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KEY WORDS
Caecilian
Amphibian
Evolution
Phylogenetic tree
Taxonomy
Variation
Adaptation

No it's a caecilian!

Caecilians have a range of remarkable characteristics that make them unique. This article explains what makes caecilians so fascinating and what we can learn about evolution from studying them.

Caecilian, pronounced 'siss-ee-lee-an', is the common name for a group of amphibians that are relatively unknown to many people, and so are usually mistaken for other animals. Those caught during fishing are often mistaken for eels, which is why one aquatic species has the common name rubber eel (see Figure 1). Other examples of mistaken identity are as earthworms and snakes.

Caecilians and other amphibians

All amphibians have moist skin without scales or hairs. Caecilians (see Box 1 on p. 18) differ from other amphibians in many ways. They have no limbs, and so superficially resemble snakes. The scientific name for

Kingdom	Animalia
Phylum	Chordata

Caecilians		Humans	
Class	**Amphibia**	Class	**Mammalia**
Order	**Gymnophiona**	Order	**Primates**
Family	**Typhlonectidae**	Family	**Hominidae**
Genus	***Typhlonectes***	Genus	***Homo***
Species	***natans***	Species	***sapiens***

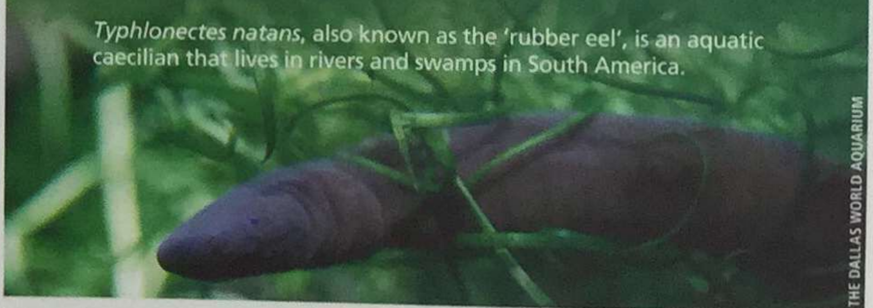

Figure 1 The taxonomic classification system. Caecilians and humans are both animals with a backbone but differ — for example, amphibians have moist skin, mammals have hair.

BOX 1

Caecilian fact file

- Caecilians form one of three orders of living amphibians; the other two orders comprise frogs and toads, and newts and salamanders (see pp. 20–21).
- There are approximately 180 species of caecilians currently known, making them a comparatively small order of vertebrates.
- They are carnivorous, eating mostly invertebrates such as termites and worms.
- Many species burrow in soil or hide under leaf litter, often only coming out on the surface at night.
- One family is fully or semi-aquatic, inhabiting rivers, swamps and flooded forests.
- They live in the moist tropical regions of South and Central America, sub-Saharan Africa, India and southeast Asia, and the Seychelles.

Figure 3 A caecilian (left) trying to eat a large earthworm.

the order to which caecilians belong is Gymnophiona, which derives from the Greek words meaning 'naked snake'. Like snakes, caecilians are slender and elongate. The longest species of caecilian is *Caecilia thompsoni* from South America, which can grow to a length of more than 150 cm. The smallest species is *Idiocranium russeli* from Cameroon, which is about 10 cm long. Their bodies have ring-shaped folds, which give them a segmented appearance. This is why they are often mistaken for earthworms. Caecilians either have a very small tail or no tail at all.

Senses

The name caecilian derives from the Latin word *caecus*, meaning 'blind', but caecilians are not blind, they just have small eyes that are covered by skin. Some species spend all their life underground and their eyes have become covered by bone. In these species, the eye no longer has a lens although it retains the retina and optic nerve. Vision in caecilians is quite unlike most amphibians or indeed humans, and is similar to deep-water and cave-dwelling **vertebrates**. Usually, the vertebrate retina is made up of two types of cells that detect light — rods and cones. Rods are more numerous and more sensitive than cones, so they can work in less intense light. Caecilians have only rods and no cones. They cannot see colour but their eyes are tuned to maximise the absorbance of even the weakest light.

Caecilians make up for having relatively poor vision by having a good sense of smell and taste. Unique to caecilians, the tentacle is a sensory structure found between the eye and nostril (see Figure 2). The caecilian tentacle is thought to be important for chemoreception — it can detect certain chemical stimuli in the environment, such as **pheromones**. So the tentacle gives caecilians a 'sixth sense'. The tentacle can also serve as a sensitive organ for touch. Caecilians are able to sense vibrations and low sound frequencies. They have ears but the ear is not visible on the outside of the head and so they are unlikely to be able to detect higher frequency sounds.

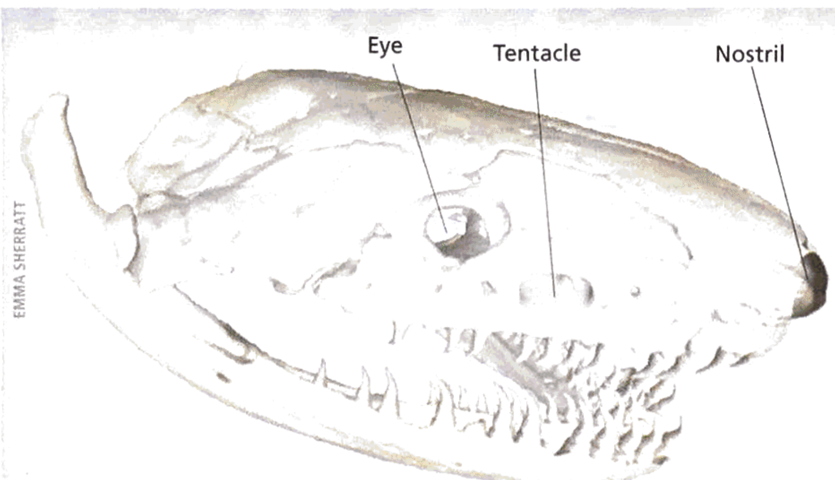

Figure 2 A caecilian skull and head. Caecilians have a unique sense organ — the tentacle — that helps them to 'taste' the environment.

Movement

Caecilians have no legs. The way they move on land and in water is by forming S-shaped curves with their whole body. In narrow tunnels in soil, caecilians move more like earthworms in a concertina-like fashion; the caecilian bends its backbone to form S-shaped curves, and when it is straightened, the head is pushed forward.

Caecilians in the food web

Caecilians are an important link in the tropical food web. As predators, caecilians eat soil-dwelling invertebrates and leaf-litter-dwelling invertebrates such as termites and worms. Some species are known to prey on large worms (see Figure 3) and even small vertebrates. Like worms, they loosen and turn the soil as they burrow, so caecilians are welcomed in cultivated areas. Caecilians are thought to have toxic skin that makes them distasteful to predators. However, they are known to fall prey to several species of snakes and birds.

Reproduction and motherhood

Caecilians (and some salamanders) differ from other amphibians in the way they mate. Male caecilians have an external copulatory organ that they use to internally fertilise the female. Once pregnant, there are several different strategies used by caecilian mothers to have babies, including egg-laying and giving birth to live young. Egg-laying caecilian mothers protect their young by curling around the eggs. Some terrestrial caecilians lay eggs adjacent to water, from which aquatic larvae hatch. These larvae live in the water until they change (metamorphose) into an adult and leave to live on land. This is similar to frogs that have frogspawn and tadpoles.

Caecilian species that live away from free-standing water can also lay eggs. Their young metamorphose inside the egg and are born to move on land like adults. Two such species are known to take the mothering behaviour one step further: they provide food for their newborns by secreting a special layer of skin that contains important nutrients such as lipids. The young peel off and eat this. These young have specialised teeth that can scrape the skin (see Figure 4).

Some caecilian mothers give birth to live young. There are still eggs but they are retained inside the body for hatching. Their parental care is equally extreme. By retaining the young in their bodies for extended periods, they can better protect the brood from predators. Moreover, the young also feed off their mother. These young have specialised teeth, which they use to scrape the lipid-rich lining of the oviduct. Aquatic caecilians also retain their eggs until they hatch but give birth to aquatic larvae with large external gills. The gills are lost when the larva metamorphoses into an adult.

TERMS EXPLAINED

Live bearer A species that gives birth to live young, as opposed to laying eggs.

Natural selection A mechanism of evolution. It is the process by which a trait (for example, body size, plumage colour) becomes more or less common in a population because of the differential reproduction of its bearers.

Pheromone A chemical secreted by the animal's body that triggers a response in members of the same species.

Phylogenetic tree A branching diagram that represents the evolutionary relationships among species based on similarities and differences in their physical characteristics and/or DNA.

Tetrapod A group of vertebrates that includes amphibians, reptiles, birds and mammals (i.e. all non-fishy vertebrates). The name comes from the Latin meaning 'four-footed' to distinguish them from finned fish but is somewhat inaccurate when it comes to the limbless snakes, caecilians and some lizards.

Vertebrates Animals in the phylum Chordata that have a spinal column protected by bone or cartilage.

Caecilian diversity and the tree of life

We know that caecilian species are diverse, differing from each other in many ways, such as in their eyes, body size and their life history. In order to understand why species differ from each other, how those differences come about and why differences are maintained, we need to know how species are related.

The evolutionary relationships among caecilian species have been deduced by comparing their DNA. Species with similar genetic make-up are more closely related, while species with different genetic make-up

(*continued on p. 23*)

Figure 4 Yummy mummy! Baby caecilians eating their mother's skin.

An animal tree of life

This diagram outlines some of the key developments that are used to classify animals and fit them into evolutionary trees. The photos show some of the species that have stemmed from the evolutionary steps made over time, during which simple single-celled animals gave rise to complex multi-celled animals. An important dividing point was when animal ancestors diverged into those with radially symmetrical bodies, such as jellyfish and sea anemones, and those with bilaterally symmetrical bodies. Worms, snakes and caecilians are all bilaterally symmetrical, so it is this path that the diagram focuses on. The figures illustrate a tiny fraction of the diversity of animals. For a detailed tree of life, with many more species, visit **http://is.gd/sD3m0T**

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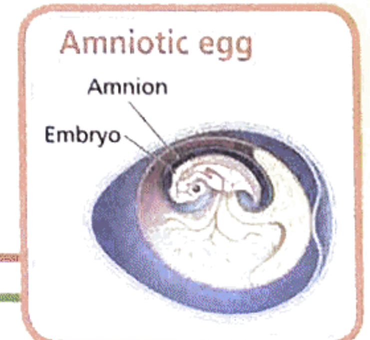
Fact file

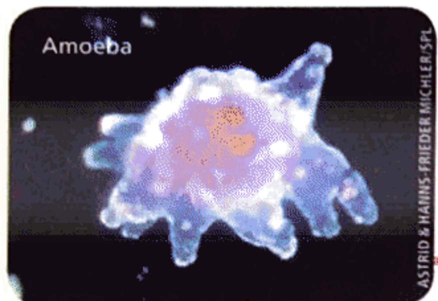
Earthworms are **invertebrates**, which means they do not have a backbone, but they are able to stiffen and move their bodies thanks to a hydrostatic skeleton — see http://is.gd/GTQt6W. This is a mechanism based on pumping fluid from one segment into another, which allows worms to move across surfaces and to burrow through soil. Each segment is connected to the next but there is a partition that almost closes each one off from the other, and which allows a damaged segment to be sealed off so that the worm can regenerate the missing part (or even the rest of the worm).

Fact file

Caecilians are vertebrates — their backbone is a stiffened rod of tissue that runs along the animal's back. They are amphibians. The most familiar amphibians, such as many frogs and salamanders, lay their eggs in water; the young hatch into an aquatic phase before a dramatic change (metamorphosis) into a form that can breathe air and live on land. Many caecilians do not lay their eggs in water, however, and their key feature is a lack of limbs.

All amphibians are descended from four-legged (**tetrapod**) ancestors, but caecilians (like snakes) have lost their limbs over time.





Bilateral symmetry

Backbone

Lungs

Limbs

Radial symmetry

Vertebrates
Invertebrates
Amphibians
Reptiles

Fact file

Snakes are vertebrates and they are reptiles. Reptiles are characterised by having scaly skin, which protects the animal and helps it to withstand the drying effects of terrestrial life. Most snakes give birth to live young, or lay eggs that are capable of surviving on land because they are encased in a protective covering and contain a pool of nutrients. The embryo is suspended in this pool of nutrients and cushioned from the outside world by an amniotic sac, just like the one that we all had around us before we were born. Snakes may have lost their limbs during evolution, but it is still possible to see vestiges of their four-limbed past in species which have tiny spurs (see inset) that emerge from their otherwise smooth exterior.

BOX 2

Evolution of the caecilian skull

Many caecilians use their heads to burrow through soil, as well as for feeding, breathing and sensing the environment. These different functions are all likely to influence selection for a particular shape of the skull. Biologists have noticed that different species have very different shaped skulls. By comparing skull shape between many species, we are able to understand how the diversity came about.

How to study shape

The caecilian skull can be measured using landmarks, which are coordinates that describe precisely the position of particular features (for example, the tip of the snout, corner of mouth — see Figure 6A), just like geographic coordinates on maps. Several landmarks together describe a shape, that is, three landmarks make a triangle. The measurements are then scaled to remove variation due to size. We focus on the differences in shape rather than size because we are interested in the proportions and not the scale. Finally, statistical analyses are used to make a graph that summarises the shape variation (see Figure 6B). By drawing the phylogenetic tree on the graph, and then joining the dots that represent one species, it is possible to follow the history of skull evolution.

What does the graph tell us?

The *x*-axis describes the variation between wide skulls with pointy snouts and narrow skulls with blunt snouts. The *y*-axis represents the variation in the position of the teeth, sitting in line with the front of the snout or recessed under the snout. These axes describe the main shape features of the caecilian skull. The pattern of species positions in this graph, known as a shape space, can tell how the caecilian skull evolved.

We see that each family of caecilians evolved to have a different skull shape, illustrated by the starbursts pattern and clusters of coloured dots. This pattern informs us that early in the history of caecilians there was a burst of diversification in skull shape.

What brought about this diversification?

From our knowledge of the lifestyle habits of modern species, we predict that the ancestors of these families were taking advantage of new environments (for example, aquatic, terrestrial, subterranean).

We also find that some species have broken from this orderly pattern and have skulls shaped similarly to other, unrelated species (as shown by the overlap of coloured dots on the right side of Figure 6B). On closer inspection, we find these species with similarly blunt snouts and teeth recessed far under the snout are the dedicated-burrowing caecilians that have eyes covered by bone. This suggests that natural selection is the mechanism by which the skull evolved, as these animals became specialist burrowers.

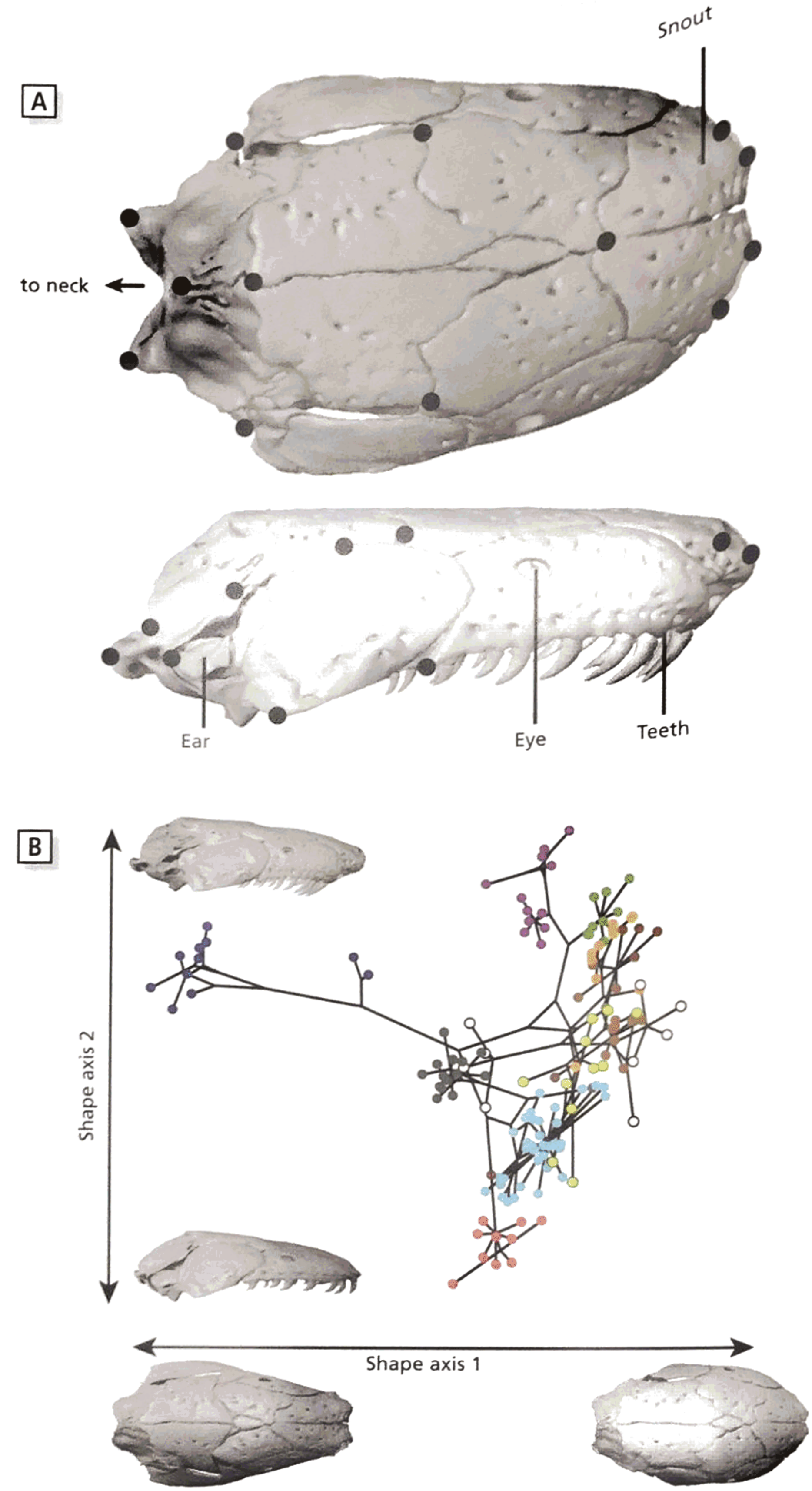


Figure 6 (A) A caecilian skull is measured using many landmarks (•), here shown from the top and the side of the skull. (B) A graph summarising the variation in skull shape. Each dot is one species, coloured by family. The lines connecting the dots are the branches in the phylogenetic tree.

FURTHER READING

News article on the skin-feeding caecilians with video footage: Vince, G. (12 April 2006) '"Yummy mummy" worms feed their skin to offspring', *New Scientist* (**http://tinyurl.com/zw8v3**).

Websites about caecilians:
http://tinyurl.com/6p6hkl5
http://tinyurl.com/85jtmfu

To find out more about studying the diversity of life:
http://evolution.berkeley.edu
http://tolweb.org/tree
Futuyma, D.J. (2009) Evolution, 2nd edn, Sinauer Associates. (**www.sinauer.com/evolution**)

are more distantly related. What we actually detect are similarities and differences in the sequence of the four bases that make up DNA. These change through mutation. We use this information on similarities and differences in DNA sequences to build a caecilian tree of life, or **phylogenetic tree** (see Figure 5). Phylogenetic trees represent patterns of ancestry. They also bring a meaning to the taxonomic classification system. A collection of species that share a common ancestor will be in the same family, and in turn these families share an even older ancestor, together making up an order. The caecilian phylogenetic tree is only a small part of the tree of life. To learn more, visit **http://tolweb.org/tree**.

Biologists use phylogenetic trees to understand biological diversity. We overlay information about organisms onto the phylogenetic tree, and then the patterns we observe inform us about evolution. For example, imagine two species that have similar traits (such as diet, physical characteristic, or life history). If they are situated close together on the phylogenetic tree, this tells us that the similarity has arisen because they share a common ancestor that already possessed this particular trait, and so are closely related (genetically similar). If, however, the two species are found on different branches of the phylogenetic tree, then we may conclude that the particular trait has evolved twice independently, and that the species are similar because they have adapted to similar environmental factors.

In caecilians, we find many instances where two species that are not closely related have similar traits that give the animal an advantage in their environment (for example, **live-bearers**, eyes covered by bone) (see Box 2). The repeated evolution of these characteristics gives important evidence for **natural selection** and other mechanisms of evolution.

In conclusion, the theory of evolution tells us that life on Earth has evolved and that species share common ancestors. It is a theory backed by a great deal of evidence from the natural world. Yet we are still trying to understand about how evolution happens. Building the tree of life is an important part in assimilating the evidence needed to better understand the mechanisms of evolution.

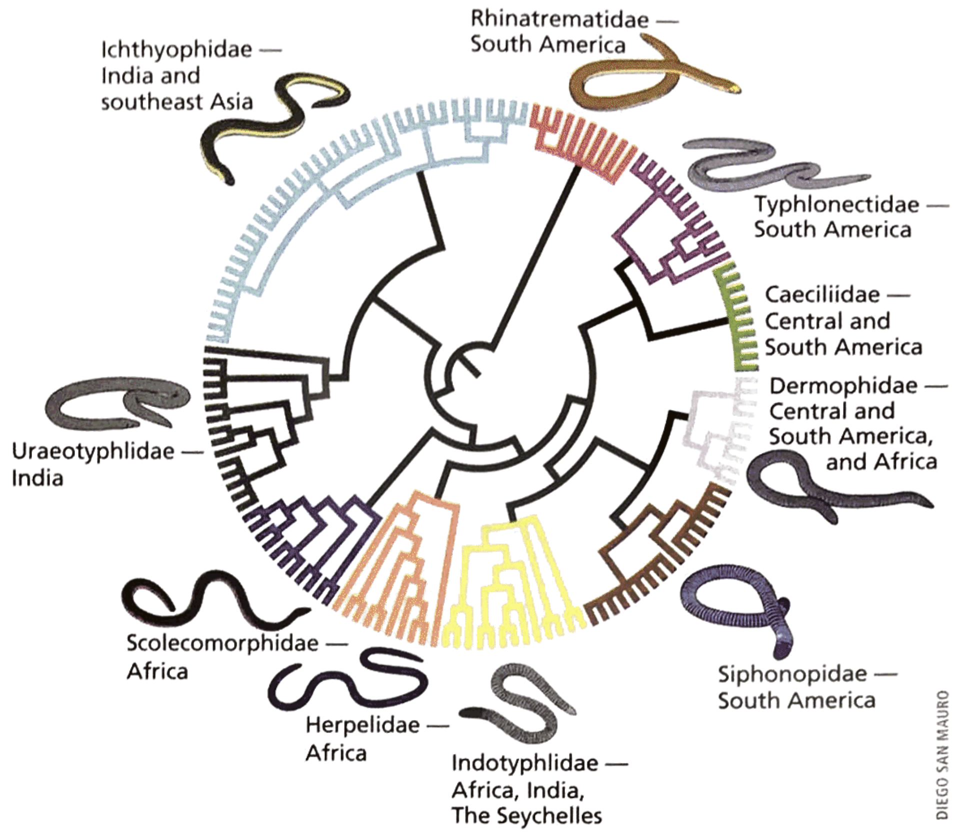


Figure 5
Phylogenetic tree (family tree) of caecilians. Each of the outermost branches represents one species.

Things to do

- Think of some examples where animals have similar characteristics (for example, look the same, show the same behaviour) but are not closely related. What do they have in common? Where do they live, or what do they eat?
- Test your skills on judging who's who on the tree of life. Play the game at: **http://tinyurl.com/dnzf9o**
- Watch these videos:
  - David Attenborough's 'Life in cold blood' footage — skin-feeding baby caecilians in action: **http://tinyurl.com/bmthae9**
  - The birth of an aquatic caecilian: **http://tinyurl.com/d3vzz8**
- You can see live caecilians at Chester Zoo and London Zoo.

Dr Emma Sherratt did her PhD at the University of Manchester and the Natural History Museum, London, and is now a postdoctoral researcher at Harvard University. Her research interests are in evolutionary biology, reptiles and amphibians.

KEY POINTS

- Caecilians are limbless amphibians that live in the tropics; they are terrestrial and burrow into moist soil, or aquatic and live in rivers and swamps.
- Some caecilian mothers take parental care to the extreme — their young feed by scraping their mother's skin with specialised teeth.
- Biologists study how species are related (make phylogenetic trees) and examine particular traits of these species to understand the mechanisms of evolution.
- The evolution of caecilians involved adaptation and selection, which contributed to the apparent diversity among the species we observe today.