

The body of predatory leeches are similar, though some may also have a protrusible proboscis which is retracted in their mouth. Such leeches are often ambush predators, which lie in wait, and strike their prey using their proboscis in a spear-like fashion.

It was long thought that bacteria in the gut carried on digestion for the leech instead of endogenous enzymes which are very low or absent in the intestine. Relatively recently it has been discovered that all leeches and leech species studied do produce endogenous intestinal exopeptidases, which can unlink free terminal-end amino acids, one amino acid monomer at a time, from a gradually unwinding and degrading protein polymer. However, unzipping of the protein can start from either the amino (tail) or carboxyl (head) terminal-end of the protein molecule. It just so happens that the leech exopeptidase (arylamidases), possibly aided by proteases from endosymbiotic bacteria in the intestine, starts from the tail or amino protein, free-end, slowly but progressively removing many hundreds of individual terminal amino acids for resynthesis into proteins that constitute the leech. Since leeches lack endopeptidases, the mechanism of protein digestion can not follow the same sequence as it would in all other animals where exopeptidases act sequentially on peptides produced by the action of endopeptidases. Exopeptidases are especially prominent in the common North American worm-leech *Erpobdella punctata*. This evolutionary choice of exopeptic digestion in Hirudinea distinguishes these carnivorous clitellates from Oligochaeta.

Deficiency of digestive enzymes (except exopeptidases) but more importantly deficiency of vitamins, B complex for example, in leeches is compensated for by enzymes and vitamins produced by endosymbiotic microflora. In *Hirudo medicinalis* these supplementary factors are produced by an obligatory symbiotic relationship with two bacterial species, *Aeromonas veronii* and a still uncharacterized *Rikenella* species. Non-bloodsucking leeches such as *Erpobdella punctata* are host to three bacterial symbionts, *Pseudomonas sp.*, *Aeromonas sp.*, and *Klebsiella sp.* (a slime producer). The bacteria are passed from parent to offspring in the cocoon as it is formed.

Leech bites

Effects

Though certain species of leeches feed on blood, not all species can bite; 90% of them solely feed off decomposing bodies and open wounds of amphibians, reptiles, waterfowl, fish, and mammals (including, but not limited to, humans). A leech attaches itself when it bites, and it will stay attached until it has had its fill of blood. Due to an anticoagulant (hirudin) that leeches secrete, bites may bleed more than a normal wound after the leech is removed. The effect of the anticoagulant will wear off several hours after the leech is removed and the wound is cleaned.

Leeches normally carry parasites in their digestive tract which cannot survive in humans and do not pose a threat. However, bacteria, viruses, and parasites from previous blood sources can survive within a leech for months, and may be retransmitted to humans. A study found both HIV and hepatitis B in African leeches from Cameroon.

Removal

Hand removing a land leech—since they do not burrow into the skin nor the head in the wound. A sore develops and lasts for about a week. Grande Ronde River, Oregon (U.S.)

One recommended method of removal is using a fingernail or other flat, blunt object can break the seal of the oral sucker at the anterior end (the smaller, thinner end) of the leech, repeating with the posterior end, then flicking the leech away. As the fingernail is pushed along the person's skin against the leech, the suction of the sucker's seal is broken, at which point the leech should detach its jaws.

Common but medically inadvisable techniques to remove a leech are to apply a flame, a lit cigarette, salt, soap, or a chemical such as alcohol, vinegar, lemon juice, insect repellent, heat rub, or certain carbonated drinks. These cause the leech to regurgitate its stomach contents into the wound and quickly detach. However, the vomit may carry disease, and thus increase the risk of infection.

An externally attached leech will detach and fall off on its own when it is satiated on blood, which may be anywhere from 20 min. to 2 hours or more. Usually an hour is needed After finishing his dinner the leech will detach and move away or just roll off that portion of the body. Internal attachments, such as nasal passage or vaginal attachments, are more likely to require medical intervention.

Treatment

After removal or detachment, the wound should be cleaned with soap and water, and bandaged. Bleeding may continue for some time, due to the leech's anti-clotting enzyme. Bleeding time will vary with location (some areas of the back bleed less than areas on the calves or thighs for example). Bleeding time may vary from just a few hours to perhaps as much as three days. This is a function of not only the hirudin but of other compounds(unspecified) that reduce the surface tension of the blood. Another factor would be if the patient were on anti-clotting medications at the time of leech therapy. Applying pressure can reduce bleeding, although blood loss from a single bite is not dangerous. The wound normally itches as it heals, but should not be scratched as this may complicate healing and introduce other infections. An antihistamine can reduce itching, and applying a cold pack can reduce pain or swelling.

Some people suffer severe allergic or anaphylactic reactions from leech bites, and require urgent medical care. Symptoms include red blotches or an itchy rash over the body, swelling away from the bitten area (especially around the lips or eyes), feeling faint or dizzy, and difficulty breathing.

Prevention

There is no guaranteed method of preventing leech bites in leech-infested areas. The most reliable method is to cover exposed skin. The effect of insect repellents is disputed, but it is generally accepted that strong (maximum strength or tropical) insect repellents do help prevent bites.

Leech socks can be helpful in preventing bites when the full body will not be at risk of contact with leeches. Leech socks are pulled over the wearer's trousers to prevent leeches reaching the exposed skin of the legs and attaching there or climbing towards the torso. The socks are generally a light color that also makes it easier to spot leeches climbing up from the feet and looking for skin to attach to.

There are many home remedies to help prevent leech bites. Many people have a great deal of faith in these methods, but none of them have been proven effective. Some home remedies include: a dried residue of bath soap, tobacco leaves between the toes, pastes of salt or baking soda, citrus juice, Neem oil and eucalyptus oil. Diluted calcium hydroxide may also be used as a repellent, but may be damaging or irritating to the skin. One other remedy commonly practiced in the western ghats of southern India is castor oil mixed with snuff powder, or powdered tobacco.

Hirudotherapy

The term refers to the use of leeches in medicine.

The use of leeches in medicine dates as far back as 2,500 years ago when they were used for bloodletting in ancient India. Leech therapy is explained in ancient Ayurvedic texts. Many ancient civilizations practiced bloodletting including Indian and Greek civilizations. In ancient Greek history, bloodletting was practiced according to the humoral theory, which proposed that when the four humors, blood, phlegm, black and yellow bile in the human body were in balance, good health was guaranteed. An imbalance in the proportions of these humors was believed to be the cause of ill health. Records of this theory were found in the Greek philosopher Hippocrates' collection in the fifth century B.C. Bloodletting using leeches was one method used by physicians to balance the humors and to rid the body of the plethora.

The use of leeches in modern medicine made its comeback in the 1980s after years of decline, with the advent of microsurgery such as plastic and reconstructive surgeries. In operations such as these, one problem that arises is venous congestion due to inefficient venous drainage. Sometimes because of the technical difficulties in forming an anastomosis of a vein, no attempt is made to re-attach a venous supply to a flap at all. This condition is known as venous insufficiency. If this congestion is not cleared up quickly, the blood will clot, arteries that bring the tissues their necessary nourishment will become plugged and the tissues will die. To prevent this leeches are applied to a congested flap and a certain amount of excess blood is consumed before the leech falls away. The wound will also continue to bleed for a while due to the anticoagulant (hirudin) in the leeches' saliva. The combined effect is to reduce the swelling in the tissues and promoting healing by allowing fresh, oxygenated blood to reach the area.

The active anticoagulant principle of leech saliva, is a small protein, hirudin. Discovery and isolation of this protein led to a method of producing it by recombinant technology. Recombinant hirudin is available to physicians as an intravenous anticoagulant preparation for injection, particularly useful for patients who are allergic to or cannot tolerate heparin.

Embryonic development

The first cleavage during early embryonic development in leech occurs at stage 2. This cleavage gives rise to an AB and a CD blastomere and is in the interphase of this cell division when a yolk-free cytoplasm called teloplasm is formed. The teloplasm is known to be a determinant for the specification of the D cell fate. In stage 3, during the second cleavage, an unequal division occurs in the CD blastomere. As a consequence, it creates a big D cell on the left and a smaller C cell to the right. This unequal division process is dependent on actinomycin, and by the end of stage 3 the AB cell divides. On stage 4 of development, the micromeres and teloblast stem cells are formed and subsequently, the D quadrant divides to form the DM and the DNOPQ teloblast precursor cells. By the end stage 6, the zygote contains a set of 25 micromeres, 3 macromeres (A, B and C) and 10 teloblasts derived from the D quadrant.

The teloblast are pairs of five different types (M, N, O, P and Q) of embryonic stem cells that form segmented columns of cells (germinal-band) in the surface of the embryo. The M-derived cells make mesoderm and some small set of neurons, N results in neural tissues and some ventral ectoderm, Q contributes to the dorsal ectoderm and O and P in the leech are equipotent cells (same developmental potential) that produce lateral ectoderm; however the difference between the two of them is that P creates bigger batches of dorso-lateral epidermis than O. The sludgeworm *Tubifex*, unlike the leech, specifies the O and P lineages early in development and therefore, these two cells are not equipotent. Each segment of the body of the leech is generated from one M, O, P cell types and two N and two Q cells types.

The ectoderm and mesoderm of the body trunk is exclusively derived from the teloblast cells in a region called posterior progress zone. The head of the leech that come from a non-segmented region, is formed by the first set of micromeres derived from A, B, C and D cells, keeping the bilateral symmetry between the AD and BC cells.

Chapter- 5

Echiura and Haplodrili

Echiura

Echiura	
Temporal range: Upper Carboniferous–Recent	

Bonellia viridis, female

Scientific classification	
Kingdom:	Animalia
Phylum:	Annelida
Class:	**Echiura** Newby, 1940

Orders

Echiuroidea
Heteromyota
Xenopneusta

The **Echiura**, or spoon worms, are a small group of marine animals. They are often considered to be a group of annelids, although they lack the segmented structure found in other members of that group, and so may also be treated as a separate phylum. However, phylogenetic analyses of DNA sequences place echiurans and pogonophorans within the

Annelida. The Echiura fossilise poorly and the earliest known specimen is from the Upper Carboniferous (called the Pennsylvanian in North America). However, U-shaped fossil burrows that could be Echiuran have been found dating back to the Cambrian.

Echiurans are marine worms similar in size and habit to sipunculans. Many genera, such as *Echiurus*, *Urechis*, and *Ikeda*, live in burrows in sand and mud; others live in rock and coral crevices. One species, *Thalassema mellita*, which lives off the southeastern coast of the US, inhabits the tests (exoskeleton) of dead sand dollars. When the worm is very small, it enters the test and later becomes too large to leave.

The majority of echiurans live in shallow water, but there are also deep sea forms. About 140 species have been described.

Anatomy

Echiura at a market in South Korea

Echiurans have a worm-like body with a large flattened proboscis projecting forward from the head. The body is typically drab in colour, but bright red and green species are known. The proboscis is a sheet-like structure, rolled around into a cylindrical tube with an open gutter at the ventral surface. The length of the proboscis varies greatly between species, and in some species is many times longer than the rest of the body. It is probably homologous with the prostomium of other annelids.

Compared with other annelids, echiurans have relatively few setae. In most species, there are just two, located on the underside of the body just behind the proboscis. In others, such as *Echiurus*, there are also further setae near the posterior end of the animal. Unlike other annelids, adult echiurans have no trace of segmentation.

The digestive system consists of a simple tube running the length of the body, with the anus being at the posterior end. The tube, however, is highly coiled, giving it a considerable length in relation to the size of the animal. A pair of simple or branched diverticula are connected to the rectum. These are lined with numerous minute ciliated funnels that open directly into the body cavity, and are presumed to be excretory organs.

Although some species lack a blood vascular system, where it is present, it resembles that of other annelids. The blood is essentially colourless, although some haemoglobin-containing cells are present in the coelomic fluid of the main body cavity. There can be anything from one to over a hundred metanephridia for excreting nitrogenous waste, which typically open near the anterior end of the animal.

Echiruans do not have a distinct respiratory system, absorbing oxygen through the body wall.

The nervous system consists of a brain near the base of the proboscis, and a ventral nerve cord running the length of the body. Aside from the absence of segmentation, this is a a similar arrangement to that of other annelids. Echiurans do not have any eyes or other distinct sense organs.

Feeding

Typical spoon worms, including *Bonellia*, are suspension feeders, projecting their proboscis out of their burrows, with the gutter projecting upwards. Edible particles will then settle onto the proboscis and a ciliated channel conducts the food to the trunk.

Perhaps the most remarkable feeding adaptations among the spoon worms can be seen in *Urechis*. *U. caupo* lives in a large, U-shaped burrow and by pulsating its body it drives water through its lair. To feed, it produces a conical mucus net that lines the burrow as water is sucked in at a rate of about 18L per hour. Edible particles are caught on the net, and after some time the worm slowly eats the net and all the edible matter sticking to it.

Reproduction

Echiruans are dioecious, with separate male and female individuals. The gonads are associated with the peritoneal membrane lining the body cavity, into which they release the gametes. The sperm and eggs complete their maturation in the body cavity, before being released into the surrounding water through the metanephridia. Fertilisation is external.

The species *Bonellia viridis*, also remarkable for the possible antibiotic properties of bonellin, the green chemical in its skin, is unusual for its extreme sexual dimorphism. Females are typically 8 centimetres (3.1 in) in body length, excluding the proboscis, but the males are only 1 to 3 millimetres (0.039 to 0.12 in) long, and spend their lives within the uterus of the female.

Fertilized eggs hatch into free-swimming trochophore larvae. In some species, the larva briefly develops a segmented body before transforming into the adult body plan, supporting the theory that echiruans evolved from segmented ancestors resembling more typical annelids.

Haplodrili

Haplodrili, or **Archiannelida**, is a primitive marine worm part of the annelid phylum. Zoologist Ray Lankester gave it its name of Haplodrili, while zoologist Berthold Hatschek named it Archiannelida.

Overview

Polygordius and Protodrilus live in sand, but while the former moves by means of the contraction of its body-wall muscles, Protodrilus can progress by the action of the bands of cilia surrounding its segments, and of the longitudinal ciliated ventral groove. Saccocirrus, which also lives in sand, and more closely resembles the Polychaeta, has throughout the greater length of its body on each segment a pair of small uniramous parapodia bearing a bunch of simple setae. No other member of the group is known to have any trace of setae or parapodia at any stage of development.

Commonality

These three genera have the following characters in common. The body is small and resembles polychaete larvae, epidermis ciliated, the number of segments varies from five and up or can be completely absent, small prostomium with or without appendages, parapodia absent, septa reduced or absent, the nervous system consists of a brain and longitudinal ventral nerve cords closely connected with the epidermis (withotit distinct ganglia), widely separated in Saccocirrus, closely approximated in Protodrilus, fused together in Polygordius; the coelom is well developed and the dorsal and ventral longitudinal mesenteries are complete; the nephridia are simple, and open into the coelom. Polygordius differs from Protodrilus and Saccocirrus in the absence of a distinct suboesophageal muscular pouch, and in the absence of a peculiar closed cavity in the head region, which is especially well developed in Saccocirrus, and probably represents the specialized coelom of the first segment.

Moreover, in Saccocirrus the genital organs of a transverse section of Saccocirrus showing on the left side the organs in a genital segment of a male, and on the right side the organs in a genital segment of a female.

Chapter- 6

Earthworm

Earthworms

Lumbricus terrestris, the Common Earthworm

Scientific classification	
Kingdom:	Animalia
Phylum:	Annelida
Class:	Clitellata
Order:	Haplotaxida
Suborder:	**Lumbricina**

Families

Acanthodrilidae
Ailoscolidae
Alluroididae
Almidae (disputed)

Criodrilidae
Eudrilidae
Exxidae
Glossoscolecidae
Hormogastridae
Lumbricidae
Lutodrilidae
Megascolecidae
Microchaetidae
Ocnerodrilidae
Octochaetidae
Sparganophilidae

Earthworm is the common name for the largest members of Oligochaeta (which is either a class or subclass depending on the author) in the phylum Annelida. In classical systems they were placed in the order **Opisthopora**, on the basis of the male pores opening posterior to the female pores, even though the internal male segments are anterior to the female. Theoretical cladistic studies have placed them instead in the suborder **Lumbricina** of the order Haplotaxida, but this may again soon change. Folk names for the earthworm include "dew-worm", "Rainworm", "night crawler" and "angleworm" (due to its use as fishing bait).

Earthworms are also called **megadriles** (or big worms), as opposed to the microdriles (or small worms) in the families Tubificidae, Lumbriculidae, and Enchytraeidae, among others. The megadriles are characterized by having a distinct clitellum (which is much more obvious than the single-layered one of the microdriles) and a vascular system with true capillaries.

Anatomy

The basic body plan of an earthworm is a tube, the digestive system, within a tube, the muscular slimy, moist outer body. The body is annular, formed of segments that are most specialized in the anterior. Earthworms have a simple closed circulatory system. They have two main blood vessels that extend through the length of their body: a ventral blood vessel which leads the blood to the posterior end, and a dorsal blood vessel which leads to the anterior end. The dorsal vessel is contractile and pumps blood forward, where it is pumped into the ventral vessel by a series of "hearts" (aortic arches) which vary in number in the different taxa. The blood is distributed from the ventral vessel into capillaries on the body wall and other organs and into a vascular sinus in the gut wall, where gases and nutrients are exchanged. This arrangement may be complicated in the various groups by suboesophageal, supraoesophageal, parietal and neural vessels, but the basic arrangement holds in all earthworms. Most earthworms are decomposers feeding on undecayed leaf and other plant matter, others are more geophagous.

Reproduction

Earthworm reproduction

Earthworms are hermaphrodites: They typically have two pairs of testes, surrounded by 2 pairs of testes sacs. There are 2 or 4 pairs of seminal vesicles which produce, store and release the sperm via the male pores, and ovaries and ovipores in segment 13 that release eggs via female pores on segment 14. However, most also have one or more pairs of spermathecae (depending on the species) that are internal sacs which receive and store sperm from the other worm in copulation. Some species use external spermatophores for transfer instead.

Earthworm cocoons from *L. terrestris*

An earthworm cocoon from *L. rubellus*

Copulation and reproduction are separate processes in earthworms. The mating pair overlap front ends ventrally and each exchanges sperm with the other. The clitellum becomes very reddish to pinkish in color. The cocoon, or egg case, is secreted by the clitellum band which is near the front of the worm, but behind the spermathecae. Some time after copulation, long after the worms have separated, the clitellum secretes the cocoon which forms a ring around the worm. The worm then backs out of the ring, and as it does so, injects its own eggs and the other worm's sperm into it. As the worm slips out, the ends of the cocoon seal to form a vaguely lemon-shaped incubator (cocoon) in which the embryonic worms develop. They emerge as small, but fully formed earthworms, except for a lack of the sex structures, which develop later in about 60 to 90 days. They attain full size in about one year, sometimes sooner. Scientists predict that the average lifespan under field conditions is 4–8 years, still most garden varieties live only one to two years. Several common earthworm species are mostly parthenogenetic, that is, with asexual reproduction resulting in clones.

Digestion

There is a digestion system in an earthworm. The process of nutrition begins in the mouth, where food is sucked in by a muscular pharynx. From there, food goes down the esophagus through peristalsis(muscle contractions.) After this, the food is stored in the crop, which retains food and has the ability to expand. From there, food goes into the gizzard where sand and muscular contractions churn the food and increase the surface area. From there, food enters the intestine which has the ability to absorb food, then food exits through the anus. A rectum is unnecessary because an earthworm is in a moist environment and thus does not require water reclamation.

Regeneration

Earthworms have the ability to regenerate lost segments, but this ability varies between species and depends on the extent of the damage. Stephenson (1930) devoted a chapter of his monograph to this topic, while G.E. Gates spent 20 years studying regeneration in a variety of species, but "because little interest was shown", Gates (1972) only published a few of his findings that, nevertheless, show it is theoretically possible to grow two whole worms from a bisected specimen in certain species. Gates's reports included:

- *Eisenia fetida* (Savigny, 1826) with head regeneration, in an anterior direction, possible at each intersegmental level back to and including 23/24, while tails were regenerated at any levels behind 20/21.
- *Lumbricus terrestris* Linneus, 1758 replacing anterior segments from as far back as 13/14 and 16/17 but tail regeneration was never found.
- *Perionyx excavatus* Perrier, 1872 readily regenerated lost parts of the body, in an anterior direction from as far back as 17/18, and in a posterior direction as far forward as 20/21.
- *Lampito mauritii* Kinberg, 1867 with regeneration in anterior direction at all levels back to 25/26 and tail regeneration from 30/31; head regeneration was sometimes believed to be caused by internal amputation resulting from *Sarcophaga* sp. larval infestation.
- *Criodrilus lacuum* Hoffmeister, 1845 also has prodigious regenerative capacity with 'head' regeneration from as far back as 40/41.

An unidentified Tasmanian earthworm shown growing a second head is reported here:.

Behavior

Rainstorms and "Stranding" Behavior

Earthworms can sometimes be found on the surface of the ground following heavy rain storms, as a storm may flood the soil with excessive water. However, if the surface where they find themselves is unexpectedly paved, rocky, or compacted (hardened), they may become stranded, potentially suffering injury or death from causes such as heat, exposure, dehydration, or predation. Note, there are some earthworm species that can survive for several days in water if it is sufficiently oxygenated.

Earthworms may also come to the surface during rain in order to mate, and therefore, an alternative hypothesis concerning "stranding" behavior is that as some species (notably *Lumbricus terrestris*) come to the surface to mate they may become stranded. However, this behavior is limited to only a few species and *L. terrestris* is rarely, if ever, one of those found stranded on impermeable surfaces, this hypothesis does not seem likely to be true.

Another hypothesis is that the worms may be using the moist conditions on the surface to travel more quickly than they can underground, thus moving to and colonizing new areas more quickly. Since the relative humidity of the surface and air is higher during and after rain, they do not become dehydrated quite as rapidly. However, if true, this is a very risky behavior near dawn, in high summer, or in the daytime, since earthworms die quickly when exposed to direct sunlight with its high heat, light and strong UV content, and are more vulnerable to predators such as birds.

An earthworm being eaten by an American Robin

A further hypothesis is that, because there are many other organisms beside the earthworm in the ground as well, and these organisms all tend to increase respiration as water content of the soil increases, carbon dioxide gas may dissolve into the rainwater forming a higher than usual acid content carbonic acid in the soil area. As the soil becomes too acidic for the worms, they seek a more neutral environment on the surface.

Locomotion and importance to soil

Close up of an earthworm in garden soil

Earthworms travel underground by the means of waves of muscular contractions which alternately shorten and lengthen the body. The shortened part is anchored to the surrounding soil by tiny claw-like bristles (setae) set along its segmented length. In all the body segments except the first, last and clitellum, there is a ring of S-shaped setae embedded in the epidermal pit of each segment (perichaetine). The whole burrowing process is aided by the secretion of lubricating mucus. Worms can make gurgling noises underground when disturbed as a result of the worm moving through its lubricated tunnels. They also work as biological "pistons" forcing air through the tunnels as they move. Thus earthworm activity aerates and mixes the soil, and is constructive to mineralization and nutrient uptake by vegetation. Certain species of earthworm come to the surface and graze on the higher concentrations of organic matter present there, mixing it with the mineral soil. Because a high level of organic matter mixing is associated with soil fertility, an abundance of earthworms is beneficial to the organic gardener. In fact as long ago as 1881 Charles Darwin wrote: *It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures.*

Benefits

The major benefits of earthworm activities to soil fertility can be summarized as:

- **Biological**. In many soils, earthworms play a major role in converting large pieces of organic matter (e.g. dead leaves) into rich humus, and thus improving soil fertility. This is achieved by the worm's actions of pulling down below any organic matter deposited on the dried dirt, such as leaf fall or manure, either for food or when it needs to plug its burrow. Once in the burrow, the worm will shred the leaf and partially digest it, then mingle it with the earth by saturating it with intestinal secretions. Worm casts (see below) can contain 40% more humus than the top 9" of soil in which the worm is living.

Faeces in form of casts

- **Chemical**. As well as dead organic matter, the earthworm also ingests any other soil particles that are small enough—including stones up to 1/20 of an inch (1.25mm) across—into its gizzard wherein minute fragments of grit grind everything into a fine paste which is then digested in the intestine. When the worm excretes this in the form of casts which are deposited on the surface or deeper in the soil, minerals and plant nutrients are made available in an accessible form. Investigations in the US show that fresh earthworm casts are 5 times richer in available nitrogen, 7 times richer in available phosphates and 11 times richer in available potash than the surrounding upper 6 inches (150 mm) of soil. In conditions where there is plenty of available humus, the weight of casts produced may be greater than 4.5 kg (10 lb) per worm per year, in itself an indicator of why it pays the gardener or farmer to keep worm populations high.
- **Physical**. By its burrowing actions, the earthworm is of great value in keeping the soil structure open, creating a multitude of channels which allow the processes of both aeration and drainage to occur. Permaculture co-founder Bill Mollison points out that by sliding in their tunnels, earthworms "act as an innumerable army of pistons pumping air in and out of the soils on a 24 hour cycle (more rapidly at night)". Thus the earthworm not only creates passages for air and water to traverse, but is itself a vital component in the living biosystem that is healthy soil. Earthworms continue to move through the soil due to the excretion of mucus into the soil that acts as a lubricant for easier movement of the worm.

The earthworm's existence cannot be taken for granted. Dr. W. E. Shewell Cooper observed "tremendous numerical differences between adjacent gardens" (*Soil, Humus And Health*), and worm populations are affected by a host of environmental factors, many of which can be influenced by good management practices on the part of the gardener or farmer.

Darwin estimated that arable land contains up to 53,000 worms per acre (13/m²), but more recent research from Rothamsted Experimental Station has produced figures suggesting that even poor soil may support 250,000/acre (62/m²), whilst rich fertile farmland may have up to 1,750,000/acre (432/m²), meaning that the weight of earthworms beneath the farmer's soil could be greater than that of his livestock upon its surface. One thing is certain however: rich, fertile soil that is cared for organically and well-fed and husbanded by its steward will reap its reward in a healthy worm population, whilst denuded, overworked, and eroded land will almost certainly contain fewer, scrawny, undernourished specimens.

Earthworms as invasive species

From a total of around 6,000 species, only about 120 species are widely distributed around the world. These are the peregrine or cosmopolitan earthworms.

Australia

Australia has 650 known species of native earthworm that survive in both rich and in nutrient-poor conditions where they may be sensitive to changes in the environment. Introduced species are commonly found in agricultural environments along with persistent natives. Most of the 75 or so exotics have been accidentally introduced into Australia. The total species numbers are predicted to exceed 2,000.

North America

A total of approximately 182 earthworm taxa in 12 families are reported from America north of Mexico, i.e., USA & Canada, of which 60 (ca. 33%) are exotic/introduced. Only two genera of Lumbricid earthworms are indigenous to North America while introduced genera have spread to areas where earthworms did not formerly exist, especially in the north where forest development relies on a large amount of undecayed leaf matter. When worms decompose that leaf layer, the ecology may shift making the habitat unsurvivable for certain species of trees, ferns and wildflowers. Another possible ecologic impact of greater earthworm numbers: larger earthworms (e.g. the night crawler, *Lumbricus terrestris*, and the Alabama jumper, *Amynthas agrestis*) can be eaten by adult salamanders, and when the salamanders do consume the earthworms they are more successful at reproduction. However, those earthworms are too large for juvenile salamanders to consume, which leads to a net loss in salamander population.

Currently there is no economically feasible method for controlling invasive earthworms in forests. Earthworms normally spread slowly, but can be quickly introduced by human activities such as construction earthmoving, or by fishermen releasing bait, or by plantings.

United Kingdom

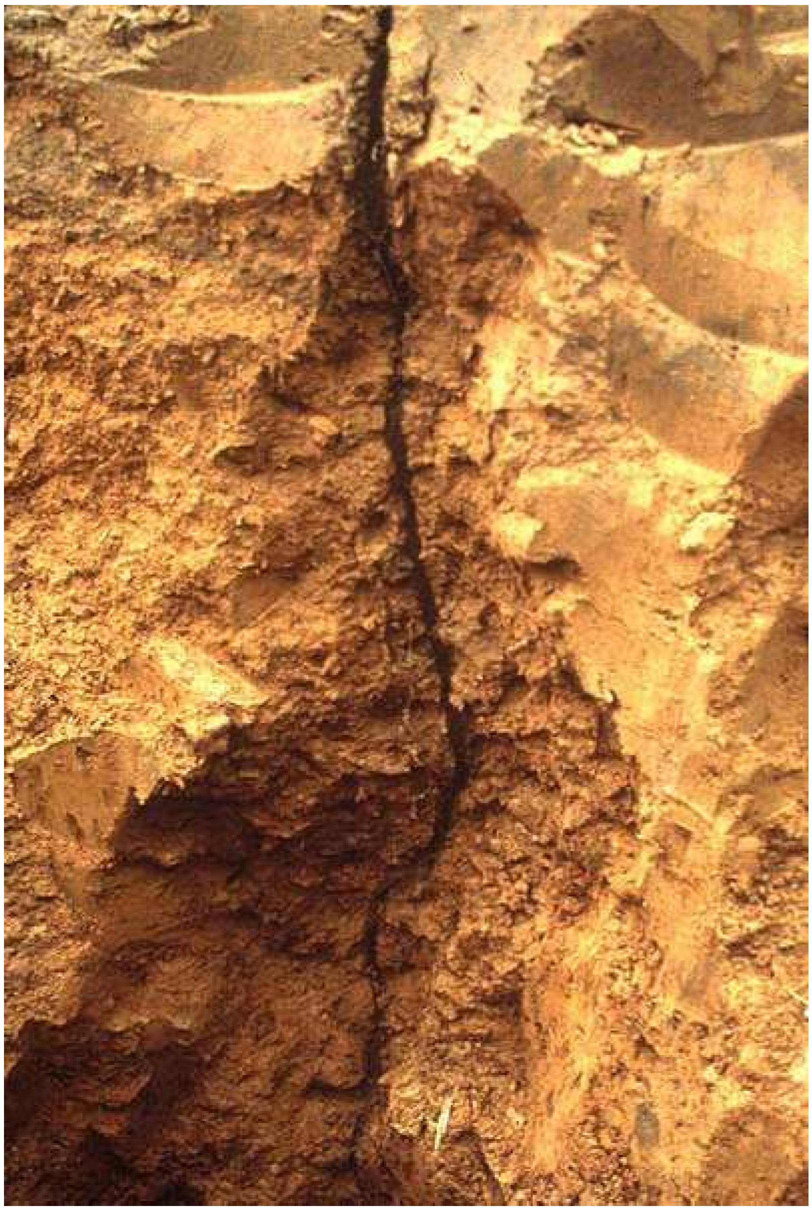
A recent threat to earthworm populations in the UK is the New Zealand Flatworm (*Artiposthia triangulata*), which feeds upon the earthworm, but in the UK has no natural predator itself. At present sightings of the New Zealand flatworm have been mainly localised, but this is no reason for complacency as it has spread extensively since its introduction in 1960 through contaminated soil and plant pots. Any sightings of the flatworm should be reported to the Scottish Crop Research Institute, which is monitoring its spread.

Special habitats

While, as the name *earthworm* suggests, the main habitat of earthworms is in soil, the situation is more complicated than that. The brandling worm *Eisenia fetida* lives in decaying plant matter and manure. *Arctiostrotus vancouverensis* from Vancouver Island and the Olympic Peninsula is generally found in decaying conifer logs or in extremely acidic humus. *Aporrectodea limicola* and *Sparganophilus* and several others are found in mud in streams. Some species are arboreal. Even in the soil species, there are special habitats, such as soils derived from serpentine which have an earthworm fauna of their own.

Ecology

Earthworms are classified into three main ecophysiological categories: (1) leaf litter/compost dwelling worms (epigeic) e.g. *Eisenia fetida*; (2) topsoil or subsoil dwelling worms (endogeics); and (3) worms that construct permanent deep burrows through which they visit the surface to obtain plant material for food, such as leaves (anecic), e.g. *Lumbricus terrestris*.



Permanent vertical burrow

Earthworm populations depend on both physical and chemical properties of the soil, such as soil temperature, moisture, pH, salts, aeration and texture, as well as available food, and the ability of the species to reproduce and disperse. One of the most important environmental factors is pH, but earthworms vary in their preferences. Most earthworms favor neutral to slightly acidic soil. However, *Lumbricus terrestris* are still present in a pH of 5.4 and *Dendrobaena octaedra* at a pH of 4.3 and some Megascolecidae are present in extremely acid humic soils. Soil pH may also influence the numbers of worms that go into diapause. The more acidic the soil, the sooner worms go into diapause, and remain in diapause the longest time at a pH of 6.4.

Ocypus olens trying to prey on *Lumbricus* sp.

Earthworms form the base of many food chains. They are preyed upon by many species of birds (e.g. starlings, thrushes, gulls, crows, European Robins and American Robins), snakes, mammals (e.g. bears, foxes, hedgehogs, moles) and invertebrates (e.g. ground beetles and other beetles, snails, slugs). Earthworms have many internal parasites including Protozoa, Platyhelminthes, Nematodes; they can be found in the worms' blood, seminal vesicles, coelom, intestine, or in the cocoons.

The application of chemical fertilizers, sprays and dusts can have a disastrous effect on earthworm populations. Nitrogenous fertilizers tend to create acid conditions, which are fatal to the worms, and often dead specimens are to be found on the surface following the application of substances like DDT, lime sulphur and lead arsenate. In Australia, changes in farming practices such as the application of superphosphates on pastures and a switch from pastoral farming to arable farming had a devastating effect on populations of the Giant Gippsland earthworm leading to their classification as a protected species.

Therefore, the most reliable way to maintain or increase the levels of worm population in the soil is to avoid the application of artificial chemicals. Adding organic matter, preferably as a surface mulch, on a regular basis will provide them with their food and nutrient requirements, and also creates the optimum conditions of heat (cooler in summer and warmer in winter) and moisture to stimulate their activity.

Economic impact

Various species of worms are used in vermiculture, the practice of feeding organic waste to earthworms to decompose and compost food waste. These are usually *Eisenia fetida* (or its close relative *Eisenia andrei*) or the Brandling worm, also known as the Tiger worm or Red Wiggler, and are distinct from soil-dwelling earthworms.

Earthworms are sold all over the world. The earthworm market is sizable. According to Doug Collicut, "In 1980, 370 million worms were exported from Canada, with a Canadian export value of $13 million and an American retail value of $54 million."

Earthworms are also sold as food for human consumption. Noke is a culinary term used by the Māori of New Zealand, to refer to earthworms which are considered delicacies.

Taxonomy and distribution

The families, with distribution of the main ones:

- Acanthodrilidae: Africa, midland and southeastern North America, Central and South America, Australia and Oceania.
- Ailoscolidae
- Alluroididae
- Almidae (disputed): Africa, South America.
- Criodrilidae
- Eudrilidae: Tropical Africa.

- Exxidae: Central America/Caribbean.
- Glossoscolecidae: Central and northern South America.
- Hormogastridae: Europe.
- Lumbricidae: Temperate Northern Hemisphere from Vancouver Island, Canada to Japan, mostly Eurasia.
- Lutodrilidae
- Megascolecidae: South East Asia, Australasia and Oceania, northwestern North America.
- Microchaetidae
- Ocnerodrilidae: Central and South America, Africa.
- Octochaetidae: Central/South America, western Africa, India, New Zealand, Australia.
- Sparganophilidae: North America.

Chapter- 7

Machaerid and Scolecodont

Machaerid

Machaerid Temporal range: Ordovician (or earlier?) – Carboniferous	
Scientific classification	
Kingdom:	Animalia
Phylum:	?Annelida
Families	
plumulitids turrilepadids lepidocoleids	

Machaeridians are a group of armoured, segmented annelid worms, known from the Early Ordovician (Late Tremadoc) to Carboniferous. The group consist of three distinct families: the plumulitids, turrilepadids and lepidocoleids.

Fossils

Only the calcitic scleretomes ("armour plates") of these worms tend to be preserved in the fossil record. These are tiny, and usually found disarticulated: articulated specimens reach about a centimeter in length, and are incredibly rare – hence the limited degree of study since their description in 1857. Scleritomes which bear a strong resemblance to the machaeridians are found in the small shelly fauna of the early Cambrian, 530 million years ago, suggesting an early origin of the group.

The machaeridians are characterized by having serialized rows of calcitic shell plates. The dorsal sclerites were convex and almost isometric; lateral sclerites were flatter and longer. The plates comprised two calcite layers: the outer layer is thin and formed by lamellar deposition, whereas new elements were added to the thicker inner layer as it grew. Scales are ridged with growth lines, implying that they grew episodically. A few taxa experimented with different approaches to scale formation; some were only very weakly calcified and may have mainly been organic in nature. They were never moulted, and each scale could be moved with an attached muscle.

The front two segments of the machaeridians were commonly different from the rest, bearing fewer spiny projections.

The plumulitids are flattened from above and looks much like the coat of mail armour of chitons. The two other families are laterally compressed and some lepidocoleids formed a dorsal hinge, which make these machaeridians look like a string of bivalves.

Ecology

Machaeridians are often found in association with stylophorans - the cornutes and mitrates. This suggests that they possessed a similar ecology. They probably fed on organic detritus, perhaps even the faeces of the accompanying stylophorans.

Their scales almost certainly performed a defensive role.

The organisms would have had limited ability to flex to the right and left (in the sagittal plane), but would have been able to roll up. While most possessed bilateral symmetry, the scales on the right and left side of *Turrilepas wrightiana* are different in shape and form. The Plumulitid machaeridians would have moved across the surface of the sea floor using parapodia, whereas the fully-armoured Turrelepids and Lepidocoelids burrowed in a peristaltic fashion reminiscent of their evolutionary cousins, the earthworms. This burrowing role has subjected them to the same evolutionary pressures which affect burrowing bivalves; convergent evolution as a result of their shared function probably contributed to early suggestions that the machaeridians should be classified with the molluscs.

Taxonomic affinity

The group had been variously assigned to the echinoderms, barnacles, annelids and mollusks, before the discovery of a fossil preserving soft tissue allowed a firm classification to the annelids, in 2008. This annelid affinity came as some surprise, as it is the only instance of this group developing calcitic armour. The exact relationship to crown group annelids are still unresolved, but some characters indicate a relationship to Aphroditacean annelids (Vinther et al. 2008). Caron (2008) suggested that machaeridians must be a stem group based on number of specialised features. However, one cannot assess crown group/stem group affinities based on autapomorphies, but on shared morphological traits or the lack thereof. He also suggested that machaeridians might be polyphyletic, but machaerdians are a well defined group with a number of shared characters and morphological gradations between all three families.

Scolecodont

An Ordovician scolecodont from Estonia

A **scolecodont** is the jaw of a **polychaete** annelid, a common type of fossil-producing segmented worm useful in invertebrate paleontology. **Scolecodonts** are common and diverse microfossils, which range from the Cambrian period (around half a billion years ago at the start of the Paleozoic era) to the present. They diversified profusely in the Ordovician, and are most common in the Ordovician, Silurian and Devonian marine deposits of the Paleozoic era.

Relatedly, more problematic worm-like fossils have been described in even older, Neoproterozoic era deposits in the Ediacaran Hills of southern Australia and in mid-Cambrian deposits of Burgess shale in British Columbia.

Since the other classes of annelids (specifically, the earthworms and leeches) lack hard parts, only the sea-dwelling **polychaetes** are frequently represented in the fossil record. Polychaetes are commonly fossilized due to their chitinous teeth and their dwelling tubes made of durable calcite (a calcium carbonate), hardened mucus (a.k.a. parchment), and/or chitin-like cement.

Scolecodonts belonging to the extinct families Atraktoprionidae, Hadoprionidae, Kalloprionidae, Mochtyellidae, Paulinitidae, Polychaetaspidae, Ramphoprionidae, Rhytiprionidae, Skalenoprionidae, Symmetroprionidae, Xanioprionidae, and the still-extant (living) family Oenonidae (which includes the Arabellidae) are known from Silurian rocks in Scotland. Scolecodonts representing the present-day families Onuphidae and Dorvilleidae first appeared in Mesozoic era deposits.

Chapter- 8

Chordate

Chordata Temporal range: Early Cambrian – Recent, 540–0 Ma	

X-ray tetra (*Pristella maxillaris*), one of the few chordates with a visible backbone. The spinal cord is housed within its backbone.

Scientific classification	
Kingdom:	Animalia
Superphylum:	Deuterostomia
Phylum:	**Chordata** Bateson, 1885

Chordates (phylum **Chordata**) are animals which are either vertebrates or one of several closely related invertebrates. They are united by having, for at least some period of their life cycle, a notochord, a hollow dorsal nerve cord, pharyngeal slits, an endostyle, and a post-anal tail. The phylum Chordata consists of three subphyla: Urochordata, represented by tunicates; Cephalochordata, represented by lancelets; and Craniata, which includes Vertebrata. The Hemichordata have been presented as a fourth chordate subphylum, but they are now usually treated as a separate phylum. Urochordate larvae have both a notochord and a nerve cord which are lost in adulthood. Cephalochordates have a notochord and a nerve cord (but no brain or specialist sensory organs) and a very simple circulatory system. Craniates are the only sub-phylum whose members have skulls. In all craniates except for hagfish, the dorsal hollow nerve cord is surrounded with cartilaginous or bony vertebrae and the notochord is generally reduced; hence, hagfish are not regarded as vertebrates. The chordates and three sister phyla, the Hemichordata, the Echinodermata and the Xenoturbellida, make up the deuterostomes, one of the two superphyla that encompass all fairly complex animals.

Attempts to work out the evolutionary relationships of the chordates have produced several hypotheses, but the current consensus is that chordates are monophyletic, meaning that Chordata contains all and only the descendants of a single common ancestor *which is itself a chordate*, and that craniates' nearest relatives are cephalochordates. All of the earliest chordate fossils have been found in the Early Cambrian Chengjiang fauna, and include two species that are regarded as fish, which implies that they are vertebrates. Because the fossil record of chordates is poor, only molecular phylogenetics offers a reasonable prospect of dating their emergence. However, the use of molecular phylogenetics for dating evolutionary transitions is controversial.

It has also proved difficult to produce a detailed classification within the living chordates. Attempts to produce evolutionary "family trees" give results that differ from traditional classes because several of those classes are not monophyletic. As a result vertebrate classification is in a state of flux.

Definition

Chordates form a phylum of creatures that are based on a bilateral body plan, and is defined by having at some stage in their lives all of the following:

- A notochord, in other words a fairly stiff rod of cartilage that extends along the inside of the body. Among the vertebrate sub-group of chordates the notochord develops into the spine, and in wholly aquatic species this helps the animal to swim by flexing its tail.
- A dorsal neural tube. In fish and other vertebrates this develops into the spinal cord, the main communications trunk of the nervous system.
- Pharyngeal slits. The pharynx is the part of the throat immediately behind the mouth. In fish the slits are modified to form gills, but in some other chordates they are part of a filter-feeding system that extracts particles of food from the water in which the animals live.
- A muscular tail that extends backwards behind the anus.
- An endostyle. This is a groove in the ventral wall of the pharynx. In filter-feeding species it produces mucus to gather food particles, which helps in transporting food to the esophagus. It also stores iodine, and may be a precursor of the vertebrate thyroid gland.

Sub-divisions

Craniata

Craniate: Hagfish

Craniates, one of the three sub-divisions of chordates, have distinct skulls. Michael J. Benton comments that "craniates are characterized by their heads, just as chordates, or possibly all deuterostomes, are by their tails."

Most are vertebrates, in which the notochord is replaced by the spinal column.

This consists of a series of bony or cartilaginous cylindrical vertebrae, generally with neural arches that protect the spinal cord and with projections that link the vertebrae. Hagfish have incomplete braincases and no vertebrae, and are therefore not regarded as vertebrates, but as members of the craniates, the group from which vertebrates are thought to have evolved. The position of lampreys is ambiguous. They have complete braincases and rudimentary vertebrae, and therefore may be regarded as vertebrates and true fish. However molecular phylogenetics, which uses biochemical features to classify organisms, has produced both results that group them with vertebrates and others that group them with hagfish.

Cephalochordata: "The Lancelets"

Cephalochordate: Lancelet

Cephalochordates are small, "vaguely fish-shaped" animals that lack brains, clearly defined heads and specialized sense organs. These burrowing filter-feeders may be either the closest living relatives of craniates or surviving members of the group from which all other chordates evolved.

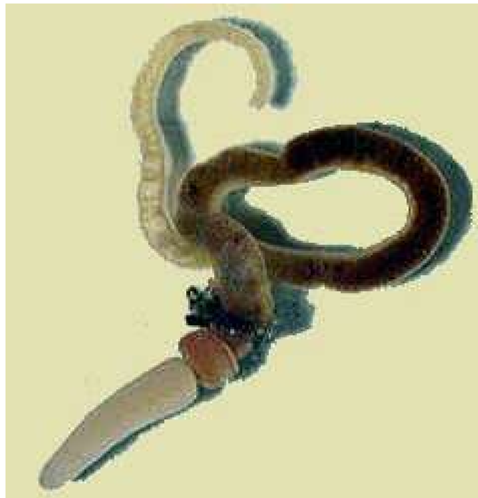
Urochordata: "The Tunicates"

Tunicates: sea squirts

Most tunicates appear as adults in two major forms, both of which are soft-bodied filter-feeders that lack the standard features of chordates: "sea squirts" are sessile and consist mainly of water pumps and filter-feeding apparatus; salps float in mid-water, feeding on plankton, and have a two-generation cycle in which one generation is solitary and the next forms chain-like colonies. However all tunicate larvae have the standard chordate features, including long, tadpole-like tails; they also have rudimentary brains, light sensors and tilt sensors. The third main group of tunicates, Appendicularia (also known as Larvacea) retain tadpole-like shapes and active swimming all their lives, and were for a long time regarded as larvae of sea squirts or salps. Because of their larvae's long tails tunicates are also called urochordates ("tail chordates").

Closest non-chordate relatives

The Hemichordates

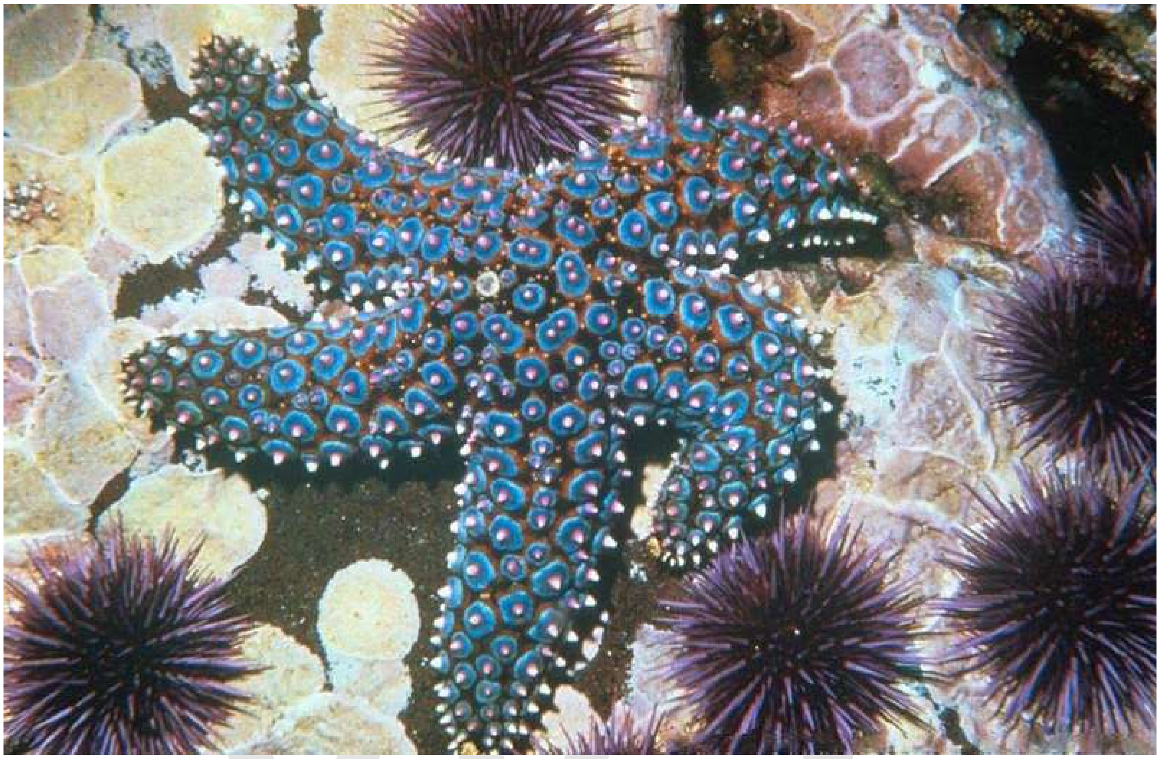


Enteropneust hemichordate: *Balanoglossus*

Hemichordates ("half chordates") have some features similar to those of chordates: branchial openings that open into the pharynx and look rather like gill slits; stomochords, similar in composition to notochords but running in a circle round the "collar", which is ahead of the mouth; and a dorsal nerve cord — but also a smaller ventral nerve cord.

There are two living groups of hemichordates. The solitary enteropneusts, commonly known as "acorn worms", have long probosces and worm-like bodies with up to 200 branchial slits, are up to 2.5 metres (8.2 ft) long, and burrow though seafloor sediments. Pterobranchs are colonial animals, often less than 1 millimetre (0.039 in) long individually, whose dwellings are inter-connected. Each filter feeds by means of a pair of branched tentacles, and has a short, shield-shaped proboscis. The extinct graptolites, colonial animals whose fossils look like tiny hacksaw blades, lived in tubes similar to those of pterobranchs.

The Echinoderms

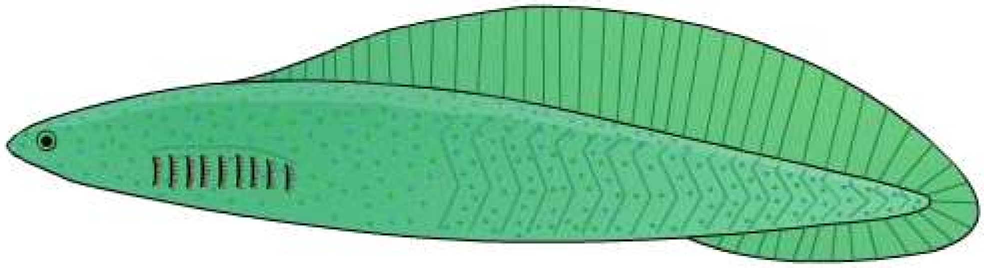


Echinoderm: starfish

Echinoderms differ from chordates and their other relatives in three conspicuous ways: instead of having bilateral symmetry they have radial symmetry, meaning their body pattern is shaped like a wheel; they have tube feet; and their bodies are supported by skeletons made of calcite, a material not used by chordates. The hard calcified shell keeps their bodies well protected from the environment, and these skeletons enclose their bodies but are also covered by a thin skin. The feet are powered by another unique feature of echinoderms, a water vascular system of canals that also function as a "lung" and are surrounded by muscles that act as pumps. Crinoids look rather like flowers, and use their feather-like arms to filter food particles out of the water; most live anchored to rocks, but a few can move very slowly. Other echinoderms are mobile and take a variety of body shapes, for example starfish, sea urchins and sea cucumbers.

Origins

The majority of animals more complex than jellyfish and other Cnidarians are split into two groups, the protostomes and deuterostomes, and chordates are deuterostomes. It seems very likely that 555 million year old *Kimberella* was a member of the protostomes. If so, this means that the protostome and deuterostome lineages must have split some time before *Kimberella* appeared — at least 558 million years ago, and hence well before the start of the Cambrian 542 million years ago. The Ediacaran fossil *Ernietta*, from about 549 to 543 million years ago, may represent a deuterostome animal.



Haikouichthys, from about 518 million years ago in China, may be the earliest known fish.

Fossils of one major deuterostome group, the echinoderms (whose modern members include starfish, sea urchins and crinoids), are quite common from the start of the Cambrian, 542 million years ago. The Mid Cambrian fossil *Rhabdotubus johanssoni* has been interpreted as a pterobranch hemichordate. Opinions differ about whether the Chengjiang fauna fossil *Yunnanozoon*, from the earlier Cambrian, was a hemichordate or chordate. Another fossil, *Haikouella lanceolata*, also from the Chengjiang fauna, is interpreted as a chordate and possibly a craniate, as it shows signs of a heart, arteries, gill filaments, a tail, a neural chord with a brain at the front end, and possibly eyes — although it also had short tentacles round its mouth. *Haikouichthys* and *Myllokunmingia*, also from the Chengjiang fauna, are regarded as fish. *Pikaia*, discovered much earlier but from the Mid Cambrian Burgess Shale, is also regarded as a primitive chordate. On the other hand fossils of early chordates are very rare, since non-vertebrate chordates have no bones or teeth, and only one has been reported for the rest of the Cambrian.

The evolutionary relationships between the chordate groups and between chordates as a whole and their closest deuterostome relatives have been debated since 1890. Studies based on anatomical, embryological, and paleontological data have produced different "family trees". Some closely linked chordates and hemichordates, but that idea is now rejected. Combining such analyses with data from a small set of ribosome RNA genes eliminated some older ideas, but open the possibility that tunicates (urochordates) are "basal deuterostomes", in other words surviving members of the group from which echinoderms, hemichordates and chordates evolved. Most researchers agree that, within the chordates, craniates are most closely related to cephalochordates, but there are also reasons for regarding tunicates (urochordates) as craniates' closest relatives. One other phylum, Xenoturbellida, appears to be basal within the deuterostomes, in other words closer to the original deuterostomes than to the chordates, echinoderms and hemichordates.

Since chordates have left a poor fossil record, attempts have been made to calculate the key dates in their evolution by molecular phylogenetics techniques, in other words by analysing biochemical differences, mainly in RNA. One such study suggested that deuterostomes arose before 900 million years ago and the earliest chordates around 896 million years ago. However molecular estimates of dates often disagree with each other and with the fossil record, and their assumption that the molecular clock runs at a known constant rate has been challenged.

Classification

Taxonomy

The following schema is from the third edition of *Vertebrate Palaeontology*. The invertebrate chordate classes are from Fishes of the World. While it is structured so as to reflect evolutionary relationships (similar to a cladogram), it also retains the traditional ranks used in Linnaean taxonomy.

- **Phylum Chordata**
    - Subphylum **Tunicata** (Urochordata) — (tunicates; 3,000 species)
        - Class **Ascidiacea**
        - Class **Thaliacea** (salps)
        - Class **Appendicularia** (larvacea)
    - Subphylum **Cephalochordata** (Acraniata) — (lancelets; 30 species)
    - Subphylum **Vertebrata** (Craniata) (vertebrates — animals with backbones; 57,674 species)
            -
            - Class **'Agnatha'** paraphyletic (jawless vertebrates; 100+ species)
                - Subclass Myxinoidea (hagfish; 65 species)
                - Subclass Petromyzontida (lampreys)
                - Subclass Conodonta
                - Subclass **Pteraspidomorphi** (Paleozoic jawless fish)
                    - Order Anaspida
                    - Order Thelodonti (Paleozoic jawless fish)
        - Infraphylum **Gnathostomata** (jawed vertebrates)
                -
                - Class **Placodermi** (Paleozoic armoured forms)
                - Class **Chondrichthyes** (cartilaginous fish; 900+ species)
                - Class **Acanthodii** (Paleozoic "spiny sharks")
                - Class **Osteichthyes** (bony fish; 30,000+ species)
                    - Subclass **Actinopterygii** (ray-finned fish; about 30,000 species)
                    - Subclass **Sarcopterygii** (lobe-finned fish)
            - Superclass **Tetrapoda** (four-legged vertebrates; 28,000+ species)
                - Class **Amphibia** (amphibians; 6,000 species)
                    - Series **Amniota** (with amniotic egg)
                - Class **Reptilia** (reptiles; 8,225+ species)

        - Subclass **Anapsida** (extinct "proto-reptiles" and possibly turtles)
        - Subclass **Synapsida** (mammal-like "reptiles"; 4,500+ species, progenitors of mammals)
        - Subclass **Diapsida** (majority of reptiles, progenitors of birds)
    - Class **Mammalia** (mammals; 5,800 species)
    - Class **Aves** (birds; 8,800–10,000 species)

Chapter- 9

Craniata

Craniata **Temporal range: Early Cambrian - Recent**	
 A Pacific Hagfish, an example of a craniate	
Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
(unranked):	**Craniata** Linnaeus 1758:240
Subphyla	
Petromyzontida (lampreys) (disputed) Myxini (hagfishes) Vertebrata	

Craniata (sometimes **Craniota**) is a proposed clade of chordate animals that contains the Myxini (hagfish), Petromyzontida (including lampreys), and Gnathostomata (jawed vertebrates) as living representatives. As the name suggests, Craniata are animals with a (hard bone or cartilage) skull in Chordata.

Craniata as an unranked taxon replaces the former use of Vertebrata (Vertebrata *sensu lato*). The main difference of the old and new (Vertebrata *sensu stricto*) interpretation of

Vertebrata is that Myxini and sometimes the Petromyzontida are no longer included in Vertebrata. The Myxini lack proper vertebrae, which are characteristic for vertebrates according to the new interpretation, whereas traditionally, and confusingly, they were not (Hickman et al., 2007).

Characteristics

In the simplest sense craniates are chordates with heads, thus excluding members of chordate subphyla Urochordata (tunicates) and Cephalochordata (lancelets), but including Myxini, which have cartilaginous skulls and tooth-like structures composed of keratin. Craniata also includes all lampreys and armored jawless fishes, sharks and rays, bony fish, amphibians, reptiles and mammals. The craniate head consists of a brain, sense organs including eyes, and a skull.

In addition to distinct crania (sing. *cranium*), craniates possess many derived characteristics which have allowed for more complexity to follow. Molecular-genetic analysis of craniates reveals that, compared to less complex animals, they developed duplicate sets of many gene families that are involved in cell signaling, transcription, and morphogenesis.

In general, craniates are much more active than tunicates and lancelets and as a result have greater metabolic demands, as well as several anatomical adaptations. Aquatic craniates have gill slits which are connected to muscles and nerves which pump water through the slits (as opposed to lancelets, whose pharyngeal slits are used only for suspension feeding), engaging in both feeding and gas exchange. Muscles line the alimentary canal, moving food through the canal, allowing higher craniates like mammals to develop more complex digestive systems for optimal food processing. Craniates have cardiovascular systems which include a heart with two or more chambers, red blood cells, and O_2 transporting hemoglobin, as well as kidneys.

Systematics and taxonomy

Linnaeus (1758) used the terms 'Craniata' and 'Vertebrata' interchangeably to include lampreys, jawed fishes, and terrestrial vertebrates (tetrapods). Hagfishes were classified as Vermes, possibly representing a transitional form between 'worms' and fishes. Dumeril (1806) grouped hagfishes and lampreys in the taxon 'Cyclostomi', characterized by horny teeth borne on a tongue-like apparatus, a large notochord as adults, and pouch-shaped gills (Marspibranchii). Cyclostomes were regarded as either degenerate cartilaginous fishes or primitive vertebrates. Cope (1889) coined the name 'Agnatha' (jawless) for a group that included the cyclostomes and a number of fossil groups in which jaws could not be observed. Vertebrates were subsequently divided into two major sister-groups; Agnatha and Gnathostomata (jawed vertebrates). Stensiö (1927) suggested that the two groups of living agnathans (i.e., cyclostomes) arose interpedently from different groups of fossil agnathans. Løvtrup (1977) argued that lampreys are more closely related to gnathostomes based on a number of uniquely derived characters, including: arcualia (serially arranged paired cartilages above the notochord), extrinsic eyeball muscles, radial muscles in the fins, a closely-set atrium and ventricle of the heart, nervous regulation of the heart (by the vagus nerve), a typhlosole (spirally coiled valve of the intestinal wall), true lymphocytes, a differentiated anterior lobe of the pituitary gland (adenohypophysis), three inner ear maculae (patches of acceleration sensitive 'hair cells' used in balance) organized into two or three vertical semicircular canals, neuromast organs (composed of vibration sensitive hair cells) in the laterosensory canals, an electroreceptive lateral line (with voltage sensitive hair cells) and electrosensory lateral line nerves, and a cerebellum (i.e., the multi-layered roof of the hindbrain with unique structure [characteristic neural architecture including direct inputs from the lateral line and large output Purkinje cells) and function [integrating sensory perception and coordinating motor control]. In other words, the 'cyclostome' characteristics (e.g., horny teeth, "tongue", gill pouches) are either instances of convergent evolution for feeding and gill ventilation in animals with an eel-like body shape, or represent primitive craniate characteristics subsequently lost or modified in gnathostomes. Janvier (1978) proposed to use the names 'Vertebrata' and 'Craniata' as two distinct and nested taxa.

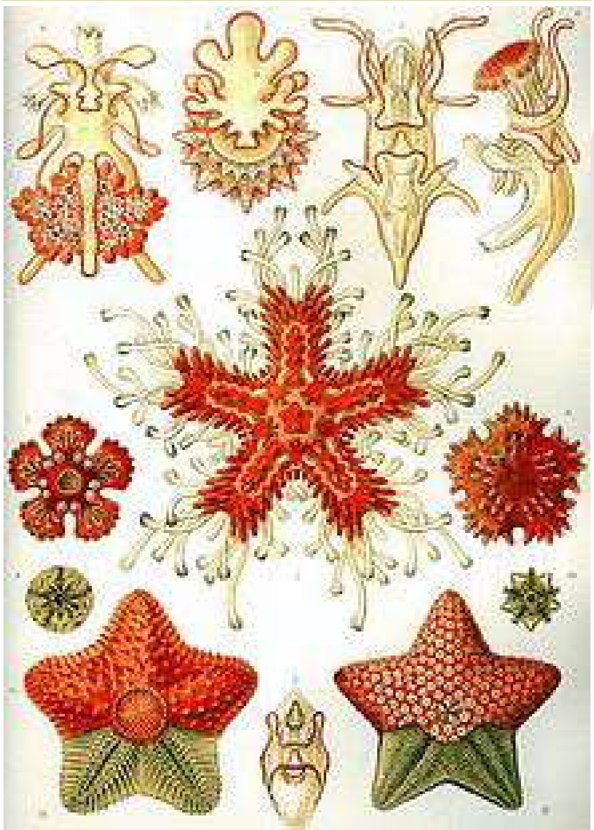
Validity

The validity of the taxon "Craniata" was recently examined by Delarbre et al. (2002) using mtDNA sequence data, concluding that Myxini is more closely related to Hyperoartia than to Gnathostomata - i.e., that modern jawless fishes form a clade called Cyclostomata. The argument is that if Craniata is indeed monophyletic, Vertebrata would return to its old content (Gnathostomata + Cyclostomata) and the name Craniata, being superfluous, would become a junior synonym.

However, mtDNA may not be a reliable marker for phylogenetic analysis of such ancient divergence times, due to its rapid rate of mutation. Further, the root of the molecular phylogeny for Craniata may be difficult to resolve due to the very poor representation of deep branches among living taxa; in other words that the taxon sampling afforded by extant taxa alone results in very long branches, within the basal craniate lineages, and among their closest relatives (i.e., *Branchiostoma*). Because extinction has eliminated so much of the important transitional states needed to reconstruct the early branching order of craniate lineages, the molecular tree of these taxa may effectively be an unrooted network.

Chapter- 10

Echinoderm

Echinoderm **Temporal range: Cambrian–recent**	
 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

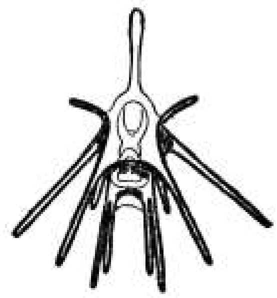
Echinoderms become sexually mature after approximately two to three years, depending on the species and the environmental conditions. The eggs and sperm cells are released into open water, where fertilization takes place. The release of sperm and eggs is coordinated temporally in some species, and spatially 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.

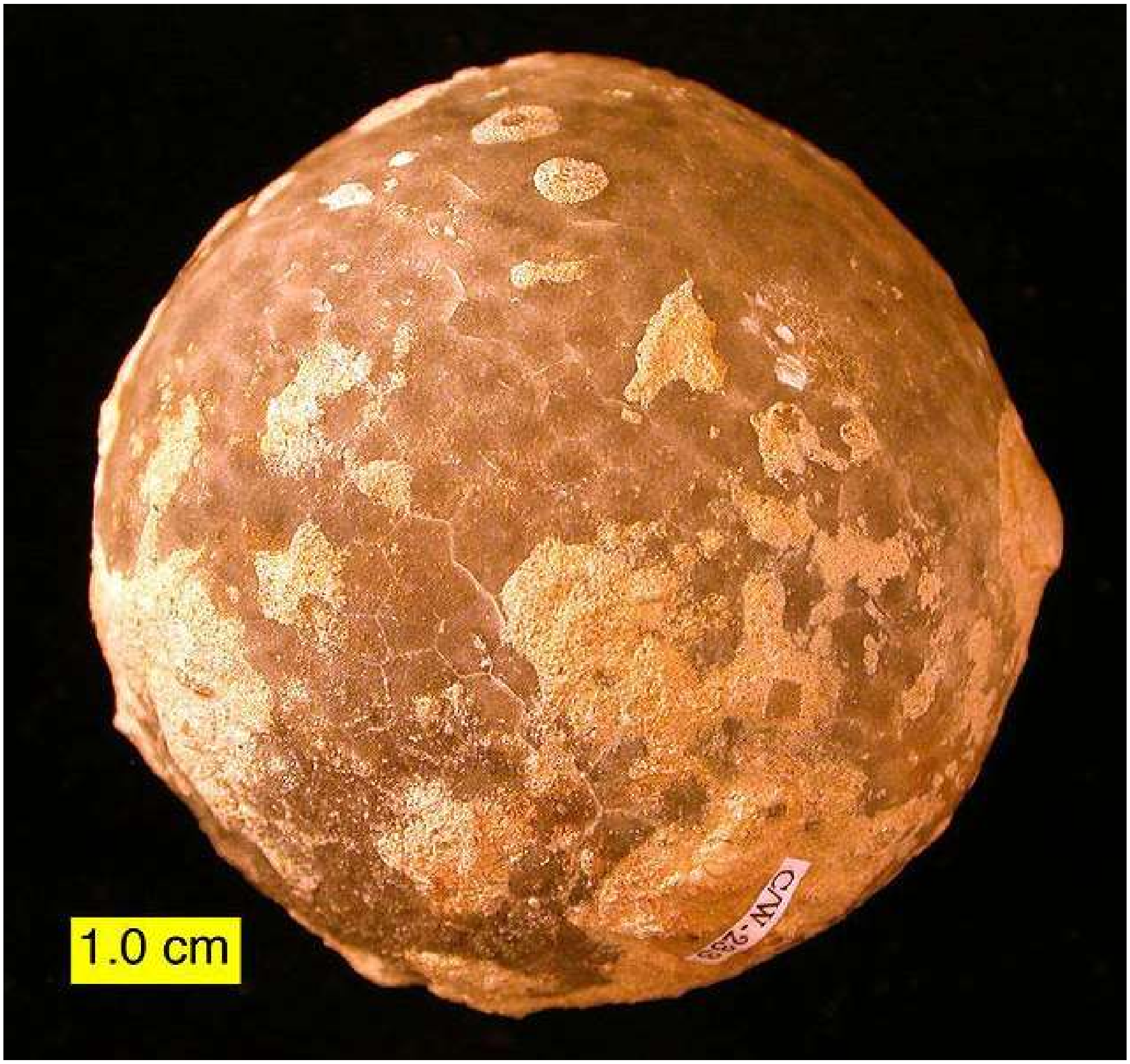
Sea cucumbers may be suspension feeders, sucking vast quantities of sea water through their guts and absorbing any useful matter. Others use their feeding apparatus to actively capture food from the sea floor. Yet others deploy their feeding apparatus as a net, in which smaller organisms become ensnared.

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- 11

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)

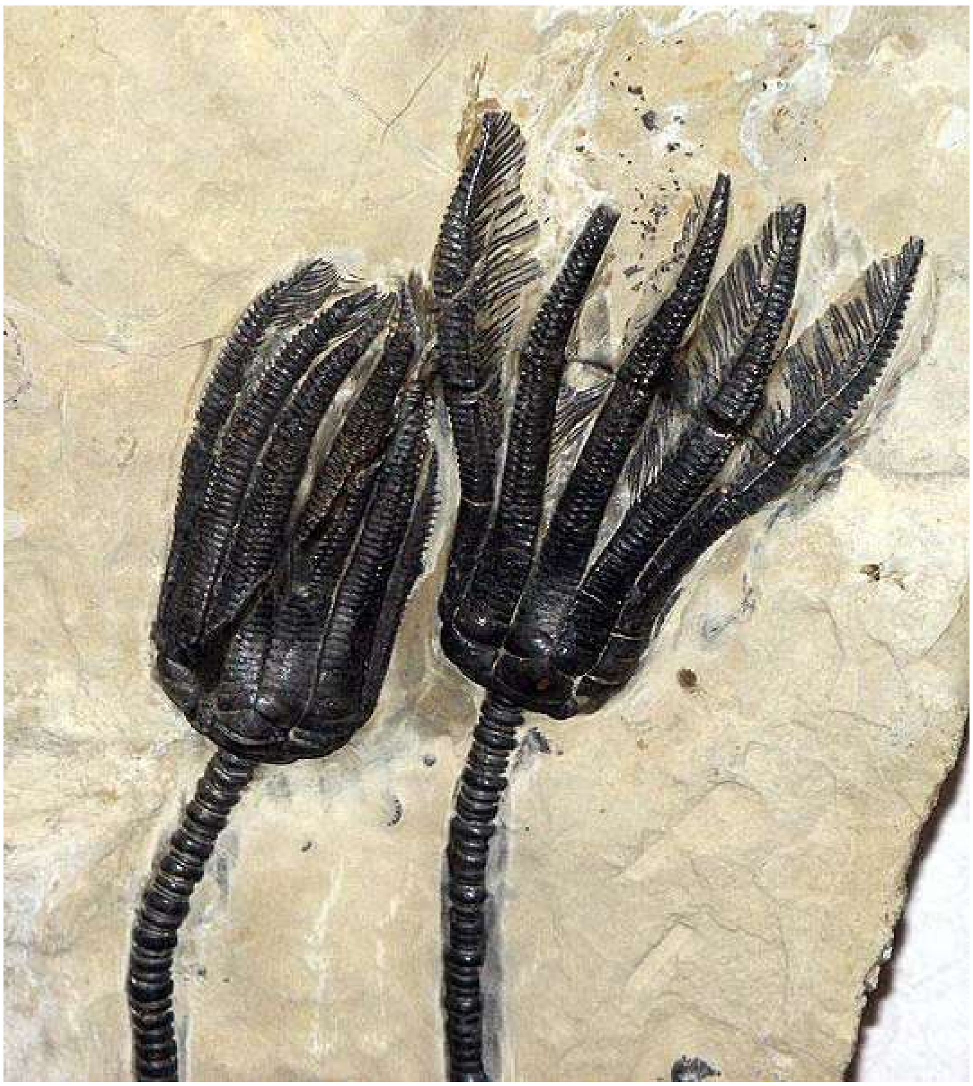
Crinoids are marine animals that make up the class **Crinoidea** of the echinoderms (phylum Echinodermata). Crinoidea comes from the Greek word *krinon*, "a lily", and *eidos*, "form". They live both in shallow water and in depths as great as 6,000 meters. **Sea**

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

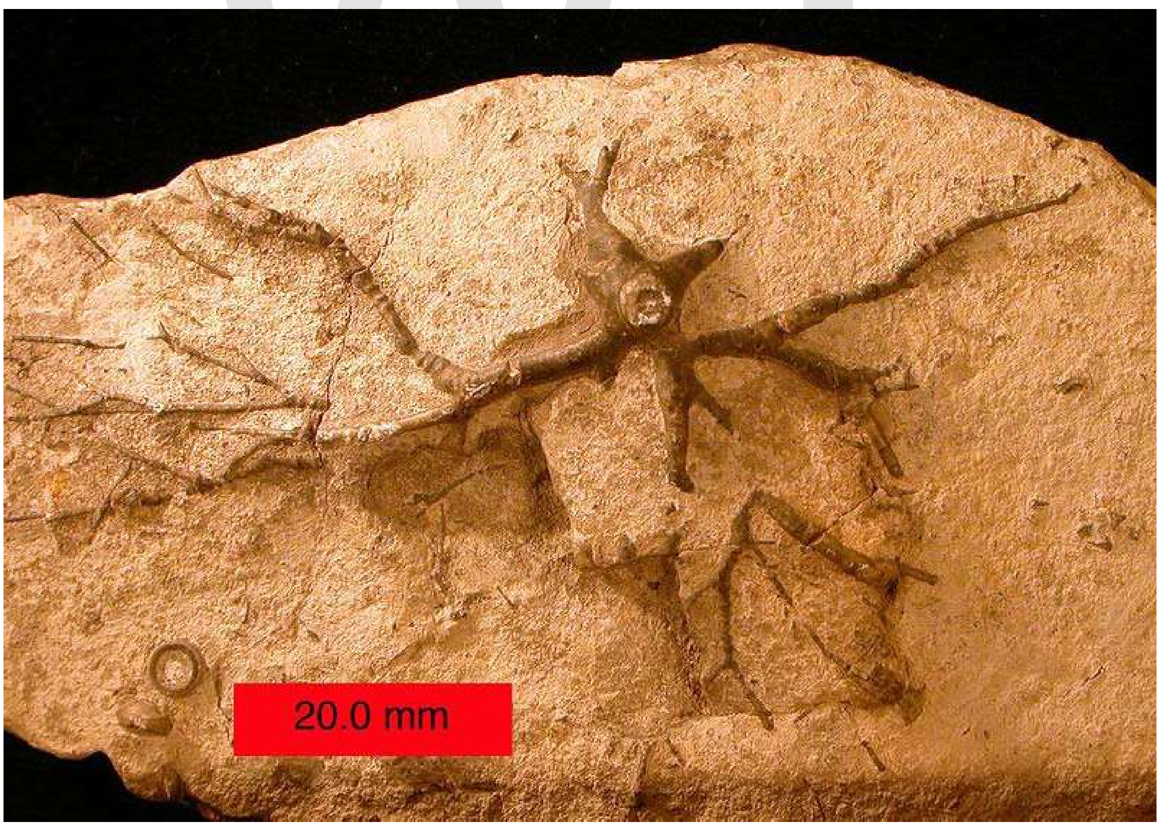
The crinoids underwent two periods of abrupt adaptive radiation; the first during the Ordovician, the other after they underwent a selective mass extinction at the end of the Permian period. This Triassic radiation resulted in forms possessing flexible arms becoming widespread; motility, predominantly 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.

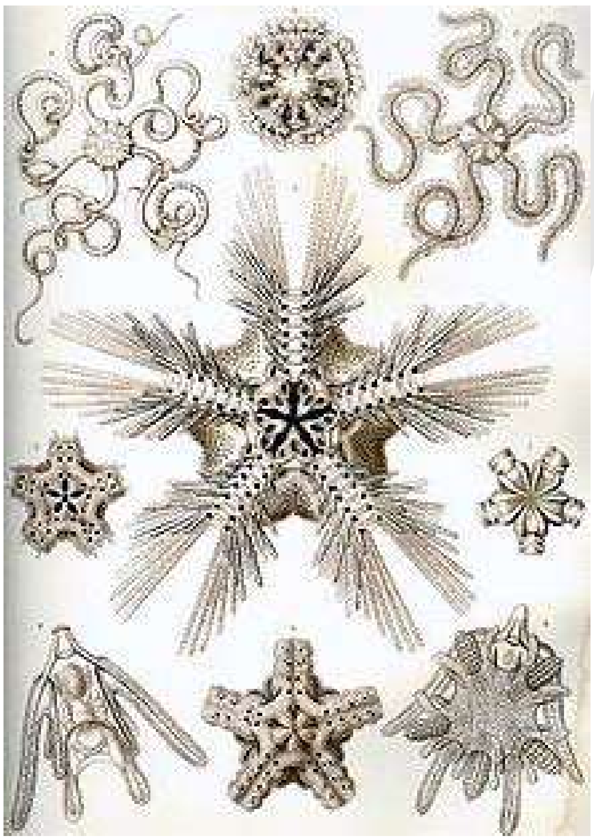
Crinoid uses

- 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- 12

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

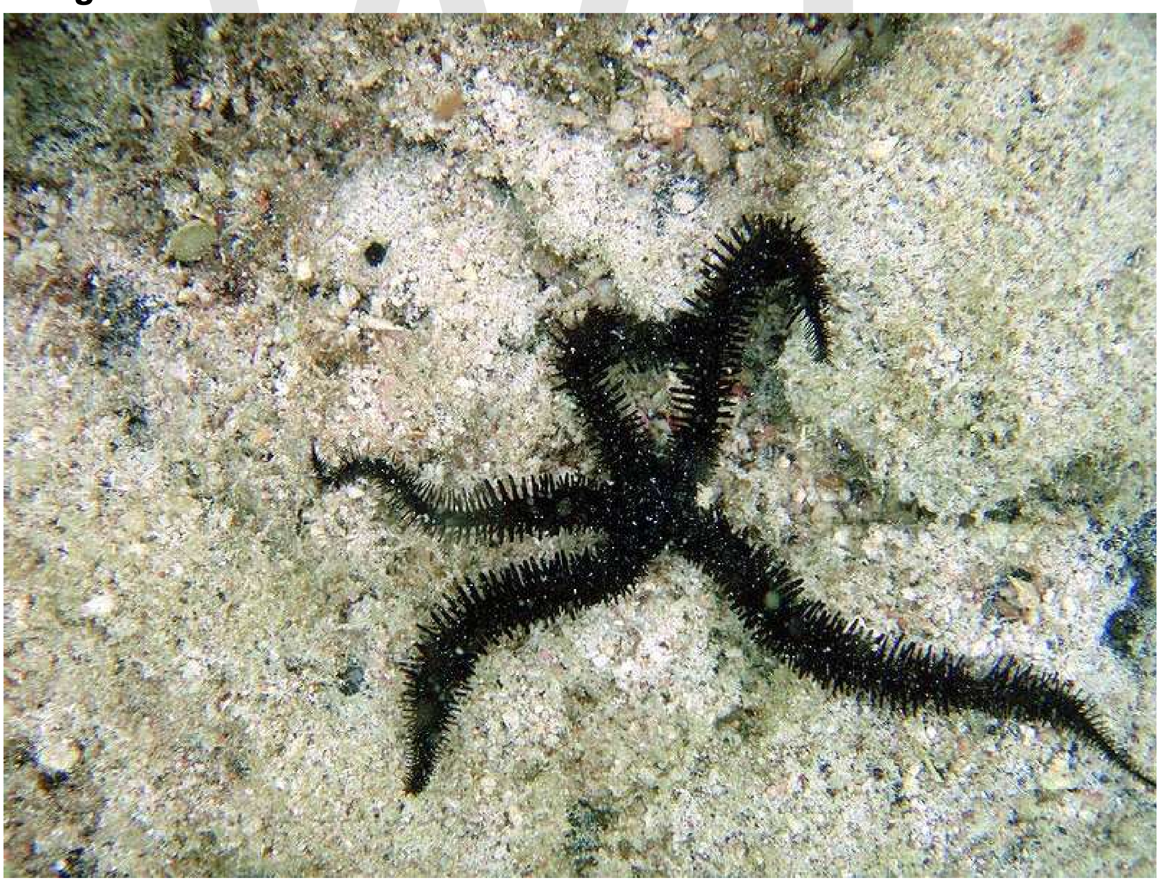
Orders
Oegophiurida Ophiurida Phrynophiurida

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.

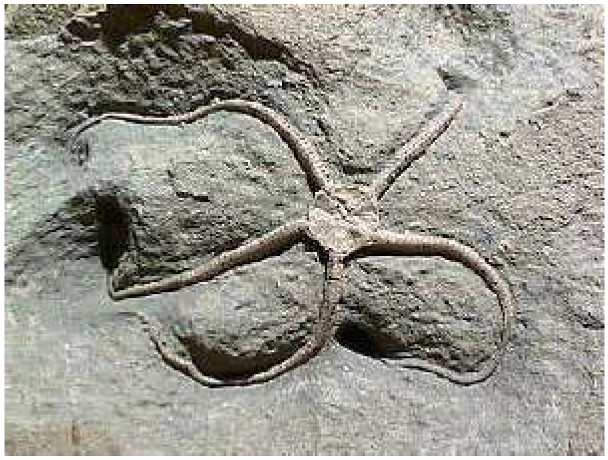
Ophiuroidea contains two large clades, Ophiurida (brittle stars) and Euryalida (basket stars). Many of the ophiuroids are rarely encountered in the relatively shallow depths normally visited by humans, but they are a diverse group.

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

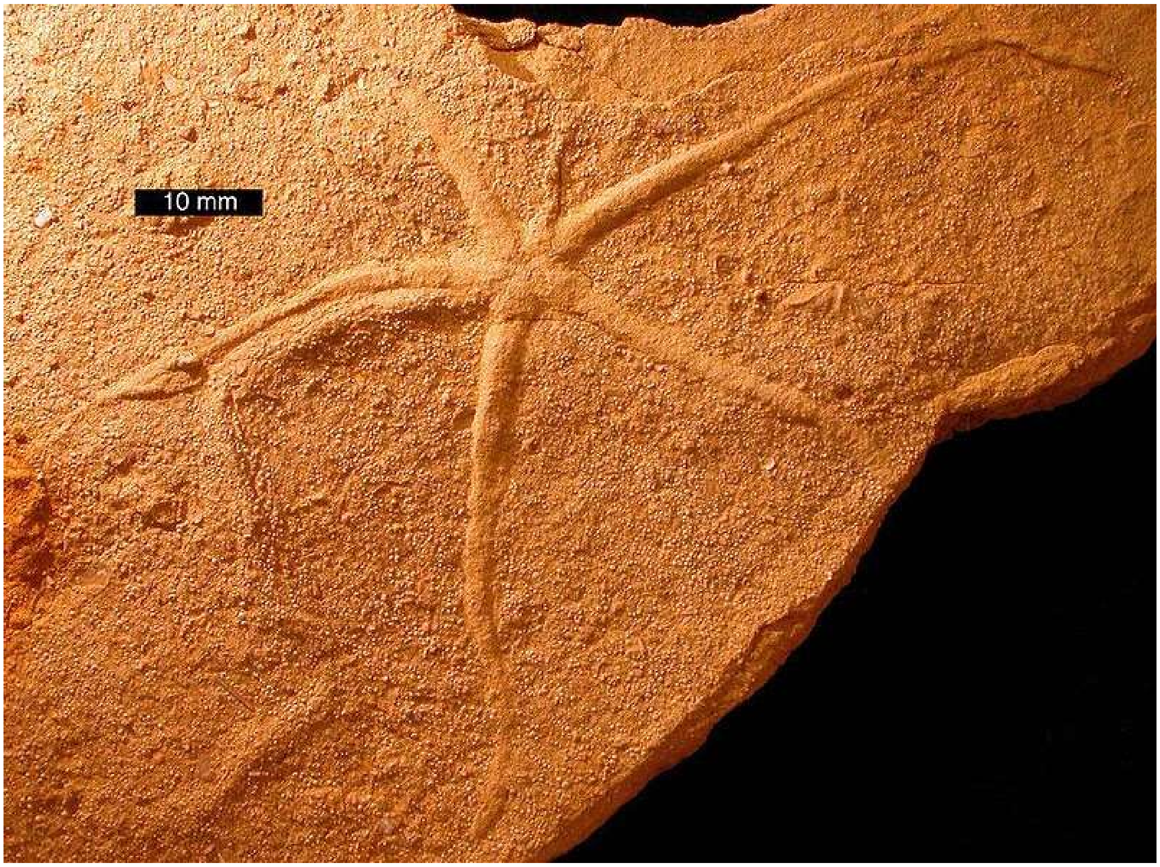
There are roughly 1900 extant species in 230 genera, grouped in the three orders currently living: Oegophiurida, Phrynophiurida, and Ophiurida. There is also a Paleozoic order, the Stenurida.

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

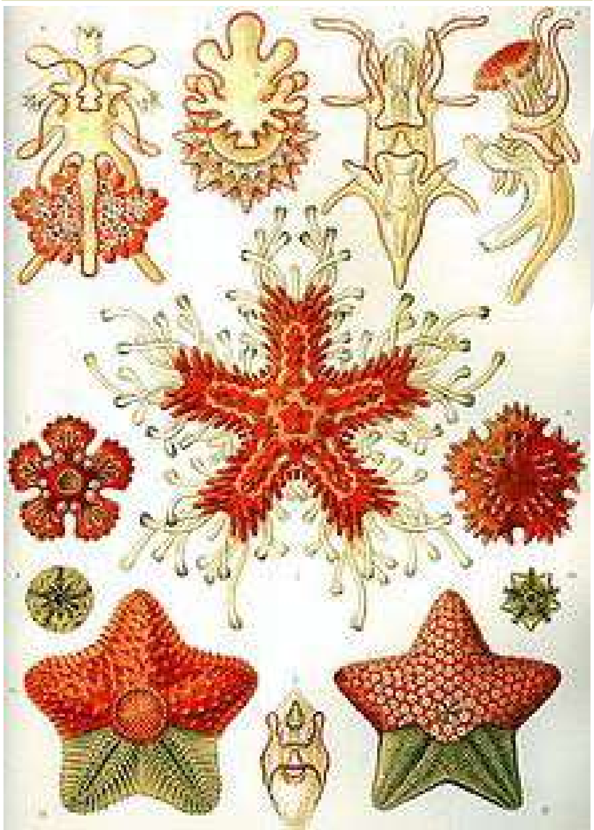
Brittle stars are a moderately popular invertebrate in fishkeeping. They can easily thrive in marine tanks, in fact the micro brittle star is a common "hitchhiker" that will propagate and become common in almost any saltwater tank, if one happens to come along on some live rock.

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- 13

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)

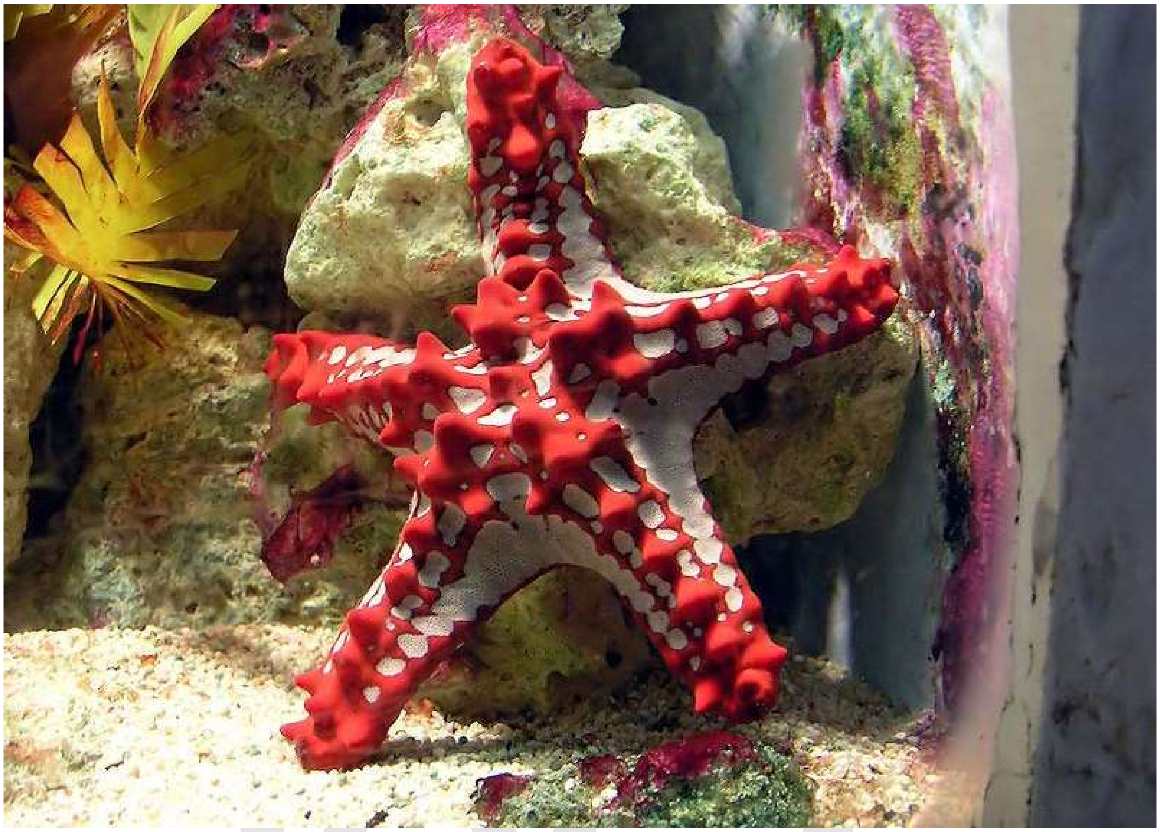
Starfish or **sea stars** are echinoderms belonging to the class **Asteroidea**. The names "starfish" and "sea star" essentially refer to members of the Class Asteroidea. However, common usage frequently finds "starfish" and "sea star" also applied to ophiuroids which are correctly referred to as "brittle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

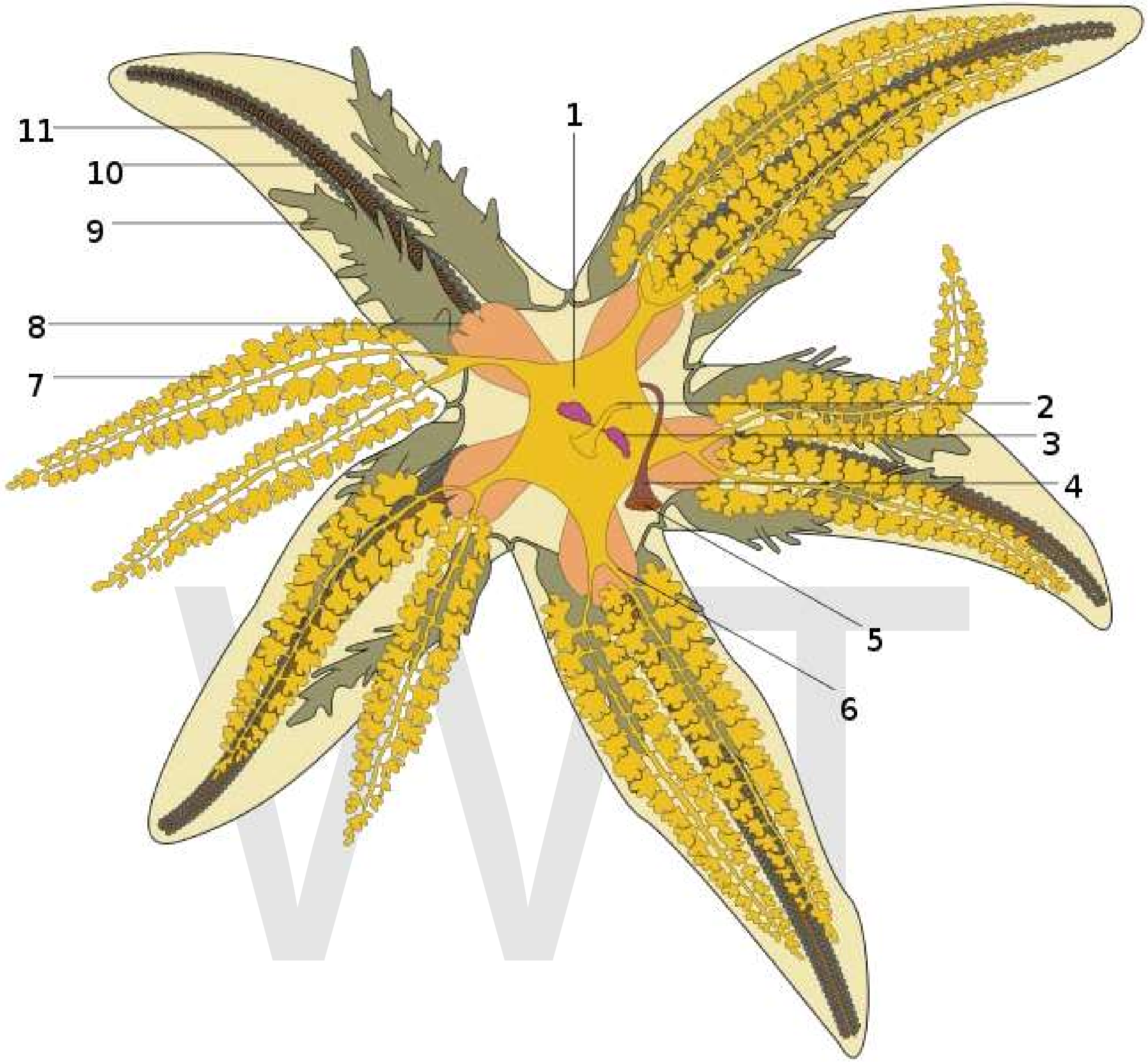
The body surface of sea stars often has several structures that comprise the basic anatomy of the animal and can sometimes assist in its identification.

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.

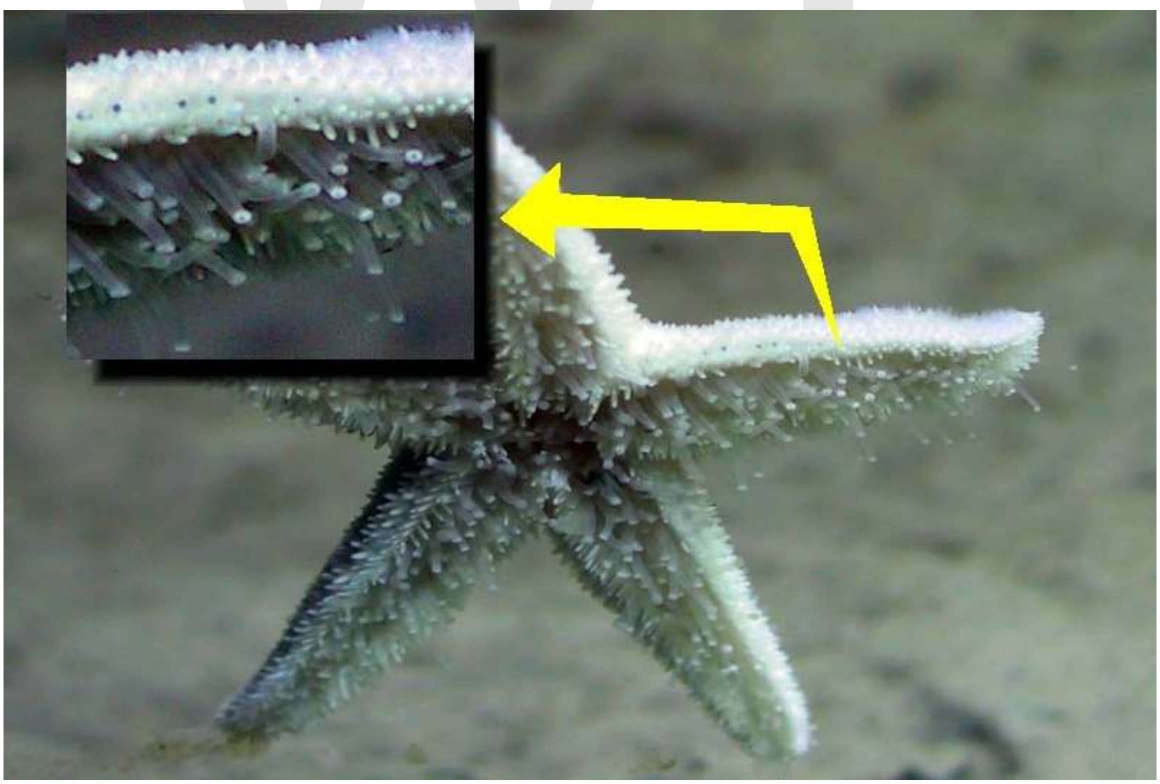
Nervous system

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

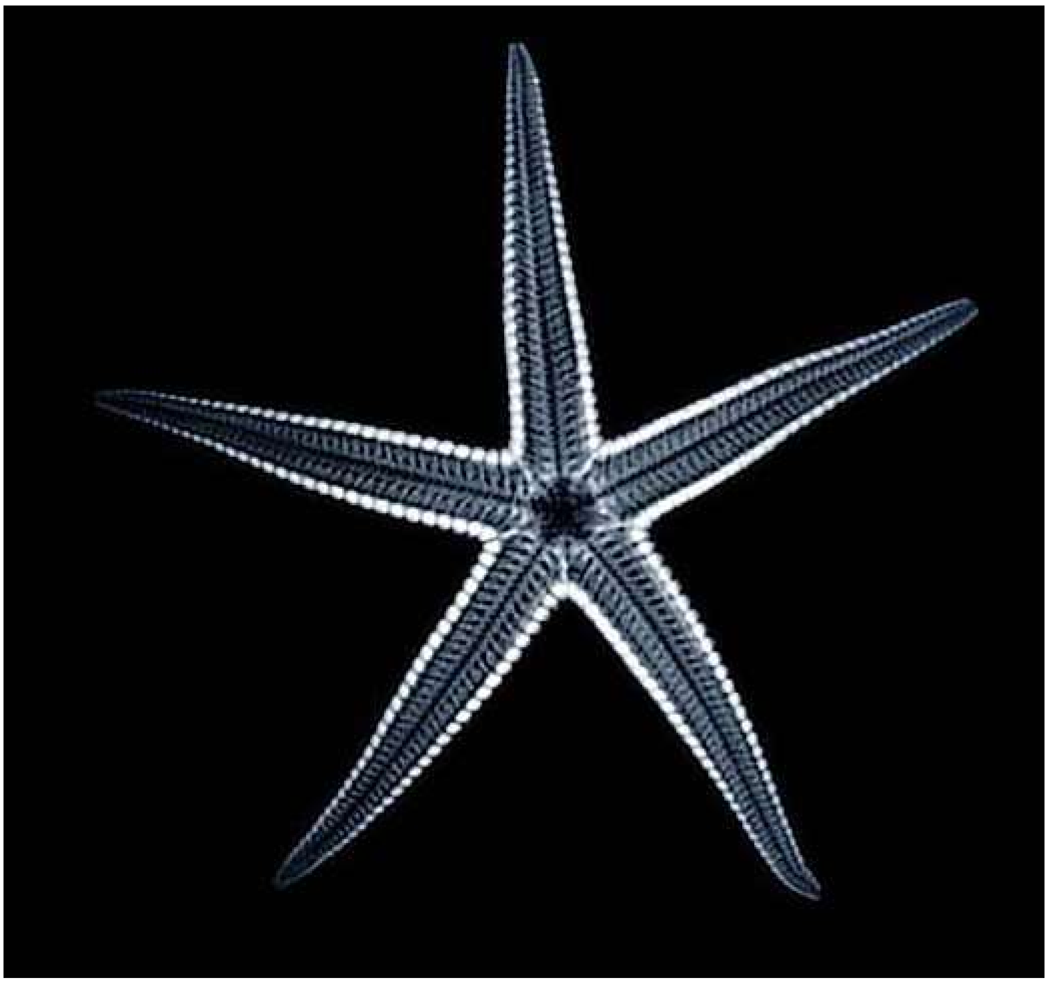


The underside of a sea star. The inset shows a magnified view of the tube feet.

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.

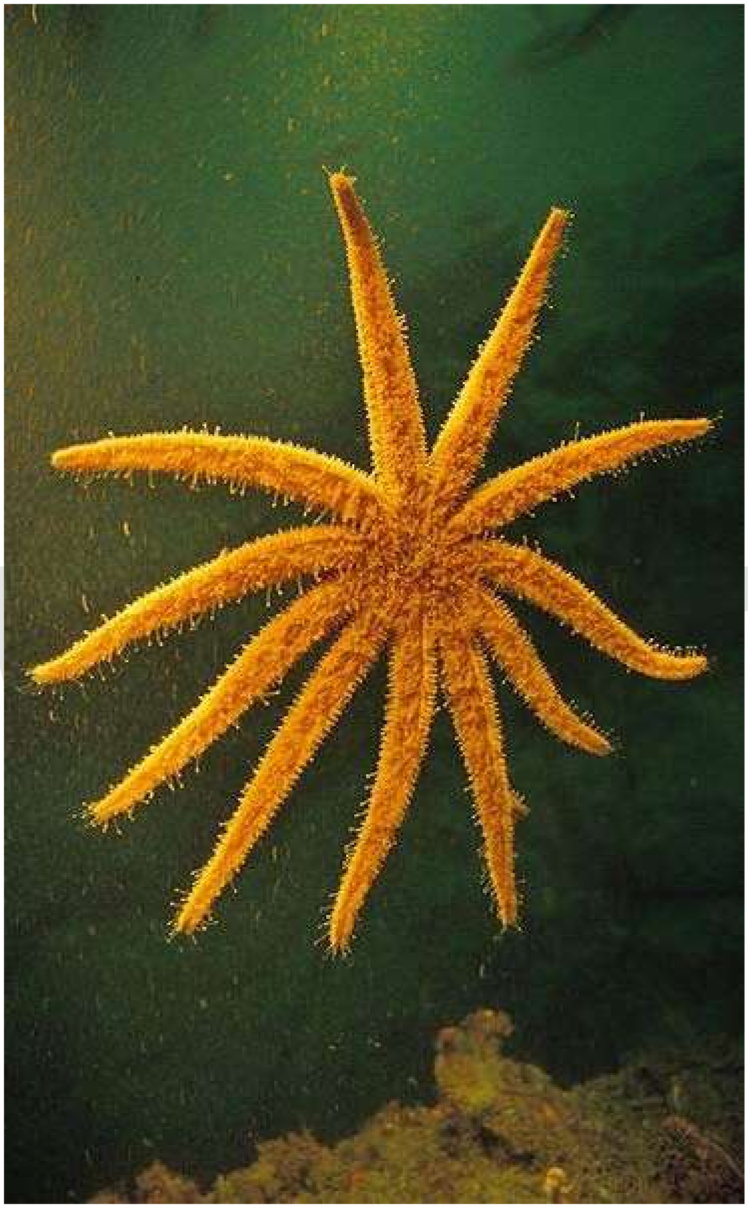
Starfish do not appear to have any mechanisms for osmoregulation, and keep their body fluids at the same salt concentration as the surrounding water. Although some species can tolerate relatively low salinity, the lack of osmoregulation likely explains why starfish are not found in fresh water, or even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

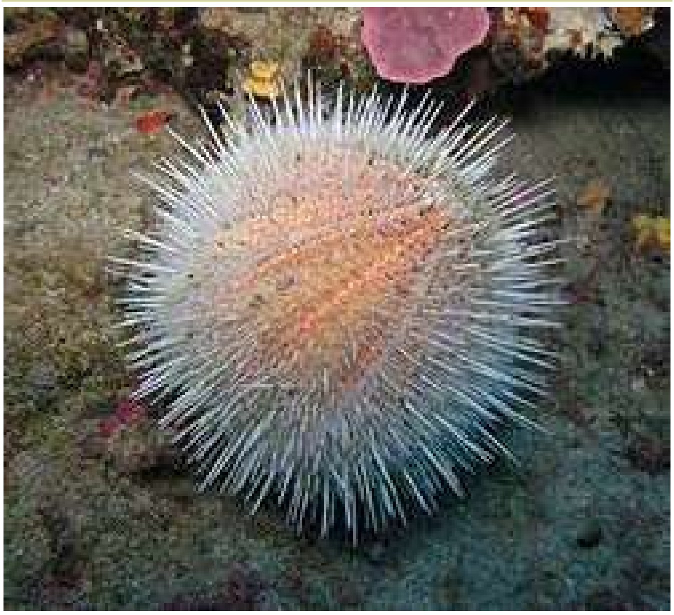
Threats

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- 14

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

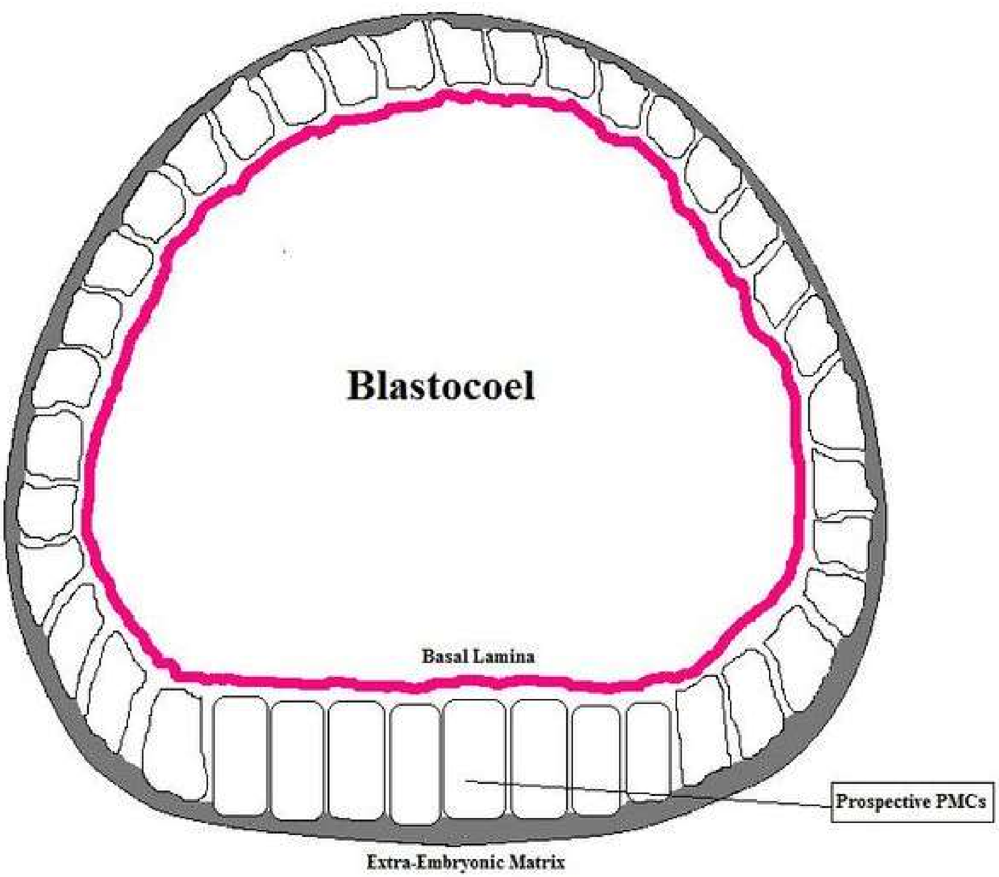
The nervous system of sea urchins has a relatively simple layout. There is no true brain. The center is a large nerve ring encircling the mouth just inside the lantern. From the nerve ring, five nerves radiate underneath the radial canals of the water vascular system, and branch into numerous finer nerves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

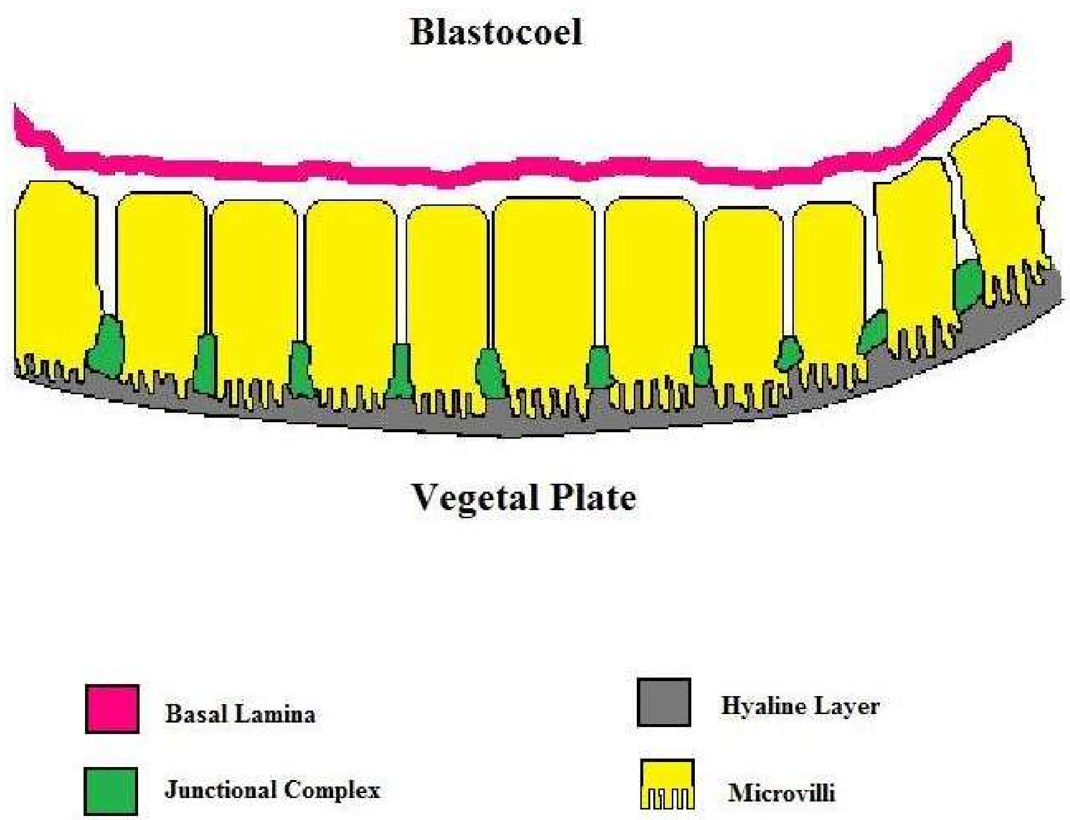
Ingression of primary mesenchyme cells



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.

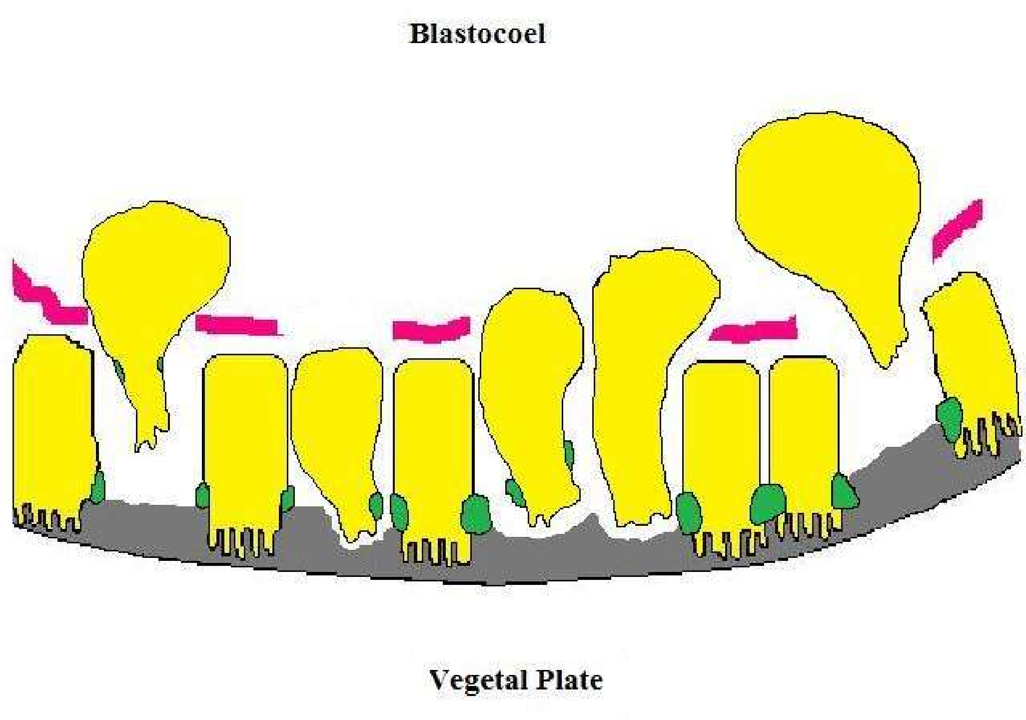
The first step of gastrulation is the epithelial to mesenchymal transition and ingression of primary mesenchyme cells into the blastocoel. Primary mesenchyme cells, or PMCs, are cells located in the vegetal plate that are specified to become mesoderm. Prior to ingression, PMCs exhibit all the features 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

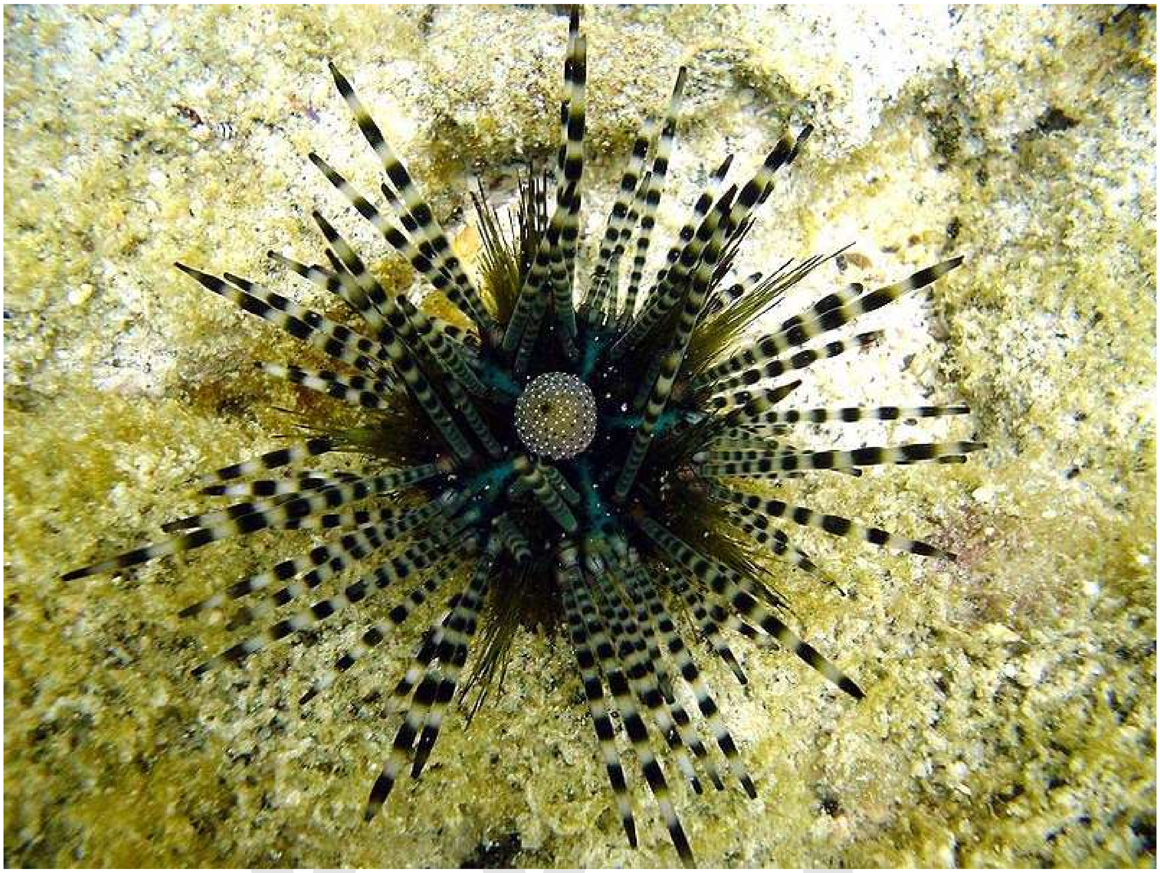
At first glance, sea urchins often appear sessile, i.e., incapable of moving. Sometimes the most visible life sign is the spines, which attach to ball-and-socket joints and can point in any direction. In most urchins, touch elicits a prompt reaction from the spines, which converge toward the touch point. 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- 15

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- 16

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.

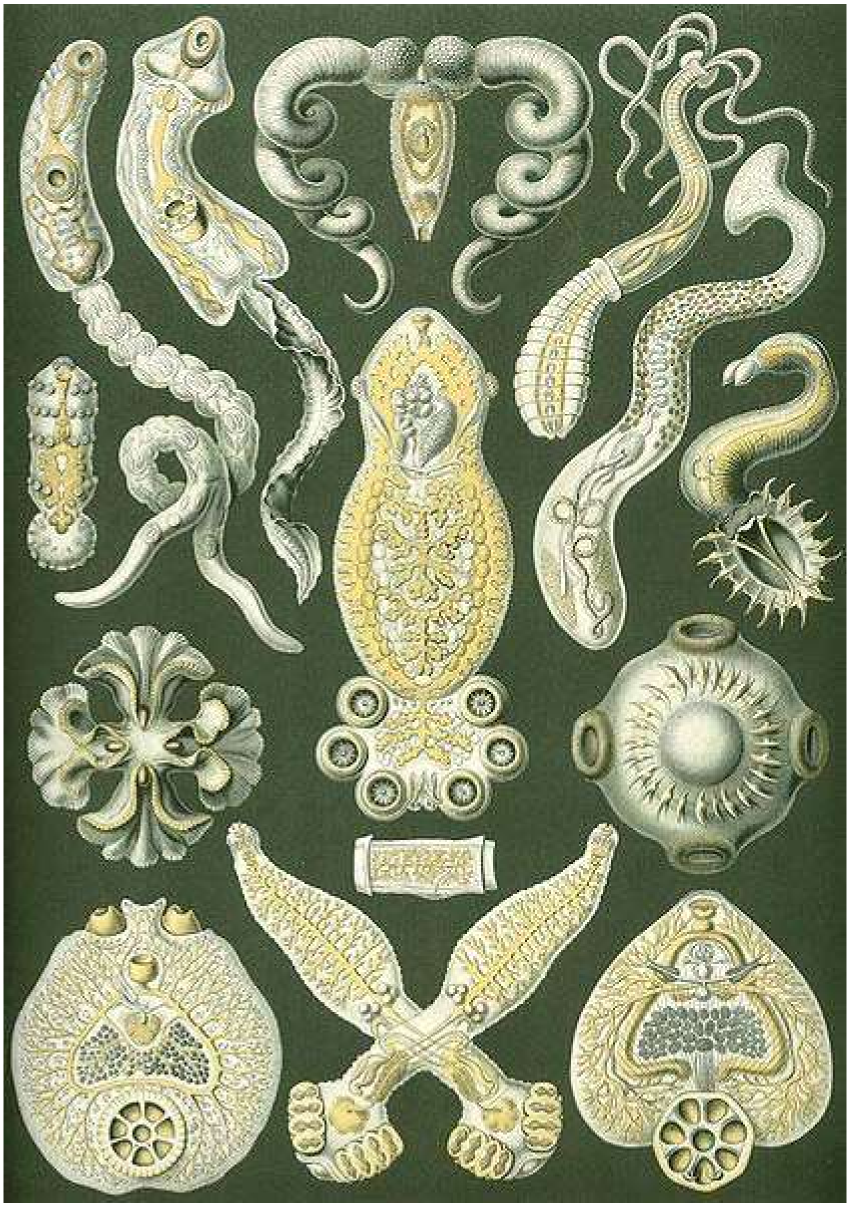
In traditional zoology texts Platyhelminthes are divided into Turbellaria, which are mostly non-parasitic animals such as planarians, and three entirely parasitic groups: Cestoda, Trematoda and Monogenea. Turbellarians are mostly predators, and live in water or in shaded, humid terrestrial environments 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.

<table>
<tr><th></th><th>Cnidarians and Ctenophores</th><th>Platyhelminthes</th><th>More "advanced" bilaterians</th></tr>
<tr><td>Bilateral symmetry</td><td>No</td><td colspan="2">Yes</td></tr>
<tr><td>Number of main cell layers</td><td>Two, with jelly-like layer between them</td><td colspan="2">Three</td></tr>
<tr><td>Distinct brain</td><td>No</td><td colspan="2">Yes</td></tr>
<tr><td>Specialized digestive system</td><td>No</td><td colspan="2">Yes</td></tr>
<tr><td>Specialized excretory system</td><td>No</td><td colspan="2">Yes</td></tr>
<tr><td>Body cavity containing internal organs</td><td colspan="2">No</td><td>Yes</td></tr>
<tr><td>Specialized circulatory and respiratory organs</td><td colspan="2">No</td><td>Yes</td></tr>
</table>

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

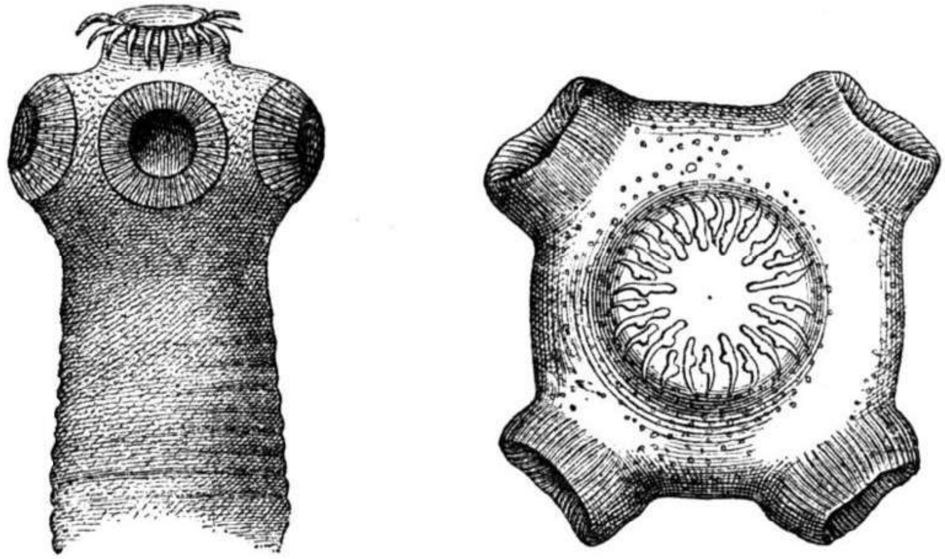
This group of parasites attach themselves to the host by means of disks that bear crescent-shaped hooks. They are divided into Monogea and Cestoda.

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- 17

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- 18

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.

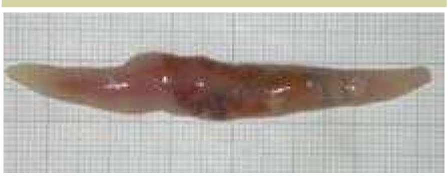
- Genus *Protopolystoma,* found in aquatic clawed toads (*Xenopus* species).

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

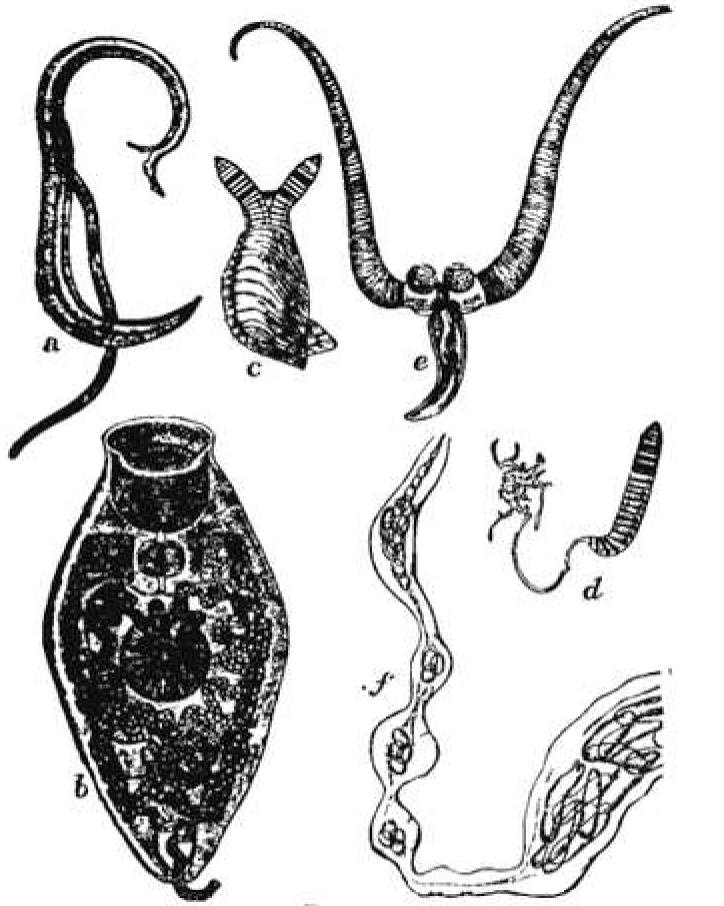


FIG. 9.

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 *Bucephals* 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.