SPOTLIGHT

Cephalopods

Adaptations of successful carnivores

The class Cephalopoda includes nautilus, cuttlefish, squid and octopus. All have a range of adaptations for a carnivorous lifestyle. Zoologist Ashley Le Vin investigates how these adaptations make them so successful

Cephalopods are in the phylum Mollusca, from the Latin *mollis* – soft. All molluscs have a soft body, although some are protected by a hard external shell. Molluscs include commonly known animals such as snails and oysters, as well as the less commonly known sea-butterflies and chitons.

Cephalopods are the most physically and behaviourally advanced of the molluscs. They are found throughout the world's oceans and many live at depths shallower than 200 m, while some go as deep as 1200 m. They range in size from a few centimetres, such as the Hawaiian bobtail squid, to an estimated 20 m for the giant squid (the length of 2.5 London buses). They show a range of adaptations that have made them successful in their carnivorous lifestyles. Many are active and ferocious predators, others are 'sit-and-wait' predators.

Streamlined jet-propelled swimmers

The cephalopods include species with and without shells, but as they have evolved their shells have progressively been reduced and then lost. Nautilus are the only subclass with an external shell, cuttlefish have a small internal shell, squid have only a thin internal vestigial shell made of chitin (the same material as insect exoskeletons) and octopus have no shell. A reduced shell allows a streamlined body form that moves more easily through the water. This, together with an ability to jet propel at great speed, helps squid and octopus capture prey and escape becoming dinner themselves. Jetting is achieved through nervous control, muscular movement and the use of a siphon (see Figure 1).

Cephalopods have giant nerve axons with wide diameters, which allow nerve impulses to be sent rapidly through the body to stimulate muscles in the mantle (the main body) of the animal. The first muscles to contract are radial muscles, which attach across the width of the mantle (see Figure 2). This reduces the mantle thickness and expands the volume of the mantle cavity, causing water to be pushed down a pressure gradient. This water travels over the gills and oxygen diffuses into the animal. Then, to propel the animal, the circular muscles that surround the mantle cavity contract. This reduces the volume of the mantle cavity, causing an increase in the pressure that quickly expels water out of the siphon, pushing the animal along. In order to ensure that the water exits out of the siphon and not out the way it has come in, there are valves to prevent the backflow of water.

This forceful ejection of water can generate swimming speeds of 40 km h^{-1}, allowing pursuit and capture of prey. One species even uses jetting to propel itself out of the water to 'fly'. Japanese flying squid jet out of the ocean and use their lateral fins to 'fly' over the surface, covering large distances. This may be to escape predators but could also be a more efficient way of travelling since there is less resistance in the air than in water.

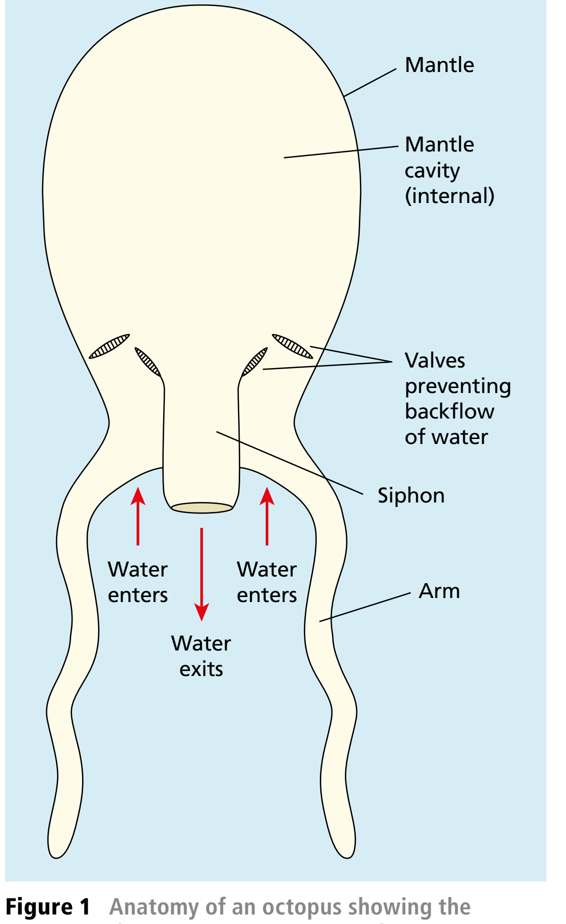
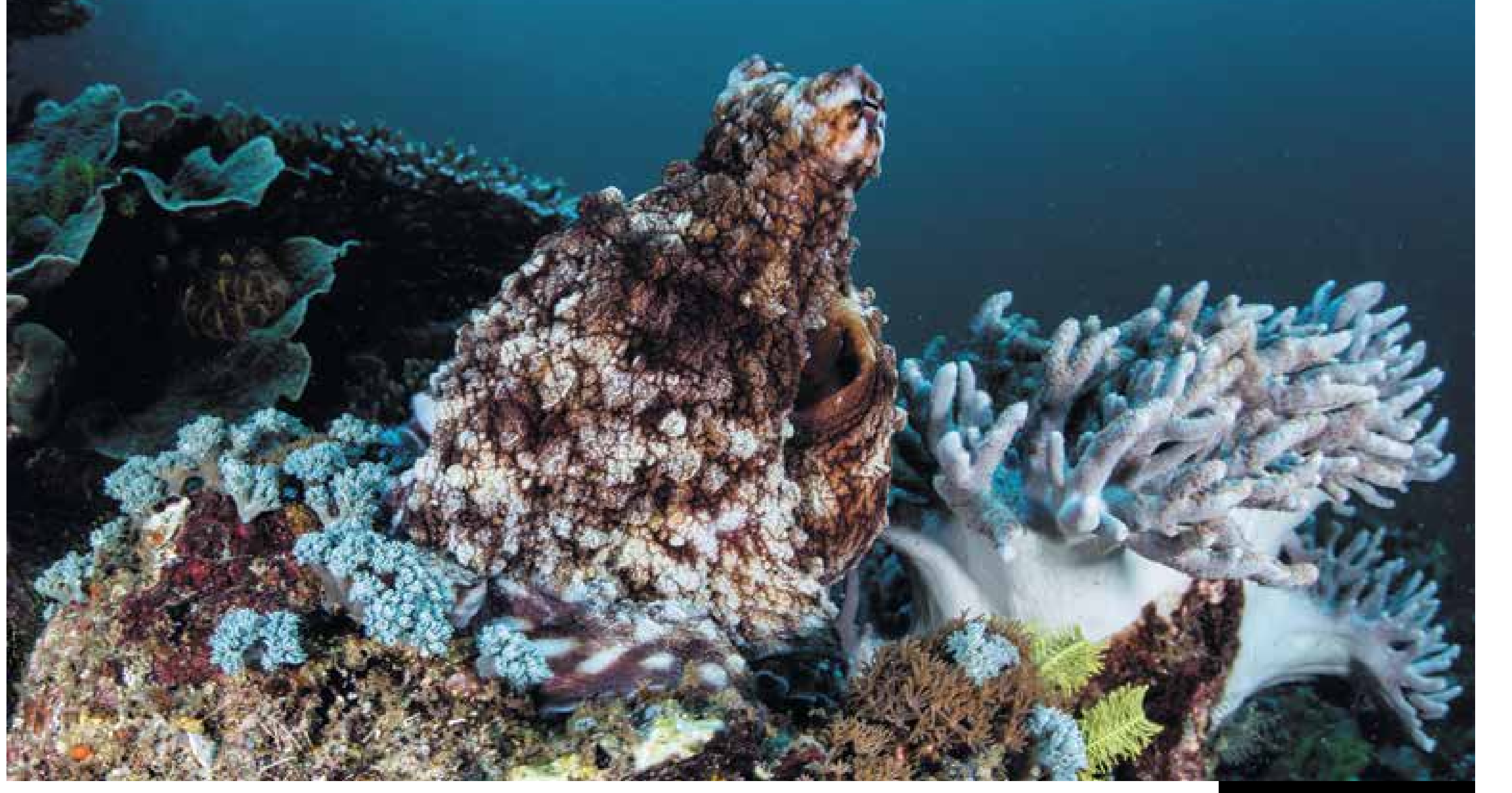


Figure 1 Anatomy of an octopus showing the direction of water movement, which facilitates jetting



Octopus on a coral reef showing postural crypsis. The skin of the animal is textured and coloured like the reef, camouflaging the animal

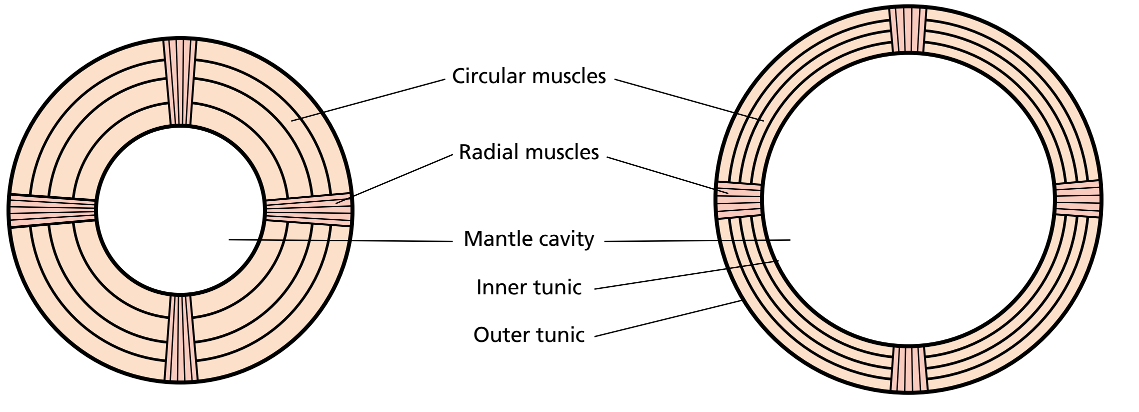


Figure 2 Transverse section through a cephalopod mantle depicting the muscles involved in (a) jetting and (b) movement of water into and out of mantle cavity for jetting

Triple heart circulation

Jetting is energetically costly and is facilitated by cephalopods having a ready supply of oxygen to the tissues in their body. What enables them to achieve this is their three hearts, allowing effective transport of blood around the body (see Figure 3). Cephalopods can also increase their heart rate and stroke volume (the amount of blood pumped with each beat) in order to more quickly move oxygenated blood around the body.

Although it may seem peculiar to have two different functioning types of heart, their hearts are essentially the same as ours. The right side of our heart acts like an accessory **branchial** heart supplying deoxygenated blood to the lungs, while the left side of our heart acts like a systemic heart supplying the body's tissues with oxygenated blood.

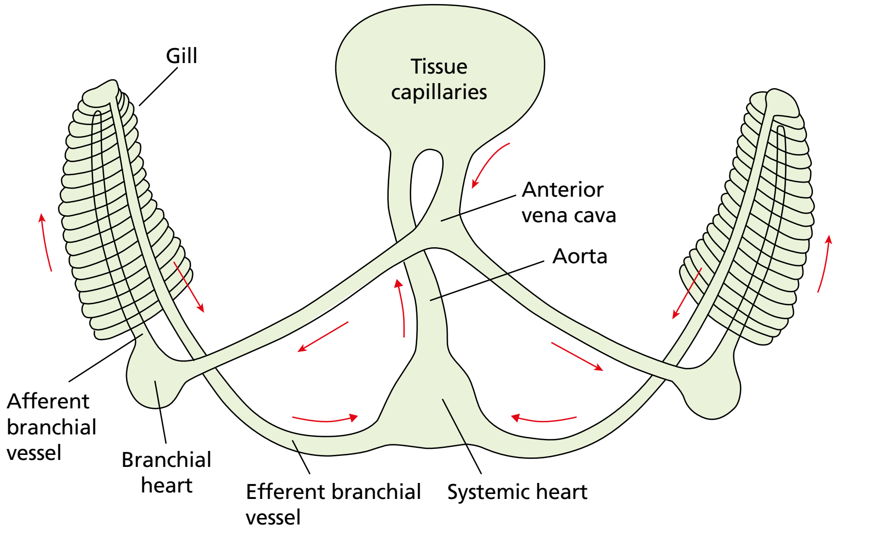


Figure 3 The three hearts found in cephalopods. Two branchial hearts found at the top of each gill pump deoxygenated blood into the gills where it becomes oxygenated and then moves to the third heart, which is called the systemic heart. This takes the oxygenated blood and pumps it to all the tissues in the body. The arrows show the direction of movement of the blood

Examples of the main groups of cephalopods: (a) nautilus, (b) cuttlefish, (c) squid, (d) octopus

Colour change and postural crypsis

Many cephalopods, such as the Hawaiian bobtail squid, act as 'sit-and-wait' predators in order to capture their prey. Most cephalopods are colour-blind and their eyes contain only one type of light receptor, meaning they see in black and white. One species, the firefly squid, shows amazing displays of **bioluminescence**, and has been found to have three types of light receptors. They are the only species of cephalopod so far investigated thought to have simple colour vision. Nevertheless, although cephalopods are unable to see colour, most can change their colour patterns to match to the contrast and brightness of their surroundings in order to camouflage themselves. However, the mechanisms by which they match colour are still not understood by scientists.

The major organs involved in colour change are pigment cells called chromatophores, providing yellows, oranges, reds, browns and black. Each chromatophore consists of a single pigment cell surrounded by 10–30 radial muscles, controlled by the nervous system. The muscles can be contracted, stretching the cell out to 14 times its original length, dispersing the coloured pigment over a larger area. The density of chromatophore cells can range from 8 to 230 chromatophores per mm^2 of skin, allowing huge variation in the colour patterns formed. **Iridophore** cells reflect pinks, greens, blues or silvers, giving a metallic appearance. Leucophores reflect mainly white light and are thought to contain guanine. These, coupled with other reflecting cells, create amazing colour patterns under nervous control, allowing instantaneous colour change.

So cephalopods are excellent at camouflaging, allowing them to 'jump out' unnoticed at passing prey. Cuttlefish and octopus go even further and display postural crypsis. Here, they not only change the colour of their body but also its shape, allowing them to mimic natural objects such as seaweed or rocks. Their skin contains papillae, which are under nervous control and can extrude from under the skin to create texture to the body of the animal, which further enhances their disguise.

Toothed rings surrounding suckers of a Humboldt squid

TERMS EXPLAINED

Bioluminescence The production of light by a chemical reaction in the body of a living organism (see Biological Sciences Review, Vol. 33, No. 1, pp. 11–14).

Branchial Of, or relating to, the gills.

Buccal Relating to the cheek or mouth.

Iridophores Pigment cells containing guanine that reflect light giving iridescent/metallic colouration.

Radula A tongue-like feeding organ. The shape, size, number and arrangement of the teeth varies between species and can be used for species identification.

Amazing appendages

With the prey in sight, either from being actively hunted or through sit-and-wait strategies, the cephalopod must now capture its prey, using some of its well-adapted appendages. Cephalopods have two types of appendages – arms and tentacles. Tentacles are longer than arms and extendable; arms are not extendable. Nautilus have 60–90 tentacles, squid and cuttlefish have eight arms and two tentacles, and octopus, as the name suggests, have eight appendages, all arms. Species with tentacles can rapidly extend these out to grab at prey items, quickly bringing them towards their mouth. The cuttlefish *Sepia officinalis* has a strike faster than a praying mantis, being able to strike and capture prey items in under 15 milliseconds.

Nautilus have a series of ridges on their tentacles and adhesive glycoprotein secretions to stick and grip to their prey – e.g. small crabs or shrimps. They are also opportunistic and will scavenge on dead carrion they find on the ocean floor. Squid and cuttlefish have suckers on their tentacles, which often have small, chitinous, ringed 'teeth' surrounding the suckers that help them to grip their prey.

A beak from a colossal squid

Colossal squid have hooks on their tentacles and arms with some hooks able to rotate 360° so that struggling prey find it almost impossible to escape. These adaptations, combined with the hugely muscular appendages, mean prey stand little chance of escape once the cephalopod has hold of them. In addition, the length of the appendages allows cephalopods to grasp animals bigger than themselves.

Monstrous mouths and venomous saliva

Once trapped in the cephalopod's appendages, the prey is brought towards its mouth, which is located between its arms/tentacles. Here we find a rather small, odd-looking feature that may look more at home in a bird's mouth – a beak. The beak is composed mainly of water, chitin and proteins, as well as a pigment giving it a dark colour at its tip. The strength of the beak increases with increasing protein and pigment levels at the tip, making it one of the hardest organic structures known. The beak is surrounded by a mass of muscle, the **buccal** mass, making it a great tool for tearing off chunks of flesh. The beak of the Humboldt squid can even sever the spinal cord of the fish it catches, paralysing them.

Paired with the beak is a **radula** – a feature of the majority of molluscs. This thin tongue-like rasping organ is covered with microscopic teeth that help to rasp away at flesh or begin to bore holes in shells. However, many species, such as the greater blue-ringed octopus, have another trick up their beak – venomous saliva produced in the salivary glands. The venom of the greater blue-ringed octopus can be fatal to humans. Research in this area is limited, but common toxins include neurotoxins which affect the nervous system of prey and can weaken or paralyse them swiftly to allow easier handling. The beak can then be used to tear off chunks of flesh, or in some species where prey such as crabs are eaten, digestive enzymes are released to break down tissues from within the crab's carapace. All in all, members of the class Cephalopoda show a huge range of adaptations to make them remarkable carnivores.

Things to do

- Look for some molluscs in your garden or local park. Place a slug on a piece of clear plastic or glass and observe the underside. You should be able to see its mouth and radula scraping along the surface.
- Watch videos on colour change and postural crypsis in cephalopods, e.g.:
  - 'How octopuses and squids change colour', Smithsonian Ocean: **https://tinyurl.com/y4ey7rzh**
  - 'The imitation game', *The Biologist*: **https://tinyurl.com/y6cuh2g5**
- Investigate other features of cephalopods, such as their well-developed eyes and intelligence, and consider how these have also aided them in becoming successful carnivores.

RESOURCES

TED talk on cephalopod brains and skin: **https://tinyurl.com/y63zjvcv**

'Cephalopods', Smithsonian Ocean: **https://tinyurl.com/yxa7nfc5**

'Cephalopods as predators', Frontiers in Physiology: **https://tinyurl.com/yyz4sdwo**

Squid jet propulsion: **www.youtube.com/watch?v=9OIjaHIrM0U**

My Octopus Teacher, available on Netflix.

Dr Ashley Le Vin is a lecturer in zoology and marine and freshwater biology at the University of Glasgow and has a keen interest in molluscs and animal behaviour.