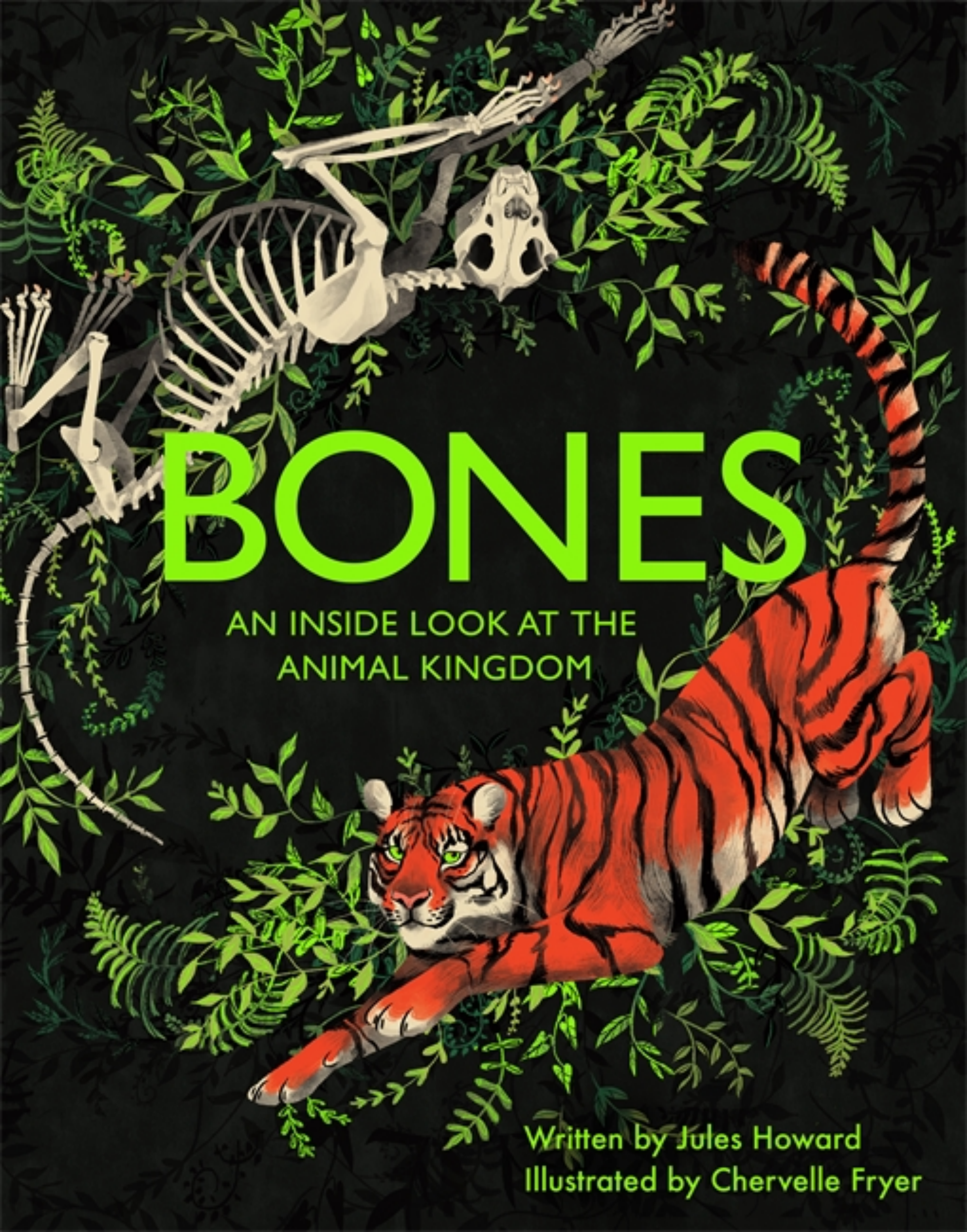
BONES
AN INSIDE LOOK AT THE ANIMAL KINGDOM
Written by Jules Howard
Illustrated by Chervelle Fryer

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AN INSIDE LOOK AT THE ANIMAL KINGDOM

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THE WONDER OF BONES

Skeletons are the architecture for much of life on Earth. Every single second of every moment you've been alive is because of the bones within you, providing you with health and life and strength. But your bones have a secret to tell . . .

Though we like to consider ourselves uniquely human, our bones are anything but unique. Look inside the bodies of many animals and you will come to realise that our bones are the same as theirs, just stretched in a particularly unique way. This is the hidden beauty of animal skeletons – the same old bones stretched hundreds of different ways.

For instance, dogs and cats have nearly all the same bones as us. Even though they walk on four legs, if you look inside their bodies you will see that the same bones are there: four fingers and a thumb, seven neck bones, shoulder blades, a pelvis, a ribcage, jaws filled with familiar molar teeth, canine teeth and incisor teeth. The same is true of bears and bats and mice and meerkats – all have the same bones stretched in different ways to assist them in different styles of life. Even fish, a very distant relative of ours, have a skeleton similar to our own – a skull with a jaw that moves up and down at one end, connected to its tail by a long chain of bones (vertebrae) that make up the backbone or spine. Together, creatures with back bones are called vertebrates. If you look inside the bony animals that live on Earth, you will see a simple vertebrate skeleton adapted for a thousand different purposes.

This book is a celebration of bones. On its pages you can see how animals achieve so much with this simple vertebrate body plan. You will see how they leap, how they jump, how they sprint and how they flap. You will learn how they grasp, how they swim, how they dig and how they bite and chew.

The story of animals and their success on Planet Earth is really a story of skeletons. So turn the pages of this book, and learn what makes the bones in us – all of us – so special.

A. There are 206 bones in the human body, though babies are born with more than 300. This is because, as skeletons grow, some bones join together.

B. The human skeleton is very much a mammal skeleton. Mammals, such as monkeys, often have two sets of teeth: milk teeth and adult teeth. Most mammals have three tiny ear bones. We give birth to live babies, rather than lay eggs with a shell.

C. Birds are all that is left of the dinosaur family. Their skeletons are adapted to a life in the sky. Their wrist bones are fused and they have a curved breastbone onto which flight muscles attach.

D. Most amphibians lay eggs in water that hatch into tiny fish-like babies (called tadpoles in frogs and toads). Their skeletons are more fish-like and simple, though some species, like frogs, are incredibly good at adapting to new ways of life.

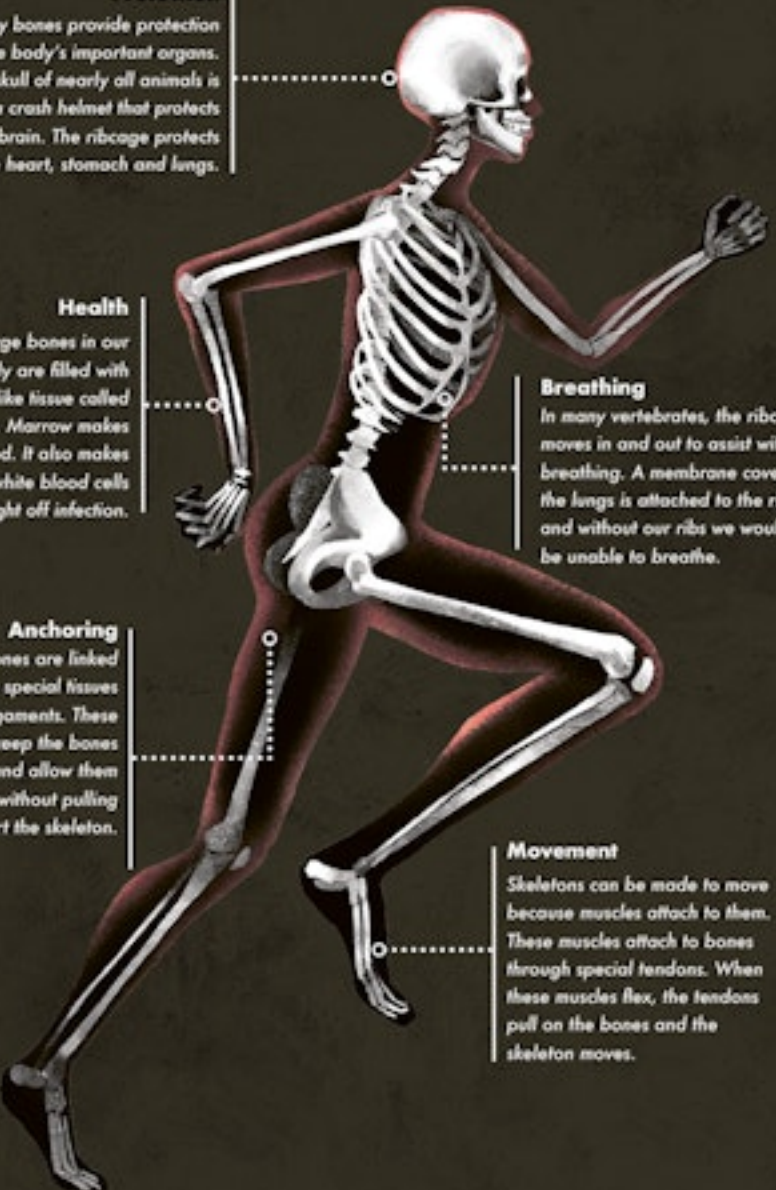
E. If you lined up every species of bony animal on Earth, most of them (more than 28,000) would be fish. Bony fish (Osteichthyes) have a long spine that can wiggle right and left and a lower jaw that moves up and down.

F. On the whole, reptile skeletons have four legs, though some lizards and snakes have had their legs reduced over many millions of years so that they are now legless. Most reptiles lay eggs with a protective shell.

WHAT ARE BONES?

Without bones, you and I would be unable to move or know much about the world at all. But bones are about more than body support – bony skeletons help animals in a lot of different ways.

Protection
Many bones provide protection to the body's important organs. The skull of nearly all animals is like a crash helmet that protects the brain. The ribcage protects the heart, stomach and lungs.



Health
The large bones in our body are filled with bubble-like tissue called marrow. Marrow makes blood. It also makes special white blood cells which fight off infection.

Breathing
In many vertebrates, the ribcage moves in and out to assist with breathing. A membrane covering the lungs is attached to the ribs, and without our ribs we would be unable to breathe.

Anchoring
Our bones are linked together by special tissues called ligaments. These ligaments keep the bones together and allow them to move without pulling apart the skeleton.

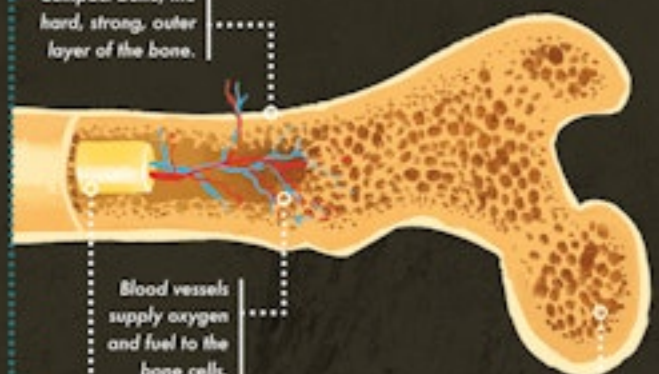
Movement
Skeletons can be made to move because muscles attach to them. These muscles attach to bones through special tendons. When these muscles flex, the tendons pull on the bones and the skeleton moves.

BONES vs CARTILAGE

Sharks and rays have skeletons made of softer and more flexible bone, called cartilage. This lightweight type of bone contains special cells (chondrocytes) that produce an elastic-like material, which make the bones spring back into shape. Unlike most bones, cartilage quickly decays after an animal dies. For this reason, studying shark skeletons can be tricky. Usually only their teeth remain, some of which may turn into fossils.

Cartilage is not unique to sharks and rays. A layer of cartilage is also found on the tips of most animal bones, including our own. This cartilage allows bones to move against one another without wearing out. For this reason, it is sometimes called connective tissue. In humans, our noses and ears are also made of cartilage. This is what makes them so bendy.

All vertebrates begin life with a skeleton made of cartilage. In the early months of life, as we grow, our skeleton gradually becomes replaced with true bone.



Compact bone, the hard, strong, outer layer of the bone.

Blood vessels supply oxygen and fuel to the bone cells.

Bone marrow makes blood cells and stores fat.

Spongy bone, the strong, lightweight, inner layer of bone.

WHAT ARE BONES MADE OF?

Bone is eight times stronger than concrete. So what makes it so strong? The outside part of most bones is called compact bone. Here, tiny cylinders of crystallised calcium mixed with special proteins are packed tightly against one another to provide an armour-like coating. This is what gives bones their super-strength. Tiny blood vessels run through the centre of each tiny cylinder. This means that inside our bodies, when we're alive, our bones are actually pink!

THE FIRST BONES

Haikouichthys is one of the first creatures to have had a hint of skeleton. This simple creature lived 525 million years ago and shared the ocean with many early life forms. It had a defined skull and a long cord of nerve tissue running down its body. Though it was little more than a swimming worm-like creature, within a few million years this simple body plan would give rise to a new branch of the animal family tree, the vertebrates.

LIFE STORY

Fossils are found in sedimentary rock which forms in special layers called strata. Often, the deeper scientists dig, the further back in time the fossils they discover go. By investigating these layers of strata, scientists see how the skeletons of many animals gradually change as the years pass.

Generation by generation, after many thousands or millions of years, it seems that skeletons can gradually change bit by bit and become exaggerated or reduced in different ways. This is called 'evolution'. Fossils are an exciting way for scientists to study how animal skeletons have evolved over many millions of years.

HUMAN REMAINS

Much of what we know about human history is down to the hard work of archaeologists who dig up and study human remains. From bones, these scientists can gather information about the diet and culture of ancient people whilst also gathering DNA to discover who the bones belonged to and where they were from. By looking at the chemical signature of bones, particularly a natural form of the element carbon (C-14), scientists can also work out how old the bones are.

THE SCIENCE OF BONES

Sometimes bones can be buried by mud or sand and, over time, are replaced with minerals so that they become fossils. Fossil bones and skeletons are incredibly valuable to scientists, particularly scientists that study ancient life – the palaeontologists.

Palaeontologists carefully dig up and clean fossil bones, many of which are sent to museums where other scientists will study and describe them in special reports. Fossils from dinosaurs, many of whom were large and had big teeth, are particularly prized. So far, scientists have discovered more than 1,000 different types of dinosaur by studying fossils and new dinosaur species are dug up about once every two weeks.

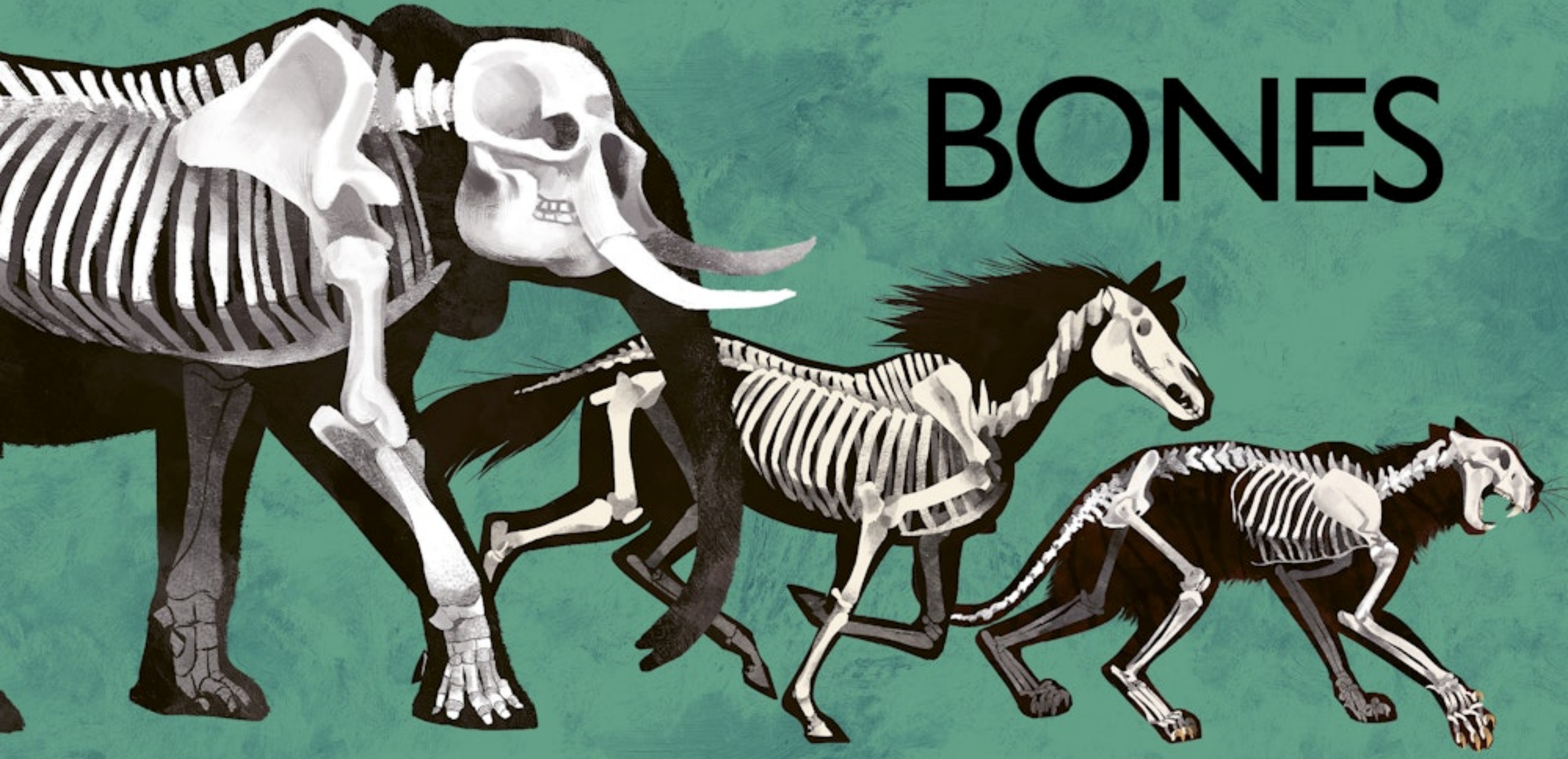
But bones aren't only for palaeontologists. Amateur naturalists, archaeologists and zoologists also collect and study bones from animals that have recently died. These scientists take measurements of these animal bones and keep them in special reference collections that are a bit like libraries. Sometimes, if the bones are still a bit covered in flesh, they use special beetle grubs to clean the remaining meat off the bones.

EVOLUTION

Evolution is perhaps most striking in mammal skeletons. In mammals, a relatively simple mouse-like mammal that lived in the shadow of the dinosaurs appears to have evolved in the most incredible ways into the mammals that we see around us today.

Not all skeletons evolve in obvious ways however. Some animals hit upon a skeletal structure that proves unbeatable. Turtles are an example of this. Turtles evolved more than 200 million years ago and have changed very little since this time. Their hard shell, it seems, cannot be bettered, so their evolution appears to have slowed to a halt.

BONES

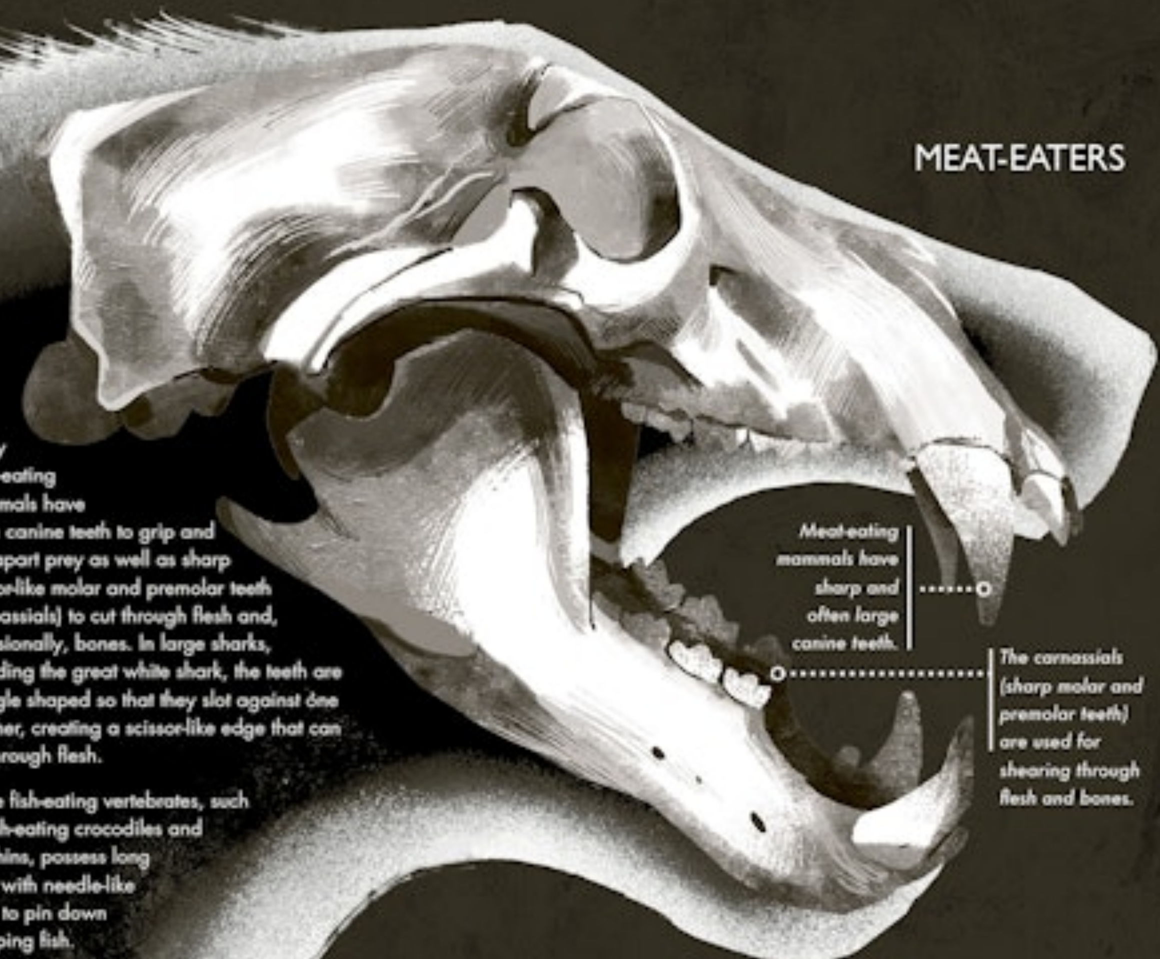


BITING AND JAWS

Four hundred and thirty million years ago in the early days of life on Earth, a small family of fish hit upon something truly spectacular. By evolving a long, hinged gill bone along the underside of the mouth they gained jaws, a muscular mouth capable of pulling apart plants and other animals. This simple bony innovation (called the mandible) allowed these early vertebrates to explore whole new habitats and ways of life. Today, the jawed creatures of Earth rule. And you are one of them.

In the modern age, animals use jaws for far more than just eating. Jaws can be used as weapons to fight off rivals. They can be used to hoover up ants or to snap at passing flies. In snakes, they provide a mechanism for delivering venom. In some dolphins, they can be used to detect electricity. In the case of toothed whales, they can be used as a hearing aid. In fact, in one small family of apes, jaws provide a mechanism through which to utter words and sentences. That family is *Homo sapiens* – human beings. Every word you've ever spoken came courtesy of your jawbone.

MEAT-EATERS



Many meat-eating mammals have large canine teeth to grip and pull apart prey as well as sharp scissor-like molar and premolar teeth (carnassials) to cut through flesh and, occasionally, bones. In large sharks, including the great white shark, the teeth are triangle shaped so that they slot against one another, creating a scissor-like edge that can cut through flesh.

Some fish-eating vertebrates, such as fish-eating crocodiles and dolphins, possess long jaws with needle-like teeth to pin down escaping fish.

LEAF-EATERS

Plant-eating mammals often have large, heavy-duty molar teeth used for crushing leaves and branches. In giraffes, deer and sheep, the front upper teeth have been replaced by a large muscular pad which can be used to strip leaves off branches.

SEED-EATERS

Rodents are specialised gnawers. Their long incisors can chisel through nuts and other hard foods. These incisors are unusual because they continue growing throughout life. Rodents keep them sharp by rubbing them against one another.

TOOTH REPLACEMENT

Having wobbly teeth during childhood is a distinctly mammal thing. Nearly all mammals have two sets of teeth in their life – the baby (milk) teeth and adult teeth. In most cases, if mammals lose an adult tooth it won't be replaced.

Reptiles are better able to replace lost teeth. An adult crocodile, for instance, may go through 50 sets of teeth in its lifetime, regrowing 3,000 teeth in total. The same is likely to have been true for their dinosaur cousins.

Sharks are most famous for their ability to replace teeth. Like a conveyor belt, rows of razor-sharp teeth grow from the jaw and are slowly flipped around to the front of the mouth. An adult shark may go through 30,000 teeth in its life.

SPERM WHALE

Physeter macrocephalus

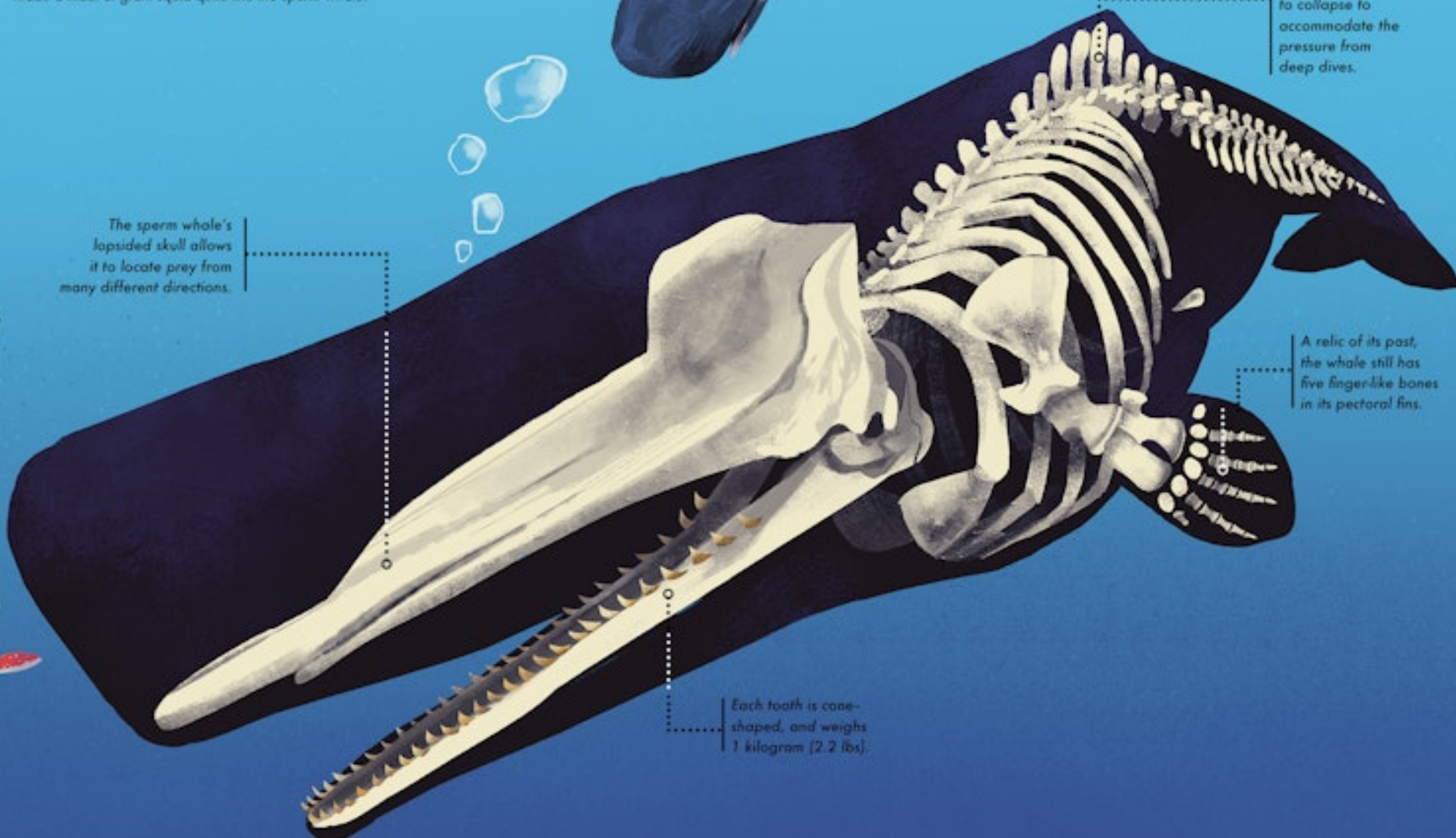
Right now, as you read these words, somewhere on Earth a sperm whale is fighting with a giant squid, deep underwater. Due to a number of impressive adaptations, it is likely that the sperm whale will emerge as the victor.

The sperm whale finds squid using a charismatic giant skull within which sits the largest brain in the animal kingdom. Their brain is five times heavier than a human brain. A set of complex organs attaches to the roof of the enormous skull through which powerful and focused clicking sounds are made. The echoes from these clicks are received and channelled towards the brain through the whale's lower jaw. Like dolphins, the sperm whale hunts through echolocation.

The jaw of the sperm whale has 18 to 26 teeth that resemble those of a *Tyrannosaurus rex* in size and strength. Their long jaws can be used to hold squid in place before swallowing, though mature male sperm whales can sometimes use them against one another when competing for the attentions of a female.

Diving to extreme depths to hunt prey is not easy. Firstly, sperm whales need power. They possess the largest tail for their size of any whale, which drives them deep into the water. Sperm whale skeletons have adapted to cope with the immense pressure of the deep sea by evolving ribs bound to the spine by a special flexible cartilage. This hinge-like structure allows the ribcage to collapse as the whale dives without shattering any bones.

Even with these adaptations, they pay a price for their deep dives – adult sperm whale bones often show the tell-tale pits and tiny cracks that signal bouts of decompression sickness. Still, theirs is a prey worth stalking – no other mammal has made a meal of giant squid quite like the sperm whale.



TIGER

Panthera tigris

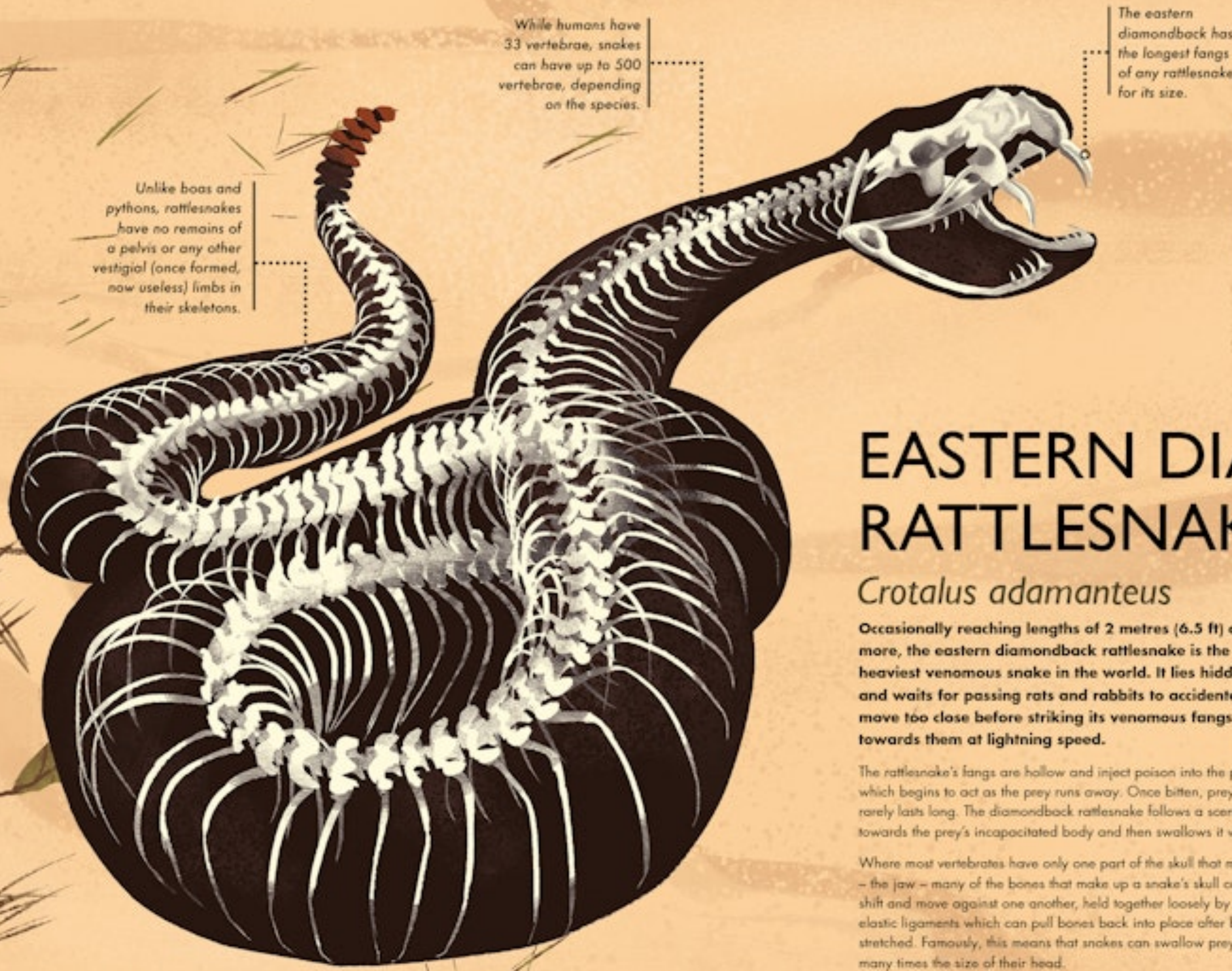
As far as killers go, few skeletons can match that of a tiger. Every single curve or ridge on its bones hints at its predatory lifestyle. And nowhere is this more apparent than its skull. Tigers have shorter, stouter faces than many predators. Unlike crocodiles which must snap at passing prey with long jaws, tigers pull down their prey with killer claws. Their jaws aren't for catching. They are for killing.

Tiger canines are among the longest of all big cats, sometimes measuring up to 8 centimetres (3 in) long. Tigers use them to bite down on the neck bones of their prey, often severing the spinal cord of a potential meal within seconds with a single bite. Like all big cats, these canines are lined with pressure-sensitive nerves that allow them to use their teeth to feel the location for the perfect bite.

To administer their killer blows, tigers have large holes (zygomatic arches) on the sides of the skull through which impressive jaw muscles pass. A distinctive arch that runs along the top of the skull (the sagittal crest) increases the area to which these muscles can attach.

Compared to other mammals, the back teeth of tigers are especially sharp. When opening and closing its jaws, the molars and premolars of the upper and lower jaw slot together perfectly like blades on a pair of scissors. The tiger's tough jaws exert enormous pressure across these molars, meaning that these teeth are strong enough to shear through tough flesh and even bone. A tiger's bite can generate seven times the amount of pressure that a human bite can.

Even the front teeth (incisors) have a function. Tiger incisors can be used to strip meat from bone or, occasionally, to pluck feathers from birds. These, along with the giant front-facing eyesockets (orbits) that contain enormous eyes for spotting prey, and the enlarged skull that houses an impressive brain, gives tigers a suite of killer adaptations few predators can match. The tiger possesses an almost weaponised skull, perfected for catching and killing prey.



EASTERN DIAMONDBACK RATTLESNAKE

Crotalus adamanteus

Occasionally reaching lengths of 2 metres (6.5 ft) or more, the eastern diamondback rattlesnake is the heaviest venomous snake in the world. It lies hidden and waits for passing rats and rabbits to accidentally move too close before striking its venomous fangs towards them at lightning speed.

The rattlesnake's fangs are hollow and inject poison into the prey, which begins to act as the prey runs away. Once bitten, prey rarely lasts long. The diamondback rattlesnake follows a scent trail towards the prey's incapacitated body and then swallows it whole.

Where most vertebrates have only one part of the skull that moves – the jaw – many of the bones that make up a snake's skull can shift and move against one another, held together loosely by elastic ligaments which can pull bones back into place after being stretched. Famously, this means that snakes can swallow prey many times the size of their head.

To pull large prey successfully down their throat, snakes can move the left and right sides of their jaws independently. Using this adaptation, they can slowly 'walk' their jaws over their meal, stretching their mouth around the prey's body until it is fully enclosed and ready to be swallowed. Their ribs are loose and capable of being easily spread apart once prey makes it to the stomach. Theirs is a skeleton that stretches like no other.

The eastern diamondback rattlesnake likes to shelter in gopher burrows. When threatened by predators, they can rear up like a coiled spring onto the lower half of their body and, using powerful muscles attached to their ribs and spine, strike with their fangs in self-defence. As the name implies, they can also rattle their tail.

The rattlesnake's famous rattle is actually made of segments of shed skin rather than bone. The muscles that work this rattle are the fastest known, capable of firing at 50 times per second or more.

DIGGING

Moving through soil takes time and requires an incredible amount of effort. Yet, for the animals that master it, this subterranean way of life offers rich rewards by way of untapped food resources and shelter from predators or extreme weather.

The skeletons of most digging animals require something spade-like to move soil. In moles and other smaller subterranean mammals, it is the paws that provide the digging surface. In armadillos and anteaters it is the claws. Many toads use their hind legs as spades. By churning up the soil around them, they can shuffle backwards into the soil leaving only their eyes exposed. The African bullfrog can use its long back legs to dig channels that provide water for its developing tadpoles. But other animals use a host of other anatomical features to help them dig.

THE BIGGEST DIGGER

For a long time, a series of enormous burrows known from Brazil mystified scientists. Up to 2 metres (6.5 ft) deep and 4 metres (13 ft) in width, the cavernous tunnels were thought to be archaeological remains of some kind. The truth turned out to be far stranger. Scratch marks were found on the walls of the caves: the tunnels had been dug by the claws of an unknown giant mammal.

We now know that these tunnels were dug by the extinct giant ground sloth, a cousin of armadillos and anteaters. At 4 tonnes (4.4 tons) and measuring up to 6 metres (20 ft) from head to tail, this giant herbivore possessed sickle-shaped claws useful for digging and pulling down tall branches upon which it would feed.

HEADBUTTING

Caecilians are worm-like amphibians that dig through wet soils. After anchoring their tail into position, they thrust their head through the earth like a battering ram. Their skulls are pointed, and fused in various places to provide extra strength.

SAND SWIMMING

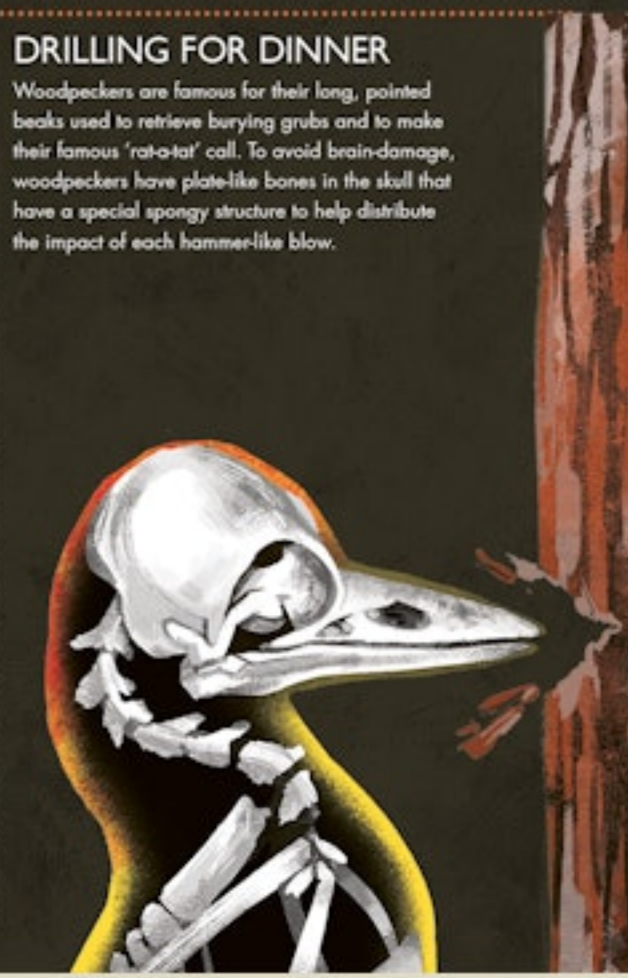
Golden moles home in on the tell-tale movements of insects by feeling for their vibrations in the sand and then 'swimming' towards them. Though not closely related to true moles, golden moles possess the same bullet-shaped (fusiform) skeleton and the same powerful forearms. Instead of spades, each forearm ends in something a little more like a miner's pickaxe.

TEETH TUNNELLING

The naked mole rat uses its long incisor teeth to tunnel. Naked mole rats are rather like ants and wasps. Sterile workers are in charge of digging tunnels to find roots and tubers. Together, they chew a tunnel system that can stretch up to 5 kilometres (3.10 m) in length.

DRILLING FOR DINNER

Woodpeckers are famous for their long, pointed beaks used to retrieve burying grubs and to make their famous 'rat-a-tat' call. To avoid brain-damage, woodpeckers have plate-like bones in the skull that have a special spongy structure to help distribute the impact of each hammer-like blow.



EUROPEAN MOLE

Talpa europaea

The most celebrated mole bone is their extended wrist (sesamoid) bone, which has become almost claw-like. In life, this strange sixth finger is covered with skin. Unlike true fingers, it has no joints. This unusual adaptation extends the surface area of the paw whilst adding strength and extra firmness to the digging blades. Mole paws are, quite literally, like giant shovels.

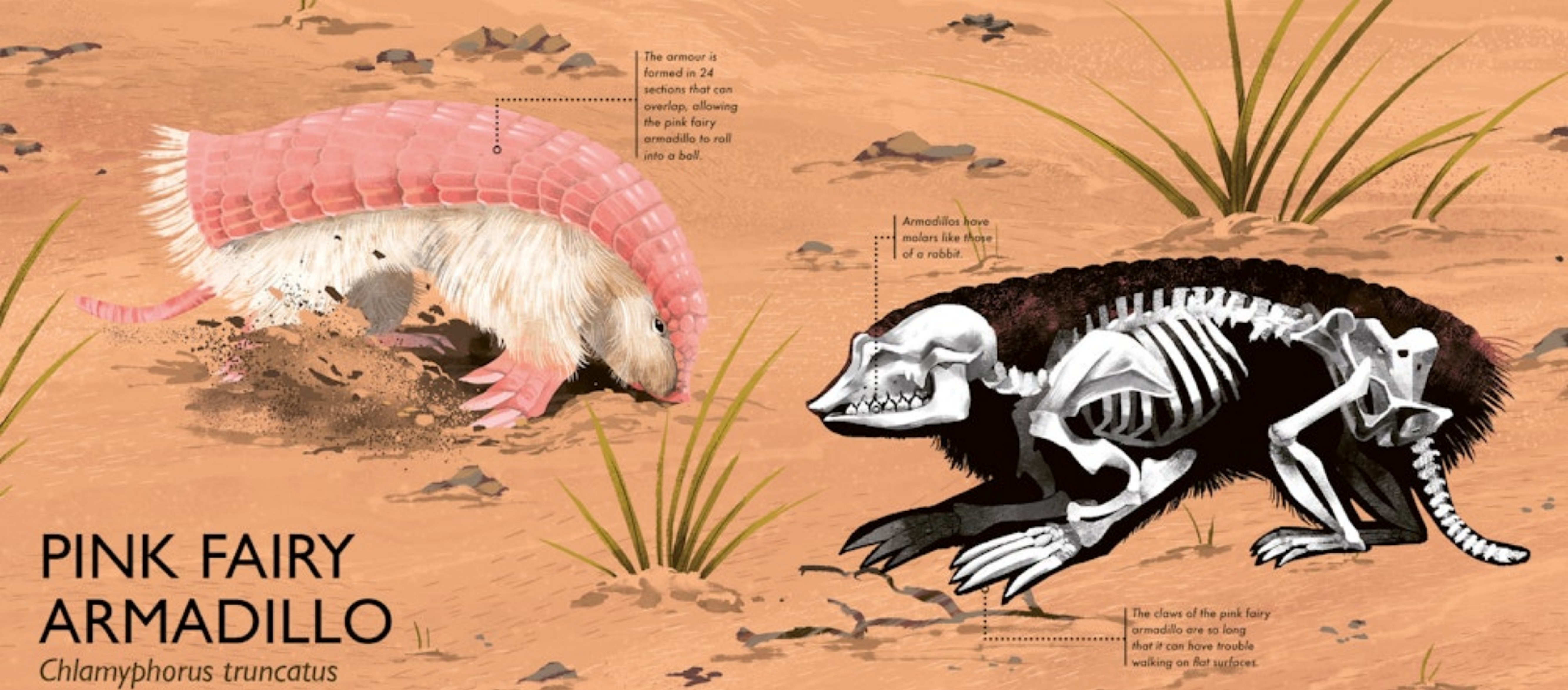
Moles are one of a few mammals to have had their sesamoid bones adapted in such a way. Others include pandas (for grasping) and elephants (for bearing weight). Sesamoids are the go-to bones for acquiring new fingers, it seems.

Moles are highly adapted to detect and then kill prey, mostly beetles and earthworms. Unlike other small mammals, mole skulls have a large empty space at the front in which are found unusual arrangements of curly bones called turbinates that improve the mole's sense of smell. Their teeth are sharp, especially the large upper canines used to bite and paralyse their invertebrate (animals without a backbone) prey, which they carry to special underground larders. Moles can eat around half of their body weight in worms and other invertebrates each day.

Though you may never have considered them so, moles are extremely well-muscled. They possess enlarged lever-shaped ulna bones in their forearms which allow more space for the giant muscles required to push through their subterranean habitat.

In fact, most of the bones in their forearms are covered with special ridges (called processes) onto which muscles and tendons attach, and a special extension bone called the keel also increases the surface onto which the chest (pectoral) muscles attach. Some moles can dig tunnels 200 metres (656 ft) long, which is equivalent to a human digging through 2.5 kilometres (1.5 miles) of soil with his or her bare hands.

With their well-muscled top-heavy skeleton, moles are built like an Olympic swimmer. Yet the substance they swim through isn't water. It's soil.



PINK FAIRY ARMADILLO

Chlamyphorus truncatus

The pink fairy armadillo is the world's smallest and most secretive armadillo. With its torpedo-shaped skeleton it burrows beneath Argentina's desert-like shrublands, searching for ants and insect larvae.

On both its front and hind legs are enormous claws for slicing through the soil and sand. Its eyes and ears are small and very mole-like. In order to help stop its tunnels from collapsing, it uses its wide tail to firm up the soil as it digs.

Armadillos are well known for their hard and bony covering. This protective armour consists of two layers, an upper surface rich in keratin (the same protein found in mammal horn, hair and nails) and a harder, bony surface deeper beneath the skin made up of interlocking sheets of solid bone called osteoderms. Armadillos are the only living mammal group to have hit upon the evolution of this kind of armour. In fact, beneath the skin, armadillos resemble mammalian turtles.

In the pink fairy armadillo this armour is dramatically reduced. Being adapted to desert environments, fairy armadillos have special blood vessels near the surface of the plates which can be used like radiators to get rid of excess heat and keep the body cool. These blood vessels are what give the pink fairy armadillo its unusual colour. Essentially, when it gets hot, they blush.

Though less armoured than other armadillos, their shell still offers plenty of protection from most predators. Indeed, like many armadillos, the pink fairy armadillo can roll up into a protective ball.

Armadillos, anteaters and tree sloths are a distinct and unusual part of the mammal family tree. They are called xenarthrans (meaning 'strange joints') because their vertebrae link together in a way that strengthens the lower back and hips, allowing for a more powerful digging stance.

GREATER BILBY

Macrotis lagotis

The greater bilby is known as a 'scratch digger'. Each of its forearms works like the bucket of a mechanical digger, clawing sand downwards towards the hind legs which kick the sand backwards. When furiously pumping these bucket-like paws, an impressive amount of sand is shifted. Within minutes, the greater bilby can barely be seen at all.

Bilby shelters are spiral-shaped burrows up to 3 metres (9.8 ft) long and 2 metres (6.5 ft) deep. When hungry predators attempt to dig them out, bilbies have been known to frantically extend the tunnel in the other direction to get out of harm's way.

To maximise the rate at which its arms can scratch up and down, the greater bilby has shorter bones in the forearms than many marsupials. It also possesses three stout claws on its forearms, along with two unclawed toes that help sweep sand downwards.

Unlike moles and fairy armadillos, the greater bilby does not spend all of its time underground. Instead, it moves from burrow to burrow, sometimes occupying home ranges that span across 5 kilometres (3.10 miles). Although they possess kangaroo-like bones in the hind legs, they trot upon all four legs whilst moving, rocking backwards and forwards in a manner that is almost like a rocking horse.

Living in the dry, arid regions of central Australia means that to survive, the greater bilby has to find a variety of food sources. Greater bilby teeth are able to pull apart a range of items, including grubs, fungi, seeds and fruit. Their long, pointed skull is adapted for pushing into the sand, a behaviour that helps them smell for potential food buried nearby.

Like all marsupials, the greater bilby has a pouch. As with wombats and marsupial moles, their pouch points backwards so that it doesn't fill with sand whilst digging.

The well-developed ears suggest that the greater bilby has excellent hearing. They are hairless, which may help regulate body temperature.

The well-developed digging forearms weigh down the upper body, meaning that when the bilby moves it must do so on four legs rather than two.

The greater bilby has a tail that ends in a spur or nail-like structure, and nobody is sure yet what function this strange tail performs.

GRASPING AND CLAWS

By turning the pages of this book, you are doing something most animals cannot. A complicated network of 27 bones in your hand and fingers is allowing you to grasp and carefully manipulate sheets of paper. Only humans, monkeys and apes (together called primates) can achieve manual dexterity like this.

Unlike most bones, the bones in our fingers have no muscles attached. They are pulled by special tendons that attach to muscles in the palm and wrist. You can see these tendons moving when you look at the inside of your wrist whilst wiggling your fingers.

Primates evolved grasping hands as an adaptation to life in the trees. Over time, their claws gave way to flatter fingernails and large fleshy fingertip pads to assist with grip. But grasping is not unique to primates. Many other creatures have bony adaptations to assist with carefully gripping a host of objects.

Try using your thumb to touch each of your fingers. Animals that can manage this feat are said to have true 'opposable thumbs'. Opposable thumbs allow for greater ability to manipulate objects as well as the ability (in some species) to use tools.

PREHENSILE TAILS

Some animals have long, muscular tails that help them to grasp objects or that allow them to hang from nearby vegetation. These are prehensile tails. Seahorses use their prehensile tails to anchor themselves onto seaweeds so that they aren't washed away by strong currents. The so-called 'climbing salamanders' use their muscular tails as a prop to help them move up trees. Chameleons use their more mobile 'prehensile' tail to assist with movement between branches whilst in the treetops.

BABY ON BOARD

Some animals use their jaws as a grasping device to carefully pick up babies. Crocodiles carefully scoop up their young in their mouths, keeping them safe from snakes and other predators.

CHIMPANZEE

Pan troglodytes

It is almost impossible to look at a chimpanzee skeleton without noticing the similarities to our own. This is because, like them, we have inherited an ape skeleton from an unknown ancestor that we shared seven million years ago.

Look closely, however, and you will notice the differences. Where human bones are adapted for marathon-runner-like endurance, chimpanzee skeletons remain more multipurpose, adapted for a forest habitat with many unique ways of finding food and water.

First, the arms and hands. The bones within the hands of chimpanzees allow for manipulation of objects but also, crucially, they can be used as extra supports to assist movement. Chimpanzee phalanges (the bones in the hands and feet) are long and curved when compared to our own, which is an adaptation seen in apes that climb and walk on their knuckles. Yet their arms are also vital for supporting body weight. This 'quadruped' lifestyle means that chimpanzee skeletons differ in their posture, compared to humans. Chimpanzee legs are set wide apart, and they transfer their weight from side to side when they walk. Their pelvis is long and thin, providing a rigid structure that keeps them upright with minimal effort, assisted by long bones within the forearms that support weight. Most noticeably, the hole through which the spinal cord plugs into the skull (the foramen magnum) is at the back of the skull in chimpanzees and other apes – their torso fits behind the skull rather than below it, like our own.

Like all apes, chimpanzees have thumbs capable of moving freely and independently – the so-called opposable thumbs. Yet they possess something we do not. Chimpanzees possess a toe-thumb on each foot. This elongated toe-thumb is vital for gripping branches and trunks whilst climbing.

GIANT PANDA

Ailuropoda melanoleuca

It is mind-boggling to think that the Western world only came to know about the panda relatively recently. For millennia, this charismatic bear hid amongst China's bamboo forest, unseen even to the human residents with whom it shared its habitat. Then it all changed. In the 20th century, the panda received global attention, and its host of unique skeletal adaptations became known to scientists for the first time.

Pandas are almost unique among mammals because they possess an extra finger. Rather than the standard mammal paw-plan – four fingers and a thumb – pandas possess a sixth 'finger', which they use to grip bamboo whilst chewing. Though it does have a tough pad like its other fingers, this extra finger is unusual in that it has no claw and it cannot bend. It is not a true finger, but rather an extension of a sesamoid bone in the wrist. For this reason, many scientists refer to this extra digit as a 'pseudo-finger'.

The only other bear-like animal to have evolved a similar sixth 'pseudo-finger' is also a bamboo-eater – the red panda (actually not a panda, but a weasel-like creature). Natural selection does this sometimes, stretching the same bones in distantly related creatures to get the same job done. This is called convergent evolution.

The panda's skull shape is that of a once-carnivorous bear that is evolving to become ever-more vegetarian. The wide molars have been co-opted for chewing plants rather than biting through bones and they have now become a bit like those of a horse or an elephant. The zygomatic arches are wider too, allowing for larger and more effective jaw muscles that provide the power to crunch, munch and swallow.

Pandas also possess a long tail, at least for a bear. Though only 10–15 centimetres (4–6 in) long, this tiny white tail has its uses. Most notably, it can be used like a paintbrush to smear special odours that come from the panda's bottom onto rocks and trees. These stinky secretions help wild pandas keep in touch with one another. Theirs is the longest of all bear tails, second only to the sloth bear.

Compared to other bears, pandas have fewer vertebrae. This may be an adaptation to help pandas spend more time sitting upright.

RED HOWLER MONKEY

Alouatta seniculus

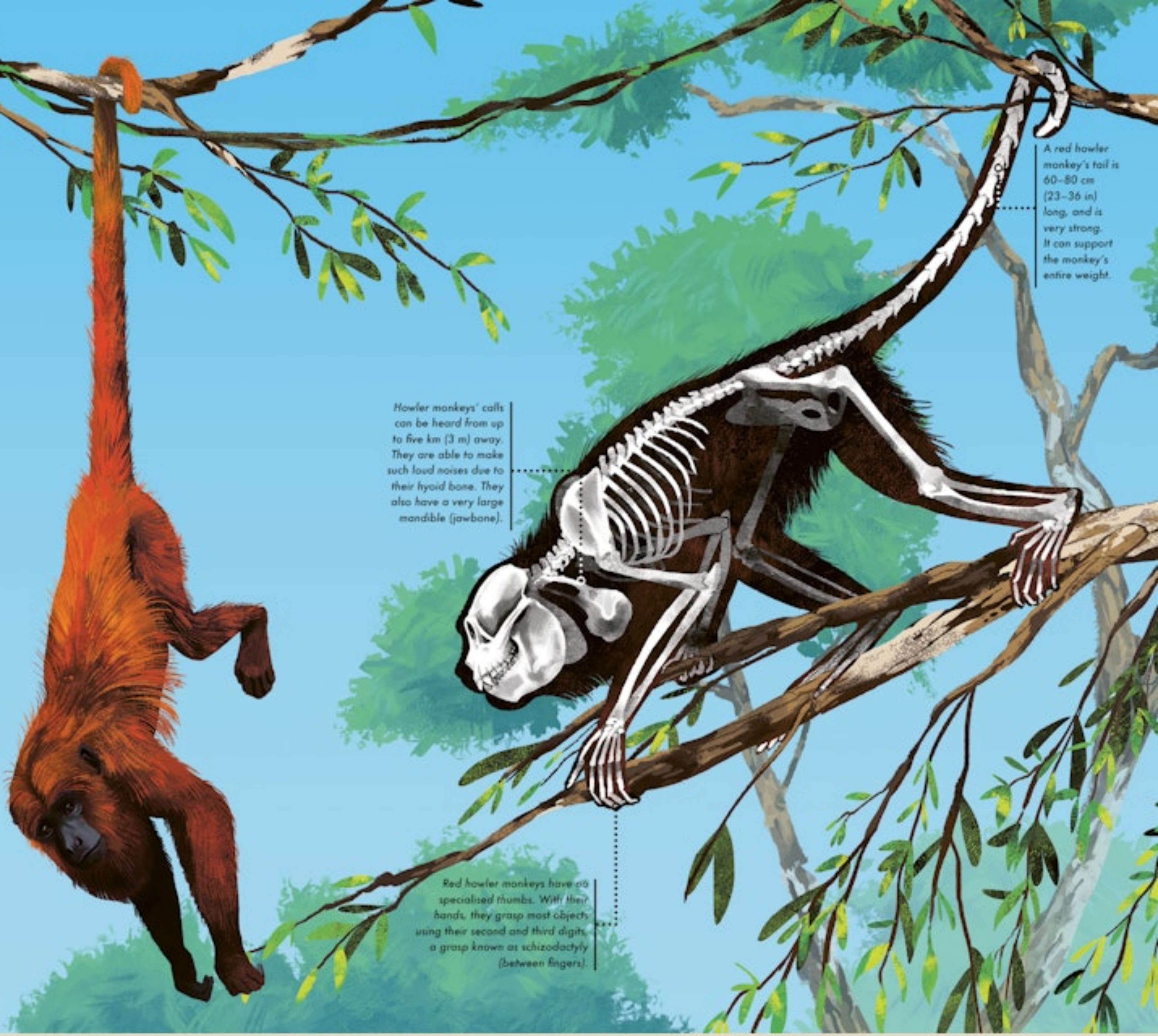
For howler monkeys, a life in the trees comes courtesy of a tail almost unmatched in nature. Wrapped around a branch, this long tail can easily support its entire body weight. Creatures that can manage such a feat have so-called 'prehensile tails'.

To allow greater flexibility, the tail bones (vertebrae) within the tail of the red howler monkey are numerous. Though small, each tiny vertebra allows for many large muscle attachments. This means that howler monkey tails are far stronger than they look. Almost like the tentacle of an octopus, the red howler monkey's tail can grip, pull and carefully grasp and manipulate items of food. The red howler monkey's tail is also used to balance whilst climbing.

As well as a grasping tail, howlers have hands and feet which have wide separations between the second and third digits of the hand to provide extra grasping options.

To assist them in their leaf-based diet, the red howler monkey has a larger jawbone than other howler monkeys. Their jaws contains strong, shearing molar teeth for chewing and slicing plant matter. Beneath this jawbone is an unusual bony structure called the hyoid bone. This bone works like an echo chamber, allowing howler monkeys to make arguably the loudest noise of any land animal. Theirs is a booming roar that can be heard almost 5 kilometres (3.10 m) away. Howler monkeys use these calls to mark their territory and encourage rivals to move on.

Howler monkeys are unique among South American monkeys for having a hairless patch on their tail (the 'friction pad') which helps with gripping and can even sense touch and pressure. Incredibly, this special patch has a fingerprint which is unique to each individual monkey.



HOLDING WEIGHT

Though many science-fiction stories like to imagine giant creatures like Godzilla or King Kong, the truth is that bony animals on Earth could never evolve to be so large and walk upon two legs. If they were, their leg bones and joints would fracture like tiny twigs.

This is because animal skeletons are pulled downwards by an unseen force, gravity. The scaling laws of gravity mean that increasing the size of an object by ten times would make it one thousand times heavier. This causes problems for giant animals. The larger an animal becomes, the more it must invest in bones to keep it from collapsing.

Large vertebrates solve the problems of gravity through a variety of skeletal adaptations that help to keep them from falling apart under their own weight.

HOW DID THE DINOSAURS DO IT?

The long-necked sauropod dinosaurs reached a size far greater than we see in modern-day animals. Some species, such as *Argentinosaurus huinculensis*, were longer than three buses and may have weighed as much as ten elephants. The secret to their size was a complex system of air-filled cavities in their long bones that kept their skeletons light and strong. Sauropods also had giant cylinder-shaped legs, with bones that dwarf those of modern-day animals. The femur (thigh bone) of *Argentinosaurus*, for instance, was significantly longer and heavier than an adult human.

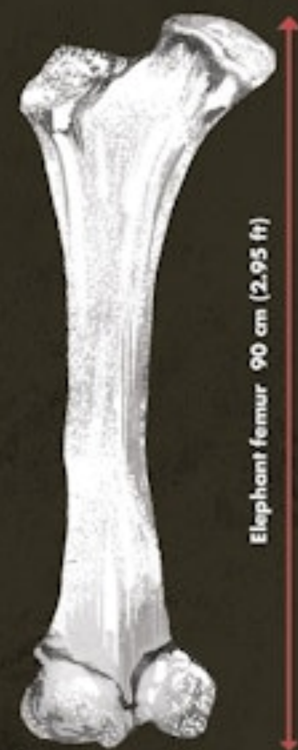
TAKE A WEIGHT OFF

There is one environment on Earth that allows some animals to grow to a larger size – the oceans. Being denser than air, water provides a cushion against the effects of gravity. It is no surprise that the largest mammals on Earth exist in the oceans. Some, like the manatee, can no longer return to land – its body is too heavy to support the skeleton.

PILLARS OF STRENGTH

The legs of large land animals are often cylindrical, spreading the weight of each leg over a wide surface area. In elephants, the round feet are lined with special protective tissues which add cushioning, rather like comfortable shoes.

The largest bone in many land-living vertebrates is the thigh bone (femur). This cylinder-shaped bone bears much of the weight of the skeleton and is loaded with compact bone. In humans, the femur can handle about 6 tonnes (6.6 tons) of pressure – roughly equivalent to the weight of four cars.



The bones in the ball and socket joint would not withstand incredible friction without these cartilaginous zones.

WEAR AND TEAR

In larger animals, cartilaginous zones between each bone become ever more important. This squishy bone acts a bit like the oil in a hinge, reducing friction as bones move against one another. Even with this useful adaptation however, bones can only withstand the forces of gravity for so long before a range of ailments occur. In humans, bone ailments most often show themselves as backache or joint pain in the legs and hips.

WILD HORSE

Equus ferus

Horse skeletons appear to achieve the impossible. They allow a large, heavy-bodied grass-eater to sprint for longer and faster than any predators. They achieve this feat through a host of adaptations, many of which are as much about reducing wear and tear as they are about adding strength and power.

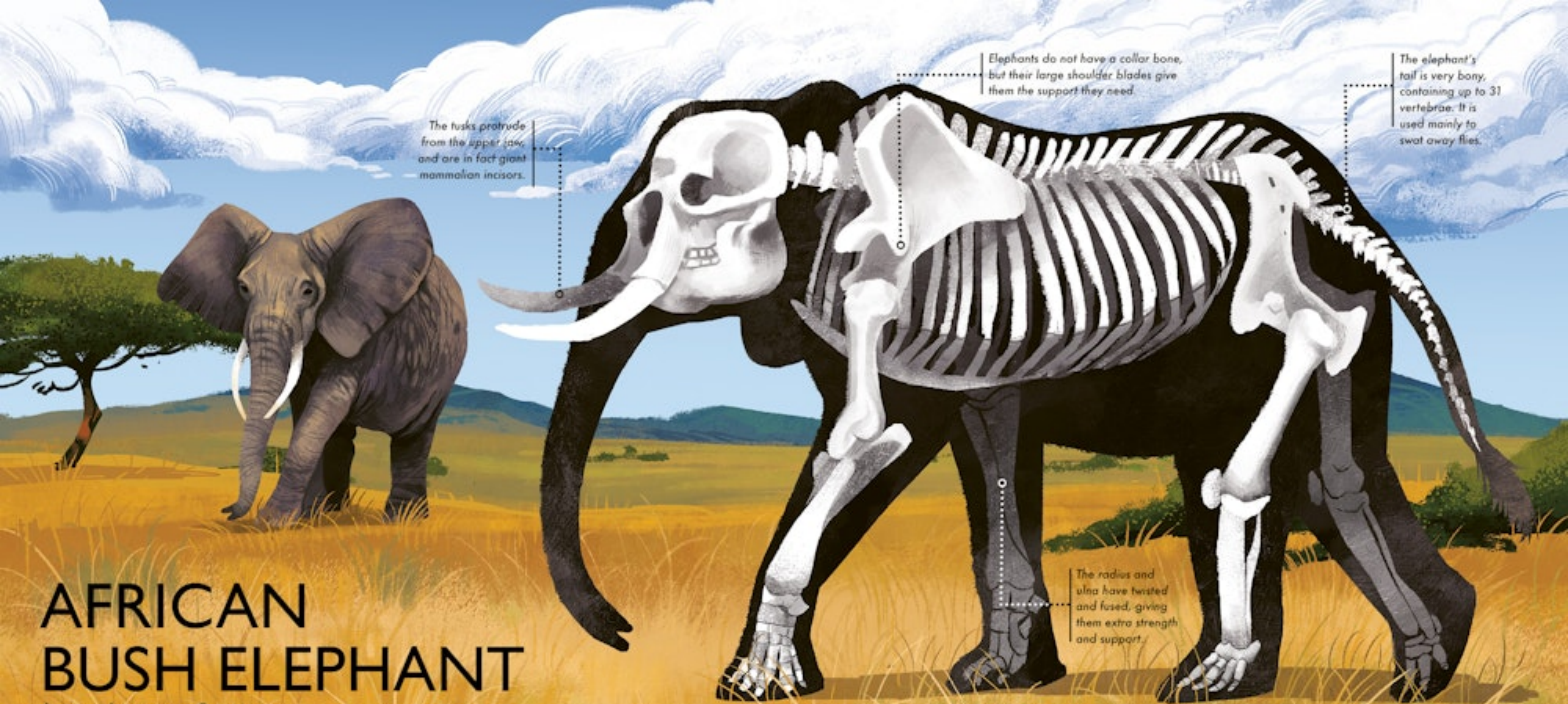
In the limb bones of horses, one can see clearly the fusing of crucial weight-supporting bones like the radius and ulna in the forelimbs, and the tibia and fibula in the hindlimbs. This fusing of bones limits the rotational movement of the limbs whilst running, allowing the stability required to support such a heavy-bodied creature whilst sprinting. Other adaptations allow for greater speed. The long, thin shoulder blades enable a lengthy stride. This, along with the long limbs, allows the horse to cover more distance with each forward thrust of its limb.

Most celebrated of all horse skeletal adaptations are the hooves. These act like shock absorbers whilst the horse is running, distributing energy evenly back into the limbs.

Although hooves look like unique skeletal additions, each hoof represents a single mammalian finger that has adapted to hold weight over millions of years. Their ancestors' fossils suggest that the other fingers shrank to help minimise the number of joints in the foot, reducing the number of components that can suffer wear and tear damage over time. In effect, today's hooves act like running blades, and are incredibly efficient at absorbing and redistributing energy, with very few parts that can go wrong.

Many modern humans still depend on horses for travel, for sport, for work and for farming. They have almost unrivalled strength and athleticism in nature.

Horses evolved over millions of years in grasslands rich in predators, where only the fastest and most athletic individuals endured. Theirs is an origin story like few others. One written in the footprints of ancestors – footprints that became, in time, fingerprints.



AFRICAN BUSH ELEPHANT

Loxodonta africana

At almost 4 metres (13 ft) tall and sometimes weighing more than 10 tonnes (11 tons), the African bush elephant is the largest, heaviest land animal on Earth today. This is an animal built to withstand gravity.

Most notable about their skeletons are the four pillar-like legs. They hang like columns beneath the body, providing direct support underneath the barrel-like skeleton. The leg bones of the African bush elephant are long and thick and filled with a lightweight ultra-strengthening filling that makes them almost spongy in places.

Unlike in many herbivorous mammals, the elephant pelvis points downwards just like in the human skeleton. Likewise, the forelimbs are held firmly in place by a pair of sturdy scapulae (shoulder blades). The lower bones in their forelimbs (the radius and ulna) are twisted and have fused, which provides extra strength.

The African bush elephant spreads its weight upon five true toes which remain hidden within a layer of tissue in life, covered with tough skin. Like the panda, it has an an enlarged wrist (sesamoid) bone that works a little like a sixth finger, offering added support on each foot.

The bottom of the elephant's foot is mainly composed of a special fatty tissue, which offers elastic properties that help turn each foot into a gigantic shock absorber when the elephant walks or runs. This is why elephant footsteps are so notoriously quiet.

The African bush elephant has an extremely large skull held up by the vertebrae in its neck, which are short and nearly horizontal to the ground. These special neck vertebrae have added spiny hooks onto which muscles attach, providing the power needed to lift the skull and its two enormous tusks.

These tusks, prized by poachers, are little more than highly modified incisor teeth. They replace the milk teeth in the elephant's first year of life and grow continuously at a rate of around 17 cm (6.5 in) a year.

Like the largest dinosaurs, elephants have had to dedicate much of their skeleton to the demands of holding up their vast bulk. In fact, the African bush elephant skeleton accounts for 16 per cent of its total body weight, notably more than most mammals of such a large size.

COMMON HIPPOPOTAMUS

Hippopotamus amphibius

The common hippopotamus has a skeleton built to sink. Their barrel-shaped ribcage, heavy-boned legs and enormous skull provide the weight necessary to bounce along river- and lakebeds, which they do with a peculiar kind of grace when under the water.

The common hippopotamus hangs its 1.5-tonne (1.65-ton) weight upon a thick spinal column, made of extra-strong vertebrae that fit together like a rigid iron beam. Their 13 stout ribs are bent into a barrel-like cage and help contain the hippo's enormous gut.

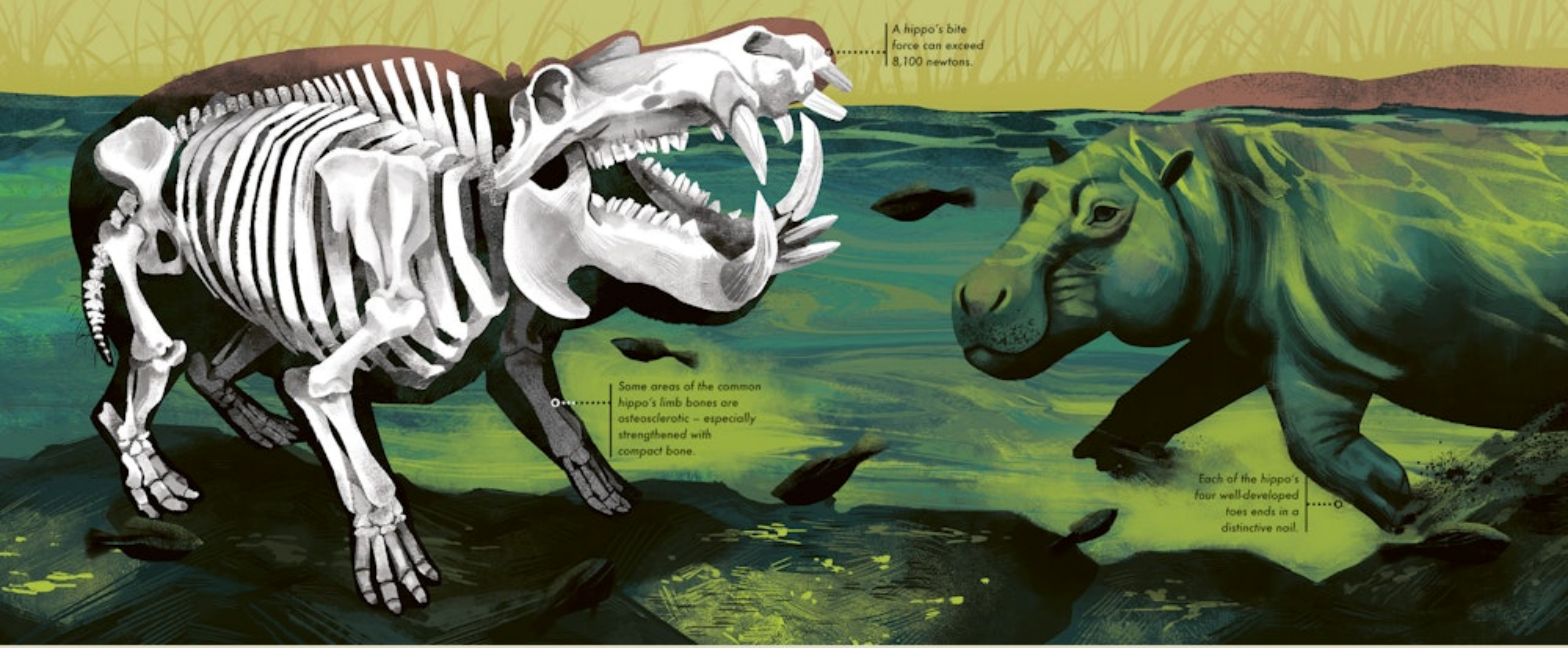
As with elephants, the shoulder blades (scapulae) point downwards, attaching to vertical pillar-like legs which provide extra support.

The common hippopotamus is a fantastic example of a 'graviportal' skeleton – a skeleton evolved to bear great weight. Yet, almost impossibly, hippos carry their weight on land, too, running in short bursts of up to 30 kilometres per hour (18 mph) on land whilst scaring off intruders. This violent territoriality is what makes hippos one of the deadliest animals on Earth.

Hippopotamuses have long jaws with a hinge that is very far back in the skull. This allows them to open their jaws almost 180 degrees. The eye sockets (orbits) are raised onto the top of the skull, allowing the hippo to scan for rivals whilst still in the water.

Their teeth are very large. The lower canines and lower incisors of the common hippopotamus can measure more than 40 centimetres (15.7 in) and, as in rodents, they continue growing throughout life and can be sharpened by grinding them together. They mostly eat grass, though they will sometimes eat carrion (decaying dead animals) when food is scarce.

These teeth are used mostly in combat, displayed as a warning or used as weapons during attack. They can also be used to attack predators. A large muscle-laden sagittal crest on the skull means that hippos can bite with twice the force of a lion, easily enough to scare off even large crocodiles and ensure that snap-happy tourists stay far back.



FITNESS FLAGS

Many grass eaters like springbok indulge in a strange behaviour called pronking. They can leap 2 metres (6.5 ft) vertically into the air, lifting all four feet off the ground in a stiff stance, while bending their heads low. The behaviour may help indicate to predators that they are fit and healthy and not worth chasing.

JUMPING

For bony creatures, becoming airborne even for a few moments requires a lot of energy. Yet many animals need to hop or jump to stay alive. Some animals, including jerboas or wallabies, jump to travel from place to place. Some animals, like frogs, jump to escape predators. Other animals, including antelope and goats seem to jump because, well, it's fun.

But things that go up must come down. The sudden impact of landing puts enormous stress on bones meaning that limb bones, particularly, must be able to handle many times their weight or risk breaking or shattering to pieces. For this reason, all animals built for jumping are also built for landing. Some animals, including kangaroos and humans, have found a way of recycling the force of impact, turning it into a springboard for the next leap.

LAUNCH IGNITION

Most small birds jump into the air as they begin to flap their wings. For this they require powerful muscles attached to their leg bones. In starlings, 90 per cent of the energy involved in upward take-off comes from the legs rather than the wings.

MOUNTAIN RANGING

Mountain goats are well known for being able to jump up and down steep cliff faces. Powerful muscles that attach to the shoulder blades (scapulae) provide the strength to jump between boulders. They also have wide cloven hooves and dewclaws that work a little like ice picks.

SIDEWAYS SIDLE

The sifaki uses its long legs to jump between branches, but sometimes it must move along the ground between trees. It jumps by leaping sideways, keeping its hands outstretched for balance.

SHOWING OFF

Upon its long legs and toe bones, the male lesser florican springs into the air. After an elegant flap of its wing it falls back into the grass whilst pulling a statue-like pose. This strange mating display is undertaken hundreds of times each day. The tallest and most statue-like jumpers attract the most females.

LONG-EARED JERBOA

Euchoreutes naso

Deserts and parched grasslands offer little by way of food, but the long-eared jerboa has made such habitats its own by quite literally making every step count.

Jerboas spring themselves forwards by catapulting their lightweight bodies off long, fused bones within their hind feet. Almost like tiny kangaroos, they range from place to place in search of insect prey which they detect with large ears and keen eyes.

In such sparse habitats as the Gobi Desert, energy-saving adaptations are vital. The light weight of the jerboa skeleton is one such adaptation.

Though they have a body almost equivalent in size to a chicken's egg, long-eared jerboas weigh half as much. Rather than relying on muscle, which is a heavy tissue, the long-eared jerboa relies on special tendons for locomotion. These elastic tendons absorb the energy of each foot – landing, recycling and reusing this energy for the next push-off. Essentially, each time it lands, the long-eared jerboa is propelled into the next step.

The long-eared jerboa depends on insects and spiders for food, and much of their skull anatomy is given over to the ears. Their skulls possess enlarged middle-ear cavities, which help them listen for the tell-tale sounds of prey in the cold desert night. In fact, they have the largest ear-to-body ratio of any animal on Earth.

The long-eared jerboa has a tail almost twice as long as its body. A little like a car with four-wheel steering, jerboas use their long tail as an energy-saving counterbalance, allowing them to change direction quickly whilst travelling at high speed. This allows them to dodge and weave the advances of predators including their mortal enemy, the little owl.

In addition to the enlarged middle-ear cavities, jerboas have large orbits (eye sockets) that help them to spot both prey and predator.

RED KANGAROO

Macropus rufus

Kangaroos are super-charged athletes that manage something few animals can match – they possess both speed and endurance. The secret to their success comes from a skeleton brimming with adaptations to reduce weight and reuse elastic energy. Forget marathon running, kangaroos are marathon jumpers.

In a single leap, the red kangaroo can cover a distance of 8–9 metres (26–29 ft), reaching heights of almost 3 metres (9.8 ft).

They achieve this incredible feat by reusing the kinetic energy gathered from their previous jump. With each bounce, stout tendons in the kangaroo's legs turn kinetic energy into stored elastic energy that can be reused in the next leap. These tendons, attached to long bones on the legs, essentially serve to catapult the body forward. This impressive adaptation means that kangaroos use far less energy when travelling at speed than other animals. In fact, what galloping horses manage in eight footsteps, kangaroos manage with two.

As with other leapers, including frogs and jerboas, kangaroos spring off long toes. In fact, most of their weight is taken on the kangaroo's lengthened fourth toe. The second and third toes are fused to provide a neat little comb for grooming their fur.

Kangaroos have impressively muscled tails. The long, bony tail of the red kangaroo serves partly as a counterbalance whilst running but it can also be used as a handy prop when resting. But there's more to their tails than just this. Scientists recently discovered that kangaroos can use their tails like a third leg that pushes them forward when moving from low speed to high speed.

In fact, the force the tail exerts on the ground at low speeds generates more lift than even its legs. The up-and-down motion of the the tail while running even helps to inflate the lungs, saving the kangaroo more energy. Male red kangaroos have even been known to use their tail as a sort of third leg from which to launch kicks at rival kangaroos.

AMERICAN BULLFROG

Lithobates catesbeianus

The key characteristic of most frogs and toads is the long, powerful back legs which can be adapted for a variety of purposes including jumping, digging and swimming. In the American bullfrog, these legs make for an explosive leap. The American bullfrog can jump ten times its body length, making it one of the most impressive leapers of its kind.

To find out how frogs manage this impressive feat, scientists use slow-motion photography to study the muscles and bones in their legs. Like grasshoppers and locusts, just before they leap, frogs tense special tendons attached to their long legs. As the body moves forward, they allow these tendons to snap back into place like elastic bands, catapulting the frog forwards with a nitro-like injection of extra speed. The long bones in their feet (tarsals, metatarsals and phalanges) provide the foundation for added lift-off. Yet there is more to frogs than just their legs.

In most species, the bones of frogs are light and dramatically reduced. This allows them to stay in the air for longer.

Frogs barely have ribs – the short rib-like bones are actually a part of their spine and frogs don't use them to breathe. Instead, they pull air in and out of their bodies by pumping their chins.

To allow for a safe landing, the American bullfrog has extra-strong limb bones. Unlike most vertebrates, the lower forearm bones (the radius and ulna) are fused, and likewise, the two bones in the lower legs (tibia and fibula) are also fused. They also benefit from a sternum (the long, flat bone in the center of the chest) that works a little like a shock absorber.

The American bullfrog is, like all frogs, a creature shaped by predators. Every living frog you have ever seen is like a loaded spring, watchful for advancing carnivores. In the long legs held beneath their bodies, tendons are primed and readied for release. They jump. They land. They live to survive another day.

GLIDING AND FLIGHT

The only dinosaurs that remain today are those that took to the skies, the creatures we call birds. Today, almost 10,000 bird species rule the skies (and occasionally the land) and each has the same basic dinosaur pattern: two legs for walking and two forearms upon which arm and finger bones have been adapted into flapping sails that we call wings.

But birds are not alone in being airborne. Many bony animals have also taken to the skies and had their bones adapted into wings of different shapes and styles. Some, like bats, are true fliers – like birds, their wings allow for powered flight with purpose. Others, like flying squirrels or draco lizards, are gliders. Like paper aeroplanes they can dive with style between trees or cliffs using flaps of skin or even long, webbed toes.

In vertebrates, the story of flight is really a story of bones stretching out generation by generation over many millions of years to become powered or gliding wings. And each animal family has its own unique story – its own unique skeletal adaptations to provide a life in the atmosphere above.

BIRDS

Bird skeletons are based on the two-legged dinosaurs (theropods) from which they evolved. Their lower arm bones (the radius and ulna) are long and the wings ends in the alula – an adapted dinosaur 'thumb'. This thumb bone controls special flight feathers which, when stretched out, can assist in flying slowly or landing.

BATS

Within the wings of bats are four familiar mammal finger bones stretched wide over many millions of years. Their paired thumbs are clawed and stick out from the front of the wing to assist in gripping when not in flight. Like birds, their bones are incredibly light which helps to keep them airborne for longer.

PTEROSAURS

This enormous family of flying reptiles dominated the skies for more than 150 million years. They flew with wings that were mostly held together by a dramatically lengthened fourth finger. From this finger was stretched a membrane made of muscle and skin that was capable of connecting with the hind legs to form a vast, flapping super-sail.

MICRORAPTORS

Unlike birds, some dinosaurs evolved four wings rather than two. Microraptor is one of a number of recently discovered fossils from China that show extra flight feathers attached to the legs. It may have been that these extra wings helped Microraptor and its relatives manoeuvre through dense forests or allowed these reptiles to 'parachute' onto their prey.

THE GLIDERS

A host of tree-living animals have evolved to become gliders that can move from tree-to-tree to find food or escape predators.

Slithering sails

Whilst falling from the tops of trees, the so-called flying snake can suck in its abdomen and stretch its ribs wide to create a 'pseudo-concave wing'. By continuing its s-shaped movement while falling, it can effectively slither through the air, landing up to 100 metres (330 ft) away.

Skin flaps

About 50 species of flying squirrel exist. They have a long membrane (the patagium) that stretches from wrist to ankle and allows them to glide almost 100 metres (330 ft) to safety.

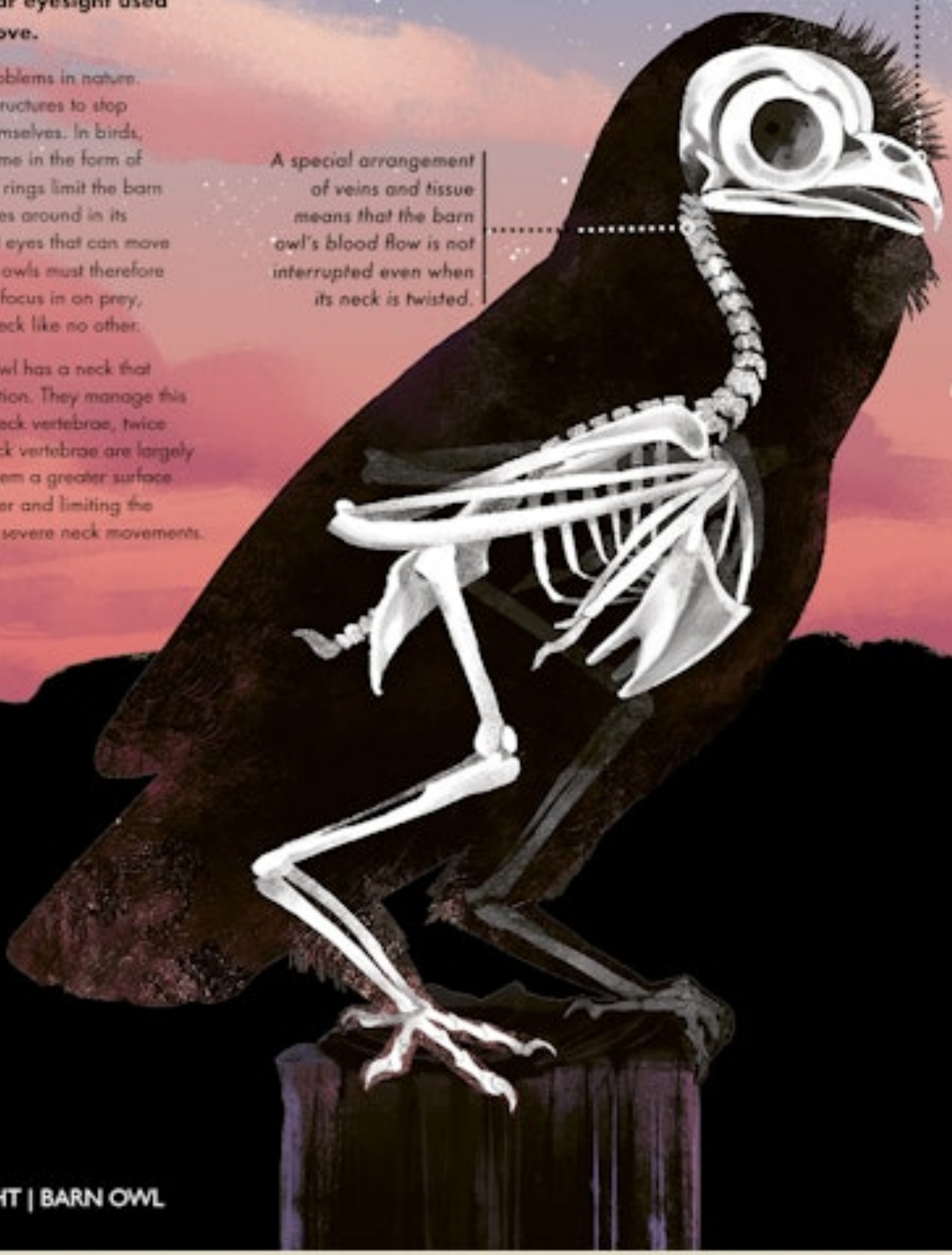
BARN OWL

Tyto alba

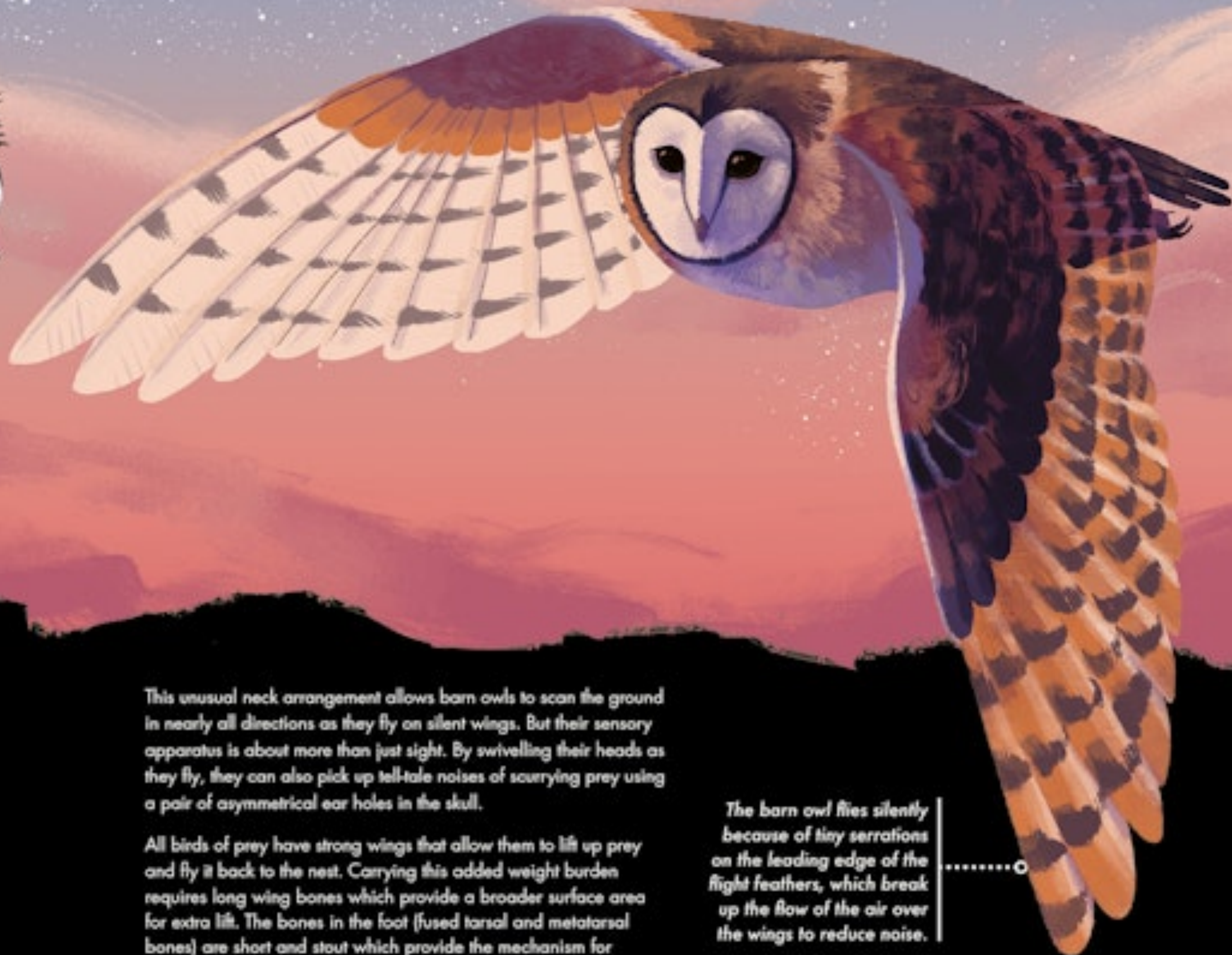
To a rodent, a single look from a barn owl spells almost certain death. Its eye sockets (orbits) are enormous, and they face directly forwards meaning that the field of vision in each eyeball overlaps. This provides binocular eyesight used to spot prey from above.

But big eyes come with problems in nature. Big eyes require internal structures to stop them from falling in on themselves. In birds, these internal structures come in the form of sclerotic rings. These bony rings limit the barn owl's ability to move its eyes around in its sockets as we can.Without eyes that can move independently of the skull, owls must therefore move their entire heads to focus in on prey, and for that they need a neck like no other.

Like many owls, the barn owl has a neck that allows for 270-degree rotation. They manage this because they possess 14 neck vertebrae, twice that of mammals. These neck vertebrae are largely saddle-shaped, allowing them a greater surface upon which to slide together and limiting the chance of damage during severe neck movements.



The fastest recorded flight speed of the barn owl is 80 kph (50 mph).



This unusual neck arrangement allows barn owls to scan the ground in nearly all directions as they fly on silent wings. But their sensory apparatus is about more than just sight. By swivelling their heads as they fly, they can also pick up tell-tale noises of scurrying prey using a pair of asymmetrical ear holes in the skull.

All birds of prey have strong wings that allow them to lift up prey and fly it back to the nest. Carrying this added weight burden requires long wing bones which provide a broader surface area for extra lift. The bones in the foot (fused tarsal and metatarsal bones) are short and stout which provide the mechanism for working sharp claws capable of both carrying and killing.

COMMON FLYING DRAGON

Draco volans

In the treetops of Southeast Asia there exists a lizard with a secret. When being hunted by predators this lizard relies on a truly spectacular adaptation. The common flying dragon lizard can leap from trees and, as if by magic, unfurl vast wings upon which it glides away. But these are not wings like those of birds or bats. Their wings are an extension of their ribs.

Dragon lizards have a set of specially adapted ribs covered in a membrane of skin between the forelimbs and hindlimbs. At rest, four or five of these thoracic ribs fold against one another and are held tight against the body. When spooked, dragon lizards erect these special ribs, creating giant sails (patagia) which catch the wind and can be used to escape.

But dragon lizards have another trick up their sleeve. Their wrist bones are more mobile than most lizards, allowing them to actually grasp their strange wing membranes as they fly. Using their claws, they can stretch their wing membranes extra wide after take-off, much like a superhero using its cape to glide off a building.

The common flying dragon lizard is assisted in its gliding flight by a long tail which can be used like the rudder on an aeroplane to steer through the air. Their bones are light, allowing them to stay airborne for longer. Some dragon lizards can make flights of 10 metres (32 ft) or more from tree to tree, which is impressive for an animal little more than the size of a mouse.

But gliding flight isn't all about escaping predators. The common flying dragon lizard is incredibly territorial. If a male spots an interloper on their turf, they will immediately swoop down on them, exposing their blue undersides as a warning. Special yellow flaps behind their neck serve as an extra method of intimidation. Of course, these special flaps (called throat lappets) also help them to glide.

The common flying dragon also uses its patagium to swoop down upon potential rivals.

While all other lizards breathe by expanding and contracting their ribcage, the flying dragons have adapted to use the muscles in their chest – its ribs are being used for something else!

The female common flying dragon has a pointy skull which she uses to dig burrows to lay her eggs in.

Bat's claws are capable of locking in place while they hang upside down on branches to sleep.

LARGE FLYING FOX

Pteropus vampyrus

With a wingspan of up to 1.5 metres (5 ft), the large flying fox is the largest bat on Earth. Like us, this fruit bat has molar teeth, incisor teeth and canine teeth; it has seven neck bones, a rib cage and pelvis, and, like us, it has distinctive mammal hands with four fingers and a thumb – a familiar mammalian skeleton, but this one is built for flight.

Unlike insects and birds, which have quite rigid wings that can only move in a few directions, bats have more than two-dozen joints in their wings. They have a huge amount of control over how each of the joints move, allowing them to adjust their flight accordingly.

A bat's wing membrane (patagium), is supported by the arm and by four highly elongated fingers. The patagium extends all the way around to the bat's hind legs and tail, where it forms a flap called the uropatagium, supported by specialised foot bones called calcars. The uropatagium not only helps the bat fly and manoeuvre ; in some bat species it is also used to sweep prey, such as insects, into the bat's mouth while the bat is in flight.

The skull of the large flying fox is heavier than most bats. In some ways, its skull resembles a crash helmet. In large groups, the large flying fox will smash into the tree canopy, grabbing onto passing branches with its claws before tearing fruits apart with large canines and molars that are sharpened like scissor blades. Bats can break bones while landing in this way, but they are impressive healers.

Flying foxes are the largest members of the fruit bat family, the *Megachiroptera*. Most scientists think that by losing their ability to echolocate many millions of years ago, this large family of bats unlocked the ability to evolve to greater size. Today, there are 186 known species of living fruit bat, and the large flying fox is the biggest of them all.

Many fruit bats, including flying foxes, also drink from flowers. They use long hairy tongues to lap up nectar which they keep rolled up deep within their rib-cages when not being used.

RUNNING

In grasslands where predators lurk, it is often the fastest individuals that live to survive another day. In this way, over many years, the presence of predators causes prey to evolve. The skeletons of many prey species have therefore become adapted for speed.

But predators can also evolve. As prey get faster, so too must the predators. In this way, predator and prey can sometimes become entangled in an evolutionary battle (or arms race) that can go on for millions of years and reach dizzying speeds.

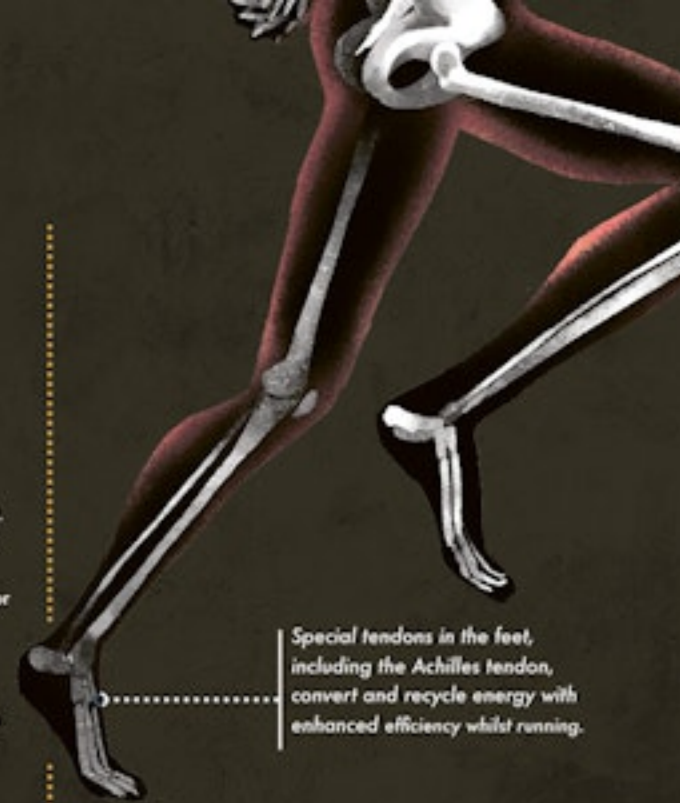
Running speed isn't only about short distance battles between predators and prey. Running fast can help animals in a number of ways, as you can see on these pages.

A. In their seasonal search for food, caribou make a journey of more than 4,830 kilometres (3,000 miles) each year, occasionally clocking speeds of up to 80 kph (50 mph). For them, time is of the essence. Their long leg bones and sturdy toe bones provide marathon-runner endurance. Like their predators, caribou are also built for sudden bouts of speed. Within 24 hours of being born, a caribou could outrun an Olympic sprinter.

B. African wild dogs work in packs to wear out and exhaust their fleeing prey. With comparatively sturdier legs than other dog species, they will hound and harass a potential meal for up to 60 minutes or more, maintaining speeds of up to 48 kph (30 mph). Eventually their prey collapses with exhaustion and the kill is made.

C. Some crocodiles, such as Australian freshwater crocodiles, can literally gallop towards threats in an attempt to scare them off. By pushing off with both hindlimbs at the same time, and landing with the forelimbs before pushing off again, their unusual running style resembles that of a rabbit. By galloping like this, they can manage a speed of 16 kph (10 mph) – pretty impressive for a crocodile on land.

D. Basilisk lizards have a running style like no other. When confronted by predators, they run on their hind legs towards water and sprint along the surface. Their long bony claws are attached to flaps of skin that capture a layer of air bubbles, keeping the lizard afloat while it sprints. Young basilisks can run up to 20 metres (65 ft) along the water's surface.



Special tendons in the feet, including the Achilles tendon, convert and recycle energy with enhanced efficiency whilst running.

HOMO SPRINTIAN

Compared to other primates, humans have a variety of skeletal features that help us to run long distances. For our overall size, the bones that make up human legs are long. Like enormous pole vaults, these propel the body forwards using less energy per stride. Human leg bones also have large joint surfaces to more widely spread the forces created during running.

CHEETAH

Acinonyx jubatus

Occasionally reaching speeds of 112 kilometres per hour (70 mph), the cheetah is the fastest land animal on Earth. Each of its bones is optimised for speed and its skeleton chiselled to almost defy gravity.

The two most effective bony adaptations that the cheetah possesses are long legs and a long, flexible spine. Each time a cheetah's feet hit the floor it flexes its spine, stretching its body right out to maximise the distance between each stride. Stride length is also increased through lengthened lower leg bones, which push the body forwards over greater distance.

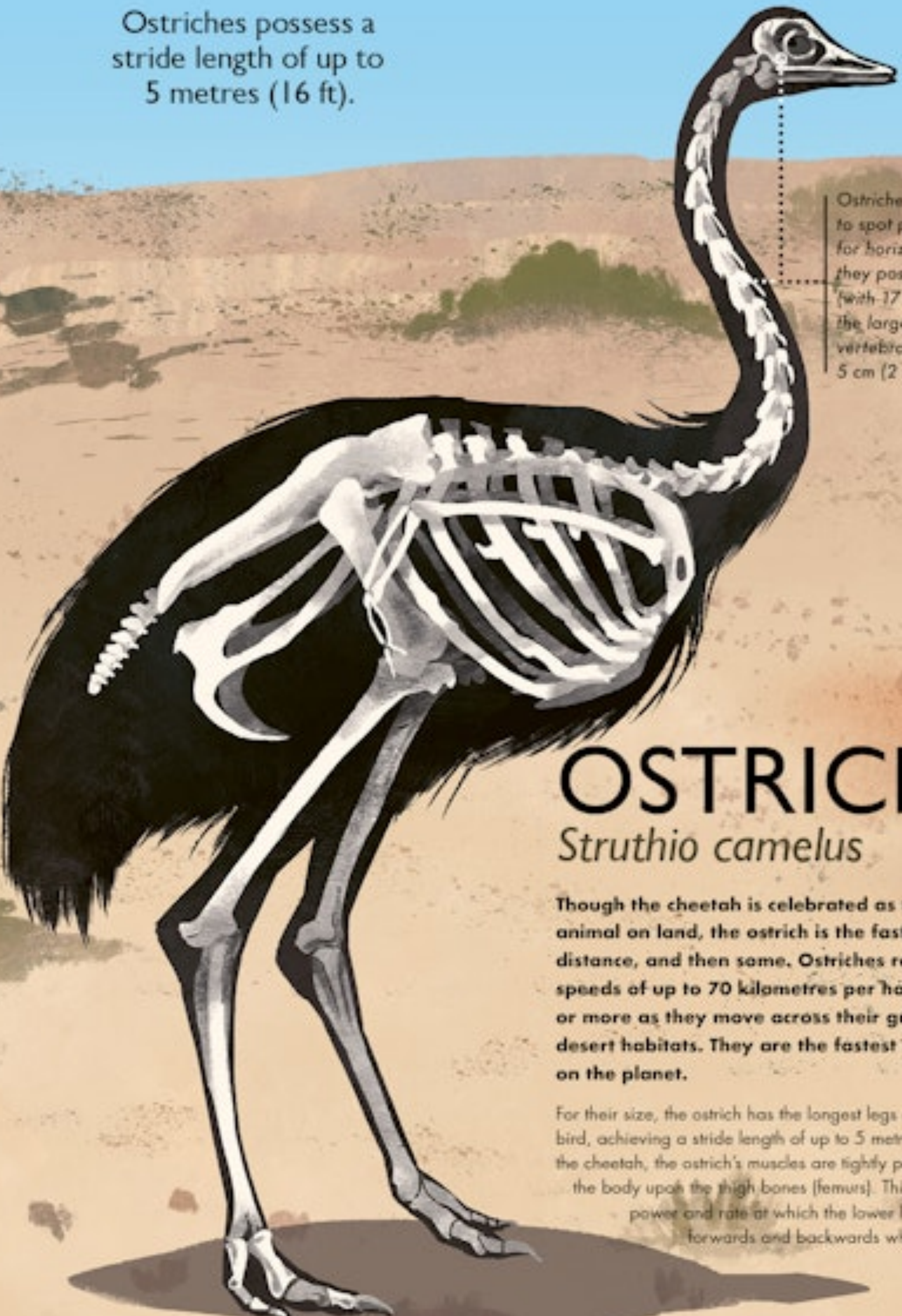
With each thrust of the legs, the cheetah achieves a stride length that averages 6.7 metres (22 ft). For half of the time that it is sprinting, it has all four feet off the ground. Lightweight bones allow the cheetah to stay in the air for longer, but come with a downside – they can break more easily. To reduce wear and tear on the lower leg bones, their tibia and fibula are bound tight, meaning that they work a bit like shock-absorbers.

The cheetah's long tail allows it to make sudden changes in direction whilst running at top speed, using it as a counterbalance and allowing the cheetah to make incredible turns at breakneck speeds without falling. They also have long claws that grip like an athlete's trainer-spikes – the cheetah is a master of momentum.

As well as being the fastest land animal, the cheetah is also the fastest at accelerating. It can achieve a speed of almost 80 kilometres per hour (50 mph) in just two seconds, accelerating at roughly the speed of a rock falling from a cliff. Research involving the use of satellite trackers on wild cheetahs suggest that it is this, rather than speed, that is the most critical part of a successful hunt.

To allow extra grip, the pads of the cheetah's toes are patterned, like the soles of running shoes.

Ostriches possess a stride length of up to 5 metres (16 ft).



OSTRICH

Struthio camelus

Though the cheetah is celebrated as the fastest animal on land, the ostrich is the fastest over distance, and then some. Ostriches regularly reach speeds of up to 70 kilometres per hour (43 mph) or more as they move across their grassland and desert habitats. They are the fastest sprinting bird on the planet.

For their size, the ostrich has the longest legs of any living flightless bird, achieving a stride length of up to 5 metres (16.4 ft). As with the cheetah, the ostrich's muscles are tightly packed high up into the body upon the thigh bones (femurs). This maximises the power and rate at which the lower legs can be flicked forwards and backwards whilst running.

As with horses' hooves, ostrich feet are a slimmed down and simplified version of what they once were. Where most birds walk on four toes, the ostrich is the only living bird to walk on two toes.

The big toe supports the majority of body mass, and the smaller toe acts like a stabiliser, helping the ostrich dodge and weave advancing predators. Like a sprinter in running spikes, the larger claw can penetrate the ground whilst achieving high speeds, assisting with grip.

Yet even with these adaptations, the stamina and speed that ostriches so effortlessly maintain appear other-worldly. How do they manage it? The secret lies in their tendons, which are far more elastic than other creatures of their size. As they release their elastic energy these tendons fling the limb bones forwards, providing 83 per cent more by way of output with each stride when compared to human sprinters.

So full of speed and stamina are ostriches that, if they were undertaking a 42-kilometre (26-mile) marathon alongside the best human athletes, they would complete the race twice as fast, using half the energy that a human would require.

Pronghorns have been known to cover 11 km (6.8 miles) in just ten minutes.

PRONGHORN ANTELOPE

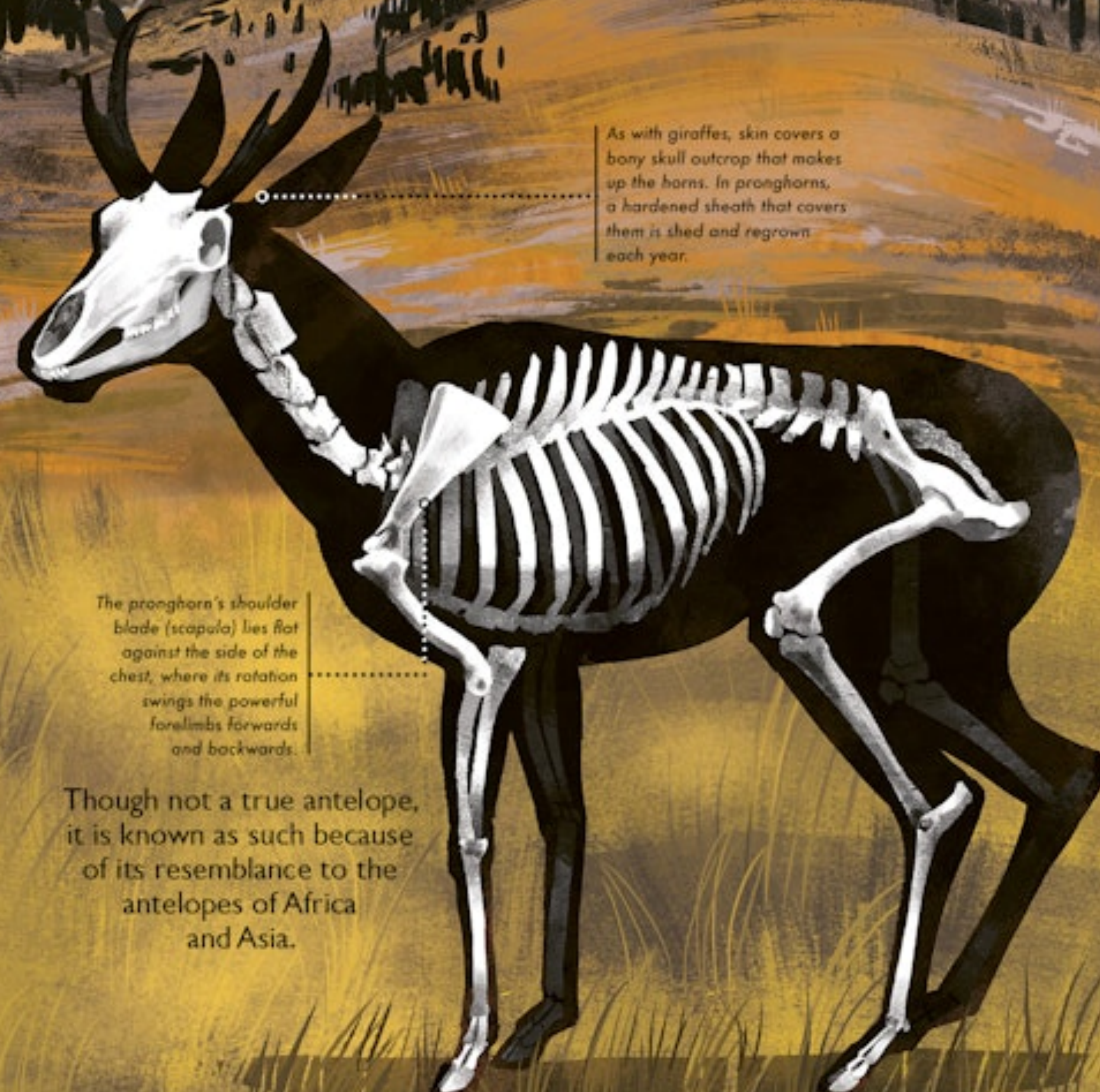
Antilocapra americana

Occasionally clocking speeds of 88 kph (55 mph) or more, the pronghorn antelope is the fastest land animal in the Americas. Yet what makes the pronghorn stand out compared to other sprinting animals is that it can endure speeds like this over very long distances. Pronghorn can maintain their top speed for almost a kilometre (around half a mile), easily more than enough to outrun its predators.

The secret of the pronghorn's success lies mostly in its leg bones. As with their giraffe and okapi cousins, the pronghorn antelope takes much of its weight on two long pointed toes, which are specially cushioned to limit the impact of each step. Their long toe bones increase stride length, which means that each push off the ground gathers greater distance. To reduce wear and tear, the pronghorn antelope also possesses special interlocking grooves in the joints of its leg bones, which ensure that they move together almost as if on hinges. This limits the likelihood of sprains and fractures. The ulna and radius are also partially fused, to further limit the likelihood of breakages.

The pronghorn antelope has a large, barrel-shaped ribcage in which is found an impressive wind pipe, giant lungs and a slightly larger than expected heart, which helps pump blood to the muscles of the legs. As with many prey species, the eye sockets (orbits) of pronghorn antelope are large and sideways pointing, meaning that pronghorns can keep an almost 360-degree watch for predators.

Predators have clearly had a big impact on the pronghorn antelope. Their speed hints that, at one point in recent history, they lived alongside a very fast predator which must have provided the driving force for their evolution. The prime candidate is the mysterious American cheetah, a creature that disappeared from the North American plains more than 10,000 years ago.



As with giraffes, skin covers a bony skull outcrop that makes up the horns. In pronghorns, a hardened sheath that covers them is shed and regrown each year.

The pronghorn's shoulder blade (scapula) lies flat against the side of the chest, where its rotation swings the powerful forelimbs forwards and backwards.

Though not a true antelope, it is known as such because of its resemblance to the antelopes of Africa and Asia.

SWIMMING

Moving through water is more difficult than moving through air because water molecules bind tightly with one another. This means that underwater creatures often have streamlined skeletons that slice through water, giving them a torpedo-like (fusiform) shape.

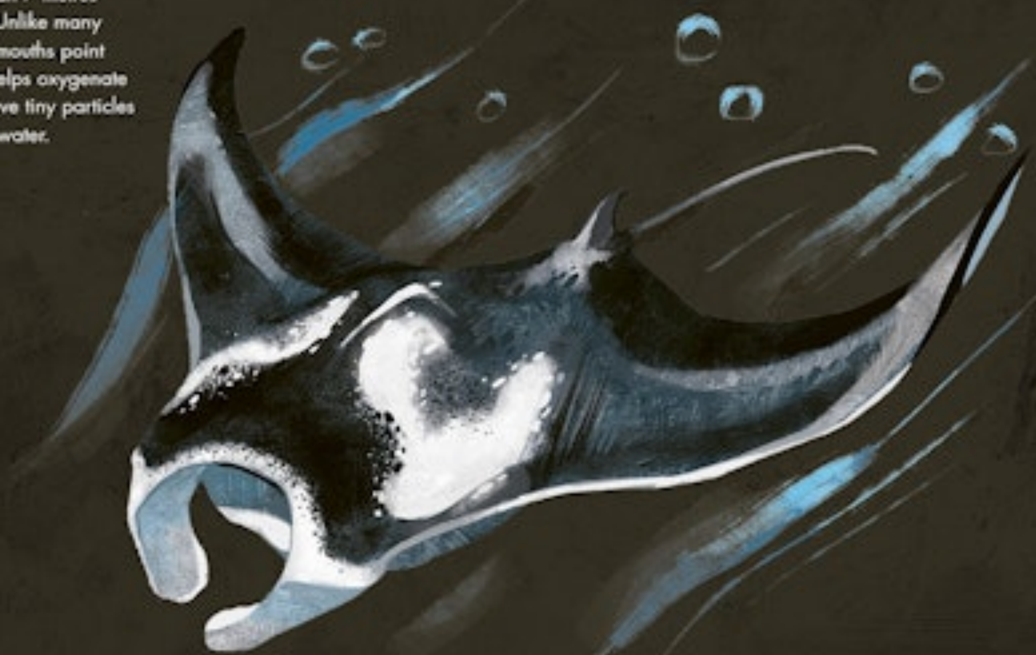
To move through water also requires a means through which to propel the body forwards. While many animals like whales and sailfish depend on muscle-laden tail vertebrae to drive the body forwards, some creatures have hit upon other skeletal adaptations to push their way through water, as you can see on these pages.

ROWING

Leatherback turtles have long bony flippers measuring up to 2.7 metres (8.8 ft) which they use to row the body forwards. They use their hind legs to steer their body through the water. Leatherback turtles are the only living sea turtles that lack a bony carapace (the upper part of the shell).

FLAPPING

Manta rays propel themselves forwards by undulating enormous flattened pectoral fins that can measure more than 7 metres (22 ft) tip to tip. Unlike many rays, manta ray mouths point forwards – this helps oxygenate their gills and sieve tiny particles of food from the water.



CRAWLING

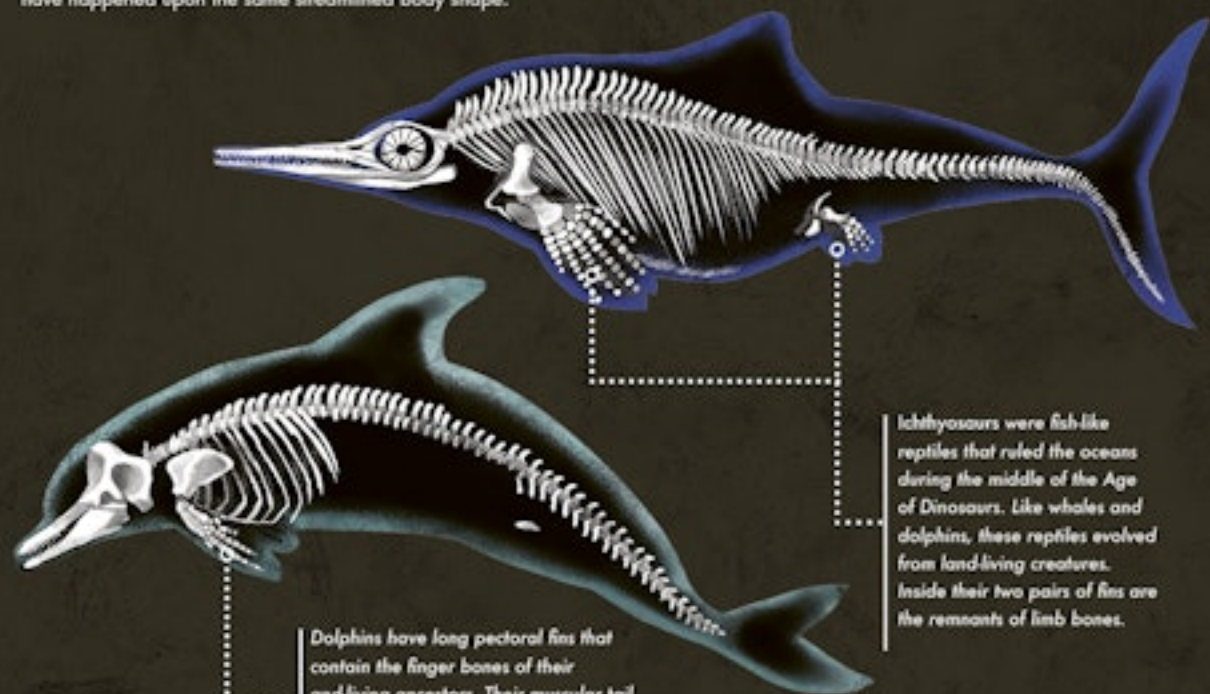
The tub gurnard has long pectoral spines which project from the sides of the body. They use these spines like fingers to help them move across the bottom of the sea. These strange spines are also highly sensitive to movement. They help the gurnard detect potential prey beneath the sand.

UNDULATING

Pipefish have an armour-plated skeleton with a long dorsal fin that is capable of undulating like a ribbon. These frequent undulations move in waves down the body, powering forward movement. This helps the pipefish move quietly through its seagrass habitats without drawing attention from predators.

CONVERGENT EVOLUTION

Throughout the history of life on Earth, fusiform shapes have ruled the oceans. Here are two very different skeletons that have happened upon the same streamlined body shape.



Ichthyosaurs were fish-like reptiles that ruled the oceans during the middle of the Age of Dinosaurs. Like whales and dolphins, these reptiles evolved from land-living creatures. Inside their two pairs of fins are the remnants of limb bones.

Dolphins have long pectoral fins that contain the finger bones of their and-living ancestors. Their muscular tail is attached to a spine that goes up and down. Their tail is flattened horizontally rather than vertically.

BLACK MARLIN

Istiompax indica

The black marlin is one of the world's fastest fish, sometimes reaching speeds of more than 129 kilometres per hour (80 mph) as it travels through the open ocean. Its missile-shaped skeleton has been fine-tuned to travel fast in short bursts, all the while using the least amount of energy possible.

To propel itself through water, the black marlin uses its strong muscular tail. Along its spine there are numerous places where muscles attach to provide extra power. Many of these muscles are 'high-twitch' muscles which allow for intense bursts of power.

Unlike other marlins, the black marlin has pectoral fins which are locked in place. Like enormous aeroplane wings, they maintain upward lift and stabilise the marlin as it glides through its watery environment. A long, thick dorsal fin, which looks almost like a crest, offers added support.

Marlin skeletons may grow more than any other creature on Earth. When baby marlin first hatch from eggs, they are about the size of a pea. As adults, less than ten years later, they reach more than 4 metres (14 ft) in length and may be as much as a million times heavier.

Marlin are best known for their pointed upper jaw, the rostrum. With this charismatic sword-like adaptation, the black marlin is like a knife that cuts, quite literally, through the water.

But there is more to its sword than this. Marlin can swipe their rostrum at passing shoals of fish like a master swordsperson, stunning and killing those fish that accidently get too close. Scientific research has shown that it is strengthened along its top and sides, making it much stronger than it looks. Though almost iron-like, marlin bills do occasionally snap off. Sometimes they are found impaled in other sea creatures, including sharks.

BLUE WHALE

Balaenoptera musculus

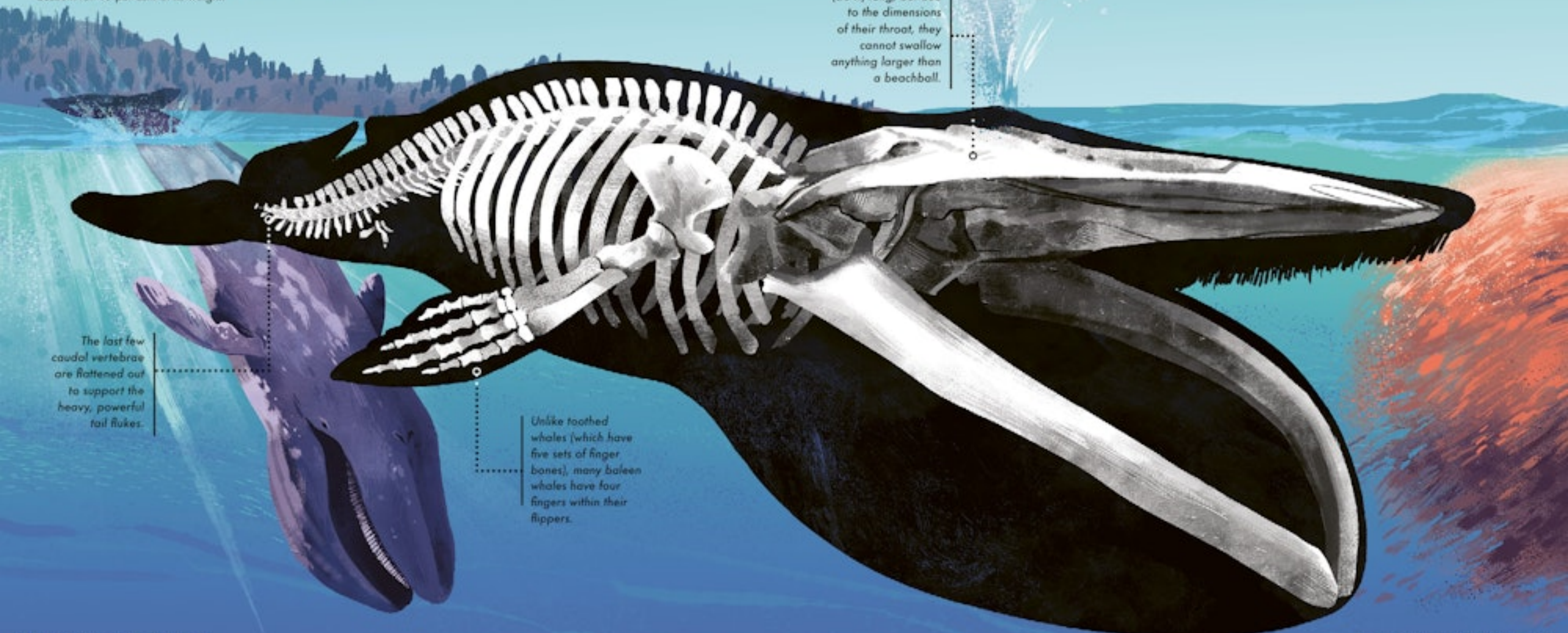
With a skeleton upon which can hang 200 tonnes (220 tons) of flesh, the blue whale is perhaps the biggest animal that has ever lived. Almost every single bone has been stretched to the limits of physics.

The blue whale is an ocean traveller that can sometimes cover almost 450 kilometres (280 miles) in a single day as it journeys between feeding places. Like a giant ocean liner it is powered by an impressive engine – a tail densely packed with muscles which account for 40 per cent of its weight.

These muscles attach to the lower spine of the blue whale. Each tail vertebra is more than a metre (3.3 ft) wide and contains outstretched regions called neural spines and transverse processes (the bony projections on either side of the vertebrae) onto which broad tail muscles can attach. Unlike most mammals, the middle part of the spine is rigid, rather like an iron girder.

Blue whales grow to such enormous size partly because of their bounteous food source, krill. Using vast bony plates made of fingernail-like material (baleen) that hang from their long jaws, they sieve these tiny crustaceans from the water with the help of a powerful tongue. To provide the anchoring required for these heavy baleen plates, the whale's top jaw is fused to the skull.

Though well adapted, whale skeletons retain many of the features of their land-living mammalian ancestors. They have four sets of finger bones (phalanges) in each flipper, shoulder blades (scapulae), seven stiff neck vertebrae and distinct nostrils that form the blowhole. Indeed, their spine moves up and down in a charismatic mammal way rather than left and right like a fish. There are even so called 'vestigial bones' found deep within the belly that hint at their land-living past. These unusual bones are the remains of tiny hind limbs that today serve no purpose, rather like the tail bone of apes, and the wings of the flightless kiwi.



EMPEROR PENGUIN

Aptenodytes forsteri

On land, emperor penguins look almost comical. But under the water, a penguin is a fish-eating submarine torpedo, with a skeleton chiseled to perfection for flying through aquatic environments.

Compared to volent (aerial-flying) birds, the most striking thing about penguins is how heavy their bones are. They lack the air pockets that most birds possess which reduces their buoyancy (the ability to float in water) and allows them to chase fish far deeper than expected without being pulled back up. Emperor penguins have been known to dive as deep as 500 metres (1640 ft) below the water, a feat impossible without weighty bones.

Flying through water is harder than flying through air. The density of water means that every flap takes more energy. Every thrust takes effort. But penguins make use of something that aerial birds cannot – the upward stroke.

Most flying birds make use of downward strokes only to gather lift, but penguins – being surrounded on all sides by liquid – can generate thrust from both upward and downward strokes. For this reason, compared to birds that fly, they have highly developed muscles associated with upward flapping that attach to giant paddle-like shoulder blades (scapulae).

And then there are the phalanges the bones within the fingers. Within their wings, most birds possess three fingers onto which are anchored feathers, particularly those feathers that guide steered flight and controlled landings. Penguins, of course, have little need for such feathers.

Their phalanges instead have become long and flat, almost like a pancake. The third finger, normally tiny in birds, is enormous in penguins. These wide phalanges improve the surface area of the wing, greatly influencing the thrust that they can achieve with each wing stroke.

These are the engines that propel penguins forwards during the chase, after all.

Their stomachs full, they come back to land. Shuffling, squawking, ungainly once again. And we chuckle, unaware of the aquanautic feats that such a skeleton permits beneath the waves.

GLOSSARY

Acceleration
Speeding up

Adaptation
The way an organism changes over generations to be better at surviving and thriving in its environment

Asymmetrical
Not even on both sides

Baleen
The bony plates found in the mouths of some whales used to filter food

Carapace
A shield or shell (sometimes made of bone, chitin or exoskeleton) covering some or all of an animal's upper or lower side

Carnassials
Paired upper and lower teeth that are used for cutting, rather than tearing

Carnivorous
An animal that eats meat; a carnivore

Cartilage
A firm, flexible, connective tissue found in many areas of the body, including in between joints. Some animals have skeletons made only of cartilage

Cavity
An empty space within a solid object

Charismatic
A feature or attribute of an object or body part that gives it unique charm which is recognised and celebrated by those that study it

Coccyx
A set of compressed bones that sit at the very bottom of the spine and represent a vestigial tail

Decompression sickness
A painful condition where bubbles of nitrogen form in your bones, caused by diving too deep underwater and surfacing too quickly

Diastema
The space between two teeth

DNA
The chain of molecules that carries the genetic instructions for growth, development, function and reproduction for all living things

Echolocation
A technique used by animals, such as some whales and bats, to locate objects using reflected sound (echoes)

Endurance
The ability to do something for a long time, or over a long distance

Evolution
The gradual changes observed in a species over time, caused primarily by natural selection

Foramen magnum
The hole in the base of the skull through which the spinal cord passes

Fossil
The preserved remains or impression of any once-living thing from another geological age

Fusiform
A shape that is wide in the middle and tapers at both ends

Herbivore
An animal that eats plants as the main component of its diet

Interlocking
Two objects that overlap or fit together

Interloper
An intruder

Invertebrate
A creature without a backbone

Keel
A curved extention of the breastbone on to which flight muscles attach, usually found in birds and bats

Kinetic energy
Energy generated through movement

Ligament
Connective tissue

Mandible
The jaw or jawbone of an animal

Marrow
A soft, fatty substance found in the hollow parts of bones

Marsupial
A type of mammal which carries its young in a pouch, like a kangaroo or a koala

Membrane
A thin layer of tissue forming a barrier or lining

Opposable thumb
A thumb that is able to face and touch all of the fingers on the same hand

Patagium
The membrane or fold of skin between the forelimbs and hindlimbs of animals like bats and gliding lizards

Prehensile
Part of the body, usually a tail, that is capable of grasping

Quadruped
An animal which has four feet

Rostrum
The beak-like projection evolved from the jawbone, like the sword-like beak of a marlin

Sagittal crest
A ridge of bone running along the top of the skull, usually indicating that there are very strong jaw muscles

Sauropods
A group of dinosaurs with four thick, pillar-like legs, long necks, long tails and small heads that appeared in the late Triassic period

Schizodactyly
A term used to describe grasping with the second and third digit fingers, instead of the thumb and any other digit

Sclerotic rings
Rings of bones found inside the eyes of several groups of vertebrates. They support the eye

Sedimentary rock
Rocks formed by sediments that have settled at the bottom of a lake, sea or ocean

Serrated
With a jagged edge

Strata
A single layer of sedimentary rock

Subterranean
Underground

Territorial
When an animal is protective of a certain area and defends it from intruders

Undulating
Moving with a smooth, rippling motion

Venomous
An animal that is able to inject venom, often through hollow fangs or a stinger

Vertebra
One of the small bones that forms the backbone

Vertebrate
An animal with a backbone

Vestigial
When only a very small of part of something that was once much bigger remains, usually due to having become functionless in the course of evolution

Zygomatic arch
The obvious bony arch above the cheek and behind the eyes in mammals

CREDITS

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Jules Howard is a zoologist, non-fiction author and international ambassador for science. As well as writing regularly for the *Guardian* and the BBC, Jules offers support to a number of non-fiction book publishers working on zoological themes.

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Chervelle Fryer is an illustrator hailing from Cardiff, Wales. She specialises in character illustration, and loves to work mostly with organic themes in bright colours and heavy textures.

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