



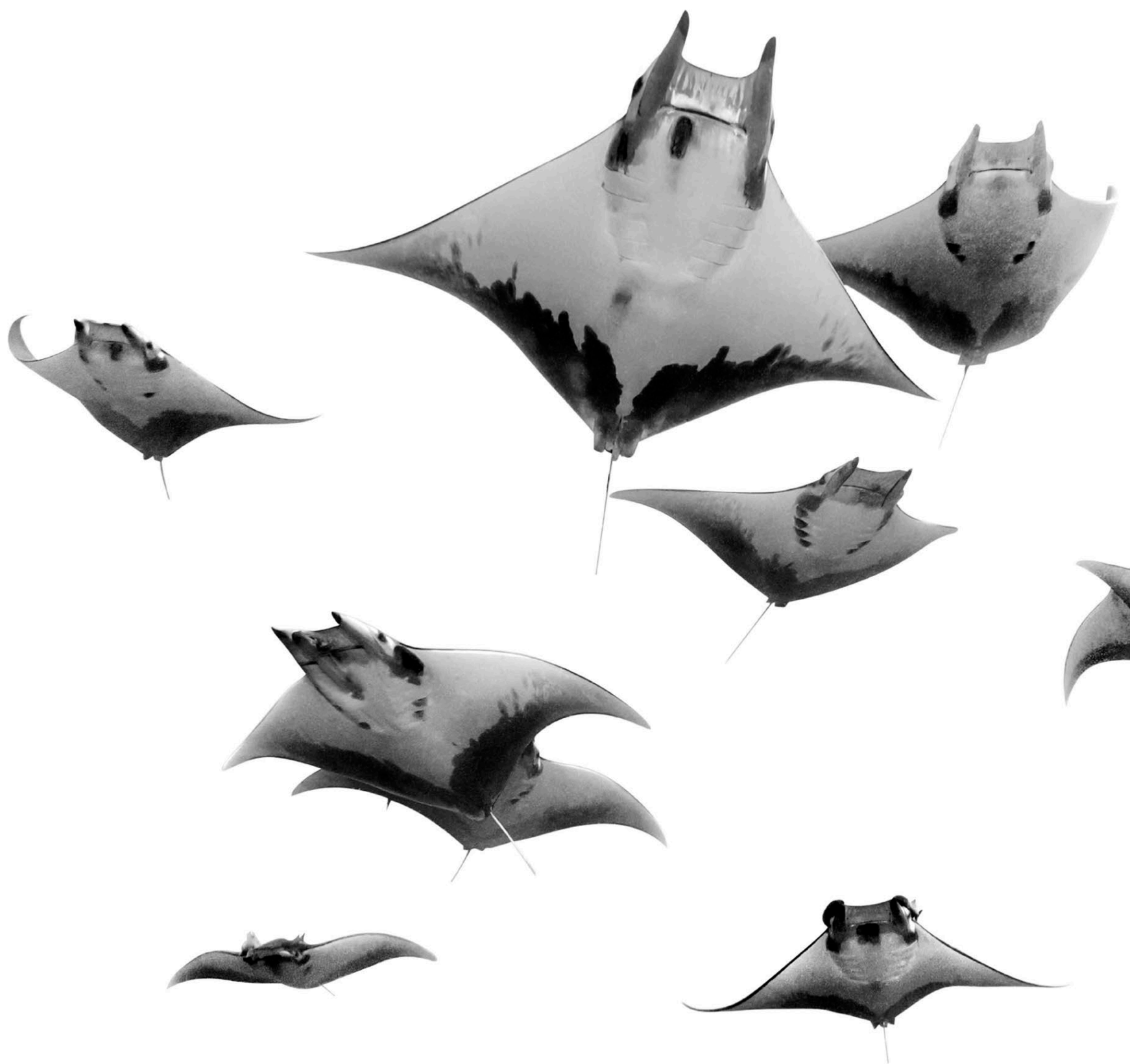
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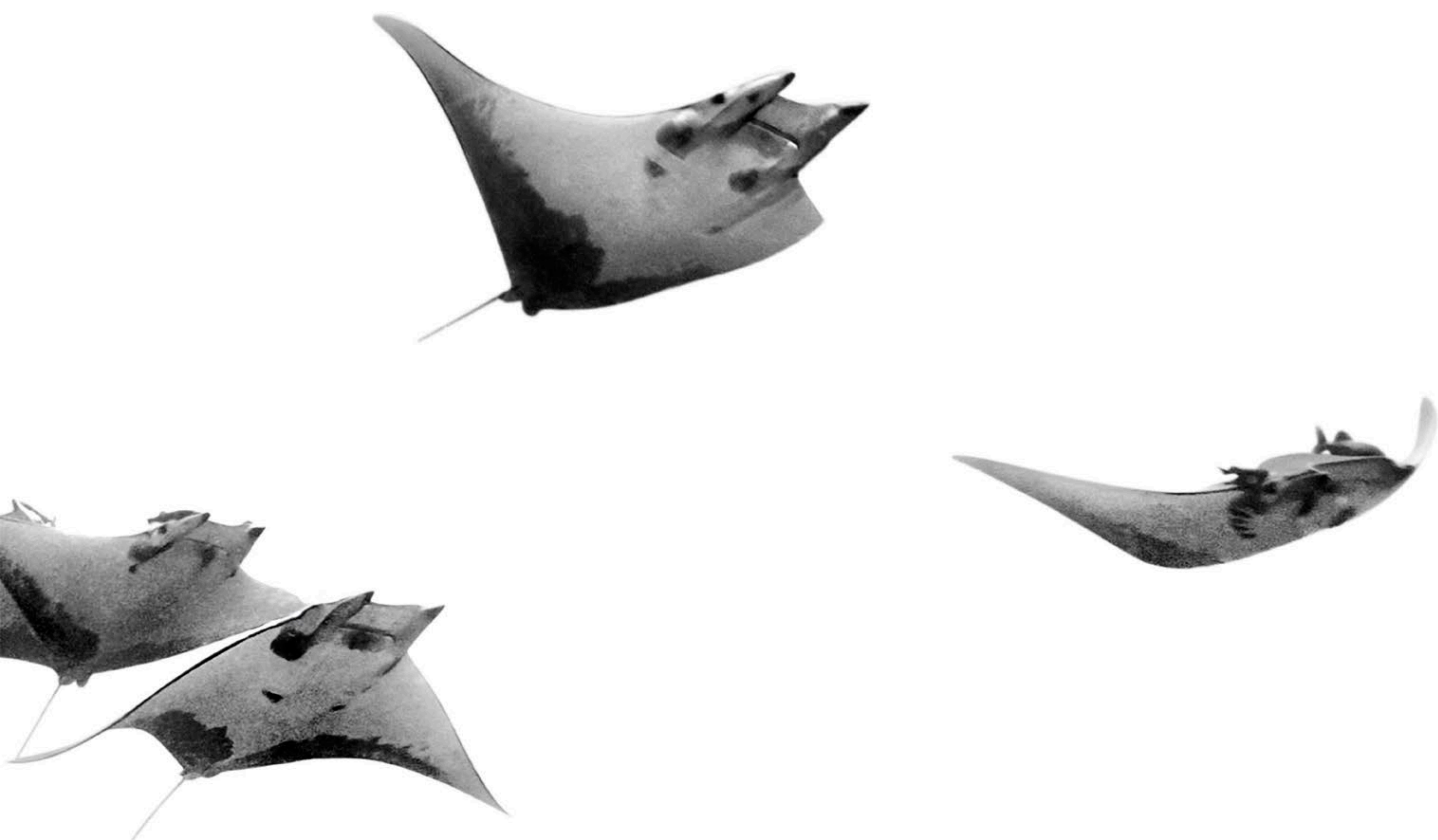


OCEANOLOGY

THE SECRETS OF THE SEAS REVEALED







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OCEANOLOGY



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Established in 1846, the Smithsonian Institution—the world's largest museum and research complex—includes 19 museums and galleries and the National Zoological Park. The total number of artifacts, works of art, and specimens in the Smithsonian's collections is estimated at 156 million, the bulk of which is contained in the National Museum of Natural History, which holds more than 126 million specimens and objects. The Smithsonian is a renowned research center, dedicated to public education, national service, and scholarship in the arts, sciences, and history.

Half-title page Pale octopus (*Octopus pallidus*)
Title page Giant devil rays (*Mobula mobular*)
Above School of barracuda (*Sphyaena*) in the Red Sea
Contents page Flower hat jellyfish (*Olindias formosus*)

contents

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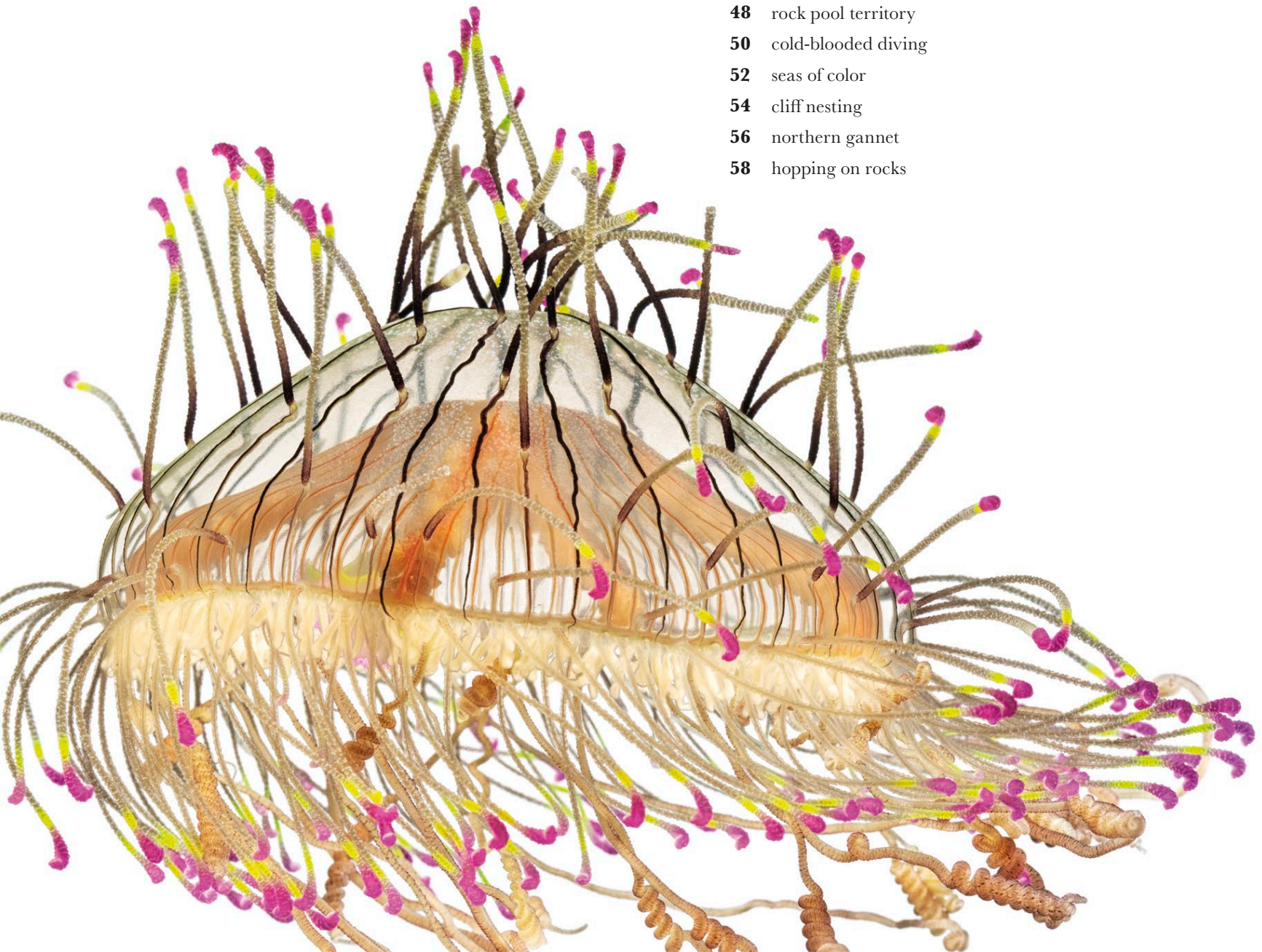
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foreword

We manifest an intrinsic fascination with those things on the brink of our knowledge. There's a romance, a yearning, seemingly a need to wonder about things beyond our reach. Deep space, other planets, aliens... but, as is often cited, we may actually know more about these phenomena than about the inhabitants of our own oceans because 80 percent of them are unmapped, unobserved, and unexplored for the so very simple reason that this environment is beyond your reach and mine. We are terrestrial, air-breathing mammals, and while some humans swim well, free dive, or use increasingly sophisticated scuba kit or robots to explore the oceanic unknown, the rest of us "land lubbers" just watch the waves.

Beneath those waves is another world—one that, thanks to science and technology, we are learning a lot more about, a lot more quickly. And, as this fabulous book shows, it is almost incomprehensibly beautiful and fantastic. From the smallest to the largest, the shallows to the deep, the fierce to the fearful, these organisms share our planet but live in a different dimension. How exciting!

So here is an opportunity to meet the neighbors, the "wet ones," the extraordinary diversity of miraculous life that has evolved in the oceans. And yet, remote as it can seem, the cultural aspects of our relationship with the sea reveal how we have always had a close connection to this charismatic, dangerous, and rewarding realm. But the tides have turned. Now we are the greater danger, and no drop of our seas is secure. Coral reefs are bleached. Plastic litters the greatest depths and fills the bellies of turtles and whales and chokes albatross chicks. The acidification of the water, pollution, and overfishing threaten the entire ocean ecosystem. There has never been a more important time to immerse ourselves in the wonder of the briny world and thus learn to love and protect it. Dive in, swim among stranger things, and then stand up for our oceans.

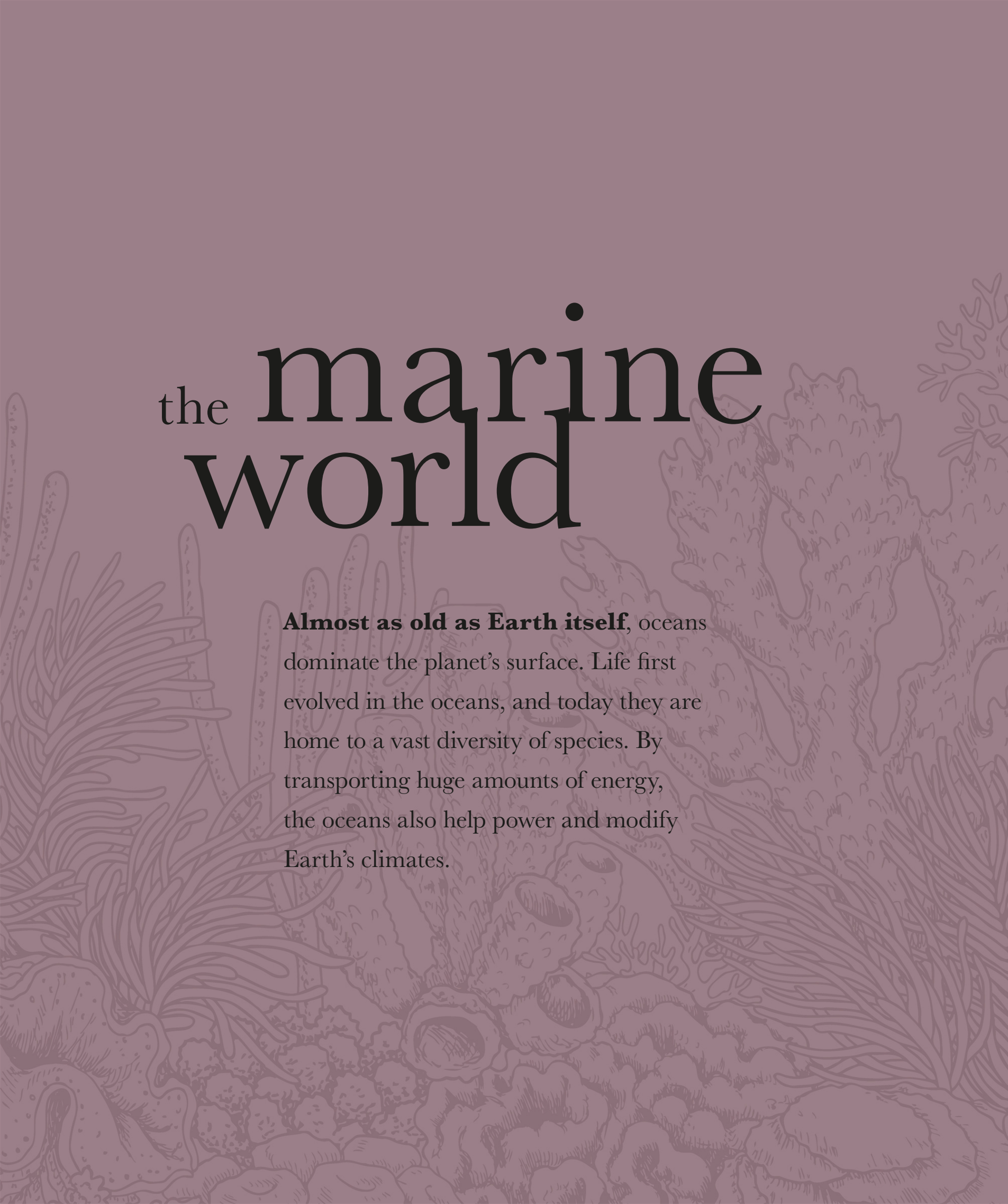
CHRIS PACKHAM

NATURALIST, BROADCASTER,
AUTHOR, AND PHOTOGRAPHER





SILKY, DUSKY, BLACK-TIP, AND GALAPAGOS SHARKS FEED WITH YELLOWFIN TUNA AND RAINBOW RUNNERS ON A SHOAL OF SCAD

A detailed line drawing of a coral reef ecosystem, featuring various types of coral, sea anemones, and fish, rendered in a light purple tone that serves as a background for the text.

the marine world

Almost as old as Earth itself, oceans dominate the planet's surface. Life first evolved in the oceans, and today they are home to a vast diversity of species. By transporting huge amounts of energy, the oceans also help power and modify Earth's climates.

what are oceans?

Earth is a watery world, with 68 percent of the surface covered by saltwater oceans. Each of the five major ocean basins (the Arctic, Atlantic, Indian, Pacific, and Southern) is a deep depression in Earth's surface. Connected to the oceans, and typically partly enclosed by land, are numerous smaller seas such as the Mediterranean and Bering Seas. The oceans are partially separated by landmasses but are all interconnected.



The second largest **ocean basin**, the Atlantic spans around 20 percent of Earth's surface

Oceans from space

Composite satellite images from space show clearly how oceans predominate over land. This view of Earth's Western Hemisphere shows the Atlantic Ocean.

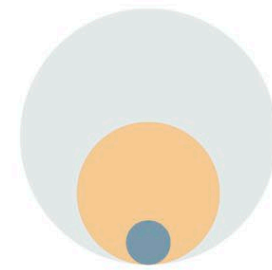
Ocean strength

The oceans reveal their strength in the waves that crash onto shorelines around the world. Heading toward a shallow reef, this mountain-shaped wave off the south coast of New South Wales, Australia, will break as its base touches the seabed and frictional drag slows it down.



EARTH'S PROPORTIONS

Oceans are immense, holding most of the water on Earth and having an average depth of about 12,000 ft (3,700 m) and a total volume of 321 million cubic miles (1.34 billion cubic km). Around 2 percent of Earth's water is locked up as snow and ice, leaving 1 percent as free-moving fresh water. The largest ocean is the Pacific, spanning 59 million square miles (153 million square km) and containing 49 percent of Earth's salt water.



KEY

- Salt water (68%)
- Land (29%)
- Fresh water (3%)



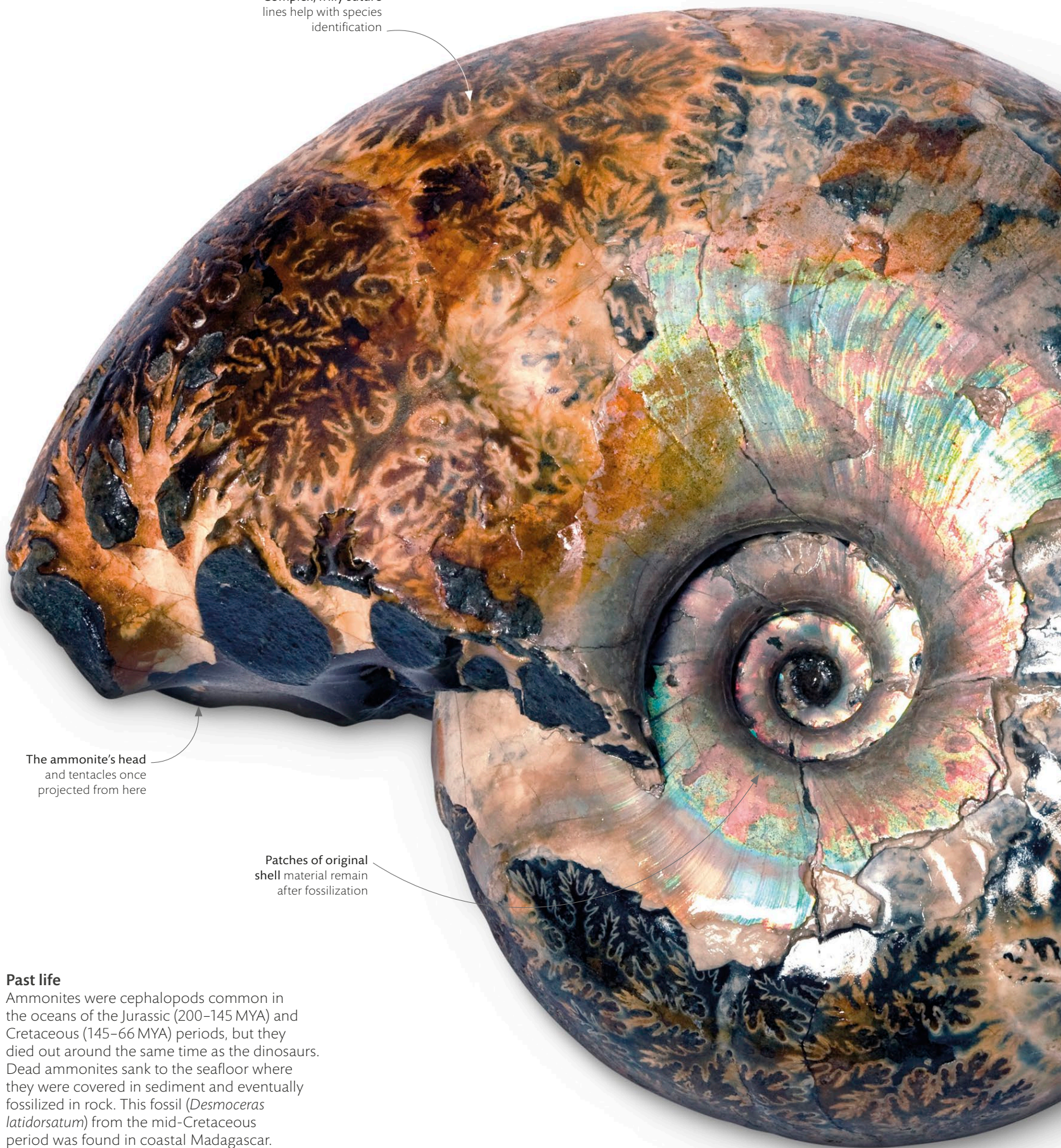
Complex, frilly suture lines help with species identification

The ammonite's head and tentacles once projected from here

Patches of original shell material remain after fossilization

Past life

Ammonites were cephalopods common in the oceans of the Jurassic (200–145 MYA) and Cretaceous (145–66 MYA) periods, but they died out around the same time as the dinosaurs. Dead ammonites sank to the seafloor where they were covered in sediment and eventually fossilized in rock. This fossil (*Desmoceras latidorsatum*) from the mid-Cretaceous period was found in coastal Madagascar.





Coral fossil

Evidence that chilly Scotland was once part of a landmass near the equator comes from warmth-loving fossil corals found there and dating to around 350 million years ago.

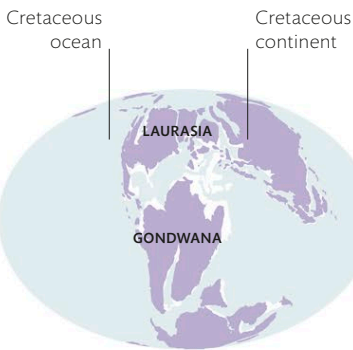


ocean history

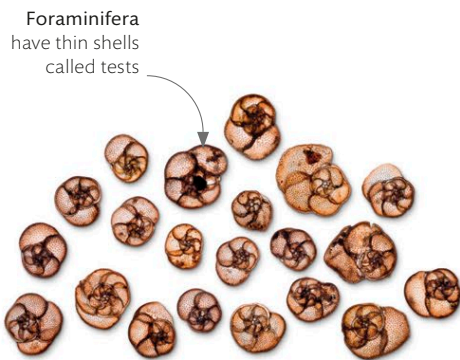
The familiar layout of Earth’s continents and oceans is very different from the way it was in the prehistoric past. Today’s oceans and their seas arose gradually as early landmasses split up and moved apart. Scientific evidence suggests that the original ocean formed from water vapor that escaped from the molten surface of the planet. Around 3.8 billion years ago, conditions cooled and this vapor started to condense and fall as rain.

OCEANS OF THE PAST

Continents have come together and moved apart several times in Earth’s history. Evidence for this comes from the “jigsaw” fit of continents such as South America and Africa, as well as palaeontology studies. Continents slowly change their positions through volcanic processes happening deep beneath the oceans. Today, the Atlantic Ocean is getting bigger and the Pacific Ocean and Red Sea are getting smaller, but by less than 3/4 in (2 cm) per year.



CRETACEOUS PERIOD C.130 MYA



Ocean thermometers

Analyzing the chemical composition of sand-grain-sized fossil shells of microorganisms called foraminifera can help determine past sea-surface temperatures. Living foraminifera such as *Rosalina globularis*, above, are still found throughout the oceans.

Stormy seas

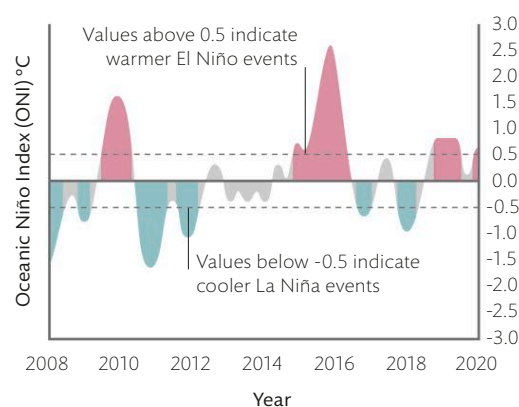
Oceans, atmosphere, and land all interact to create our climate and weather. Dramatic supercell thunderstorms over land or sea—here, above Australia's Queensland coast—occur when wind conditions cause strong rotating updrafts. The frequency and intensity of extreme weather events is increasingly linked to human-instigated climate change.

ocean climates

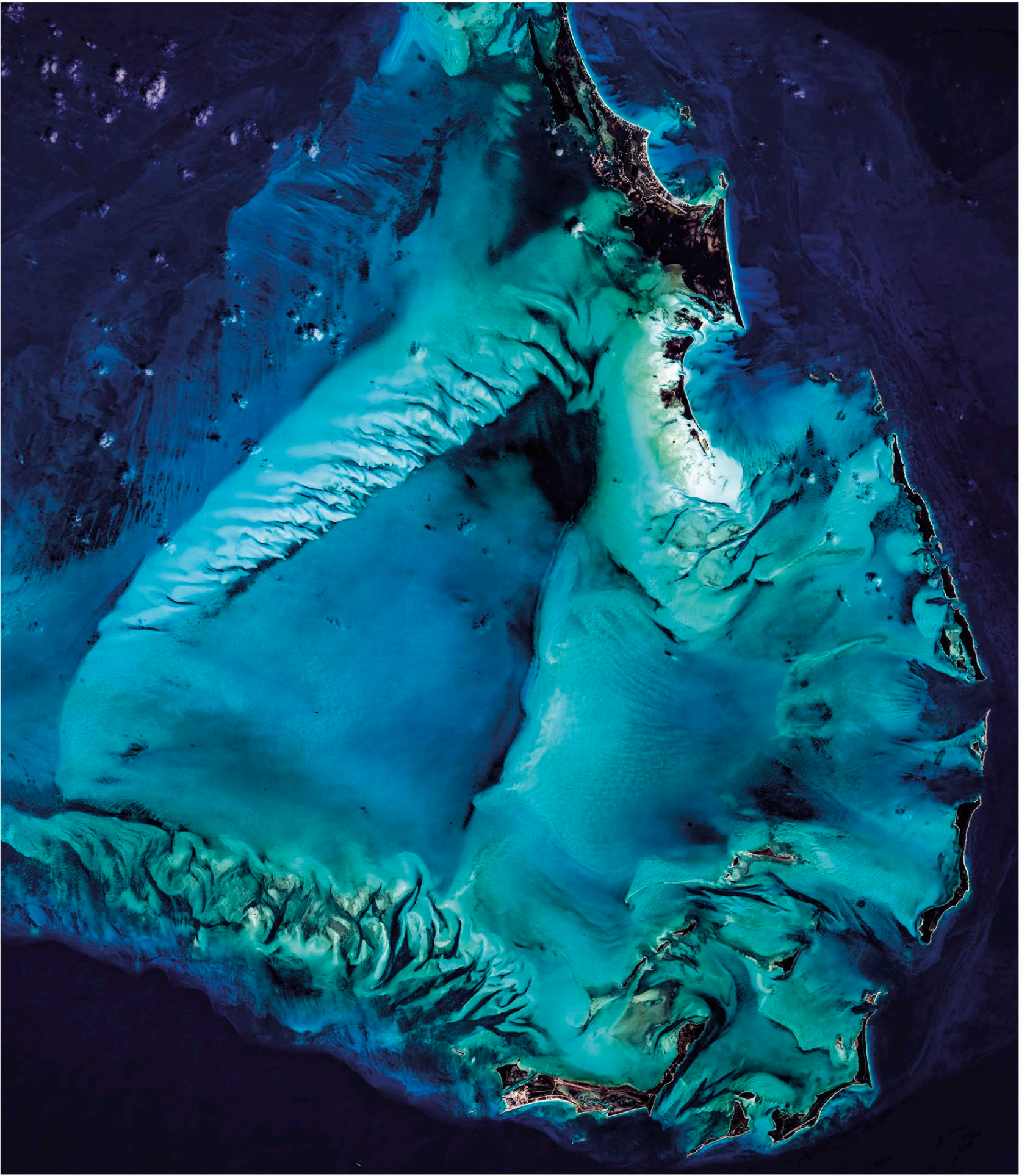
The world's oceans and their climates are inextricably linked through a complex web of interactions. The oceans absorb and store heat from the Sun, especially at the equator. From here, wind-driven surface ocean currents circulate water around each of the main ocean basins. In turn, the Sun's heat and Earth's rotation set the pattern of prevailing winds. Rainfall is highest in tropical areas, because the oceans are warmest here, so evaporation is high. The oceans slowly release heat, which is why the oceanic climate found around continental coastlines is less extreme than the climate far inland.

CLIMATIC DISTURBANCES

Increased carbon dioxide in the atmosphere traps heat and causes ocean temperatures to rise as it absorbs extra heat. This can also lead to more extreme instances of the climatic disturbances known as El Niño and La Niña. The El Niño effect occurs where winds and currents in the equatorial Pacific are disrupted, leading to above-average sea-surface temperatures. The ONI records the difference between recent averages and the 30-year average temperature.







ocean depths

Marine organisms inhabit a vast, three-dimensional space and can be found from the water surface down to the deepest depths. An organism near the surface will experience very different conditions from one in the deep ocean. Scientists divide the oceans into zones of decreasing sunlight and temperature, but pressure increases continuously from the surface to the deep. Surface layers are well-lit and have a good supply of nutrients and food. In deep zones, the sunlight fades and temperatures decrease, which limits life there.

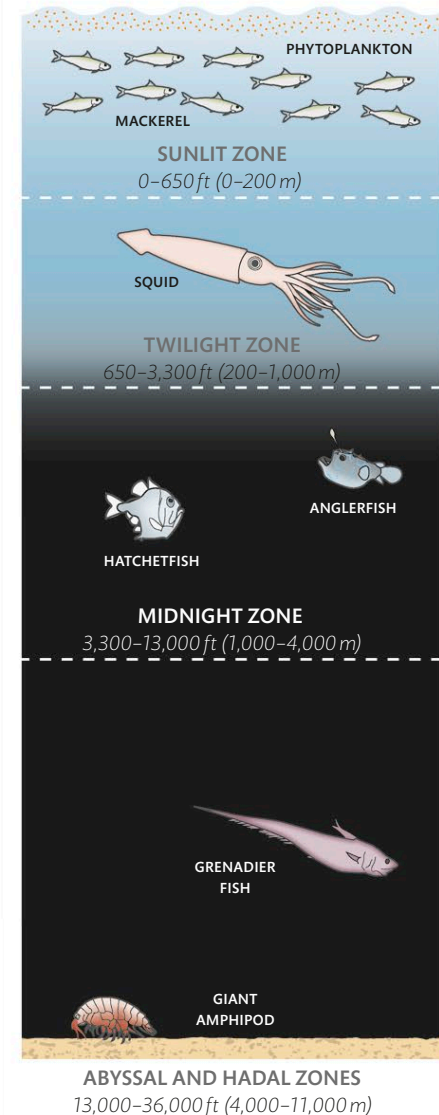
Deep ocean and sandy shallows

In the Bahamas, the Berry Islands form a semi-circle enclosing sheltered, sandy plateaus. This satellite image shows depth contours beneath the clear water. Deep ocean borders the land at the top, while Chub Cay at the bottom drops into the tongue of an ocean canyon.



DEPTH ZONES

Marine life has adapted to the different ocean depths. Phytoplankton, the basis of almost all ocean food webs, only grow in the sunlit zone. In the twilight zone, where light is limited, animals swim upward at night to feed on plankton and then down for safety in the day. In the dark midnight zone, animals produce bioluminescent light to hunt or communicate, while abyssal animals gather dead material or particles that drift down from above. Deep ocean trenches form the dark hadal zone.



Cold-water coral

Most corals live in shallow waters, but cold-water corals, such as *Lophelia pertusa*, form reefs in twilight and midnight zones. Without the nutrients provided by surface-level symbiotic algae, these corals grow very slowly.

rocky coasts

A rocky coast provides a solid, dependable foundation for many plants and animals.

Although there is often a risk of being swept away, a tidal pool or high-rise cliff can also provide a refuge.





The branching straps of *Ramalina* form scattered clumps on the rocks

Tufted lichen

Gray *Ramalina siliquosa* and some other lichens grow as upright tufts. *Ramalina* usually lives at a higher level than yellow *Xanthoria* (see right) on European shores.

Maritime lichen

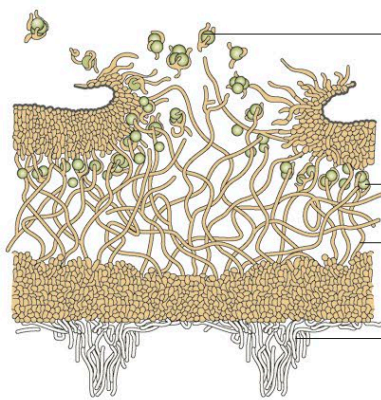
The sunburst lichen (*Xanthoria parietina*) of northwest Europe is typically found inland, but it can also tolerate the salty habitat of rocky shorelines. Its flat orange body, or thallus, may occasionally even be covered by the highest spring tides.

surviving in the splash zone

Little life can thrive on wave-splashed rocks, which are too far from the reach of the tide for underwater organisms to survive and too hard for plants to root. But lichens have the resilience to grow here. In fact, they are so successful that in places they grow in prominent, colorful patches along the coastline. Key to their success is an intimate partnership: each kind of lichen consists of a nutrient-absorbing fungus that clings firmly to the rock and a pigmented alga that photosynthesizes to make food.

INTIMATE PARTNERSHIP

The bulk of a lichen consists of the filaments of a fungus. Called hyphae, these filaments attach to the hard substrate and, as in other fungi, provide a large surface area for absorbing nutrients from organic food such as detritus and bird droppings. But more than 50 percent of the lichen's food is made from atmospheric carbon dioxide by its photosynthetic algae, which share the food they produce with the fungus.



SECTION THROUGH A LEAFY LICHEN

Algae and hyphae filaments disperse on wind to establish new lichen colonies

Algal cells

Fungal hyphae

Rootlike hyphae called rhizines attach the lichen to the rock







The photosynthetic frond produces sugars, including mannitol, which is often exuded as a sweet powder on the frond's surface, thus inspiring this species' name

Giant seaweed

Sugar kelp (*Saccharina latissima*) of the northeast Atlantic grows particularly well when sheltered from extreme waves. Here, on the lower shore, its fronds can reach 13 ft (4 m) in length, which helps them extend farther upward to catch sunlight when lifted by the high tide.

The stipe, or stem, keeps the frond raised toward the light at high tide for photosynthesis

In the core of the stipe, filaments of conduction cells help transport sugars around the kelp; seaweeds lack the transport vessels of true plants

The holdfast, unlike the roots of true plants, does not take up any nutrients, leaving the frond to absorb most of the material needed for photosynthesis



A crinkly edge to the frond is a characteristic of the sugar kelp

Holdfast communities

Branching holdfasts can provide a microhabitat for diverse marine invertebrates. Among the holdfasts of kelp growing on California's Pacific coast live scavenging brittle stars and purple urchins that graze on the seaweed.



Brittle stars cling to the holdfast with their sinuous arms

Purple urchins are the dominant grazers of California kelp

anchoring to the seabed

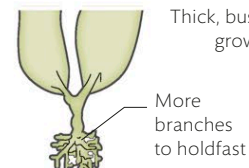
Hard, rocky coastlines are impossible habitats for true plants to send down roots, but here—between the tides—conditions are perfect for the leafy algae popularly known as seaweeds. Instead of roots that penetrate, seaweeds have structures called holdfasts that cling to the substrate. Some holdfasts are like suckers, but others grow dense thickets of tendrils that anchor the seaweed to the seabed and shelter tiny invertebrates, while the alga's long, trailing fronds absorb light for photosynthesis.

HOLDFASTS

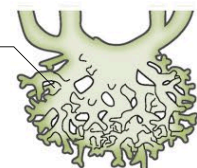
A young seaweed develops into a frond, stipe (stem), and holdfast. The holdfast consists of branching, fingerlike projections called haptera, which envelop rocks and stones and become bushier in deeper water. It secretes mucopolysaccharide—a natural adhesive—as it grows larger to support a bigger frond.



SHALLOWS

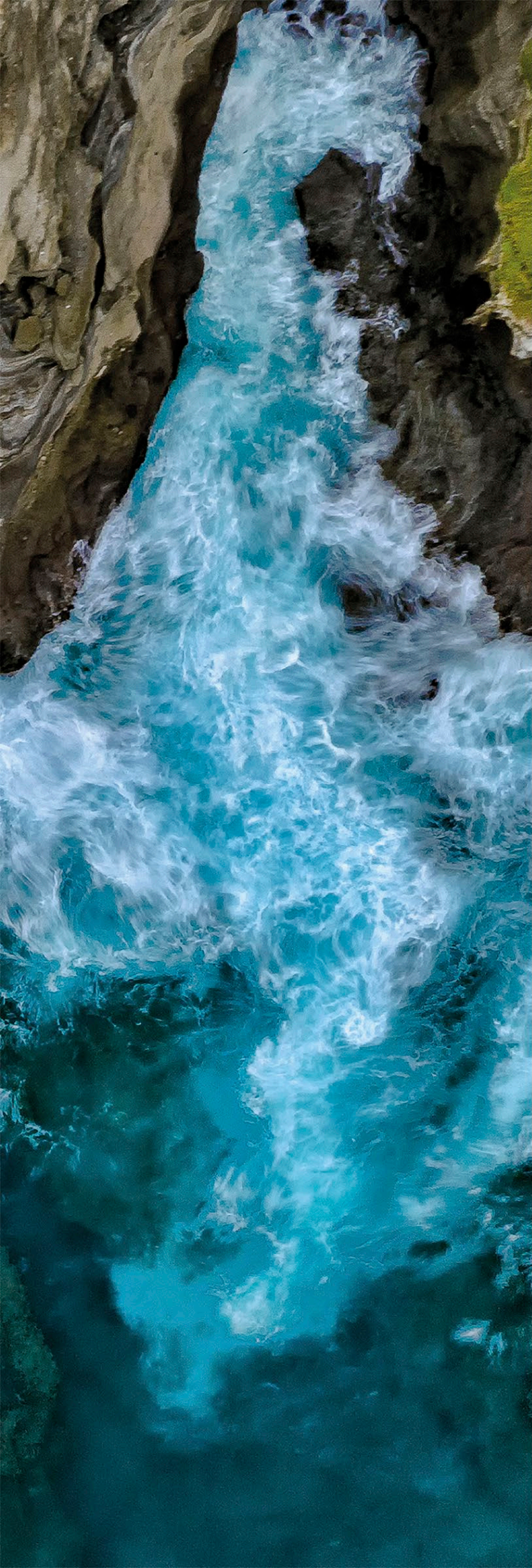


MID-DEPTHS



DEEP WATER





Worn away by waves

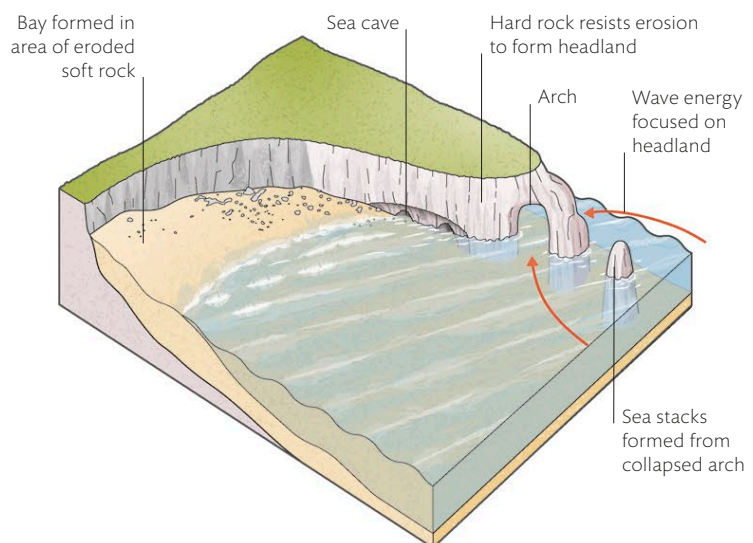
Over millennia, the forceful churning action of waves crashing against this coastline on the Hawaiian island of O'ahu has unevenly worn away the rock to create a network of inlets and promontories.

coastal erosion

The coastlines of every continent undergo constant change. In some areas, the land area expands, but in others, the coastline is worn away by erosion. Coastal erosion is determined by three main interacting factors: marine energy (waves, storms, and tides); the relative hardness of the rock; and tectonic activity (earthquakes and uplift). The rate of coastal retreat can be more than 330 ft (100 m) per century in areas where severe storms pound a soft sand-and-clay shoreline. Hard granite cliffs may remain stable for hundreds of years. Landslides, rockfalls, chemical attack, wave impact, and relentless abrasion by sand and gravel all help break down rocks and boulders along the shore. Storms, tidal currents, and rip currents carry the sediment out to sea.

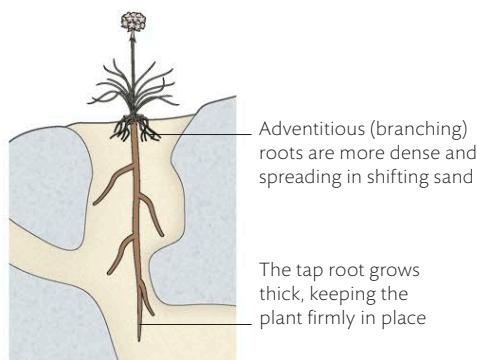
HEADLANDS, ARCHES, AND SEA STACKS

Soft rock on a coastline is worn back by wave action into bays, while harder rocks provide more resistance and form headlands, which are subject on three sides to focused wave action. Eventually, this creates notches and sea caves at the waterline. The caves enlarge from either side of a headland, and the sea eventually breaks through to form arches, which later collapse, leaving isolated sea stacks.



TAP ROOTS

Sea thrift has a woody tap root that can reach more than 5 ft (1.5 m) into coastal sediment, often winding between rocks or plunging into cliff faces. The tap root typically grows vertically downward and helps anchor the plant firmly onto a shoreline that may be buffeted by strong winds.



ROOT SYSTEM

Tough plant

Sea thrift (*Armeria maritima*) thrives on windswept coasts around the Northern Hemisphere. By hugging close to the ground, its leaves are able to resist the elements, while its salt-tolerant tissues help the plant grow in soil that may get occasionally inundated by extreme tides.

growing above the tides

On the very edge of the ocean world, beyond the reach of normal tides, is a community of coastal species that belong to the land but live exposed to the sea's spray. Salt and wind are dehydrating: salt landing on foliage draws water from tissues by osmosis, while wind increases evaporation. The flowering plants that survive here must be adapted to resist these effects. Some, such as sea thrift, have thin, straplike leaves with a small surface area that reduces evaporation and a thick cuticle that traps water inside.

A butterfly feeding on nectar helps cross-pollinate sea thrift; even the pollen of this plant is salt-tolerant



Coastal pollinator

There are few marine insects, but some land species, such as this black-veined white butterfly (*Aporia crataegi*), are drawn to the nectar of coastal blooms, such as sea thrift. Other insects feed along the strand line of the beach.



TRIFT, ARMERIA VULGARIS WILLD.

Retracted tentacles reduce the animal's surface area, so there is less evaporation when it is uncovered by the retreating sea

Dealing with exposure

By pulling its tentacles into its body column, a beadlet anemone not only avoids predators but also retains more water while exposed to the air at low tide.



Body column contains muscle fibers that contract to pull the tentacles inside

surviving low tide

The intertidal zone is the place where the ocean meets the land, but the living things that make it their permanent home come from the sea. Most of these organisms need to be underwater to breathe, feed, and reproduce. At low tide, those that can walk, such as crabs, can follow the water or shelter under rocks. Others that are fixed to the spot, including anemones, have no option but to wait for the waters to return.

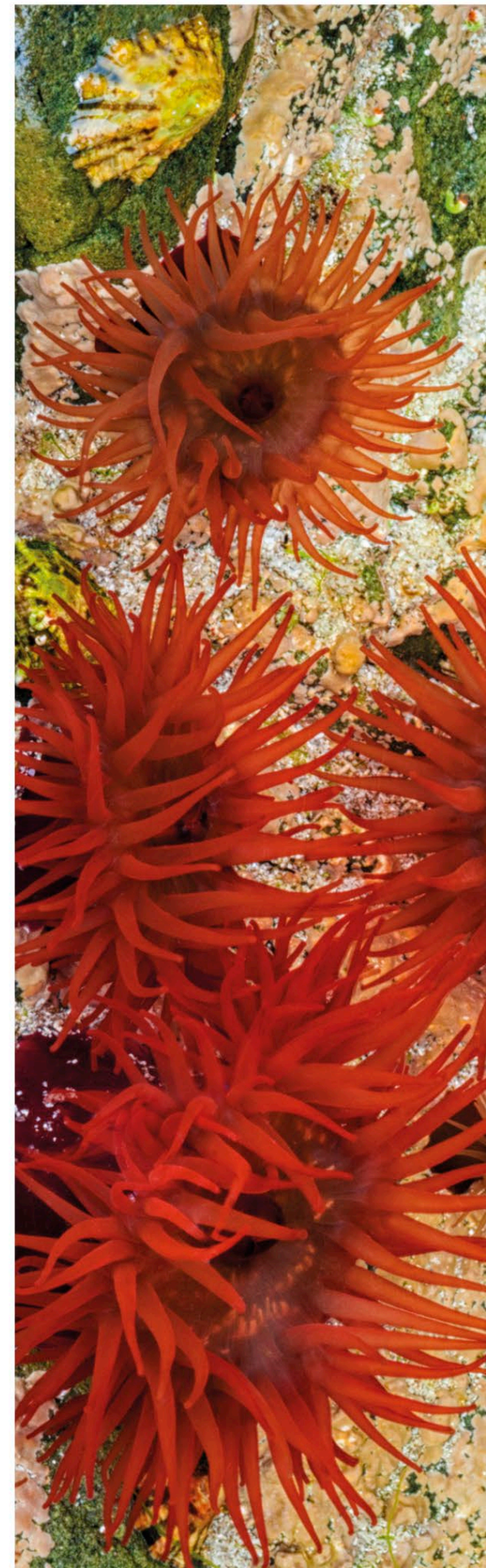
Tidal pool

A pool on a rocky shore left by the ebbing tide is a safe haven for beadlet anemones (*Actinia equina*). Here, ocean animals can stay active, even when the surrounding rocks are left high and dry.

INTERTIDAL ADAPTATIONS

These shore anemones illustrated in Ernst Haeckel's *Kunstformen der Natur* (1904) have variable intertidal adaptations. The daisy anemone (*Cereus pedunculatus*; top middle) lives partly buried and retracts completely when disturbed or exposed. Less-retractile species rely on a sheltered location to survive. The jewel anemone (*Corynactis viridis*; bottom left), drawn here with drooping tentacles, prefers rocky caves, while the plumose anemone (*Metridium senile*; bottom right), with featherlike tentacles, hangs limp from rocky overhangs at low tide. Such vulnerable species are more abundant where they are permanently submerged.

HAECKEL'S SEASHORE ANEMONES

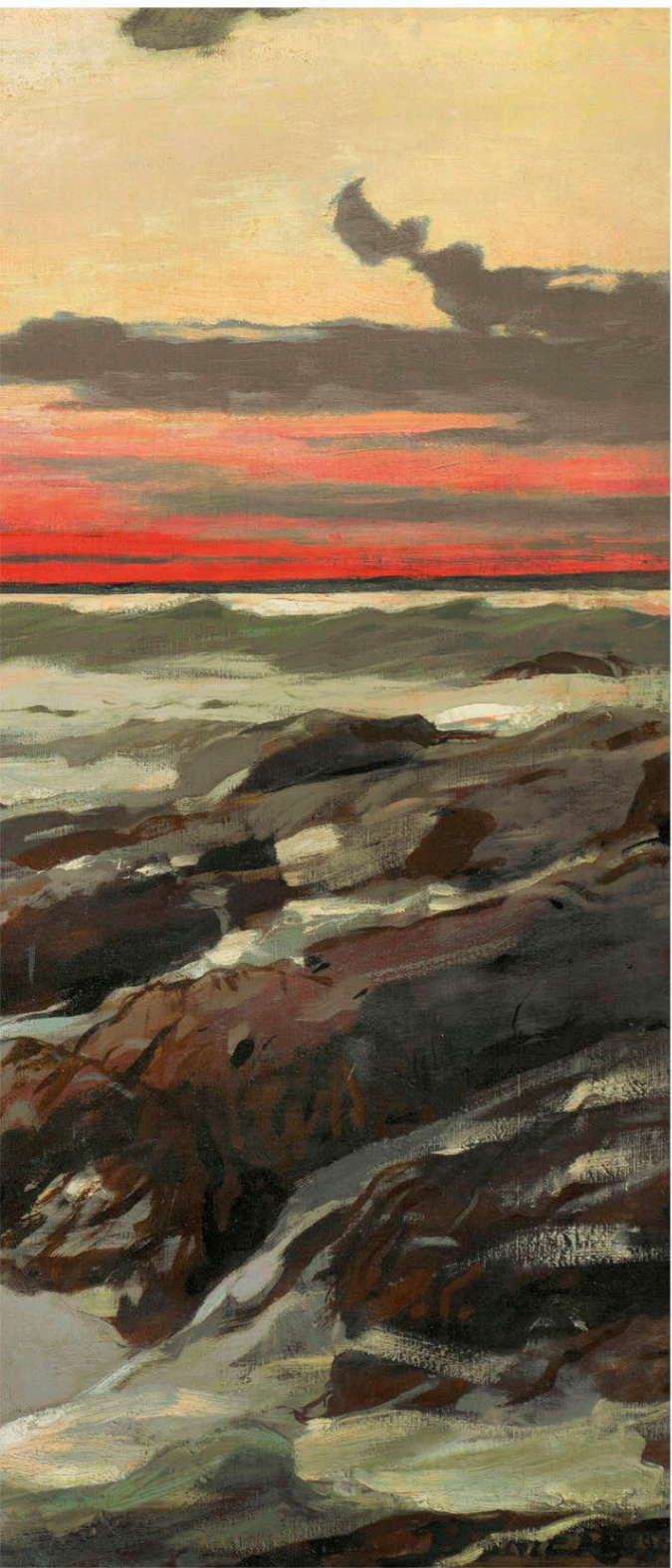






West Point, Prouts Neck (1905)

US artist Winslow Homer painted his favorite watercolor just after sunset, capturing a column of seaspray leaping above the rocks. It followed several days of intense observation of the light and tides across Saco Bay, close to the artist's studio in Maine. The vivid reds and pinks drenching the sky and sea and the bold composition show leanings toward Expressionism.



The Life Boat (1881)

In the 1880s, Winslow Homer's art focused mainly on the struggle of fishing communities against the sea. This atmospheric pencil and wash study, which was the basis for a larger watercolor, depicts men in oilskins forging toward a ship in danger.



the ocean in art

from coast to coast

In the second half of the 19th century, the US was a young country in search of an art culture that would reflect back the glory of a new nation. Artists sought to introduce audiences in the eastern states to the awe-inspiring mountains, plains, and seascapes to the west. The patriotic spirit captured in their work was reinforced by songs such as *America the Beautiful*, which celebrated a land that stretched “from sea to shining sea.”

While Impressionist artists in Europe were rebelling against classical art forms, these were still preferred by many contemporaries in the US. The sublime landscapes of English-born American artist Thomas Cole, founder of the Hudson River School, an art movement that flourished in the mid-19th century, drew on Romanticism, as well as realist and naturalist styles. The German-American painter Albert Bierstadt's grandiose peaks and plains, sketched during an expedition in the American West, were romantic constructs that sold idealized notions of the American Frontier to new settlers. He

also traveled to the West Coast, where he painted rugged rocks and crashing waves. Meanwhile, in the east, Fitz Henry Lane painted the coastlines of Maine and Massachusetts in Luminist style—a form of realist landscape painting characterized by precise brushwork and ethereal light.

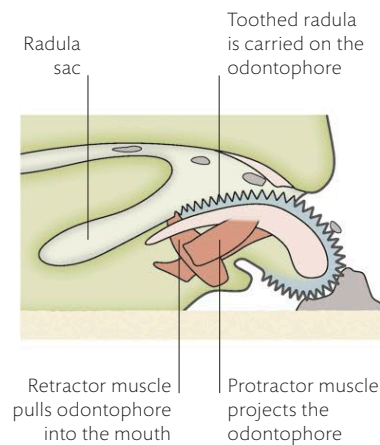
Arguably, the preeminent American marine artist in the 19th century was Winslow Homer, known mainly for his oil paintings and watercolors. His early works depicted scenes of contemporary life in the US, but his art gained new depth after he spent 18 months on the British Tyne and Wear coast, where he painted the daily lives and hardships of local fishermen and women. He later retreated to a remote cottage and studio in Prouts Neck, on the East Coast in Maine, where he created magnificent seascapes that captured the energy and raw beauty of the ocean. Although he traveled and painted the iridescent seas off Bermuda and Florida, he always returned to Prouts Neck, where the ocean continued to provide a source of inspiration until his death in 1910.

“When you paint, try to put down exactly what you see. Whatever else you have to offer will come out anyway.”

WINSLOW HOMER, TO ARTIST FRIEND WALLACE GILCHRIST, c.1900

THE MOLLUSKAN RADULA

A snail's "tongue"—correctly termed an odontophore—moves in and out of the mouth. In doing so, it rubs the radula over the substrate. The radula is covered with tiny teeth made from hard chitin (the same material found in invertebrate exoskeletons). As the teeth get worn down, the radula is regenerated, growing from a sac at the base of the odontophore.



RADULA STRUCTURE



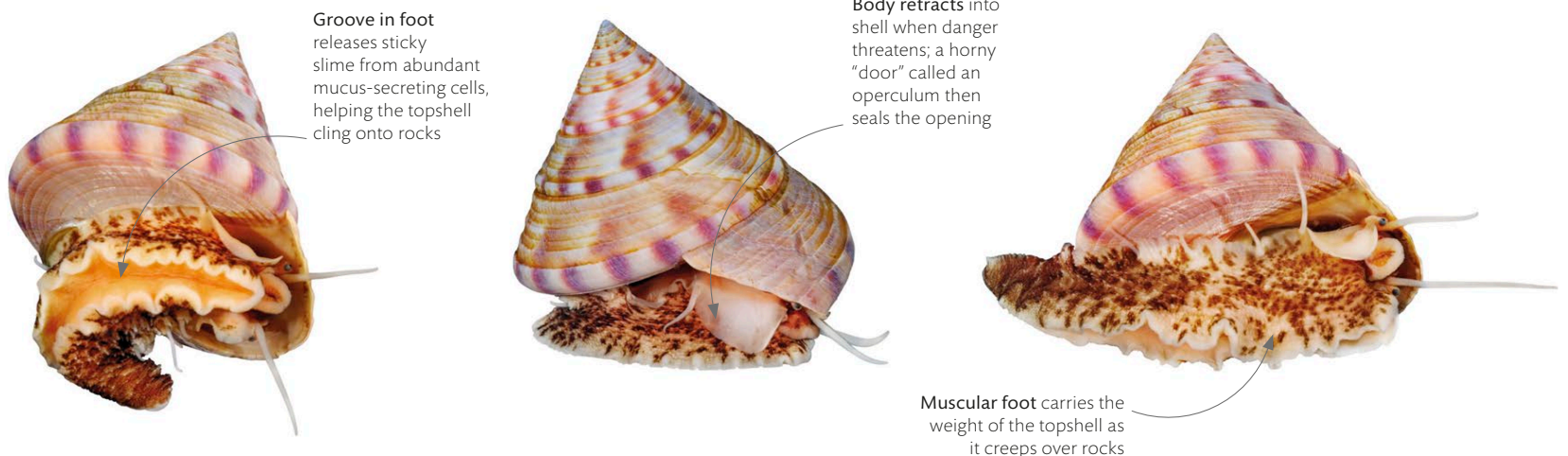
Visible scratches are left because the limpet's radula is harder than the surface rock

Abrading limpet

To dislodge the toughest algae, the radula of a limpet (*Patella vulgata*) has teeth reinforced with an iron compound. The material of these teeth is the hardest produced by any animal.

rasping rocks

Sea-covered rocks are coated in a film of microorganisms, algae, and organic detritus, providing a source of food for many grazing animals. Dominant among them are mollusks, including a huge variety of herbivorous snails and limpets that rasp the surface as they crawl from place to place. Key to their success is their grazing equipment: a muscular "tongue" that scrapes the rocks with an abrasive ribbon called a radula, dislodging the nutritious material, which is then swallowed.



Sweeping snail

The painted topshell (*Calliostoma zizyphinum*) is a subtidal grazer of rock-dwelling microorganisms, found at depths of up to 1,000 ft (300 m). As in most topshell species, its radula works like a fine brush to sweep loosely bound food particles from rocks; unlike that of a limpet, it lacks the resilience to harvest algae that adhere more tightly.

The shell stays looking bright and unworn—perhaps the result of the topshell sweeping its mucus-coated foot over the shell's surface, which deters algal growth

Spots and bands of purple and crimson pigments, called porphyrins, pattern the shell; the pigments may be derived from the topshell's diet

Tentacle contains tactile and chemical sensors to help with navigation while grazing on rocks

Small, cup-shaped eye on a short stalk senses light and dark; the eyes help the animal stay in the shade and avoid being exposed to predators by sunlight when grazing







Attached by a thread

California mussels (*Mytilus californianus*) lack the limpet's clinging foot. Instead, they tether themselves to rocks with a bundle of protein fibers known as a byssus.



Fibers adhere to rock with a kind of protein glue (a different protein to that forming the fibers)

clinging on

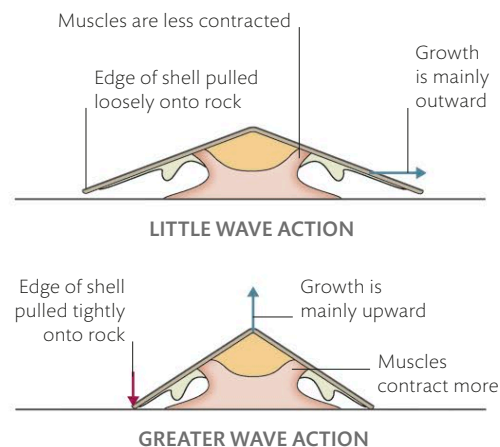
Organisms that live on rocky shores exposed to battering waves are constantly at risk of being washed away. Those that lack the agility to dodge the breakers and find shelter in crevices must do what limpets do—cling on tightly. Limpets are well equipped to survive the worst of the ocean's fury: they have a cone-shaped shell that clamps down firmly, a muscular foot that works like a suction cup, and sticky mucus that acts like glue.

Intertidal life

Common limpets (*Patella vulgata*) of northwest Europe—seen here sharing their rocky habitat with smaller periwinkles and barnacles—hold fast at low tide during the day. They emerge from their shells only when submerged, or at night, to graze on algae.

WAVES AND SHELL SHAPE

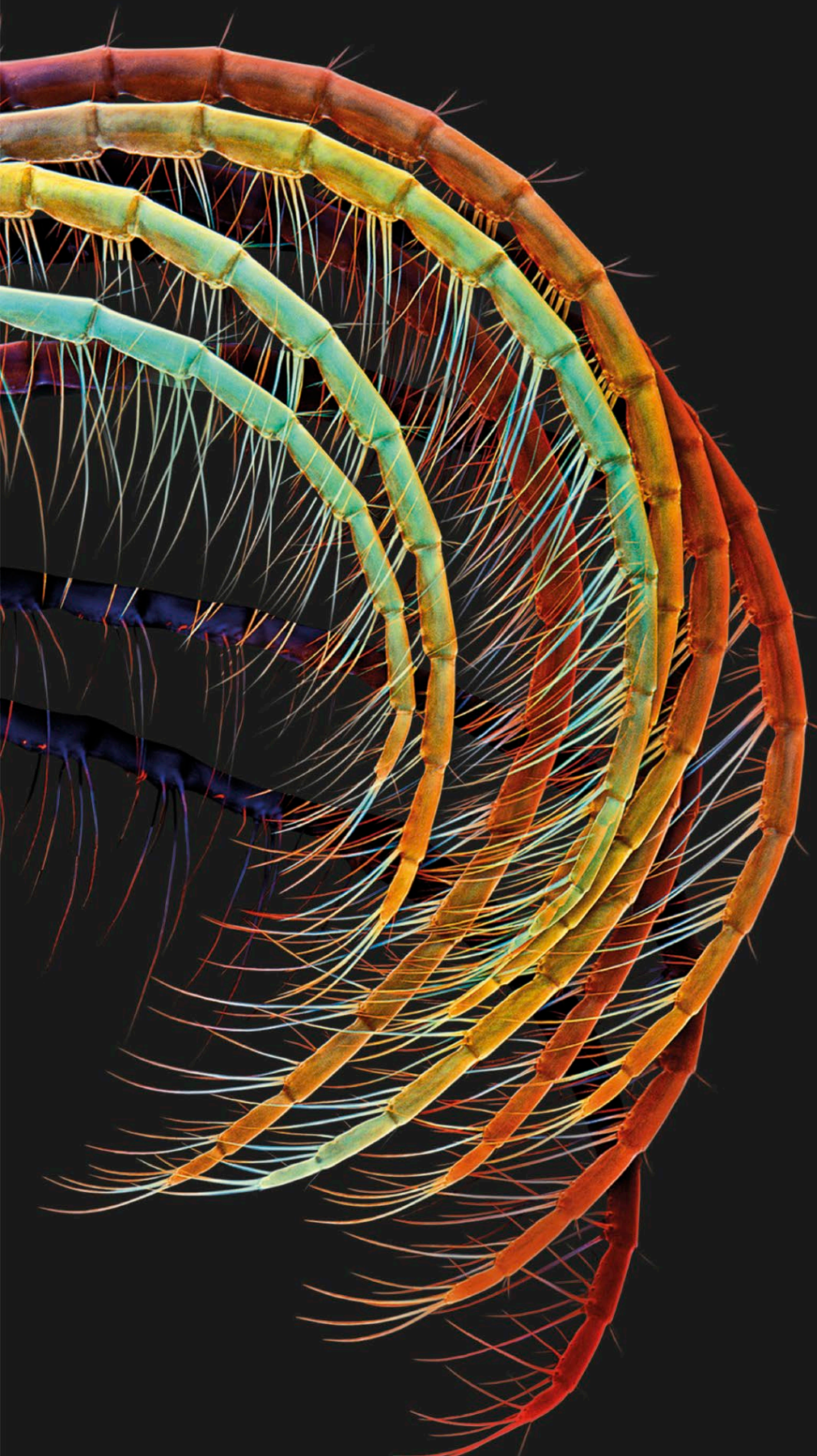
A limpet clamps down by contracting muscles that pull the shell toward the rock, reducing pressure under the foot so that it functions as a sucker. The foot also secretes sticky mucus that helps seal the attachment. Where there is little wave action, limpets grow flatter shells. Stronger waves cause the limpet's muscles to contract more in order to take the extra strain. This affects the shell-secreting tissues, producing a taller and more conical shell shape.



combing for plankton

Acorn barnacles can be so abundant on a rocky shore that their small, volcano-shaped shells form a distinct white band. Each “volcano” opens at high tide so that the feathery limbs of the crustacean inside can reach up into the water. By quickly waving back and forth in a combing motion—or simply letting the backwash run through their “feathers”—the limbs catch nutritious detritus, algae, and the tiniest animals of the zooplankton.





ZONES ON SHORELINES

Barnacles more tolerant of dehydration can live farther up the shore, where low tide exposes them for long periods. In Europe, for example, *Chthamalus montagui* can survive above *Semibalanus balanoides*, but it cannot thrive lower down due to competition from *S. balanoides* for space to feed. Similar barnacle zonation occurs around the world.

HIGH TIDE

Smaller *Chthamalus montagui* predominate on upper shore

Larger *Semibalanus balanoides* predominate on middle shore

Predation and competition from other animals prevents barnacles colonizing lower shore

LOW TIDE

Casting the net

Magnified many times, the thoracic limbs, or cirri, of a gray acorn barnacle (*Chthamalus fragilis*), from eastern North America, are seen to carry long hairs, called setae. The setae overlap to create a trap that catches particles as small as two-thousandths of a millimeter in size.

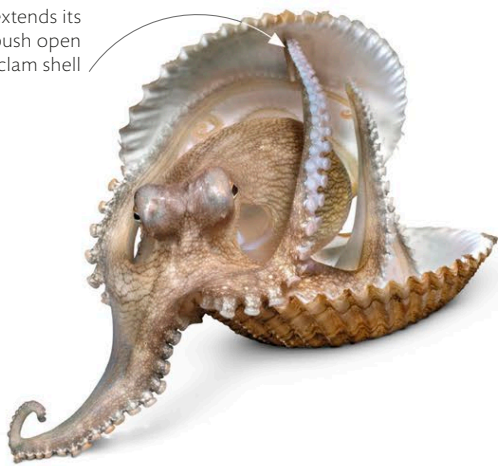
A diamond-shaped aperture, here closed at low tide, is characteristic of the northern acorn barnacle (*Semibalanus balanoides*) of Europe and North America



Exposed and closed

Barnacles cannot feed at low tide, so they withdraw their limbs, then close their shells using movable plates that seal the entrance. Like this, they are protected from desiccation until the tide returns and they become active again.

Octopus extends its arms to push open the clam shell



Flexible arms coil around the body so the octopus can fit into the shell

Suckers grip the shell as the arms pull it closed



Octopus in a shell

Hermit crabs are not the only animals to use shells for protection. Along tropical shores, the coconut octopus (*Amphioctopus marginatus*) sets up home in a variety of objects, including coconut shells and, as here, the hinged shells of clams.

lodging in a shell

Only the top of a hermit crab's head is shielded by a hard carapace; the rear half of its body is soft and vulnerable. For this reason, hermit crabs spend their lives lodged for protection inside a coiled snail's shell. They use their strong limbs to drag this mobile sanctuary with them wherever they go. When a crab grows too big for its shell, it seeks an upgrade—carefully testing the new shell's size and weight before making the switch.

The crab's borrowed shell is often colonized by other animals; this whelk shell is covered in snail fur (*Hydractinia echinata*), a kind of colonial hydrozoan



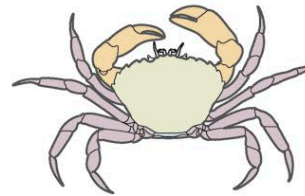
Two larger pairs of legs are used for walking; two smaller pairs, hidden from view, are used to grip the inside of the shell

CRAB ANATOMY COMPARED

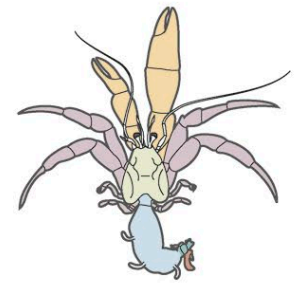
Most crabs have a short, flaplike abdomen that folds beneath the hard carapace of their body and is all but concealed. But in hermit crabs, the long, soft abdomen twists to one side, which enables it to fit more easily into a coiled snail shell. Tiny, hook-shaped structures called uropods at the abdomen's tip and small legs along its sides grip the inside of the shell to hold the crab in place.

KEY

- Carapace
- Abdomen
- Walking leg
- Claw/pincer
- Telson
- Uropod



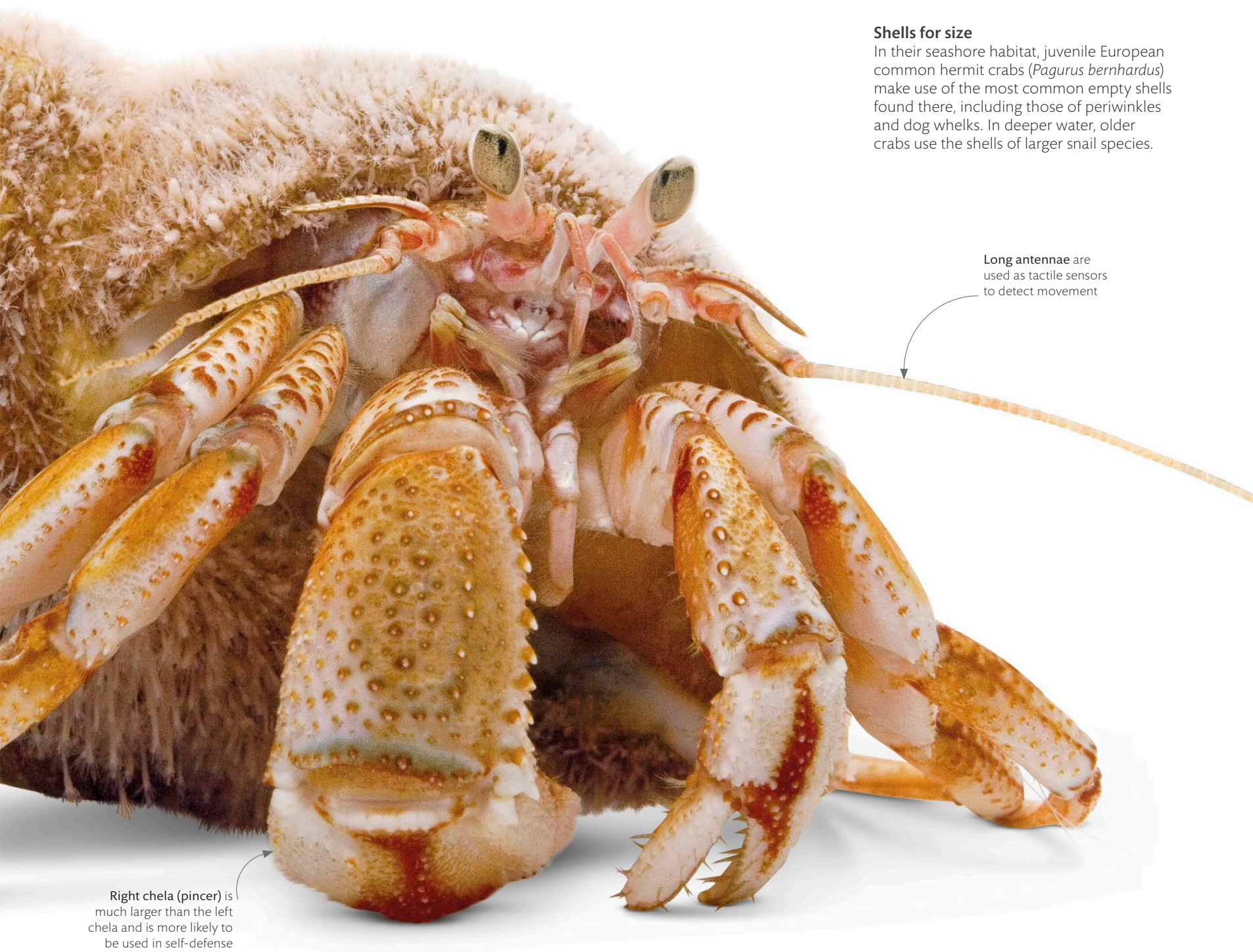
COMMON CRAB



HERMIT CRAB

Shells for size

In their seashore habitat, juvenile European common hermit crabs (*Pagurus bernhardus*) make use of the most common empty shells found there, including those of periwinkles and dog whelks. In deeper water, older crabs use the shells of larger snail species.



Long antennae are used as tactile sensors to detect movement

Right chela (pincer) is much larger than the left chela and is more likely to be used in self-defense





Breaking wave

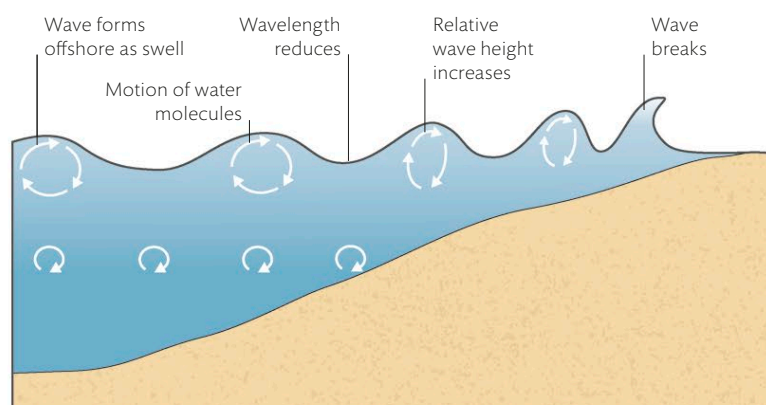
This image shows the moment when a wave formed in the open ocean approaches the shore and the rolling “tube” of water collapses to form a breaking wave.

waves

A wave is a disturbance in the surface of the sea produced by the transfer of energy from wind to water. Wind-generated waves range in size from a barely ruffled surface and snaking ripples to huge rogue waves reaching a height of up to 33 ft (10 m) that can snap in half a giant tanker. Major storm waves generated in the Southern Ocean around Antarctica can travel for nearly 2 weeks across the Pacific before breaking on the remote shores of Alaska. Their size is diminished, but their distinctive pattern remains the same as when first formed. The amount of energy stored in waves is enormous—a single storm wave can exert up to 4.3 pounds per square inch (3 tonnes per square m) as it breaks.

WAVE FORMATION

The three stages in wave development are known as sea, swell, and surf. The state of random choppiness building to larger irregular waves is known simply as sea. As these waves leave the region in which they were generated, wave interaction slowly develops a distinctive pattern of waves known as swell. Eventually, as a wave train enters shallow water, it interacts with the seafloor. The movement slows, and the distance between the waves reduces, resulting in a relative increase in wave height. Eventually, the ratio of wave height to wavelength reduces to the point where the wave topples forward and breaks as surf.



Flexible hunter

The small epaulette shark (*Hemiscyllium ocellatum*) has several adaptations that allow it to hunt in very shallow intertidal pools, where it targets worms, crabs, shrimp, and small fish. The shark is 28–35 in (70–90 cm) long, slender, and flexible, and thus able to maneuver easily in small spaces using its sturdy fins. Its flattened underside and blotchy coloration allow it to lie undetected until prey ventures within range.

Short snout, with electroreceptive barbels on the underside, is used to turn over small rocks or burrow in the sand as the shark searches for food

Blotchy upper side provides camouflage against highly textured reef surfaces

Small teeth are suited to grasping and crushing prey

Sturdy, paddle-shaped fins are used for both swimming and “walking”

THE WALKING SHARK

Epaulette sharks often venture into pools and channels too narrow or shallow for swimming and may find themselves completely stranded by the tide. In these circumstances, they are able to “walk,” or crawl, over rocks or sand using coordinated movements of the paired pectoral and pelvic fins.

Fins operate in coordinated diagonal pairs

Body flexes

CRAWLING MOTION

fish on land

The intertidal zone is a challenging habitat, with extreme fluctuations in temperature, salinity, and oxygen levels. But it also offers rich feeding opportunities and safety from large marine predators. Fish that live in these waters include the epaulette shark, which can last a few hours out of water, and mudskippers, which can spend up to 18 hours a day on land. To cope with oxygen-depleted waters at low tide, they shut down non-essential metabolic functions, reduce their heart rate and blood pressure, and prioritize the supply of oxygen to the brain.



Eyes can retract into water-filled skin folds to prevent them from drying out on land

Fish out of water

Found on mudflats, in estuaries, and in swamps, mudskippers (here, *Periophthalmus barbarus*) are the only fish to walk, eat, and court on land. They survive by carrying water in gill chambers.

Prominent shoulder markings (or "epaulettes") resemble huge eyes and may deter predators

Flexible spinal column allows movement in tight spaces

Flattened underside allows the shark to press itself to the seabed without casting a tell-tale shadow and provides stability on land



Tapering at head and tail permits fast open-water swimming



FUSIFORM
Atlantic cod
Gadus morhua



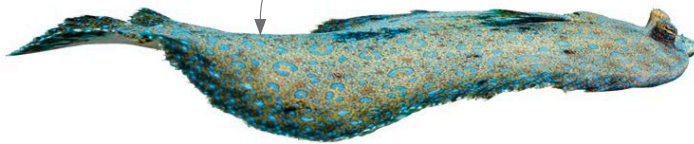
Lateral flattening gives quick bursts of speed, sharp turning, and the ability to fit through narrow spaces



COMPRESSIFORM
Emperor angelfish
Pomacanthus imperator



Flattened shape enables fish to live on the seabed; it flaps its fins up and down like a bird for swimming



DEPRESSIFORM
Pacific leopard flounder
Bothus leopardinus



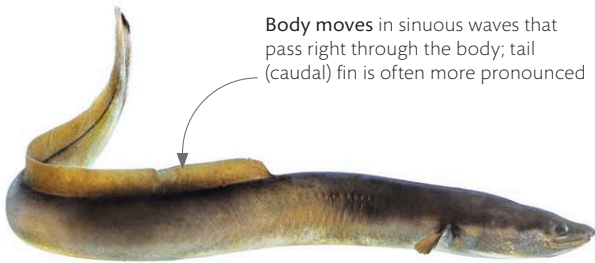
Spherical-bodied fish are slow swimmers that rely on camouflage and adaptations to avoid predators and capture prey on the seabed



GLOBIFORM
Warty frogfish
Antennarius maculatus



Body moves in sinuous waves that pass right through the body; tail (caudal) fin is often more pronounced



ANGUILLIFORM
European eel
Anguilla anguilla



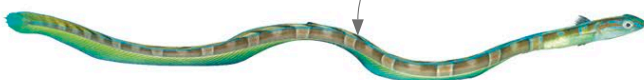
Elongated beak and arrowlike body enables fish to swim fast over short distances



SAGITTIFORM
Longnose gar
Lepisosteus osseus



Thin, threadlike body slithers through water like a snake



FILIFORM
Hair-tail blenny
Xiphias setifer

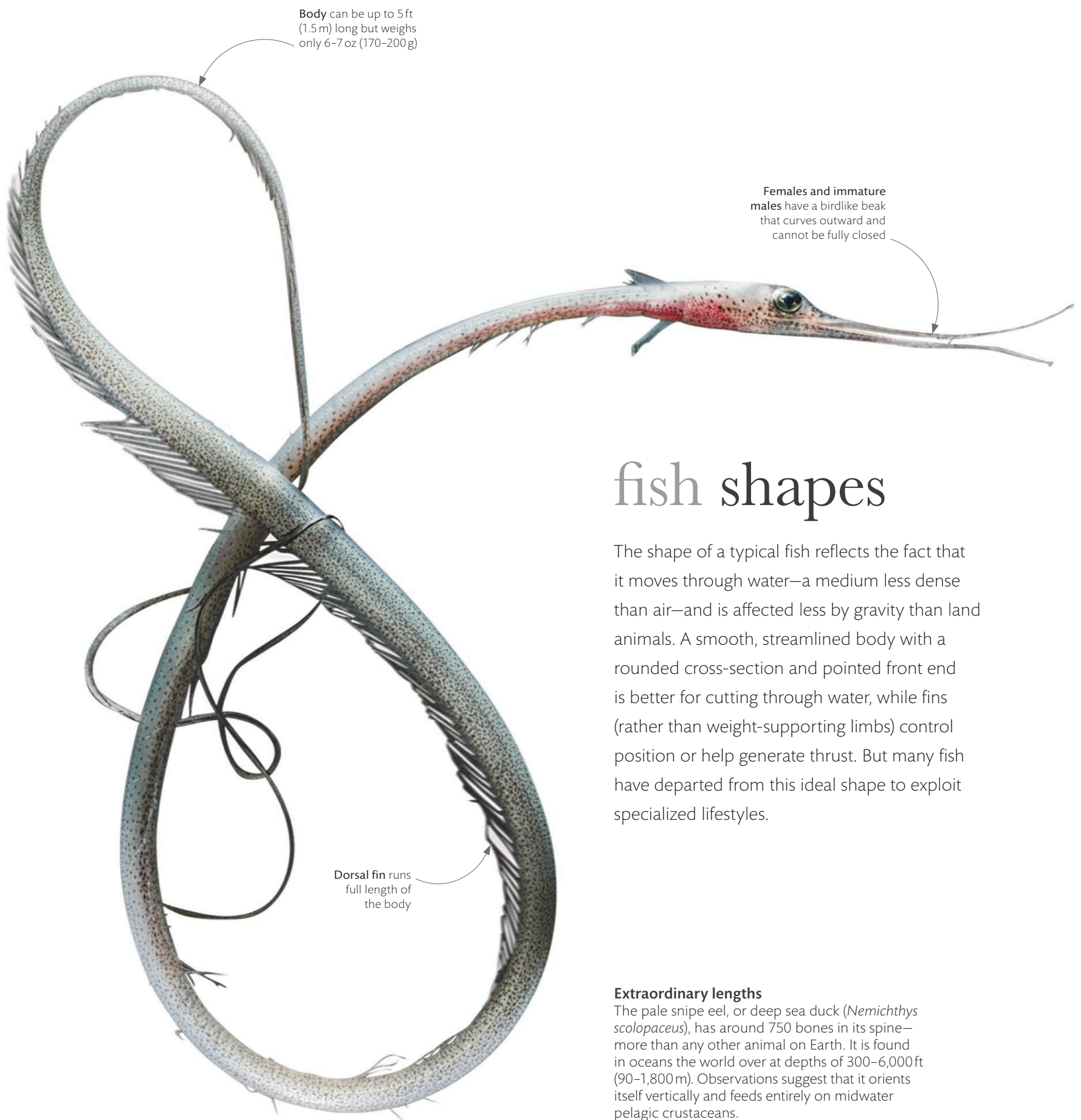


Ribbon shape enables fish to hide in rock crevices, but it is a slow swimmer



TAENIFORM
Crescent gunnel
Pholis laeta



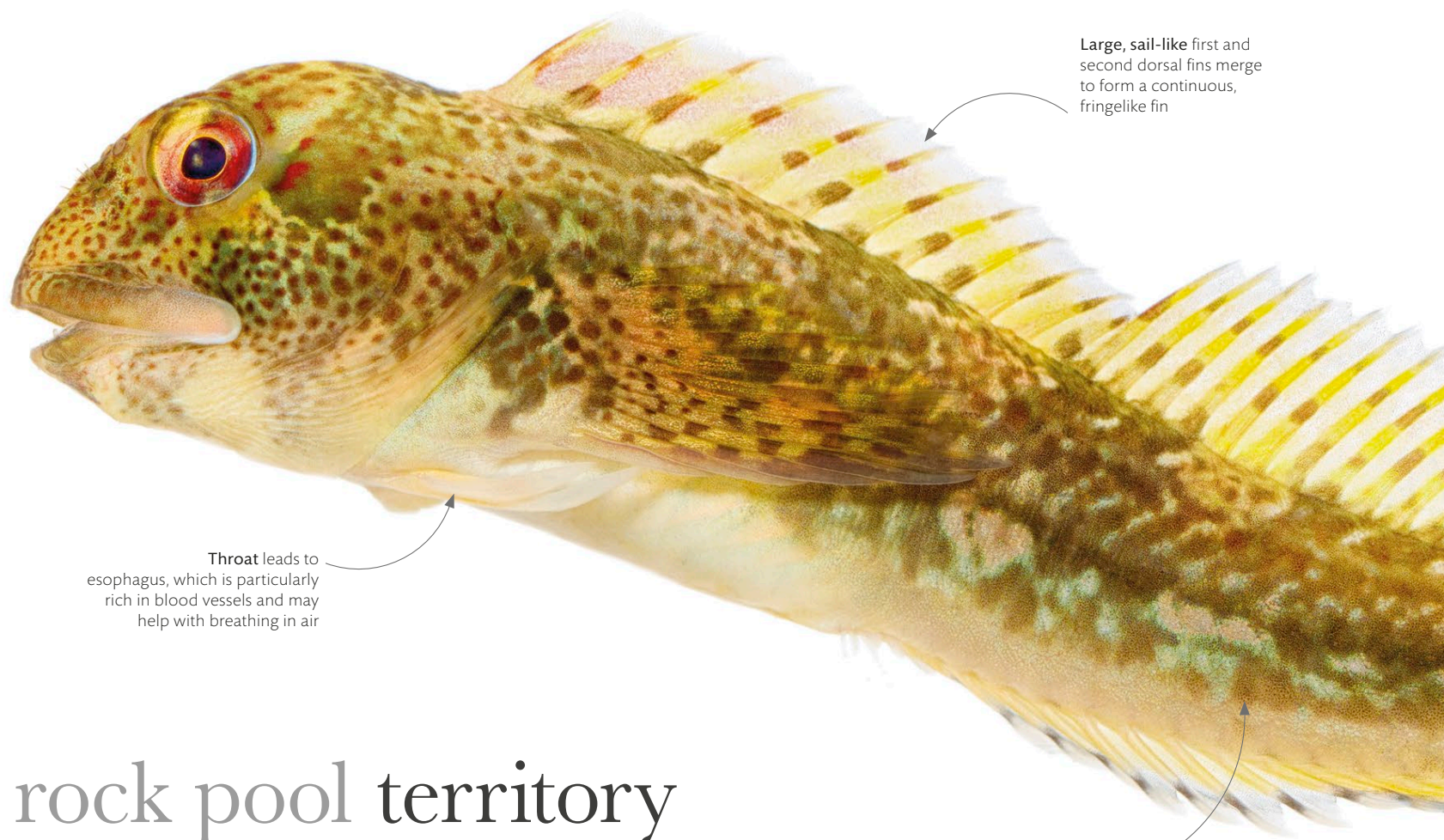


fish shapes

The shape of a typical fish reflects the fact that it moves through water—a medium less dense than air—and is affected less by gravity than land animals. A smooth, streamlined body with a rounded cross-section and pointed front end is better for cutting through water, while fins (rather than weight-supporting limbs) control position or help generate thrust. But many fish have departed from this ideal shape to exploit specialized lifestyles.

Extraordinary lengths

The pale snipe eel, or deep sea duck (*Nemichthys scolopaceus*), has around 750 bones in its spine—more than any other animal on Earth. It is found in oceans the world over at depths of 300–6,000 ft (90–1,800 m). Observations suggest that it orients itself vertically and feeds entirely on midwater pelagic crustaceans.



Large, sail-like first and second dorsal fins merge to form a continuous, fringelike fin

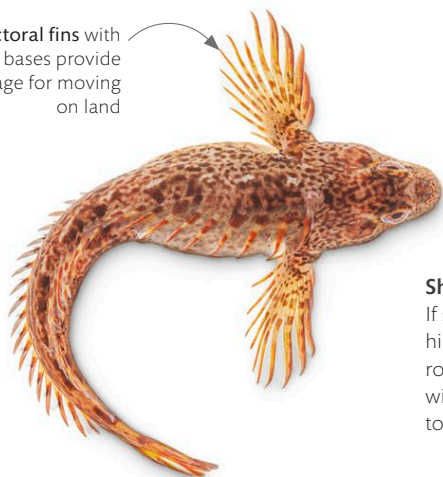
Throat leads to esophagus, which is particularly rich in blood vessels and may help with breathing in air

Mottled coloration provides camouflage and becomes much darker in brooding male

rock pool territory

A territory is an area of habitat that a single animal, a pair, or a group defends from others of the same species or other species, earning them exclusive access to food, mates, and hiding places. For the shanny (*Lipophrys pholis*), the advantages of a rock pool territory cut off from others at low tide balance the challenges of life in the intertidal zone (see p.45). Several female shannies may deposit eggs in a pool guarded by one male. At high tide, the male will attack almost any animal venturing near.

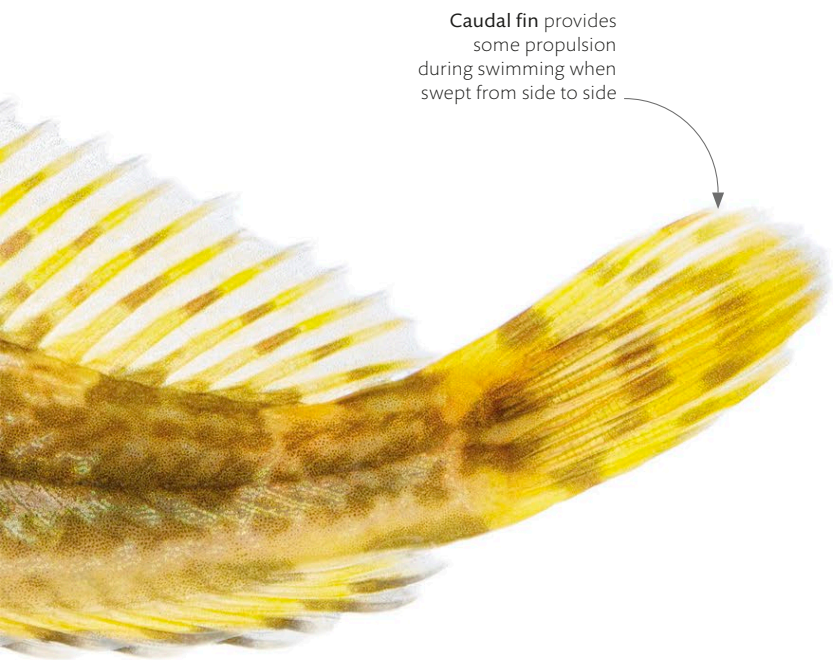
Large pectoral fins with stout bases provide leverage for moving on land



Shanny on land

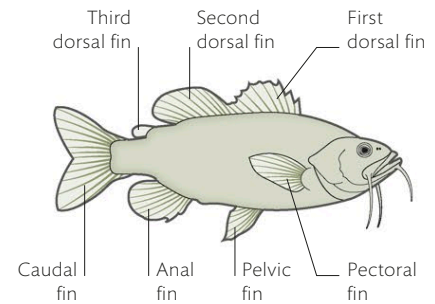
If stranded by the tide, the shanny hides in crevices or moves over rocks. Its tail sweeps back and forth with enough traction on the ground to help push the fish forward.





TYPES OF FINS

All bony fish share a similar arrangement of dorsal, anal, and caudal fins along the midline and paired pelvic and pectoral fins. However, some fins are modified according to the species' mode of living. For example, the fins of the shanny enable it to swim quickly and strongly against tidal currents and to crawl over land.



FINS ON A BONY FISH

Living with limits

The shanny's ability to exchange respiratory gases in air as well as water is a vital adaptation to the oxygen-depleted environment of a rock pool. At low tide, when feeding opportunities are limited, the fish adopts a relatively low-energy lifestyle, lurking hidden until high tide or until roused to territorial defense.



cold-blooded diving

A lizard that relies on the Sun's rays to stay warm and active is an unlikely cold-water diver—but along the rocky coastlines of the Galápagos Islands in the eastern Pacific Ocean, the marine iguana (*Amblyrhynchus cristatus*) does just that. On this volcanic archipelago, where competition for land-sourced food is intense, the marine iguana has evolved to eat seaweed. Females and juveniles usually graze between the tides. Large males dive deeper, enduring the chilly Humboldt Current, which comes straight up from Antarctica and streams around these islands.



Blunt face allows front teeth to get close to rock when grazing seaweed

Specialized teeth

The iguana's jaws are lined with three-pronged teeth, which spear the seaweed fronds that the lizard rips from the rock.

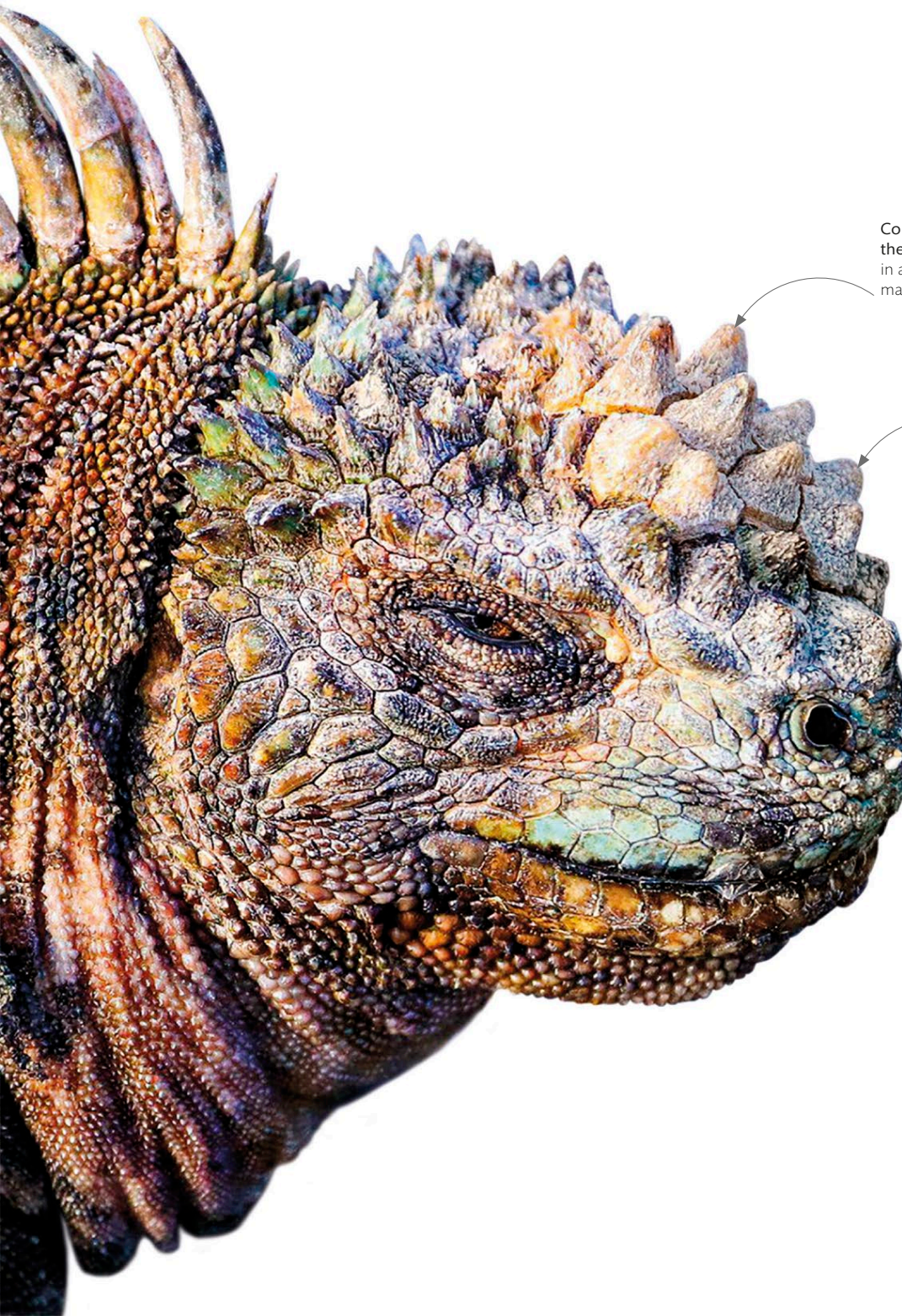
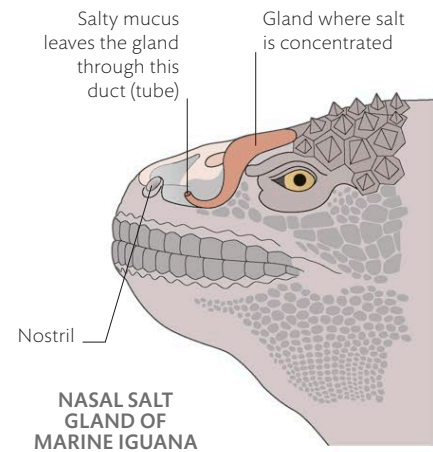
The skin's covering of beadlike scales protects the body from physical injury and reduces water loss by evaporation

Dark skin patches absorb the Sun's radiation well, warming the blood



SNEEZING SALT

A diet of seaweed quickly loads the body with too much salt, which would disturb the body's salt/water balance, damaging cells. Sea reptiles and seabirds possess glands that actively pump salt from the blood into salt-secreting glands, from where it leaves the body. The marine iguana, like seabirds, has paired nasal salt glands: the excess salt mixes with mucus and is periodically forced out by sneezing through the nostrils.

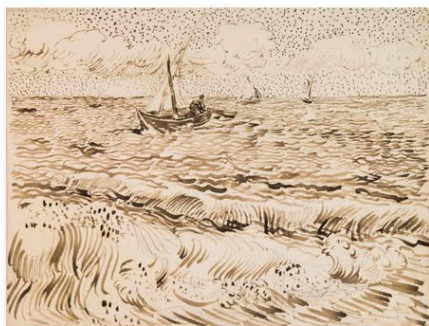


Conical spines on the head develop in adult, sexually mature iguanas

A white crust of salt, expelled from glands in the nostrils, often covers the top of the head

Cold-blooded diver

Like all reptiles, the marine iguana is ectothermic—meaning that it depends upon its surroundings for its warmth. It can last for just over an hour in the cold sea around the Galápagos. Then, before it chills too much to function, the iguana must return to land to bask in the Sun to recharge with solar heat.



A Fishing Boat at Sea (1888)

The emotional energy captured in the most simple brushwork in Vincent van Gogh's work was an inspiration to the Fauves.

Port-Miou (1907)

Georges Braque's headlong plunge into Fauvism is signaled in his passionate coloring of the high ridges and trees fringing the long inlet of Port-Miou on the coast near Marseille, France. There is a suggestion of Cubism in the diamonds on his cobalt-blue sea.

the ocean in art

seas of color

When the first Fauve paintings went on show in 1905 at the Salon d'Automne in Paris, France, a critic compared them to the "naive games of a child playing with a paint box." Here were landscapes, seascapes, portraits, and nudes that dispensed with all notions of representation and fidelity to nature. Color was redefined: flattened shapes of saturated hues were elements of the painting in their own right and vehicles to express the artists' emotions.

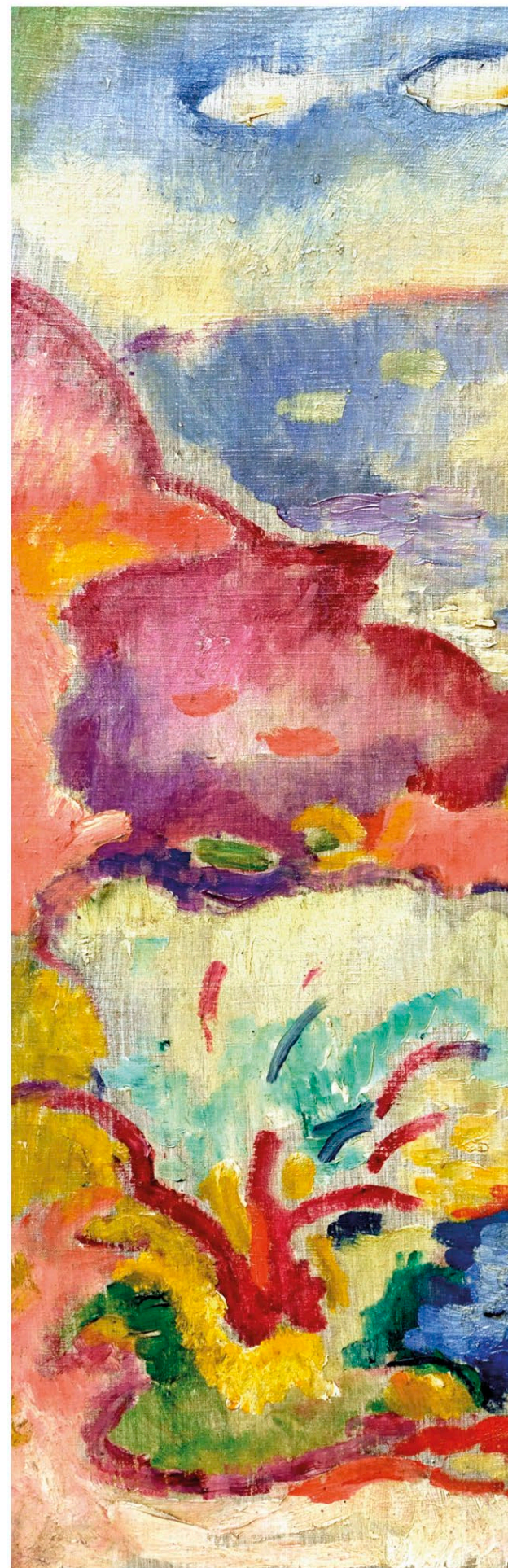
The Fauves drew their inspiration from the late 19th-century Postimpressionists, such as Vincent van Gogh, who brought an ecstasy and anguish to color and brushwork that transformed his subjects. In 1881, Paul Gauguin urged fellow artist Paul Sérusier to use not just green for a tree, or blue for a shadow, but the most *beautiful* green and the *bluest* blue.

Fauve theories, which would underpin Expressionist, Cubist, and modern art to the present day, emerged while Henri

Matisse and André Derain spent the summer in the fishing port of Collioure, France, in 1905. They experimented with line and color to capture the enhancing effects of Mediterranean light. Similarly, Georges Braque produced his first Fauvist work in L'Estaque, near Marseille, in 1907. All three artists flooded their canvasses of ports and coasts with bold colors and simplified forms that expressed their subjective response and intensity of feeling rather than objective reality.

“ We were always intoxicated with color, with words that speak of color, and with the sun that makes colors live. ”

ANDRÉ DRAIN, 1880–1954





Rictal rosette is a fleshy flap around the base of the bill's gape; it gets bigger and turns yellow-orange in breeding birds

The bill's **horny outer sheath**—the **ramphotheca**—grows thicker and more pigmented in breeding puffins, making the bill bigger and more colorful; this helps reinforce the bond between monogamous pairs

Counter-shaded body plumage—black above and white below—may help disguise the bird against ocean water when fishing at sea, protecting it from both aerial and underwater predators





Broad bill enables each parent to hold many sand eels—crosswise—at once

Clifftop chick

Like puffins, the closely related razorbill (*Alca torda*) divides responsibility when raising its brood: both parents feed the chick with sand eels caught by diving.

EGGS ON LEDGES

Eggs are vulnerable in a cliff face colony. Guillemots—relatives of puffins—lay spotted, pear-shaped eggs on exposed ledges, contrasting with whiter, rounder, typically spot-free puffin eggs hidden in crevices. Distinct spotted patterns may help guillemot parents recognize their own eggs. The eggs' less-rounded shape lets them sit flatter and more securely on the nest and spreads the stress of knocks from jostling birds over more of the egg surface, reducing the risk of breakage.

GUILLEMOT EGGS



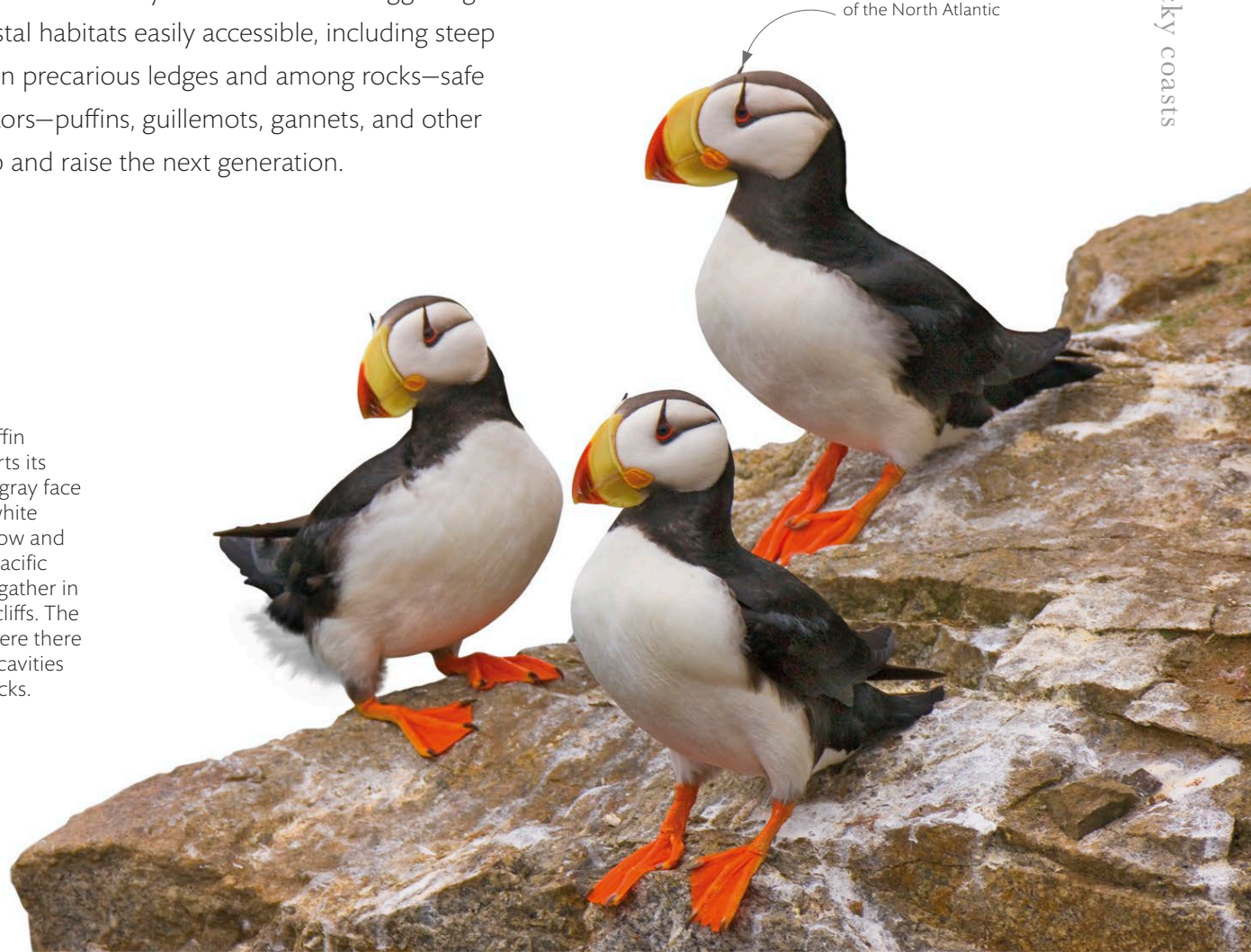
cliff nesting

Many birds depend entirely upon the ocean for food, but all must return to land to breed and lay their hard-shelled eggs. Flight makes a range of coastal habitats easily accessible, including steep cliffs and rockfaces. On precarious ledges and among rocks—safe from nonflying predators—puffins, guillemots, gannets, and other birds gather to pair up and raise the next generation.

Colorful colonist

In summer, the horned puffin (*Fratercula corniculata*) sports its breeding colors: its winter gray face becomes an immaculate white mask, and its bill turns yellow and bright red. Around north Pacific coastlines, horned puffins gather in colonies to nest on rocky cliffs. The densest colonies occur where there are plenty of crevices and cavities to shelter the eggs and chicks.

A dark fleshy “horn” projects above each eye in sexually mature adults, unlike in puffins of the North Atlantic



spotlight species

northern gannet

With a wingspan of up to 6 ft (1.8 m), the northern gannet (*Morus bassanus*) is the north Atlantic's largest seabird. A strong flier, this bird spends most of its life at sea, regularly making 336-mile (540-km) foraging expeditions; tagged birds have been recorded making even longer journeys. It soars over northwest Europe's coastal waters year-round, but its range extends from the southern Arctic to the Gulf of Mexico on a seasonal basis.

Oily fish and squid comprise most of a gannet's diet—herring, mackerel, and sprats are its preferred prey—but, as opportunists, these birds also steal any type of fish from nets and other seabirds. They often follow fishing boats far out to sea in the hope of feasting on discarded bycatch. More commonly, the northern gannet stays closer to shore, flying above the water at heights of 33–130 ft (10–40 m) at an average speed of around 10 mph (15 kph). It searches the surface for schools of fish, identifying food sources by tracking dolphins or larger predatory fish. Some gannets hunt alone, but they typically feed in flocks of up to a thousand. When they spot their prey, hundreds plummet head-first into the sea, often from a considerable height, to grab a meal.

Pairs of gannets mate for life, reinforcing bonds through behaviors

such as “mutual fencing” (knocking together of bills), and they return each year to nest in large, raucous colonies, known as gannetries. Although there are a few sites around North America, most northern gannets breed in 32 gannetries located between Brittany, France, and Norway that contain more than 70,000 breeding pairs. The female lays a single egg in late spring in a mounded nest of seaweed, feathers, and plant matter. Parents take turns incubating the egg by covering it with their feet, and they vigorously defend nests and young by stabbing intruders with their bills.

Diving for food

Gannets hunt by plunging into the sea beak-first, with their wings folded back, at speeds of up to 53 mph (86 kph). Most plunge dives are relatively shallow, but they can be as much as 72 ft (22 m) deep.

Rocky roost

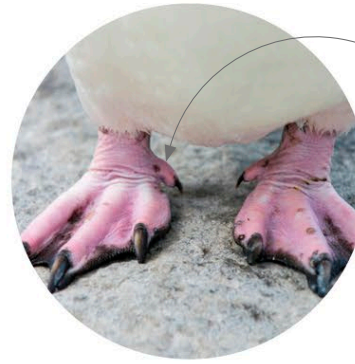
Gannetries are usually located on rocky coastlines, protected by the rugged terrain, like this one on the Shetland Isles. Although adult gannets have few natural predators, their eggs and chicks may be stolen by gulls, ravens, foxes, or weasels.





hopping on rocks

For most seabirds that can fly, the journey between water and land typically presents few problems. But for flightless penguins, a rocky shoreline battered by waves is a constant challenge. Rockhopper penguins must brave the choppy waters as they dive for krill, and then—using little more than their clawed, webbed feet and willpower—scale the rocks on their return.



Vestigial hind toe does not reach the ground

Sole-walkers

Penguins have plantigrade feet, which means that they walk on the soles of their feet, giving better traction. Other birds are digitigrade—they walk on their toes.

Island penguin

Southern rockhopper penguins (*Eudyptes chrysocome*), of the Falklands and other subantarctic islands, thrive on coastlines jagged with solidified lava, where they clear steep gullies in single jumps. The habitat, although harsh and craggy, provides shelter for the birds' nests and pools of fresh drinking water that collect between the rocks.



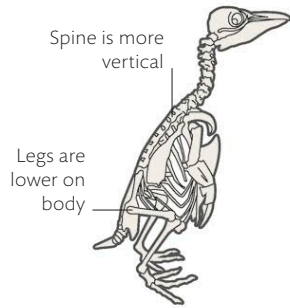
Short, stout bill, which is used for grabbing krill when diving, may also be used like a grappling hook when climbing steep slopes

Three forward-pointing toes have thick, strong claws that can grip rock; the toes are connected by webbing for surface paddling

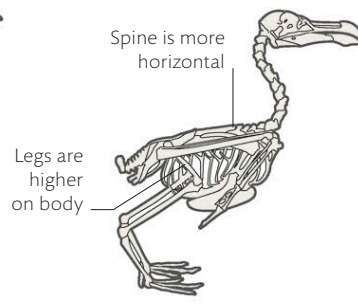
Short, thick legs are powered by strong thigh muscles that help the bird hop from rock to rock

PENGUIN POSTURE

A streamlined body with legs set far back enables a penguin to cut through water like a torpedo. But adaptations that perfect swimming and diving leave a penguin ungainly on land. Compared to a gull, the legs of a penguin are lower down on the body, forcing the bird to stand more upright and giving it a waddling gait.



ROCKHOPPER PENGUIN SKELETON



GREAT BLACK-BACKED GULL SKELETON

Stiff, flat wings are held outward for balance when jumping; they are used as paddles for propulsion when the bird dives



sandy beaches

The shifting surface of a sandy beach is a difficult place to put down roots or dig a burrow but it also presents opportunities. Flotsam arriving on a shoreline attracts scavengers, and gently sloping beaches allow large air-breathing animals to come ashore.





Making dunes

Wind-blown sand gathers around plants and other obstacles to create dunes. With their deep network of roots, marram grasses stabilize dunes and enable them to increase in size.

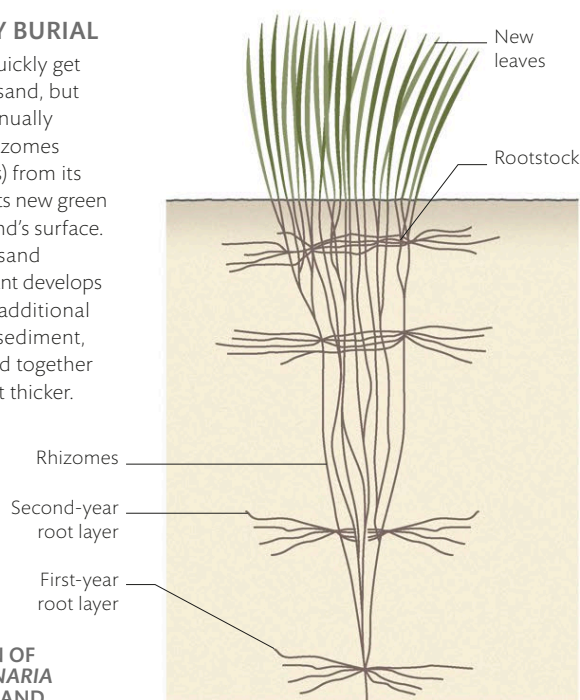
Lines of new plants are produced from rhizomes that grow horizontally through the sand

growing in wind-blown sand

A sandy seashore exposed to gales can be a harsh environment for a plant: the salty wind dries tender shoots, and the sand it carries scours leaves and buries new growth. In these tough conditions, marram grasses not only survive—they thrive. They have wind-resistant leaves and a regrowth system that continually pushes the plants upward from beneath rising piles of sand.

STIMULATED BY BURIAL

Most short plants quickly get covered by shifting sand, but marram grass continually sends up vertical rhizomes (underground stems) from its rootstock and sprouts new green leaves above the sand's surface. As more and more sand accumulates, the plant develops layer upon layer of additional roots higher in the sediment, which binds the sand together as the root fibers get thicker.

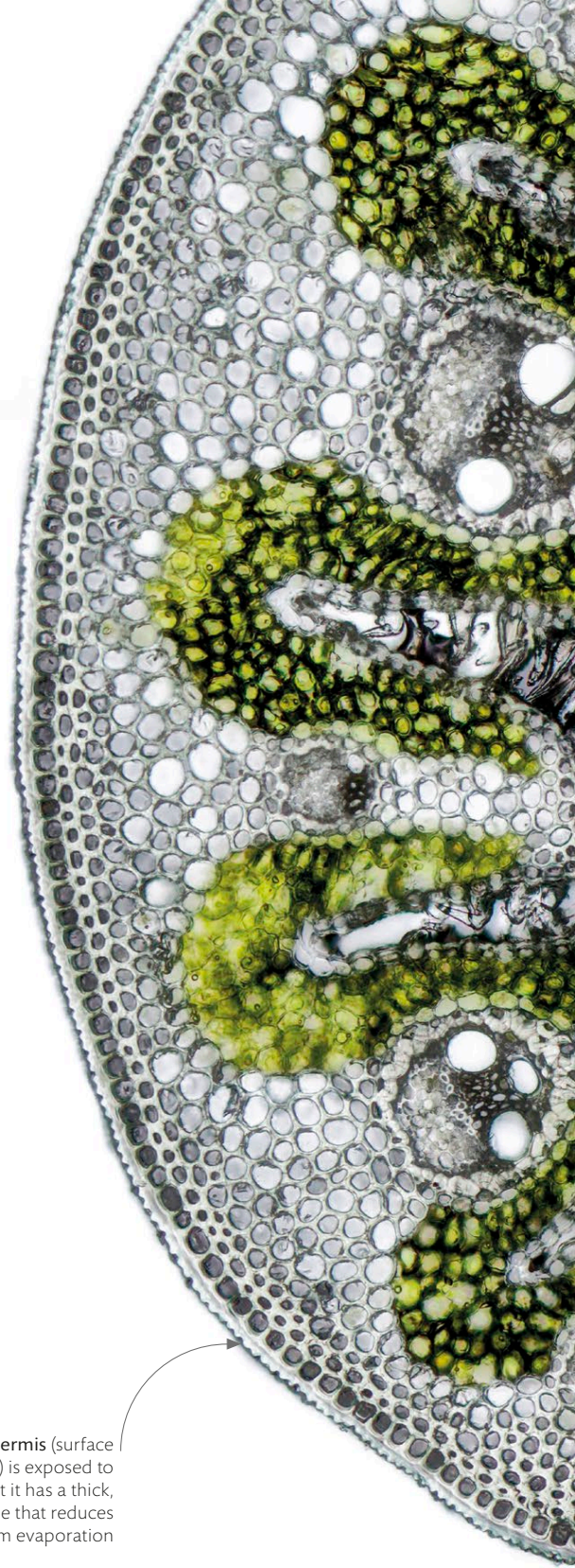


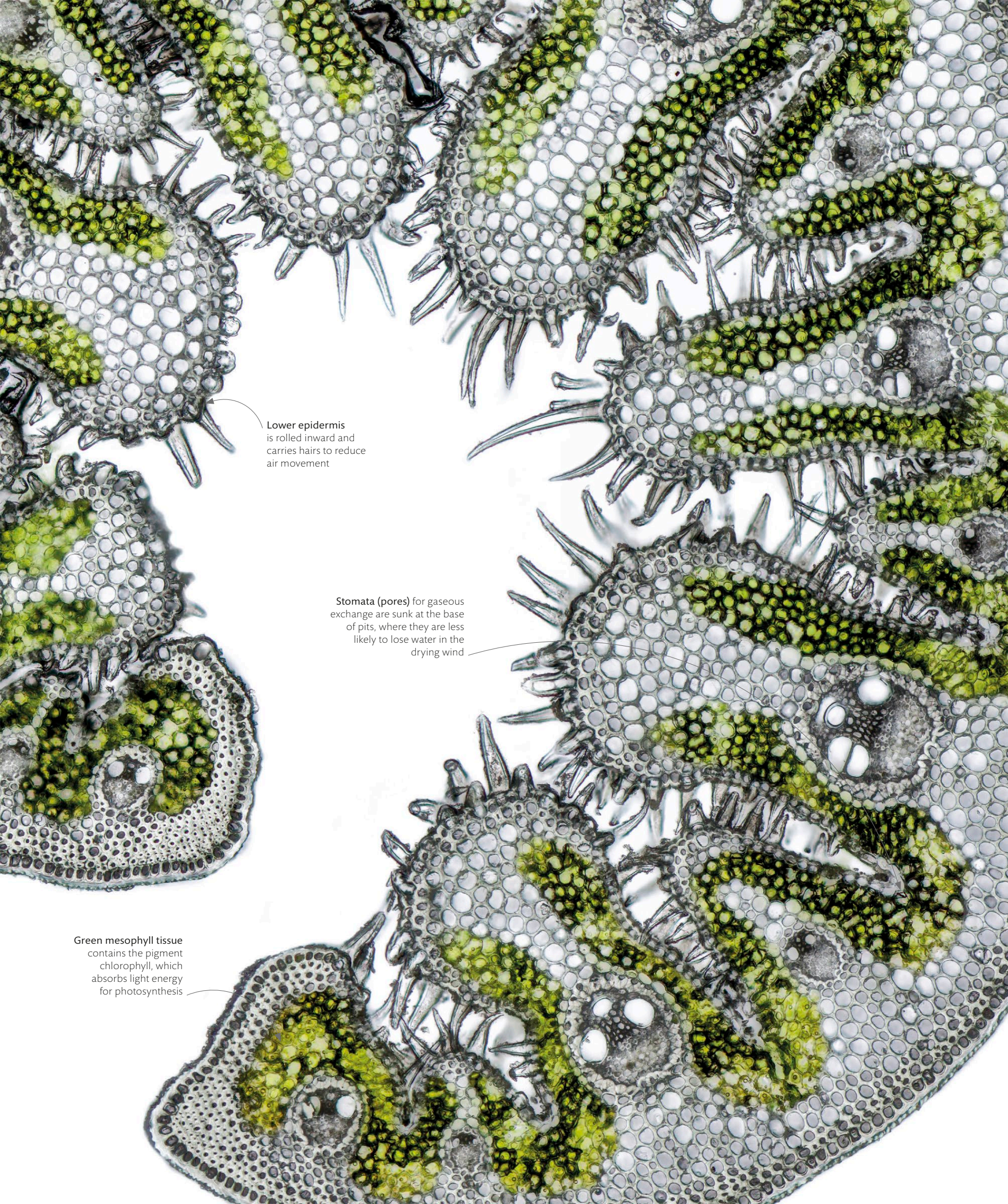
GROWTH PATTERN OF *AMMOPHILA ARENARIA* AFTER BURIAL IN SAND

Upper epidermis (surface layer of cells) is exposed to the wind, but it has a thick, waxy cuticle that reduces water loss from evaporation

Wind tolerance

A cross-section through common marram grass (*Ammophila arenaria*) shows how the leaf blade is rolled inward, sheltering the stomata—minute pores that exchange gases for respiration and photosynthesis. The curled shape screens the stomata from the drying effects of the wind, while the central channel keeps moist air trapped close to more vulnerable, porous tissue layers.





Lower epidermis
is rolled inward and
carries hairs to reduce
air movement

Stomata (pores) for gaseous
exchange are sunk at the base
of pits, where they are less
likely to lose water in the
drying wind

Green mesophyll tissue
contains the pigment
chlorophyll, which
absorbs light energy
for photosynthesis

Ocean Surface (1983)

In this masterwork of close observation and technical precision, Vija Celmins uses drypoint engraving, in which the image is cut into a plate using a sharply pointed tool, to recreate wave formations in her limited-edition monochromatic prints.



the ocean in art

lifelike seas

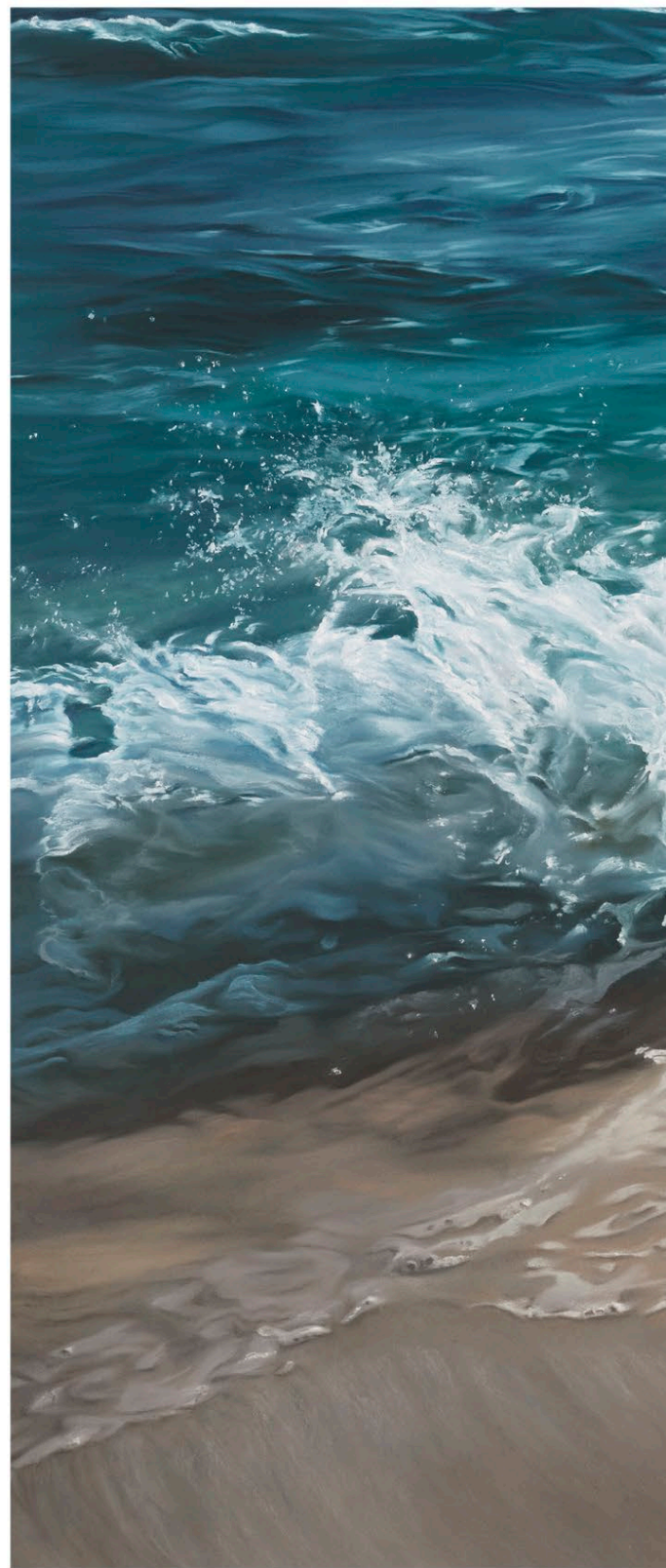
In the 20th century, a new art movement known as Photorealism emerged. This involved artists using a photograph as their primary visual reference to produce images that are so lifelike it is barely believable they have been created by the artist's hand. This art form continues to evolve, with artists using the latest technologies. Among the most astonishing works are the super-realistic seascapes, with their almost tangible waves and sand.

Inspired by Pop Art in the 1960s, the work of the first Photorealists in the 1970s was a commentary on the conflict between art and the explosion of photography in the 20th century. Artists projected the outline of a photograph onto canvas or paper, then demonstrated their extraordinary prowess in mimicking the textures and reflective surfaces of consumer culture icons, such as camping vans and sauce bottles, often using an airbrush. Here were banal subjects lacking any emotional depth presented with the technical skills of an 18th-century portrait artist perfecting the sheen on silks or the texture of fur.

Since the early 1990s, technical advances in digital photography have taken Hyperrealism (as Photorealism is now more commonly known) into different realms. US artist Zaria Forman has flown with NASA survey missions over Arctic and Antarctic seas and has traveled to Greenland to photograph polar ice. In the Maldives, the lowest and flattest region on Earth, she photographed coastlines under threat as sea levels continue to rise. Her

message about the beauty and fragility of our world is writ large on vast canvasses of pristine ice masses and tropical waves. Each work captures a photographic moment in time and takes up to 400 hours to recreate.

Latvian-American artist Vija Celmins also works on meticulous renderings of natural phenomena, such as waves, night skies, and the desert floor, often in somber, dark gray tones. In the late 1960s, she produced highly realistic pencil drawings of the surface ripples in a small area of the Pacific Ocean; more recently, she has replicated those pencil strokes using an engraving tool to create remarkable prints.



“ My drawings celebrate the beauty of what we all stand to lose. I hope they can serve as records of sublime landscapes in flux. ”

ZARIA FORMAN, TED TALKS LIVE, NOVEMBER 2015



Maldives No. 11 (2013)

Zaria Forman conjures up mesmerizing waves lapping on a Maldives shore using only pastel crayons and her fingers and palms. Her giant canvases, produced from her own photographs of vanishing equatorial coastlines and melting ice in polar regions, reflect a planet in peril from climate change.

**Race for the sea**

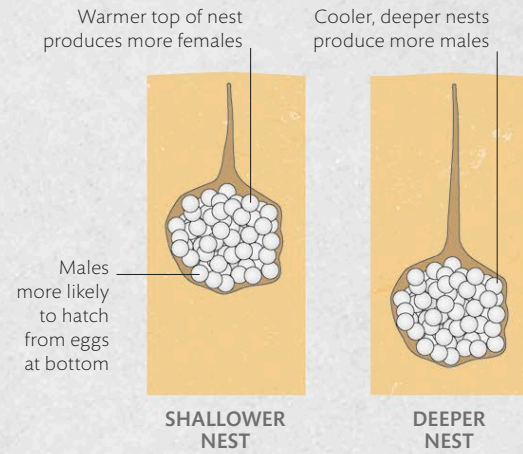
Two baby loggerhead turtles (*Caretta caretta*) head for the ocean on Florida's east coast. Most marine turtles hatch at night, when land predators are less likely to spot them. They scurry off in the most brightly lit direction—where moonlight or starlight reflects off the water—and away from the shadows of vegetation farther inland.

nesting on beaches

With their paddlelike limbs, marine turtles are superbly adapted to life in water, but their existence is not wholly separate from the land. Their young, like those of terrestrial tortoises, hatch from hard-shelled, air-breathing eggs. The female turtles bury them on sandy beaches, but the strategy is not without risk. On exposed shores, hatchlings must brave land predators in the brief—but perilous—scamper to the sea. Females offset the certain loss by producing huge clutches, typically containing more than 100 eggs.

TEMPERATURE AND SEX

The sex of a turtle embryo is determined by temperature. Above 84°F (29°C), sex organs are more likely to become ovaries, producing females; below this, they develop as male testes. Buried eggs incubate as sunshine warms the sand, but the temperature inside the nest is not uniform—eggs buried deeper are slightly cooler. This temperature variation ensures that roughly equal numbers of females and males hatch.



Each turtle crawls beyond the reach of the tide to lay its eggs; the entire beach visit lasts about an hour

Natal rookery

Female olive ridley turtles (*Lepidochelys olivacea*) return in their thousands to the beach nesting grounds of their birth, called rookeries. They use their hind legs to dig a hole in which to lay eggs, then bury the clutch and return to the sea.



Sculpted by the wind

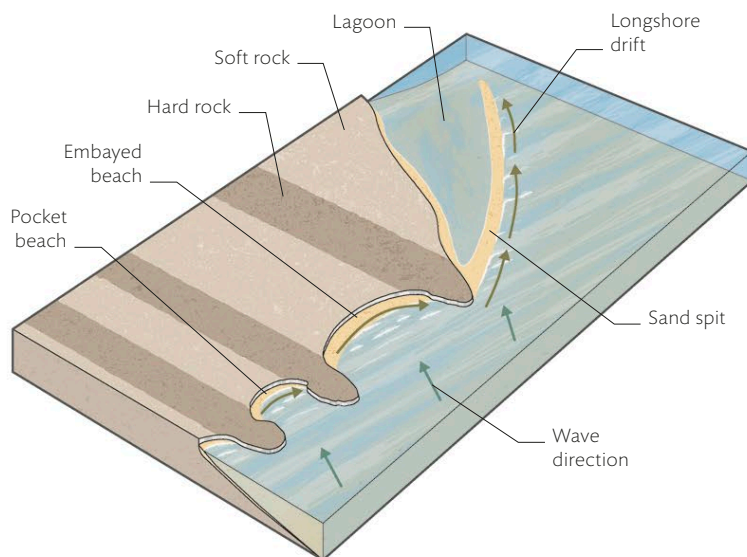
Barchan dunes form when the wind, coming predominantly from one direction, blows the sand into distinctive crescent shapes as on Isla Magdalena, on the Pacific coast of Baja California, Mexico.

beaches and dunes

Beaches are zones where sediment in the form of sand—created by the action of rivers, cliff erosion, and transport from deep water toward the shore—accumulates before eventually being carried back to the sea by wave action. Beaches lose sand to the sea by the action of strong offshore rip-currents and winter storms. Sand may also be transported inland by wind to form dunes. The most important force for sand transport is persistent longshore drift, which drives a conveyor belt of supply and removal. The color of sand varies according to the type of rock: gray-black from volcanic rocks; glistening white from coral and limestone; or golden, mainly comprising quartz coated with iron oxide.

TYPES OF BEACH

Pocket and embayed beaches nestle in the more protected regions between headlands. Broad sandy beaches with gentle gradients are often flanked by dunes. Where wave energy is greater, sand is washed away and steep pebble beaches are built up. Where waves approach a shoreline obliquely, they move sand by a process of longshore drift and create sand spits, barrier islands, and sheltered lagoons.







“ Aloft all hands, strike the top-masts and belay;
Yon angry setting sun and fierce-edged clouds
Declare the Typhoon’s coming. ”

J. M. W. TURNER, UNTITLED POEM (1812) ACCOMPANYING *THE SLAVE SHIP*, 1840



The Slave Ship (1840)

In J. M. W. Turner's celebrated work, the churning waves look as though they are on fire and the ship plows ominously into the storm as the captain carries out his evil mission. Turner's full title, *Slavers Overthrowing the Dead and Dying—Typho[on] Coming On*, supplies the narrative for the carnage in the foreground: the flailing, shackled limbs of submerged slaves who have been thrown into the shark-infested sea.

The Sea of Ice (1823–1824)

The seascapes of German artist Caspar David Friedrich evoke awe in the natural world and a sense of human irrelevance in the face of an almighty power. Here, a ship is crushed in its ice tomb, while the jagged ice is driven into pinnacles against the infinite blue of the sky.



the ocean in art

drama on the seas

In the Romantic movement, which spanned most of the 19th century, inspiration, originality, and imagination were key. Artists dispensed with neoclassical rules and norms to focus on their emotional response to the natural world and to the plight of individuals. Many iconic seascapes of the period, featuring towering waves and apocalyptic skies, tell contemporary stories about human endeavor, disaster, and oppression.

The 19th-century French poet and art critic Charles Baudelaire described Romantic art as “precisely situated neither in choice of subject, nor in exact truth, but in a way of feeling.” For some artists, the freedom to work outdoors (made easier by the invention of paint tubes) fueled a deeper engagement with land and sea. In studios, experimentation with brushwork, color, and form fostered a range of individual techniques.

Russian marine artist Ivan Aivazovsky conjured a sense of the ocean's sublime magnitude with vast canvasses saturated with color and light. In *The Ninth Wave* (1850), the rising Sun lights a huge wave that is threatening to engulf the survivors clinging to the wreckage of their ship.

In a period when European colonialists were exploiting overseas territories and scientists and explorers were sailing to remote regions, outrage and adventure surfaced in Romantic art. French painter Théodore Géricault's *The Raft of the Medusa* (1819) is a striking recreation of the true story of crew and

passengers abandoned by officers when the French frigate *Meduse* ran aground on its way to Senegal. In this work, the deceased slip from a poorly made raft, survivors cling to life, and hope of rescue is encapsulated in a makeshift flag waved toward a brightening sky. More fancifully, English artist Sir Edwin Landseer imagined the outcome for Sir John Franklin's failed attempt to find a Northwest Passage through Arctic seas. In his *Man Proposes, God Disposes* (1864), polar bears invade the ice-trapped wreckage to feed on human bones.

A large proportion of the 19,000 watercolors and oils painted by the English artist J. M. W. Turner were seascapes. Over a lifetime, he perfected washes of paint, textures, and bursts of light to create the natural phenomena of rain, fog, storm, sunrise, and sunset. He based his painting and poem *The Slave Ship* on the true story of the captain of the *Zong*, who ordered his crew to throw sick and dying slaves into the sea to guarantee insurance payments—a common practice in slave shipment.

spotlight species

american crocodile

The American crocodile (*Crocodylus acutus*) exists in a range of habitats, from freshwater rivers to brackish swamps and coastal waters, and is found in regions as far apart as Florida and the Caribbean, as well as off both the Atlantic and Pacific coasts of South America.

The American crocodile is one of the largest of the crocodile species; adults have an average length of 14 ft (4.3 m). Like all crocodiles, it has salt glands on its tongue that remove excess salt, helping it survive in higher salinities.

The American crocodile has an especially large range of tolerance: most populations live in brackish lagoons, mangroves or estuaries, but others live in freshwater rivers and reservoirs much further inland. The largest Caribbean population – in the Dominican Republic – even succeeds in a salt lake with water that can be three times saltier than the ocean. A wide distribution across the American tropics is testament to the apparent adaptability of the American crocodile. The fact that it has colonized islands, including coral atolls, is proof that it often swims far out to sea, possibly aided by tidal currents.

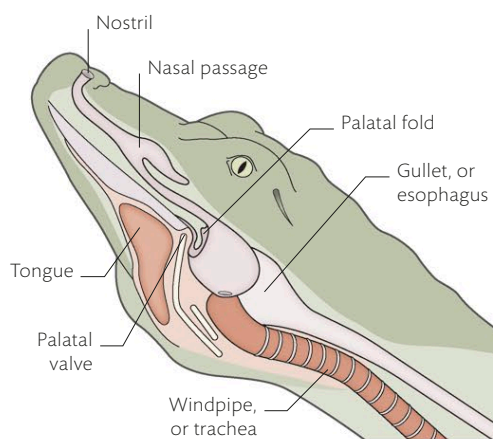
While an American crocodile's jaws can exert hundreds of pounds of pressure when it bites, easily crushing an adult turtle shell, they can also be very gentle. Females can pick up and carefully squeeze unbroken eggs to help the young crocodiles hatch, and they often carry their young in their mouths to transport them to the water. A crocodile's cone-shaped teeth are designed for grabbing and holding prey but not for chewing. They are constantly being replaced, and an animal may go through 8,000 teeth during its lifetime.

Adapted for hunting

A crocodile senses prey by smell and via sensory bumps on the sides of its jaws that detect vibrations. They can swim open-mouthed and have excellent vision; a transparent third eyelid protects the eye when the animal is submerged.

SURVIVING UNDERWATER

A crocodile's mouth is not watertight, so to prevent water flooding its lungs and gut when underwater, a palatal valve – a large flap behind the tongue – seals the entrance to the windpipe and gullet. At the same time, smaller nostril valves close the nose. In this way, a crocodile can stay submerged without breathing for over an hour, and it can even open its mouth wide enough to grab or manipulate prey. The raised position of the open nostrils also allows the crocodile to breathe air while swimming or hanging just below the water surface.



CROSS-SECTION OF A CROCODILE'S THROAT





beachcombing

A sandy beach can provide a good living, even for animals that never enter the water. Each tide brings a deposit of natural flotsam in the form of seaweed. This, in turn, attracts swarms of flies, beetles, and tiny crustaceans—food for shorebirds, such as plovers. Up beyond the ocean's reach, among the sparsely vegetated dunes, birds build their nests with sticks, stones, shells, and anything else they might collect as they forage along the water's edge.

Life above the tides

Along the southern Australian coastlines, the hooded plover (*Thinornis cucullatus*) prefers beaches strewn with plenty of seaweed. Its legs are too short to wade for its food, so it sticks to the shoreline when foraging for invertebrates.

Large eyes help the bird spot small prey among the tideline debris





Disguised egg clutch

The bird's speckled eggs resemble the surrounding pebbles. The nest may be lined with seaweed and shell fragments for additional camouflage. Once hatched, the sandy-colored chicks blend in, too.

The hooded plover's nest is a shallow depression called a scrape

NESTING TOGETHER

Even when partly concealed by the spoils of beachcombing, the nests of hooded plovers are vulnerable to predation. Being territorial breeders, hooded plovers prefer to nest over 66 ft (20 m) apart. Ground-nesting birds often breed in loose colonies, typically with mixed species for extra vigilance, and hooded plovers may be joined by pied oystercatchers (*Haematopus longirostris*).



PIED OYSTERCATCHERS

Seaweed fronds detached by wave action attract kelp flies and other decomposers, providing a ready source of food for birds



Coastal devastation

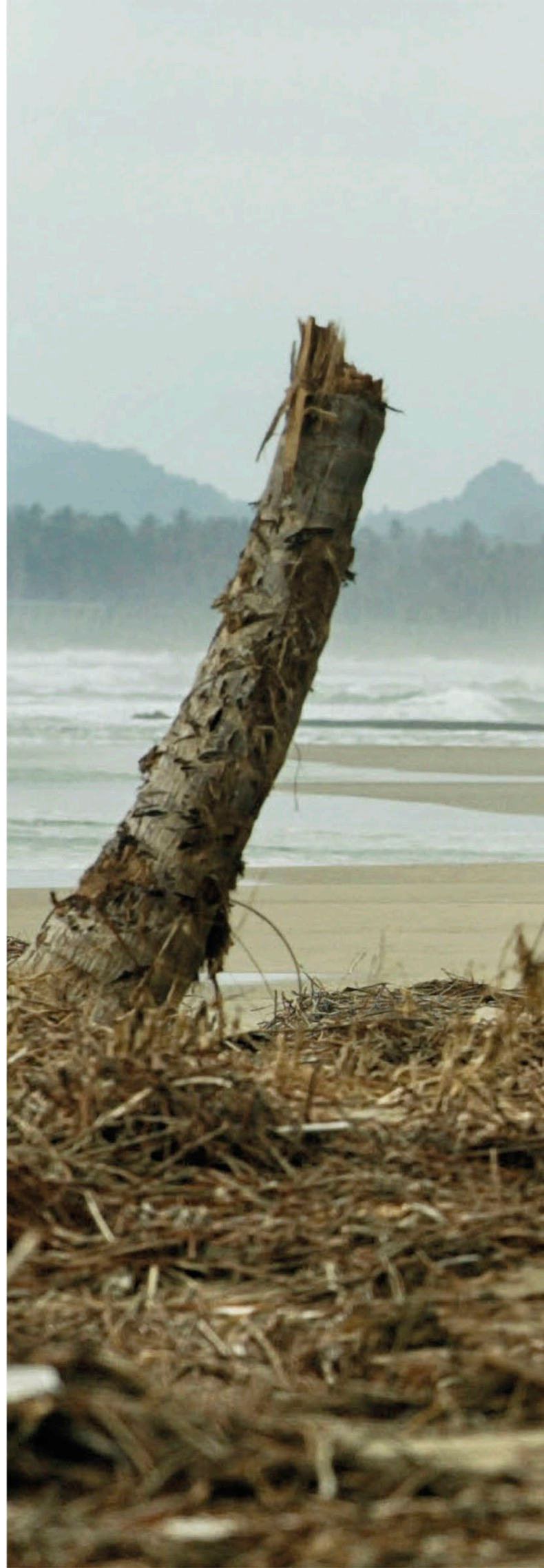
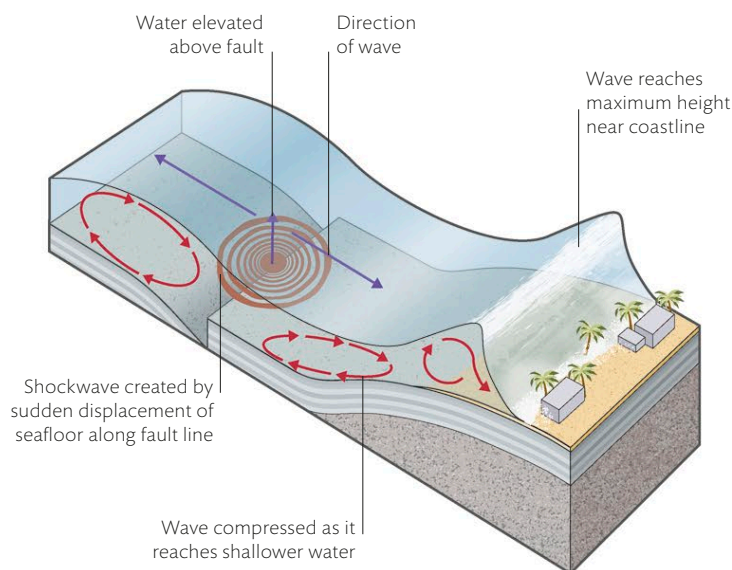
The aftermath of the 2004 tsunami that ravaged the west coast of Aceh, Indonesia, pictured in 2005, testifies to the destructive power of this ocean event over wide tracts of the formerly tree-covered shoreline.

tsunamis

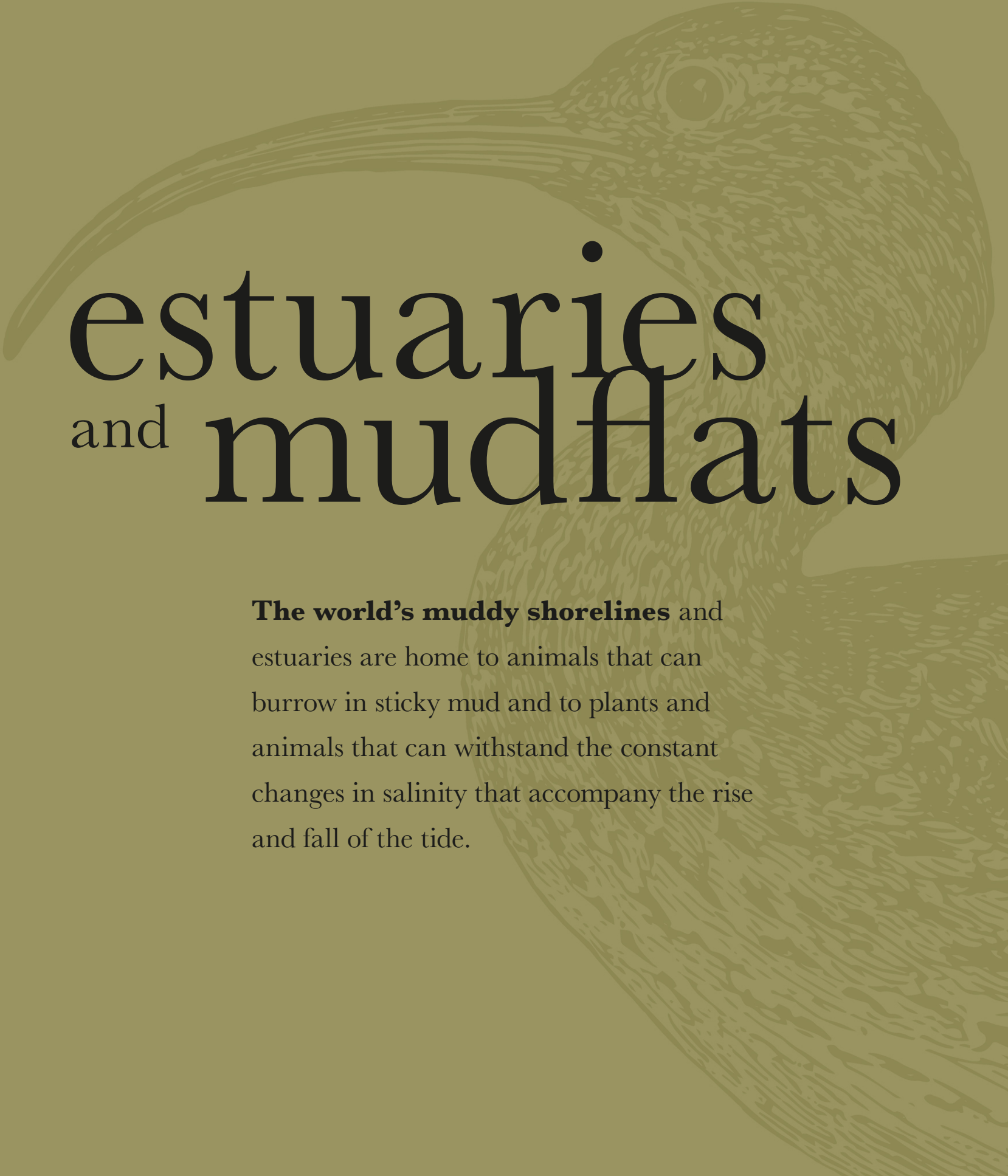
Tsunamis are unusual waves of extreme wavelength (up to 125 miles/200 km) that can travel across an entire ocean at a speed of up to 500 mph (800 kph). A common cause of tsunamis is the sudden vertical movement of the seafloor due to earthquakes or giant submarine slides under the sea. They may also be caused by events on land that deposit vast amounts of material into the sea, such as avalanches, landslides, volcanic eruptions, or the calving of large icebergs from ice sheets or glaciers. In each case, the enormous volume of ocean water displaced gives a tsunami its huge power and velocity. Tsunamis can originate in any ocean but are most common in areas of frequent volcanic activity.

FROM UNDERSEA SHOCK TO COASTAL DESTRUCTION

A tsunami often starts with a sudden displacement of the ocean floor, which causes a large movement of water that produces a long, low, almost imperceptible wave in the open ocean. The wave's height increases dramatically as it crosses the shallow continental shelf and sweeps toward land, forming a giant wall of water—up to 100 ft (30 m) high—that surges inland, wreaking havoc along the coast.







estuaries and mudflats

The world's muddy shorelines and estuaries are home to animals that can burrow in sticky mud and to plants and animals that can withstand the constant changes in salinity that accompany the rise and fall of the tide.

living in sediment

Among the invertebrate animals that live in mud are many kinds of bivalve: mollusks with a two-part shell, such as clams and cockles. They use their gills to filter particles of food, including the organic detritus and microorganisms that typically enrich the seafloor. Many bivalves use their muscular foot to burrow into the substrate, away from surface predators. Surrounded by sediment, these mollusks then draw water through their body to extract both oxygen and nourishment.



The foot can extend up to 2.5 in (6 cm) as it burrows

Burrowing bivalve

A prickly cockle (*Acanthocardia echinata*) pushes its muscular foot into the sand. The foot then expands near its tip to achieve traction before pulling the rest of the cockle's body beneath the surface.

Crenulated edges of valves interlock when shell closes

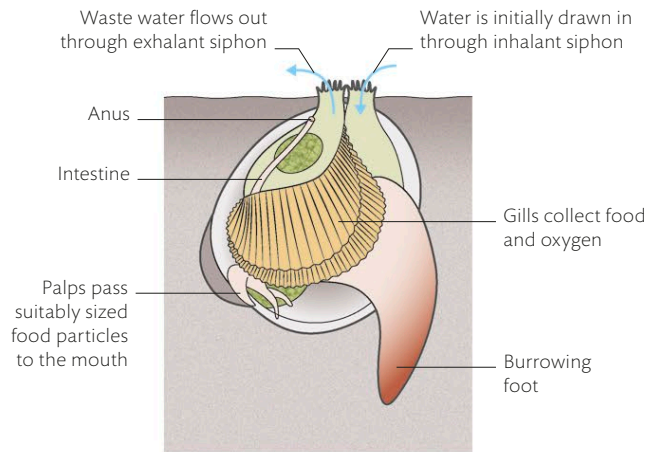


The hinge of the shell is surrounded by a flat platform shaped like the deck of a ship, inspiring the name "ark shell"

SIPHONING WATER

Water does not easily circulate through sticky mud, so many burrowing bivalves use siphons to draw water down from the surface. The siphons extend when the valves open. Those with the longest siphons can burrow the deepest. Cockles, with short siphons, and ark shells, which lack siphons, live closer to the surface.

CROSS-SECTION OF COCKLE FILTER FEEDING IN MUD



Hinged shell

Like other bivalves, the Indo-Pacific blood clam (*Tergillarca granosa*) from tropical coastal muds has a shell made of two parts, or valves, connected by a hinge of tough ligament. The valves are pulled shut by muscles when danger threatens. As these muscles relax, the shell gapes open, enabling the mollusk to extend its muscular burrowing foot and circulate water for filter feeding.

Fleshy foot is powered by multiple muscles that extend the foot or move it from side to side when burrowing



Ripples in the sand

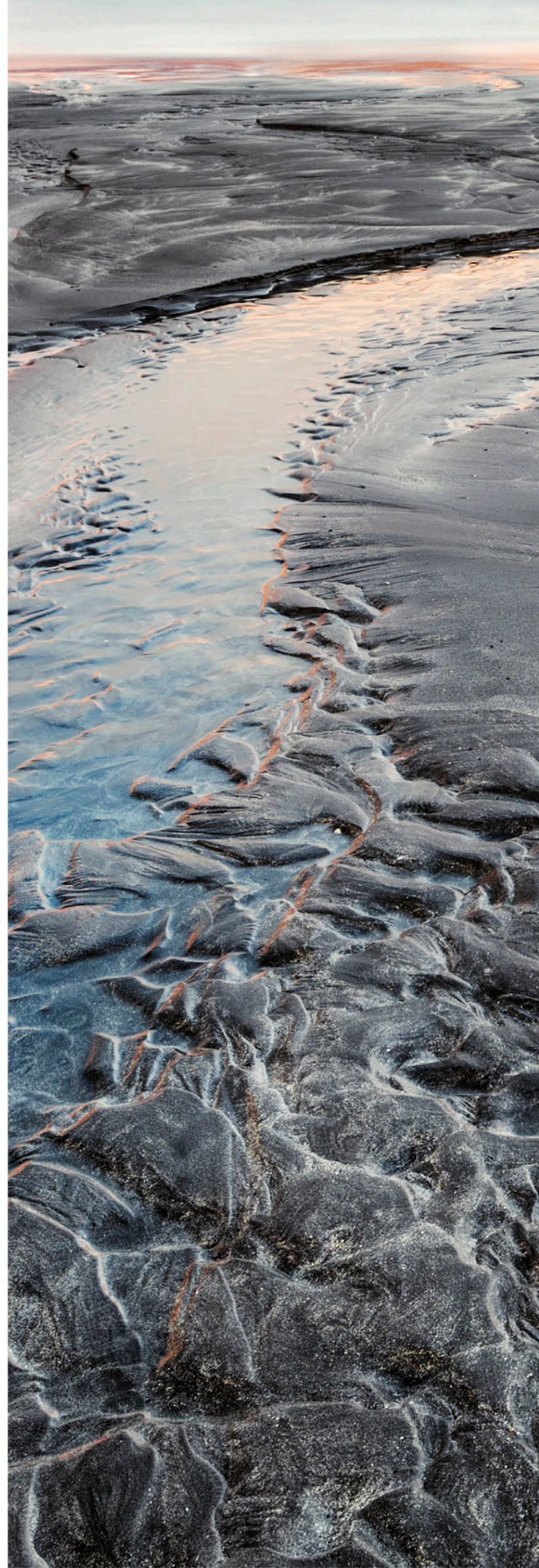
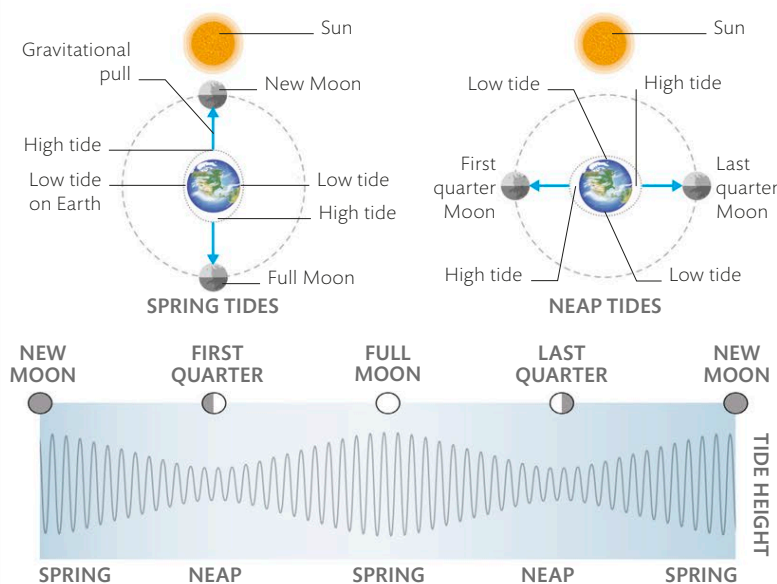
As the tide retreats on the Scottish Hebridean island of Eigg, the action of the water molds the fine sand into distinctive ripples. The metallic sheen of the sand is the result of its high content of volcanic material.

tides

The regular—usually twice daily—rise and fall of sea level, known as the tide, has been a constant phenomenon since the oceans first formed 4 billion years ago. Tides are waves with very long wavelengths that sweep around the planet, moving up and down the low-lying coastal zone, with dramatic effect on life in the shallows. High tides are the crest of the wave, and low tides are the trough. The difference in height between high and low tides is called the tidal range. This varies from less than 3 ft (1 m) to just over 53 ft (16 m). Tides are caused by the combined effects of the gravitational pull of the Moon and Sun and the rotation of Earth and the Moon.

MONTHLY CYCLES

The influence of the Moon's gravitational pull is greater than that of the Sun. Ocean water is pulled into a bulge on the side facing the Moon, while centrifugal force creates an equal bulge on the opposite side of Earth. When the Sun and Moon are aligned, the tidal bulge is at its maximum (the spring tide). When they are at right angles, the tidal bulge is at its minimum (the neap tide).





seabed stinger

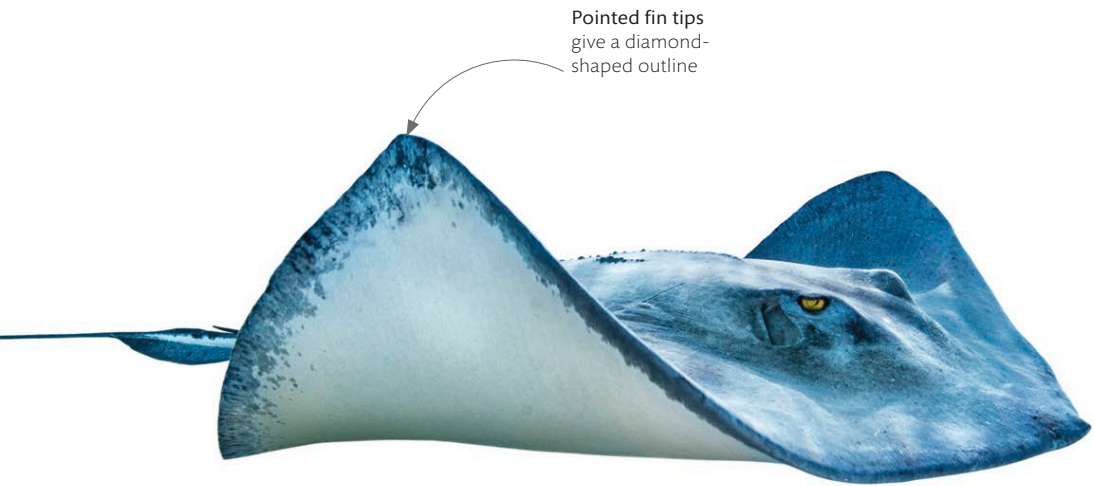
While some sea animals use venom to attack prey, many fish sting only in self-defense. Stingrays, which are cartilaginous fish related to sharks, spend their time resting on the seafloor and hunting prey in the sediment. In this position, with their mouth on the underside, they are vulnerable to attack from above. If they perceive a direct and inescapable threat—for example, when trodden on—they lash their barbed tail upward and deliver their venom.



Sand is whipped up by stingray feeding

Feeding in the sand

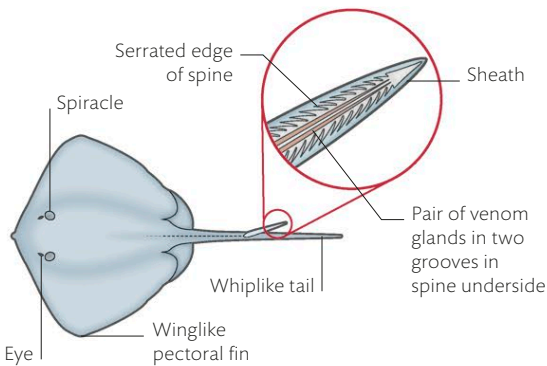
When a stingray hunts, it fans its fins and squirts jets of water from its mouth in order to dislodge its prey (small fish and invertebrates) buried in sediment on the seabed.



Pointed fin tips give a diamond-shaped outline

WHIP AND BARB

The narrow tail of a stingray can be moved at whiplike speed. When the stingray strikes, the tail flicks forward over the head to stab the target with a serrated spine sheathed in venomous mucus. The spine may break off, but it can regrow within several months.



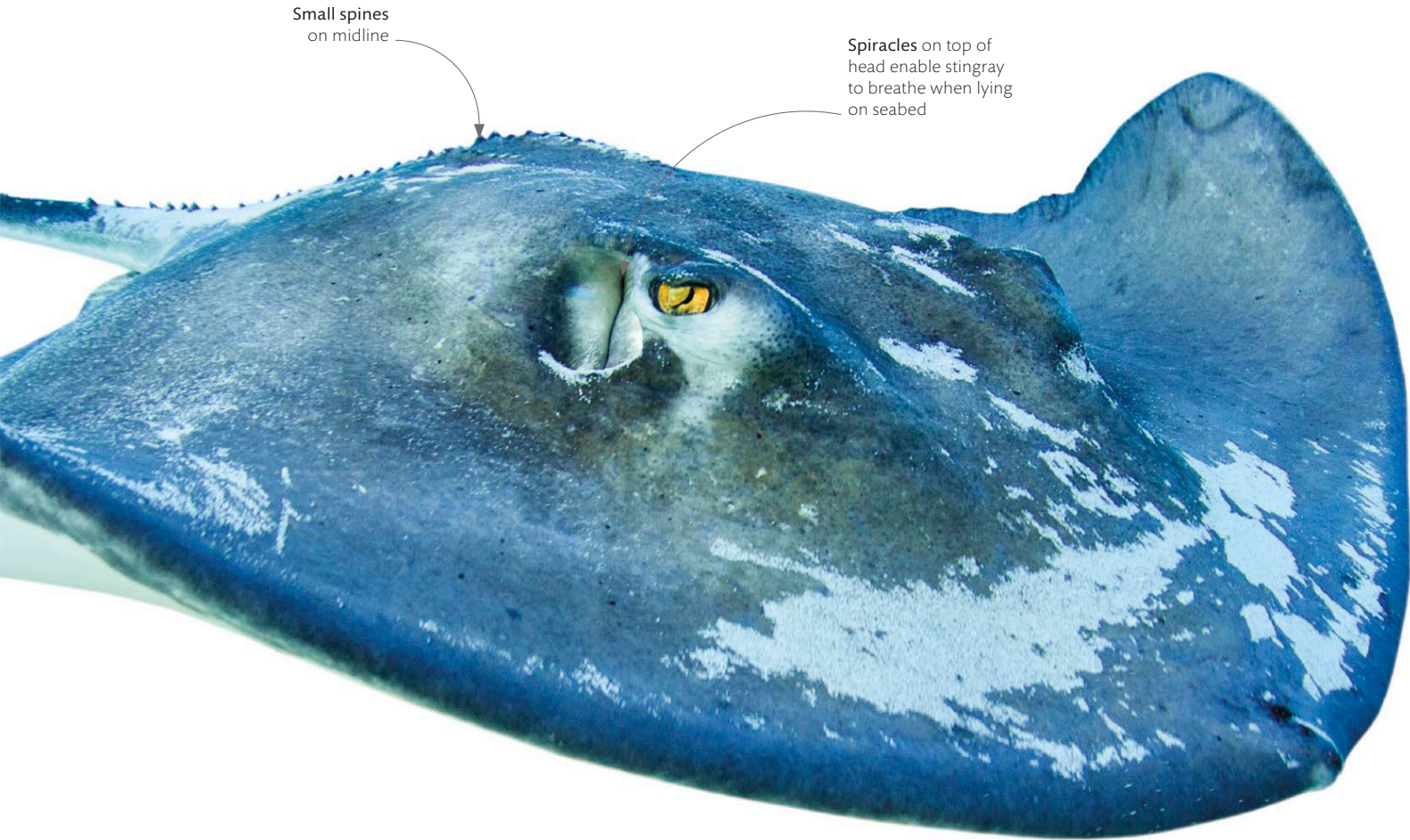
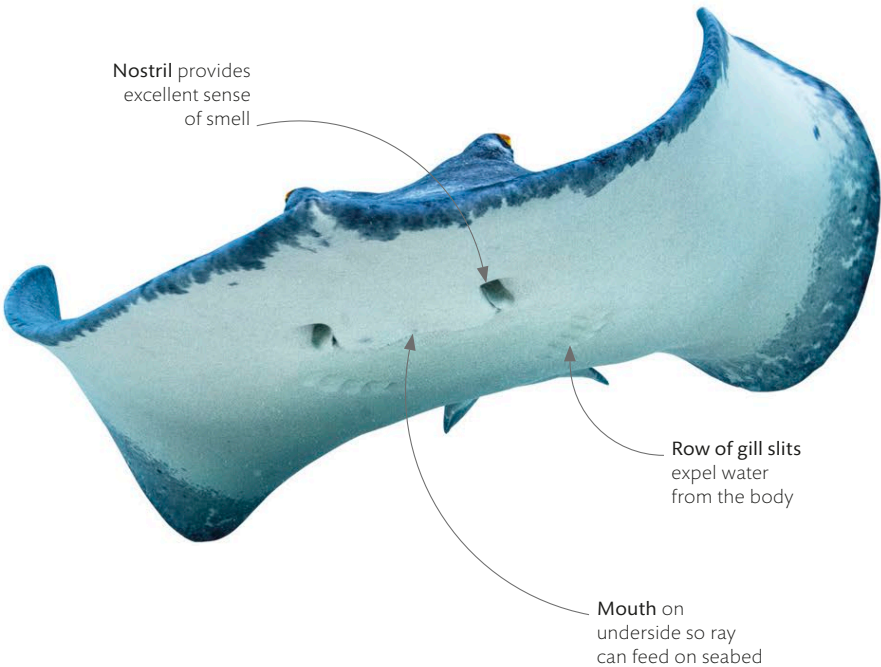
STINGRAY (UPPER SIDE)



Light coloration of underside provides camouflage, making the stingray harder to see from below

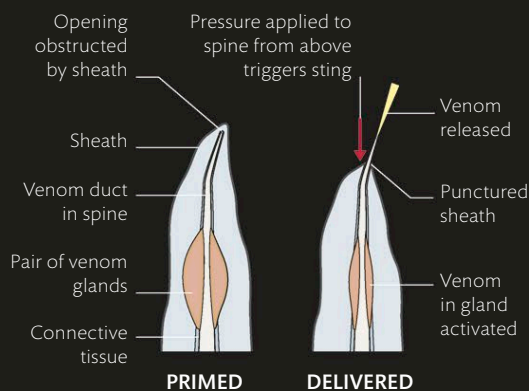
Lying low

Like all rays, the southern stingray (*Hypanus americanus*) is dorsoventrally flattened, with a low profile suited to life on the seabed. The mouth is on the underside to enable it to feed in the sediment. To prevent sand from clogging the gills, water is taken in via spiracles on top of the head. These draw in water, which is passed over the gills and expelled from its gills on the underside.



LETHAL VENOM

Stonefish are the world's most venomous fish, although they use their sting defensively rather than for hunting. Stored in a pair of venom glands, the poison is delivered via 13 modified dorsal fin spines. These act like hypodermic needles to inject a cocktail of toxins that attack a victim's muscles, nerves, blood cells, and cardiovascular system, causing agonizing pain, shock, paralysis, and severe tissue damage.



Engulfed in an instant

The chief hunting aids of the reef stonefish (*Synanceia verrucosa*) are its prominent eyes and large mouth, the outlines of which are disguised by highly textured skin. When the stonefish spots its prey, such as smaller fish or crustaceans, its mouth opens in less than a fiftieth of a second, creating suction that prey are powerless to resist.

concealed danger

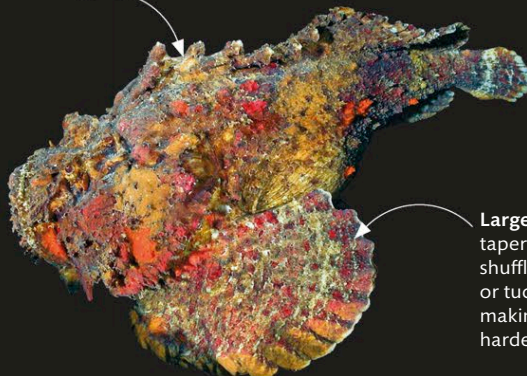
Scorpionfish and stonefish are ambush predators, but unlike stargazers (see pp.232–33) and anglers, which use a lure to tempt prey closer, they rely purely on camouflage and an ability to remain perfectly still for hours at a time. Some scorpionfish and stonefish species are able to change color to match their background, and each fish appears to select resting places that best match their individual coloration.

Skin is highly textured and sometimes carries algae, which may attract herbivorous prey closer to the stonefish

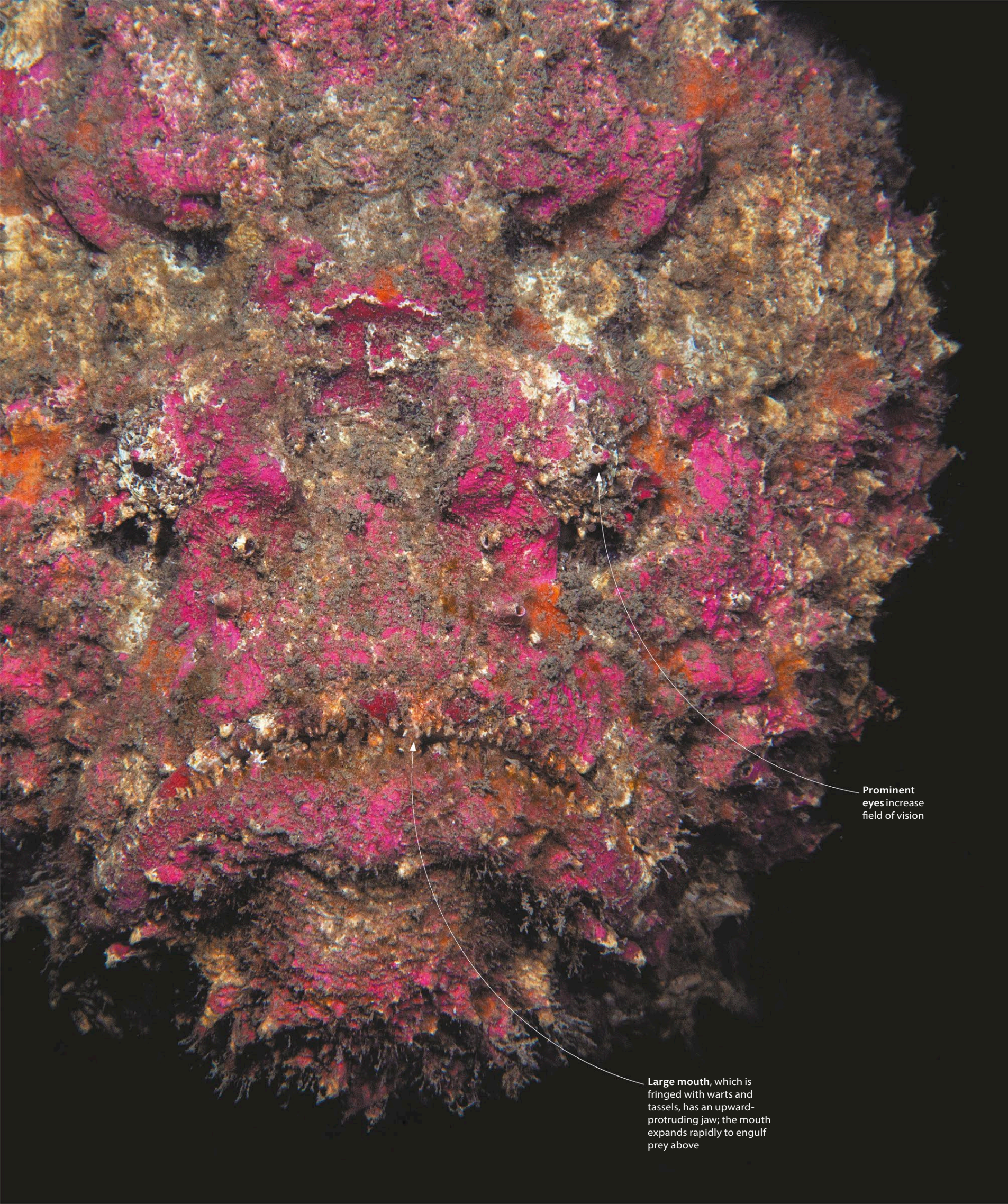
Hiding in plain sight

Lurid pink, orange, and purple are not obvious camouflage colors, but set against the complex background of a coral reef, a reef stonefish can remain invisible to prey and predators until it moves. Despite their camouflage and venom, small stonefish are occasionally eaten by predators such as sea snakes, sharks, and rays.

Dorsal fin contains spines that deliver venom

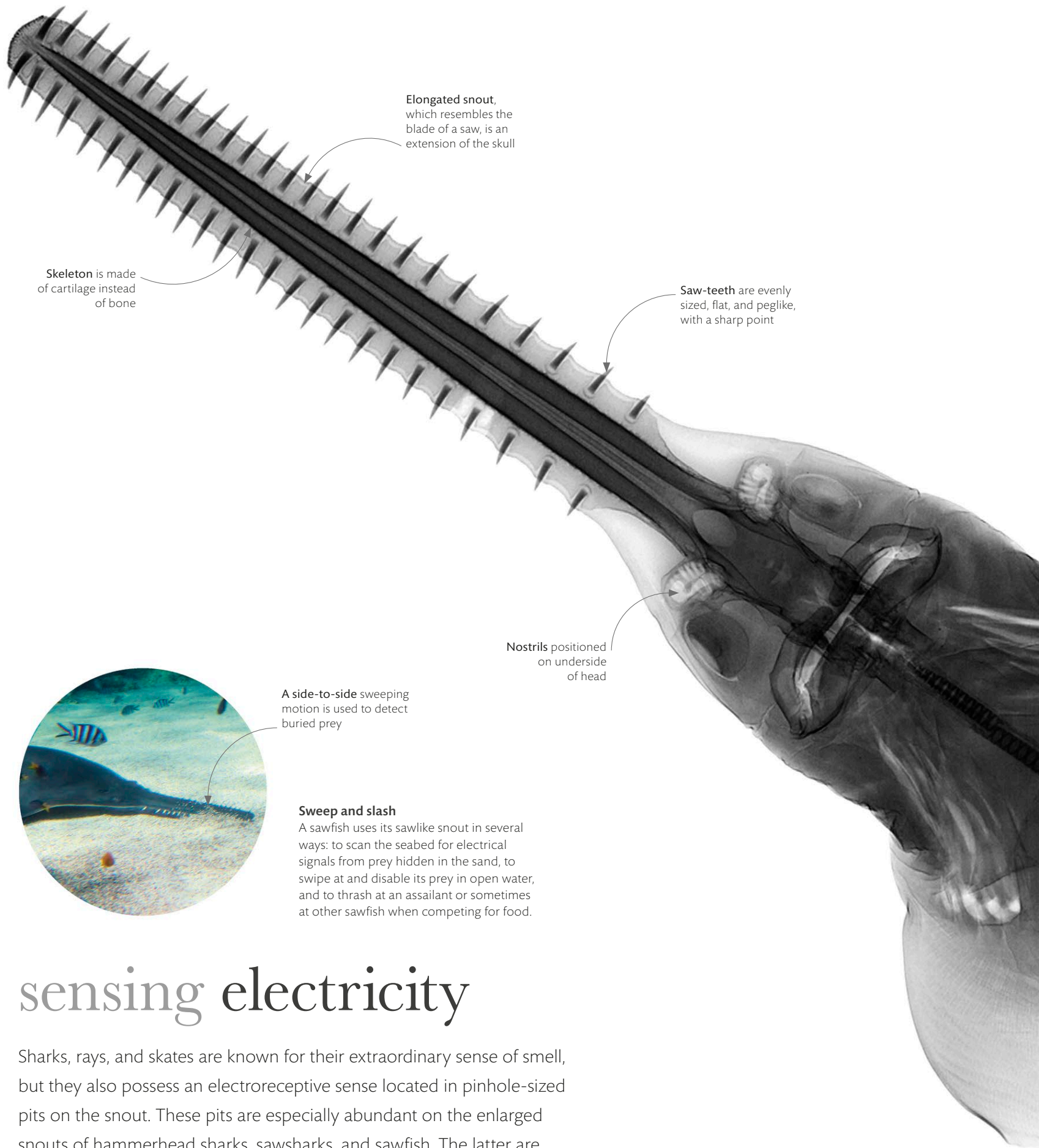


Large pectoral fins and tapered tail are often shuffled under sediment or tucked into crevices, making stonefish even harder to spot



Prominent
eyes increase
field of vision

Large mouth, which is
fringed with warts and
tassels, has an upward-
protruding jaw; the mouth
expands rapidly to engulf
prey above



sensing electricity

Sharks, rays, and skates are known for their extraordinary sense of smell, but they also possess an electroreceptive sense located in pinhole-sized pits on the snout. These pits are especially abundant on the enlarged snouts of hammerhead sharks, sawsharks, and sawfish. The latter are actually rays and only distant cousins of sawsharks. Their similar-looking "saws" are examples of convergent evolution, whereby different species have evolved similar traits in order to adapt to the same environment.

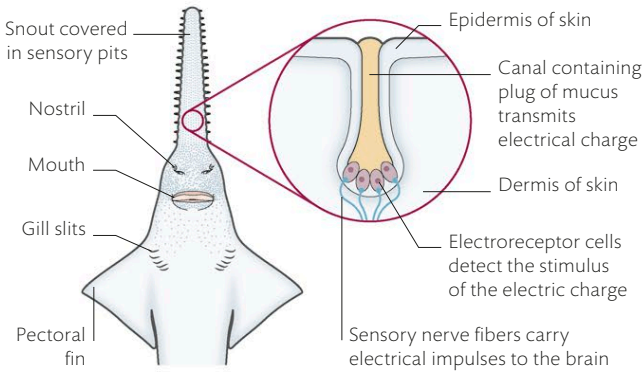
Sawfish teeth

Like all sawfish, the smalltooth sawfish (*Pristis pectinata*, shown here as an X-ray) has a long, narrow snout (rostrum) and two sets of teeth. The most obvious are the large, robust, sharply pointed saw-teeth, which are found all along the snout. In addition, the mouth contains a set of tiny, blunt teeth, arranged in 10–12 rows, which are used for crushing prey.

SENSORY PITS

Sharks and rays detect electrical activity in the muscles of their prey using jelly-filled pits known as ampullae of Lorenzini on their snout and around their mouth. Each pit has a neural connection to the brain, which creates an electrical picture of the surroundings.

SAWFISH (UNDERSIDE)



migrating to breed

Many fish return to the place where they began life in order to breed.

In doing so, they increase the likelihood that their offspring will have similar success. For salmon, which spend most of their adult lives at sea, the return journey to their home rivers and streams is particularly challenging. First, they undergo physiological changes to enable them to reacclimatize to fresh water. During the upstream journey, which can cover hundreds or even thousands of miles, they have to battle swift currents and leap waterfalls, usually without feeding. The strain of the journey combined with hormonal changes lead to programmed death within days of spawning.

Young eels turn from yellow to silver as they enter rivers



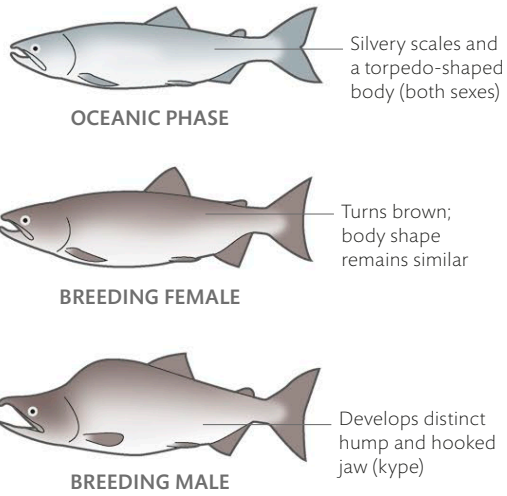
Migrations in reverse

While salmon are anadromous, migrating upstream to spawn and die, freshwater eels are the opposite (catadromous): they begin life at sea, migrate to fresh water, and return to sea to breed.



BODY CHANGES

Salmon undergo many changes in their life history. Newly hatched “fry” develop camouflage markings in the form of vertical bars (the “parr” stage), and as the fish prepare for life at sea (the “smolt” stage), they turn silver. The oceanic phase lasts up to 5 years, then salmon change color again—to brown, red, or green, depending on the species—before they return to fresh water. Breeding males of several species undergo changes in shape, most notably the pink salmon (right).



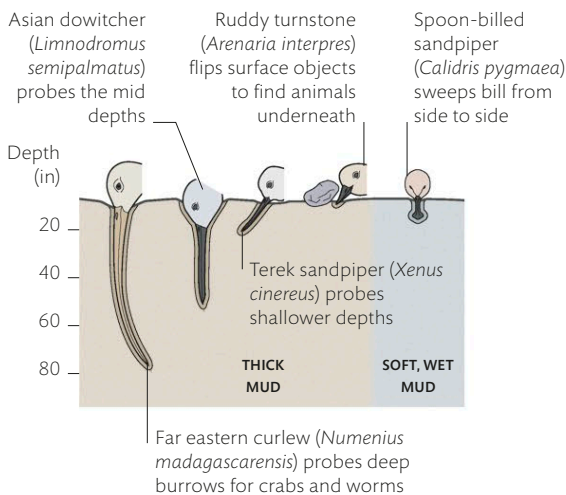
Homing instinct

Salmon rely on two main senses to navigate their way back to their spawning grounds. An ability to detect Earth's magnetic field leads them to their home river, then they use their acute sense of smell to find the gravel bed where they hatched. Here, pink salmon (*Oncorhynchus gorbuscha*) in Alaska are heading upriver to breed.



BILLS FOR PURPOSE

Having different bills with different uses reduces competition for food among shorebirds—even between related species, such as sandpipers. Long, pointed bills—curved or straight—can penetrate deep into thick sediment in search of invertebrate food. Shorter bills are more useful for foraging near or at the surface of the intertidal mud.



BILL ADAPTATIONS IN EAST-ASIAN SANDPIPERS

mud probing

Many shorebirds, including members of the sandpiper family, breed around the Arctic tundra. As the days shorten and insect food dwindles, they fly south to overwinter on intertidal mudflats around the world. Here they enjoy a rich diet of mud-dwelling invertebrates, which helps fuel their long-distance journeys and sustains them through the winter months. Each species is equipped with the perfect tool—a probing bill—to secure a meal.

Switching diets

After catching fly larvae and beetles during the Canadian summer, the short-billed dowitcher (*Limnodromus griseus*) migrates southward and repurposes its bill for probing, as it hunts for mud-burrowing worms, mollusks, and crustaceans along coastlines of the American tropics.



Shorter bill may be better for catching insects

Age-related bills

Like others of the sandpiper family, the insect-eating chicks of the black-tailed godwit (*Limosa limosa*) hatch with proportionately shorter bills than those of mud-probing adults.

The horny sheath around the bill is honeycombed with cavities containing pressure sensors, which enable the bird to detect the movements of buried prey



Slender head may be plunged partway into the mud when foraging, helping the bill reach deeper for burrowing invertebrates



Brown-gray plumage may offer some camouflage from predators when viewed against the ground, both when breeding in subarctic meadows and when feeding on mudflats



A Dutch Ferry Before a Breeze (1640s)

A red-sailed ferry carrying passengers and goods across a blustery bay showcases Simon de Vlieger's draftsmanship and command of the atmospheric effects of waves and weather.

Flying the flag (1660–80)

Celebrating trade in the Dutch Golden Age, this unnamed work by marine artist Abraham Storck depicts merchant ships and galleons at anchor in a tranquil fantasy port. It is a counterpart to another Storck work, *Dutch Ships for a Port in the Mediterranean Sea*.

the ocean in art

the dutch golden age

Riding the crest of a wave in the 17th century, the Dutch rose to great power through their mastery of the sea. Their unparalleled boat- and shipbuilding skills for transportation, trade, and war were matched by a prolific output of great art in every genre. The works of marine artists were especially popular, capturing the might of galleons; the passage of small vessels on inland waters; and the atmospheric effects of weather, sea, and sky.

In 1640, merchant and traveler Peter Mundy counted 26 trade ships arriving at the Dutch Texel Inlet from distant shores and concluded that nowhere in the world came close to it for traffic and commerce by sea. Art, he noted, was a prerequisite in even the poorest homes and in the stalls of butchers, bakers, and blacksmiths. Current-day estimates suggest that between 1640 and 1660, Dutch artists produced more than 1.3 million pictures. Paintings of huge fleets and merchant

ships in foreign ports reflected Dutch maritime and economic dominance. Major works, such as Abraham Storck's *The Four Days' Battle* (1666), showing fighting in the Anglo-Dutch War, reflected constant naval activity to keep trade routes open. Other artists, including Jan van Goyen, Ludolf Backhuysen, and Willem van de Velde the Younger, depicted coastal sailing and the quiet harbors, fishing inlets, and winter skating intrinsic to Dutch domestic life.

“As For the art off Painting and the affection off the people (of the Netherlands) to Pictures, I thincke none other goe beeyond them ...”

PETER MUNDY, *THE TRAVELS OF PETER MUNDY IN EUROPE AND ASIA*, 1608–1667





In the pink

As with flamingos and the scarlet ibis, the pink coloration of the roseate spoonbill (*Platalea ajaja*) comes from carotenoid pigments that are found in its food. The intensity of color varies according to age, season, and location, and the availability of carotenoid-rich prey.

Throat and esophagus are elastic to accommodate prey, which is swallowed whole

Head and neck become bald in adult birds

Plumage ranges from white to deep crimson



sweeping for food

For birds feeding in murky water, it is often difficult to see beneath the surface. As a result, several species have evolved a sensitive bill that enables them to detect food in shallow waters without relying on their sense of sight—an adaptation that also allows them to continue feeding at night. All six species of spoonbill hunt by “tactolocation,” detecting small fish, shrimp, and aquatic insect larvae and plant matter in lagoons, pools, and estuarine waters up to 12 in (30 cm) deep.



Orange bill of young spoonbills fades to gray in adult birds

Early days

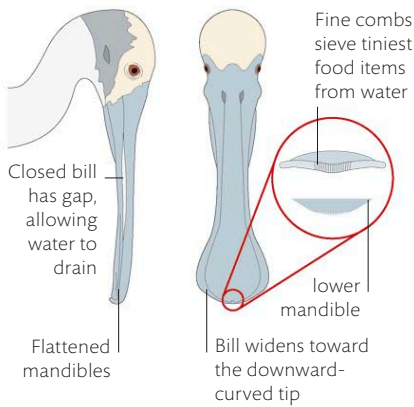
Young spoonbills start life with a short, straight beak. This elongates rapidly in the days after hatching, begins to broaden at the tip after 1 to 2 weeks, and attains the characteristic adult shape after about 1 month.



Broad-tipped bill has a touch-sensitive lining and snaps shut to trap larger prey

FEEDING TECHNIQUE

A spoonbill feeds in shallow water, sweeping its partially open bill in a side-to-side or circular motion to create a vortex. After dislodging food from the bottom, it traps the catch between its broad mandibles, lifts its head, and claps its bill shut, crushing its prey before swallowing.



SPOONBILL FEEDING



Preparing for splashdown
 Ospreys plunge from heights of 130 ft (40 m) on long, narrow wings. This wing shape is ideal not only for diving but also for hovering over large bodies of water while selecting a suitable target.

fishing with feet

Raptors—birds of prey, such as eagles and hawks—typically catch their quarry with talons that pierce the prey’s flesh. The osprey (*Pandion haliaetus*) is the only daytime raptor that feeds almost exclusively on fish. It hunts like other raptors, meaning that it dives feet first—but it does so mainly in saltwater habitats. Once its target is properly gripped, the osprey is capable of flying back to its perch carrying a fish half its body weight.

CATCHING SLIPPERY PREY

Raptors usually have an arrangement of toes with three pointing forward and one pointing back—like most types of bird. This helps with perching, as well as gripping prey. But slippery, wriggling fish need a firmer grip, so the osprey has a reversible outer toe, allowing two talons to hook either side of a catch. Smaller fish can be held with one foot, but heavier ones are secured using both feet, one in front of the other.

Normal position of outer toe

Outer toe twists backward to get a firmer grip

OSPREY FEET



Bill has a long, sharp hook that is able to penetrate the tough, scaly skin of large fish

Dense, oily plumage keeps the feathers waterproofed when diving for fish

Toes carry spiny pads on their undersides, which enable the feet to cling tightly to a fish

Coastal raptor

Despite having long legs to help reach for fish, an osprey's natural buoyancy means it cannot penetrate more than about 3 ft (1 m) underwater. It therefore catches surface-dwelling fish in shallow bays and along shorelines. This technique is successful worldwide: the osprey is one of the most wide-ranging of all bird species, found in the Americas, Africa, Eurasia, and Australasia.

mangroves and salt marshes

These tidal habitats are dominated by trees and other true plants that have adapted to life in salt water. They also protect shorelines from coastal erosion and provide homes to diverse communities of other living things.

growing in salt marshes

Plants that grow on land or rooted in fresh water rely on salts in their tissues to pull water up into their leaves; water tends to seep toward higher salt concentrations by a process called osmosis.

Plants of intertidal marshes, such as sea-blites, are specially adapted to the saltier conditions, typically with fleshy leaves that accumulate the extra salt needed to keep drawing in water.



Maturing shoots turn violet-red with betacyanin, the same pigment found in beets

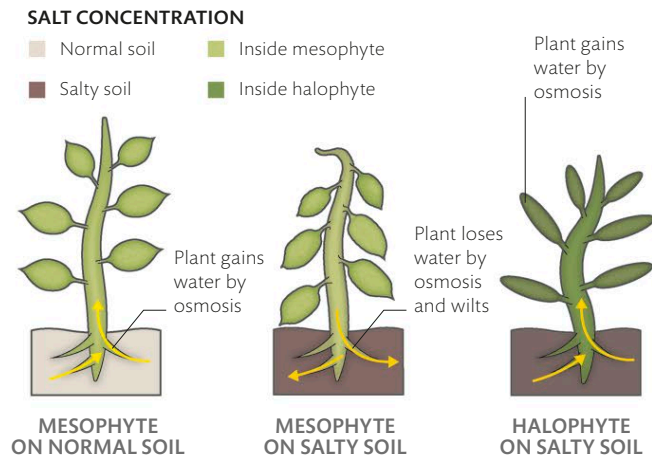
Bicolored shoots

Sea-blites, such as the Australian *Suaeda australis*, turn from green to red as they build up betacyanin—a pigment that protects cells in the salty conditions.



GAINING AND LOSING WATER

Plants adapted to salty conditions are called halophytes. By concentrating salt in their tissues—at higher levels than in their surroundings—they absorb water by osmosis, from lower to higher salt concentration. Conventional land plants, known as mesophytes, have lower salt concentrations than seawater, so they lose water by osmosis in salty conditions.



Salt marsh annual

In China's Liaohe River delta, conditions are too wet and salty for most types of plant to survive. But the Eurasian sea-blite (*Suaeda salsa*) thrives in abundance. It grows from seed each year, and during fall, its shoots gradually transform the shoreline into a spectacular red "beach."







Colorful colonists

Colonizers of mangrove roots include bluebell tunicates (*Clavelina*). Where sunlight can reach, photosynthesizing green algae thrive alongside them.

The tunicates' bottle-shaped bodies draw in water to filter out food particles

A colony of tunicates arises because each individual can produce neighboring clones



colonizing roots

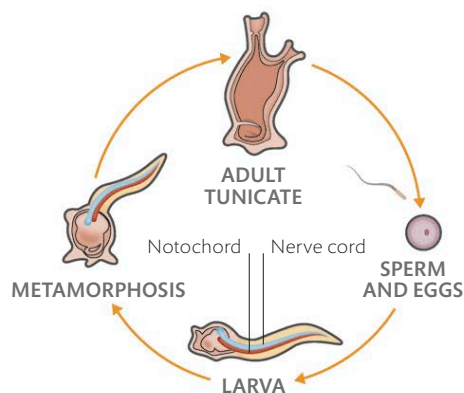
Along muddy shorelines around the tropics, mangrove roots growing like pillars in the water often provide the only solid surface in the intertidal habitat. As a result, they are quickly colonized by opportunistic algae and animals. Competition for space is intense. For the mangrove, these underwater “gardens” are a mixed blessing: they nourish the roots with their waste but also smother the pores through which the roots breathe.

Underwater garden

Submerged under nutrient-rich waters at high tide, these mangrove roots are all but hidden by plankton feeders such as tentacled polyps and bottle-shaped tunicates. Colonists that grow faster may have the advantage, but some can produce chemicals that repel their neighbors.

TUNICATE LIFE CYCLE

Tunicates, like many ocean invertebrates, have a life cycle that alternates between being attached and being free-swimming. As sedentary filter feeders, they trap food particles from seawater circulating through their soft bodies. Their nonfeeding larvae are supported by a firm rod called a notochord. This structure is anatomically equivalent to a backbone—evidence that tunicates are more closely related to vertebrates than to other invertebrates.



growing on stilts

A plant that grows into a tall tree benefits from reaching more light than its shorter neighbors. But the extra weight involved in scaling such heights needs strong support. On muddy tropical shores, salt-tolerant trees called mangroves manage on the soft ground by distributing their weight over a wide area with stiltlike roots or with buttress roots that spread horizontally along the ground. This stops the trees from toppling, even when their bases are submerged by the incoming tide. The high, arching stilts also collect vital oxygen, enabling the trees to thrive where the sludgy ground is not easily aerated and keeping the root tissues alive far below the surface.



Salt crystals form when saline water secreted by leaf glands evaporates

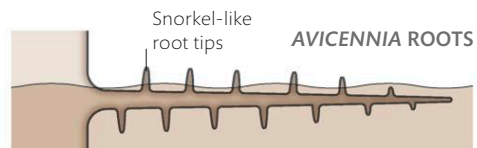
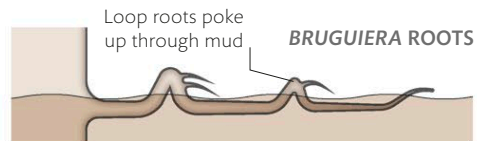
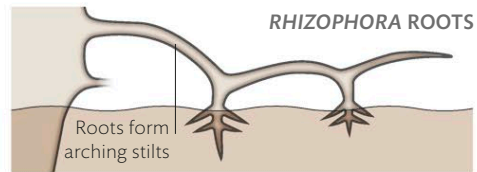
Coping with salt

Mangroves can tolerate high levels of salt in their tissues. Some species exude excess salt from their leaves, which become coated with white salt crystals.



ROOTS THAT BREATHE

In order to distribute oxygen, mangrove roots are honeycombed with air-filled spaces. Air enters the roots at high tide through pores called lenticels, but the roots' shape varies between species. Unlike the stilt-rooted *Rhizophora* mangroves, the roots of *Bruguiera* emerge from the mud as a series of loops, whereas *Avicennia* mangroves reach the air through pneumatophores—root tips that grow upward from the mud's surface, effectively acting as snorkels.



Shoreline thicket

The stilt-based architecture of mud-growing mangrove trees provides a unique forest habitat along tropical coastlines around the world. In southern Asia, the arching roots of the red mangrove (*Rhizophora mangle*) are home to small foraging animals as diverse as crabs, mudskippers, and lizards—and even to monkeys and birds.





Brown-colored symbiotic algae are concentrated in the oral arms; by swimming upside down, the jellyfish exposes the algae to sunlight

living upside down

Living in mangrove-fringed lagoons and in seagrass beds—often gathering by the hundreds—is an unusual jellyfish that lives upside down, with its stinging arms waving upward in the water. Settled on the bottom in the sunlit shallows, it relies on brown-colored algae peppering its flesh to make food by photosynthesis. Food made in this way supplements the nutrients the jellyfish derives from its captured prey.

Seabed jelly

The Indo-Pacific upside-down jellyfish (*Cassiopea andromeda*) pulsates its bell and flickers its arms in the clear, warm water. The arms are multipurpose: as they move back and forth through the water, they absorb oxygen, trap food, and expose their food-making algae to the sunlight.

Inverted bell

Like more conventional jellyfish, *Cassiopea* uses the pulsating action of its bell for propulsion, but it can do this with its arms facing upward or downward.

Oral arms are packed with stinging cells that can paralyze small prey; they may also release mucus-coated balls of stinging cells into the water

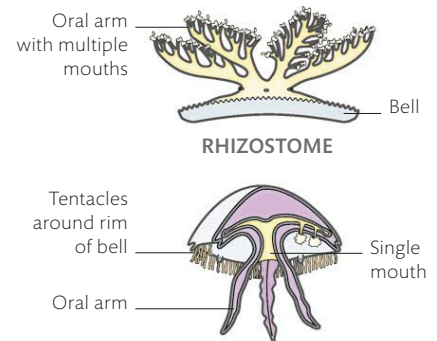
The bell is encircled by muscle fibers that contract to cause the bell to pulsate

Branching oral arms have frilly tips that give them a cauliflowerlike appearance; the tips of the arms are punctured with multiple tiny mouths

The colored streaks on the bell, which itself can be up to 12 in (30 cm) in diameter, vary from brown to blue

RHIZOSTOME JELLYFISH

Cassiopea belongs to a group of jellyfish called rhizostomes, meaning "root-mouthed." Instead of true tentacles and a single mouth, rhizostomes have oral arms that carry all the stinging cells, as well as tiny mouths. The mouths open into channels that work much like roots, collecting food particles and passing them to the stomach for digestion.



MOON JELLY ("TYPICAL" JELLYFISH)

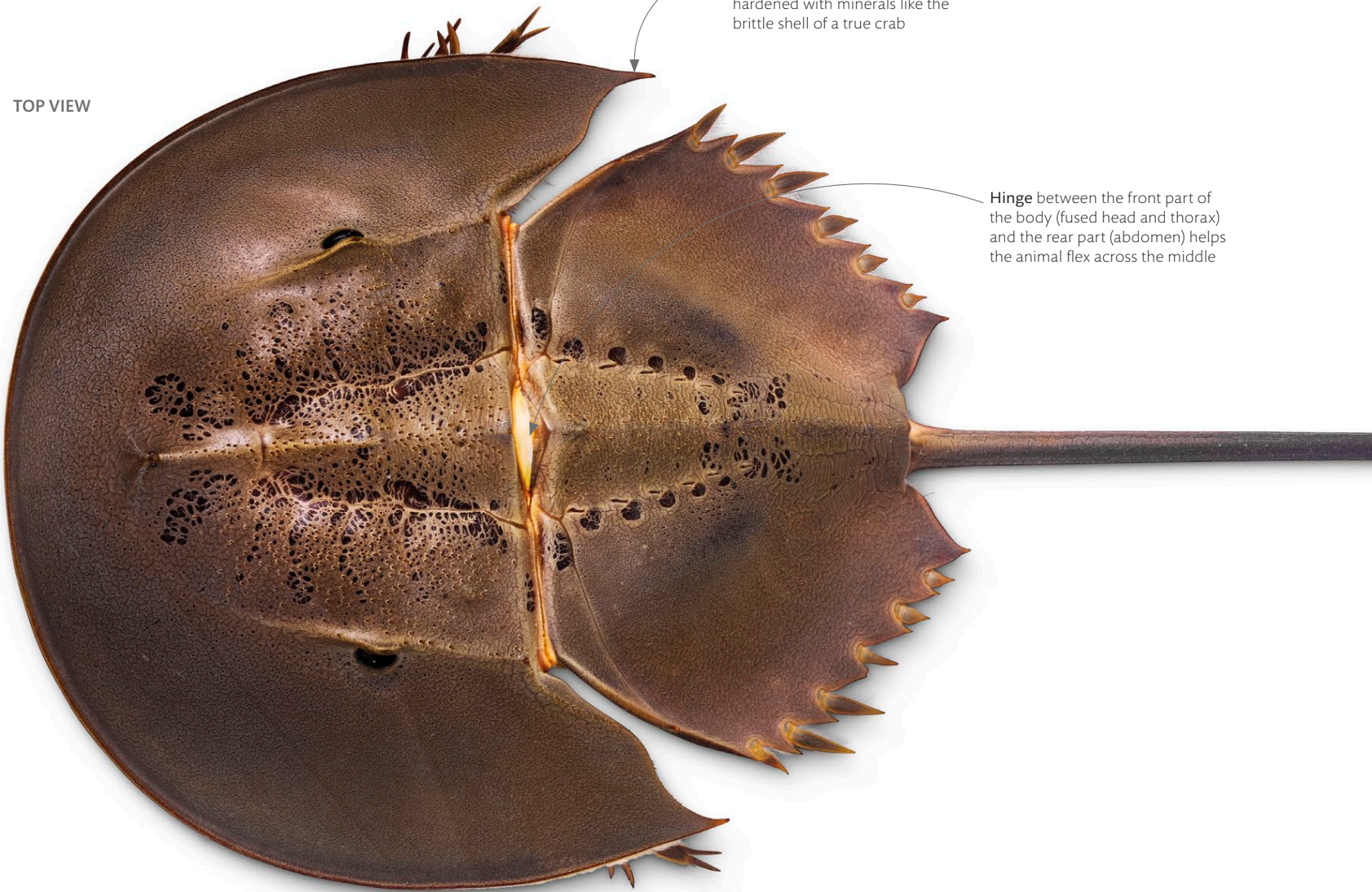
living fossil

Horseshoe crabs appeared in the oceans half a billion years ago, when the jointed-legged arthropods were diversifying via evolution into insects, arachnids, and crustaceans. Ancient, fossilized horseshoe crabs are very similar in shape to those alive today, suggesting that these animals have changed little over millions of years of evolution. Despite their name and their hard shell, they are more closely related to spiders than to true crabs.

Ancient survivor

The mangrove horseshoe crab (*Carcinoscorpius rotundicauda*) and its relatives belong to an ancient group that includes extinct giant water “scorpions” known as eurypterids. Their shared body plan—a fused head and thorax, a separate abdomen, and a shieldlike carapace—dates from the dawn of invertebrate evolution.

TOP VIEW



Carapace is stiffened with a tough material called chitin, but it is not hardened with minerals like the brittle shell of a true crab

Hinge between the front part of the body (fused head and thorax) and the rear part (abdomen) helps the animal flex across the middle

Stiff, tail-like **telson** is used as a rudder to help steer when swimming

A pincer (chela) on the end of each walking leg is used for grabbing prey and passing it forward toward the mouth

BOTTOM VIEW

Grinding plates called gnathobases at the base of the legs break up prey into pieces tiny enough to fit inside the small mouth

Males cling to females as they fertilize thousands of eggs that are then buried in sand

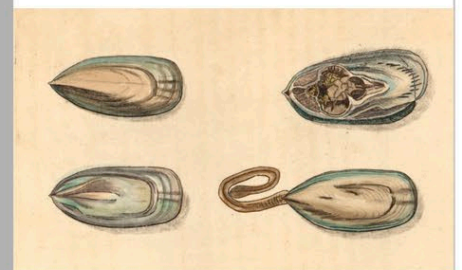


Mating horseshoe crabs

Atlantic horseshoe crabs (*Limulus polyphemus*) gather in huge numbers to breed along shallow sandy coastlines—much like their ancestors did millions of years ago.

UNCHANGED BY TIME

The stability of some ocean habitats may help explain why evolutionary change in certain groups seems minimal. *Lingula* brachiopods (shelled animals that burrow in sediment) could be the least altered of all animals. Fossil shells from the Cambrian Period, 540 million years ago, are virtually identical to shells of modern-day *Lingula*.



LINGULA BRACHIOPODS





Seeing salt

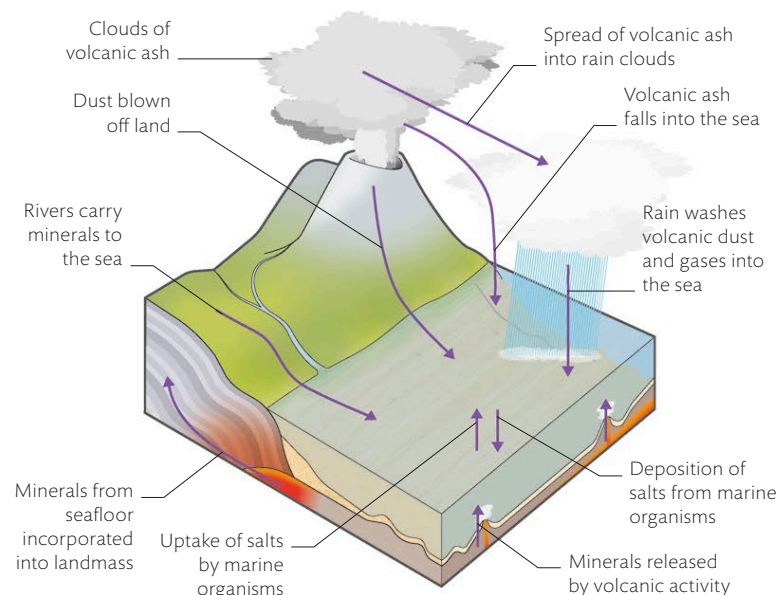
The Dead Sea, an inland sea between Israel and Jordan, has an average salinity of about 34 percent. The high rate of evaporation leads to the formation of visible deposits of salt.

salt water

The first oceans that formed on Earth some 4 billion years ago contained little salt but were weakly acidic as a result of gases released by volcanic activity. But today, as a result of dissolution of minerals from the land and the seafloor, the oceans contain over 5.5 trillion tons (5 trillion tonnes) of salts from nearly 100 different elements. The concentration of salts in the oceans is between 3.3 and 3.7 percent. Salinity is greater in warm, semienclosed seas such as the Mediterranean and the Red Sea. The two main components of ocean salts are sodium and chlorine, with smaller amounts of magnesium, sulfur, calcium, and potassium. If the oceans evaporated completely, salt residues would be equivalent to a layer 150 ft (45 m) thick over the entire planet.

THE SALT CYCLE

In the chemical balancing act that maintains the salinity of the oceans, elements from mid-ocean ridges, volcanoes, and dissolved in rivers are balanced by the removal of salts by living organisms and the deposition of their remains on the seafloor. Some salts are also removed by chemical changes (mineralization) and by incorporation of sediments into the substrate as a result of shifts in the seafloor.





Eyes on stalks allow the crab to see signals and threats from farther away

Showing off

Male crabs that have larger claws and an impressive waving display are more likely to attract a mate. It takes a strong male North American red-jointed fiddler crab (*Minuca minax*) to grow and wield a heavy appendage, but some males appear to gamble by growing impressive-looking lightweight claws that are actually too flimsy for fighting.

Waving claw, present only in males and used for attracting a female, threat displays, and fighting, can be on left or right side

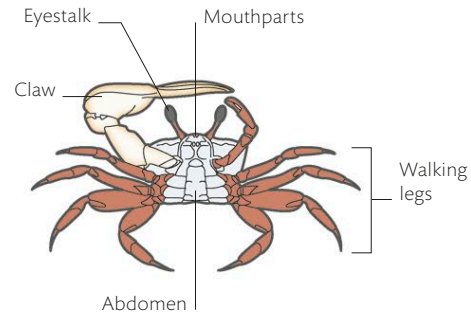


Smaller claw of male is used for feeding

Walking legs lack pincers

CRUSTACEAN APPENDAGES

Crabs, shrimp, lobsters, and crayfish are classified as decapod crustaceans, which all have a segmented body and one pair of appendages per segment. Decapod means “ten legs,” referring to four pairs of walking legs and one pair that bears the claws. Other appendages serve as antennae, antennules (small antennae), and mouthparts. Crabs differ from other decapods in carrying their abdomen tucked under their body rather than extended behind them.



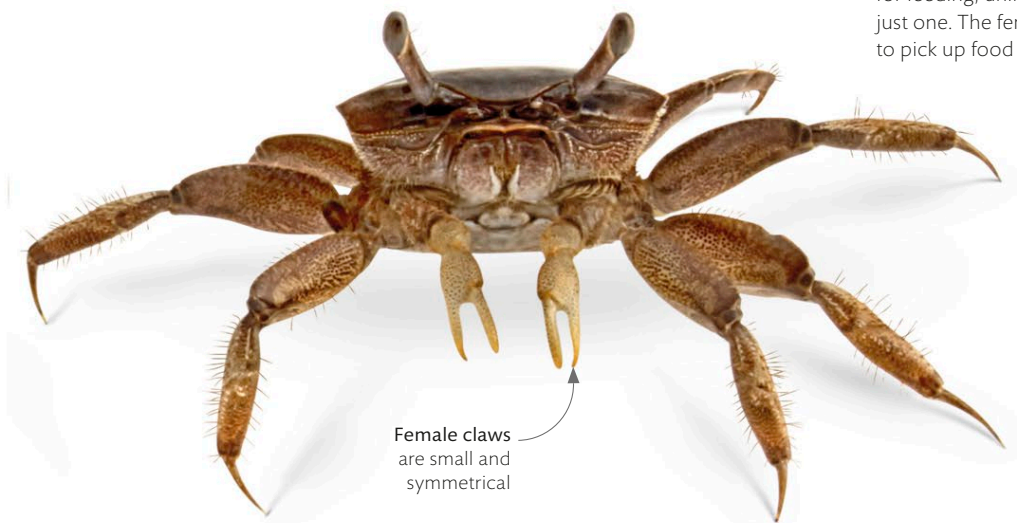
CRAB (UNDERSIDE)

waving crabs

Many species of crab exhibit pronounced differences between males and females, a phenomenon known as sexual dimorphism. The males are often equipped with outsized claws (chelae), used for fighting and social signaling, including threat displays and courtship. Most fiddler crabs live on flat expanses, such as sandy beaches and mudflats, where visual signals can be seen from relatively long distances. Males dig breeding burrows and wave from the entrance to attract passing females. Before mating, the male plugs the burrow from inside to keep rivals out and protect the female and her eggs. She emerges when her offspring are ready to hatch into the sea.

Female advantage

The female fiddler crab uses both claws for feeding, unlike the male, which uses just one. The female is therefore able to pick up food twice as fast.



hunting above water

In bankside waters, including mangrove swamps, many predatory fish supplement underwater prey with targets on overhanging vegetation above the surface. Some leap vertically upwards to catch an insect, but archerfish also use a second tactic: they spit a jet of water to topple the target. They are remarkably accurate—even in rippling, cloudy waters. Their lightning-fast speed also means they can grab the prize before nearby competitors even see it fall.



Archerfish can leap up to twice their 12-in (30-cm) body length above water

Jumping for prey

Archerfish also strike prey on low-hanging leaves by launching their whole body out of the water. This energetic hunting method can often be more successful than shooting prey.

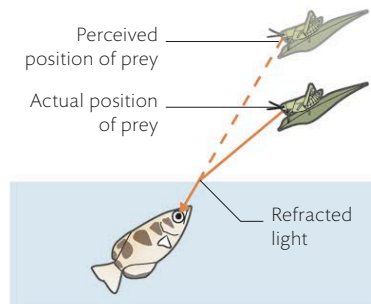


Large eyes provide acute vision, even in the low light of densely shaded mangrove swamps

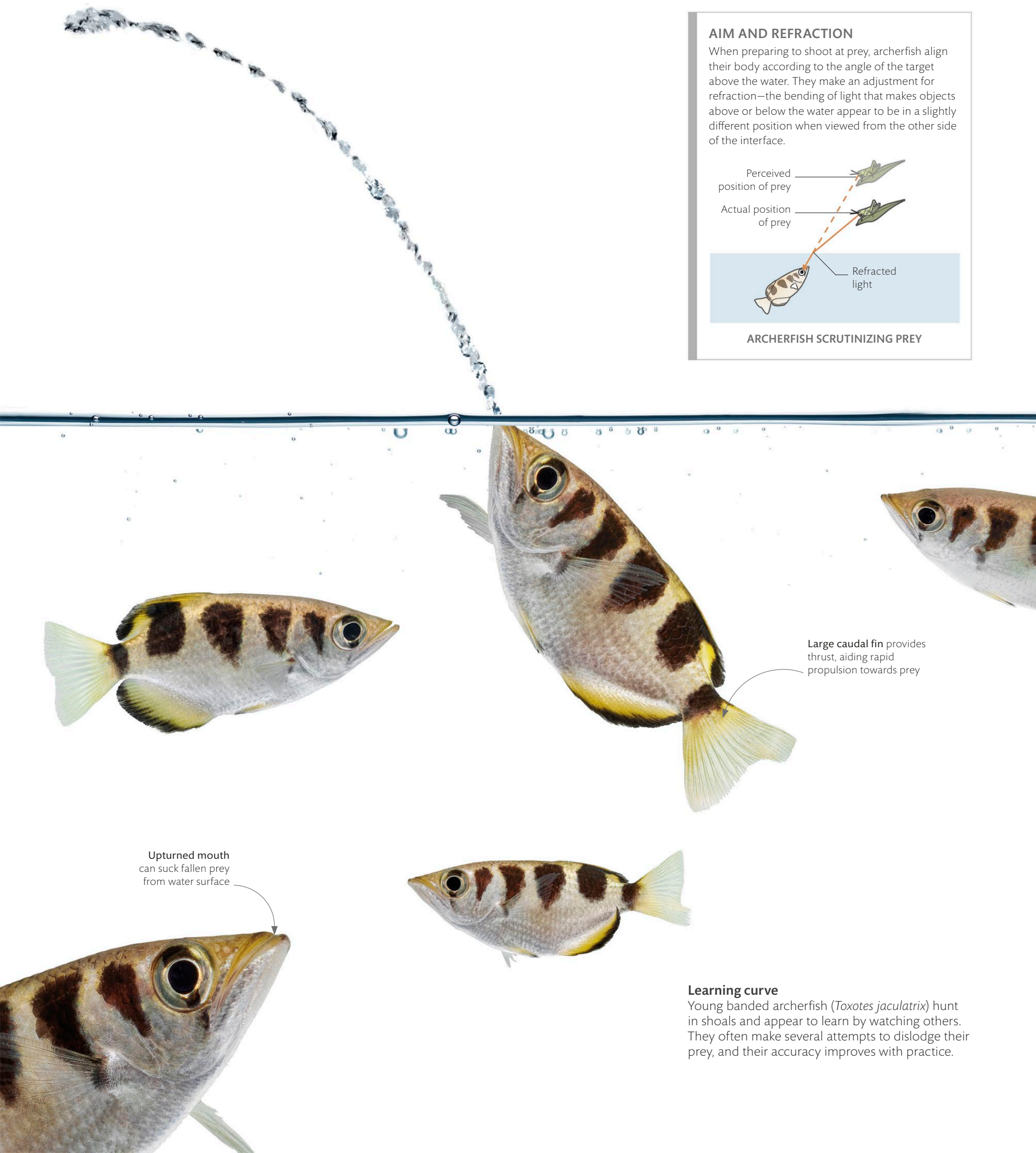


AIM AND REFRACTION

When preparing to shoot at prey, archerfish align their body according to the angle of the target above the water. They make an adjustment for refraction—the bending of light that makes objects above or below the water appear to be in a slightly different position when viewed from the other side of the interface.



ARCHERFISH SCRUTINIZING PREY

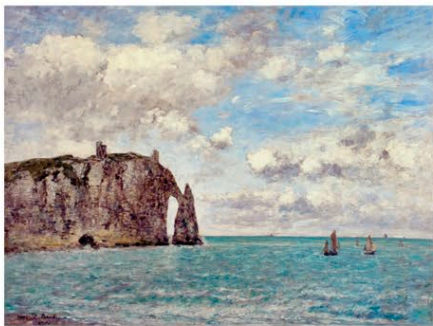


Upturned mouth
can suck fallen prey
from water surface

Large caudal fin provides
thrust, aiding rapid
propulsion towards prey

Learning curve

Young banded archerfish (*Toxotes jaculatrix*) hunt in shoals and appear to learn by watching others. They often make several attempts to dislodge their prey, and their accuracy improves with practice.



Étretat. The Cliff of Aval (1890)

A Normandy seascape by Eugène Boudin features his characteristic luminous skies and tranquil waters, but also the striking arch of rock made famous by his pupil Claude Monet.

Impression, Sunrise (1872)

Claude Monet's hazy view of the port of Le Havre, in Normandy, is credited with giving rise to the name of the Impressionist movement. Awash with colors against a vague backdrop of ships and buildings, the work was vilified when it was exhibited in Paris in 1874.

the ocean in art

impressions of the sea

Claude Monet is often regarded as the father of the Impressionist movement. In his later years, he paid tribute to the artist who taught him how to paint the sea. In 1858, Monet was an 18-year-old caricaturist from Normandy, France, when he first met Eugène Boudin, 20 years his senior. Boudin introduced the young Monet to the naturalistic approach of painting “en plein air” (outdoors), where he learned to absorb and capture the atmosphere of the coast.

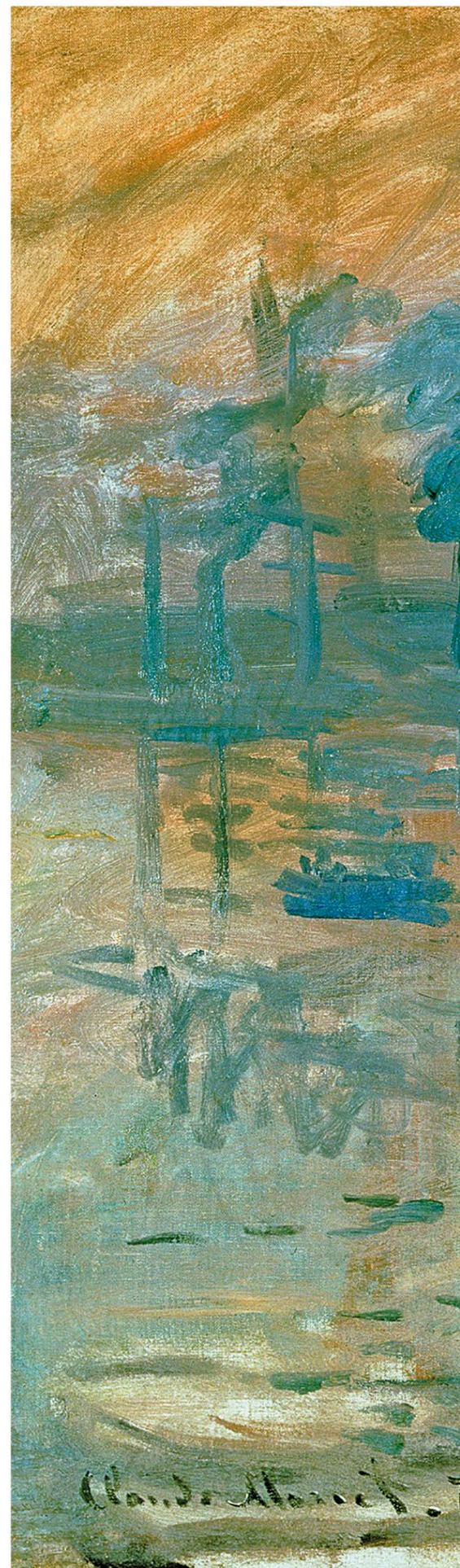
Boudin was a master of expansive seascapes, skiescapes, and tranquil scenes of gentlefolk picnicking and promenading along the shore. Monet took on board his friend's advice that he should “learn to appreciate the sea, the light, (and) the blue sky,” but he went on to develop his own Impressionist techniques to portray the dramatic Normandy coastline. His focus was on capturing the colors of shadows in different lights, eliminating black to create a more vibrant effect. He painted the arch of rock called the Manneporte

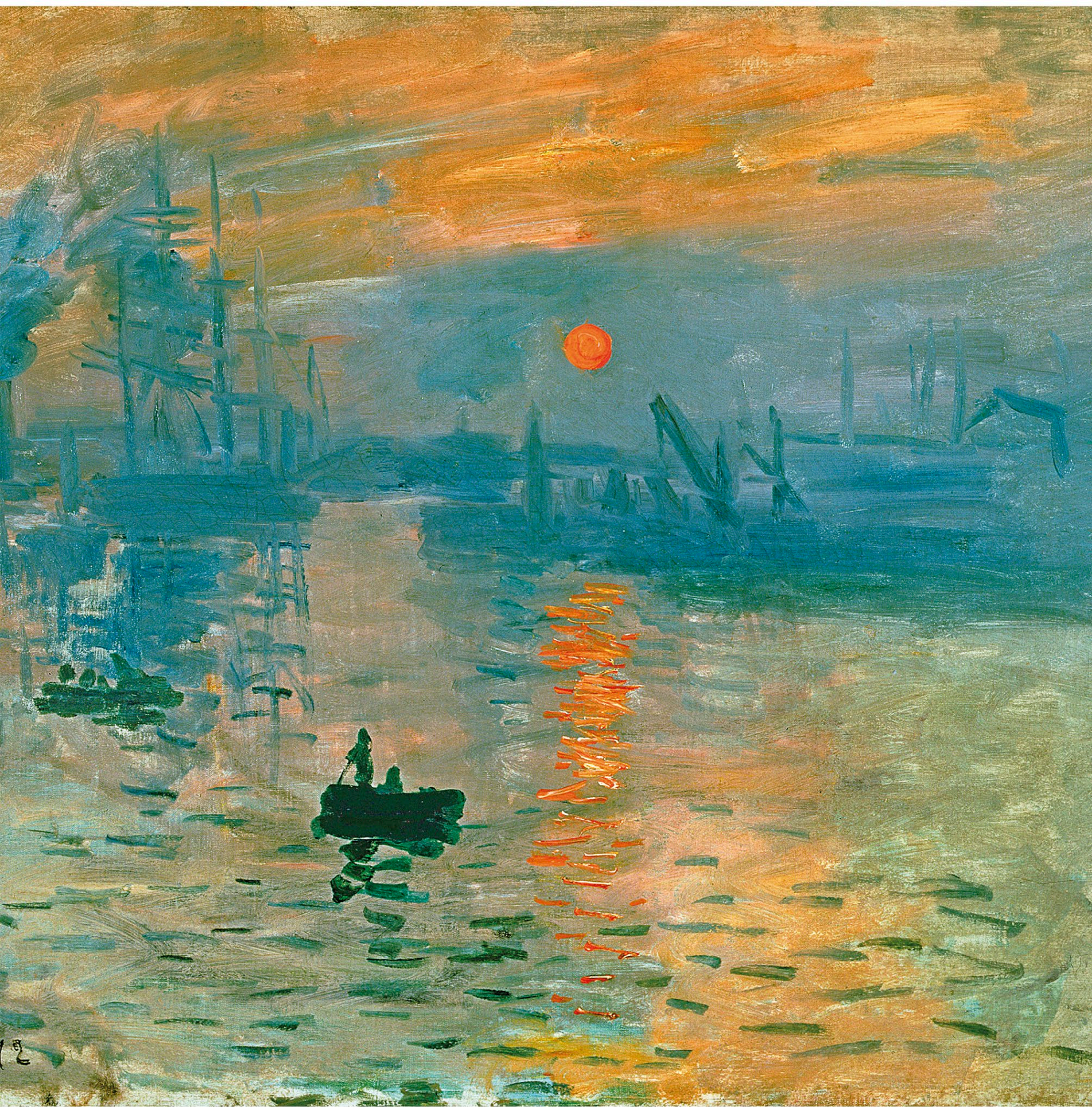
at Étretat up to 18 times, using quick dabs from loaded brushes to fix a ray of light or a cloud and layering different tints while still wet instead of mixing colors.

In his journals, the French writer Guy de Maupassant describes Monet on the beach in Étretat in 1886, switching between five or six canvases as the light changed throughout the day. On one occasion, writes Maupassant, “he took a downpour beating on the sea in his hands and dashed it on the canvas—and indeed it was the rain that he had thus painted ...”

“A landscape is only an impression, instantaneous, hence the label they’ve given us.”

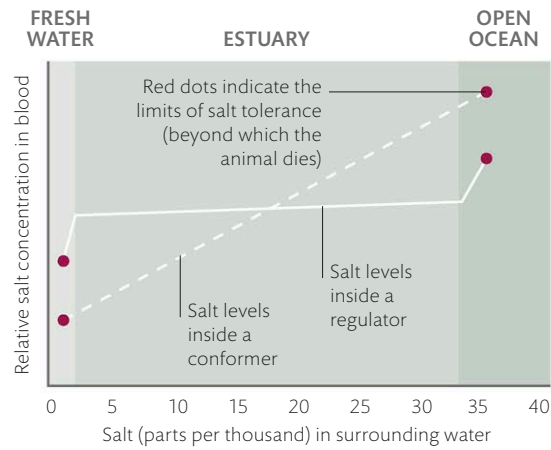
CLAUDE MONET, INTERVIEW FOR LA REVUE ILLUSTRÉE, 1889





CONFORMERS AND REGULATORS

Many marine animals—such as jellyfish, crustaceans, and starfish—have salt levels in their bodies that change, or conform, with their surroundings. Other animals, including most vertebrates, keep their salt levels constant: they regulate. Both conformers and regulators can survive the changing salinity in an estuary. The conformers tolerate extremes of salt inside the body; the regulators resist this from happening.



SALINITY IN CONFORMERS AND REGULATORS



adapting to changing salinity

Salt levels in the open ocean are relatively stable, at around 35 parts per thousand. The influence of fresh water added by rivers has little effect except near the coasts. Most ocean organisms—just like those in freshwater habitats—are so adapted to the water around them that they cannot survive changes in salinity: they are described as stenohaline. In estuaries, where salt levels fall and rise with the tides, life is euryhaline: it tolerates fluctuating salinity.

Tears produced by lachrymal glands contain a high concentration of salt; the glands secrete excess salt when the turtle gets dehydrated

Horny beak is used to crush prey such as fish and marsh snails

Foot pushes backward against the water for thrust

Skin is cornified (thickened) with plenty of reinforcing protein called keratin, which helps reduce absorption of excess salt or water

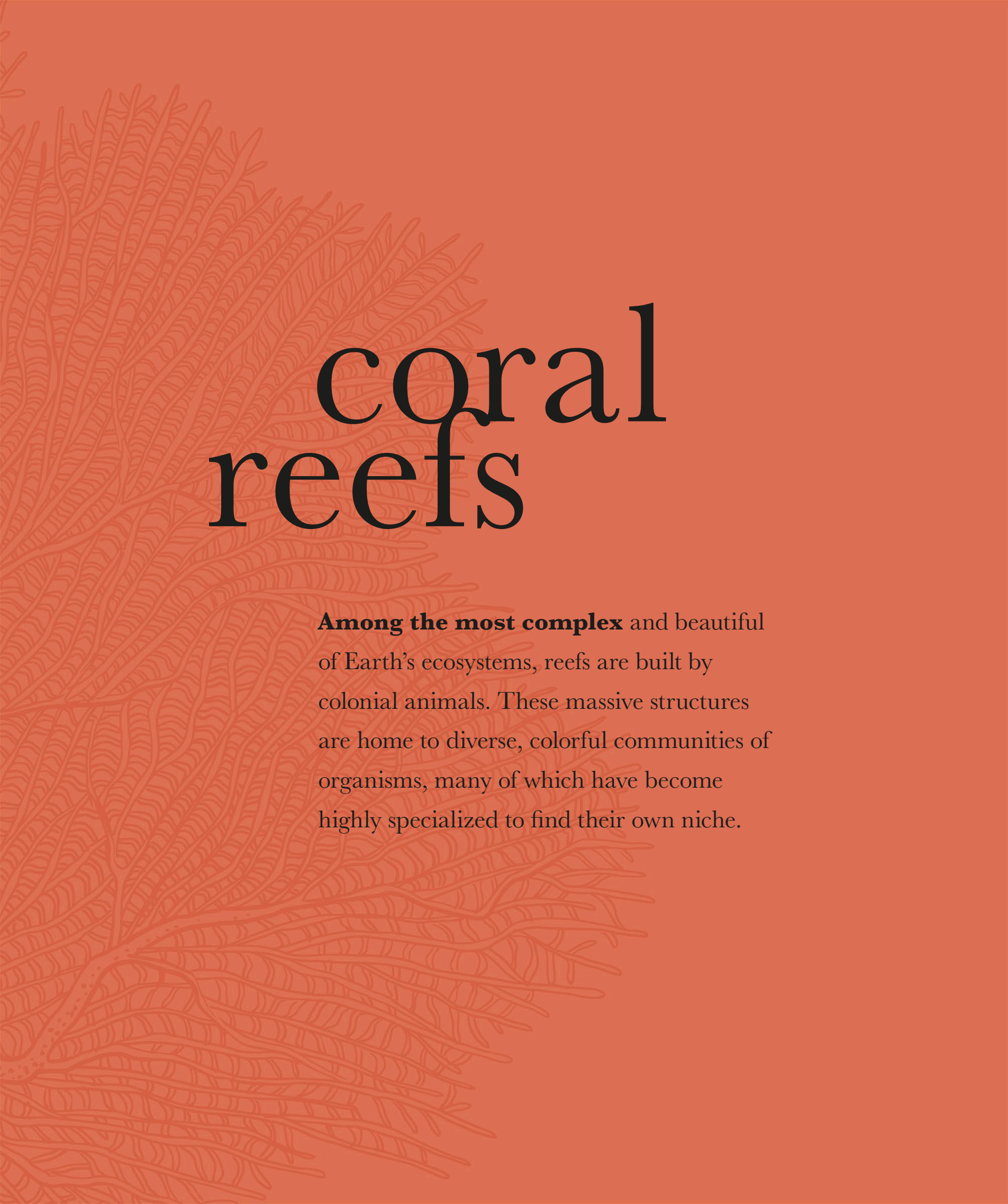
Balancing body salinity

The only claw-footed turtle to thrive in estuaries, the diamondback terrapin (*Malaclemys terrapin*) has tough skin to resist the variable salinity and tear glands to secrete excess salt. If its salt levels rise, it spends more time in fresh water, avoids the saltiest prey, and lifts its head to drink directly from the fresh water of falling rain.



Clawed, webbed feet

Like freshwater turtles and terrapins, the diamondback has clawed feet rather than flippers for walking on the ground or estuary sediment. Webbing between the toes helps with propulsion in the water.



coral reefs

Among the most complex and beautiful of Earth's ecosystems, reefs are built by colonial animals. These massive structures are home to diverse, colorful communities of organisms, many of which have become highly specialized to find their own niche.

Bottle colony

The filter-feeding “bottles” of an Indo-Pacific blue sponge (*Lamellodysidea chlorea*) are connected in a sprawling colony. In coastal seas murky with sediment, *Lamellodysidea* sponges can smother living corals—and may come to dominate a reef.

An opening, called an osculum, at the top of each bottle-shaped chamber releases water that has been filtered of food

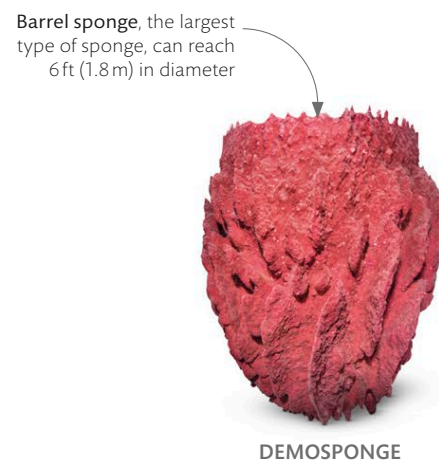
Didemnum sea squirt grows as a brightly colored, filter-feeding colony—either vivid green or pink—on almost any available surface, including the bodies of sponges

The chamber walls are peppered with cells that carry pores; each pore, called an ostium, allows water to enter the sponge



simple bodies

Oceans are home to the simplest animals—sponges. Some animals in this group can grow into giants more than 3 ft (1 m) across, but in all of them—no matter what the size—their constituent cells are so loosely connected that if the entire body is fragmented, each piece may retain its ability to develop into a new individual. Nevertheless, just as in other animals, the cells cooperate to keep the entire structure alive. They help circulate water through the porous sponge to extract suspended food.

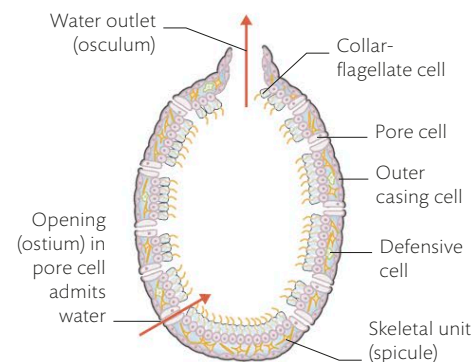


Types of sponge

A sponge's supporting skeleton is made of different possible materials: fibers of collagen (a protein) or hard spicules (mineral needles). Demosponges, generally the softest sponges, are typically dominated by collagen, while glass and calcareous sponges are supported, respectively, by silica or calcite spicules.

BODY ORGANIZATION

The different kinds of cell that make up the body of a typical sponge are organized around porous, bottlelike chambers. Collar-flagellate cells in the body lining have beating hairs that maintain water flow: in through the walls and out through an opening at the top. Each hair sits within a permeable collar that traps particles of food carried in the water stream.



CROSS-SECTION OF TYPICAL SPONGE



Each **polyp** carries a ring of tentacles for catching plankton; polyps at the ends of coral branches have 6 tentacles, and those on the sides have 12

Epidermis (surface skin) of the coral contains brown-pigmented algae called zooxanthellae, which supplement the coral's nutrition through photosynthesis

Each **branch** of the coral is supported by a rocky core that makes up most of its bulk

making rock

Some animals affect their surroundings more profoundly than others. Many corals use minerals from seawater to construct rocky skeletons that accumulate over hundreds—or even thousands—of years, producing the most celebrated of all ocean features: the coral reef. The living coral persists as scarcely more than a thin veil with tiny plankton-catching tentacles. But the rocky foundation it has made can be half a mile (a kilometer) thick and stretch for hundreds of miles across the seabed.



Coral branches

The branches of a stony coral (*Acropora* sp.) colony consist of a hard, rocky core clad in a “skin” that carries tentacled polyps. Nutrients harvested from trapped plankton are shared around the polyp colony by the skin.

A branching skeleton has a large enough surface area to support many thousands of polyps in life

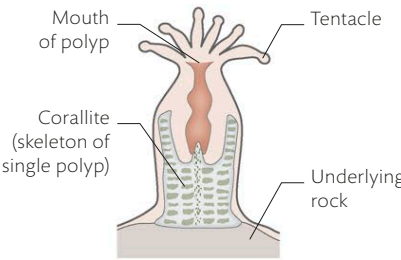
Dead coral

Stripped of living tissue, this white coral skeleton is virtually pure calcium carbonate—a chalky mineral made by the coral's living layer.

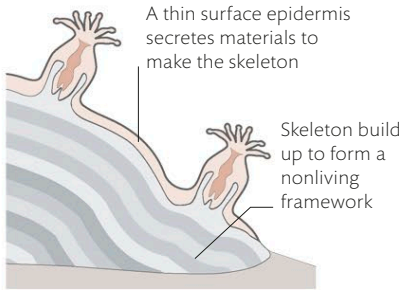


BUILDING A REEF

Microscopic planktonic coral larvae settle onto rock, where they develop into polyps. Each polyp, no bigger than a grain of rice, builds a tiny, cup-shaped rocky skeleton, known as a corallite. Over time, more interconnected polyps are generated as the colony expands outward on the surface, while the skeleton beneath thickens—by about $\frac{1}{4}$ in (0.5 cm) per year—to become the rocky foundation of a reef.



SINGLE POLYP



CORAL REEF

synchronizing spawn

Sexual reproduction for most types of ocean animals involves broadcasting sex cells into open water and relying on chance that fertilization will happen. For corals, separate patches of the same species must synchronize their spawning so that sperm and eggs are released at the same time. Environmental cues—such as a seasonal rise in temperature or phases of the Moon—trigger one of the most spectacular reproductive events on the planet: when a reef bursts with clouds of coral spawn. It has been estimated that a million eggs come from each square foot of reef.



Gamete bundle emerges from mouth of polyp

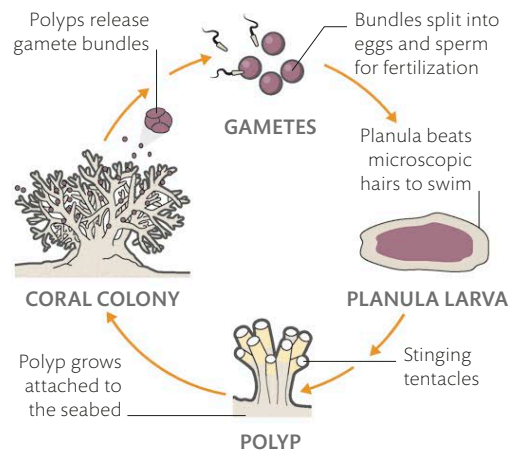
Reproductive polyp

Most corals are hermaphrodites: the polyps in their colony eject round gamete bundles that break apart into sperm and eggs within about half an hour of their release.



CORAL SEXUAL LIFE CYCLE

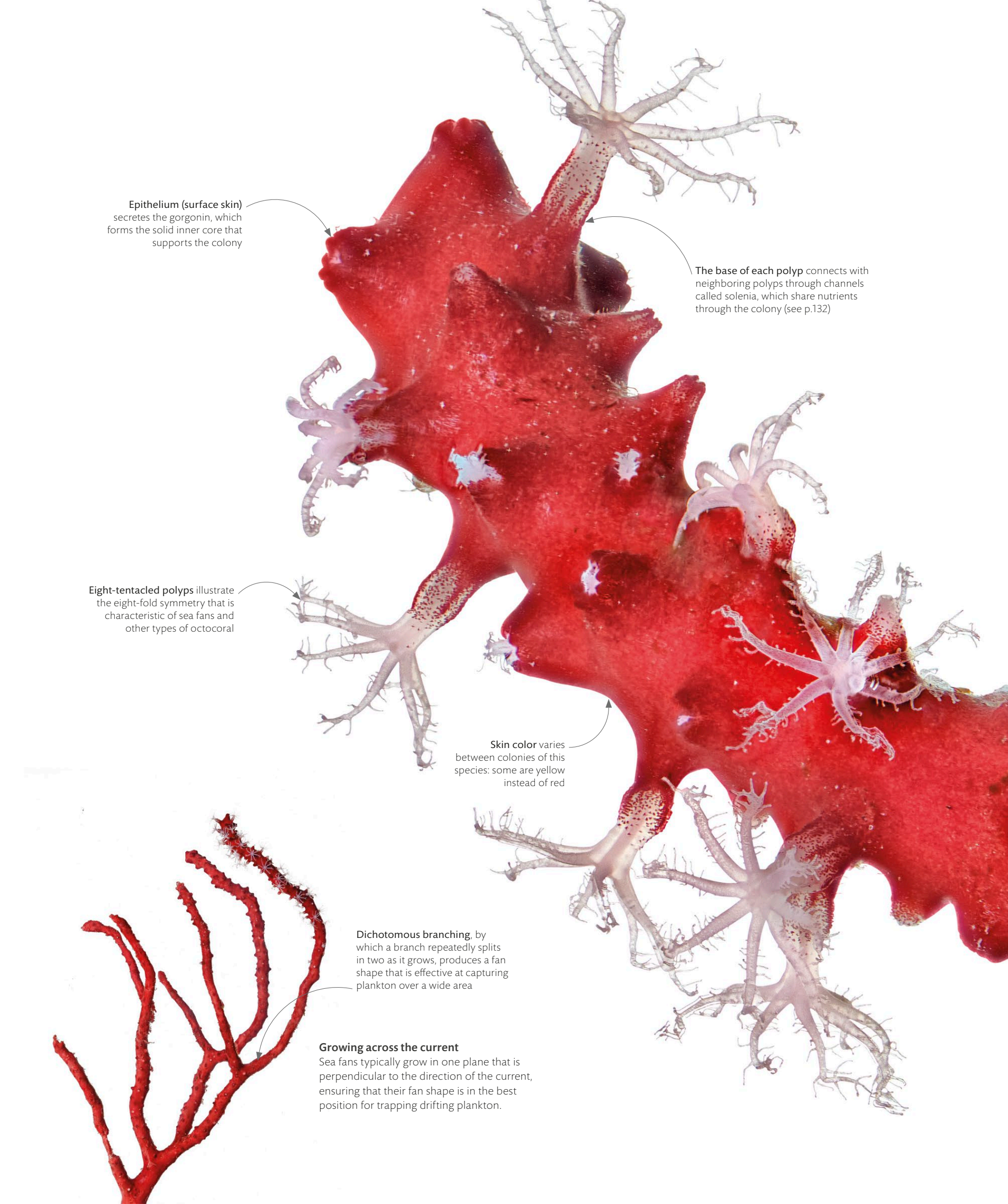
Corals and related anemones have a life cycle dominated by the sedentary polyp: a flask-shaped animal with stinging tentacles for catching planktonic prey. Colonies of coral polyps release their gamete bundles in synchrony to maximize the chances of fertilization. Each fertilized egg develops into a tiny, flat-bodied planula larva, which mixes with the drifting plankton. If it survives the attention of predators, the larva eventually settles on the seabed and transforms into a polyp. It then multiplies asexually to form a new coral colony.



Releasing gametes

In some reefs around the world, all corals spawn simultaneously, but in the Red Sea, species vary in their spawning season. This species of *Acropora* coral spawns in early summer on the night of a full Moon, releasing pink bundles of gametes by the billion.





Epithelium (surface skin)
secretes the gorgonin, which
forms the solid inner core that
supports the colony

The base of each polyp connects with
neighboring polyps through channels
called solenia, which share nutrients
through the colony (see p.132)

Eight-tentacled polyps illustrate
the eight-fold symmetry that is
characteristic of sea fans and
other types of octocoral

Skin color varies
between colonies of this
species: some are yellow
instead of red

Dichotomous branching, by
which a branch repeatedly splits
in two as it grows, produces a fan
shape that is effective at capturing
plankton over a wide area

Growing across the current

Sea fans typically grow in one plane that is
perpendicular to the direction of the current,
ensuring that their fan shape is in the best
position for trapping drifting plankton.

horny skeleton

The best-known corals are those that lay down the huge rocky foundations of a reef. But related animals build colonies in a different way. Sea fans grow branches supported by a core of hornlike protein called gorgonin. They stretch upward from the seafloor or horizontally as they suspend over steep drop-offs on the outer edge of a reef. Here, far below the ocean surface, they use their tiny polyps to trap plankton.

Branches of the deep

A single branch of the colorful sea rod (*Diodogorgia nodulifera*), from the Caribbean, is covered with plankton-trapping polyps. Unlike many stony corals growing near the surface, this sea fan contains no light-absorbing, photosynthesizing algae, so it is able to grow in the dark depths.

VARIED SUPPORT

Sea fans belong to a group called octocorals, so named because their polyps carry eight tentacles. Support structures in octocorals are more diverse than in the stony, six-tentacled hexacorals. Some, the soft corals (see pp.132–133), lack any hard skeleton at all. Gorgonians, which include sea fans, are supported by horny material called gorgonin, while the organ-pipe coral (*Tubipora musica*) is reinforced by chalky minerals.



STRUCTURE OF ORGAN-PIPE CORAL



Polyps can retract if danger threatens or extend their tentacles when catching plankton



Polyps containing photosynthetic algae cover the "mushroom's" cap, where they are exposed to light

Soft-bodied coral

Soft corals lack the hard, rocky skeletons of reef corals. Some, such as the rough leather coral (*Sarcophyton glaucum*), form giant, fleshy, mushroom-shaped colonies.

living in a colony

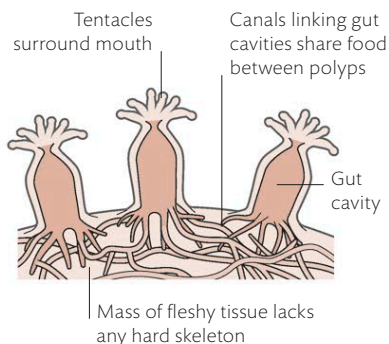
Colonial animals are common in the ocean. A mature coral consists of thousands of tiny, anemonelike polyps. Each polyp uses its stinging tentacles to catch plankton but is linked to its neighbors so that nourishment is shared. All the polyps develop from the same fertilized egg and are genetically identical, and the entire colony functions like a single superorganism. By spreading over a wide area, the colony can maximize its catch of food, as well as the number of eggs it is able to release during spawning.

Fleshy colony

Dozens of polyps pack just a thumb-sized area of a *Sarcophyton* leather coral. As well as catching plankton, each polyp is packed with photosynthetic algae, from which they gain extra nutrients. The polyps project from a mass of fleshy tissue called coenenchyme.

SHARING NUTRITION

Each coral polyp has a gut cavity that ingests planktonic food and ejects undigested waste. Nutrients from digested prey are spread throughout the colony. In stony corals, this occurs in the thin "skin" overlying the rocky skeleton. In soft corals, canals called solenia penetrate deeper into the fleshy colony to share the food.



TYPICAL SOFT CORAL STRUCTURE





Stony corals

Also known as hard corals, these are the architects of the world's coral reefs. True stony corals have rigid skeletons made of calcium carbonate—in the form of a mineral called aragonite—and each polyp sits in its own protective cup called a corallite. In areas with strong waves, these colonies develop into robust mounds or flattened shapes; in sheltered seas, the same species can form more intricate shapes with delicate branching patterns.

Dense groups, or thickets, up to 8 ft (2.4 m) across and 4 ft (1.2 m) high form in shallow waters



STAGHORN CORAL
Acropora cervicornis

Large, thick branches resembling elk antlers provide shelter for many reef species



ELKHORN CORAL
Acropora palmata

Soft corals

Also known as octocorals because their polyps have eight tentacles, these corals are soft and bendable. Often treelike in appearance, these non-reef-building colonies are supported by hornlike cores and protected by fleshy outer rinds.

Treelike species found in deep waters of the North Atlantic and the Barents Sea



CARNATION CORAL
Gersemia fruticosa

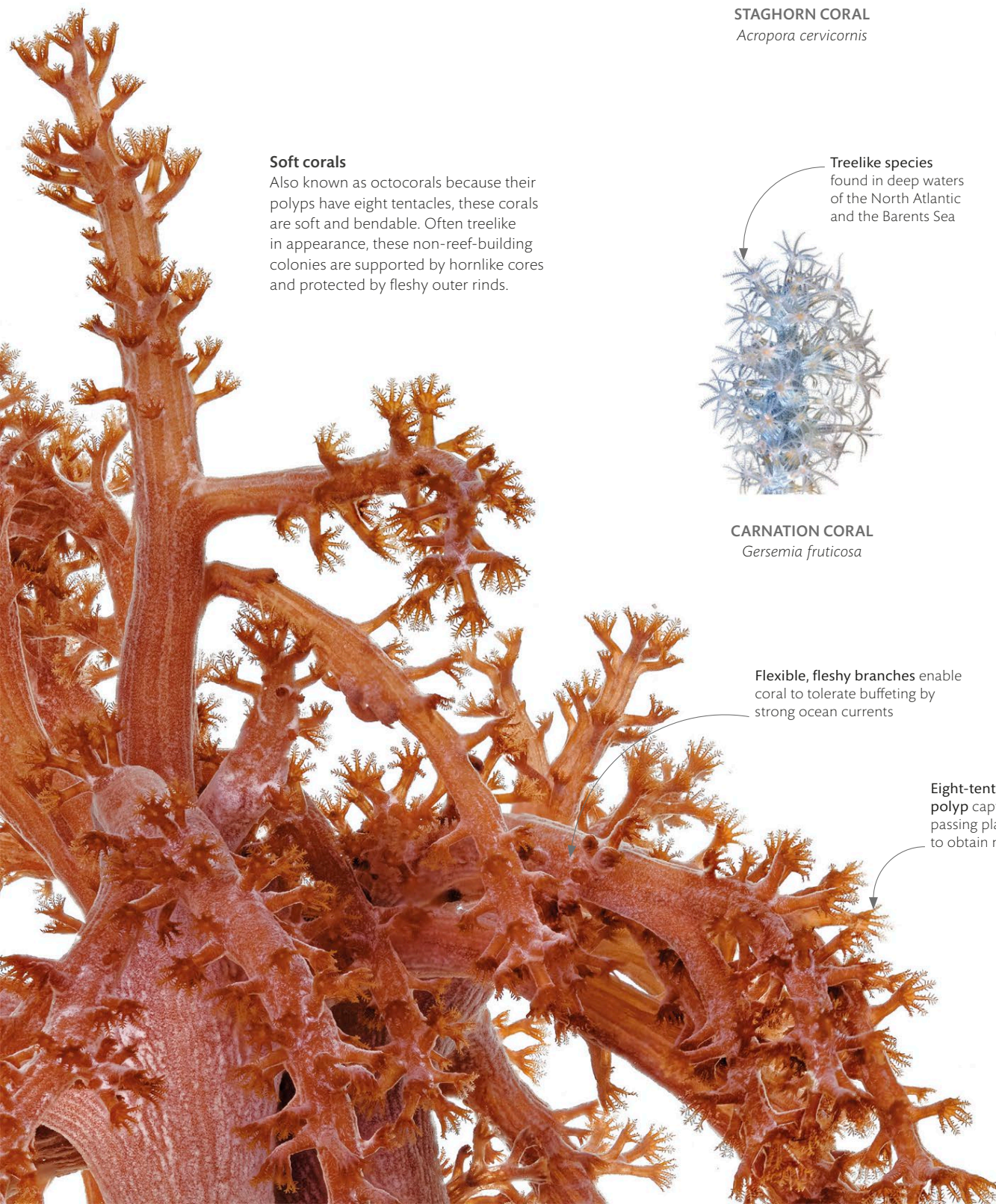
Stiff, bushlike colony grows in a single plane



GORGONIAN SEA FAN
Subergorgia

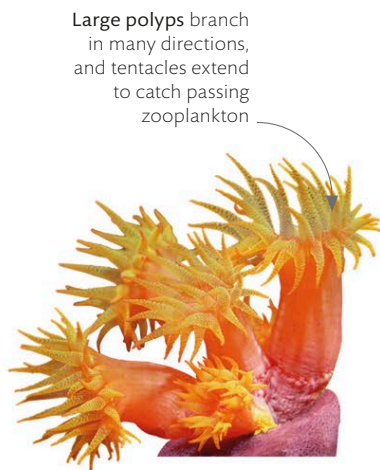
Flexible, fleshy branches enable coral to tolerate buffeting by strong ocean currents

Eight-tentacled polyp captures passing plankton to obtain nutrients



Fleshy and flexible

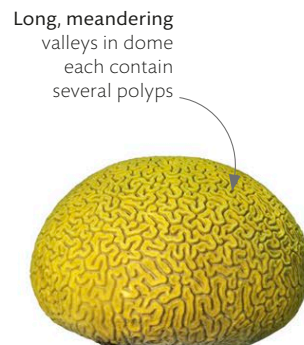
Commonly known as the Kenyan tree coral (*Capnella imbricata*), this branched soft coral emerges from a single "trunk" that is fixed to a rock. The colonies inhabit coastal shores and rocky reef slopes and can grow to around 18 in (45 cm).



TUBE CORAL
Tubastraea coccinea



PILLAR CORAL
Dendrogyra cylindrus



BOULDER BRAIN CORAL
Colpophyllia natans

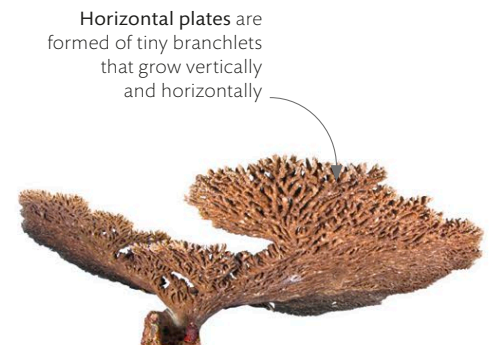
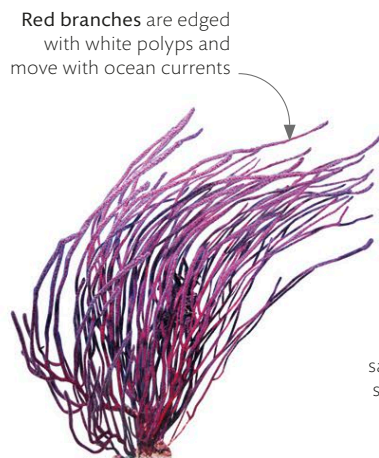


TABLE CORAL
Acropora cytherea



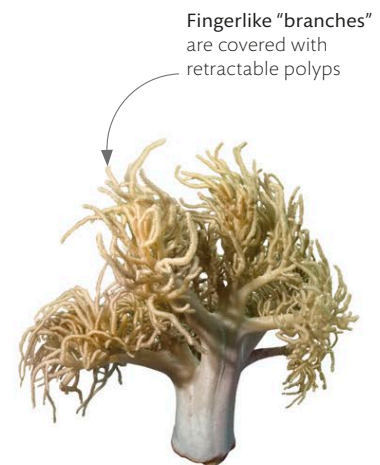
GORGONIAN SEA WHIP
Ellisella ceratophyta



SEA PEN CORAL
Pteroeides



MUSHROOM CORAL
Anthomastus



SPAGHETTI FINGER LEATHER CORAL
Sinularia flexibilis

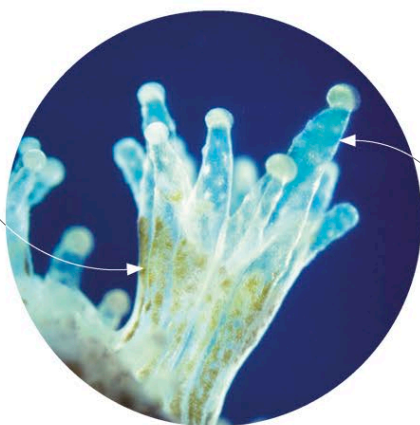
corals

Corals are found in all the oceans of the world, but reef-building species are found mainly in shallow tropical and subtropical seas. Coral is formed from huge colonies of individuals called polyps that feed on plankton. Colonies that live in shallow, warmer waters host zooxanthellae, which use carbon dioxide from the coral's respiration in photosynthesis and, in turn, pass nutrients back to the coral.

Green concentrations of zooxanthellae are found in the polyp's column, which contains the gut cavity

Algae in the flesh

When a single coral polyp is magnified, the zooxanthellae are visible as spots of green-colored cells. Each cell has light-absorbing chlorophyll—the same pigment found in photosynthesizing plants.



Transparent, jelly-packed tissues help transmit light to zooxanthellae in the gut lining

powered by sunlight

Animal flesh is nourished by food that has been digested and assimilated, but some types of marine animal are partly solar powered. Many corals and some hydrozoans, anemones, sponges, and mollusks contain photosynthetic algae called zooxanthellae. These grow and multiply in the animal's sunlit tissues and use carbon dioxide from its respiration to make food, much of which passes to the host and is key to healthy growth.

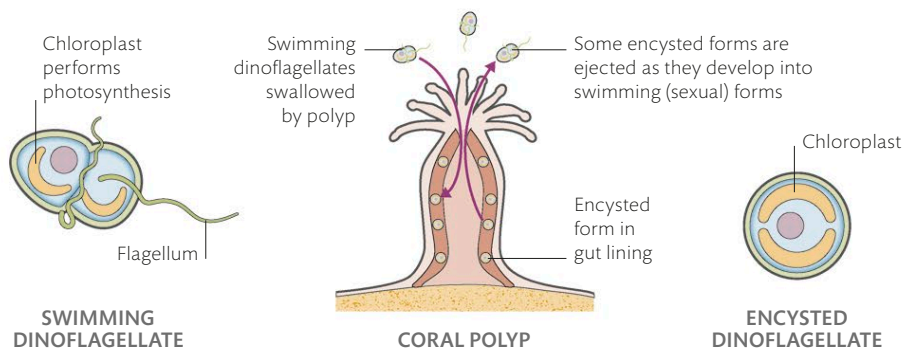
Skeleton from photosynthesis

Millepora fire hydrocorals—named for their painful sting—are colonial hydrozoans with hard skeletons, like those of true stony corals. Their dependence upon symbiotic zooxanthellae restricts them to brightly lit shallow water. They use much of the food gained from the algae's photosynthesis to build their chalky skeletons.

ZOOXANTHELLAE

The zooxanthellae of marine animals belong to a group of algae known as dinoflagellates. These have free-living forms that swim with whiplike structures called flagella, but when swallowed by coral polyps, they lose their flagella and become cysts in the

polyp's gut lining. A natural yet vulnerable balance exists between the swimming and encysted forms. Warming of the sea is leading to a net loss of cysts, bleaching corals and often killing them.







The longer tentacles of many anemone species can reach farther to overcome large prey

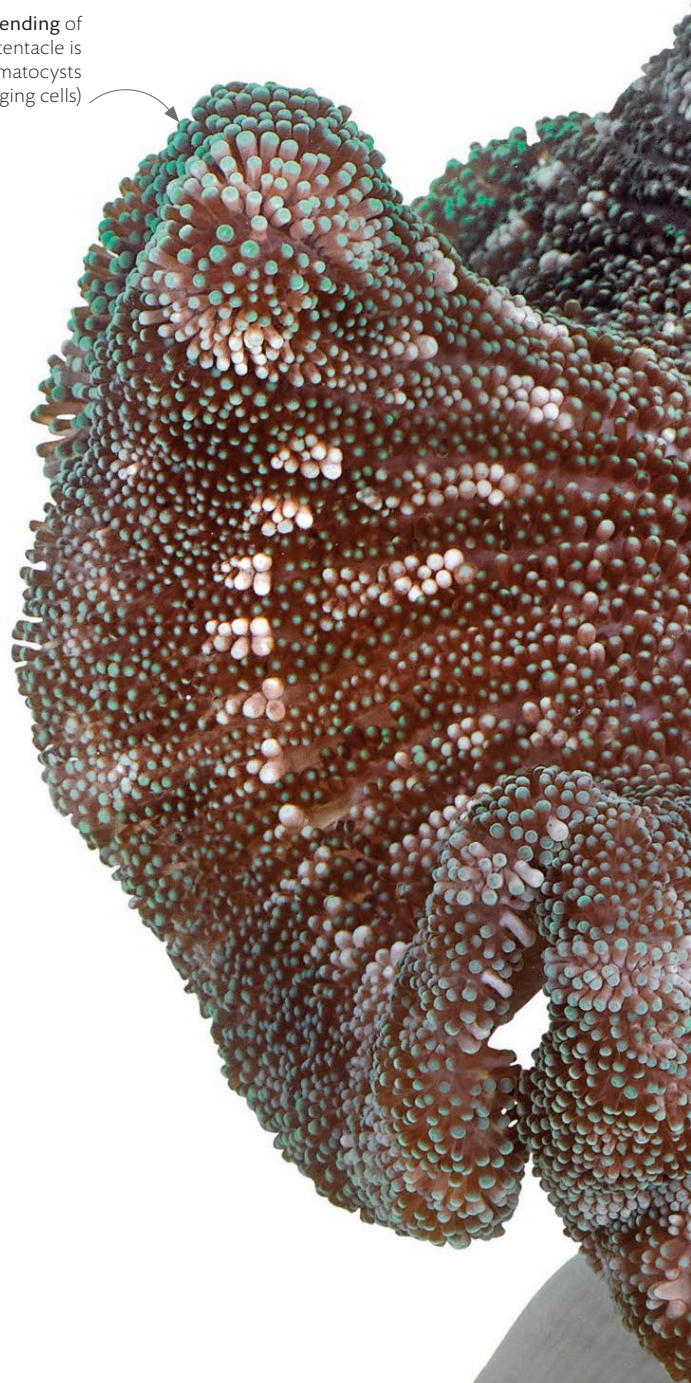
Stinging tentacles

Anemones vary in the potency of their venom. Most trap tiny planktonic animals, but some—such as this dahlia anemone (*Urticina felina*)—are able to immobilize bigger prey, including urchins.

Solar-powered mat

Like some other anemones, Haddon's carpet anemone (*Stichodactyla haddoni*), of the Indo-Pacific supplements nutrients from its prey with food produced by algae growing in the flesh of its wide oral disk. The algae use energy from sunlight penetrating the water to photosynthesize and make sugar, which they share with the anemone.

Knoblike ending of each short tentacle is coated in nematocysts (stinging cells)

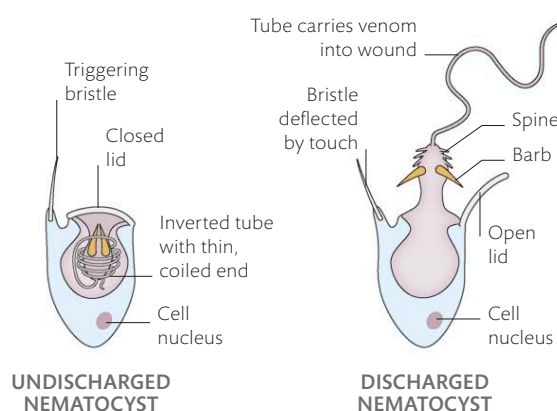


stinging for prey

For an animal that is attached to the seabed, an anemone is a surprisingly efficient predator: a fleshy column, or polyp, crowned with stinging tentacles reaches up into the water to catch passing animal prey. The tentacles bring the paralyzed victim to the mouth at the center of the polyp, which swallows the meal into the digestive cavity below. Carpet anemones are among the largest polyps of a tropical reef: a single oral disk, covered in short, budlike tentacles, can span nearly 3 ft (1 m).

FIRING VENOM

Anemones, along with corals and jellyfish, are cnidarians. These soft-bodied predators owe their stinging capabilities to unique cells, called nematocysts, in their skin. Each nematocyst contains a capsule of venom and a barbed thread like a miniature harpoon. Contact with prey triggers the harpoon to fire, penetrating the victim with a chemical cocktail that can paralyze muscles.





Fleshy oral disk surrounds a central mouth and contains contracting muscle fibers that raise its carpet of stubby tentacles upward into the water—and closer to prey

Muscular column contains a gut cavity that digests prey and absorbs nutrients

coral reefs

Reef-building corals live in shallow tropical waters, where the sea-surface temperature ranges from 68°F to 95°F (20°C to 35°C). They need a rocky surface on which to build, normal marine salinity, and waters that are free from excess sediment. Vast populations of tiny coral polyps—individuals are often no larger than a pea—work together with a host of other organisms to construct and maintain the largest living structures on Earth. The Great Barrier Reef off northeastern Australia, which comprises over 3,000 separate reefs, is even visible from space. Coral reefs are highly sensitive to changes in their ocean environment and are gradually dying as a result of rising temperatures, ocean acidification, and reduced oxygen levels.

Rich pickings

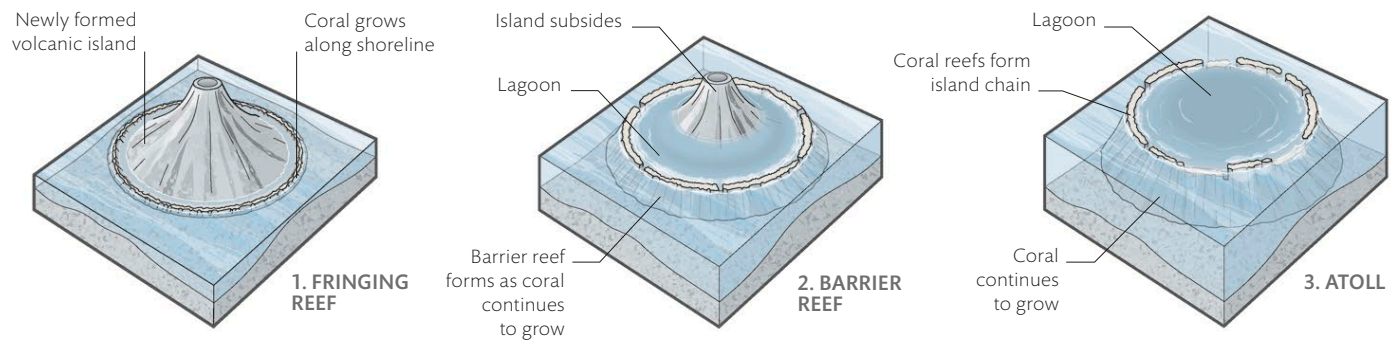
As dusk falls, shoals of epaulette soldierfish (*Myripristis kuntee*) emerge from the cover of a reef in Palau. Their big eyes help them hunt through the night on planktonic animals, such as crab larvae.



CORAL ATOLL FORMATION

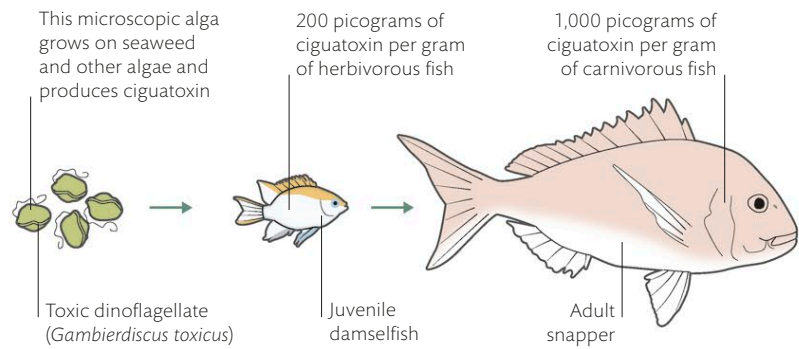
In the open ocean, coral atolls originate where reef organisms have constructed a fringing reef around the shores of newly formed volcanic islands. When volcanic activity ceases, the island subsides due to a

combination of plate movement and weathering. The reef on its flanks continues to grow upward, first becoming a barrier reef—separated from the land by a lagoon. Later the island disappears, resulting in the formation of an atoll—a ring of coral islands with no central landmass.



PASSING ON POISON

Some animals that eat zoanthids, such as crustaceans, seem to tolerate their poison. Many ocean toxins get passed along food chains in this way. Ciguatera syndrome in humans is caused by eating fish that contains high levels of ciguatoxin—a poison produced by algae called dinoflagellates. This poison is not excreted after the algae are consumed, so its concentration rises to potentially lethal levels in consumers higher up in the food chain—including fish served up on diners' plates.



BIOACCUMULATION OF TOXINS IN THE OCEAN FOOD CHAIN

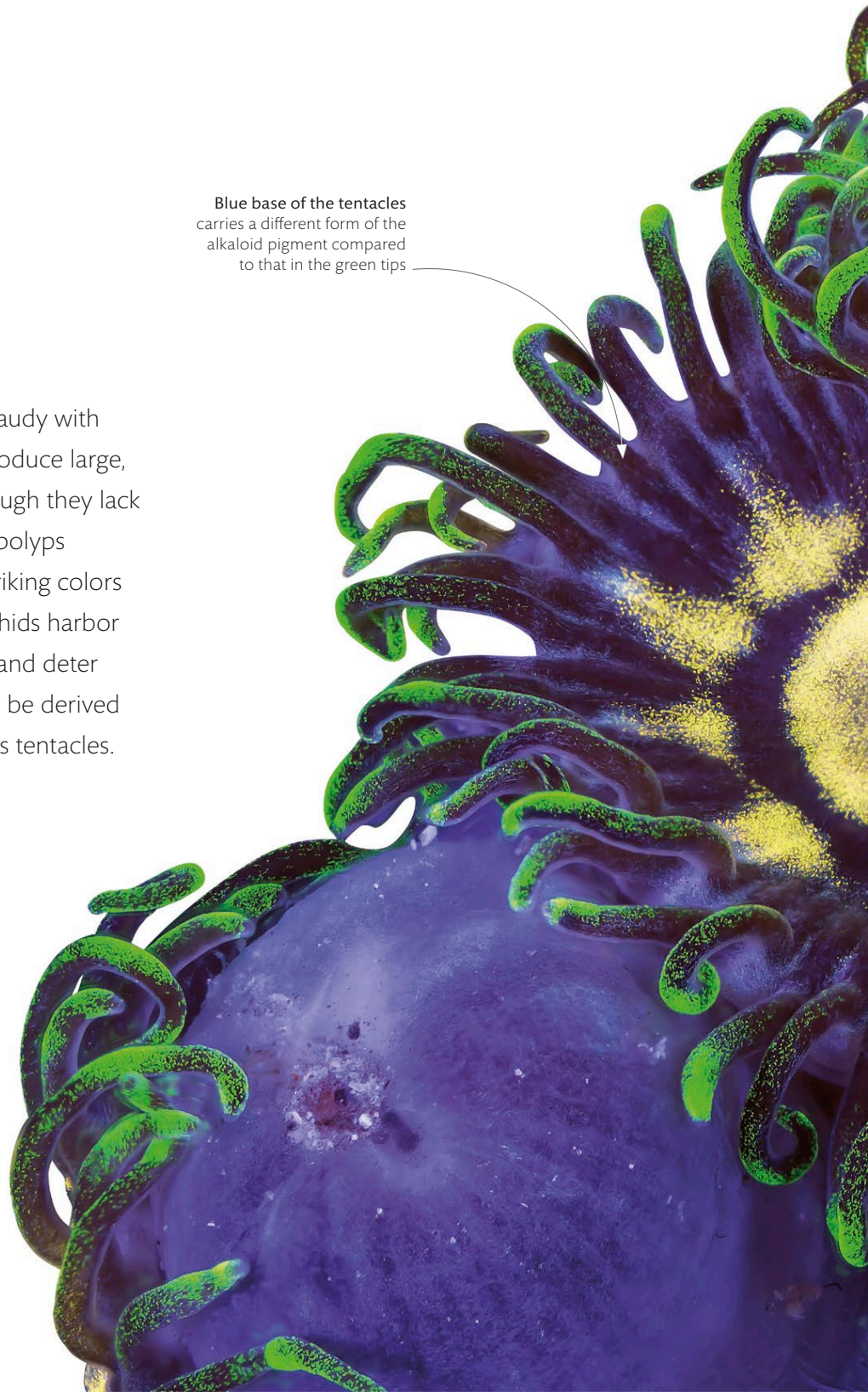
blooming with poison

Tropical sunlit coastlines around the world can be gaudy with colorful zoanthids. Like anemones, these animals produce large, soft polyps. Like corals, they grow in colonies—although they lack a hard, reef-forming skeleton. The biggest zoanthid polyps resemble mesembryanthemum flowers, but their striking colors may serve as a warning of their toxicity. Many zoanthids harbor bitter chemicals called alkaloids that are poisonous and deter grazing animals. At least some of these poisons may be derived from planktonic organisms trapped by the zoanthid's tentacles.

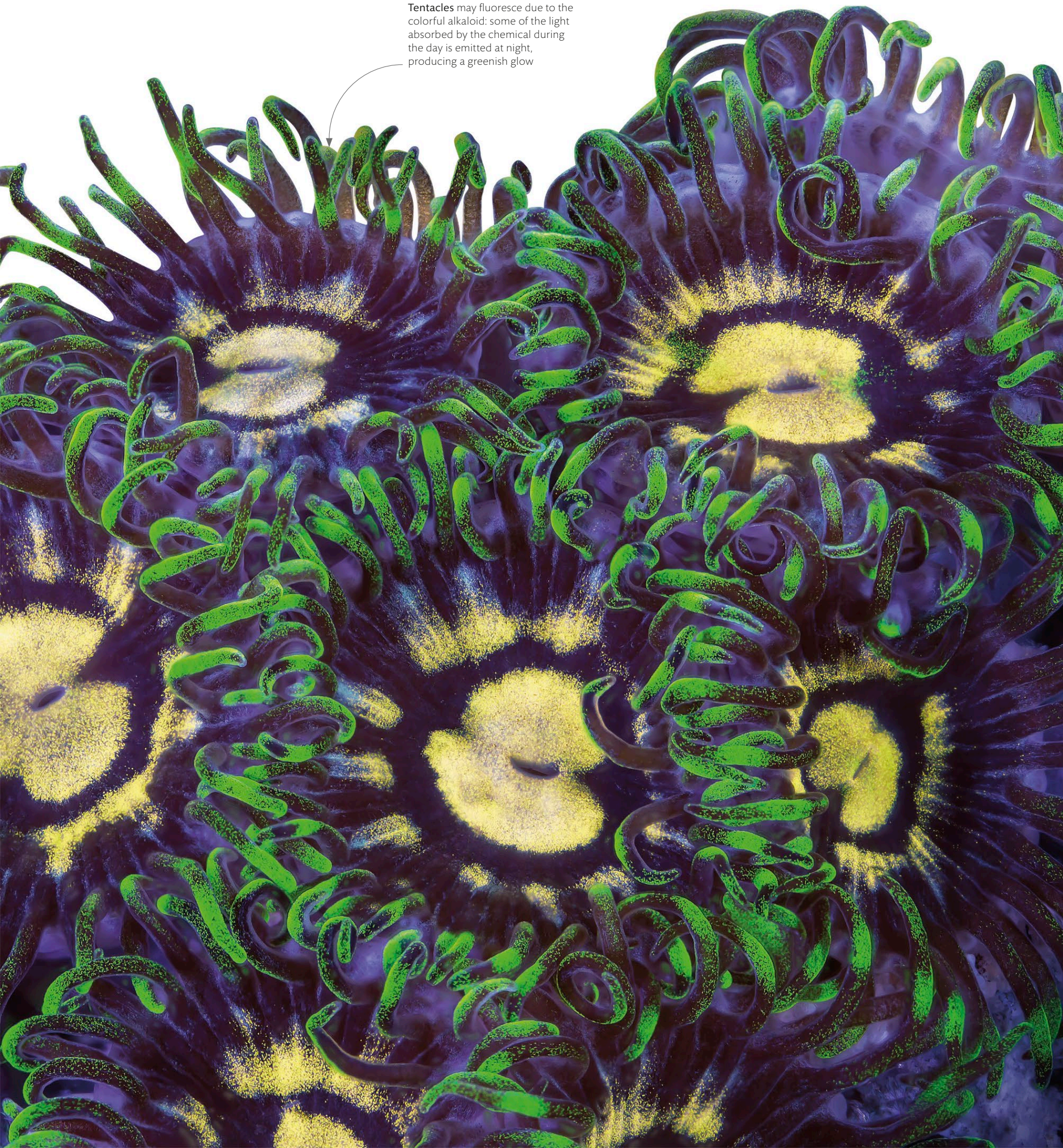
Lethal pigment

A zoanthid obtains both its color and its poison from alkaloid chemicals known as zoanthoxanthins. The alkaloids produce the vivid blue and green of the tentacles, but they are also toxic to nerves and muscles in other animals. Also present—but hidden by the alkaloids—are photosynthetic algae that provide the zoanthid with extra food.

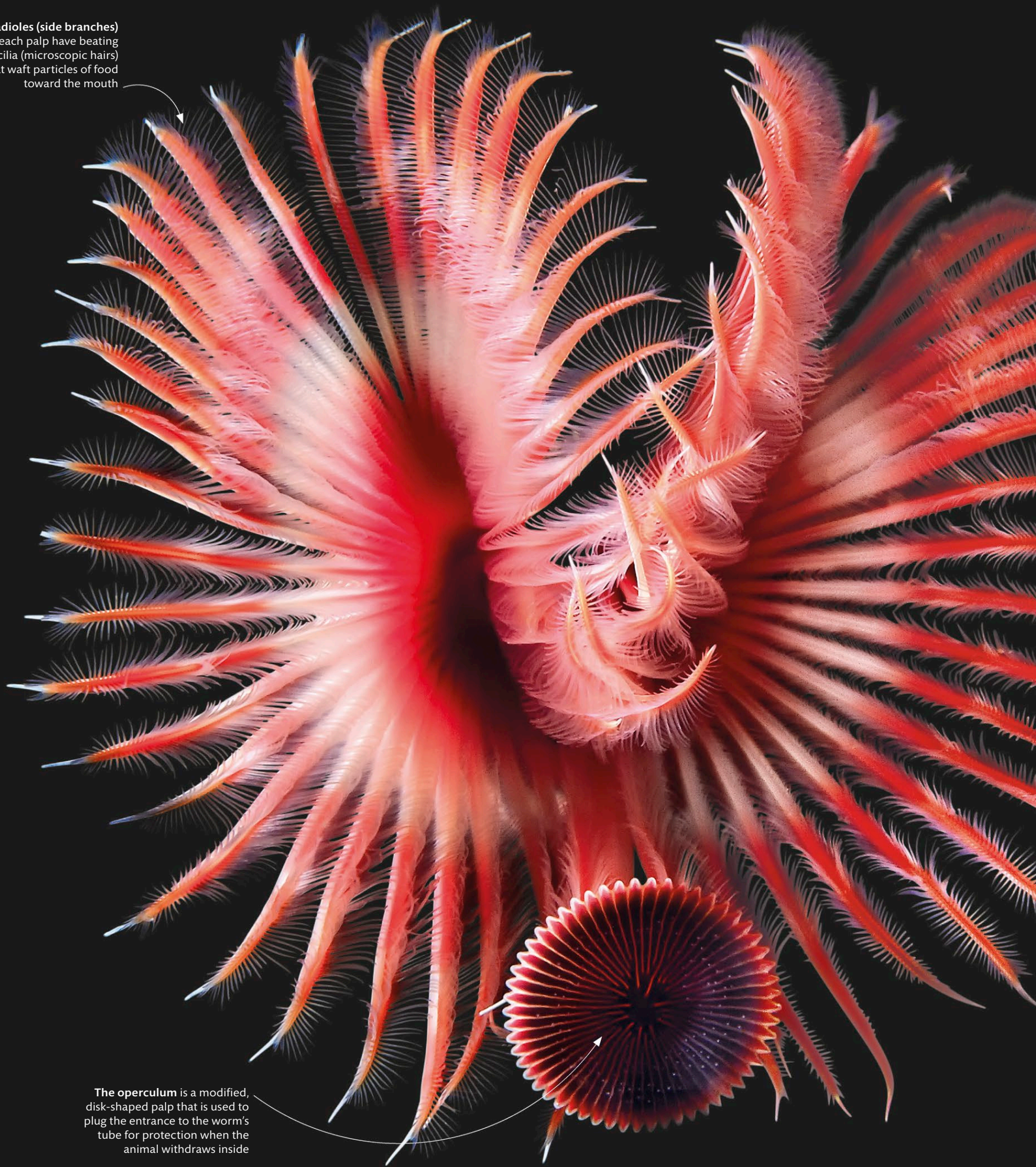
Blue base of the tentacles carries a different form of the alkaloid pigment compared to that in the green tips



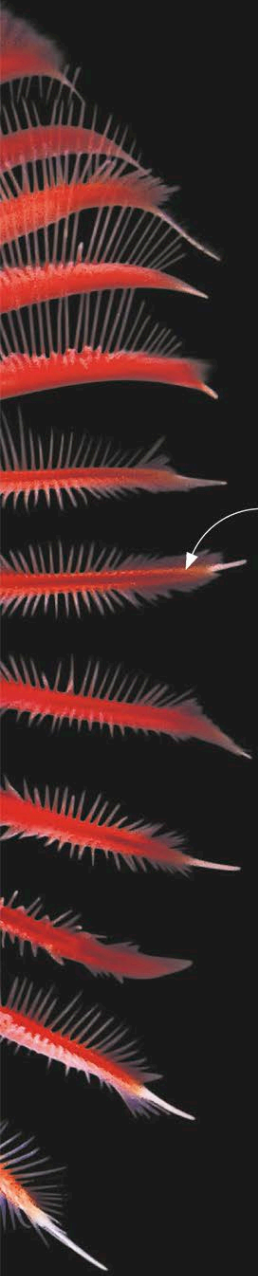
Tentacles may fluoresce due to the colorful alkaloid: some of the light absorbed by the chemical during the day is emitted at night, producing a greenish glow



Radioles (side branches)
of each palp have beating
cilia (microscopic hairs)
that waft particles of food
toward the mouth



The operculum is a modified,
disk-shaped palp that is used to
plug the entrance to the worm's
tube for protection when the
animal withdraws inside



Pink hue of palps comes from blood pigments in their tissues; the pigments chemically bind to oxygen and extract it from water for respiration

The calcareous tube is strengthened by a triangular ridge running along the top



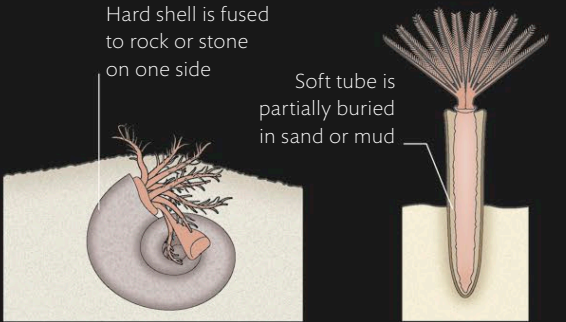
Coral-living worm
The palps of a star fan worm (*Pomatostegus stellatus*) spread out in the shape of a horseshoe. They are packed with oxygen-absorbing pigment and lined with food-collecting hairs. The rest of the worm lives inside a calcareous (chalky) tube buried within the rocky skeleton of a tropical stony coral.

Exposed tube
The hard tube of *Spirobranchus lamarcki*, a European relative of the star fan worm, is visible—typically attached to a stone, rock, or occasionally the carapace of a crab.

fanning the water

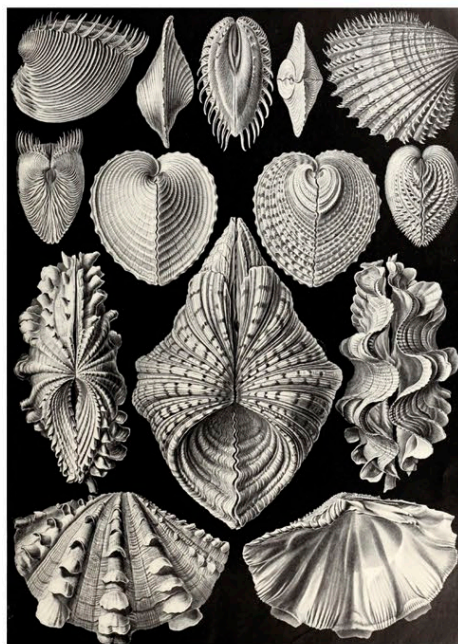
Of the thousands of species of marine annelid (segmented) worms, many use their muscular bodies for burrowing in sediment—just like earthworms, their cousins on land. Other marine annelids can swim through open water. But some, called fan worms, live in tubes, compromising their ability to swim or burrow away from danger. A fan worm’s front end reaches out into the water, where a crown of fingerlike structures, called palps, sweeps the water for oxygen and particles of food. When danger threatens, the body uses retractor muscles to pull the exposed parts completely inside the tube.

TYPES OF TUBE
Fan worms called serpulids, such as the star fan worm, build hard, chalky tubes made from calcium carbonate secreted by glands in the collar around the base of their palps. Other types of fan worm—the closely related sabellids—build soft, membranous tubes made from mucus mixed with sediment collected by the palps.



SPIRORBIS (A SERPULID) SABELLA (A SABELLID)





Water purifiers

There are more than 10,000 species of marine bivalves. All are filter-feeders, able to remove contaminants from seawater; an oyster can filter 25 gallons (95 liters) a day.

spotlight species

giant clams

Giant clams (*Tridacna*) are the biggest non-colonial animals that grow fixed to the coral reef. These heavyweight mollusks bask in the tropical sunlight of the Indian and Pacific oceans from east Africa to the Pitcairn Islands.

Like other bivalve mollusks, a giant clam has a shell formed of two valves, connected by a hinge. It contains zooxanthellae—a type of algae—that photosynthesize and make 90 per cent of the clam's food. The remainder of its nutrition comes from filter-feeding plankton. In some species, the fleshy mantle is vividly colored with pigments or reflective crystals, which help to screen ultra-violet and other potentially harmful radiation.

Just like food-making algae in coral, the giant clam has a mutually beneficial relationship with the zooxanthellae as the clam passes carbon dioxide and nitrogen

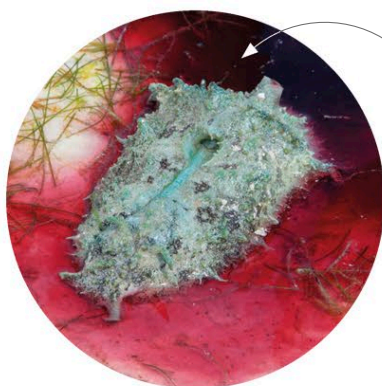
compounds that are needed to make nutrients into the zooxanthellae. This symbiosis is productive: a record-breaking specimen of *Tridacna gigas*, the largest species, weighed half a ton.

Like so many other iconic animals on the reef, giant clams help to engineer the complex community around them. Over time, their shells are colonized with life, while many animals—from crustaceans to fish—live over the mantle, some as parasites. Zooxanthellae occasionally expelled from the mantle may provide food for plankton-eaters too.

Giant clams are hermaphrodites, but release most of their sperm before their eggs to reduce the chance of self-fertilization. Like most other mollusks, the fertilized eggs develop into tiny larvae that swim in the plankton, before metamorphosing into adults and settling on the ocean bottom.

Patterned giants

The smooth giant clam (*Tridacna derasa*) of barrier reefs and island atolls, is the second largest species, growing to 24 in (60 cm) long, and has a particularly brilliant mantle pattern of blue or green.



The cloud of ink contains chemical irritants that help repel predators

Defensive ink

When disturbed, this sea hare—a kind of sea slug—releases a cloud of acrid purple ink. The ink is partly derived from the sea hare's diet of algae.

Poison alert

The vivid colors of a variable neon sea slug (*Nembrotha kubaryana*) are aposematic, meaning that they act as a warning signal to predators. This Indo-Pacific species has toxic slime, which comes from eating a particular type of sea squirt—a soft-bodied, filter-feeding animal of the seafloor.

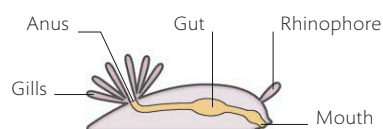
collecting weaponry

Soft-bodied mollusks lacking hard shells need alternative forms of protection against predators. Many sea slugs equip themselves with defenses acquired from their food. Some graze on toxic organisms and harbor the poisons to ooze their own noxious slime or eject repelling ink. Others eat the stinging tentacles of jellyfish or anemones and preserve the stingers (nematocysts), which become incorporated into their bodies yet remain fully capable of firing.

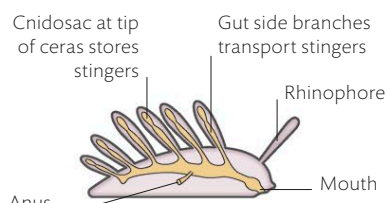


STORING STINGERS

The variable neon sea slug belongs to a group of sea slugs called dorids, which have a plume of gills and rely on toxic slime. Another group, the aeolids, store stingers from their prey in each fingerlike projection, or ceras (plural: cerata), on their back. The microscopic stingers ingested with their food are transported through side branches of the gut and held in the cerata tips, ready to fire when a predator attacks.



DORID SEA SLUG



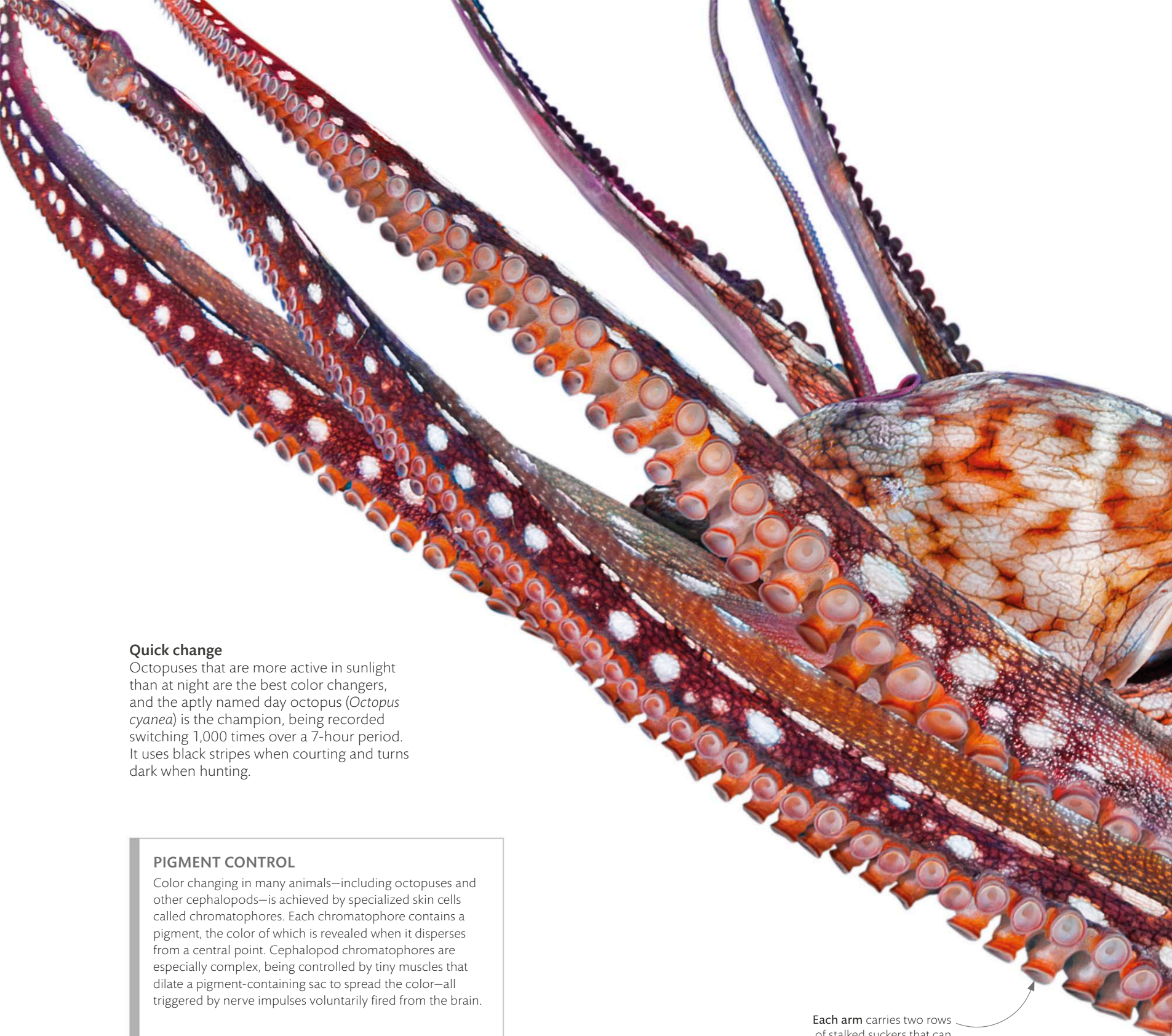
AEOLID SEA SLUG



Orange markings help reinforce the colorful warning of the animal's toxicity, but some equally poisonous individuals of this variable species are only green and black

Tentaclelike sense organ, called a rhinophore, tastes the water and can detect sea squirt prey

Plumelike gills, arranged in a circle, absorb oxygen from the surrounding water

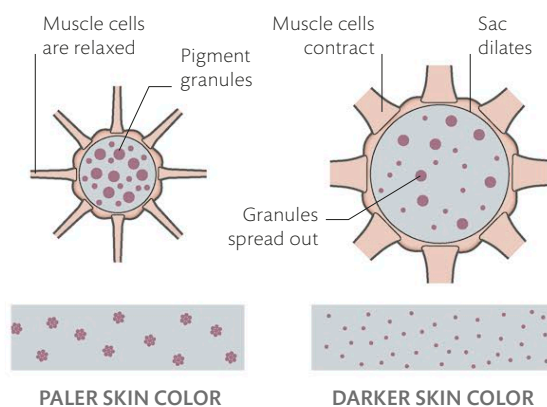


Quick change

Octopuses that are more active in sunlight than at night are the best color changers, and the aptly named day octopus (*Octopus cyanea*) is the champion, being recorded switching 1,000 times over a 7-hour period. It uses black stripes when courting and turns dark when hunting.

PIGMENT CONTROL

Color changing in many animals—including octopuses and other cephalopods—is achieved by specialized skin cells called chromatophores. Each chromatophore contains a pigment, the color of which is revealed when it disperses from a central point. Cephalopod chromatophores are especially complex, being controlled by tiny muscles that dilate a pigment-containing sac to spread the color—all triggered by nerve impulses voluntarily fired from the brain.



Each arm carries two rows of stalked suckers that can grip prey and other objects

Shape-shifting

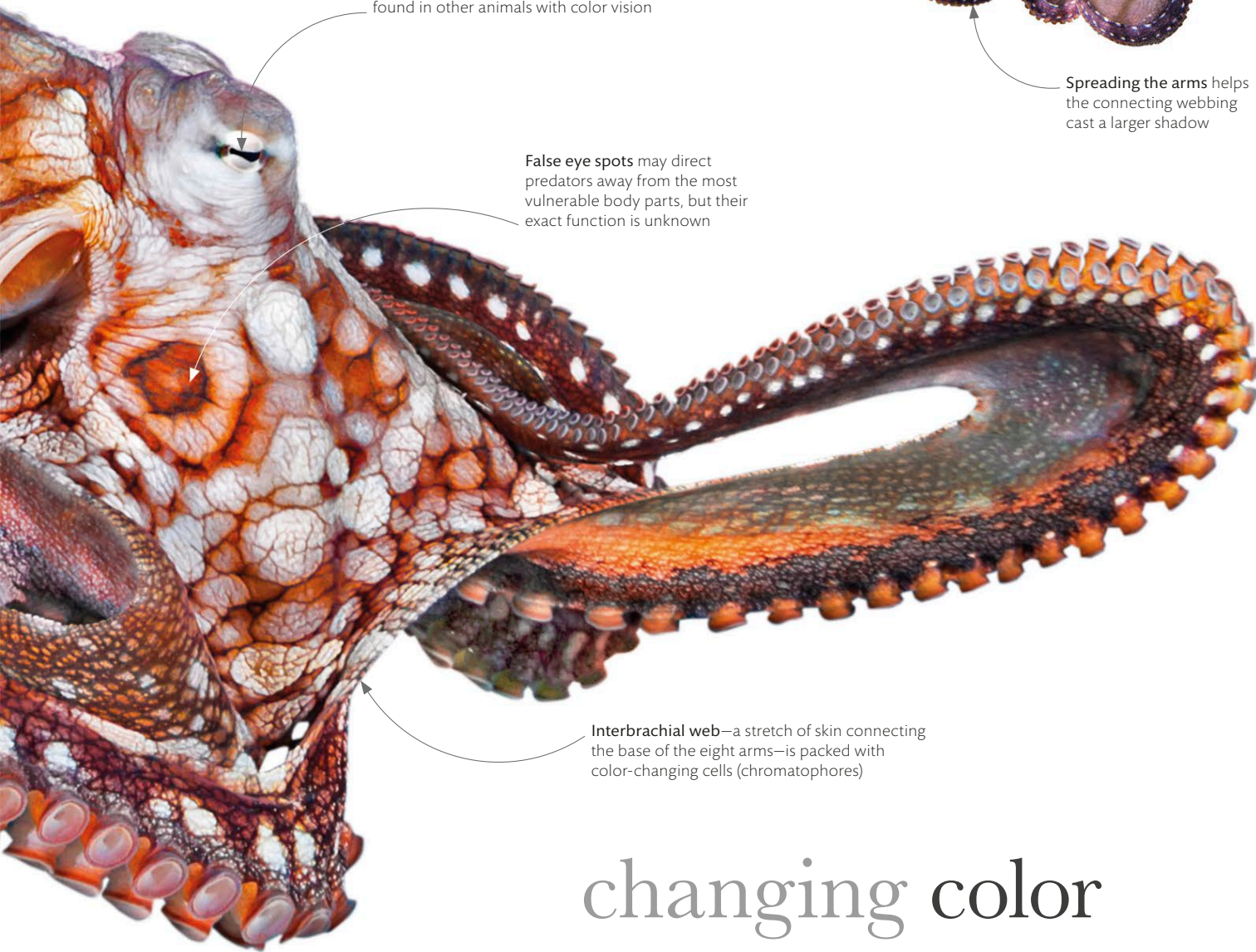
Like other soft-bodied octopus species, the day octopus can change its shape along with its color. By spreading its body and casting a shadow over lurking prey, it may encourage a shade-loving crab to venture farther from its hiding place.



Spreading the arms helps the connecting webbing cast a larger shadow

Slit-shaped pupil splits light into its constituent wavelengths, enabling the octopus to detect different colors, even though its eyes lack the color-sensing cells found in other animals with color vision

False eye spots may direct predators away from the most vulnerable body parts, but their exact function is unknown



Interbranchial web—a stretch of skin connecting the base of the eight arms—is packed with color-changing cells (chromatophores)

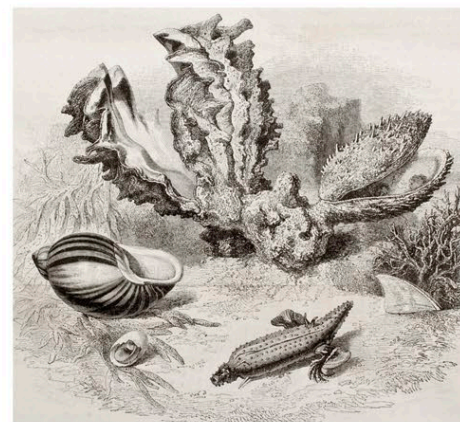
changing color

Where sunshine penetrates the sea, many animals flaunt colors, and some even change color when their behavior alters. The switch can occur rapidly because it is controlled by lightning-fast nerve impulses. Cephalopods, such as octopuses and cuttlefish, are among the most impressive color changers. Within seconds, an octopus sensing danger can blend in with the seabed and vanish or, spotting a potential mate, impress with bold patterns.



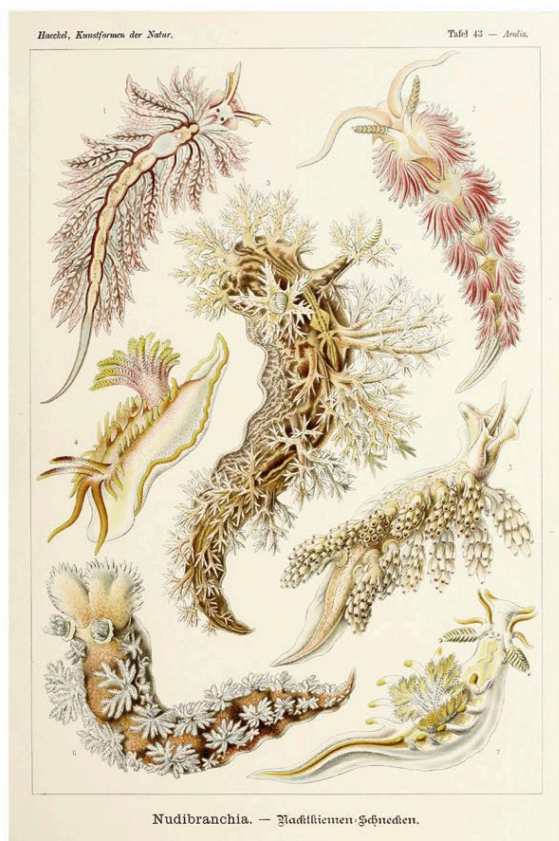
Marine science for the masses

An 1850s issue of the popular illustrated Parisian magazine *Le Magasin Pittoresque* includes a delicate wood engraving of named species of bivalves, sea snails, and a sea slug in a project to educate the wider population about marine life.



the ocean in art

art meets science



Natural history illustration came of age in the 19th century in response to public fascination with voyages to formerly remote regions and a scientific need for accurate representation of specimens. The sea was a new frontier for exploration, and the complexity and vibrancy of its myriad life forms was both a challenge and an inspiration to the artists recording them.

Describing sea creatures was historically challenging, as specimens rapidly lost their colors and shrank after being preserved in alcohol. The Zoological Society of London's solution was to use art painted at the source. From 1812, tea merchant John Reeves spent 19 years in Macao, where he commissioned Chinese artists to create detailed paintings of fish. Many of these paintings became iconotypes: the basis for the description of a new species.

Nudibranchs (1899–1904)

Crossing the boundaries between scientific illustration and art, Ernst Haeckel's nudibranchs (soft-bodied marine gastropods) are remarkable for their detail and harmonious arrangement.

Britain's HMS *Challenger* returned from a 4-year voyage around the world in the 1870s, with samples trawled from many different ocean depths and new data on the chemistry of seawater, currents, sea temperatures, and the geology of the seafloor. One of many enthusiasts fired up by the findings was German doctor and zoologist Ernst Haeckel. His major work *Kunstformen der Natur* features 100 stunning lithographs that reveal the symmetry and beauty of the ocean's smallest life forms.

A ground-breaking 1855 study of the Atlantic by US naval officer Matthew Fontaine Maury inspired naturalist James M. Sommerville to commission a dazzling watercolor illustration of its species.

Ocean Life (1859)

An idealized assembly of 75 vibrant sea creatures and corals from a variety of geographical zones was created by physician and naturalist James M. Sommerville to illustrate his pamphlet *Ocean Life*. Art professor Christian Schussele's watercolor for the lithograph has all the hallmarks of a still life painting.

“The grouping may be considered, rather as an intellectual truth than as a literal view. It might be termed a mental oasis of the sea ...”

JAMES M. SOMMERVILLE, INTRODUCTION TO OCEAN LIFE, 1859

cleaning hosts

Sunlit coral reefs are fertile, physically complex places with a rich biodiversity. As a result, more species evolve to be specialized in what they do, reducing competition in such a crowded habitat, and many are driven into close relationships. Shrimp that once scavenged for food now pick parasites and dead skin off living hosts and even advertise their services at cleaning stations. In this mutually beneficial symbiosis, visiting fish “clients” are cleared of potentially harmful pests, while the cleaner shrimp get a meal.



Cleaner shrimp may enter the host's mouth to pick food from its jaws and teeth

Cleaning the hunter

Some cleaner shrimp form strong bonds with moray eels. By sharing the eel's lair, they get some protection from predators.

Colorful cleaner

On coral reefs in the Indo-Pacific, the distinctive red-and-white pattern of the scarlet skunk shrimp (*Lysmata amboinensis*)—named for its stripes—may serve as a visual signal to fish at cleaning stations. Several species of skunk shrimp act as efficient fish cleaners in tropical waters around the world.

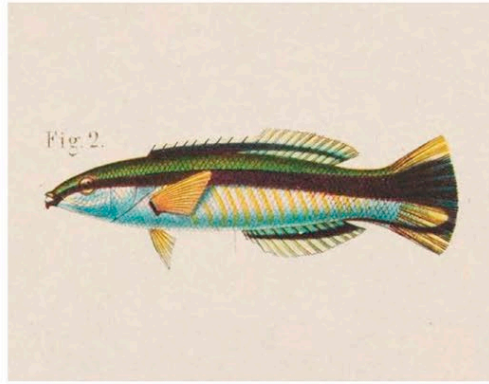
Long white antennae may be waved around as part of the visual signal that advertises the shrimp's cleaning behavior to a “client” fish

Red stripes are caused by a chemical pigment called astaxanthin in the crustacean's carapace



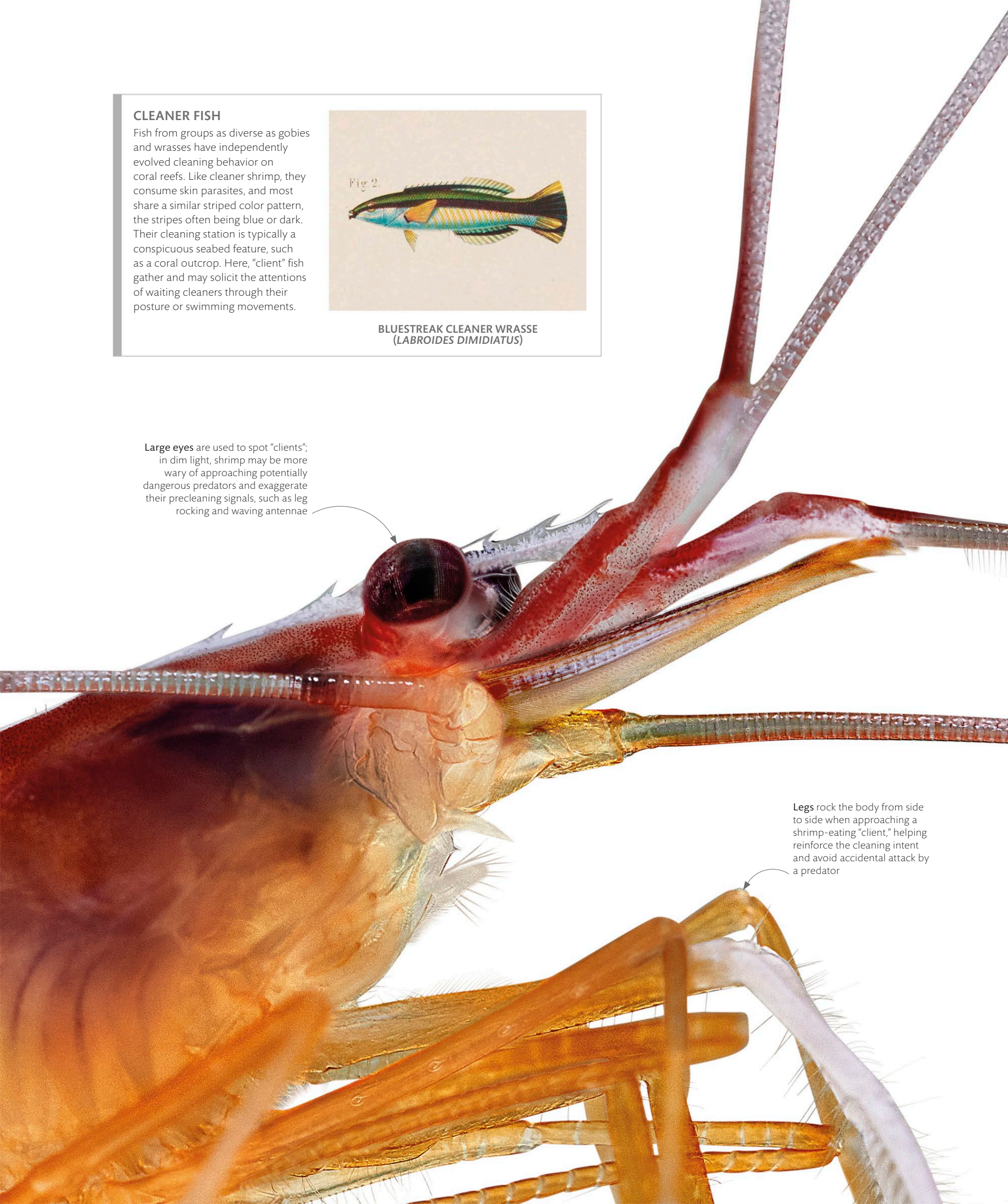
CLEANER FISH

Fish from groups as diverse as gobies and wrasses have independently evolved cleaning behavior on coral reefs. Like cleaner shrimp, they consume skin parasites, and most share a similar striped color pattern, the stripes often being blue or dark. Their cleaning station is typically a conspicuous seabed feature, such as a coral outcrop. Here, "client" fish gather and may solicit the attentions of waiting cleaners through their posture or swimming movements.



BLUESTREAK CLEANER WRASSE
(*LABROIDES DIMIDIATUS*)

Large eyes are used to spot "clients"; in dim light, shrimp may be more wary of approaching potentially dangerous predators and exaggerate their precleaning signals, such as leg rocking and waving antennae



Legs rock the body from side to side when approaching a shrimp-eating "client," helping reinforce the cleaning intent and avoid accidental attack by a predator

Under cover

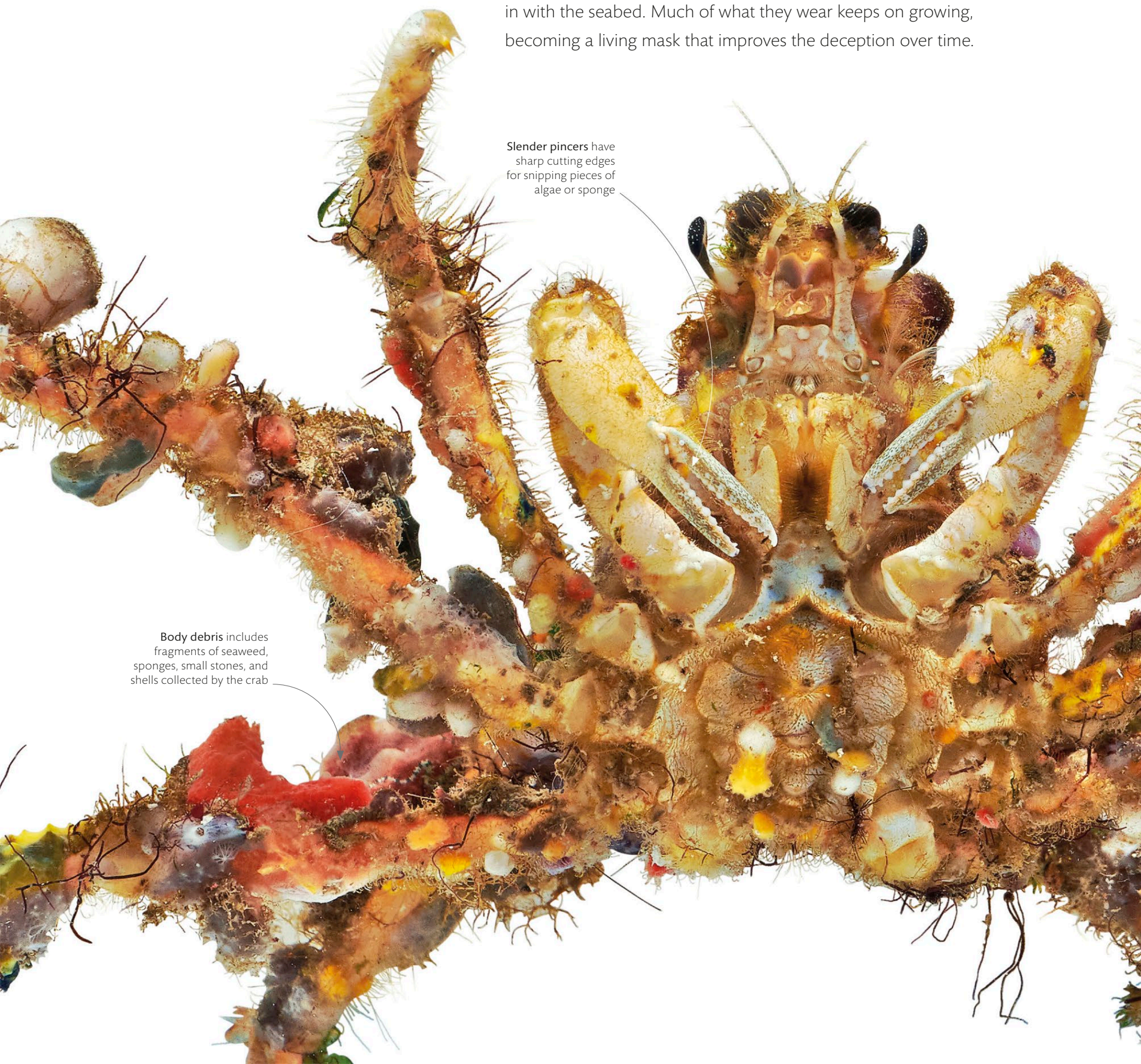
The spider decorator crab (*Camposcia retusa*) is so devoted to staying hidden that the only parts of its body not covered by debris and living things are those it uses to collect the masking material—its pincers.

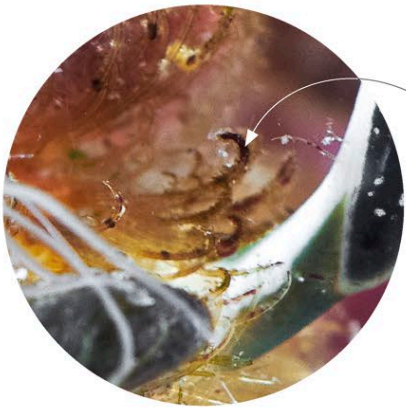
making a mask

Although crabs can famously use their pincers in self-defense, many species adopt a less confrontational approach: they wear a disguise. By plastering their body with flotsam or cuttings—anything from scraps of seaweed to colonial animals like sponges—they can blend in with the seabed. Much of what they wear keeps on growing, becoming a living mask that improves the deception over time.

Slender pincers have sharp cutting edges for snipping pieces of algae or sponge

Body debris includes fragments of seaweed, sponges, small stones, and shells collected by the crab





Hooked hairs grow in bunches, which provides a stronger grip when holding debris

Velcro crab
The body of the spider decorator crab is covered in hook-tipped hairs. The hooks work like Velcro, securing objects to the body transferred there by the pincers.

CRAB DÉCOR

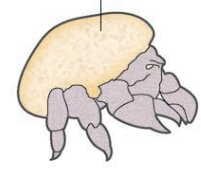
Some crab collectors are specialists. Those of the family Dromiidae camouflage themselves with sponges. They have hooked rear legs for transferring a sponge to the back of their shell. Pom-pom crabs (*Lybia*) even use décor with a sting: they carry tiny anemones (*Triactis*) in their pincers to ward off predators.

Anemones held by pincers

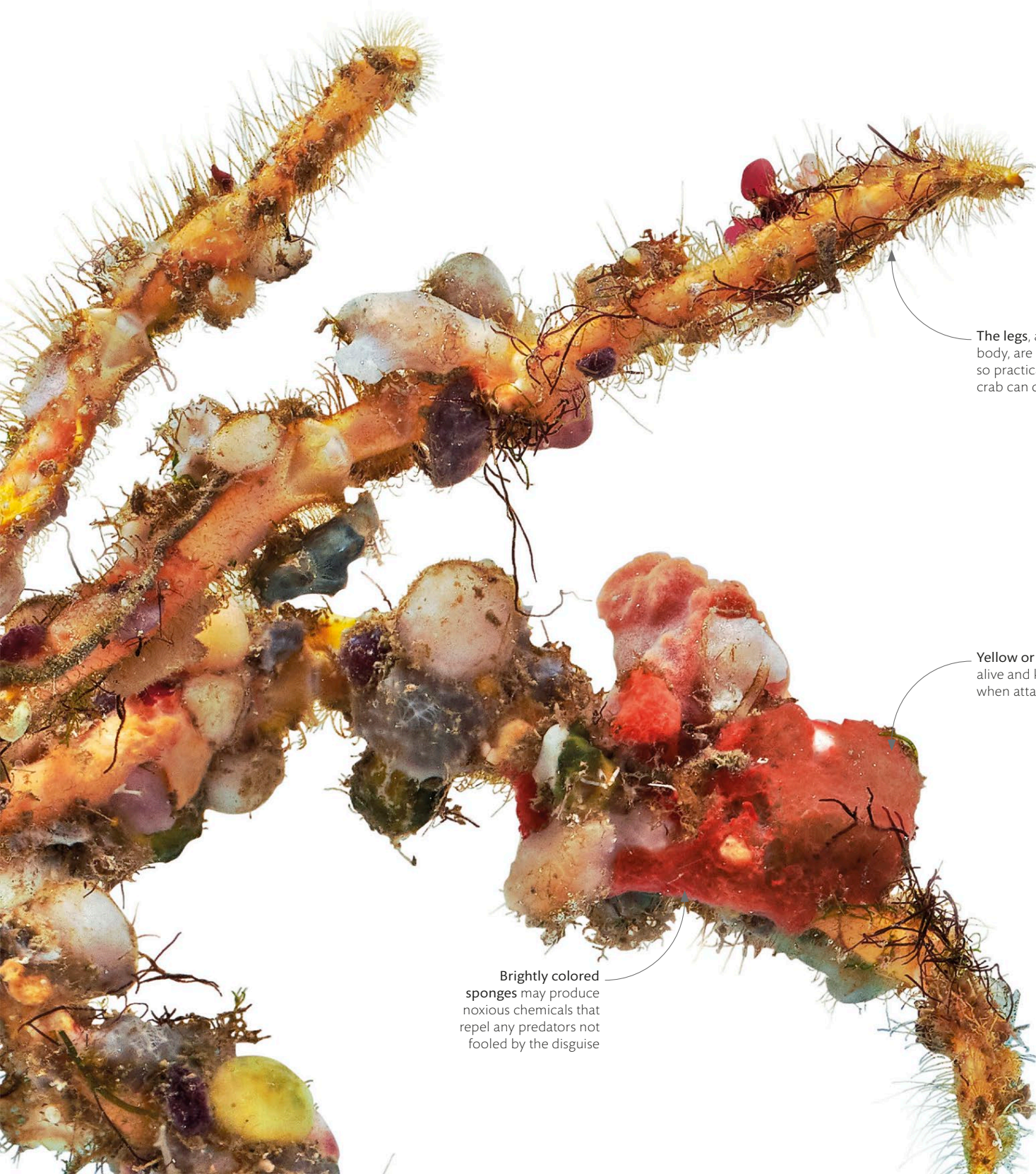


POM-POM CRAB

Sponge in place on crab's back



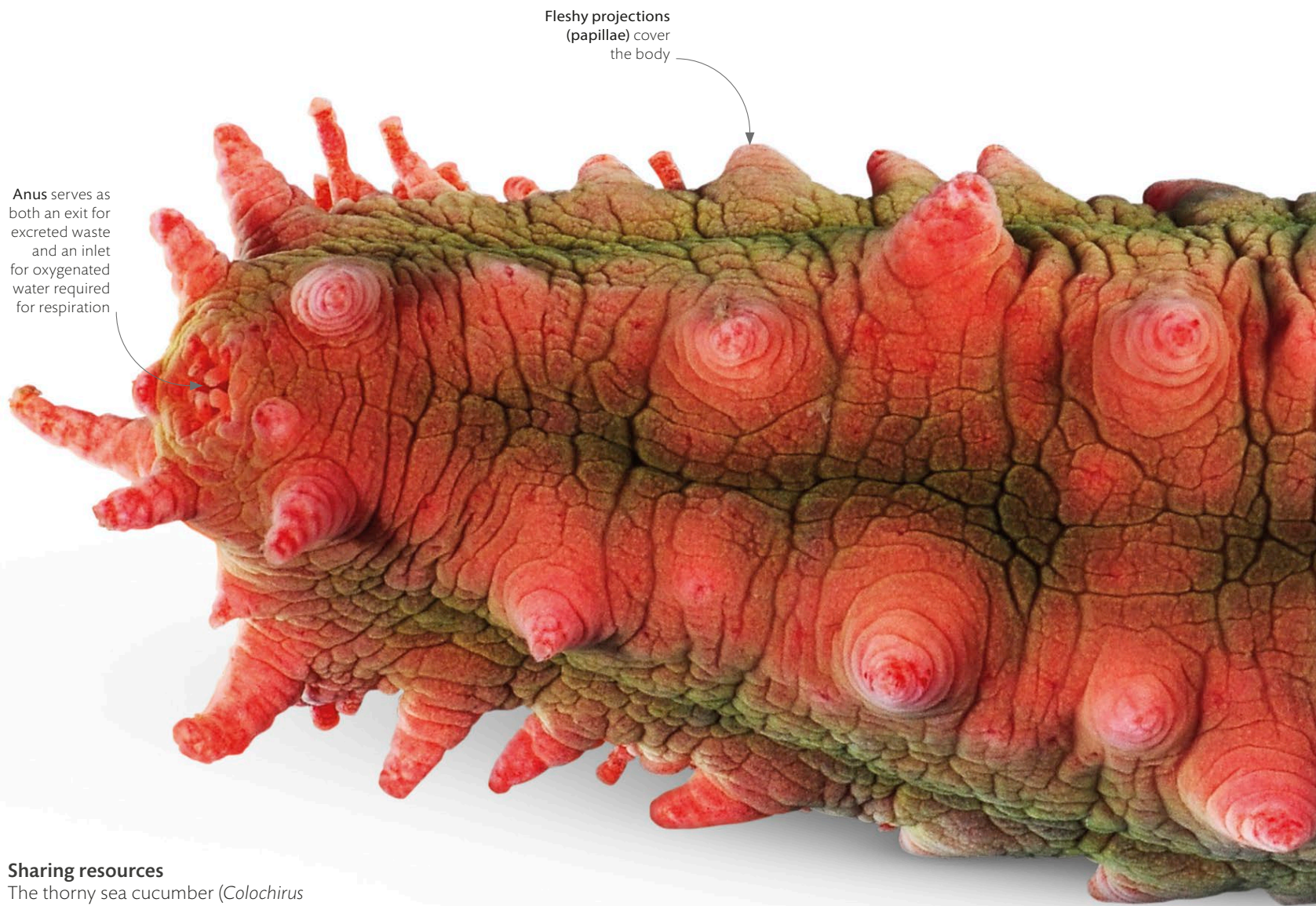
SPONGE CRAB



The legs, as well as the body, are covered in hairs, so practically the entire crab can carry debris

Yellow or red sponges stay alive and keep growing when attached to the crab

Brightly colored sponges may produce noxious chemicals that repel any predators not fooled by the disguise



Anus serves as both an exit for excreted waste and an inlet for oxygenated water required for respiration

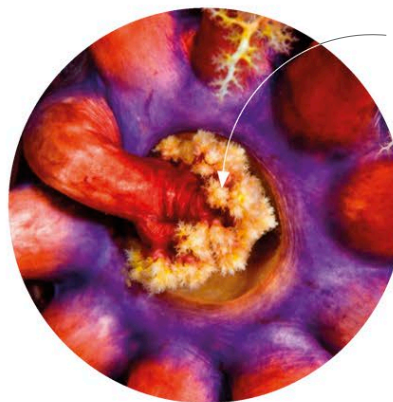
Fleshy projections (papillae) cover the body

Sharing resources

The thorny sea cucumber (*Colochirus quadrangularis*) lives in sunlit waters to about 380 ft (115 m) deep. When feeding, it rears upward and spreads its tentacles to trap food suspended in the water. Some of the food may also be taken by tiny shrimp living in among the tentacles.

seabed feeding

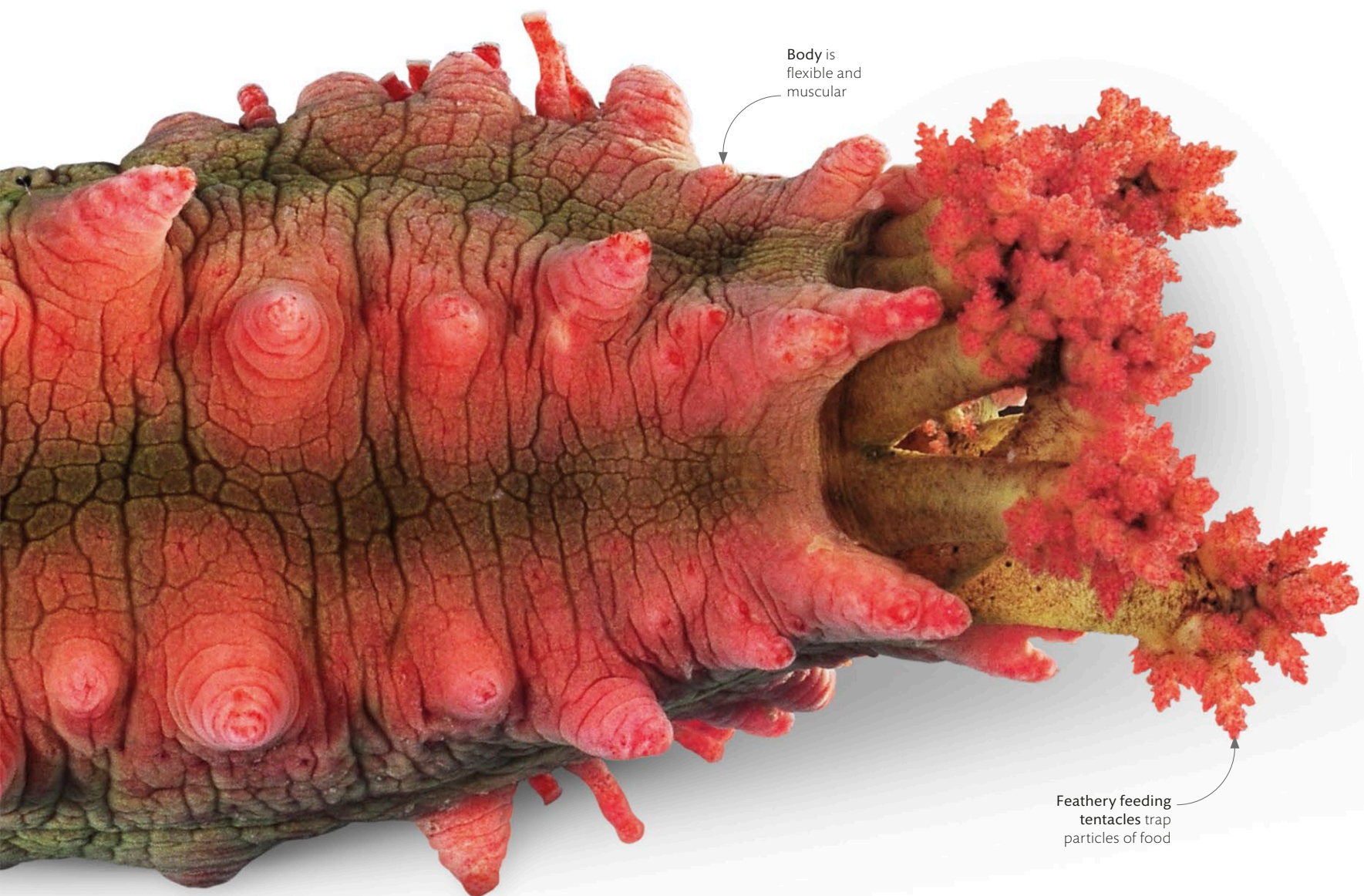
Animals that live sedentary or slow-moving lives on the seabed make the most of the food that comes to them. Suspension feeders trap particles of living or dead material from the water using bristles or tentacles. Detritivores specialize in dead material, known as detritus, which can be trapped in the water or gathered from the seabed. In deep water, detritus raining from above replaces sunlight as the main source of energy.



Tentacles carrying food are inserted one by one into the mouth

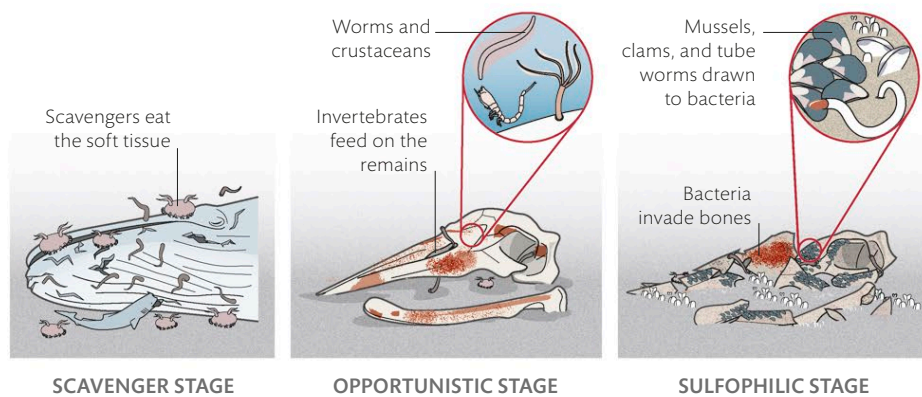
Feeding tentacles

The reef-dwelling sea apple (*Pseudocolochirus violaceus*) is a colorful sea cucumber that uses frilly tentacles to trap tiny particles, such as algae, zooplankton, and dead material, from sunlit shallow water.



WHALE FALL

Detritivores recycle matter and energy back into the food web. A dead whale first provides food for mobile scavengers, including sharks and hagfish, then slower ones like sea pigs (a type of sea cucumber), then colonists such as worms and crustaceans. When the flesh is gone, communities of bacteria in the bones produce hydrogen sulfide and use it in place of sunlight to fuel the manufacture of carbohydrate (see p.262).



Pigmented blue

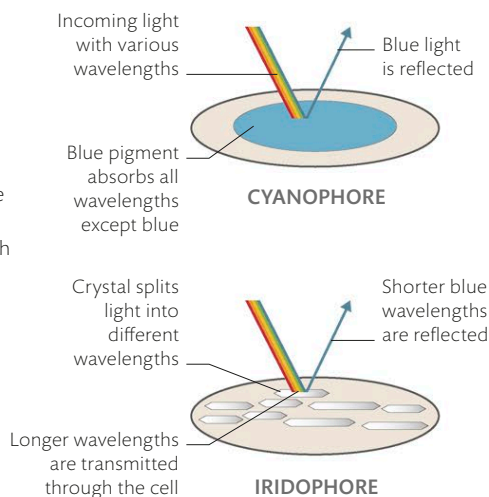
The mandarinfish (*Synchiropus splendidus*), found in shallow inshore reefs of the Western Pacific, is one of only two known vertebrate species whose blue color comes from a pigment rather than structural scattering of light. The striking blue coloration is used as a warning to predators that it is protected by a powerfully unpleasant-smelling toxic mucus secreted through the smooth, scaleless skin.

blue underwater

Vivid colors of fish on a coral reef help signal species identity in this crowded community. Blue and yellow are the most common: they contrast well and transmit far underwater, while red is effective in shallower depths. Much of this color comes from pigments that absorb some wavelengths of light and reflect others. But some—notably blue—is structural. This happens when objects, such as microscopic crystals in a fish's skin, bend wavelengths to different degrees—in the way raindrops produce a rainbow.

PIGMENTARY AND STRUCTURAL BLUES

Black, brown, yellow, and red pigments are produced in a fish's skin by cells called chromatophores. So far, blue-pigmented chromatophores (or cyanophores) are known only in the mandarinfish and a close relative. Pigments absorb wave-lengths of light, except for the color that we see, which is reflected back. Other skin cells, called iridophores, contain guanine crystals. As light passes through the crystals, the wavelengths bend to varying degrees. Shorter blue wavelengths get scattered back and intensified, so the skin appears blue. This explains the blue color of other kinds of coral reef fish.



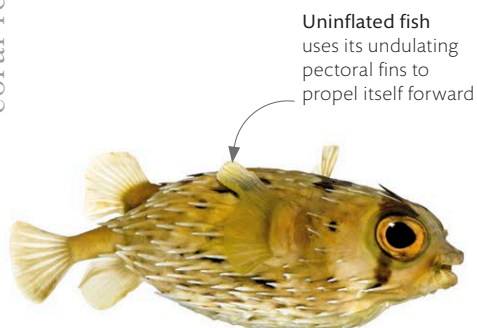


inflatable bodies

The related pufferfish, balloonfish, and porcupinefish all share the startling defensive strategy of rapid inflation of the body to a near-spherical form in order to deter attacks from larger animals. They also produce potent toxins. However, these defenses sometimes come too late—large, quick predators may snap up a fish before it has fully inflated, which can result in the death of both the fish and the predator. The unrelated swell sharks adopt a similar strategy, but they do not achieve the extreme roundness seen in the others.

Difficult mouthful

The body of the long-spine porcupinefish (*Diodon holocanthus*) is covered in rows of scales that extend into needlelike spines. In a relaxed fish, the spines lie flat against the body, but when the fish swells, the skin tautens and the spines are pulled erect, increasing the deterrent to predators.

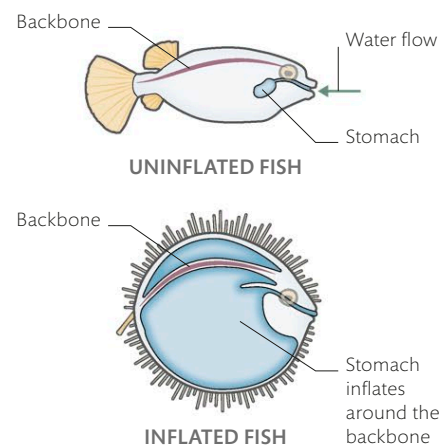


Skin contains collagen fibres, which help the skin to expand as the fish inflates



GULPING WATER

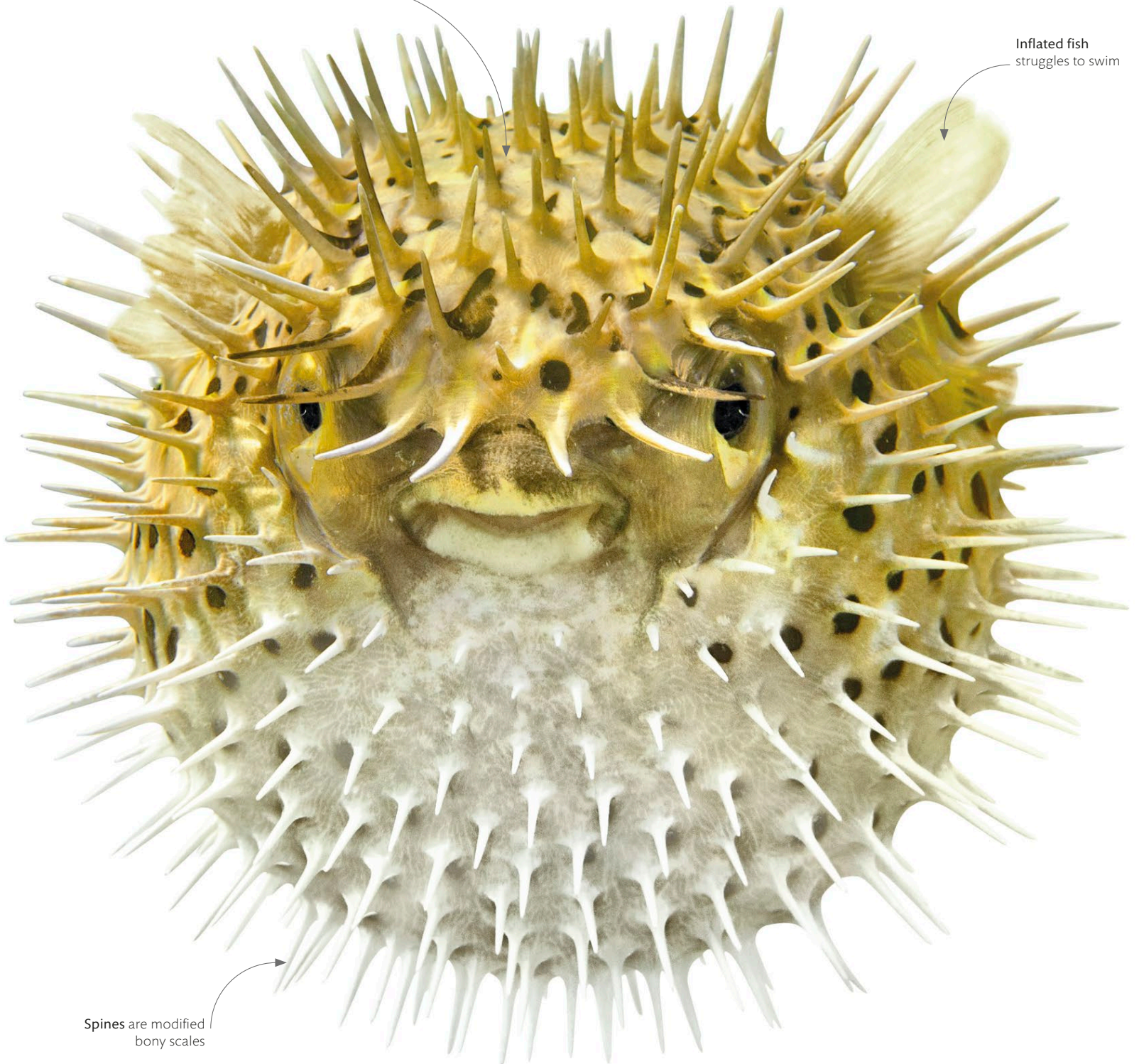
When frightened, pufferfish and porcupinefish transform by rapidly swallowing water into the stomach, which expands like a balloon, filling all available space in the body cavity. Powerful sphincter muscles at either end of the stomach prevent liquid and gas passing into the gut during inflation. When the perceived threat has passed, the water is regurgitated or belched back out of the mouth and the fish deflates.

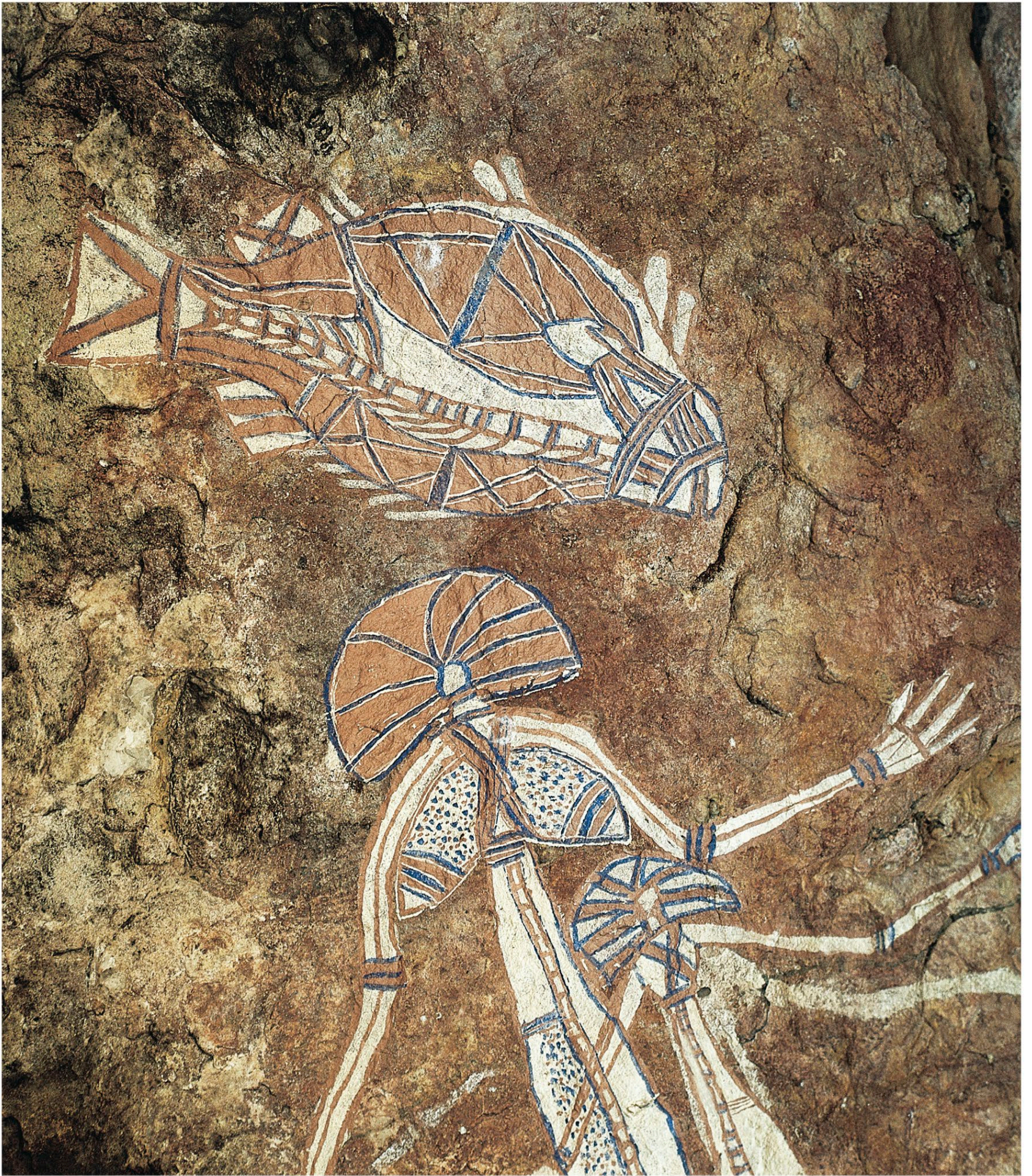


Blotchy body
coloration serves
as camouflage
against seafloor

Inflated fish
struggles to swim

Spines are modified
bony scales







Dugong Hunt (1948)

In this bark painting of fishermen in northern Australia's Gulf of Carpentaria, a dugong—a sea mammal especially valued by Aboriginal people—is pulled from the depths. The work is attributed to the Aboriginal artist Jabarrgwa "Kneepad" Wurrabadalumba.

the ocean in art

aboriginal sea stories



Barramundi (20th century)

Characteristic of western Arnhem Land art, a pair of barramundi are painted on stripped bark in the traditional X-ray style. The skeleton and organs are mapped out inside the outline of the fish.

Dreamtime Spirits and Fish (20th century)

The rock art sites in Kakadu National Park are decorated with paintings and drawings dating back to c.26,000 BCE, as well as more recent works. As is typical of Aboriginal rock art, many artists have retold stories by painting over older work. This painting of X-ray-style fish with ceremonial figures is one of 600 works at 46 sites by the artist Najombolmi.

The art of Aboriginal peoples in Arnhem Land, in Australia's Northern Territory, reflects their ancient connection with animals in coastal waters and rivers. Traditionally, Aboriginal peoples use art (and oral literature) rather than the written word to pass on their knowledge and tell stories. Works may convey practical skills, such as fishing, or legends of cultural or spiritual significance, often using symbols passed down through millennia.

Of all the fish featured in Aboriginal art, barramundi reign supreme. For millennia, they were painted on rocks in sites that are now protected by the Kakadu National Park. Today, the fish is widely reproduced on paper and in bark paintings—an art form that has become widespread in the past 70 years. The bark is stripped from gum trees, then heated and flattened to create a surface for natural pigments.

In western Arnhem Land, subjects are depicted in X-ray style (see left). In the east, sea creatures and fishermen are rendered with intricate cross-hatching, known as *raark*, using reeds or human hair like a

brush to create fine lines. In the northeast, the bark paintings of the Yolŋu people tell tales of seafaring ancestors and legendary sea creatures and impart centuries of knowledge as the caretakers of the coast.

After a barramundi fishing party illegally encroached on a sacred site in 1996, Yolŋu artists in Yirrkala produced a set of paintings known as the Saltwater Barks to explain their ancient traditions and assert ancestral rights. In 2008, the High Court of Australia confirmed that the area's Aboriginal owners have exclusive access rights to tidal waters along 80 percent of the Northern Territory coastline.

“By painting ... we are telling you a story ... We use our knowledge to paint from the ancient homelands to the bottom of the ocean.”

YOLŊU ELDER, SALTWATER: YIRRKALA PAINTINGS OF THE SEA COUNTRY, 1999



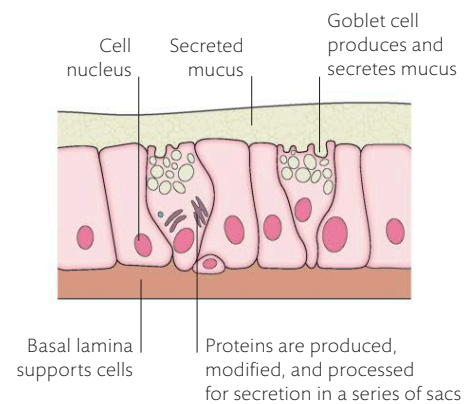
Holding fire

The stinging cells (nematocysts) on anemone tentacles are usually triggered by contact with another animal. To avoid being stung, the maroon clownfish (*Premnas biaculeatus*) secretes a body covering of mucus, to which the anemone does not react.

SECRETING MUCUS

The mucus secreted by various fish organs serves many purposes, not least acting as a barrier to pathogens. Mucus contains a cocktail of carbohydrates and proteins, which varies according to the organ and species. Some evidence suggests that clownfish skin mucus appears to lack the proteins that anemones associate with potential threats or meals, and so contact with the fish does not trigger a stinging response.

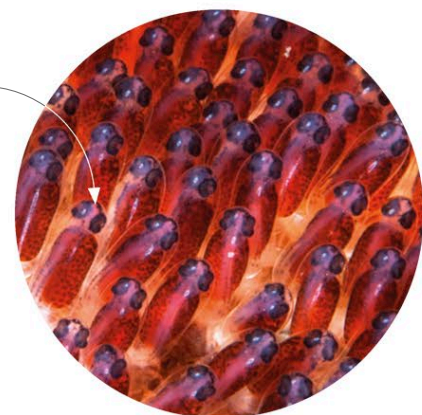
MUCUS CELLS IN SKIN



mutual protection

Several fish species live in mutually beneficial relationships with anemones, most notably clownfish. The fish gain protection from predators for themselves and their eggs among the anemones' stinging tentacles. The anemones benefit because the fish chase away anemone-eaters, drop food, and clear the anemones' tentacles of waste and debris. In addition, nutrients from the clownfish droppings boost the growth of algae (zooxanthellae), which live in even closer association inside the anemone, using light energy to make food.

Larvae hatch a week after the eggs are fertilized by the male



Safe nursery

Clownfish embryos develop from eggs laid close to anemones, and the young fish are resistant to anemone stings from the moment of hatching. All clownfish begin life as males. The oldest and largest adults switch sex to become females.

sex changer

Many fish change sex during their lifetime, which means that an individual can breed as both a male and a female at different stages of its life. These fish are called sequential (or nonsimultaneous) hermaphrodites. Most of these sex changers, including several species of wrasse, switch from females to males (protogyny). However, some species switch the other way (protandry), including the common clownfish and, according to some experts, the ribbon moray (*Rhinomuraena quaesita*).

Watching and waiting

All morays spend long periods hidden in crevices with the head protruding. Relatively large eyes, expanded nostrils, and sensitive tentacles help the ribbon moray sense prey, which it seizes with its two sets of jaws—one in the mouth, another in the throat. The ribbon moray is sometimes known as the leaf-nosed moray for its distinctive snout.

Mostly yellow individuals are thought to be females



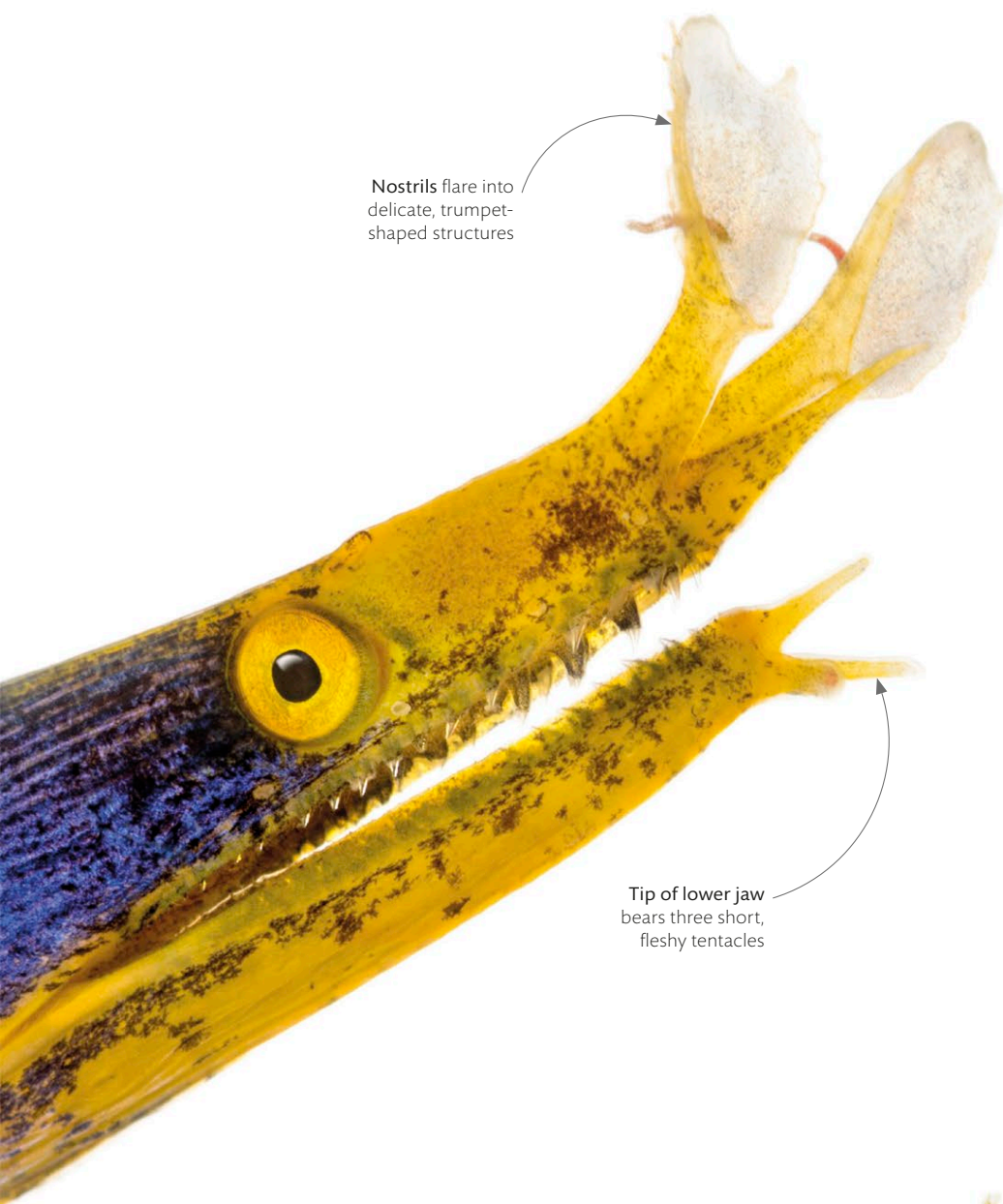
The wide gape is a threat posture typical of moray eels

The female stage

A major advantage of protandry, in which a male increases in size and becomes female, is that the larger females have greater bodily resources to invest in egg production, which requires a great deal of energy.

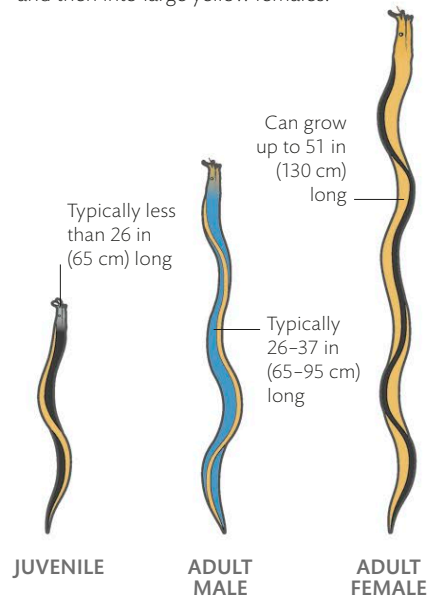
Bright blue body coloration of male





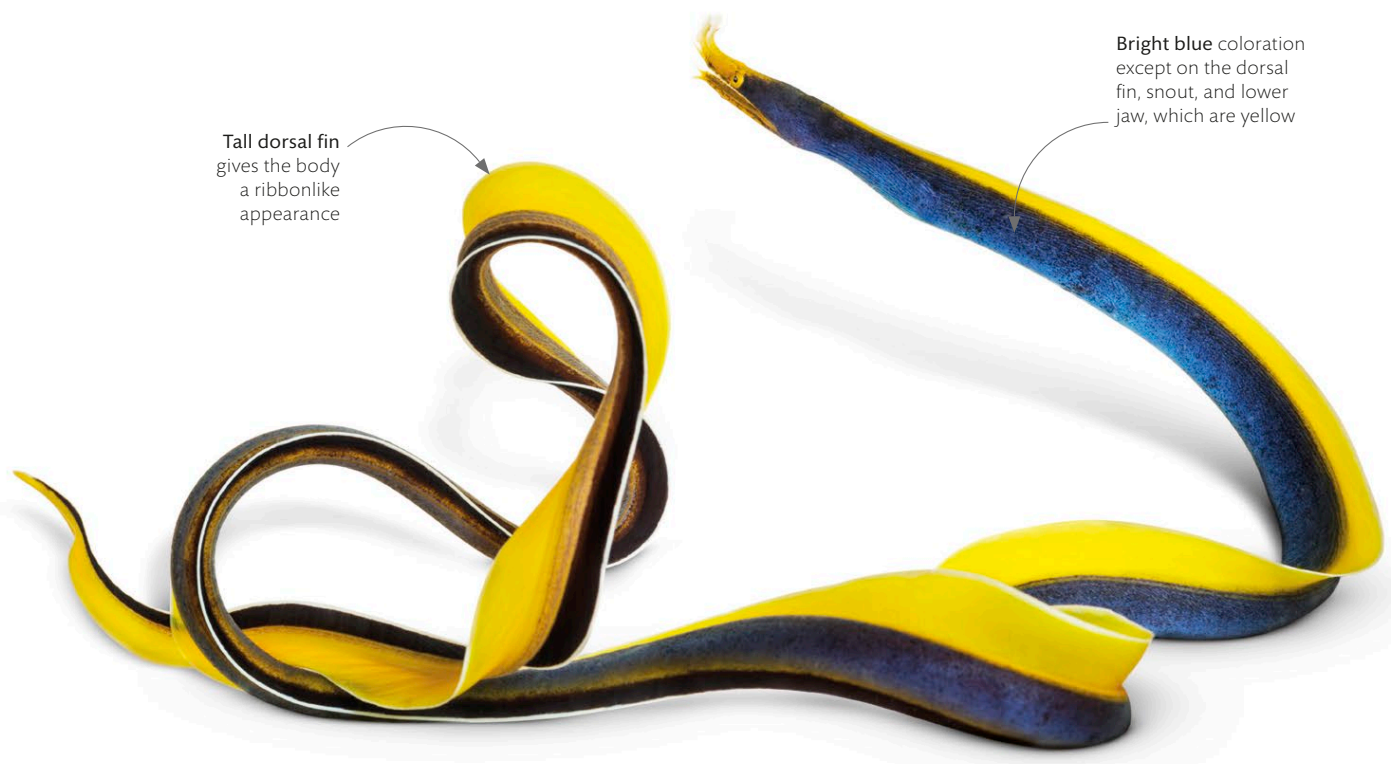
SIZE AND COLOR VARIATIONS

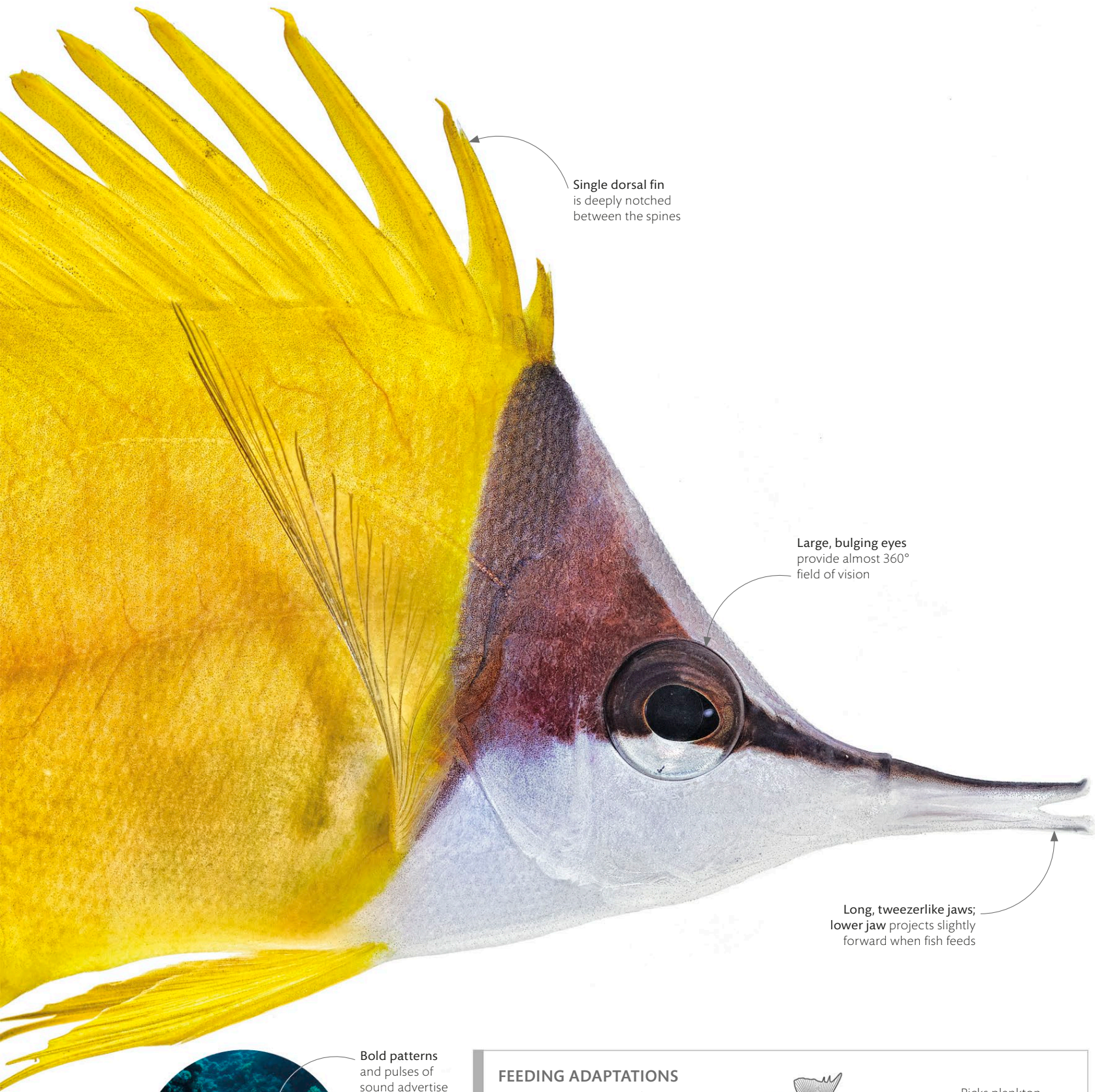
Ribbon morays were once regarded as several species, because of their striking color variation. However, some experts think that they may develop from small black juveniles into blue adult males and then into large yellow females.



The male stage

As the ribbon moray matures, the jet black of the juvenile is thought to change to a distinctive, vivid electric-blue color. Current thinking suggests this may be the male stage of its life cycle.





Single dorsal fin
is deeply notched
between the spines

Large, bulging eyes
provide almost 360°
field of vision

Long, tweezerlike jaws;
lower jaw projects slightly
forward when fish feeds



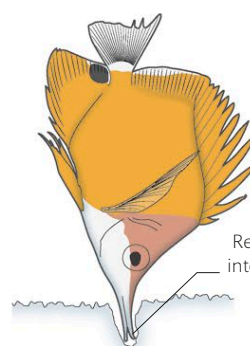
Bold patterns
and pulses of
sound advertise
territorial
boundaries

Feeding in pairs

Chaetodon lineolatus, which feed mainly on coral polyps, tend to be monogamous; pairs work together to defend a feeding territory.

FEEDING ADAPTATIONS

The long, narrow jaws of the longnose butterflyfish resemble a pair of bottlenose pliers, making them ideal for feeding in the crevices of the reef, where many other fish cannot reach. Some other butterflyfish, such as bannerfish, have shorter jaws and bristlelike teeth, which are useful for snatching small prey, such as free-floating plankton, from the water, or picking food off the surface of the reef.



LONGNOSE
BUTTERFLYFISH



BANNERFISH

Picks plankton
from the water

Reaches deep
into crevices



reef feeders

The 5,000 or more species of fish that live on coral reefs feed in many different ways. This helps them divide up the available resources and avoid competition. Only about 130 eat coral polyps directly, while many more take tiny invertebrates hidden among the coral rock. Dominant among the polyp-eaters and rock-probers are the butterflyfish. Their tiny protractile mouths, armed with comblike teeth, are perfect for foraging among crevices or rubble, from where they extract their miniature prey.

Dancing color

Butterflyfish are named for their colorful appearance and the way they flutter above the reef in "clouds." The yellow longnose butterflyfish (*Forcipiger flavissimus*, opposite) and the smaller copperband butterflyfish (*Chelmon rostratus*, above) are both found in reefs in the Indian and Pacific Oceans.



Spines of elegant unicornfish are fixed in an open position, while those of most other surgeonfish are retractable

Sharp end

Like its close relatives, the elegant unicornfish (*Naso elegans*) possesses at least two forward-pointing spines on either side of the tail. A flick of the tail can inflict serious wounds.



Dorsal fin is yellow in *Naso elegans* and mostly black in the otherwise almost identical *N. lituratus*

Sharp spines at base of tail project outward from body

Body coloration brightens with age: young specimens are gray, while older individuals have a yellow chest

bladed fish

Most fish are covered in scales, which are small, rigid plates that grow out of the skin. While all scales offer some form of protection, they vary greatly in structure and composition. Some groups have evolved modified scales that serve a particular function. Surgeonfish (also referred to as tangs or unicornfish) are distinguished by having large scales on the tail, modified into sharp spines, or scalpel-like blades. These usually lie flat, and the fish raises them when disturbed; however, in some species, they are fixed in a raised position.

Defensive weapons

Like all surgeonfish, the elegant unicornfish (*Naso elegans*), sometimes called the lipstick tang, uses its spines as a form of defense. It is rarely aggressive toward other fish and is quite confident, perhaps because of its built-in weapons.



Large eyes
provide excellent
color vision

Small mouth, with
orange "lips," contains a
single row of sharp teeth
used to shred seaweed

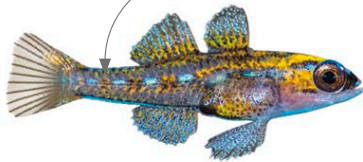
Small prey species

These fish, especially the hidden bottom-dwellers (cryptobenthics), are some of the smallest and most plentiful and account for almost 60 percent of fish consumed by larger species. Cryptobenthic larvae remain close to their parents' reefs, increasing their chances of survival, so the fish supplies are constantly replenished.



URCHIN CLINGFISH
Diademichthys lineatus

Skin is smooth and scale-less but is protected by a layer of mucus



GLASS GOBY
Coryphopterus hyalinus

Translucent cryptobenthic fish that is no more than 1 in (2.5 cm) long



MAGENTA DOTTYBACK
Pictichromis porphyrea

Long, tapered body can be 2 in (5 cm) in length

Foragers

The water column zone of a reef sees slightly larger fish that feed on the smaller bottom-dwellers, coral polyps, plankton, and micro-invertebrates. They also clean the reef and some—for example, the surgeonfish—also consume algae, which helps ensure sunlight can reach the coral for photosynthesis.



BULLSEYE CARDINALFISH
Ostorhinchus fleurieu

Head has distinctive dark stripe on the snout and electric blue lines at the eyes



FLAME ANTHIAS
Pseudanthias ignitus

Male has bright red dorsal fin that it erects during courtship

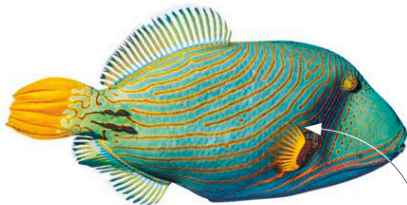


COPPERBANDED BUTTERFLYFISH
Chelmon rostratus

Laterally compressed shape enables fish to swim through narrow gaps in the reefs

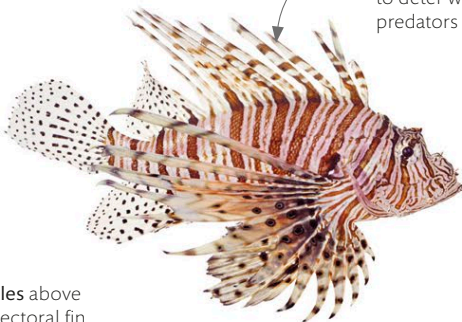
Visiting predators

The largest and most active predators of the reef's food chain are the visitors that feed voraciously on fish, crustaceans, and plankton, as well as benthic organisms such as algae, echinoderms, mollusks, tunicates, sponges, and hydrozoans. They range in size from the larger sharks and rays to huge schools of smaller species such as triggerfish and snappers.



ORANGE-LINED TRIGGERFISH
Balistapus undulatus

Enlarged scales above the base of pectoral fin, behind the gill, are used to produce sound



RED LIONFISH
Pterois volitans

Venomous dorsal spines are raised to deter would-be predators



SCHOOLMASTER SNAPPER
Lutjanus apodus

Snout is long and pointed with large mouth; upper canine teeth are sometimes visible when mouth is closed

reef fish

Coral reefs cover scarcely 0.1 percent of the world's oceans but are home to around one third of all described species of marine fish. The three-dimensional structure of a reef—as complex as a rainforest on land—has provided a rich variety of opportunities for fish to evolve in a multitude of different ways, helping them coexist and interact with the other life around them.



STRIPED BLENNY
Meiacanthus grammistes

Long, sharp preopercular spine protrudes between cheek and gill cover



SABRE SQUIRRELFISH
Sargocentron spiniferum

Upper jaw has outer row of strong canines and an inner band of small teeth



BLUEFIN TREVALLY
Caranx melampygus

Color-changing reef dweller

Streaked with blue over a pale brown ground, the elongate surgeonfish (*Acanthurus mata*) is capable of changing the background color to dark brown. The species inhabits steep slopes and rocky bottoms and is often seen in large schools. This surgeonfish feeds almost entirely on zooplankton and can live for more than 20 years.

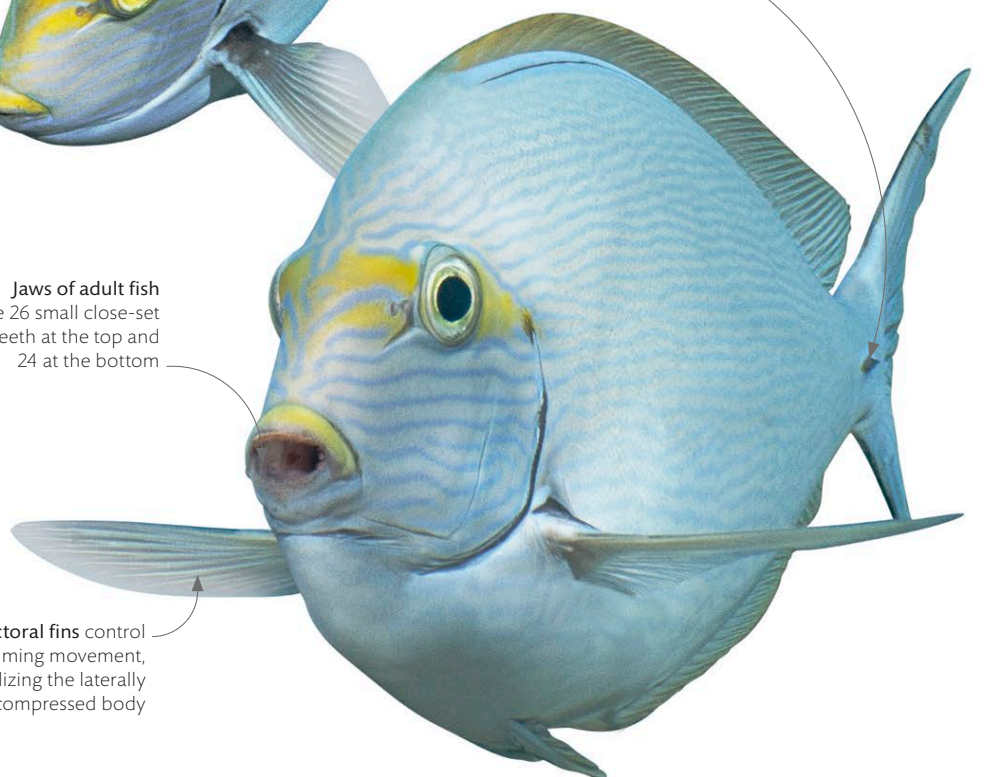


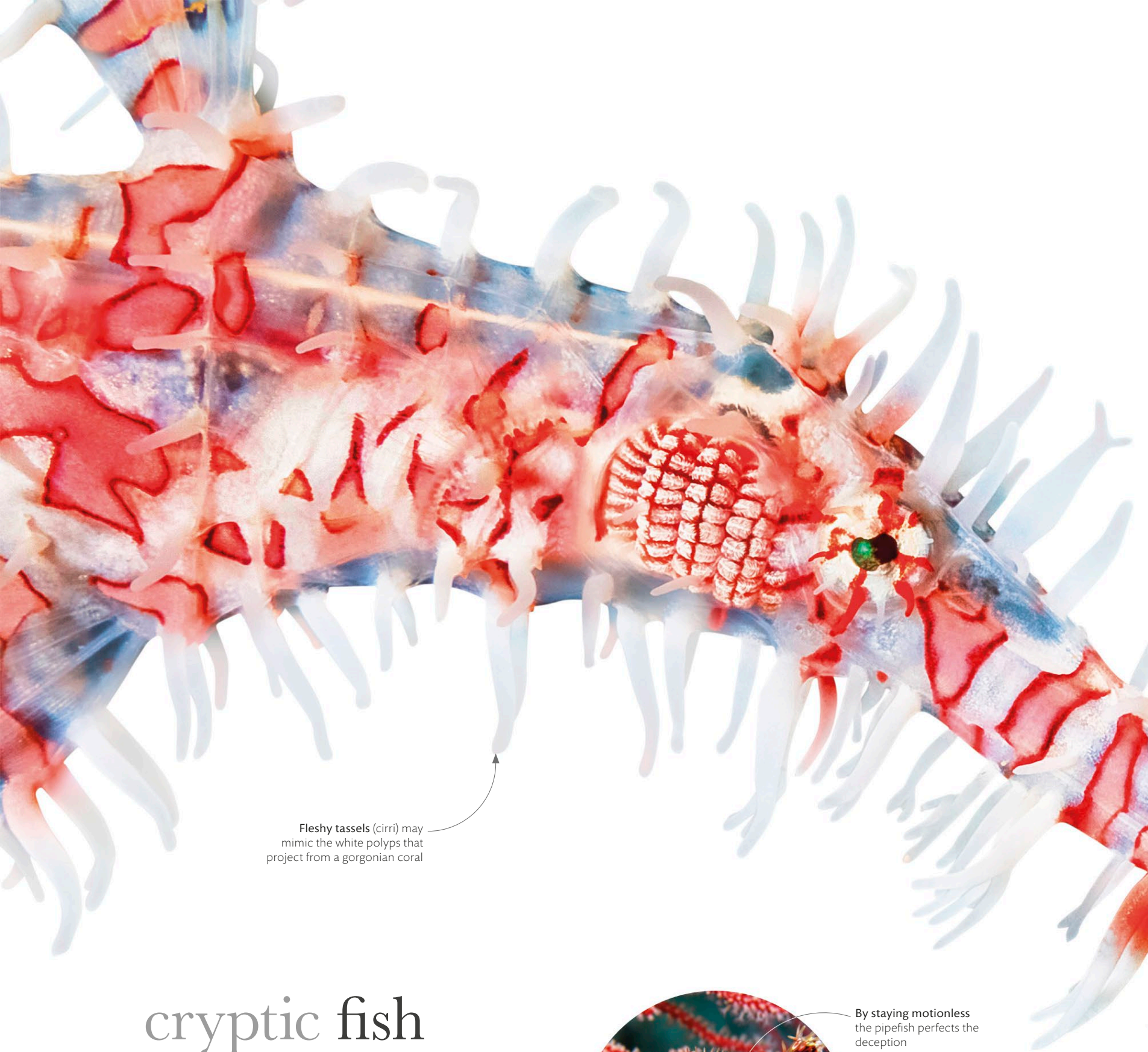
Body can be up to 20 in (50 cm) long

Sharp, lancelike defensive spines are folded into small horizontal grooves on each side of the tail

Jaws of adult fish have 26 small close-set teeth at the top and 24 at the bottom

Pectoral fins control swimming movement, stabilizing the laterally compressed body





Fleshy tassels (cirri) may mimic the white polyps that project from a gorgonian coral

cryptic fish

Coral reefs and shallow seas are visually complex environments, and many species take advantage of the intricate mix of color and texture to hide from predators and prey. Ghost pipefish are true masters of the art of camouflage and crypsis, with different species specializing in mimicking the appearance and behavior of diverse reef-dwelling organisms.



By staying motionless the pipefish perfects the deception

Perfect match

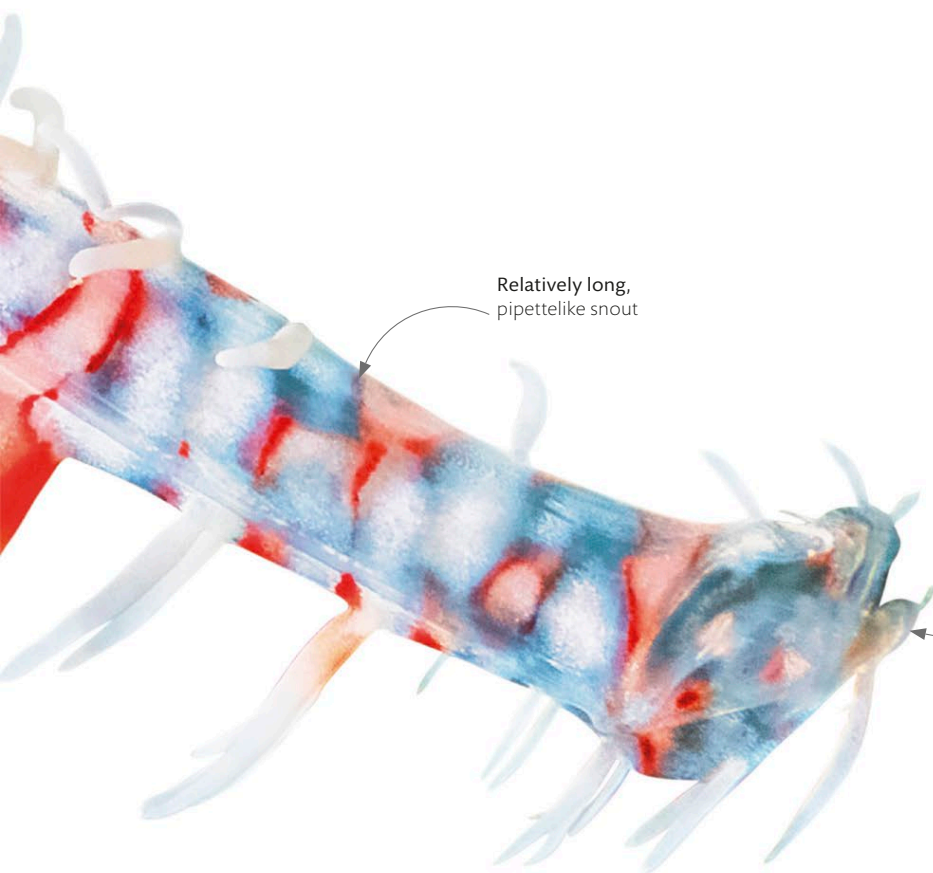
The red, elongated body and spreading fins of a harlequin ghost pipefish bear a very close resemblance to the branching colony of a gorgonian coral.

Head down

A head-standing posture may help a harlequin ghost pipefish blend in with vertical branches of coral. Other species of ghost pipefish adopt a similar behavior when hiding in seagrass.



Eyes on side of head rotate in sockets, providing all-around vision even while the fish is motionless



Relatively long, pipettelike snout

Tiny, toothless mouth at the tip of the snout sucks in prey (typically tiny crustaceans)

Color shift

The harlequin ghost pipefish (*Solenostomus paradoxus*) changes its appearance to be as inconspicuous as possible at each stage of its life. The transparent larvae start off in open water, where they live unobtrusively among the plankton. On maturity they live on the reef, where they are surrounded by gorgonian coral and crinoids and adopt strong colors and textures and a ragged outline.

specialized fins

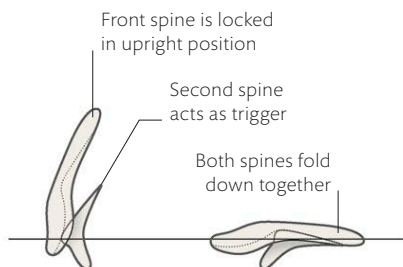
About 99 percent of all bony fish, of which there are around 30,000 species, are classified as ray-finned fish; this makes them the most species-rich class of vertebrates on Earth. All members of this group have fins made up of fine webs of skin supported by bony rays. The adaptability of this basic structure contributes to the group's success, with size, shape, and function varying to give fish the specialist abilities that set species apart. In triggerfish, the first dorsal fin is small and triangular and contains three thick, spinelike rays. If the fish is relaxed, the spines lie flush with the back, but if it feels threatened, it raises its spines so that they are perpendicular to the body.

First dorsal fin, containing three spines, is raised in self-defense



LOCKING MECHANISM

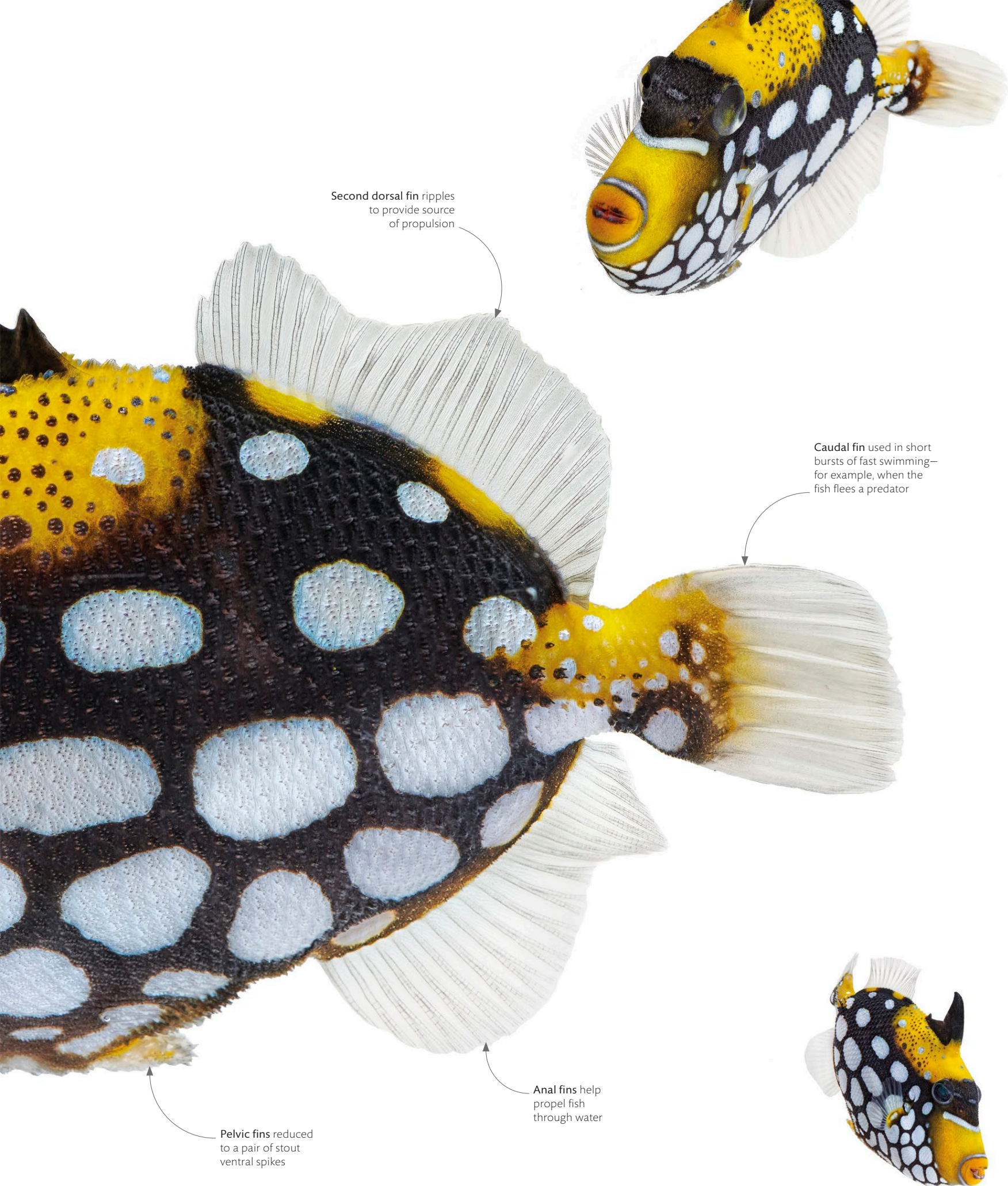
If a triggerfish feels threatened, it raises the spines in its first dorsal fin. The smaller secondary spine then slots into a groove on the back of the larger front spine, locking it in place. The front spine cannot be lowered until the secondary spine has folded back.



DORSAL FIN SPINES OF A TRIGGERFISH

Dual-purpose spine

When the reef-dwelling clown triggerfish (*Balistoides conspicillum*) is targeted as prey by larger species, the lockable spine is an important defense mechanism. In addition to making the triggerfish difficult to swallow, it can be used to wedge the fish in a crevice where the predator cannot reach it.



Second dorsal fin ripples
to provide source
of propulsion

Caudal fin used in short
bursts of fast swimming—
for example, when the
fish flees a predator

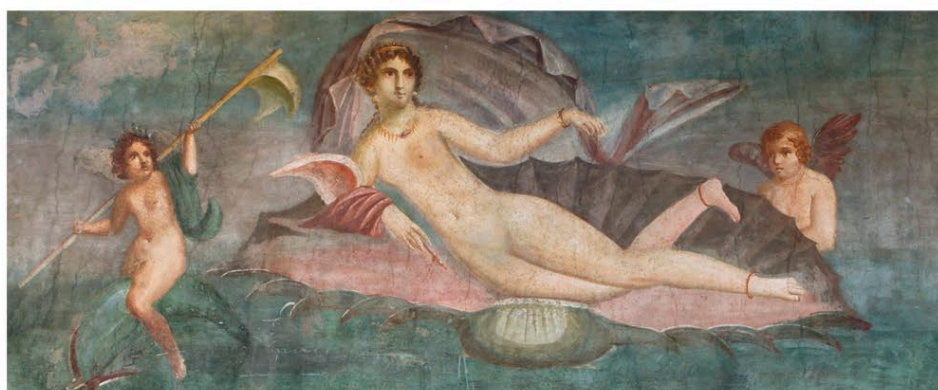
Anal fins help
propel fish
through water

Pelvic fins reduced
to a pair of stout
ventral spikes



Venus in a half-shell (1st century CE)

In the central peristyle (courtyard) of the House of Venus Marina, in Pompeii, a dazzling fresco panel of Venus takes center stage. Rising fully formed from her half-shell, she is carried forward by the wind caught in her red mantle and is attended by sea nymphs and a dolphin.



the ocean in art

seas of antiquity



An ocean floor (1st century CE)

A floor mosaic from a Roman caldarium (hot bath) features African fishermen chasing fish and sea monsters. It was recovered from the House of Menander in Pompeii.

The sea personified (2nd–3rd century CE)

In Greco-Roman mythology, Pontus or Oceanus personified the sea and fathered a panoply of sea gods and sea life. In this detail from a Roman mosaic in Utica, Tunisia, the watery god, with a beard of waves, seaweed hair, and lobster-claw horns, is attended by *erotes* (winged cupids) riding on the backs of dolphins.

The sea played a key role in the two ancient civilizations that underpinned much of Western culture. The city-states of ancient Greece fringed the Aegean and extended along the Mediterranean coast until they came under Roman rule in 146 BCE. At its peak, the Roman Empire controlled all the lands around the Mediterranean, and many beyond. For both civilizations, the sea was a major source of inspiration in their mythology and art.

The perfection of classical Greek art survives in statues, sculpted friezes, and mosaics but rarely in paint. The few frescoes that remain comprise painted tombs in Paestum, southern Italy, dating from the 5th century BCE, and fragments from the much earlier Minoan civilization on the Greek island of Crete. Two in particular honor the sea: in Paestum, a lone diver flexes his body as he swoops down to meet the water; in Crete, dolphins, painted c.1500 BCE and restored in the early 20th century, play across the walls at the palace of Knossos.

Further insights into the art of ancient Greece have emerged through Roman art, largely because the expanding empire

became a melting pot for the cultures that preceded it. Looted classical treasures, such as bronze statues and paintings of mythological scenes, were prized and preserved through faithful copies. Hellenistic gods were renamed and their stories replicated in the frescoes and mosaics that adorned the homes and gardens of wealthy Romans.

Sea-life mosaics were favored for bath houses and courtyard pools, especially in the luxury villas of Pompeii, southern Italy. A famous mosaic from the House of the Faun celebrates the coastal bounty of fish, lobsters, eels, and octopuses in a design that was widely used. In coastal colonies in Turkey and North Africa, mosaics featured sea gods and goddesses, such as Poseidon and Amphitrite, and a host of fish-tailed mythical beasts.

Dolphins were popular in mosaics and frescoes as attendants to Aphrodite or playfully circling fishermen and ships. In his *Historia Naturalis* (77–79 CE), Pliny the Elder contributed to their magic with his tale of a dolphin who befriends a boy and carries him to school every day.

“ (The dolphin) does not dread man, as though a stranger to him, but comes to meet ships, leaps and bounds to and fro ... ”

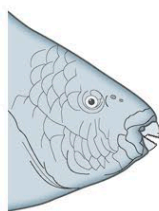
PLINY, *HISTORIA NATURALIS*, 77–79 CE



Jaws are covered with a mosaic of hard-wearing teeth, which are continually replaced throughout life

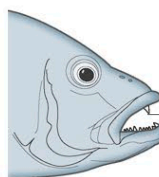
TEETH AND DIET

The jaws and teeth of fish show a huge variety of specialist forms and functions. For example, the teeth of the queen parrotfish (*Scarus vetula*), which is a herbivore, are completely blunt, with a highly resilient, replaceable surface that is used to scrape the surface of rock and coral without damaging the underlying bone. In contrast, the carnivorous northern red snapper (*Lutjanus campechanus*), which feeds on small fish and crustaceans, has needle-sharp teeth that are used as weapons for stabbing and snagging its prey.



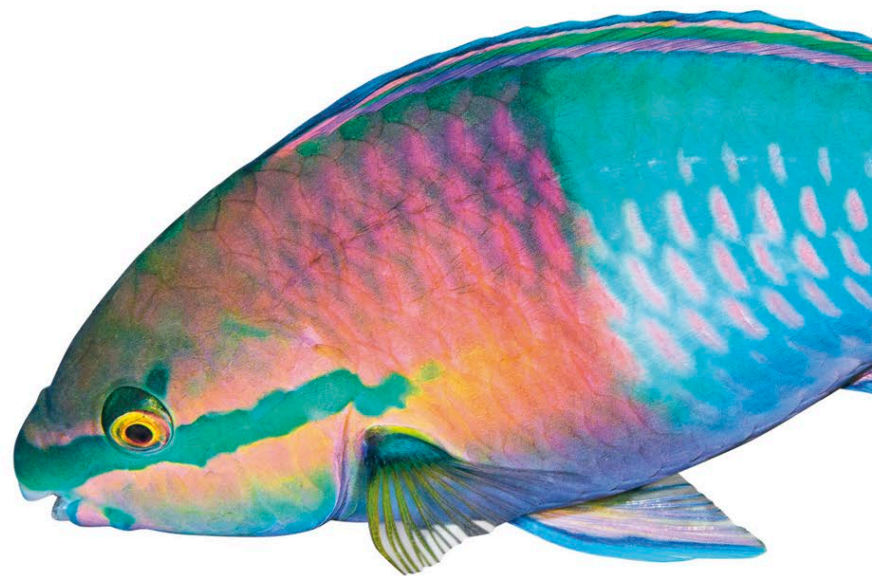
Blunt, fused teeth

HERBIVORE (QUEEN PARROTFISH)



Sharp, pointed teeth

CARNIVORE (NORTHERN RED SNAPPER)



Excreting sand

As the steephead parrotfish (*Chlorurus microrhinos*) feeds, it gouges particles of reef and rock from the substrate, which it ingests at the same time as its food. The particles pass through the gut undigested and are then excreted as fine white sand.



Robust beak and powerful jaws are typical of excavating parrotfish

reef scrapers

The sunlit surfaces of rocky and coral reefs make an ideal growing substrate for algae, which in turn provide an abundant food resource for other reef-dwellers such as parrotfish. These colorful fish, which are members of the wrasse family, have teeth and jaws that have evolved into a beaklike structure. Some species use their teeth to scrape algae from the reef surface, and in others, the beak is so tough that it can gouge into the reef. These so-called excavating parrotfish supplement their algal diet with animal matter in the form of coral polyps.

Lurid colors are indicative of males, but like most parrotfish, this species changes sex from female to male during its lifetime

**Reef resources**

The ember parrotfish (*Scarus rubroviolaceus*, far left) and yellow-finned parrotfish (*S. flavipectoralis*, left) are closely associated with tropical reefs. They feed by scraping algae from the surface of rocks and corals using their beak. As well as providing a vast surface area for feeding, the complex reef structure also provides shelter for the fish.

coastal seas

Rich in nutrients from ocean upwellings and land run-off, coastal seas have abundant plant and animal life. The shallow, light-drenched habitat is ideal for photosynthesis, especially for small plants and macroalgae rooted to the seabed.

absorbing light

Like all algae, seaweeds make food by photosynthesis, using sunlight's energy to convert carbon dioxide and water into sugar and other nutrients. All seaweeds use pigments to absorb this energy, while their fronds maximize the surface area for light capture. Different pigments absorb different color wavelengths present in white sunlight. Green chlorophyll predominates, but some seaweeds have accessory pigments that make them brown or red.

The green color of the frond is due to the photosynthetic pigment chlorophyll, which is packed inside microscopic structures called chloroplasts

Selecting the spectrum

Green seaweeds, such as sea grapes (*Caulerpa lentillifera*), lack the accessory pigments of other colored seaweeds. Their color is due largely to chlorophyll, the same pigment used by land plants. Chlorophyll absorbs red and blue wavelengths of light—for use in photosynthesis—but reflects green wavelengths.

The frond's cylindrical midrib has chloroplasts that carry out photosynthesis; it transports the nutrients produced by photosynthesis to other parts of the seaweed



Grapelike ramulus stores sugars and other nutrients that are generated by photosynthesis; each frond consists of a branchlike midrib carrying rows of ramuli



Fronds are stiffened with white mineral

Red seaweed

In addition to chlorophyll, red seaweeds—such as this *Corallina*—have accessory pigments known as phycobiliproteins, which reflect more red light and absorb more green.

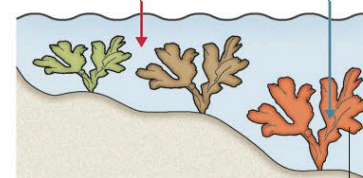


LIGHT AND HABITAT

Photosynthetic pigments help seaweeds thrive in different habitats. Blue and green light penetrate water more deeply than other wavelengths, enabling red seaweeds that absorb these colors to grow better at greater depths. But the quantity of pigment, as well as the type, is important, too: some seaweeds of other colors have higher pigment levels to absorb more light in deeper water.

Red light penetrates less than 165 ft (50 m)

Blue light penetrates more than 330 ft (100 m)



Deeper seaweeds have more pigment for absorbing available wavelengths

SEAWEED DEPTH DISTRIBUTION



spotlight species

giant kelp

Forming underwater “forests” rising more than 100 ft (30 m) from the seabed, giant kelp (*Macrocystis pyrifera*) is a type of algae that acquires food by photosynthesis. It is found off the North American Pacific coast from Canada to California and in temperate regions of all Southern Hemisphere oceans.

Giant kelp is the largest living seaweed—the term for large algae growing on ocean coastlines. They are supported by water, which enable some seaweeds to grow to enormous lengths. Giant kelp is thought to have the fastest linear growth rate on Earth and can increase its length by up to 2 ft (61 cm) per day. In clear, nutrient-rich waters where the sea temperature is 42–68°F (5–20°C), it can survive at depths of 175 ft (53 m), but it reproduces only if the water temperature is below 65–68°F (18–20°C).

A forest for carbon capture

Giant kelp forests, like this one off the coast of California where blacksmith damselfish shelter, absorb vast amounts of carbon dioxide. They act as natural carbon sinks in a similar way to terrestrial forests and lower seawater acidity levels.

Giant kelp anchors itself to the seafloor using holdfasts—rootlike attachment organs that form a tangled mass around rocks, rubble, and debris on the seabed (see p.27)—to prevent it from drifting ashore. Rocky coastlines make ideal fastening places. A primary stipe, or main stem, rises toward the surface, sending out branching side stalks with leaflike blades, each with a pneumatocyst, or gas bladder, at its base that keeps it afloat. At the surface, the kelp covers the water in a type of canopy. Unless compromised by warming seas or overgrazed by sea urchins, kelp can live up to 7 years.

Kelp forests provide a key habitat for many animals. Holdfasts shelter invertebrates, fish and their larvae, and shelter birds and sea otters during storms. Sharks, sea lions, and seals are also attracted to these rich hunting grounds.

Pneumatocysts hold the blades upright, enabling kelp to take in sunlight for photosynthesis



Staying afloat

Balloonlike pneumatocysts are filled with a mixture of carbon dioxide, oxygen, and nitrogen that giant kelp cells both produce and absorb from surrounding seawater.

underwater meadows

Most true plants cannot grow in the ocean. While the sunlit shallows can be thick with seaweeds and other algae, these are solar-powered organisms that lack true leaves, roots, and flowers. However, seagrasses, such as turtle seagrass (*Thalassia testudinum*), are flowering plants. Rather than merely tolerating the salty ocean environment, they thrive in it; they bloom and set seed below the surface and cover vast areas of the seabed. At a time of global warming, these photosynthesizing green carpets are globally important as efficient stores of atmospheric carbon.

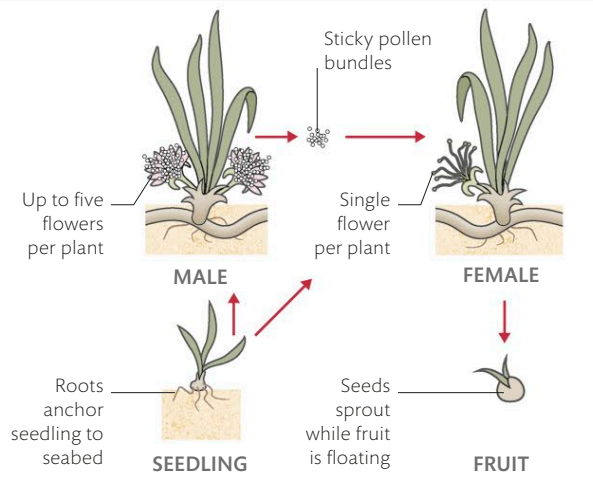
**Asexual reproduction**

Turtle seagrass produces horizontal rhizomes that sprout plant clones, helping the species form extensive swards—much like grasses do on land.



SEXUAL REPRODUCTION

In turtle seagrass, genetic diversity comes from cross-fertilization during sexual reproduction. The sexes are separate: each plant produces either male or female flowers. Male flowers release pollen at night in packages of carbohydrate-rich slime. The slime attracts hungry invertebrates, which help disperse the pollen to female flowers. Fertilized flowers form seeds encased in small fruits. The fruits float before settling on the seabed, where each seed completes its germination.



Tropical seagrass

Turtle seagrass—the favorite food of the green turtle (*Chelonia mydas*)—is a common seagrass of the Caribbean. Neighboring plants are interconnected clones, but they also reproduce sexually: their seed-packed fruits disperse on the waves and establish new colonies elsewhere.



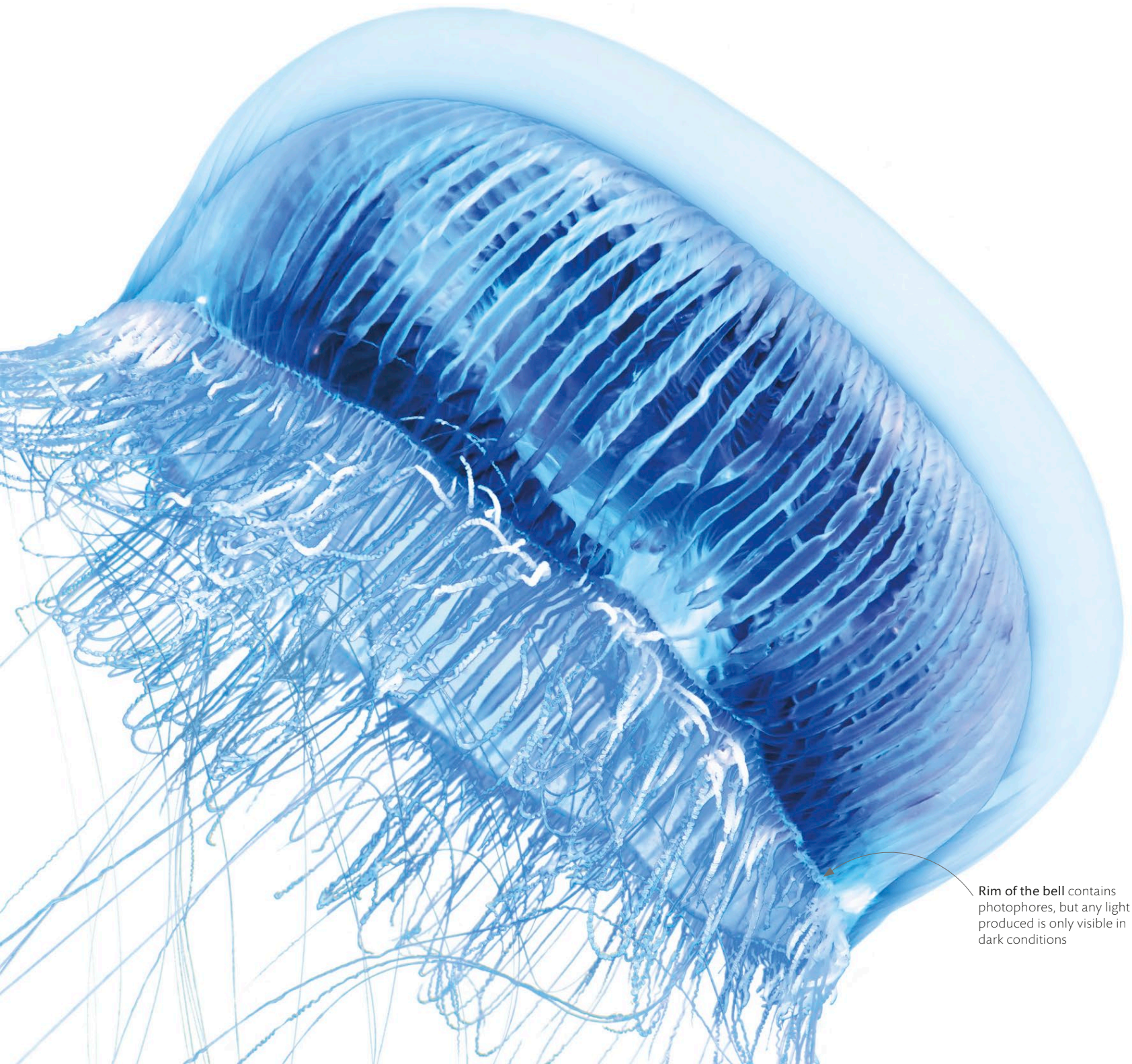
producing light

Many soft-bodied, jellylike animals of the open ocean can produce light, a phenomenon known as bioluminescence.

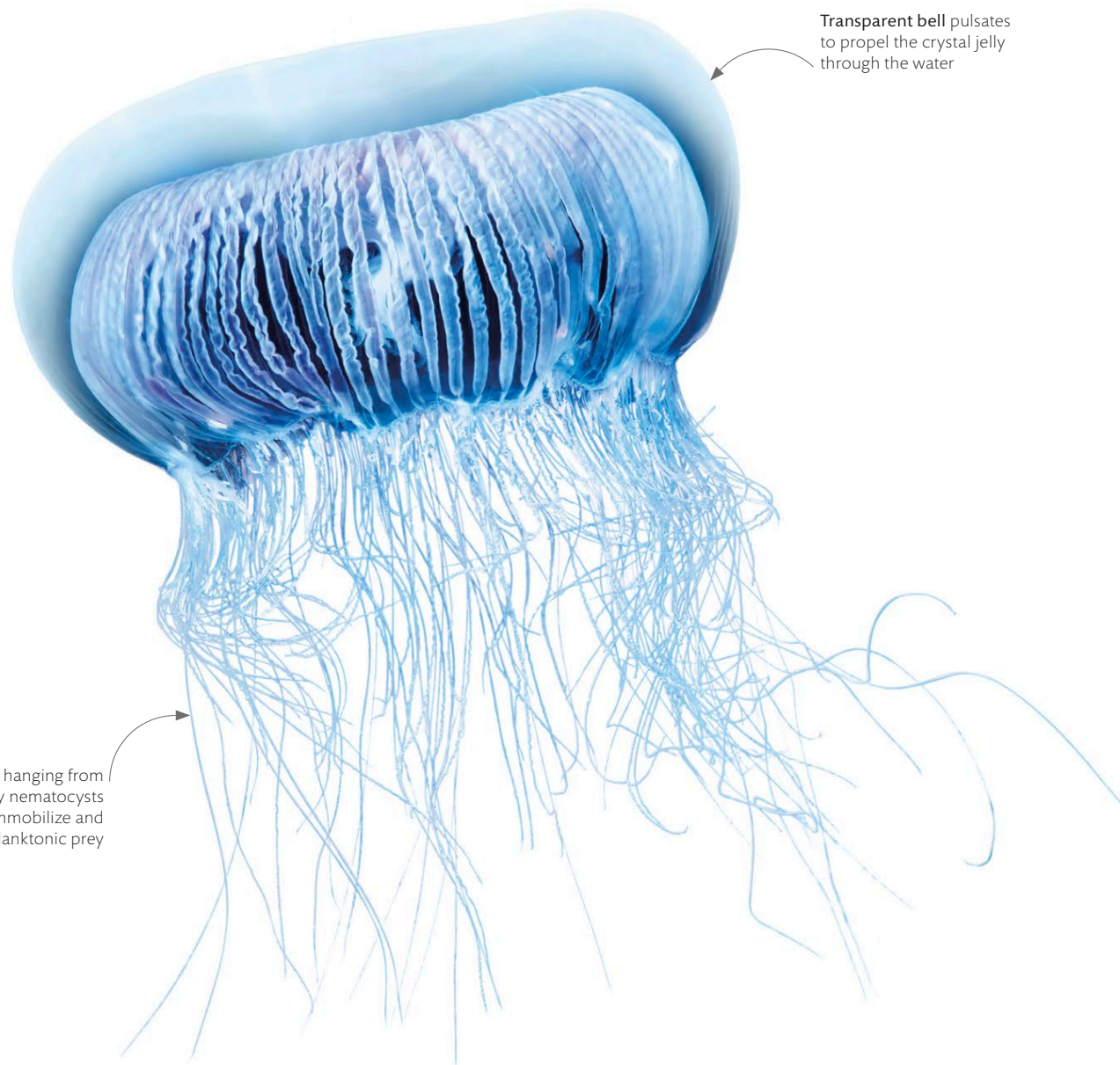
Species as diverse as jellyfish, hydrozoans, and comb jellies turn luminous if the water around them is agitated—possibly to scare predators or attract tiny planktonic prey. The light, produced by a chemical reaction in organs called photophores, is most striking when emitted in dark, deep water or at night nearer to the surface.

Colorless jelly

Like many vulnerable jellyfish, the thumb-sized crystal jelly (*Aequorea victoria*), a hydrozoan from the surface waters of the eastern Pacific Ocean, has a transparent body. This may help conceal it from predators against the open water. Its light-producing photophores, which are carried around the rim of its swimming bell, produce a momentary green glow.



Rim of the bell contains photophores, but any light produced is only visible in dark conditions



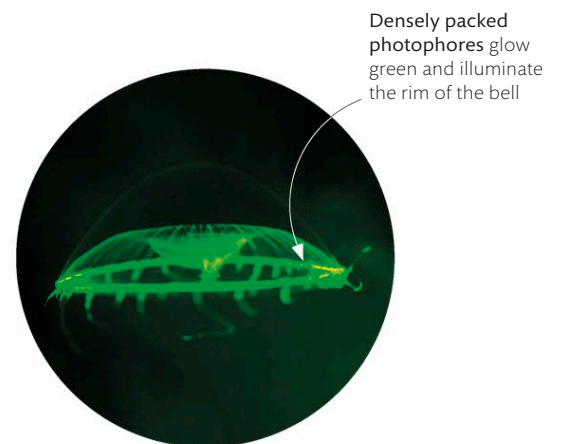
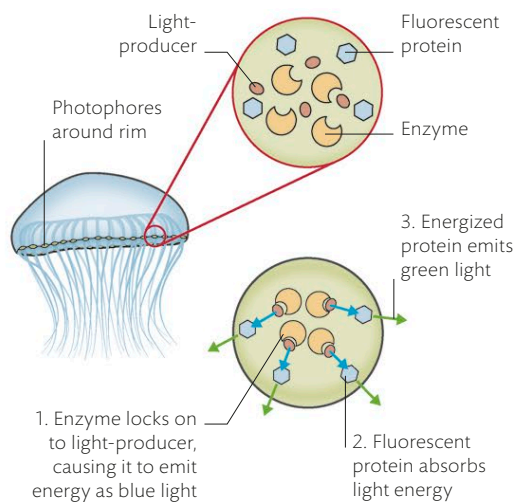
Transparent bell pulsates to propel the crystal jelly through the water

More than 100 tentacles hanging from the rim of the bell carry nematocysts (stinging cells); they immobilize and catch tiny planktonic prey

HOW PHOTOPHORES WORK

Bioluminescence typically depends upon a light-producing chemical and an enzyme. When stimulated by a trigger—such as calcium, in the case of the crystal jelly—the enzyme makes the light-producer undergo a chemical change, which releases light. The distinctive green glow of the crystal jelly happens because an additional component—a fluorescent protein—subsequently changes the wavelength of the emitted light from blue to green.

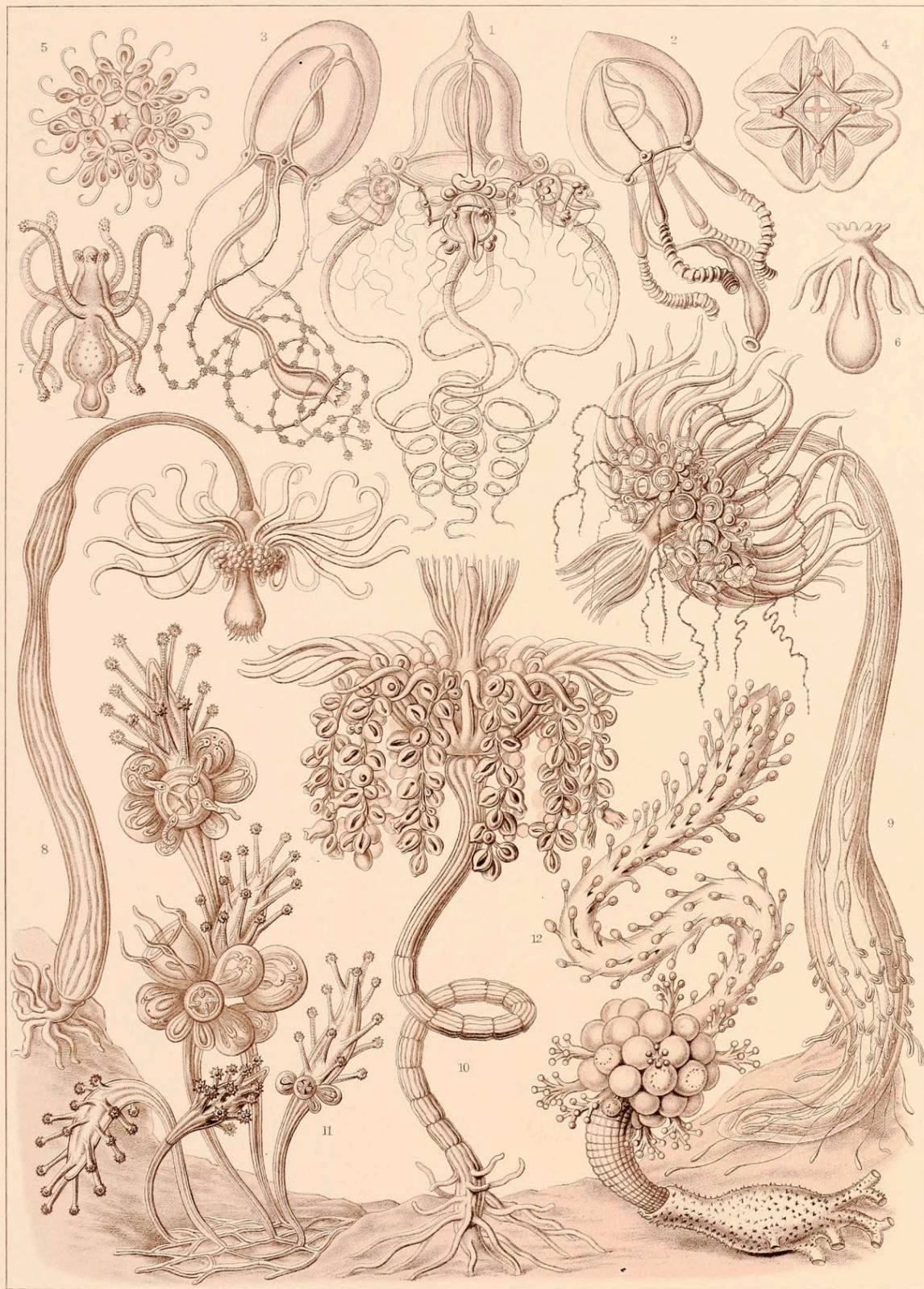
ARRANGEMENT AND FUNCTION OF CRYSTAL JELLY PHOTOPHORES



Densely packed photophores glow green and illuminate the rim of the bell

Glowing green

Once activated, a cocktail of chemicals in the photophores of a crystal jelly emits green light; each glow lasts for just a few seconds.



Tubulariae. — Röhrenpolypen.

alternating generations

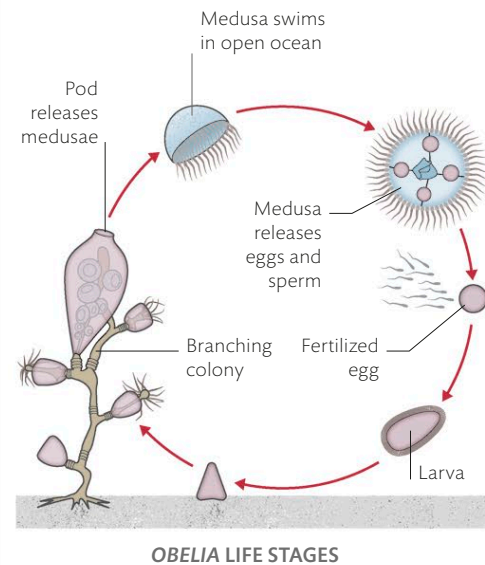
Animals that are attached to the substrate must get their nourishment close to the seabed. Hydrozoans—relatives of anemones, corals, and jellyfish—have polyps with tentacles that may rise only a short distance from where they are growing. But many also produce swimming, jellyfishlike bells, called medusae, as part of their life cycle. Medusae travel far in the water column, where they catch plankton beyond the reach of polyps. By alternating between polyp and medusa generations, food sources are more fully exploited.

Two generations

Ernst Haeckel's *Kunstformen der Natur* (1904) depicts more than a dozen species of hydrozoan—some as anemonelike polyps (bottom) and others as medusae (top). Not all have a life cycle that switches between the two stages: some do not become medusae and, like many other ocean invertebrates, experience open water only as microscopic larvae.

HYDROZOAN SEXUAL LIFE CYCLE

The hydrozoan *Obelia* grows into an upright branching colony of polyps, some of which generate pods that produce medusae. The free-swimming medusae release sperm and eggs into the water. Larvae develop from the fertilized eggs and eventually settle on the seabed, where they form new polyp colonies. The life cycles of other hydrozoans and related animals vary. Some hydrozoans—as well as corals and anemones—do not have a medusa stage, while certain jellyfish species exist only as medusae.



Polyps in close-up

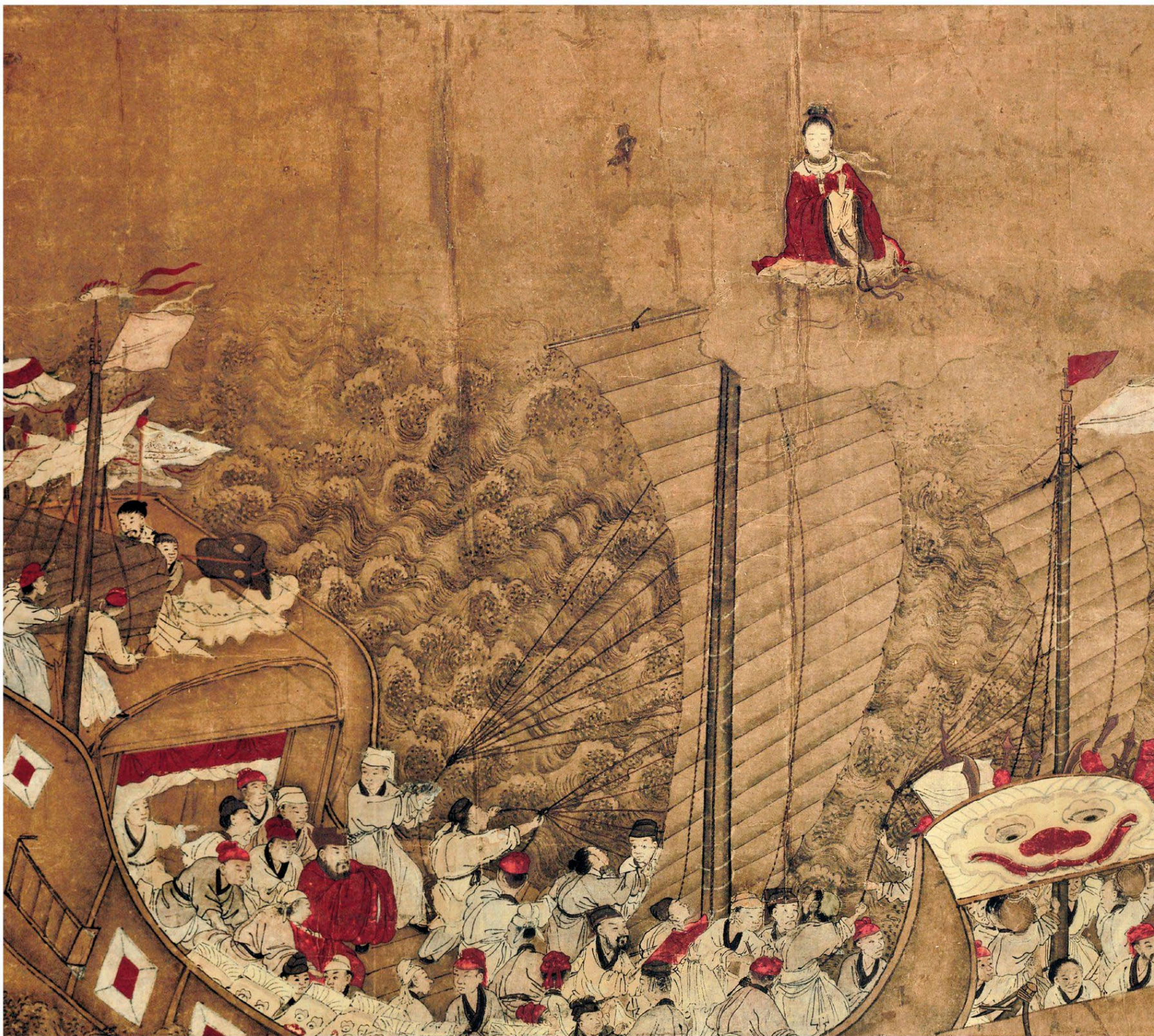
The polyps of oaten pipes (*Tubularia indivisa*)—a European hydrozoan that lacks a medusa stage—carry rings of drooping tentacles on stems that extend up to 6 in (15 cm) from their base.

Gonozooids are reproductive capsules that release larvae; the larvae develop directly into new polyp colonies



Tentacles trap microscopic plankton and transfer them to the mouth at the center





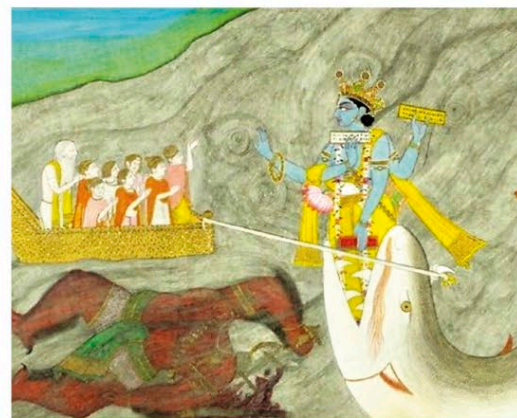
The Miracles of Mazu (18th century)

An album of seven ink drawings, now housed in the Rijksmuseum, Amsterdam, Holland, describes the sea journey of a Song dynasty deputation to the Goryeo court in Korea in 1123 CE. The Chinese ships are under the protection of the sea goddess, Mazu. She is shown here in her traditional red robes, hovering on a cloud and carrying an ivory *Hu* tablet as a symbol of power.



The Story of the Great Flood (c.1870)

In this depiction of a Hindu legend, Matsya (one of the 10 avatars of the Hindu God Vishnu) appears as half-human, half-fish. Here, together with seven great sages, he saves Manu (the first man) from the flood.



the ocean in art

asia's sea deities

Thousands of years of art and storytelling reflect humans' longstanding awe of the ocean. In most ancient cultures, the sea's unfathomable depths and unpredictability gave rise to numerous myths and beliefs, in which natural phenomena—such as storms, currents, and fair winds—were attributed to the whims and protective powers of sea gods and goddesses.

In ancient Hindu texts (Vedas), Varuna was the god of the sky, but in later tales, he came to symbolize oceans, clouds, and water. In Mysore painting, a classical art form of southern India featuring deities and mythological scenes, Varuna is often pictured riding the *makara*—a hybrid sea creature resembling a crocodile. Varuna also appears in miniatures that illustrate the 5th-century BCE Indian epic *Ramayana*, rising from the ocean to pacify Rama, an avatar of the god Vishnu. According to the legend, Rama's wife, Sita, was held in captivity across the ocean, in Lanka.

In China, from the 11th century on, the success of perilous sea journeys was often attributed to the beneficence of the

goddess Mazu. Her story varies with the telling, but she was born Lin Moniang in 960 CE in a Chinese coastal town, where she was renowned for her swimming skills. She gained mystical status after she used trancelike powers to save male members of her family from drowning at sea. In 1281, she was given the official title of Tianfei ("Princess of Heaven").

In the 1400s, Chinese admiral Zheng He had his great deeds carved in tablets of granite in two cities in China. He attributed his seafaring success to Mazu/Tianfei, describing her as a "divine light" above the mast, calming the crew in rough seas. In reality, this light was probably St. Elmo's fire, a ball of light formed from electricity that appears on ships at sea in storms. The same goddess is evoked in an 18th-century album of ink drawings (see left), where she is pictured floating above Chinese ships, providing protection.

Mazu worship spread to sailors and fishermen beyond China, and lacquered wooden statues, woodcut illustrations, and painted panels of the goddess are found in temples dedicated to her across the world.

“When we met danger, once we invoked the divine name, her answer to our prayer was like an echo.”

ADMIRAL ZHENG HE'S DEDICATION TO MAZU/TIANFEI, LIUJIAGANG TEMPLE, 1431



Inner whorl
of shorter labial
tentacles transfers
prey to the
central mouth

Tube is made from
specialized stinging cells
and sediment, all bound
together by mucus

Tube sanctuary

Tube anemones cannot retract their tentacles, but when disturbed, they pull themselves into their tube by contracting muscles along the length of their body.



The tentacles disappear as the anemone withdraws its body deep into the tube

living in a tube

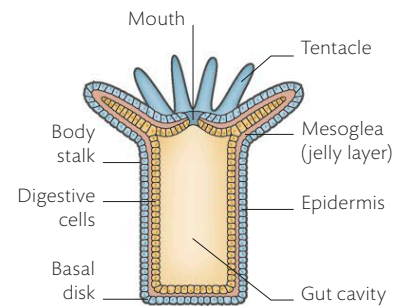
Most anemones must make a living attached to a firm surface and can reach no higher than the stretch of their tentacles, but one group has evolved the means not only to live on soft sediment, but even to move up and down on the seabed. Tube anemones live inside vertical, partially buried, feltlike tubes. Instead of being anchored to the bottom, they can slip upward through the tube or sink deeper inside when danger threatens.

Emerging tentacles

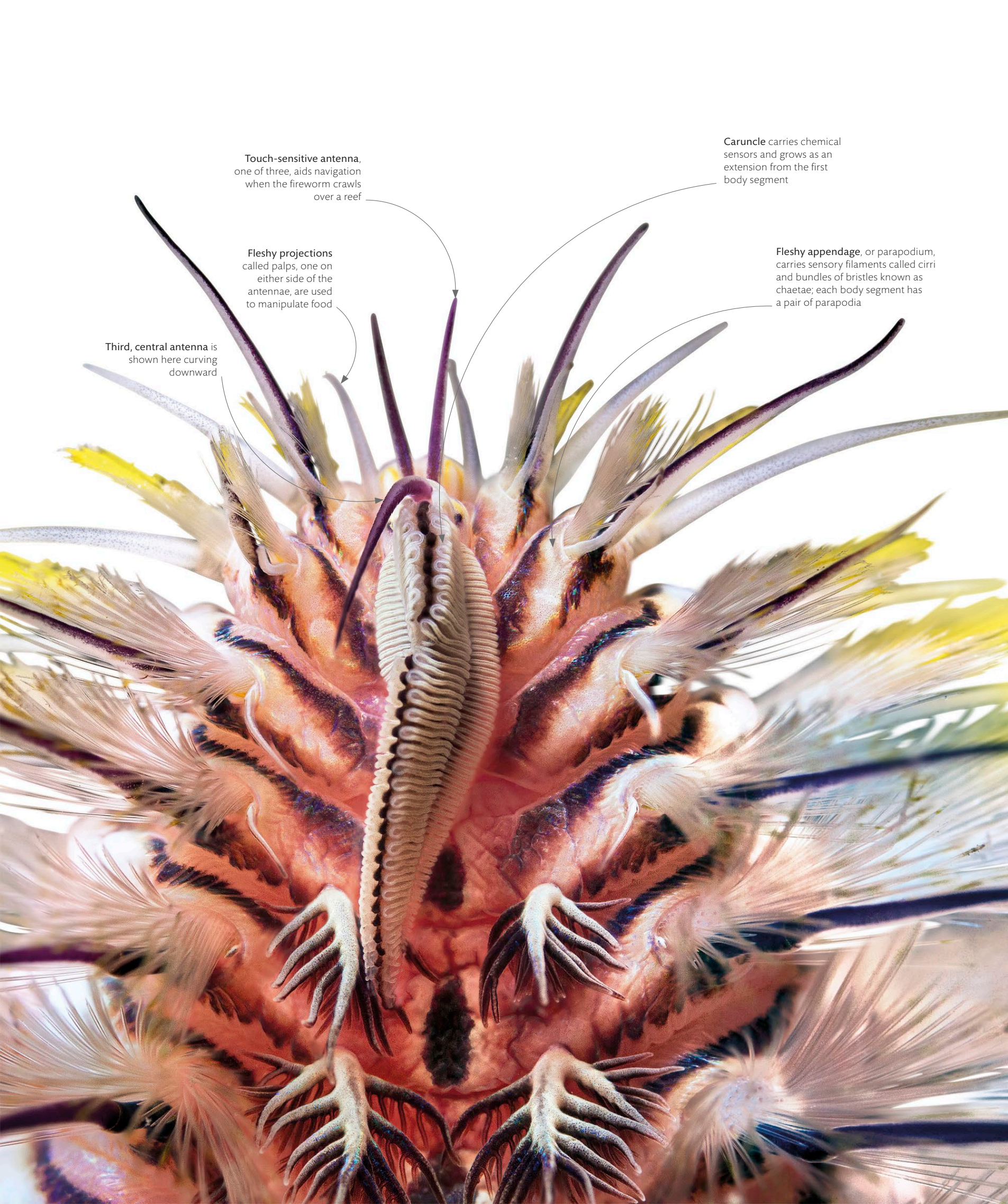
A fireworks tube anemone (*Pachycerianthus multiplicatus*), from European coastal waters, erupts from the confines of its tube to sweep the water with its tentacles for planktonic prey. A mature specimen can have tentacles that span 12 in (30 cm).

ANEMONE ANATOMY

All anemones have just one opening to their gut for ingesting food and eliminating waste. The gut is a simple cavity lined with digestive cells. Prey caught and paralyzed by the tentacles are transferred to the gut opening before being digested by enzymes released from the gut lining. The basal disk is attached to a surface in most anemones; in tube anemones, it is free to move up and down.



CROSS-SECTION OF ANEMONE



Touch-sensitive antenna, one of three, aids navigation when the fireworm crawls over a reef

Caruncle carries chemical sensors and grows as an extension from the first body segment

Fleshy projections called palps, one on either side of the antennae, are used to manipulate food

Fleshy appendage, or parapodium, carries sensory filaments called cirri and bundles of bristles known as chaetae; each body segment has a pair of parapodia

Third, central antenna is shown here curving downward



Green "bombs" are fluid-filled sacs that glow for several seconds after release

Glowing defense

The green bomber worm (*Swima bombiviridis*)—a deep-sea annelid—lacks venom but deters predators by releasing luminous "bombs" made from modified gills.

stinging bristles

Annelids are segmented worms that include many familiar animals, including intertidal lugworms and land-living earthworms. Their bodies have tiny bristles called chaetae that help with traction when crawling or burrowing. But some marine annelids use their chaetae for defense. Aptly named fireworms have brittle, venom-packed chaetae that break off to deliver a painful sting when the worm is threatened by a predator.

Each tentaclelike sensory filament, or cirrus, may be touch-sensitive

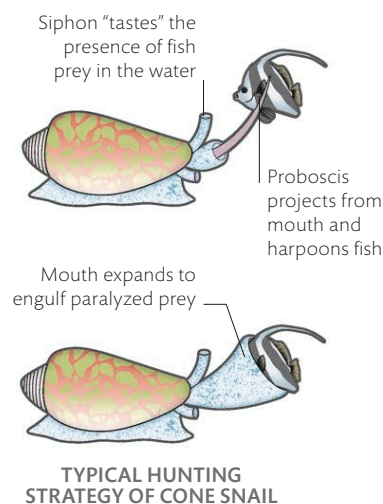
Bundle of bristly chaetae—each chaeta is reinforced with tough chitin and impregnated with chalky minerals to make it brittle, so its tip can break

Stinging worm

The predatory golden fireworm (*Chloeia flava*) is found along Indo-Pacific coastlines. This annelid tracks victims, such as anemones and sponges, using a fleshy organ called a caruncle that "tastes" the water for chemical traces of prey animals. Venomous bristles protect the animal from shorebirds and worm-eating fish.

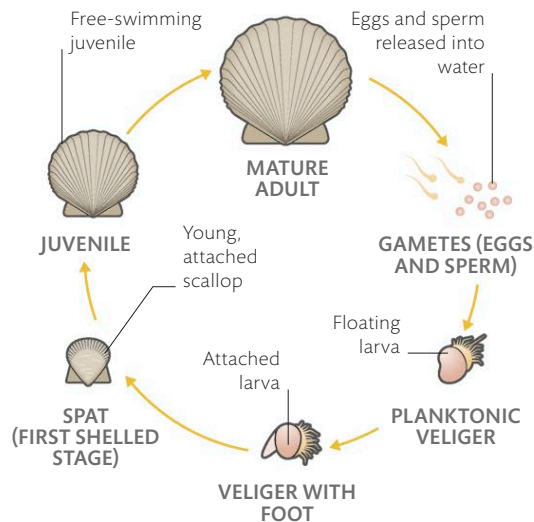
AGGRESSIVE VENOM

Venoms are toxic chemicals that are injected into a victim. Most venomous ocean animals, including fireworms, use their venom defensively, but some deploy it aggressively to catch prey. Cone snails, despite being slow crawlers, successfully hunt fish using a rapid-fire venomous dart, which causes quick paralysis. The dart is a modified radula—a mouthpart used for grazing algae in more conventional snails (see pp.34–35). It is located at the tip of the proboscis, which the snail fires from its mouth.



SCALLOP LIFE CYCLE

It is only in the juvenile and adult life cycle stages that scallops can swim independently. These mollusks are hermaphrodites: each individual releases both sperm and eggs into the surrounding water. Fertilized eggs develop into planktonic larvae called veligers—a life stage also seen in other oceanic bivalves and snails. After growing a crawling foot, each veliger settles on seagrass or weed, to which it attaches by sticky threads. Here, the scallop grows until it is big enough to escape the attention of crabs and other bottom-dwelling predators. It then develops into a free-living, sexually mature adult.



Multiple eyes

Unlike other bivalves, scallops have two rows of dozens of eyes that alert them to movement so they can swim away from danger. Each eye has a crystalline lens and a retina for image processing.



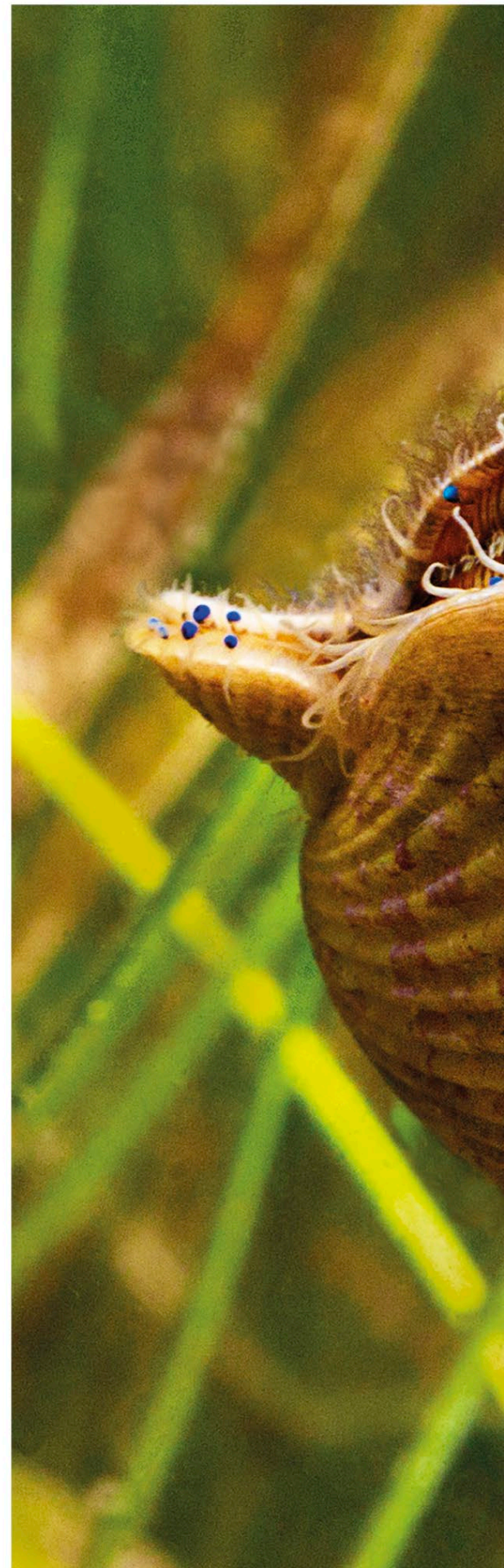
A scallop eye contains a reflective, mirrorlike layer, which improves its light-collecting ability

Escaping danger

Scallops, such as this bay scallop (*Argopecten irradians*) of North America's Atlantic coast, can use their flapping shell valves in an impressive escape response. Their complex eyes, which give sharp resolution for both peripheral and central vision, may help them recognize approaching predators.

flapping to swim

As their name suggests, bivalve mollusks have a two-part shell. Hinged across the middle, the shell is closed by muscles that span the hinge and contract to pull the halves, called valves, together. Bivalves relax these muscles to open their shells in order to strain particles of food from the water but are otherwise mostly sedentary. Scallops are exceptional: they can swim in open water by rapidly flapping their valves open and shut.







Brown and white mottling helps disguise the cuttlefish against the sediment of the seabed

Patches of yellow are flashed to startle predators when this color-changing cuttlefish is disturbed

Mantle—a sleeve of skin that envelops the cuttlefish—encloses a small cuttlebone in the front half of the body; negative buoyancy helps keep the animal near the seabed

Buoyancy in miniature

The tiny, bottom-living flamboyant cuttlefish (*Metasepia pfefferi*), of tropical Australia, has a proportionately smaller cuttlebone than midwater cuttlefish, so it regulates its buoyancy across a narrower range of depths. Its toxic flesh—signaled by warning colors—helps offset its vulnerability to more agile predators.



Knoblike papilla (one of six paired projections) on the upper body break up the outline of the cuttlefish to help with camouflage



The cuttlebone of an elegant cuttlefish (*Sepia elegans*) extends the length of its body

Each oblong chamber is less than 1 mm long

Cuttlebone

When cuttlefish die, their buoyant, gas-filled cuttlebones may wash ashore on beaches. A magnified cross-section reveals the stacks of hollow chambers inside.



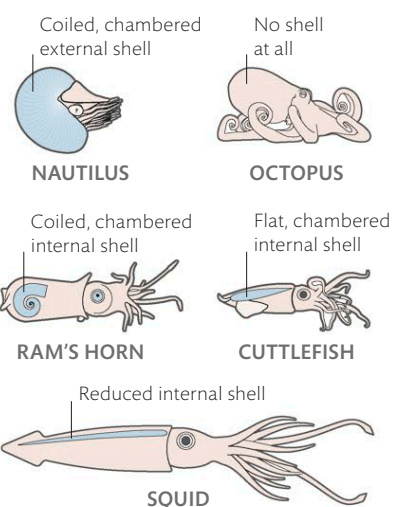
INTERNAL STRUCTURE

changing buoyancy

Unlike most fish, which stay buoyant in the water by means of an adjustable gas-filled swim bladder (see p.231), some animals change their buoyancy to sink or float. Cuttlefish do this with an internal shell—their cuttlebone. The cuttlebone's hollow chambers buoy the animal upward, which enables it to swim in open water. To descend to the seabed, the cuttlefish floods the chambers with liquid, making the animal negatively buoyant and weighing it down so that it can burrow or "walk" on the bottom.

CEPHALOPOD SHELLS

Cephalopods include a range of swimming mollusks: nautilus, octopuses, ram's horns, cuttlefish, and squid. The nautilus has an external shell, which is coiled like that of a snail yet chambered like a cuttlebone for buoyancy control. The ram's horn—a deepwater relative of cuttlefish—uses its internal coiled shell in a similar way. In squid, an internal shell is reduced to a simple, penlike structure, or gladius, for support. Octopuses lack a shell altogether, but they are more flexible as a result.



View of the vortex

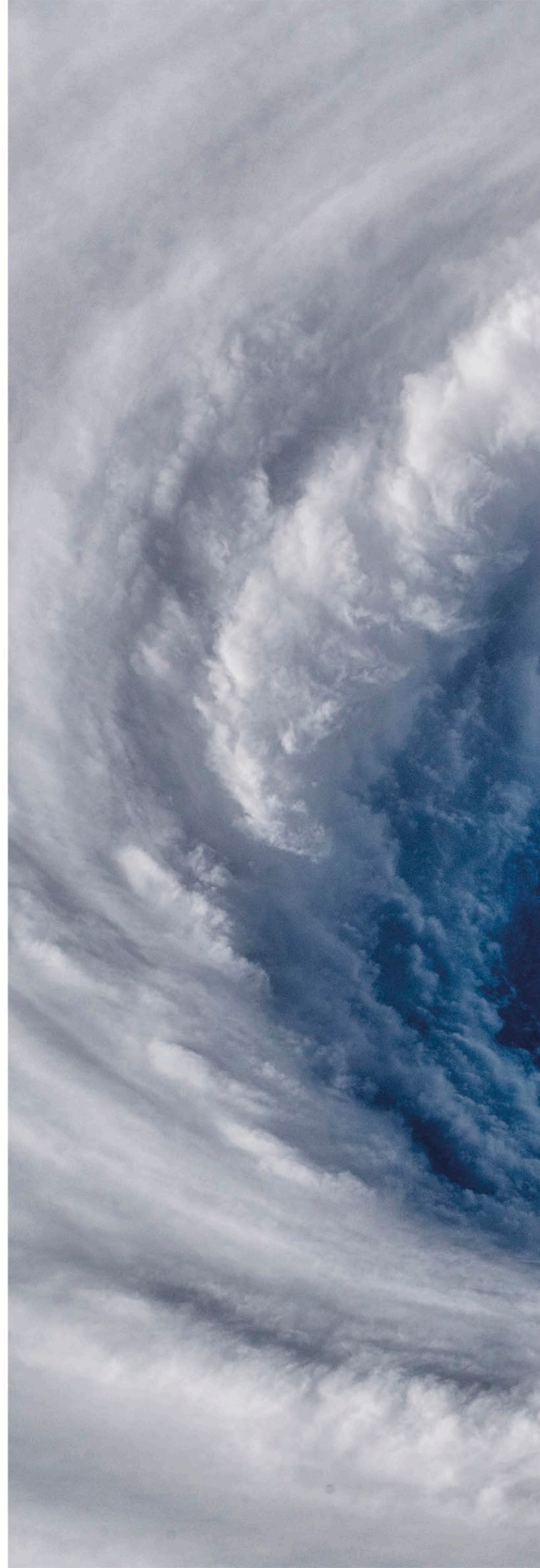
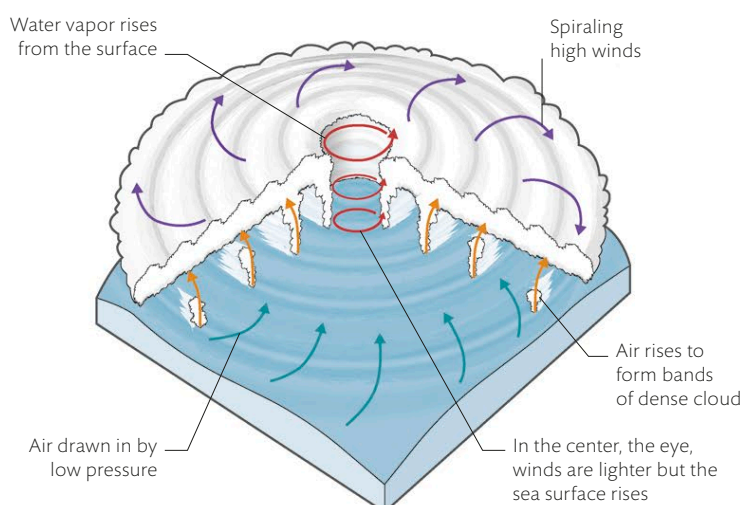
Taken from the International Space Station in September 2018, this photograph shows the spiraling movement of the vortex around the eye of typhoon Trami in the Pacific.

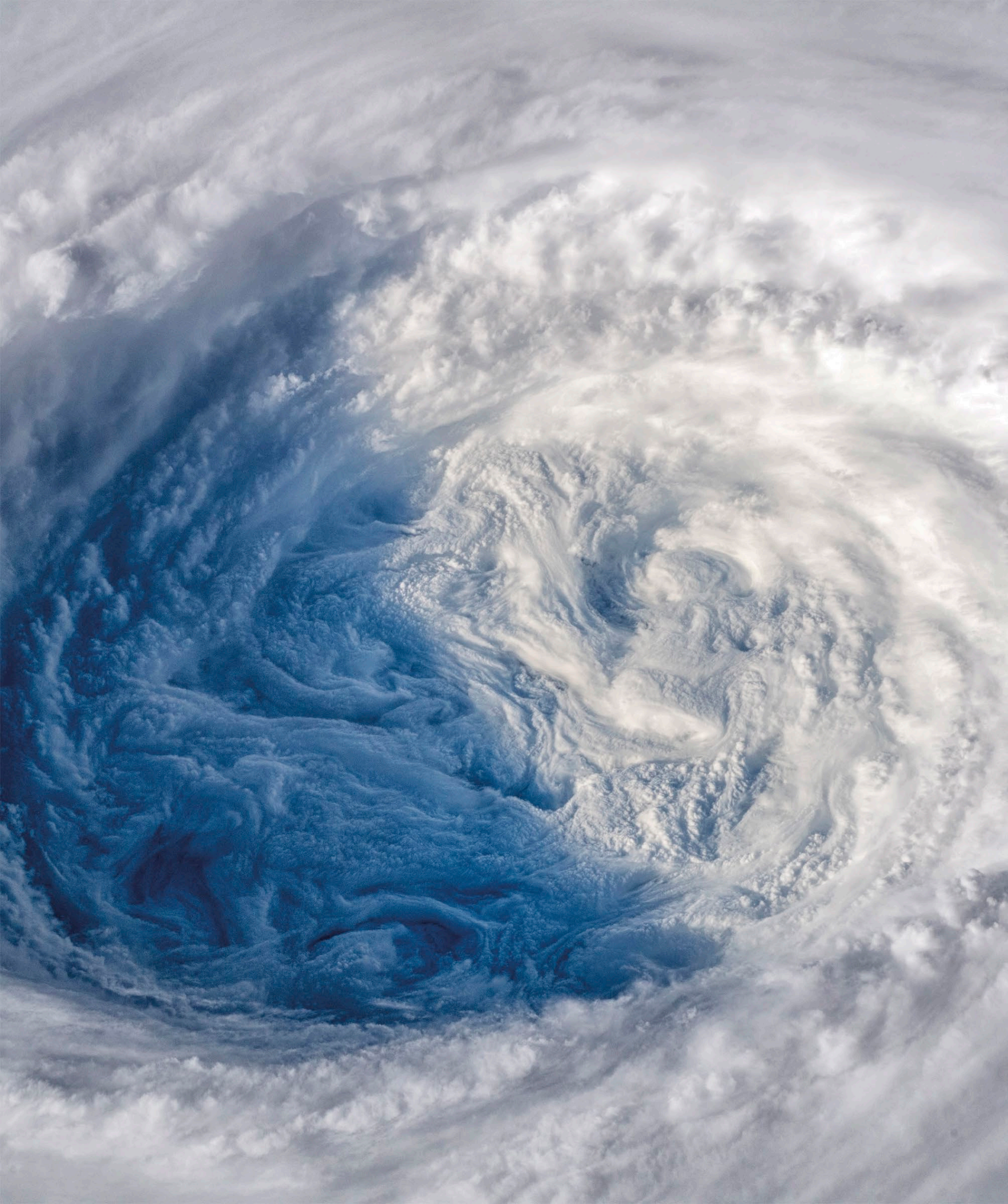
hurricanes and typhoons

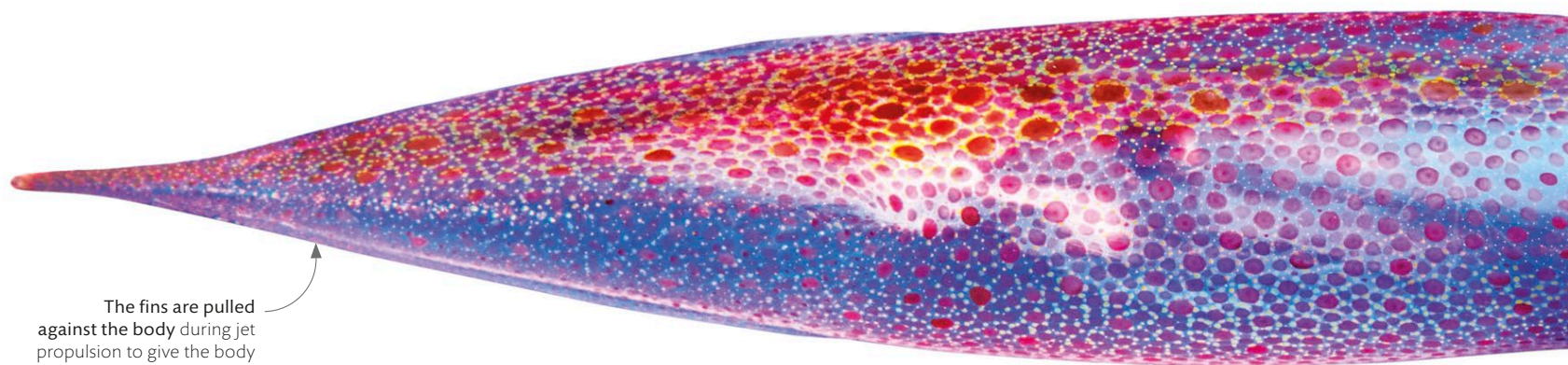
Violent tropical storms known as hurricanes (in the Atlantic) and typhoons (in the Pacific) are characterized by spiraling winds of up to 220 mph (350 kph), often accompanied by heavy rainfall. They occur when the temperature in the upper 150 ft (45 m) of the ocean exceeds 80°F (27°C). The water temperature reaches this level regularly in the equatorial ocean regions, especially in the Pacific, western Atlantic, and Indian Oceans in late summer and fall. Global warming is increasing the duration, frequency, and intensity of such storms. Hurricanes and typhoons can cause serious damage in coastal areas but abate as they move over land and lose contact with the forces that drive them.

INSIDE A HURRICANE

An increase in surface temperature causes vast amounts of water vapor to evaporate from the sea surface, which creates huge convection towers up to 10 miles (15 km) high. Low pressure at the surface pulls in more air, creating cloud systems and spiraling thunderstorms. Coriolis force (an effect of Earth's rotation) causes the winds to spin, and as the storm grows, it becomes self-sustaining.







The fins are pulled against the body during jet propulsion to give the body a more hydrodynamic shape

Each nonretractable arm has suckers along its length for gripping prey

Each retractable tentacle carries suckers on its spatula-shaped tip



jet propulsion

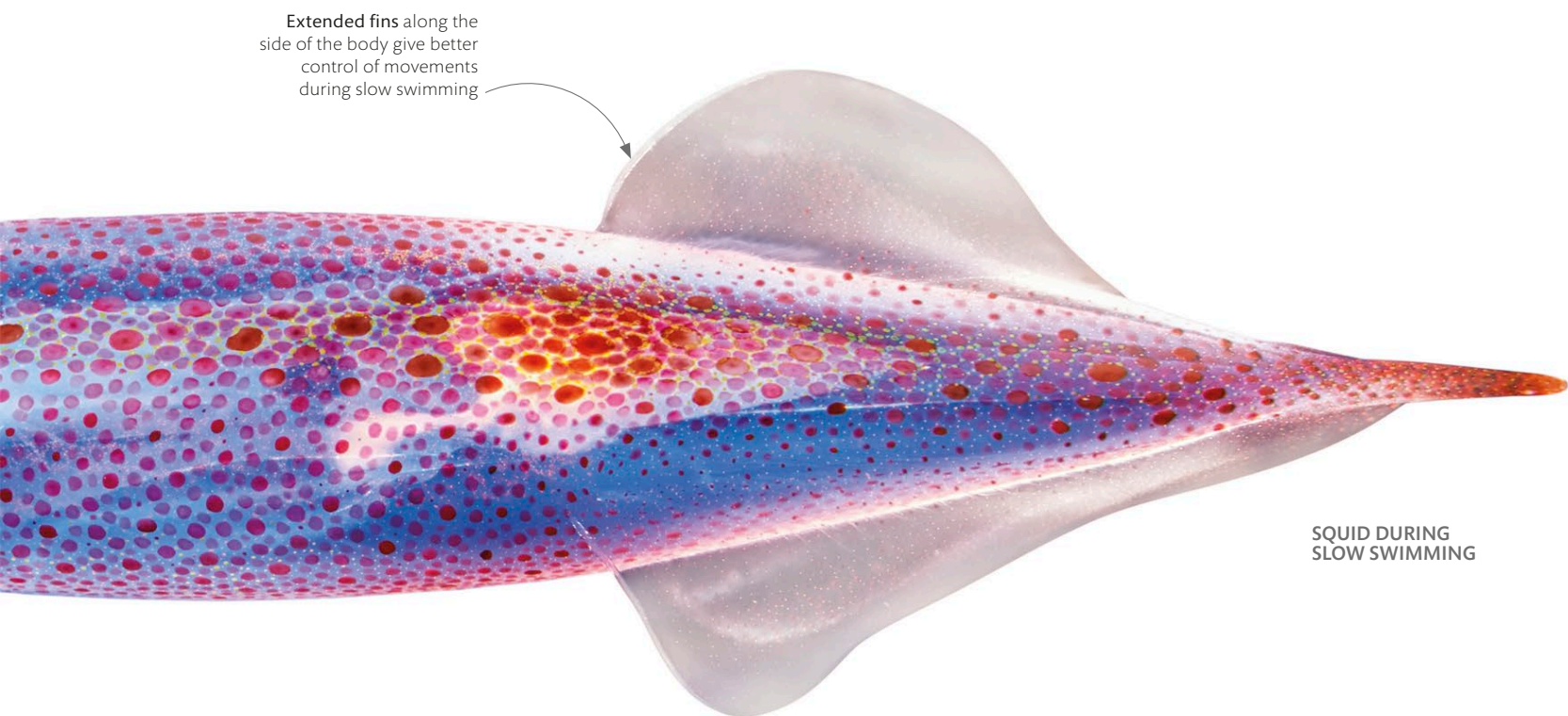
Mollusks such as snails and slugs creep slowly on a muscular foot, but some mollusks are able to swim in midwater. Cephalopods, including squid and octopuses, are the fastest of all mollusk swimmers. They adopt torpedo shapes to cut through water and can generate significant thrust, notably by shooting a jet of water from a siphon, which propels them with sudden bursts of speed.



A rippling fin runs along each side of the squid's mantle

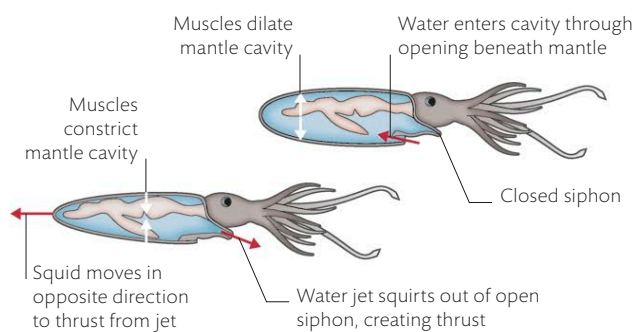
Fin power

The fins undulate to push against the water. They create most of the thrust for slower, routine swimming, when jet propulsion is not required.



CREATING THE JET

All mollusks have a skinlike mantle—a structure that produces a shell in snails but which envelops the body like a sleeve in cephalopods. Muscles in the mantle wall dilate the underlying cavity, which swells with water, then constrict to eject a water jet out of a movable siphon. By directing the siphon—and the jet's thrust—forward or backward, the squid can control the direction in which it moves.



MUSCULAR ACTION OF SQUID MANTLE IN JET PROPULSION

Speedy predator

Jet propulsion helps the European squid (*Loligo vulgaris*) cover long distances quickly. It is reserved for escaping predators and catching fast-moving prey: the eight arms and two retractable tentacles are used to grab fish and crustaceans. But jet propulsion does not allow the fine control needed for turning and other maneuvers, when the squid relies on using its fins instead.

nudibranchs

These colorful mollusks are found in shallow and deep marine waters the world over. There are more than 3,000 known species; some crawl on the seabed, while others live in the water column. Nudibranchs are divided into two groups: aeolids and dorids. Both types are hermaphrodites, with individuals having male and female sexual organs, but they cannot self-fertilize.

Collage of color

This translucent white aeolid *Coryphella verrucosa* is found in the tidal streams and sheltered parts of the northern Atlantic and Pacific Oceans. Eggs are spawned in a distinctive coiled white string, and like all nudibranchs, it loses its shell at the larval stage. This species can grow to a length of $1\frac{1}{3}$ in (3.5 cm).

Aeolid nudibranchs

This group have sense organs (rhinophores) at their heads and breathe using tentaclelike outgrowths called cerata that cover their backs. In some, their bright colors act as camouflage; for others, they warn predators of their toxicity. Several species feed on larger, well-armed prey like jellyfish, ingesting their unfired nematocysts and storing them in special pouches at the tips of the cerata—so the cerata play a role in defense, as well as gaseous exchange.



EDMUNDSELLA PEDATA
 $\frac{3}{4}$ in (2 cm) long



BERGHIA NORVEGICA
 $1\frac{1}{2}$ in (3 cm) long



FACELINA BOSTONIENSIS
 $2\frac{1}{2}$ in (5.5 cm) long

Dorid nudibranchs

This group are mostly smooth bodied. They have two rhinophores, or sense organs, at the head and tufts of featherlike gills toward the back of the mantle, which they use for breathing. In some species, these gills can be retracted into a special pouch. Like aeolids, they are grazing carnivores and feed on a variety of animals, including other nudibranchs.



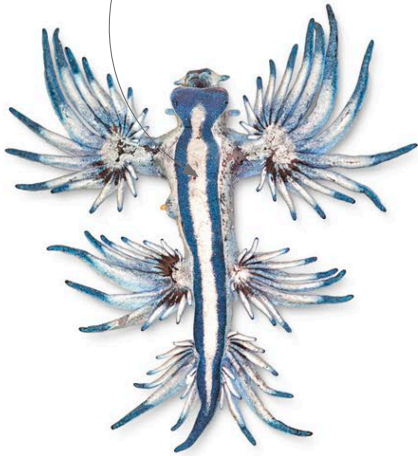
LIMACIA CLAVIGERA
 $\frac{3}{4}$ in (2 cm) long



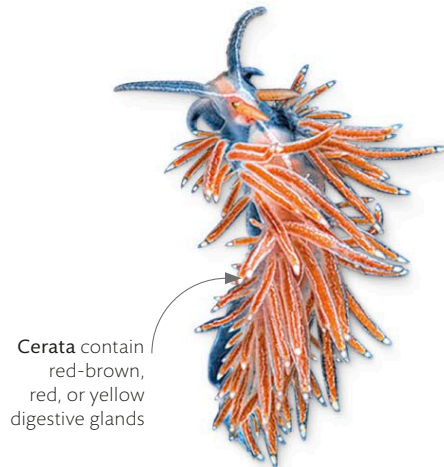
GONIODORIS CASTANEA
 $1\frac{1}{2}$ in (4 cm) long



NEMBROTHA KUBARYANA
5 in (12 cm) long



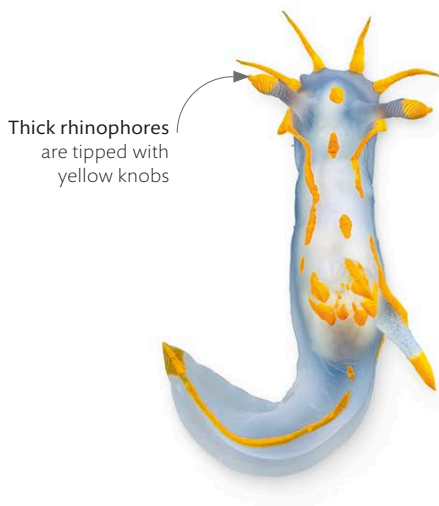
GLAUCUS ATLANTICUS
1½ in (3 cm) long



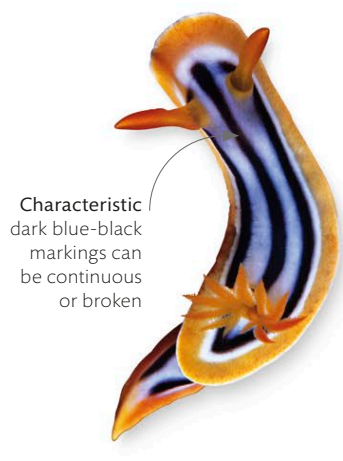
FJORDIA CHRISKAUGEI
¾–1½ in (2–3 cm) long



PTERAEOLIDIA IANTHINA
Up to 5 in (12 cm) long



POLYCERA QUADRILINEATA
1½ in (4 cm) long



CHROMODORIS ELISABETHINA
2 in (5 cm) long



HEXABRANCHUS SANGUINEUS
16 in (40 cm) long

Exoskeleton, like that of the lobster, is hardened by the mineral calcium carbonate



Land giant

The coconut crab (*Birgus latro*), reaching 9 lb (4 kg) in weight, is the biggest land invertebrate—but it is still only a small fraction of the maximum possible size for an ocean-dwelling American lobster.

Chelae (claws) have the strength to crack open coconuts for food

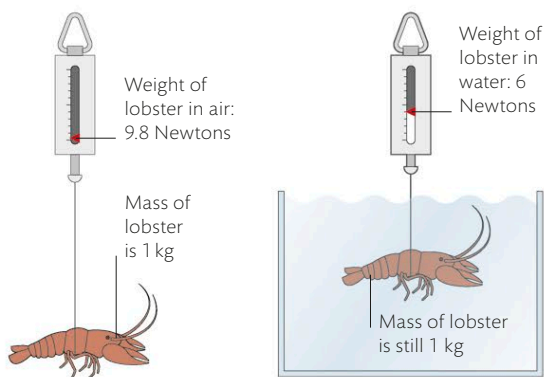


heavy bodies

For animals, growing big has pros and cons. While a large animal might overcome predators or competitors with brute strength, carrying weight puts strain on the body. Arthropods—jointed-legged animals such as crustaceans—wear their skeleton externally as a suit of armor. A bigger arthropod needs thicker armor, but this extra weight restricts movement and limits the animal's maximum possible size. It is only in water, where body weight is countered by buoyancy, that crustaceans such as the American lobster can grow into real giants.

BUOYED BY WATER

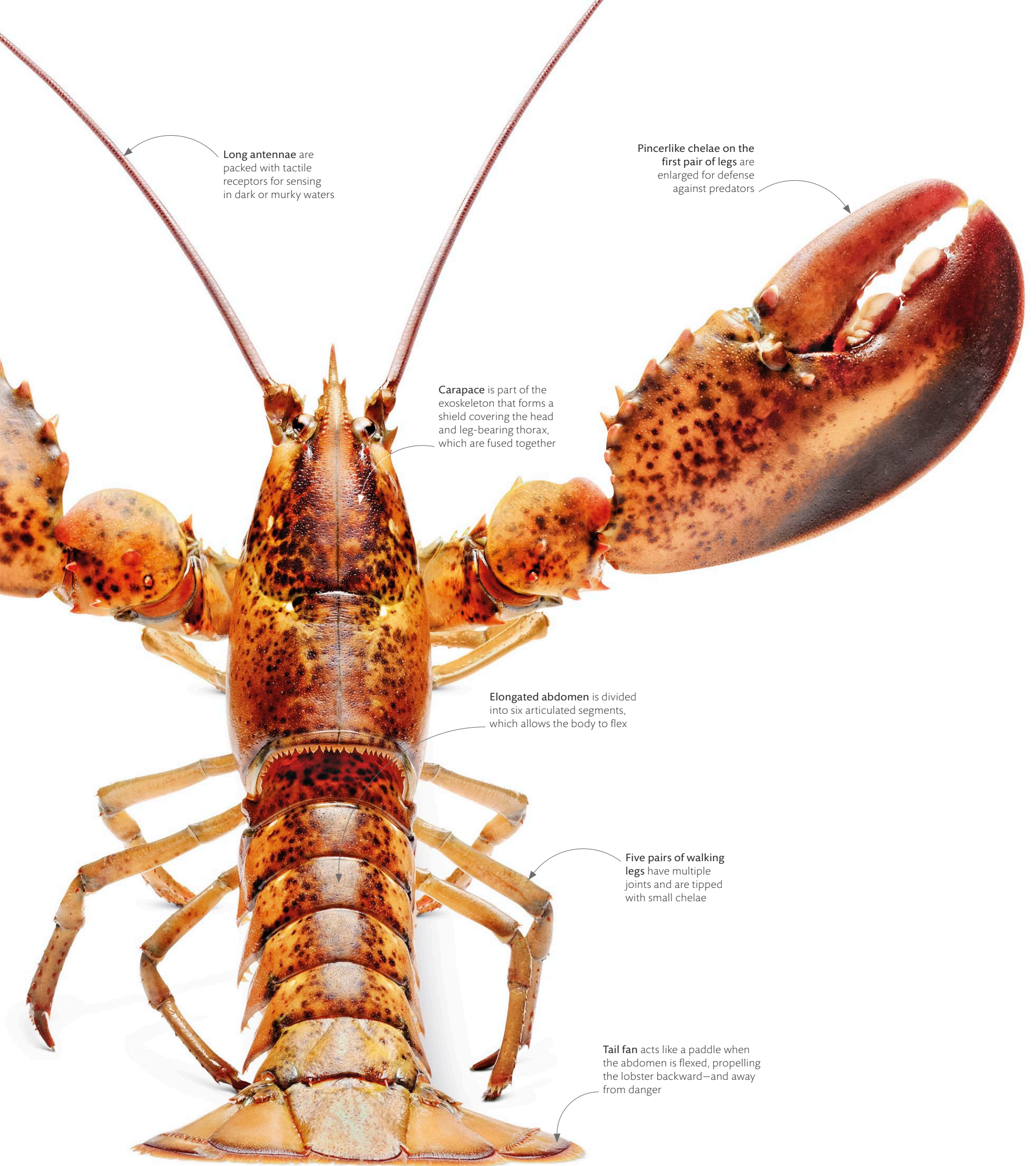
Weight—determined by the force of gravity and measured in Newtons—changes according to the medium in which an object exists (air or water). Mass—or the amount of material, measured in kilograms—is fixed. In the ocean, where gravity's pull is partly offset by upthrust from the water, a large lobster has enough muscle power to move its limbs and walk on the seabed. But on land, the lobster's weight is much greater, rendering it practically immobile.



WEIGHT AND MASS OF LOBSTER IN AIR AND WATER

Replaceable armor

Native to the northwest Atlantic, the American lobster (*Homarus americanus*) is the world's heaviest arthropod. The largest recorded specimen exceeded 44 lb (20 kg), although most of its kind weigh much less. Like all arthropods, it must periodically molt its exoskeleton and build new armor to get bigger. Because the American lobster grows throughout its life, the record-breaker might have been over a century old.



Long antennae are packed with tactile receptors for sensing in dark or murky waters

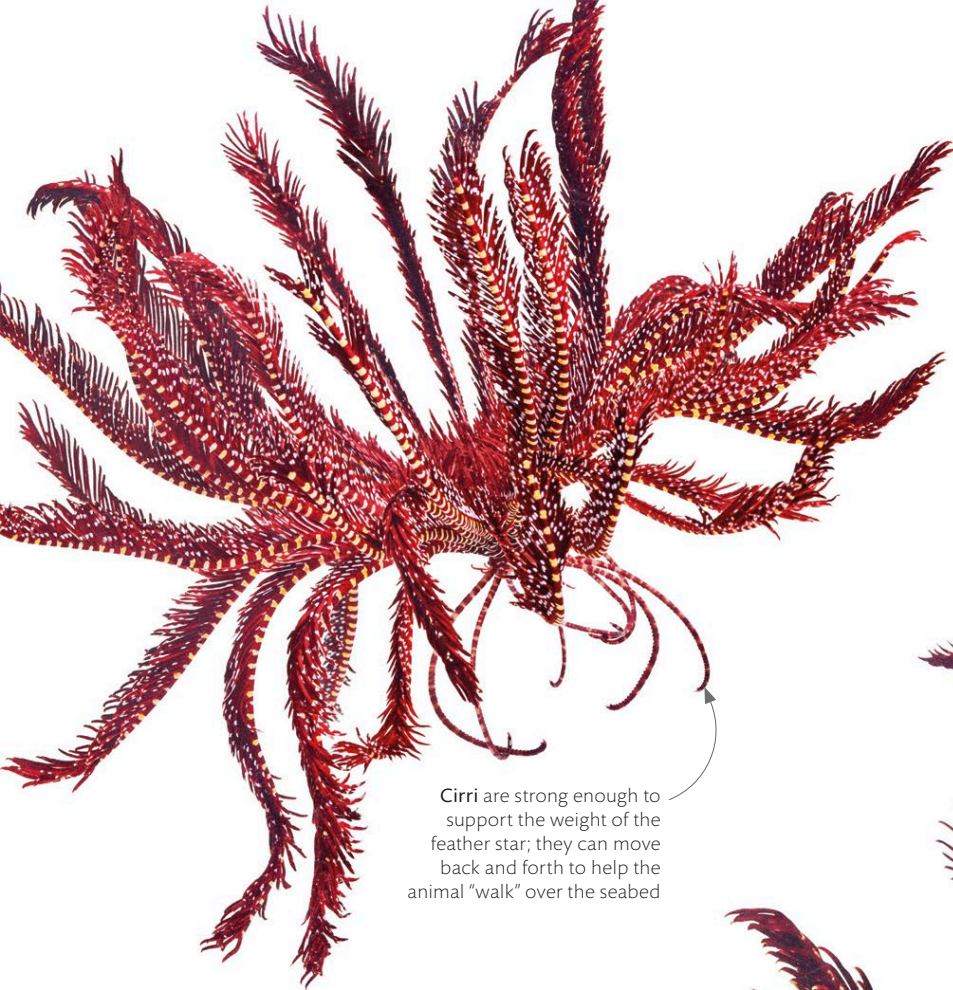
Pincerlike chelae on the first pair of legs are enlarged for defense against predators

Carapace is part of the exoskeleton that forms a shield covering the head and leg-bearing thorax, which are fused together

Elongated abdomen is divided into six articulated segments, which allows the body to flex

Five pairs of walking legs have multiple joints and are tipped with small chelae

Tail fan acts like a paddle when the abdomen is flexed, propelling the lobster backward—and away from danger



Cirri are strong enough to support the weight of the feather star; they can move back and forth to help the animal "walk" over the seabed



Arms pointing upward can better catch food particles drifting down from above

Orifices upward

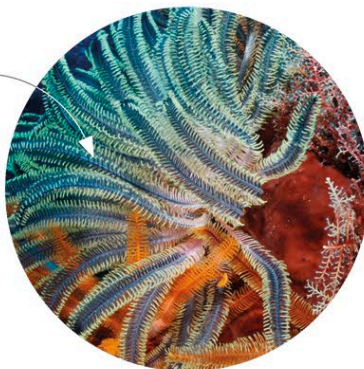
The mouth at the center of a feather star faces upward—not downward, as in starfish—so it is better positioned to receive food particles collected by the arms. Food passes through a U-shaped gut, with undigested waste emerging from an anus, which is also upward-facing.



suspension feeding

Animals that are nourished by tiny food particles suspended in seawater do better if they can spread their body over a wide area to catch more particles. Feather stars—relatives of starfish—do just that, directing feathery arms into incoming currents to trap plankton and floating fragments of detritus while they “walk” along the seabed on spindly, limblike cirri. Some feather stars can also sweep their arms up and down to swim in midwater.

Pinnules of each arm fan outward in the water to help trap food



Feathery arms

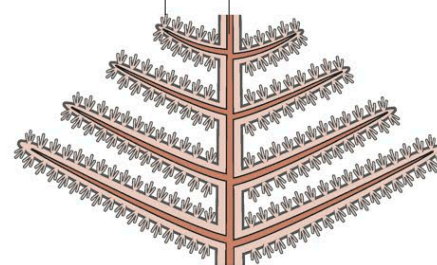
Feather stars have arms that grow in multiples of five. Some species have as many as 200 arms. Each arm is equipped with myriad side branches, called pinnules.

COLLECTING PARTICLES

True filter feeders, such as clams, pump seawater through a sievelike part of the body, but suspension feeders, such as feather stars, effectively “comb” the water to find food. Hydraulically operated tube feet along a feather star’s arms flick food into grooves, where microscopic, hairlike structures called cilia sweep it toward the mouth.

Tube feet
flick food
into grooves

Cilia in grooves
waft particles
toward mouth

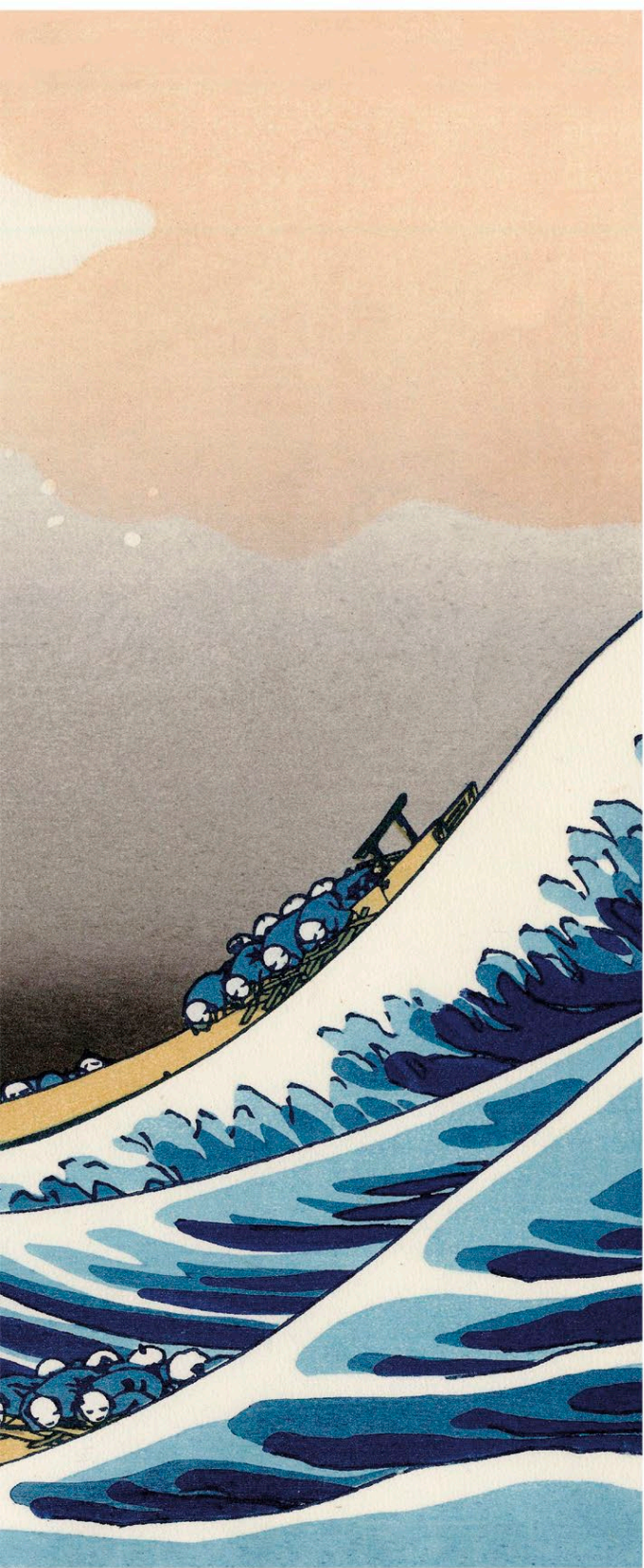


SECTION OF FEATHER STAR ARM



Under the Great Wave off Kanagawa (1829-1833)

The fierce energy of Hokusai's huge wave, poised above the boats caught in its grasp, has made this work (from Hokusai's series *36 Views of Mount Fuji*) the most recognized of all Japanese prints. Although it was common for prints at the time to feature a variety of colors, here a limited palette was used to powerful effect to emphasize the wave's dominance.



Fish in poetry

Realistic in detail and delicately colored, Utagawa Hiroshige's *Kurodai and Kodai Fish with Bamboo Shoots and Berries* is one of 20 prints that were commissioned by a poetry guild to illustrate poems about fish.

the ocean in art

the great wave

Since early times, artists in Japan—an island nation surrounded by the crashing waves of the Pacific and the complex currents and whirlpools of the Sea of Japan—have sought inspiration in the sea. In the Shinto faith, everything in nature, from the rocky shore to the ocean depths, has its own life force: it is this energy that is almost tangible in Japanese woodcuts.

Woodblock printing, the method used to create woodcuts, was introduced to Japan from China around 2,000 years ago, but it was not until the Edo period (1603–1868) that the art form was popularized. While only the wealthy could afford paintings, woodcuts were available to all, being printed in their thousands and costing as little as a bowl of noodles. The prints were a collaboration between an artist, who drew the design on paper; a cutter, who carved the design onto wooden blocks through the paper; and the publisher of the print runs. Early prints were monochrome, but by the mid-18th century, color prints—known as “brocade pictures”—were created using separate blocks for up to 20 colors.

Traditionally, the woodcuts depicted city scenes, including geisha, courtesans, and Kabuki actors and erotica. They became known as *ukiyo-e*, meaning “pictures of the floating world”—a reference to transitory pleasures. However, toward the end of the Edo period, there was an increasing interest in the natural world, and woodcut artists responded by creating landscapes and seascapes. They drew on literary traditions while engaging wholly with the moods and rhythms of the sea.

Among the most enduring of these woodcut artists are Hokusai, best known for *Under the Great Wave off Kanagawa*, and Hiroshige, often described as Japan’s last great *ukiyo-e* master. Hiroshige’s woodcuts reflect the sea in every guise, from waves crashing on rocks and a tranquil distant shore in *The Sea off Satta Peak, Suruga Province* (1858) to the treacherous currents of *Naruto Whirlpools, Awa Province* (1855).

After Japan opened up to the West in the 1850s, following centuries of isolation, such prints were avidly sought in Europe and the US and revered by Impressionist and Postimpressionist artists alike.

“These waves are claws, the boat is caught in them, you can feel it.”

LETTER FROM VINCENT VAN GOGH TO THEO VAN GOGH, 1888



Hard jaws are made up of modified ossicles

Brittle star mouth

The tube feet on a brittle star's arms pass food to tiny jaws flanking the mouth beneath the central disk. The food enters a short stomach; undigested waste passes out through the mouth, because the gut has no separate anus.



Muscular arms bend in multiple directions to enable movement across the uneven seabed

walking with arms

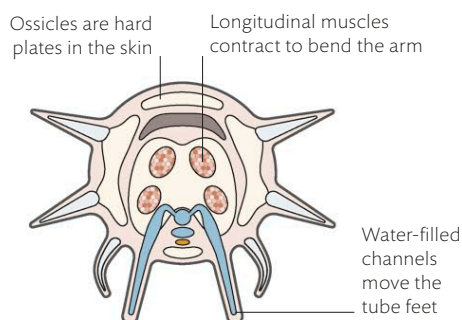
The thick, reinforced skin of a starfish undermines its flexibility, so the animal must crawl slowly using hundreds of tiny, suckerlike "tube feet" (see pp.220–221). But in brittle stars—relatives of starfish—the skin is more supple, and a complex lattice of muscles allows their arms to move more freely in the horizontal direction. By snaking back and forth, the spiny arms of a brittle star can grip the substrate and push forward; rather than being involved in locomotion, the suckerless tube feet are free to gather food particles.



Mucus-covered tube feet select particles of food and bundle them together for passage toward the mouth

BODY SUPPORTS

Like other echinoderms (urchins, starfish, feather stars, and sea cucumbers), a brittle star has a body that is supported both by hard skeletal ossicles that reinforce the skin and by a system of canals circulating seawater (a water-vascular system) that transports materials. Muscles running along the length of the arms control the arms' movements.

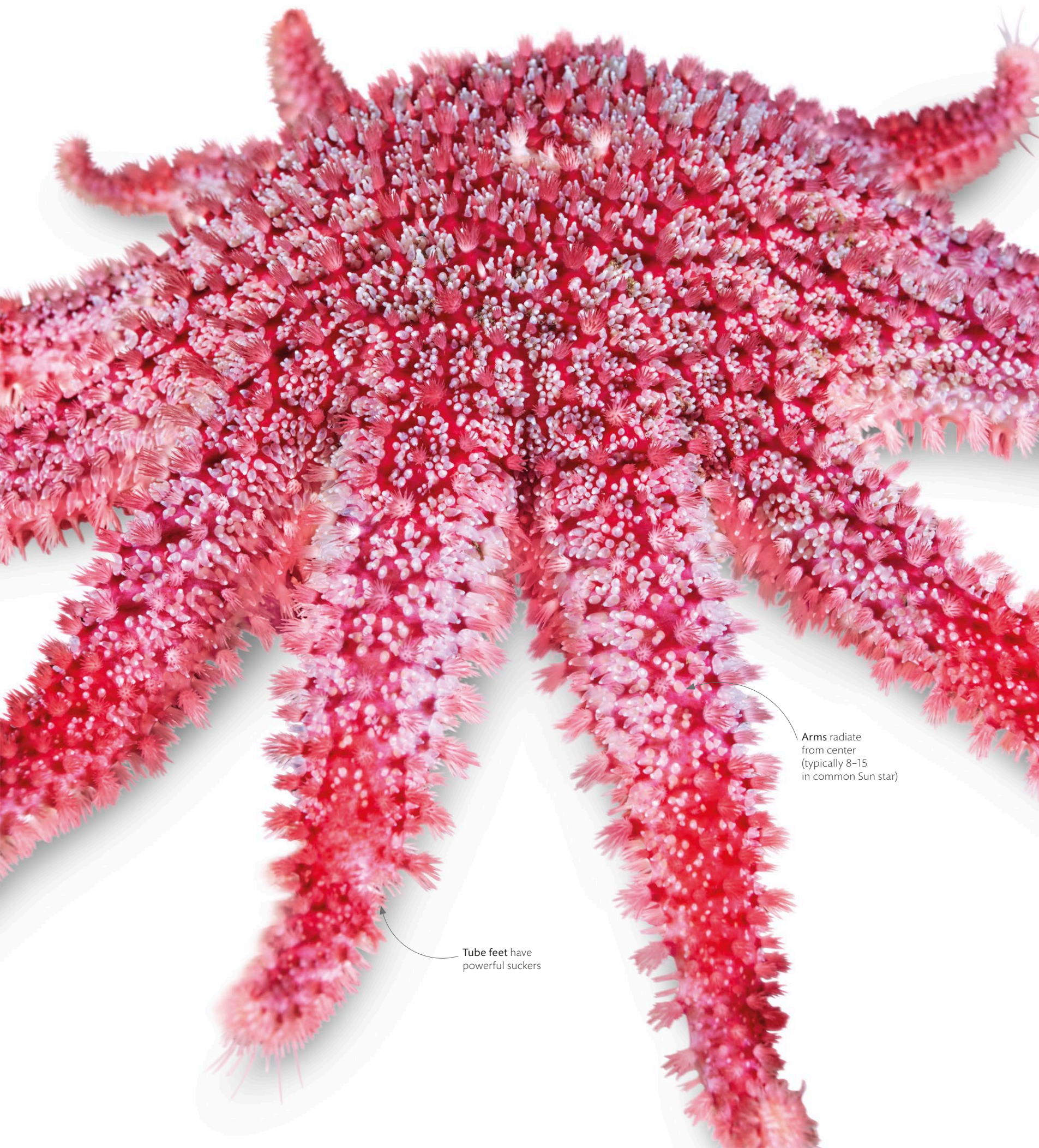


CROSS-SECTION OF BRITTLE STAR ARM

Brittle arms

A European common brittle star (*Ophiothrix fragilis*) uses its sinuous arms to walk over the seabed while the animal grazes on detritus and microbes. As the brittle star's name suggests, the arms break easily, although they can regenerate after injury.





Arms radiate
from center
(typically 8-15
in common Sun star)

Tube feet have
powerful suckers

Sticky ends

Each tube foot on a starfish ends in a disk, which secretes adhesive and de-adhesive chemicals. These allow the starfish to bind temporarily to other surfaces.



Tube feet emerge from grooves along each arm

tube feet

One of the traits that define the group of marine animals known as echinoderms is the possession of multifunctional structures called tube feet. They are the main organs of locomotion in starfish and urchins, they sometimes act as touch-sensitive feelers, and their thin skin serves as a surface for gas exchange. They also play a major role in the feeding process, helping pass tiny particles to the mouth, and in starfish, their adhesive strength is used to pry open the shells of prey such as mussels and clams.

Bunched spines aid grip on seabed

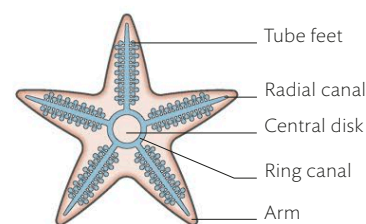
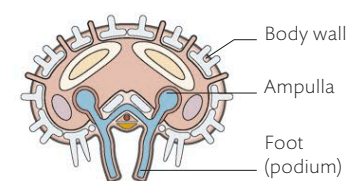
On the move

The action of tube feet allows the common Sun star (*Crossaster papposus*) to creep across horizontal, vertical, or overhanging surfaces. Each arm contains sensory structures, such as eyespots, which enable the starfish to tell light from shade.

Tip of arm contains tiny, light-sensitive eyespots

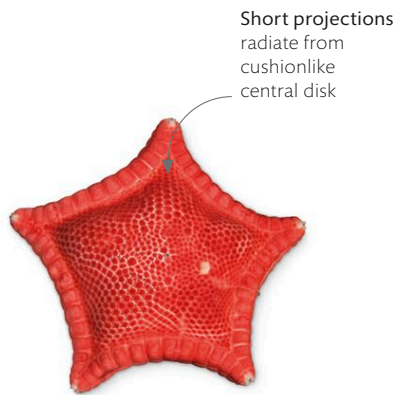
THE WATER-VASCULAR SYSTEM

Tube feet are part of a system that uses water pressure to aid locomotion, feeding, and respiration in echinoderms. In starfish, water enters (and leaves) the system via a pore on the top of the body. It then circulates to the ring canal and into the radial canals, which extend along each arm. From there, the water can pass into the tube feet, each of which comprises a bulbous sac (ampulla) and a stretchy foot (podium). Contraction of the ampulla forces water into the foot, making it extend.

**OVERHEAD VIEW****ARM CROSS-SECTION**

Number of arms

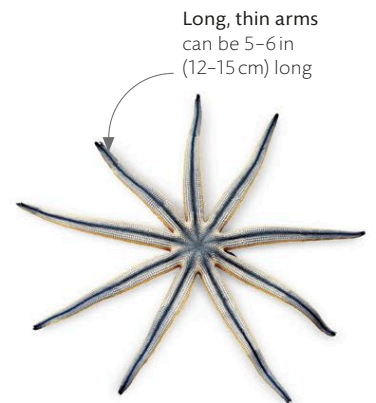
Most starfish species have five arms, but some have 10, 20, or even 50. The underside of each arm is covered in thousands of tiny tube feet, which enable the animal to “walk” over rocks, “climb” seaweed, and grab its prey. Each arm contains a full set of the starfish’s body systems, so if the animal loses a limb, it can survive without it. A starfish can also regenerate a lost arm.



CUSHION STARFISH
Cushion star
Ceramaster granularis



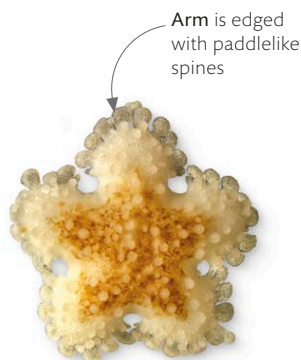
FIVE-ARMED STARFISH
Cuming’s sea star
Neoferdina cumingi



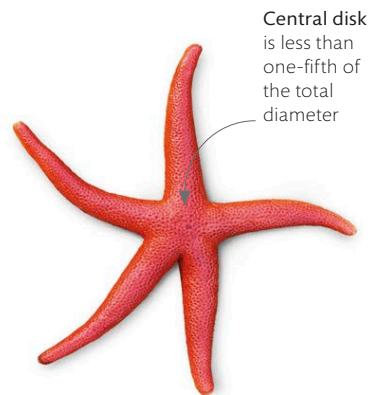
6- TO 16-ARMED STARFISH
Nine-armed sea star
Luidia senegalensis

Size

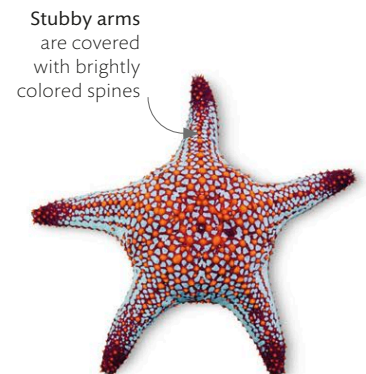
The diameter of a starfish can range from a few millimeters to 3 ft (1 m). The size of the central disk can also vary. Some, as in the Pacific blood star (*Henricia leviuscula*), are very small relative to the arm length; others are very large. The largest known species—the sunflower sea star (*Pycnopodia helianthoides*)—can weigh 11 lb (5 kg) and live for 35 years.



1/5–1/2 IN (0.5–1 CM)
Paddle-spined sea star
Allostichaster palmula



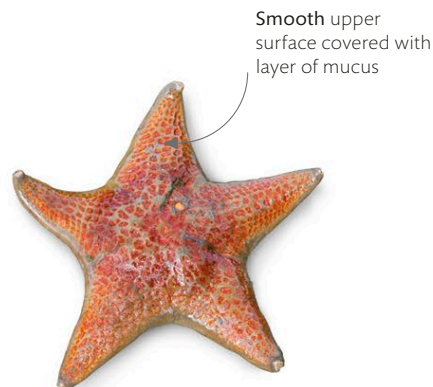
3 1/4–5 IN (8–12 CM)
Pacific blood star
Henricia leviuscula



UP TO 1 FT (30 CM)
Panamic cushion star
Pentacaster cumingi

Habitat and depth

Starfish can be found in every type of marine environment, from the icy polar oceans to tropical habitats. Some permanently inhabit shallow waters, living in tidal pools and on rocky shores, while others live on kelp beds and all parts of the coral reefs. Species have been observed at depths of 30,000 ft (9,000 m).



COASTAL TO 330 FT (100 M)
Leather star
Dermasterias imbricata



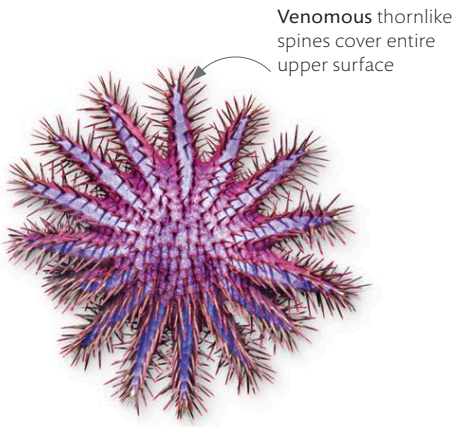
SURFACE TO 230 FT (70 M)
Blue linckia
Linckia laevigata



330–3,300 FT (100–1,000 M)
Common sunstar
Crossaster papposus

starfish

A group of more than 2,000 species of mostly predatory marine invertebrates, starfish (or sea stars) are echinoderms, closely related to sea cucumbers and sea urchins. Found in all the world's oceans, they are recognized for their—usually five-point—radial symmetry. They have no brain or blood. Instead, a water-vascular system moves seawater through their bodies, delivering the key nutrients needed for their organs to function.



16- TO 25-ARMED STARFISH
Crown-of-thorns starfish
Acanthaster planci



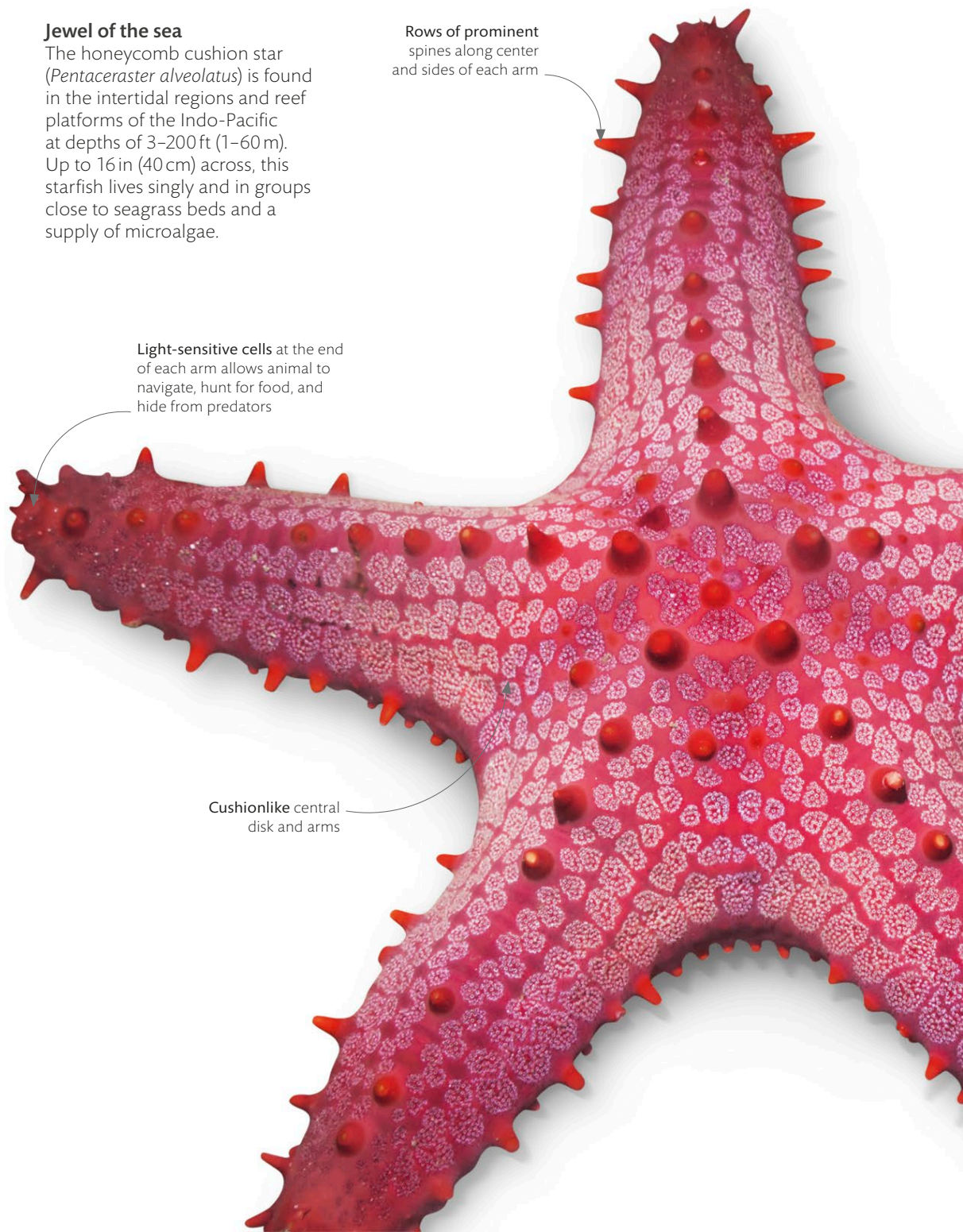
UP TO 3 FT (1 M)
Sunflower sea star
Pycnopodia helianthoides

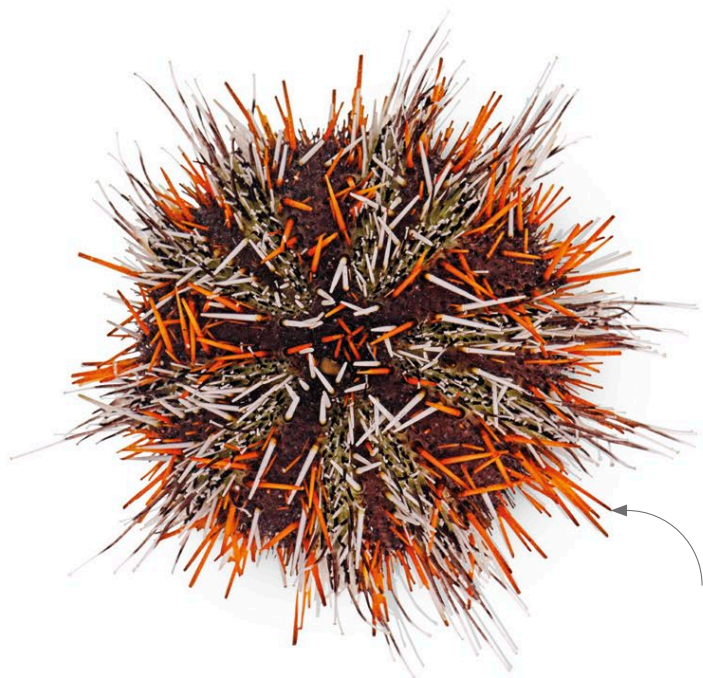


MORE THAN 3,300 FT (1,000 M)
Deep-sea star
Porcellanaster ceruleus

Jewel of the sea

The honeycomb cushion star (*Pentaceraster alveolatus*) is found in the intertidal regions and reef platforms of the Indo-Pacific at depths of 3–200 ft (1–60 m). Up to 16 in (40 cm) across, this starfish lives singly and in groups close to seagrass beds and a supply of microalgae.





Five-rayed symmetry

Most echinoderms have five axes or arms radiating from the center. On this collector urchin (*Tripneustes gratilla*), these are seen as five double rows of tube feet (see p.221), interspersed with bands of mostly orange spines.

Spines and tube feet are arranged in alternate bands radiating from the mouth

spiny skin

Echinoderms are a large and highly diverse group of invertebrates found only in the sea. Their name means spiny skin, with the spiniest in the group being the sea urchins. The bodies of sea urchins are covered in long, mobile spines, which can rotate at the base and are used for maneuvering and to repel predators or encrusting animals. The spines vary according to the species, ranging from fine and bristly to stout and pencil-like.

Hole at top is exit point for digestive and reproductive tracts and the water-vascular system (see p.221)

Pore was once the emergence point for a tube foot

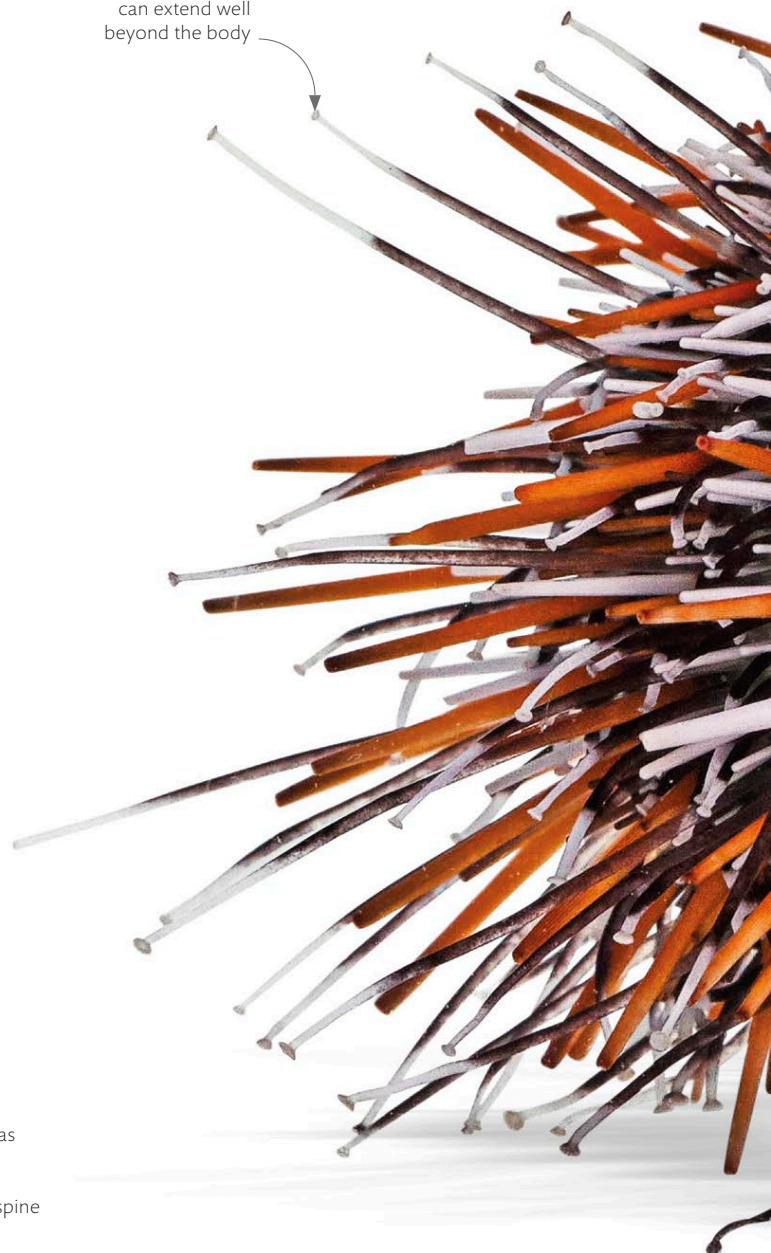
Urchin test

A sea urchin's body is supported by a shell-like skeleton called a test. When the urchin is alive, the test is covered in a thin layer of soft tissue, spines are attached to rounded protuberances (tubercles) via ball-and-socket joints, and tube feet extend from the tiny holes (pores). When the urchin dies, the spines fall off and the tube feet and tissue decay, leaving only the test.



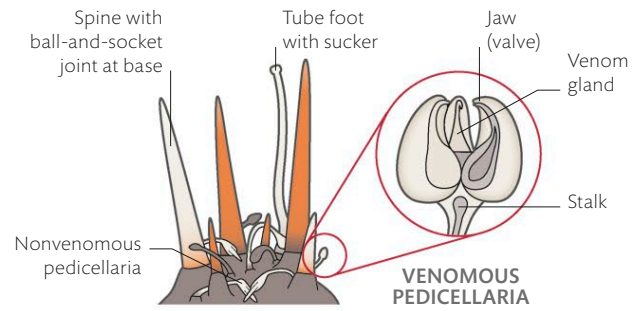
Tubercle was once the attachment point for a spine

Tube feet can extend well beyond the body



CLEANING AND STINGING

Between the spines covering a sea urchin's body are tiny, claw-shaped appendages mounted on a flexible stalk. Each appendage (pedicellaria) consists of three movable jaws (valves). Some are used as pincers to pick debris or algae from the urchin's body, while others are connected to venom glands, enabling the urchin to deliver a stinging nip.



Spines can swivel and be raised or lowered, useful for wedging the urchin into a crevice or lifting it slightly off the seabed

spotlight species

scalloped hammerhead shark

All nine species of hammerheads are instantly recognizable by their wide, flattened heads, known as cephalofoils. Despite its appearance and size, the scalloped hammerhead (*Sphyrna lewini*) is generally not aggressive to humans, but our activity has put the iconic animal on the endangered list.

Also known as the kidney-headed shark, the scalloped hammerhead is named for the notched front edge of its head. Its eyes and nostrils are positioned on each end of the “hammer,” giving it better binocular vision and a heightened sense of smell. The cephalofoil may also provide a larger surface area for the shark’s sensory cells, or ampullae of Lorenzini, which enable the animal to sense electrical fields given off by its prey. Scalloped hammerheads have relatively small mouths so live on a diet of fish and invertebrates they can swallow whole. They have been observed using one side of the cephalofoil to pin down a stingray before eating it.

Adult scalloped hammerheads grow to around 12–13 ft (3.6–4 m) long. They are found in most temperate and tropical

oceans, usually at depths of 80–900 ft (25–275 m). They often swim alone or in pairs, but periodically huge numbers of adults form schools near underwater seamounts or off island coasts.

Mature animals give birth to large litters of live young (anything from 12 to 41 pups) in coastal waters, but many are eaten by other sharks. Fishing and the shark-fin trade have also taken their toll on juvenile and adult animals.

Shark super school

Scalloped hammerheads gather in their hundreds to form huge schools. Theories as to why they do this vary from migration to aggression and sexual displays, but it makes them highly vulnerable to targeted fishing.

Front teeth are small and serrated; larger, flatter back teeth are used to grind up shellfish

Eye at each end of cephalofoil gives shark 360-degree field of vision



Whole-food diet

Scalloped hammerheads have small mouths in comparison to other sharks, so they eat prey such as sardines, mackerel, squid, and octopus, avoiding anything larger than stingrays—a favorite.



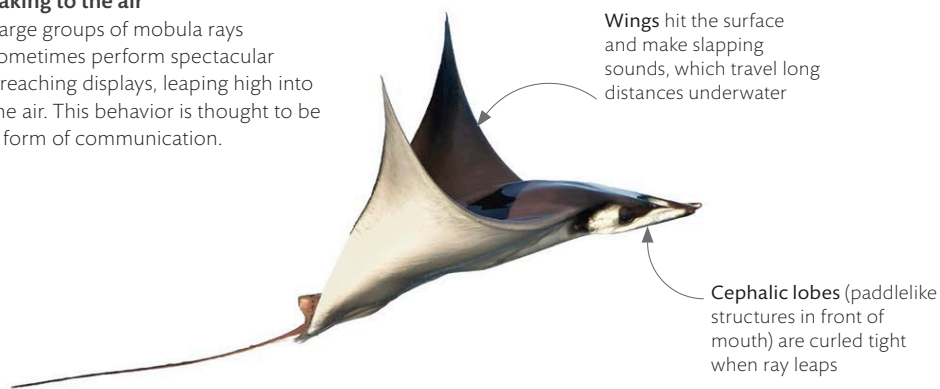






Taking to the air

Large groups of mobula rays sometimes perform spectacular breaching displays, leaping high into the air. This behavior is thought to be a form of communication.



flying underwater

Skates and rays, which are very similar-looking cartilaginous fish, have evolved a unique form and swimming style, using their flattened body and greatly enlarged pectoral fins. Many species are bottom-dwellers and ripple their fins to generate propulsion over the seabed. However, the closely related mobula and manta rays, both of which venture higher in the water column to filter feed, beat their fins up and down—a mode of swimming that resembles the flight of birds and bats.

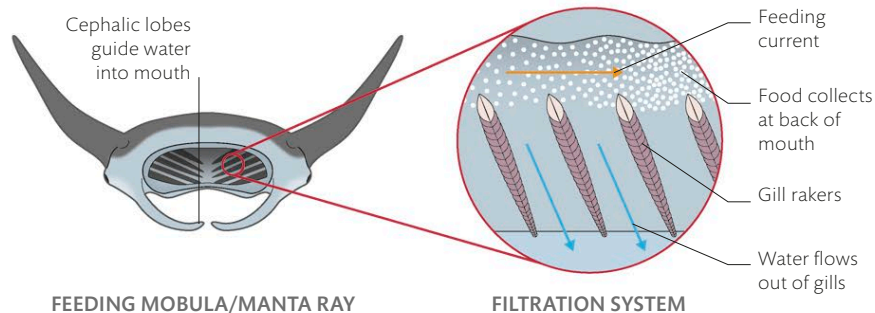
Perpetual motion

Mobula rays swim continually to maintain a flow of water over their gills. They travel widely, often swimming together in large groups as here, off the coast of Baja California, Mexico. The smaller mobulas are particularly gregarious, frequently gathering in schools of thousands.

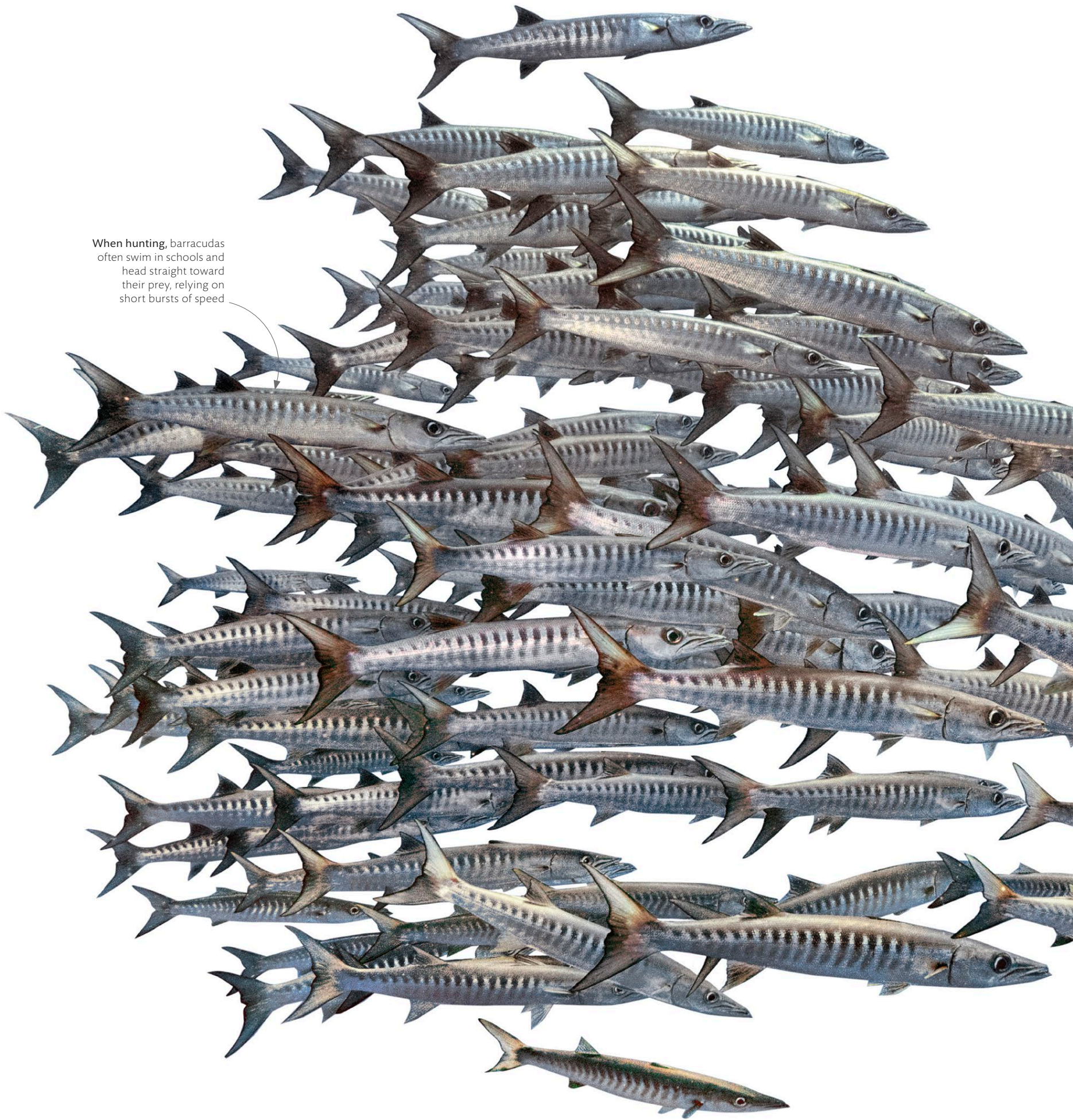
FEEDING ON THE WING

When feeding, mobula and manta rays swim slowly, using the motion to generate a feeding current. They are filter feeders, with a mouth that opens to the front rather than beneath as in other rays. A pair of cephalic

lobes unfurls to funnel seawater and plankton into the mouth. Inside, the feeding current runs over the gill rakers, causing the plankton to ricochet off the filter and flow on to the throat, while the water exits via the gills.



When hunting, barracudas often swim in schools and head straight toward their prey, relying on short bursts of speed



Careful adjustment

Chevron barracudas (*Sphyraena putnamae*) are fast-swimming predators. They have a large swim bladder, which regulates their buoyancy and saves energy. Adjusting the volume of gas in the swim bladder to compensate for pressure changes when rising or descending can slow the fish down. As a result, barracudas generally make only short vertical movements.

Torpedo-shaped, streamlined body is packed with muscle, making barracudas swift and powerful swimmers

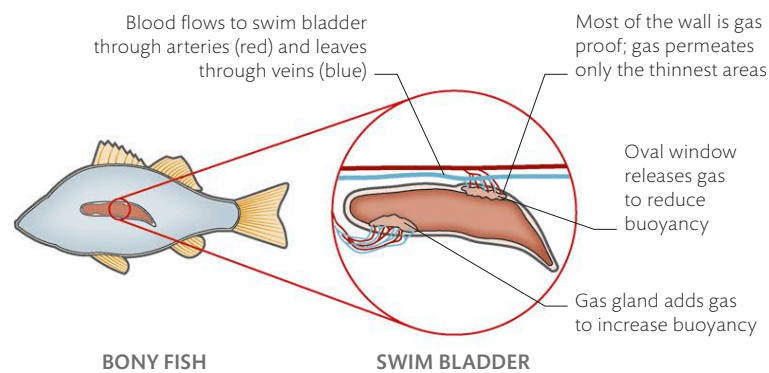


swim bladders

As every scuba diver knows, maintaining a steady position in the water can be hard work. For most bony fish living in open water, the energy-saving solution is a gas-filled swim bladder, careful control of which gives the fish neutral buoyancy and an ability to hang effortlessly at a certain depth in the water without floating upward or sinking. Bottom-dwelling fish often lack a swim bladder, and the feature is absent from sharks and rays, which rely instead on constant swimming and have a large liver filled with low-density oil, called squalene, which increases their buoyancy.

ADJUSTING BUOYANCY

The swim bladder is a thin-walled sac, which can expand and contract depending on how much gas (mostly oxygen) is inside. When a fish swims upward, the water pressure drops, which makes the gas in its swim bladder expand. To stop the fish bobbing to the surface, gas is removed from the bladder. The reverse happens when the fish swims downward: increased pressure means gas is added to prevent sinking.





keeping out of sight

Crypsis is the strategy of remaining hidden. One component of it is camouflage—blending against a background through body coloration, pattern, and texture—but behavior is also a key factor. In stargazers, the purpose of invisibility is both offensive and defensive; achieving it means remaining partially buried in sediment on the seafloor, where the fish waits for a chance to ambush prey that ventures within striking distance.

Lying in wait

The whitemargin stargazer (*Uranoscopus sulphureus*) lies partially hidden in the sand of the seabed. Patchy colors and granular skin texture blend with the sand, and by shuffling its pectoral fins and tail under the sediment, the stargazer disrupts outlines and shadows that might alert prey to danger. Sometimes only the swiveling eyes protrude.

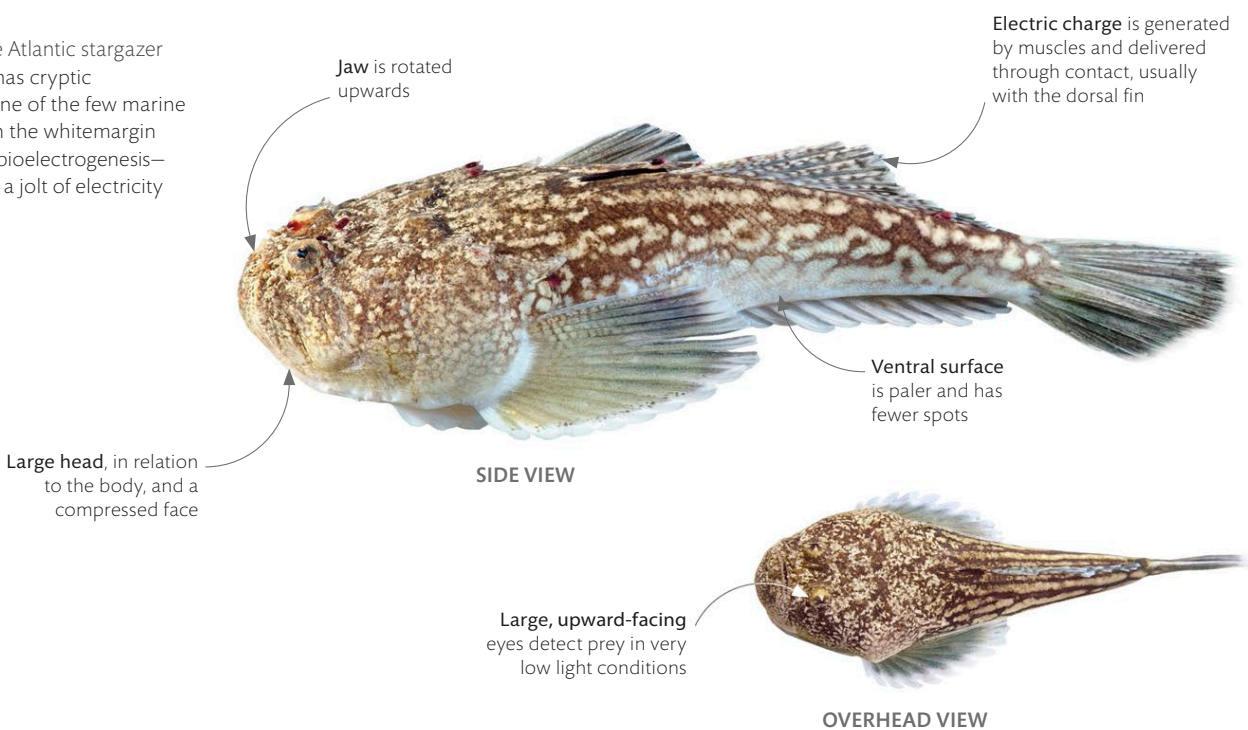
ATTRACTING PREY

Stargazers tempt prey within range using a scrap of flesh, known as a lure, protruding from the mouth. The lure resembles a small, soft-bodied invertebrate, such as a ragworm, and it can be twitched invitingly to gain the attention of potential prey. Bulging eyes watch intently, and when a smaller fish approaches closely enough, the stargazer opens its huge, upward-facing mouth in a few hundredths of a second, creating a surge of inrushing water that the prey is powerless to resist.

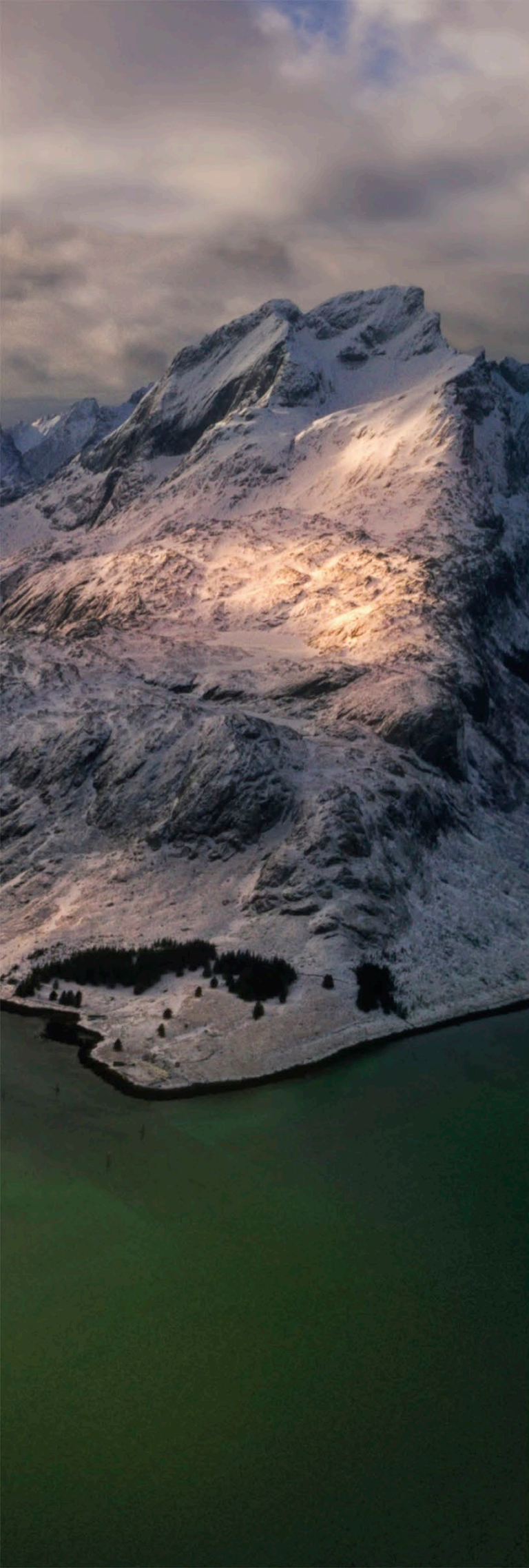


Shock treatment

Like all stargazers, the Atlantic stargazer (*Uranoscopus scaber*) has cryptic coloration. It is also one of the few marine species (together with the whitemargin stargazer) capable of bioelectrogenesis—the ability to produce a jolt of electricity to deter predators.





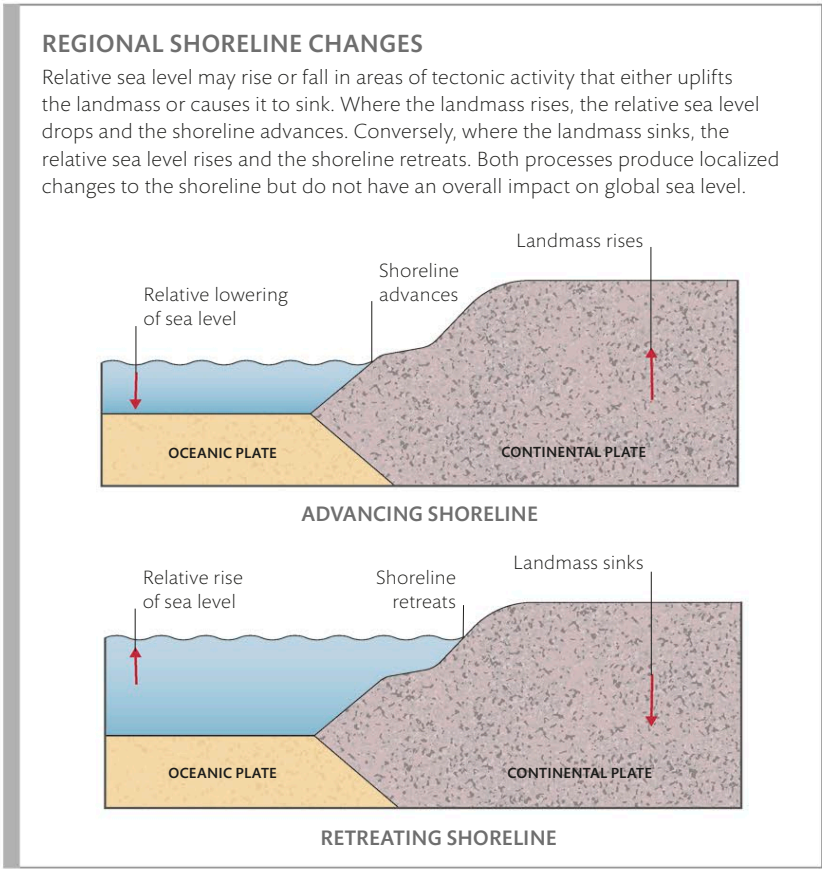


Uplifting coastline

The scenic shores of the Lofoten Islands, an archipelago off the northwestern coast of Norway, provide an example of a coastline that has been uplifted by tectonic activity.

sea-level change

Sea level is the average height of the ocean surface relative to land. This has changed throughout Earth’s history in response to climate change and the movement of tectonic plates. Eighty million years ago, as a result of an expansion of mid-ocean ridges (see pp.264–265) that caused displacement of water upward, sea level was 820–1,150 ft (250–350 m) higher than today. At the peak of the last Ice Age (about 25,000 years ago), when a huge volume of water was stored on land in polar ice caps, sea level was 400 ft (120 m) lower than it is today. As global warming melts the ice caps and warmer seawater expands, sea level is once again on the rise—possibly by as much as 20 in (50 cm) by the end of the 21st century.





Detecting movement

The striped eel catfish (*Plotosus lineatus*)—the only catfish found in coral reefs—has highly developed sensory organs, including the lateral line, which comprises a series of pores and canals along its flanks. Sensory cells in the lateral line detect vibrations (including low-frequency sound waves) and pressure changes, helping the nocturnal fish to navigate dark water and sense the movement of prey it cannot see.

Black-and-white body patterning warns that the fish is venomous

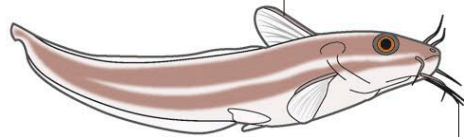
all-over senses

Water is an excellent medium for transmitting a wide range of sensory information, including vibrations and electrical signals. Many fish possess well-developed senses, with those of the catfish family being particularly acute. Their large eyes are useful because light transmission is limited in water, and their hearing is enhanced by tiny bones that transmit sound waves picked up by the swim bladder to the inner ear. In addition, catfish have chemical and electrical receptors all over the surface of their body.

CHEMORECEPTOR ORGANS

Catfish are equipped with between 250,000 and several million chemoreceptor organs, which are similar to taste buds but located all over the body, in differing degrees of density. These allow the fish to taste anything they come in contact with, enabling them to hunt effectively in the dark. The taste buds do not have to touch potential food in order to taste it. Any soluble chemicals that come from potential food can diffuse through the water to reach the taste buds and stimulate them.

High density of taste buds along leading edge of the fin



Forward position of barbels, with high density of taste buds, increases chance of finding food in front of fish

CATFISH TASTE BUDS

Elongated dorsal fin
merges with tail fin, giving
eel-like appearance



Lateral line detects
vibrations and
pressure changes



Nostrils (nares)
contain highly
sensitive smell
receptors in
the lining



**First fin ray on dorsal fin and
pectoral fin deliver a
sharp sting**

Large eye provides
excellent vision in
clear water

Barbel is
covered in taste
receptors





Sensitive body

Pressure-sensitive pores all over a sardine's body enable it to detect the movements of other fish nearby and react instantly, for example, by forming a tight group.



Light-scattering scales make it hard for predators to gain a visual fix on a single sardine

migrating in schools

Between spring and summer, an explosion of plankton growth occurs in nutrient-rich temperate seas, and many fish arrive from warmer areas to feed. Among these are sardines and anchovies, both small fish in the herring family, which migrate in vast schools of millions of individual fish, following seasonal currents. During these migrations these immense schools draw vast numbers of predators—including seabirds, sharks, dolphins, and whales—into so-called feeding frenzies.

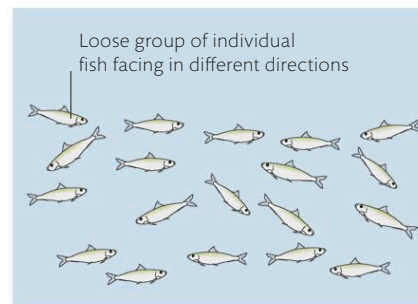
Safety in numbers

When a sardine school (in this case, *Sardina pilchardus*) senses a threat, it forms an even tighter group, with each fish attempting to stay in the center of the crowd, where it is less likely to be picked out. The swirling mass of bodies shifts and changes in shape in an attempt to confuse predators.

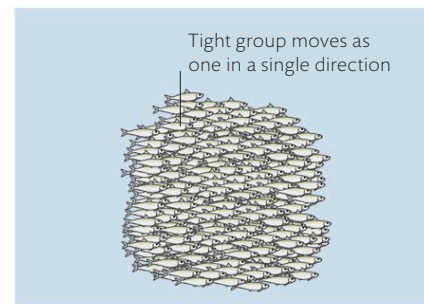
GROUPS OF FISH

Fish often gather in small or large groups. A shoal is a relatively casual aggregation of fish that move in different directions and include individuals of one or more species. A school is a much more organized group,

in which all members move in a coordinated manner. Schooling behavior almost always has a defensive function, and smaller fish, such as those in the herring family, often rely on swimming in close-knit schools for their survival.



SHOAL



SCHOOL

spotlight species

great frigatebird

Found on tropical islands in the western Atlantic, Pacific, and Indian Oceans, the great frigatebird (*Fregata minor*) soars above the waves for days, sometimes weeks, at a time. It is nicknamed the “pirate bird” due to its habit of aggressively stealing food from the beaks of other seabirds.

The great frigatebird feeds mainly on flying fish and squid and flies for hours, watching for prey to break the surface and then seizing it with its long, hooked beak. While it acquires most of its food this way, it is also a kleptoparasite—an animal that steals prey caught by another animal. Frigatebirds attack other seabirds, especially boobies, in midair as they return to their nests, harassing them into giving up meals intended for their chicks. This “mugging” of other birds has earned frigatebirds their common name, as their behavior resembles that of the man-o'-war ships, or frigates, used by pirates on ocean raids (and they are sometimes also called man-o'-war birds).

At up to 41 in (105 cm) long and weighing 3 lb 4 oz (1.5 kg), but with a wingspan of up to 7 ft 6 in (2.3 m), the great frigatebird has the largest ratio of

wing area to body mass of any living bird. The area of the wing, as well as its long, narrow shape, enables the bird to fly vast distances in search of food, although it usually stays within 100 miles (160 km) of land in order to roost.

However, this aerial specialist has a significant weakness—its feathers are not waterproof, as they lack sufficient preen oil to protect them from seawater. A frigatebird never willingly gets wet as, if its plumage becomes waterlogged, it may be unable to take off again.

Attracting a mate

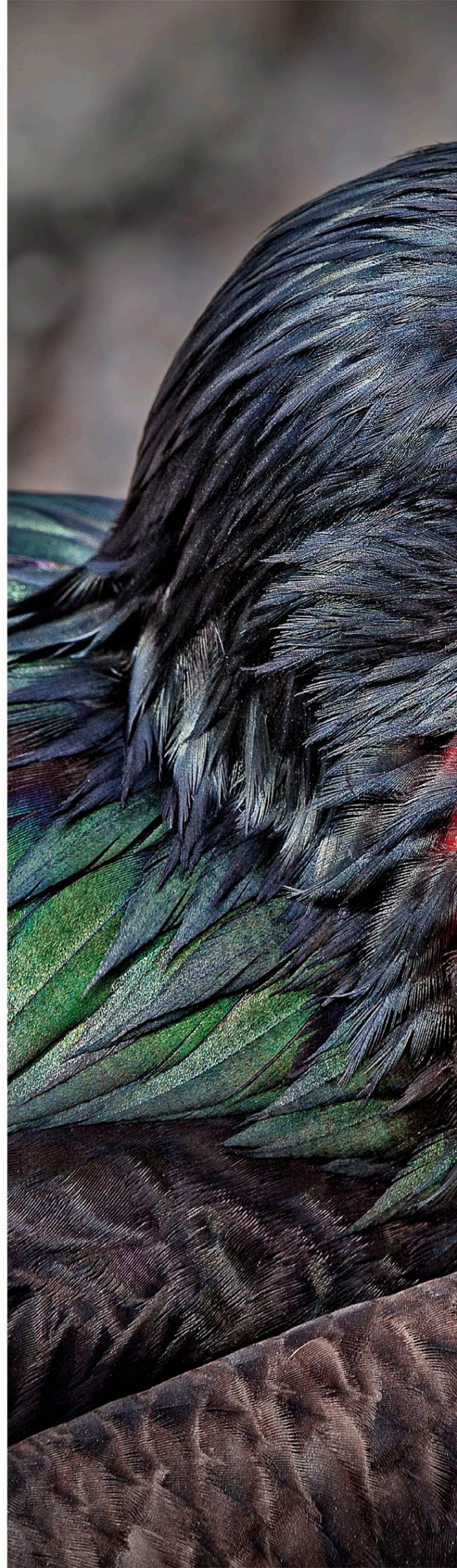
Like the related cormorants and boobies, frigatebirds have a throat pouch—called a gular sac. A male inflates his huge, bright-red pouch to attract a mate. The females also have gular sacs but never inflate them.

Wing size and shape enable the bird to utilize air currents in flight



Long-distance soaring

All birds have air-filled bones to make them lightweight, but a frigatebird skeleton forms a smaller fraction of its body weight than any other bird, making it the nimblest flyer. It can soar for weeks at a time and sleep mid-flight.







Taking the plunge

By diving from great heights—up to 65 ft (20 m)—brown pelicans can better counteract the effect of light refraction at the water's surface, improving their accuracy in catching prey.

plunge diving

Birds that catch fish underwater must overcome the buoyancy of bodies adapted for flying. But by plunging into the water from great heights, diving specialists such as gannets can reach deeper prey before floating back upward. Brown pelicans do likewise to take advantage of vast shoals in coastal seas—a strategy that sets them apart from freshwater pelicans, which scoop up their catch as they paddle over the surface.

KLEPTOPARASITES

Because pelicans spend time draining water from their pouch and manipulating their catch before swallowing it, these birds are vulnerable to thieves, or kleptoparasites. In the Caribbean, laughing gulls (*Larus atricilla*) often land on the head of juvenile pelicans because the young birds are more likely to spill their fish. But in the Gulf of Mexico, Heermann's gulls (*L. heermanni*) harass adults that have a bigger catch.



ADULT AND JUVENILE LAUGHING GULL (*LARUS ATRICILLA*)



Skin pouch hanging from the bill's lower mandible expands to accommodate several quarts of fish-filled water

Grabbing the catch

The brown pelican targets a single fish but usually scoops up several in its pouch—together with a heavy volume of water, which must be drained before the catch can be swallowed.

Coastal pelican

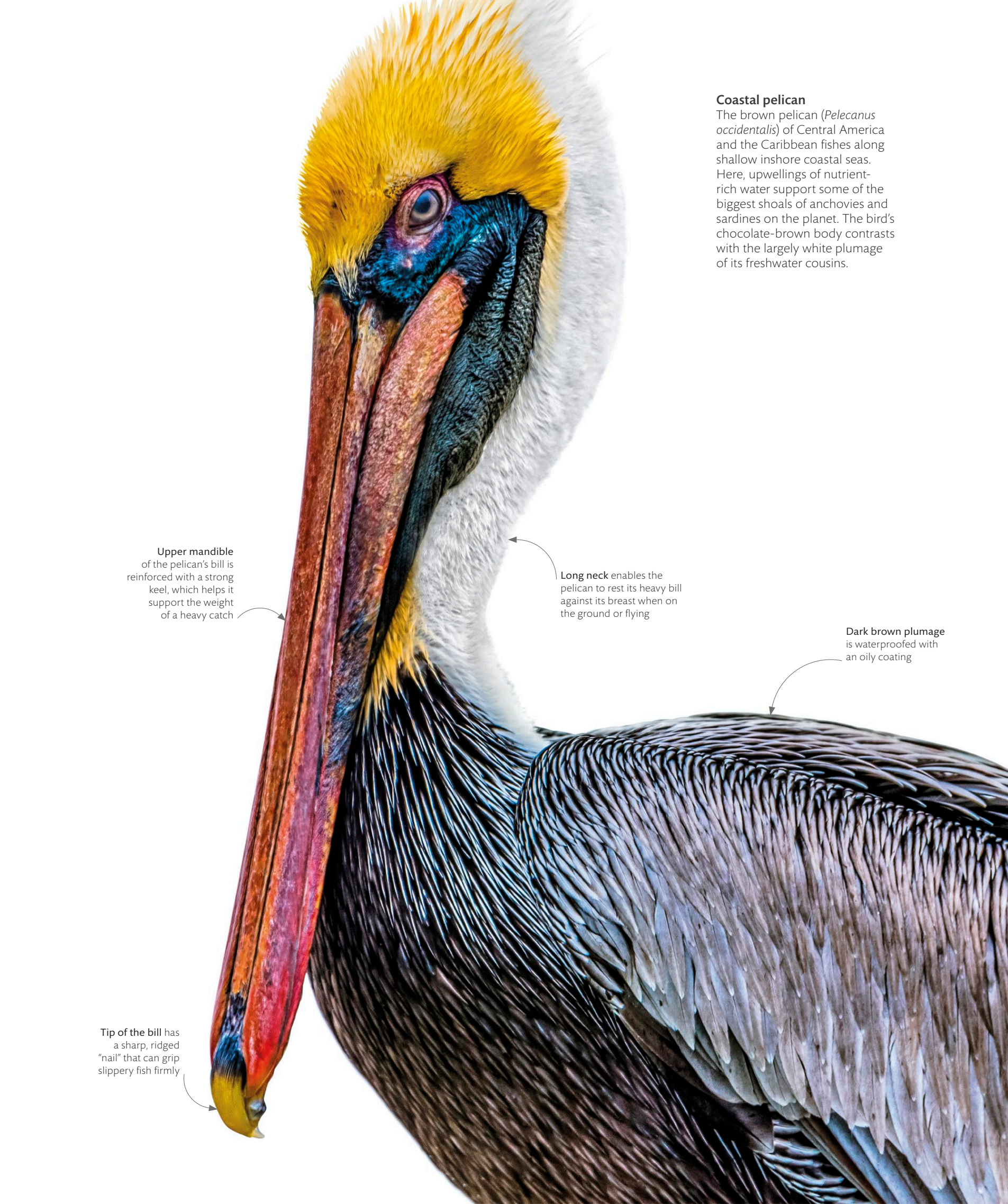
The brown pelican (*Pelecanus occidentalis*) of Central America and the Caribbean fishes along shallow inshore coastal seas. Here, upwellings of nutrient-rich water support some of the biggest shoals of anchovies and sardines on the planet. The bird's chocolate-brown body contrasts with the largely white plumage of its freshwater cousins.

Upper mandible of the pelican's bill is reinforced with a strong keel, which helps it support the weight of a heavy catch

Long neck enables the pelican to rest its heavy bill against its breast when on the ground or flying

Dark brown plumage is waterproofed with an oily coating

Tip of the bill has a sharp, ridged "nail" that can grip slippery fish firmly







Using tools

Back on the surface after a dive, an otter places a carefully chosen rock on its front, then bashes a clam against it to crack open the shell and access its meal.

spotlight species

sea otter

Superbly adapted to its coastal habitat, the sea otter (*Enhydra lutris*) has the densest coat of any animal on Earth; powerful webbed hind feet; a strong, rudderlike tail; and heightened senses of smell and touch that help it locate prey in murky waters. It is also one of the few mammals to use tools.

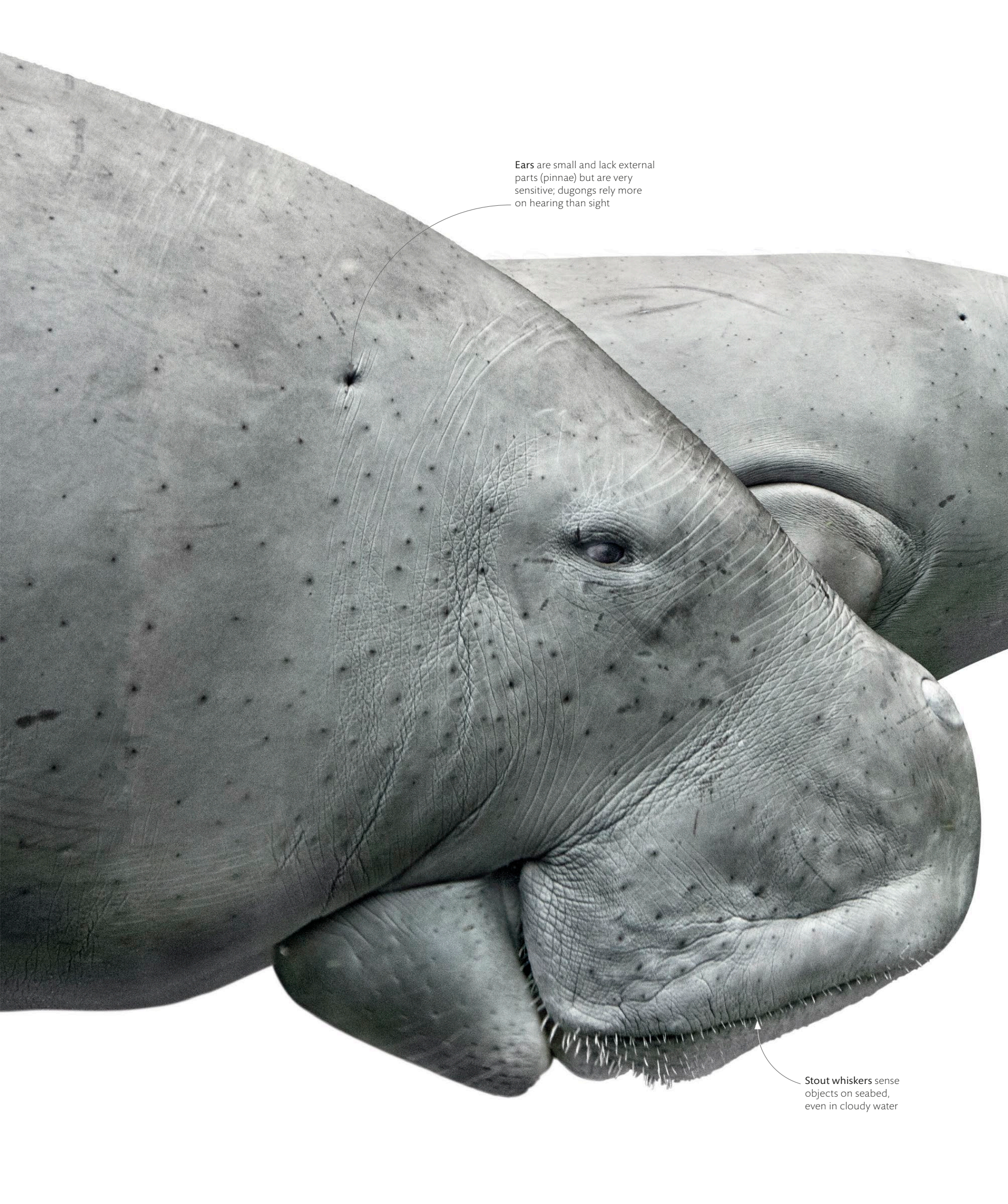
Found in the north Pacific Ocean, the sea otter is a member of the Mustelidae family, a group that includes weasels and badgers. One of the smallest marine mammals, an adult sea otter has a body length of around 4 ft (1.2 m). Its body is streamlined, highly buoyant, and—apart from its pads and nose—entirely covered in a dense, two-layered coat of fur. Short, insulating underfur contains up to 1 million hairs per sq in (155,000 hairs per sq cm), while an outer layer of longer guard hairs forms a waterproof barrier against cold seas. Grooming helps the sea

otter introduce insulating air bubbles into its fur. Unlike seals or sea lions, otters lack a blubber layer, so they are dependent on their fur to keep warm and dry.

A sea otter spends almost all its life at sea. Besides mating and giving birth in water, otters float on their backs on the surface to eat, sleep, and groom. They dive up to 250 ft (75 m) to forage on the seabed, closing their nostrils and ears while underwater. A substantial food supply is crucial—adult sea otters must eat 20–33 percent of their body weight each day to stay alive. Long whiskers and sensitive forepaws help detect vibrations in low-visibility conditions, allowing these animals to find clams, sea urchins, crabs, and other invertebrates in near-darkness. Sea otters may stash several prey items in pouches of loose skin beneath their forearms, enabling them to carry more food back to the surface.

Hanging on

Sea otters often form groups known as “rafts” when resting on the surface. As well as wrapping themselves securely in kelp, some otters prevent themselves from drifting away by holding another animal’s forepaws.



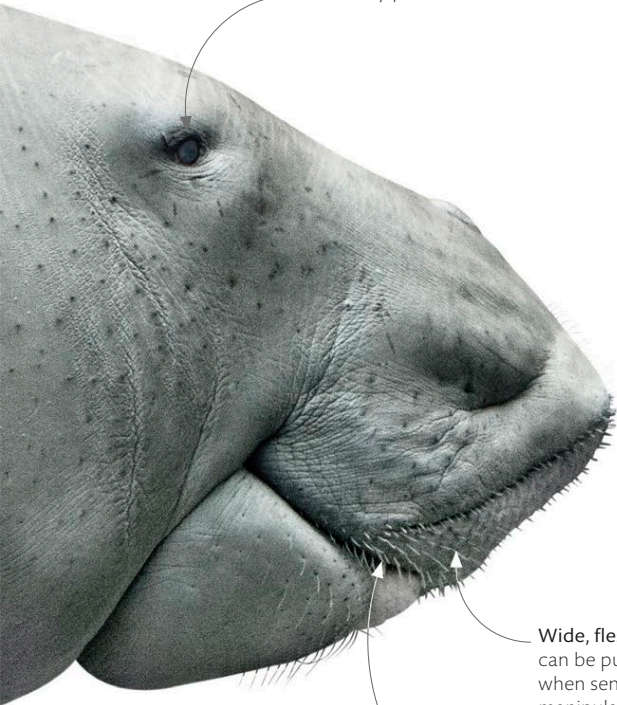
Ears are small and lack external parts (pinnae) but are very sensitive; dugongs rely more on hearing than sight

Stout whiskers sense objects on seabed, even in cloudy water

Grazing pair

Dugongs spend most of their time alone or in pairs. Their feeding habits (known as cultivation grazing) look destructive, but their regular visits result in regrowth of some seagrass varieties, which would otherwise be crowded out by tougher, more fibrous plants.

Small eyes high on head provide good field of view, although eyesight is relatively poor

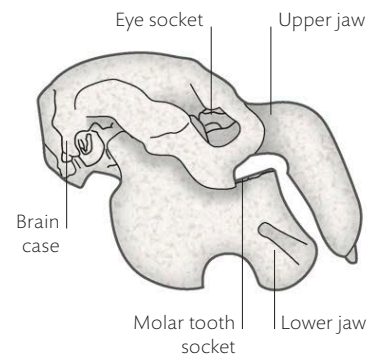


Wide, fleshy oral disk can be pushed forward when sensing or manipulating food

Muscular lips uproot plants from sediment

ADAPTED FOR GRAZING

The skull of a mature dugong is unique and remarkable. No other mammal has such a pronounced downward turn of the lower jaw (mandible) and upper jaw (premaxilla). This shape means the mouth of the dugong opens downward, allowing the animal to graze from a relaxed, horizontal position.



MALE DUGONG SKULL

grazing on grass

Sirenians are a group of unusual sea mammals that include the Atlantic manatees and the Indo-Pacific dugong (*Dugong dugon*). Collectively, they are sometimes known as sea cows because of their grazing lifestyle. They are almost wholly herbivorous, favoring tender seagrasses and algae. Because they have a low-energy diet, dugongs take life at a leisurely pace and are restricted to warmer tropical and subtropical waters, where they do not need to burn energy to maintain a constant warm body temperature.

Grazing trail

Dugongs eat every part of their food plant, including the roots, so they create meandering trails of bare sediment as they wander through seagrass beds.



Golden trevally take advantage of small invertebrates dislodged by the dugong's feeding activity

spotlight species

humpback whale

While humpback whales (*Megaptera novaeangliae*) are remarkable in many ways—their size, intelligence, and the distances they swim each year—these oceanic mammals are particularly well known for their sophisticated vocalizations, or “songs,” produced by males during mating season.

Humpbacks get their common name because of the way they arch their backs when diving, creating a humped profile. At up to 200 ft (60 m) long, they are not the largest whales in the sea, but they do hold the record for the longest pectoral fins, which can reach up to 16 ft (5 m)—up to a third of their total body length. Mothers and calves have been observed touching fins while swimming, possibly as a sign of reassurance.

Male humpbacks vocalize for up to 20 minutes at a time, creating songs that span several octaves and may be heard up to 20 miles (30 km) away. All males in a group sing the same combination of squeaks, groans, howls, and moans, sometimes adding subtle variations but keeping the theme broadly the same. However, studies show that these songs evolve, developing new themes every few years.

Humpback whales make one of the farthest migrations of any mammal on Earth. Many undertake annual round-trips of around 10,000 miles (16,100 km), spending the summer in feeding grounds rich in krill and other plankton—their main source of food—before migrating to spend the winter in the warmer waters of their breeding sites. Humpbacks were pushed to near-extinction in the 20th century. However, conservation efforts have ensured that most of the recognized populations are no longer endangered.

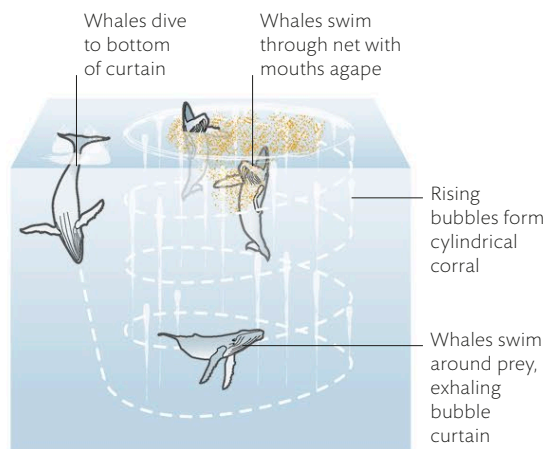
Marks of distinction

All humpbacks have dark upper bodies, but white underpart patterns—found on bellies and beneath tail flukes, as well as pectoral fins—are unique to individuals. Whales from the Southern Hemisphere have whiter undersides than Northern Hemisphere whales.

GROUP HUNTING

Humpbacks often cooperate to hunt, using various sounds and fin slaps to herd or disorient their prey. “Bubble-netting” is unique to humpbacks: the whales use their blowholes to create curtains of air bubbles, corralling prey into a dense mass before exhaling more bubbles underneath to drive them upward. They then swim open-mouthed up through the center of the net, capturing mouthfuls of prey.

BUBBLE-NET FEEDING





Rich waters

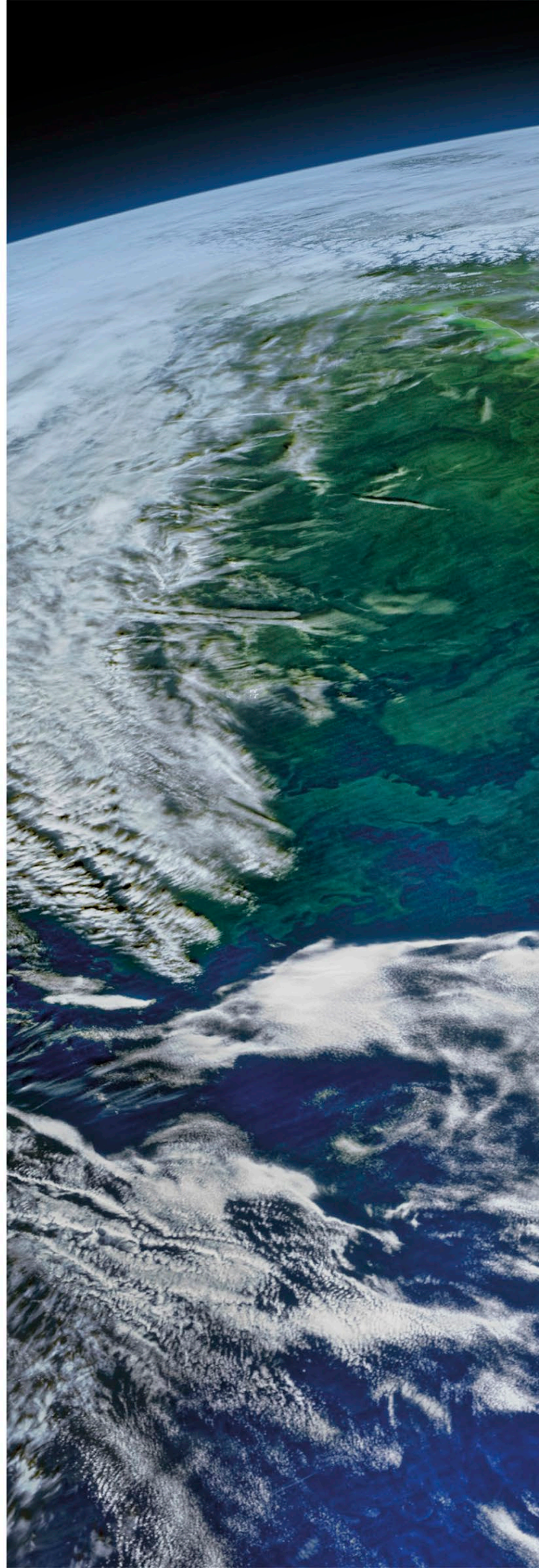
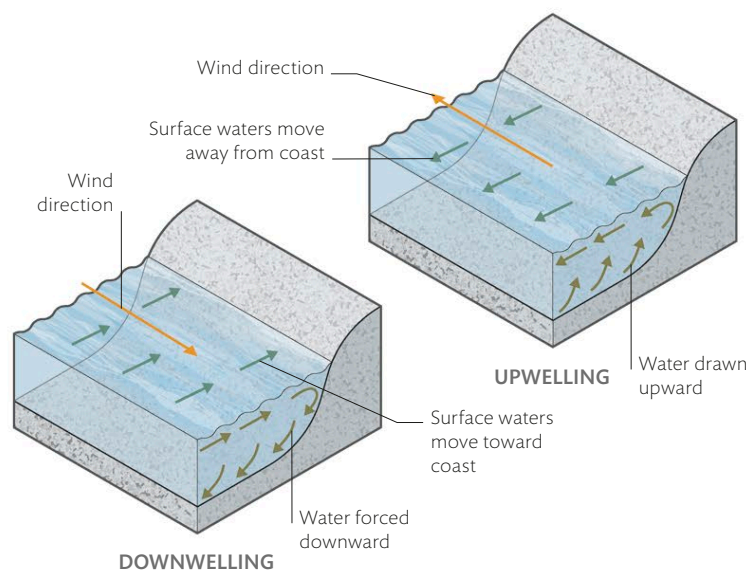
Off the coast of California, cool currents from the Arctic combine with offshore winds to bring nutrients to the surface, leading to the growth of phytoplankton, shown here in green.

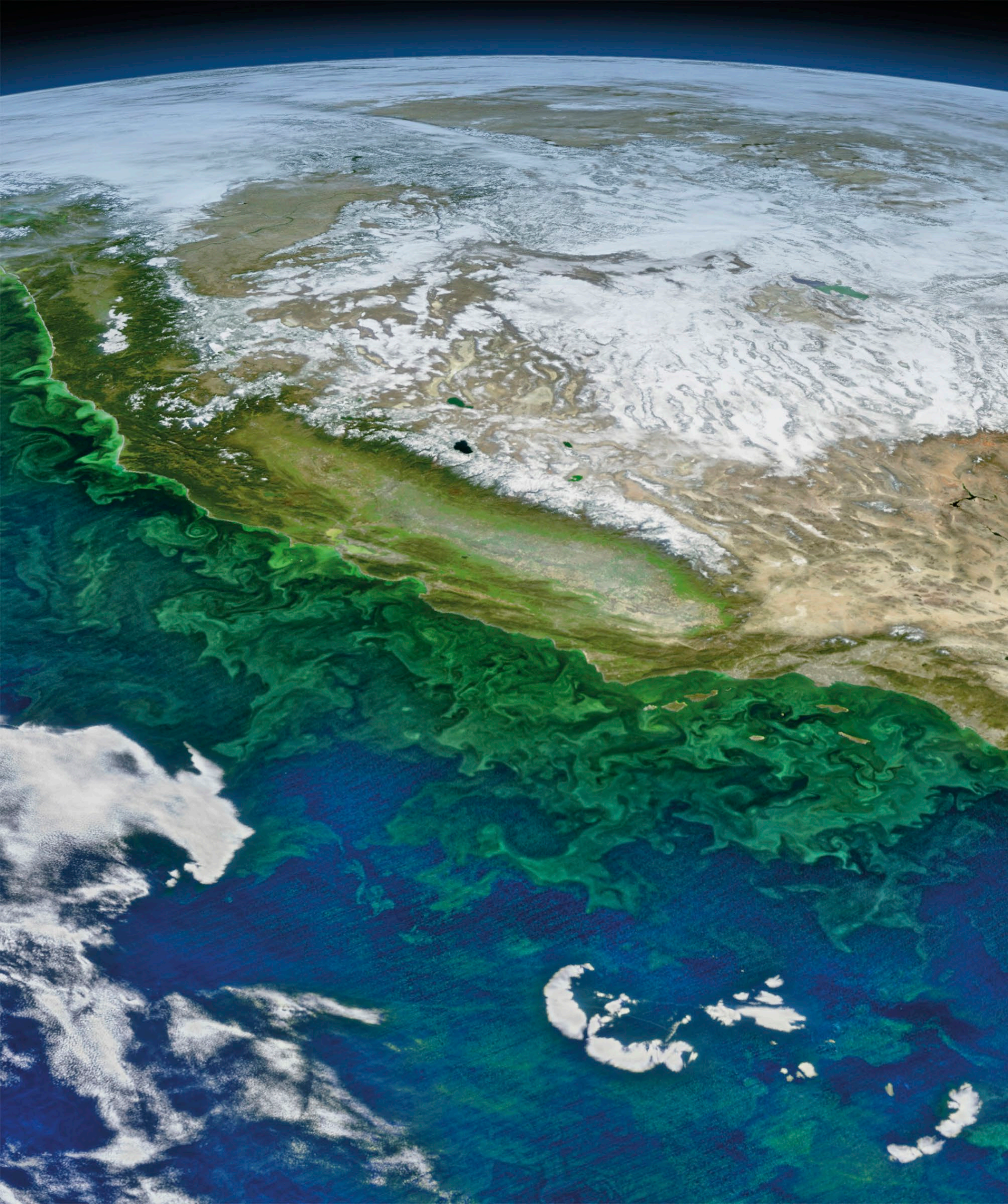
upwelling and downwelling

Vertical currents below the ocean surface bring water up toward the surface (upwelling) or carry water downward (downwelling). These currents are most common in coastal regions but can also occur far from land. The quiet central parts of ocean gyres (surface current circulation systems) are areas where deepwater currents converge and downwelling results. Extreme downwelling occurs in areas of the Norwegian-Greenland Sea and around Antarctica, where ice-cold dense water sinks and is carried south by bottom currents. When upwelling occurs, the rising current brings nutrients nearer to the surface, supporting plankton growth, which in turn attracts a wide variety of ocean life. Major upwelling zones exist off Peru, Namibia, and western Canada.

THE EFFECTS OF CURRENTS AND WINDS

Coastal upwelling of water occurs where surface currents are deflected offshore due to the effect of Earth's rotation combined with that of the prevailing winds. The movement of surface water away from the shore draws water upward from the ocean depths. In regions where currents near the surface are deflected toward the coast, the waters are forced downward to produce downwelling.





spotlight species

atlantic spotted dolphin

Inquisitive, acrobatic, playful, and highly sociable marine mammals, Atlantic spotted dolphins (*Stenella frontalis*) are found in temperate to tropical Atlantic waters from southern Brazil to New England via the Gulf of Mexico in the west, and from Angola to Morocco in the east.

Although named for their distinctive mottled skin, these dolphins are born spotless and do not acquire any speckling until they are 8 to 15 years old; some remain unspotted and so are misidentified as slender bottlenose dolphins. Calves are 2–4 ft (60–120 cm) at birth, but adults can be 5 ft 6 in–7 ft 6 in (1.7–2.3 m) long and weigh 240–310 lb (110–141 kg).

These dolphins are capable of diving to depths of 200 ft (60 m) and holding their breath for up to 10 minutes. Atlantic spotted dolphins are also found in the shallower waters of the continental shelf and come in close to shore to feed near sandbanks or surf the bow waves of recreational boats. Their diet consists mainly of small fish, as well as bottom-dwelling invertebrates, squid, and octopus. They use echolocation for navigating and finding food, and pods often cooperate to hunt, encircling prey to

prevent them from escaping. They can often be seen feeding alongside bottlenose, striped, and common dolphins, with which they regularly interact. Coastal pods may consist of as few as 5 to 15 dolphins, but the average is closer to 50. Occasionally, however, groups merge to travel in “super pods” of 200 or more.

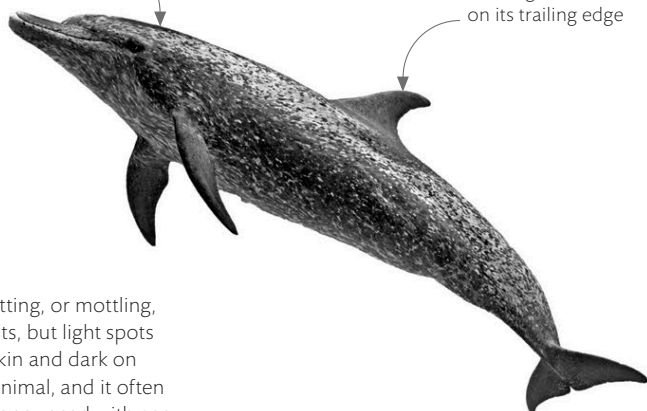
Highly communicative, Atlantic spotted dolphins use whistles, squeaks, clicks, and buzzes as well as bubbles to “speak” to each other within a group, both at close and at long range. They also use pulsed barks or “screams” to warn off rival pods.

Group activity

Pods are seen socializing in the clear shallow waters off the coast of the Bahamas. Through socializing, young males form strong, often lifelong bonds with other males.

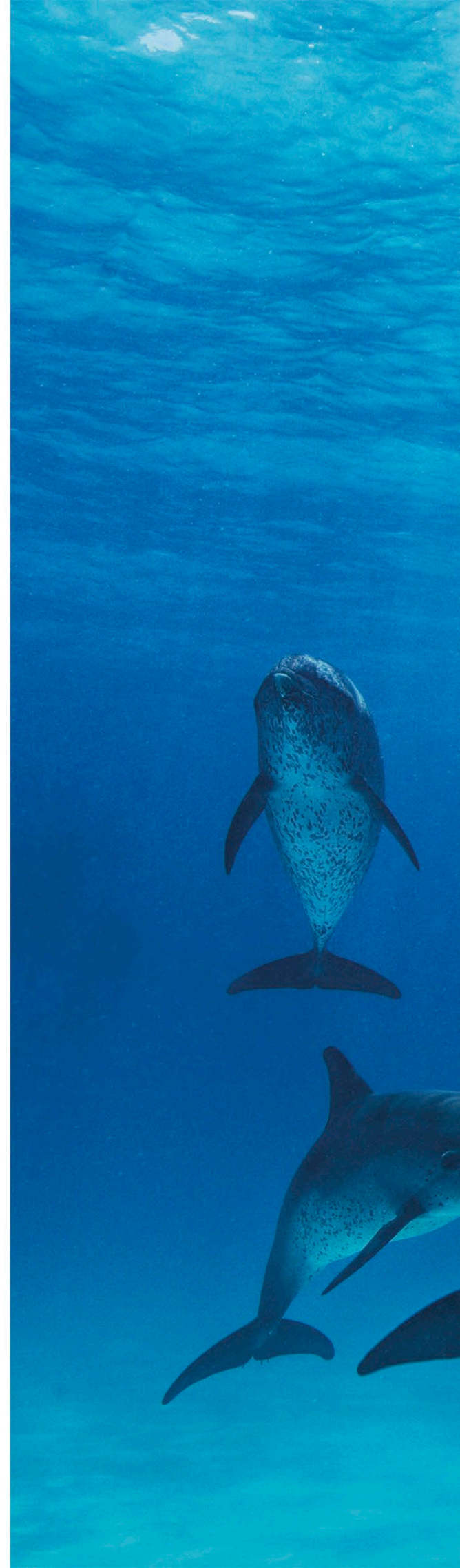
Spots appear first on back and belly as the dolphin grows to maturity

Tall dorsal fin has a strong concave curve on its trailing edge



Spot check

The degree of spotting, or mottling, varies among adults, but light spots develop on dark skin and dark on light in the same animal, and it often becomes more pronounced with age.





The background features a monochromatic blue-toned illustration of various fish species. In the top left, a large fish with a spotted pattern is shown. To its right, a smaller fish with a diamond-shaped scale pattern is visible. Below these, a medium-sized fish with a fine scale pattern is depicted. At the bottom, a large, detailed fish with a prominent, serrated lower jaw and a patterned body is shown. The text is overlaid on this background.

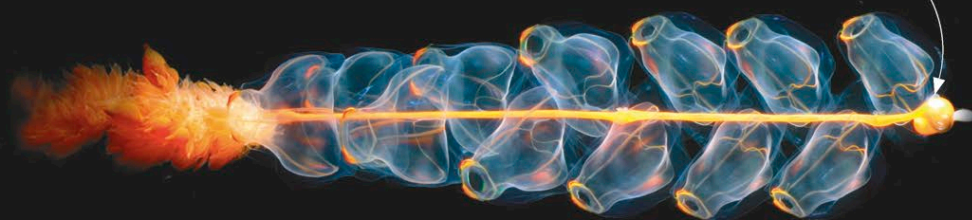
the open oceans

Many organisms live in the challenging environment of the open oceans. Strong currents and a lack of shelter have led both predators and prey to evolve adaptations for greater speed or to camouflage themselves.

Inflated float

Some siphonophores—such as the Arctic species *Marrus orthocanna*—stay buoyant with the aid of a gas-filled sac. By adjusting gas levels in the sac, the animal can control its level in the water.

Bright orange pneumatophore (gas sac) is situated adjacent to the propulsive bells



dividing labor

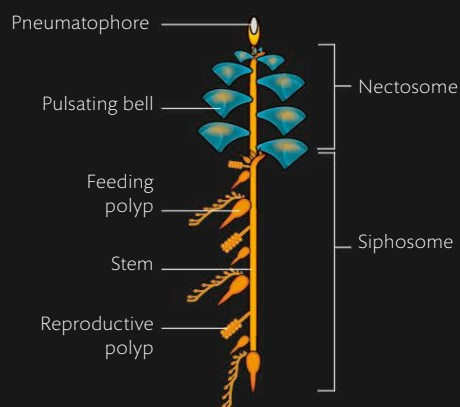
A group of animals called siphonophores swim or drift in the ocean like true jellyfish, yet they live in colonies like corals. Each colony is made up of individuals, called zooids, that are adapted to perform different tasks. This division of labor improves the overall efficiency of the colony. Some zooids attached to the colony's stem provide propulsion and function like the pulsating bells of a jellyfish; other zooids, with a specialized feeding role, have mouths and tentacles like the polyps of a coral or anemone.

Midwater colony

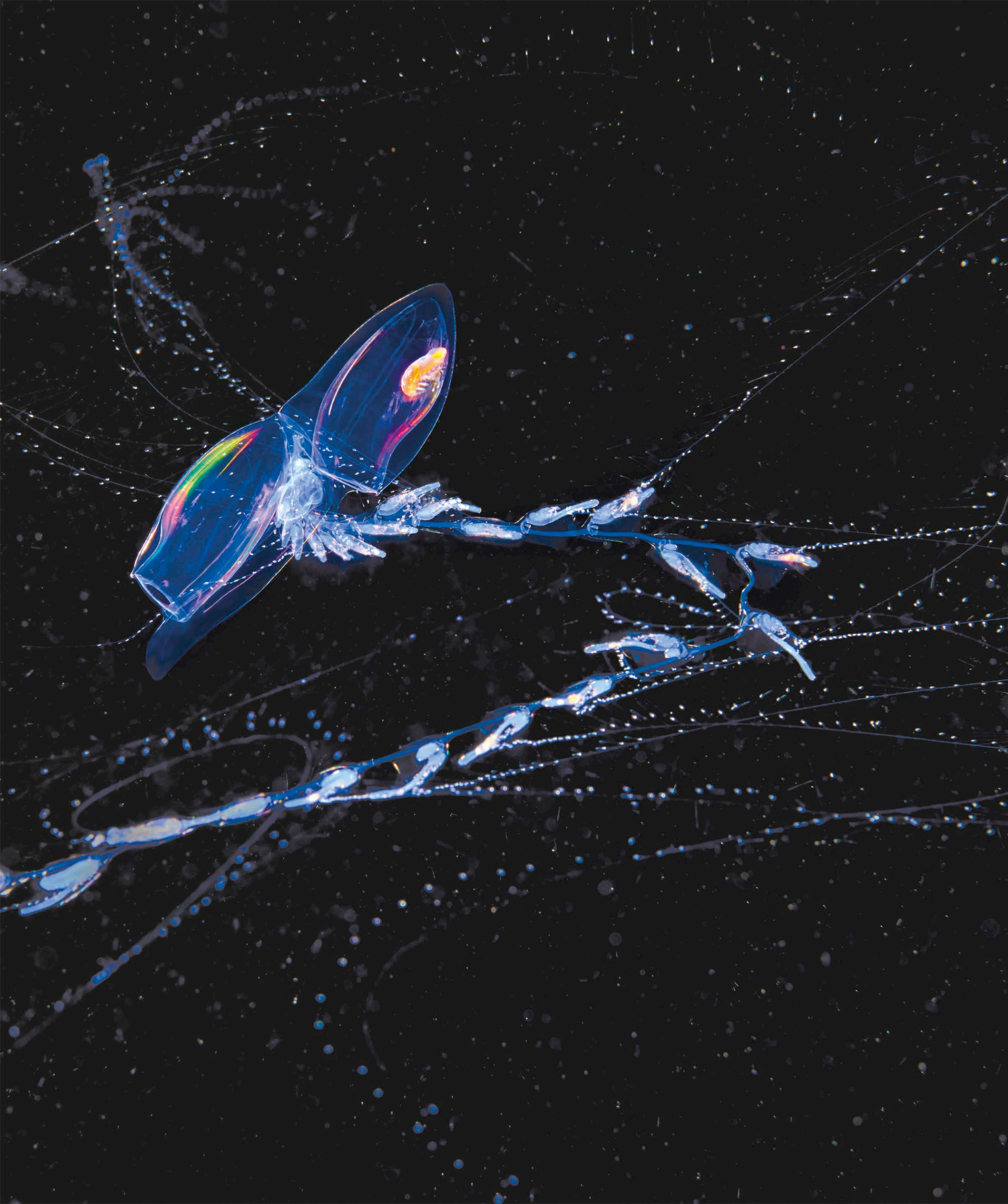
Two swimming bells of a deep-ocean, cup-bearing siphonophore (*Sulculeolaria biloba*) are attached to a soft trailing stem that carries feeding polyps with tentacles for catching planktonic prey. One of the bells has an oil droplet to help maintain buoyancy.

COLONIAL ORGANIZATION

The zooids of a siphonophore share nutrients harvested from planktonic prey through a common stem that is differentiated into two regions: one, the nectosome, with pulsating bells; and another, the siphosome, with polyps and tentacles. A gas-filled float, or pneumatophore, may also be present. In some siphonophores, such as the Portuguese man o' war, the swimming nectosome is absent and the colony floats on the ocean surface by its pneumatophore, drifting as it is blown by the wind.



GENERALIZED SIPHONOPHORE STRUCTURE



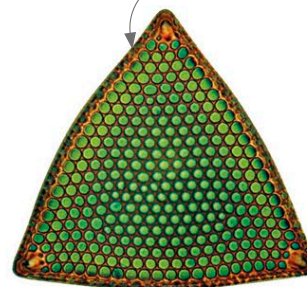
Diatoms

These are single-celled organisms whose cell walls are made from opaline silica. They are responsible for the production of much of the world's oxygen and for removing carbon dioxide from the atmosphere. The silica in the cell walls makes them heavier than other single-celled organisms, but adaptations enable them to remain at the water's surface for photosynthesis. They are also kept in suspension thanks to water turbulence.



Curved cells link to form long, spiraling chains 30–300 micrometers (millionths of a meter) long

GUINARDIA STRIATA



Body is composed of two halves that fit together like a tiny box

TRICERATIUM FAVUS



Flat, disk-shaped cell that lives singly or in colonies

PLANKTONIELLA SOL

Dinoflagellates

These are organisms with two flagella (whiplike tails) that help them move through water in a corkscrew fashion. Most have bodies covered with complex outer cell walls. Some kinds can catch and absorb other plankton. When too many nutrients are available, large blooms may form, which leads to a phenomenon called "red tides," toxic to both marine life and humans.



Bioluminescent species with numerous chloroplasts; cell size can be 30–1,000 micrometers

PYROCYSTIS PSEUDONOCILUCA



Cells lack hard outer cell walls

GYMNODINIUM



Tentacle used to sense and capture prey

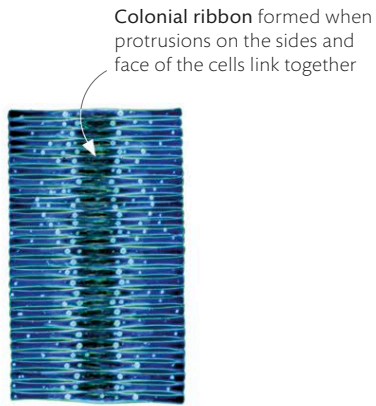
NOCTILUCA SCINTILLANS

phytoplankton

Organisms that drift with ocean currents and make their own food by photosynthesis are known as phytoplankton. They include microscopic algae and cyanobacteria. As phytoplankton are reliant on sunlight for photosynthesis, they are confined to the upper layers of the oceans. They are vital both to the global carbon cycle (they remove carbon dioxide and release oxygen) and to marine food webs, providing food for all forms of marine life, from zooplankton to whales.

Fanned colony

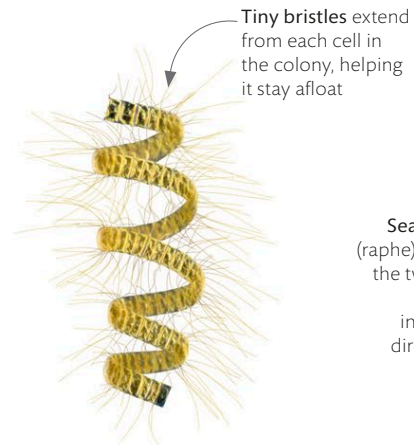
A brackish water diatom, *Licmophora flabellata* is named for the distinctive fanlike formation of the colony of cells. Adjacent cells are linked at the tips of the main axes, but by forming a "chain," they increase their overall surface area. A benthic species often attached to red and brown seaweeds, it is also found in coastal waters.



FRAGILARIA



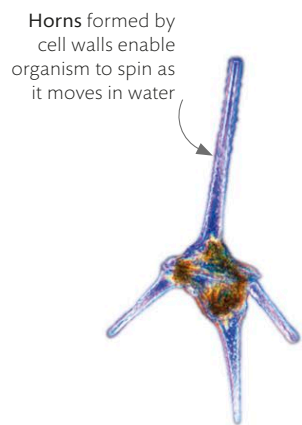
COSCINODISCUS



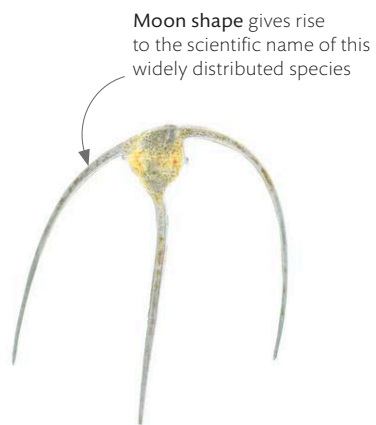
CHAETOCEROS DEBILIS



PLEUROSIGMA ANGULATUM



CERATIUM HIRUNDINELLA



TRIPOS LUNULA

Individual cells are no more than 0.25 mm long



Egg capsules suspended
beneath the raft contain
the developing larvae

Floating nursery

A floating egg mass of the violet snail (a species of *Janthina*)—here viewed from below—is carried by the drifting mother until the eggs hatch into swimming larvae. The larvae spend their early lives with other planktonic animals. As it matures, each larva then produces a thread of mucus that is tipped with air bubbles. This buoys the youngster upward and brings it to the surface, where it lives out the rest of its days as a bubble-rafting adult.





Each bubble takes about 10 seconds to make, as the snail envelopes a pocket of air with its muscular foot

The floating raft is composed of dozens of air-filled bubbles, each held in place by a thin coating of dried mucus

Buoyant snail

A violet snail clings tightly to its bubble raft with its muscular foot, while the rest of the body hangs beneath. The snail's shell is especially thin and lightweight, which helps keep it afloat.



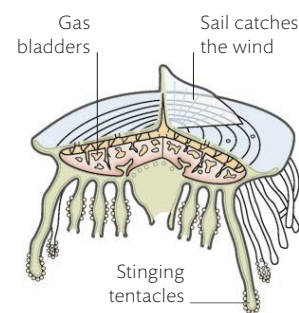
The shell is helical in shape, just like the shells of many more typical snail species

staying afloat

The ocean surface, where Sun-fueled plankton is at its most abundant, can be a profitable place to feed. The community of surface animals, called the pleuston, has some unlikely floating members. Instead of crawling over the seabed, violet snails drift in the open sea and prey on buoyant hydrozoans. They use their foot to mold mucus-coated bubbles of air that dry to form an inflated raft. This structure, though delicate, can support an adult snail, even when carrying a clutch of eggs.

PREDATORS AND PREY

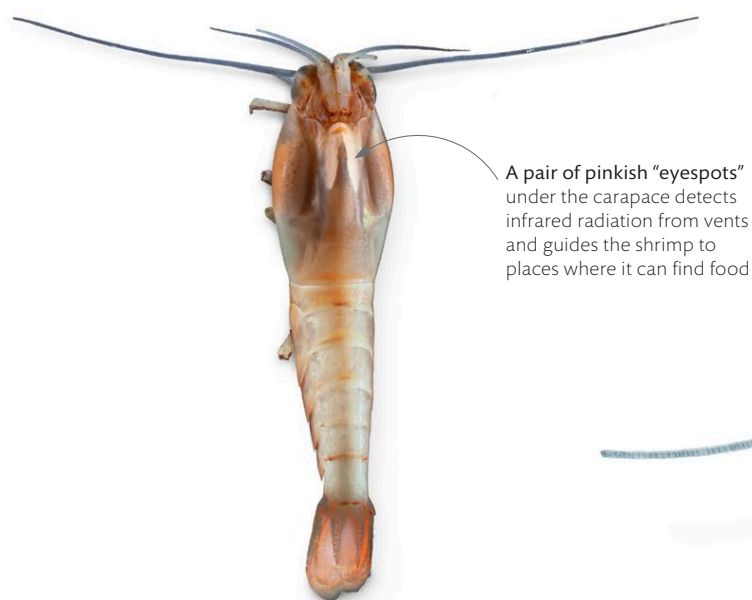
Many colonial hydrozoans, which are relatives of jellyfish and anemones, drift among the pleuston supported by gas-filled bladders. Among them are the Portuguese man o' war (*Physalia physalis*) and the by-the-wind sailor (*Velella velella*), which use stinging tentacles to ensnare planktonic prey. Other members of the pleuston—including violet snails—are predators of both.



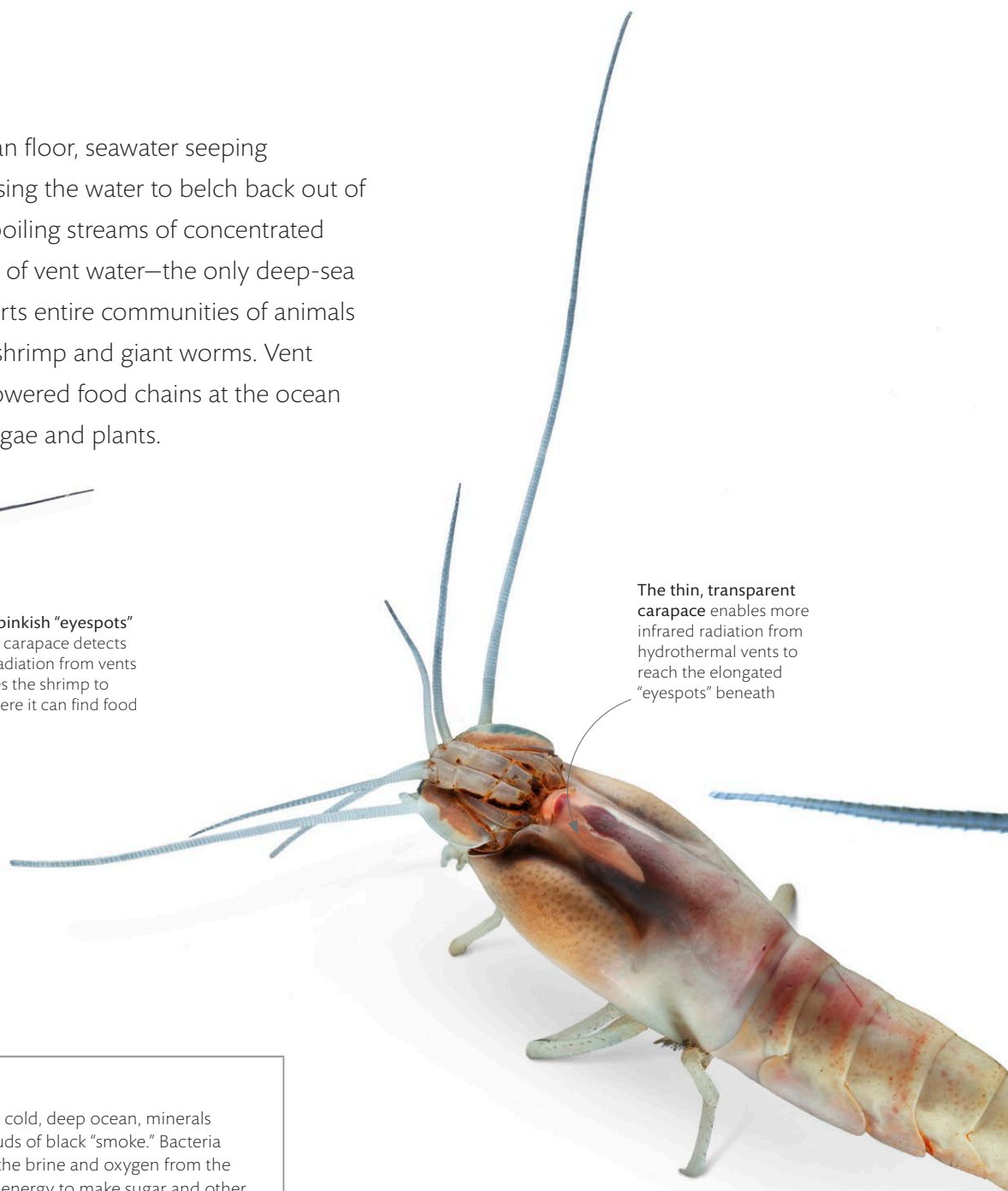
CROSS-SECTION OF BY-THE-WIND SAILOR

sustaining life in the dark

Beneath volcanic parts of the dark ocean floor, seawater seeping downward meets hot molten rock, causing the water to belch back out of fissures, called hydrothermal vents, as boiling streams of concentrated brine. Bacteria use chemicals in the jets of vent water—the only deep-sea organisms to do so. This process supports entire communities of animals around the vents, including swarms of shrimp and giant worms. Vent animals are independent of the light-powered food chains at the ocean surface and on land, which start with algae and plants.



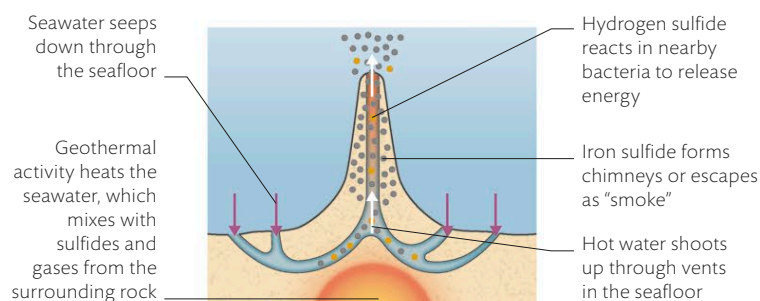
A pair of pinkish "eyespot" under the carapace detects infrared radiation from vents and guides the shrimp to places where it can find food



The thin, transparent carapace enables more infrared radiation from hydrothermal vents to reach the elongated "eyespot" beneath

HYDROTHERMAL VENTS

As hot, chemically rich brine from vents meets the cold, deep ocean, minerals such as iron sulfide solidify into chimneys and clouds of black "smoke." Bacteria on the chimney walls process hydrogen sulfide in the brine and oxygen from the surrounding water to release energy. They use the energy to make sugar and other nutrients from carbon dioxide and water in a process called chemoautosynthesis.



HOW A HYDROTHERMAL VENT SUPPORTS A FOOD CHAIN

Ocean-floor shrimp

The mid-Atlantic ridge shrimp (*Rimicaris exoculata*) grazes on food-making bacteria and organic detritus in the warm water around hydrothermal vents, often more than 1.8 miles (3 km) deep. In places, this species gathers in hordes of up to 26,900 individuals per square ft (2,500 per square m).

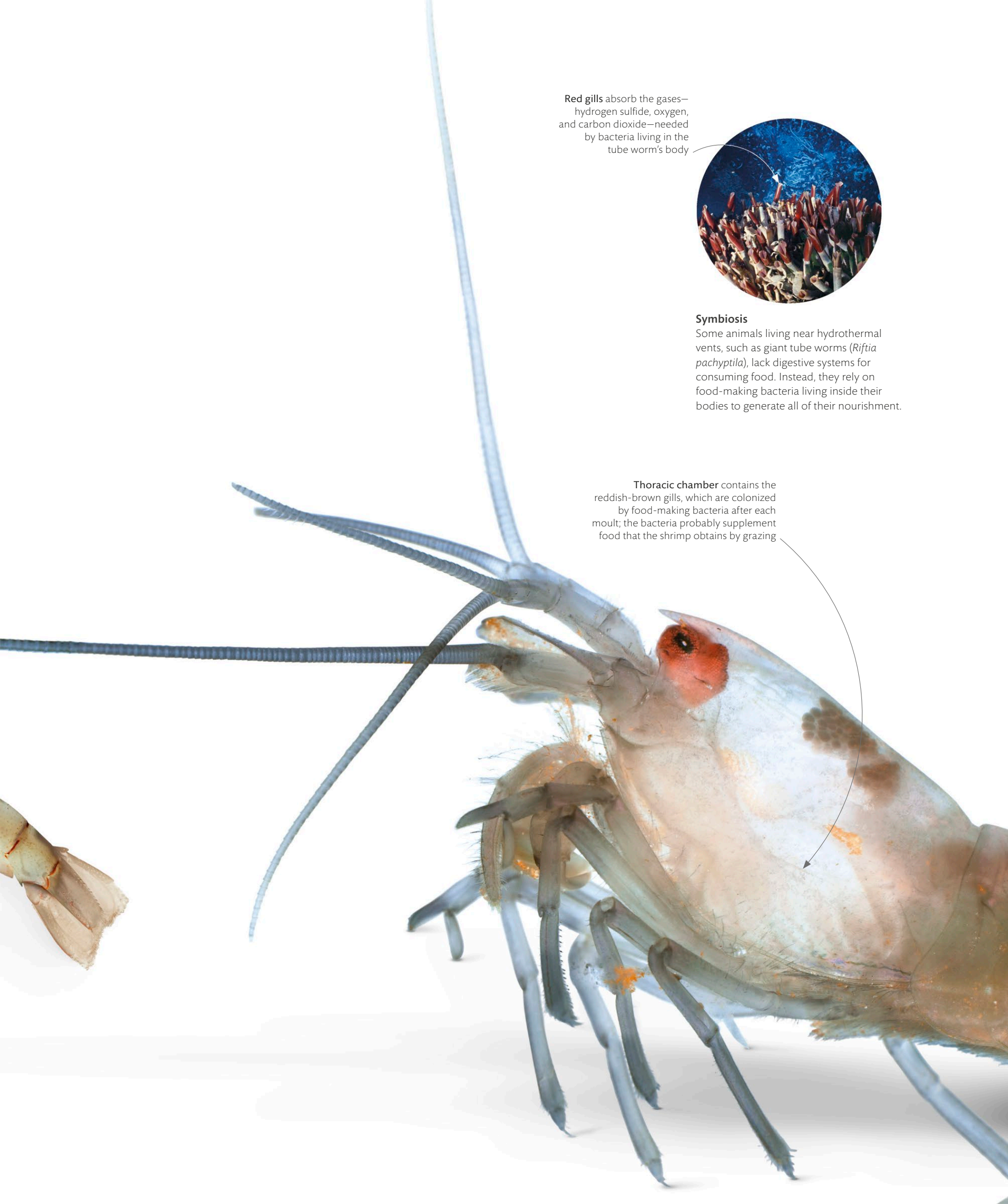
Red gills absorb the gases—hydrogen sulfide, oxygen, and carbon dioxide—needed by bacteria living in the tube worm's body



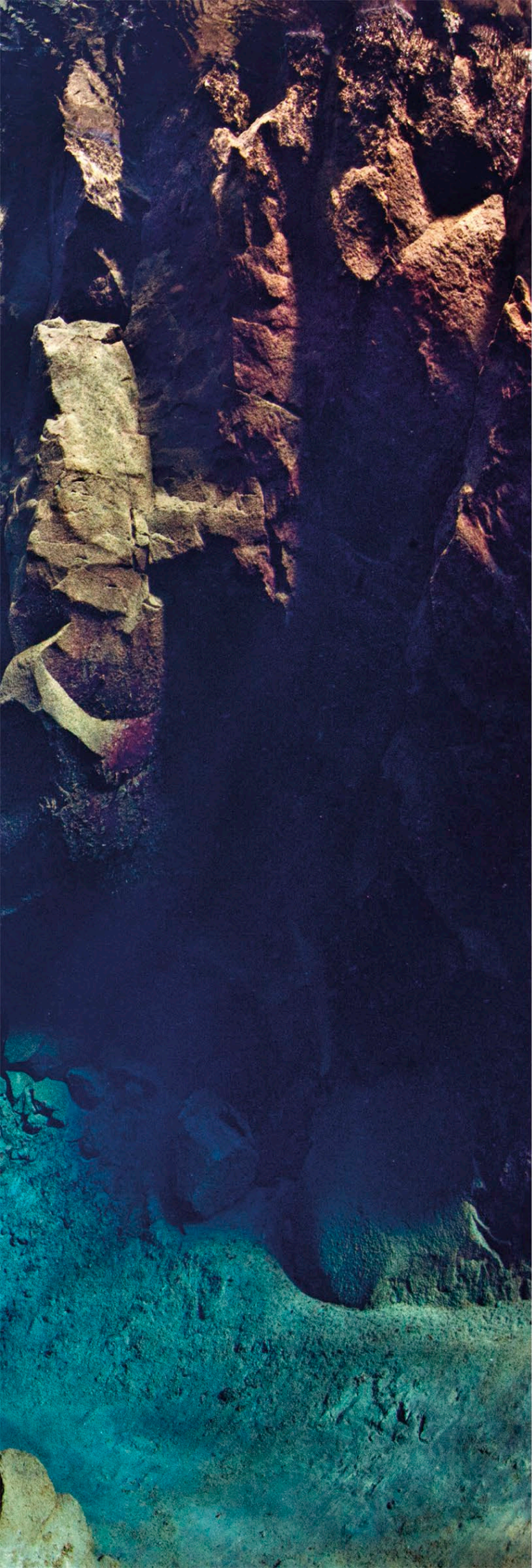
Symbiosis

Some animals living near hydrothermal vents, such as giant tube worms (*Riftia pachytila*), lack digestive systems for consuming food. Instead, they rely on food-making bacteria living inside their bodies to generate all of their nourishment.

Thoracic chamber contains the reddish-brown gills, which are colonized by food-making bacteria after each moult; the bacteria probably supplement food that the shrimp obtains by grazing







At the junction

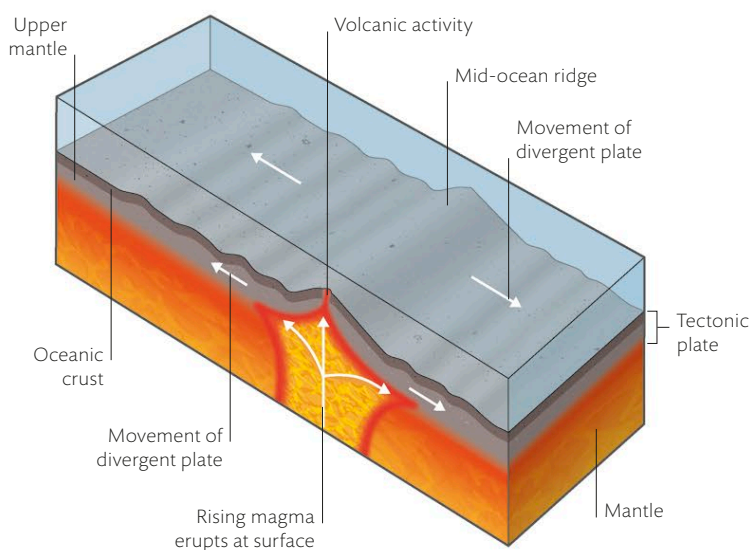
A diver descends into the rift between the American and Eurasian tectonic plates. Iceland's Silfra Canyon, which is filled with fresh water, is one of the few parts of the mid-ocean ridge that has been explored.

new ocean floor

The global mid-ocean ridge system is by far the longest mountain range on Earth, extending for over 50,000 miles (80,000 km) under every ocean worldwide. The ridge is broad and rugged, rising up to 2 miles (3 km) above the abyssal plain (the seafloor between the continental margins and mid-ocean ridge). It consists of a continuous string of active volcanoes and follows the line of divergent plate boundaries, where tectonic plates move apart. Earthquakes occur frequently along its length. New ocean floor is formed along the ridge from the upwelling of volcanic material. The vast area of the mid-ocean ridge remains almost completely unexplored. Rarely, the crest of the ridge rises above the sea—for example, in Iceland, where volcanic activity is especially intense.

THE MID-OCEAN RIDGE

New oceanic crust is formed along the mid-ocean ridge where molten lava (magma) extrudes onto the seafloor, over 1.2 miles (2 km) beneath the ocean surface. Molten magma continually oozes out through fractures in the crust and cools rapidly to form mounds known as pillow lava. Vertical sheets of dark basalt rock (dikes) harden in the fractures and slowly force apart the two sides of newly formed ocean floor.





Each armored plate that makes up the body's exoskeleton can resist the high pressure at great ocean depths

Head capsule is part of the exoskeleton that acts like a helmet and protects the brain

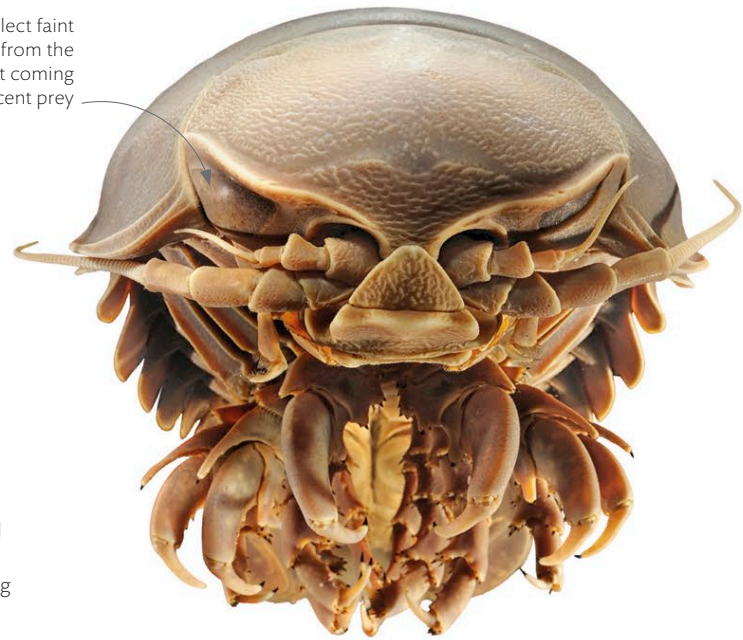
Antennae, each growing up to 8 in (20 cm) long, contain tactile and chemical sensors that help the isopod navigate in the dim light on the ocean bottom

Armored giant

The most familiar of the isopods are their small terrestrial representatives: woodlice. But some supergiant species—such as the western Atlantic giant isopod (*Bathynomus giganteus*), from below 2,600 ft (800 m)—can grow to 20 in (50 cm) long. Like a seabed armadillo, it has tough segmented armor that protects it from larger predators.

A robust, curved claw is carried on each of the 14 walking legs to help grip the ocean floor, as well as large food items, including carrion

Compound eyes collect faint sunlight reaching down from the surface, as well as light coming from bioluminescent prey



Seafloor opportunist

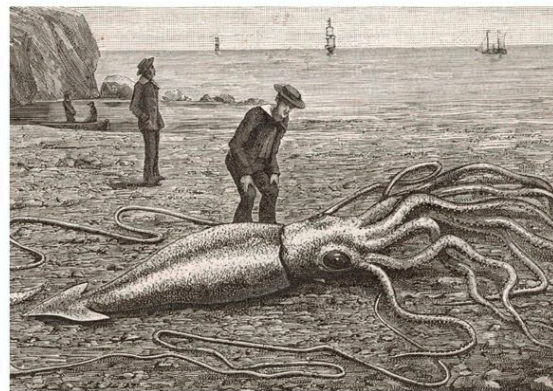
Food is scarce at the bottom of the ocean, so the scavenging giant isopod may occasionally turn predatory by using its jointed legs to grab a creeping sea cucumber or slow-moving fish.

deepwater giants

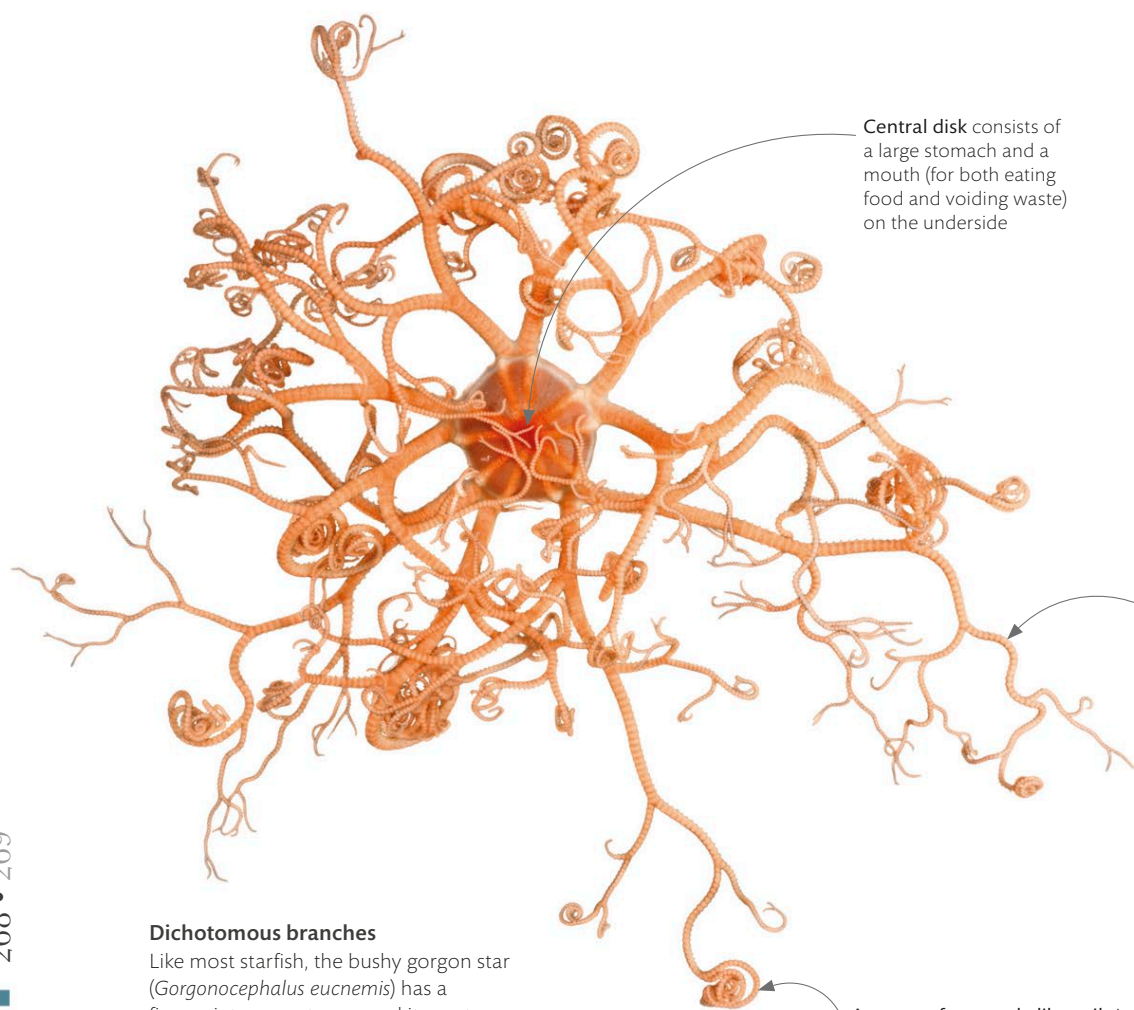
The largest animals on the planet live in the ocean. The champion of them all, the blue whale, weighs as much as 40 African elephants—the biggest living animals on land. Bodies can grow more when supported by water's buoyancy (see p.212), and although growth is slow in the cold of the greatest ocean depths, some deepwater animals live long enough to become giants of their kind. Here, there are cousins of woodlice that grow as large as miniature dogs and squid that can achieve the length of a bus.

OVERSIZE SQUID

Reaching up to 33 ft (10 m) in length, the colossal squid (*Mesonychoteuthis hamiltoni*) is the world's largest invertebrate. Giant squid (*Architeuthis*) have longer tentacles but smaller bulk. Despite their size, all these predatory behemoths—typically found at depths of more than 1,600 ft (500 m)—are rarely seen alive. Much of what is known about them comes from specimens washed ashore.



STRANDED GIANT SQUID, NEWFOUNDLAND, 1883



Dichotomous branches

Like most starfish, the bushy gorgon star (*Gorgonocephalus eucnemis*) has a five-point symmetry around its center. However, unlike starfish, each arm branches dichotomously, repeatedly splitting in two toward the tip.

Central disk consists of a large stomach and a mouth (for both eating food and voiding waste) on the underside

Web of tendrils

A view from beneath the basketlike body of an Arctic gorgon star (*Gorgonocephalus arcticus*)—here depicted in *Résultats des campagnes scientifiques du prince de Monaco* (1909)—illustrates its wide catchment area for trapping plankton. Tiny animals, such as crustaceans, are ensnared by the curling arms and passed to the mouth at the center.

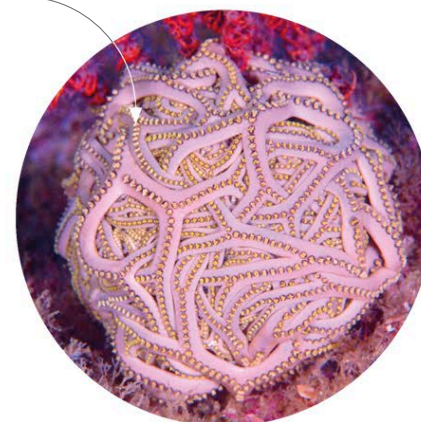
Extended arms are typically held into the water's current to catch as much plankton as possible

Arms can form snakelike coils in any direction; the arms of related brittle stars can coil only in a plane parallel to the central disk

branching arms

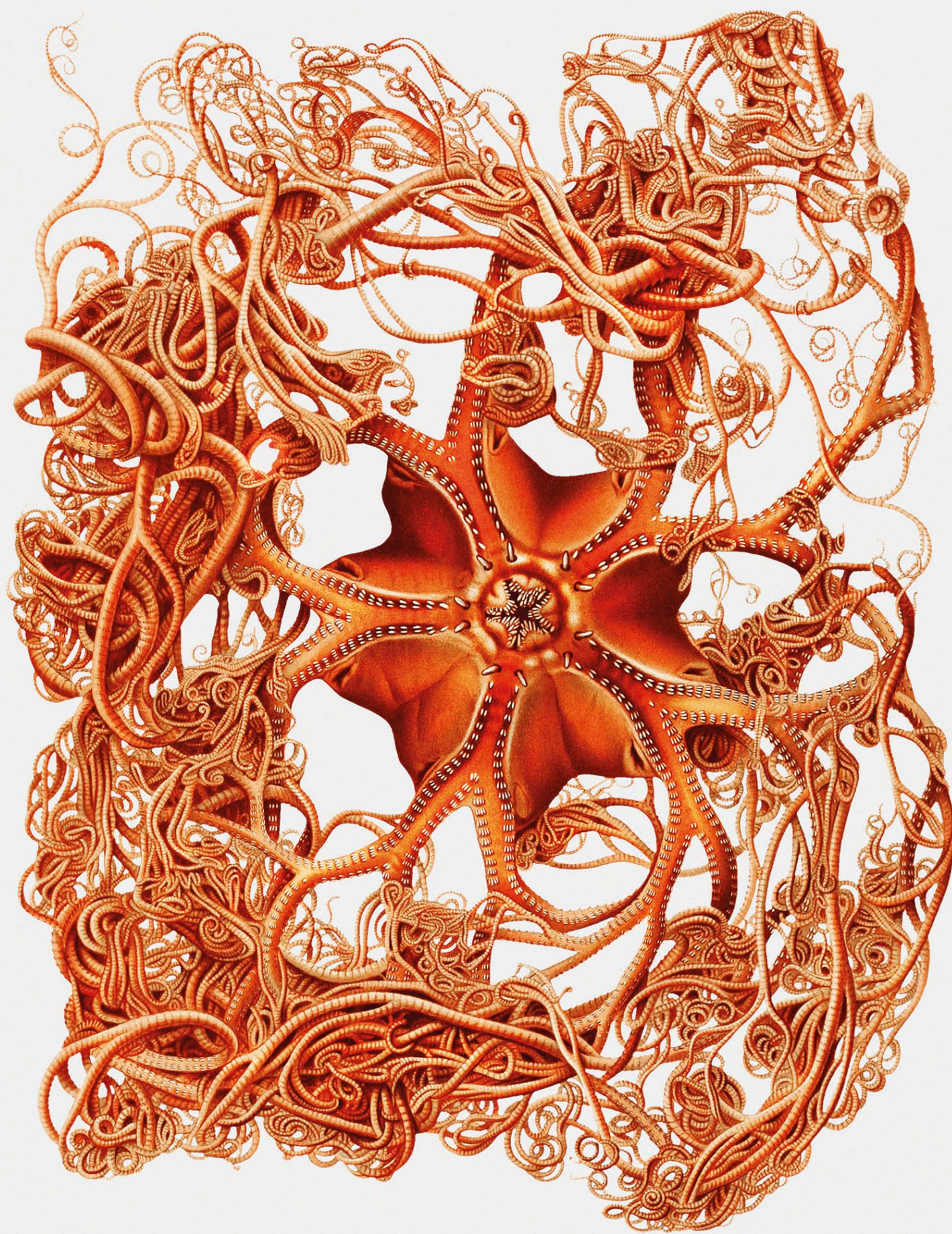
The radial arrangement of arms found in starfish and their relatives allows these animals to creep over the seabed, with movement largely restricted to the horizontal plane. But gorgon stars, cousins of brittle stars (see pp.218–219), can also reach upward into the water column. Their arms branch into a writhing mass of tendrils that is reminiscent of the eponymous Greek monster. The intertwined tendrils are an effective trap for catching small planktonic animals suspended in the water—a source of food beyond the reach of starfish and brittle stars.

Arms coiled tightly around the central disk during daylight are less vulnerable to predators



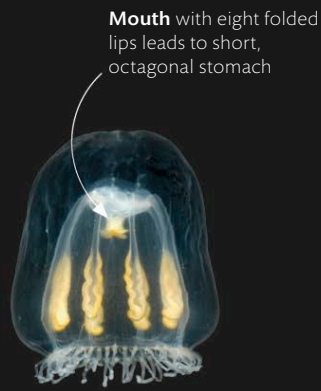
Resting by day

Gorgon stars, such as this spiny gorgon star (*Astrocanium spinosum*), keep their arms retracted during the day. They extend their arms at dusk and feed throughout the night.

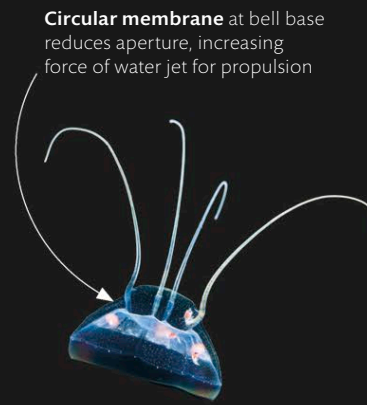


Hydrozoa

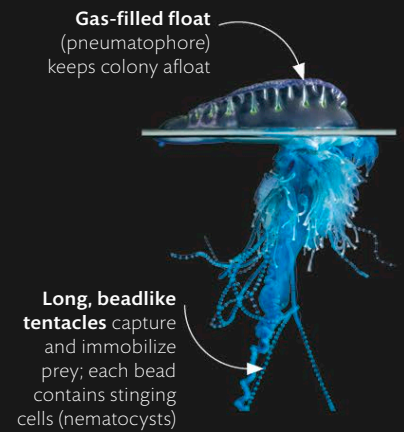
This is a very large group of animals that are seen as distinct from true jellyfish. As well as solitary organisms with a bell-shaped medusa form, the group includes some colonial forms known as siphonophores, which consist of polyps and sometimes attached medusae (missing from the Portuguese man o' war). Other hydrozoans may have medusa or polyp forms absent from their life cycle; the eight-strand jelly has a polyp stage, but the golf tee jelly does not.



EIGHT-STRAND JELLY
Melicertum octocostatum



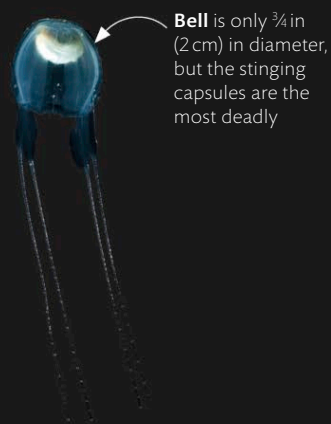
GOLF TEE JELLY
Aeginopsis laurentii



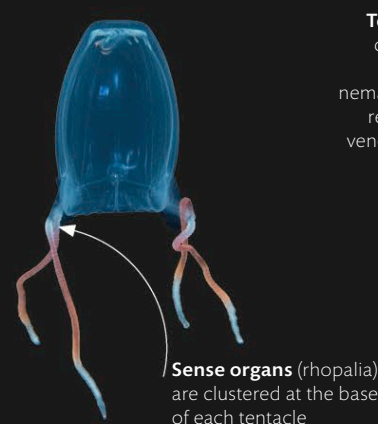
PORTUGUESE MAN O' WAR
Physalia physalis

Cubozoa

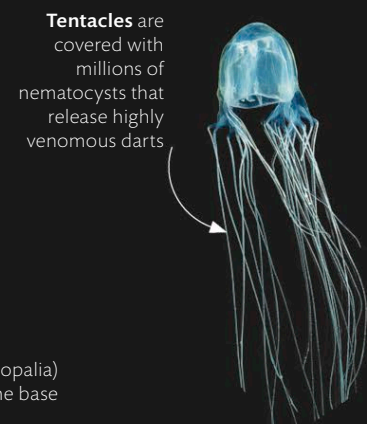
Also known as box jellies or sea wasps, cubozoa are named for their box-shaped medusa and are the most venomous cnidarians. They have muscular pads, or pedalia, at each corner of the bell canopy, with one or more tentacles attached to each one. The attached polyp stage of the life cycle metamorphoses into a medusa rather than budding to release multiple medusae as in true jellyfish.



IRUKANDJI JELLY
Carukia barnesi



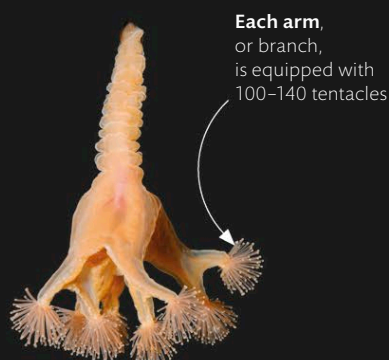
WINGED BOX JELLY
Alatina alata



COMMON BOX JELLY
Chironex fleckeri

Staurozoa

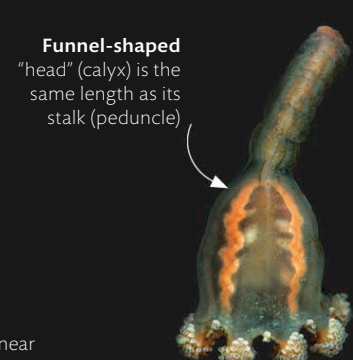
This group, known as stalked jellyfish, includes animals whose life cycle is more similar to that of a coral or anemone than other jellyfish. They have a stalked, trumpet-shaped body and do not alternate between polyp and free-swimming medusa. They attach themselves to a substrate such as coral, from which they hang for the rest of their lives.



HORNED STALKED JELLYFISH
Lucernaria quadricornis



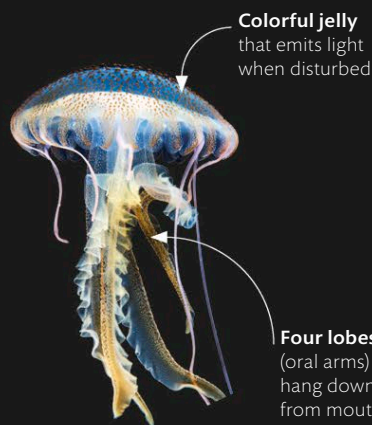
KALEIDOSCOPE STALKED JELLYFISH
Halicystus auricula



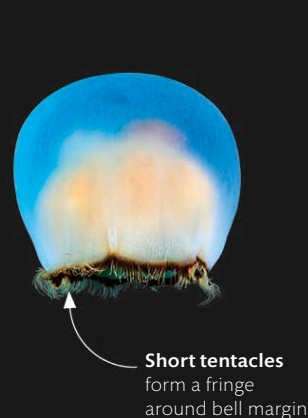
THICK-RIMMED STALKED JELLYFISH
Halicystus salpinx

Scyphozoa

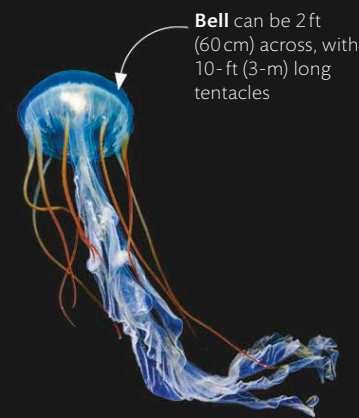
Also known as true jellyfish, this is a group of about 200 free-swimming marine species. Polyps of these animals may be less obvious but are often long-lived. They are most conspicuous in their medusa stage—that is, with an umbrella-shaped body—but this may not form the longest part of their life cycle. They move by contracting and relaxing the muscles of their umbrella.



MAUVE STINGER OR NIGHT LIGHT JELLY
Pelagia noctiluca



BROWNBANDED MOON JELLY
Aurelia limbata



NORTHERN SEA NETTLE JELLY
Chrysaora melanaster

Giant of the oceans

The largest true jellyfish species in the world, the lion's mane jelly (*Cyanea capillata*) is a continual swimmer that can cover vast distances in strong marine currents. Most are found in the Arctic, north Atlantic, and north Pacific Oceans, where they live on a diet of zooplankton, fish, Moon jellyfish, and shrimp.

Saucer-shaped bell is thick in the center and thins out toward the edge

Mane of hairlike stinging tentacles each up to 120 ft (36 m) long entangle the prey

jellyfish and hydrozoans

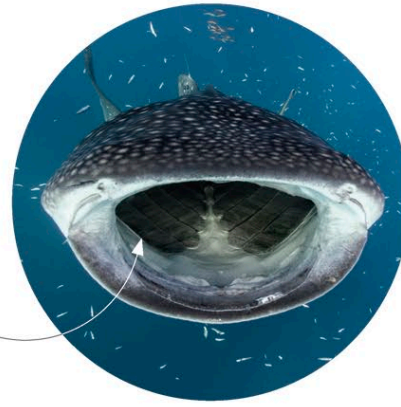
These mostly free-swimming, jellylike predatory animals belong to the group of invertebrates known as cnidarians. Most jellyfish and hydrozoans alternate between polyp and medusa (bell- or umbrella-shaped) forms. Like other cnidarians, these animals have radial symmetry and lack a heart and a brain, but they use an internal cavity to digest prey, which they catch using tentacles armed with stinging cells.





Ram filter feeding

A large whale shark swimming at 3 ft (1 m) per second can filter around 264,000 gallons (1 million liters) of seawater per hour.



Mouth contains vestigial teeth and spongy filter pads with a mesh size of about 1 mm

filter-feeding sharks

Filter feeding is an efficient feeding system that enables some of the largest animals in the ocean, including baleen whales and some sharks (basking, megamouth, and whale sharks), to feed on some of the smallest. All three shark species feed mainly by passive ram filtration, which involves swimming slowly, with an open mouth, through swarms of plankton and small squid and fish. The food is then filtered out of the water. The whale shark (*Rhincodon typus*), which is by far the largest living fish at 29–49 ft (9–15 m) long, can also generate suction to feed selectively on larger items.

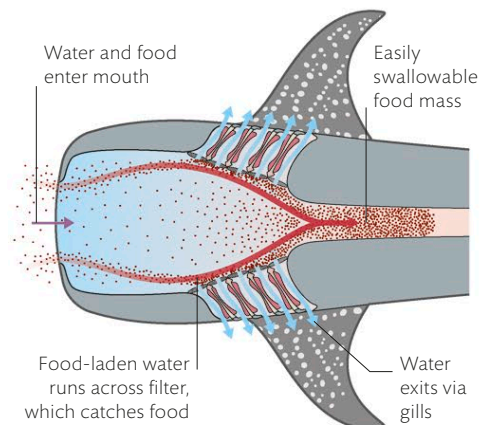
Migrating to feed

Whale sharks travel huge distances between their breeding areas and feeding waters. Here, the shark is accompanied by a remora. These fish attach to sharks by suction using their dorsal fin and feed off the sharks' feces and ectoparasites.

CROSS-FLOW FILTRATION

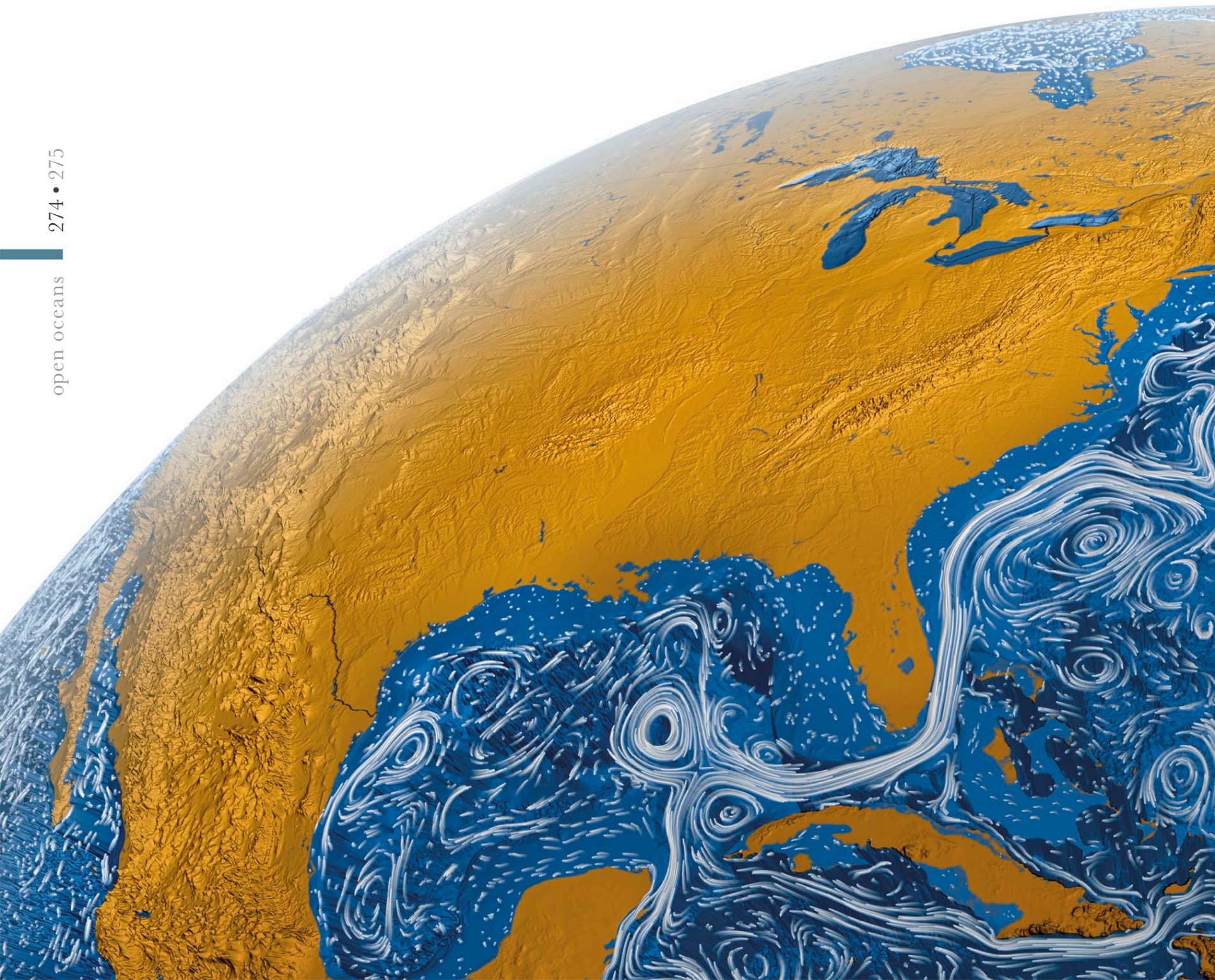
The filter-feeding system of the whale shark is known as cross-flow filtration. The feeding current flowing from the mouth passes parallel to the filter pads, where water is drawn out sideways over the gills. Food particles become concentrated into a swallowable mass at the back of the throat. This system is less prone to clogging than one in which the flow hits the filter head on, although sharks do sometimes "cough" to backwash material from their filters.

WHALE SHARK'S FILTER-FEEDING SYSTEM



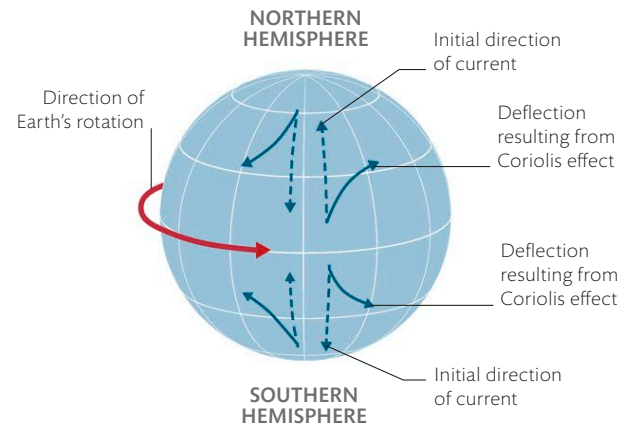
ocean currents

Wind is the principal force that drives currents in the ocean surface. It works in conjunction with pressure gradients caused by gigantic mounds of seawater built up in a series of wind-driven loops, known as gyres, and by the effect of Earth's rotation—the Coriolis effect. These currents are hugely powerful. For example, the flow of the North Atlantic Gulf Stream alone is equivalent to the total discharge of the world's top 20 rivers added together. Equally important is a vast network of slow-moving deep currents involving 90 percent of ocean water. These currents circulate energy, nutrients, salt, and sediments around the world. Surface and deep-sea currents act together to moderate Earth's climate.



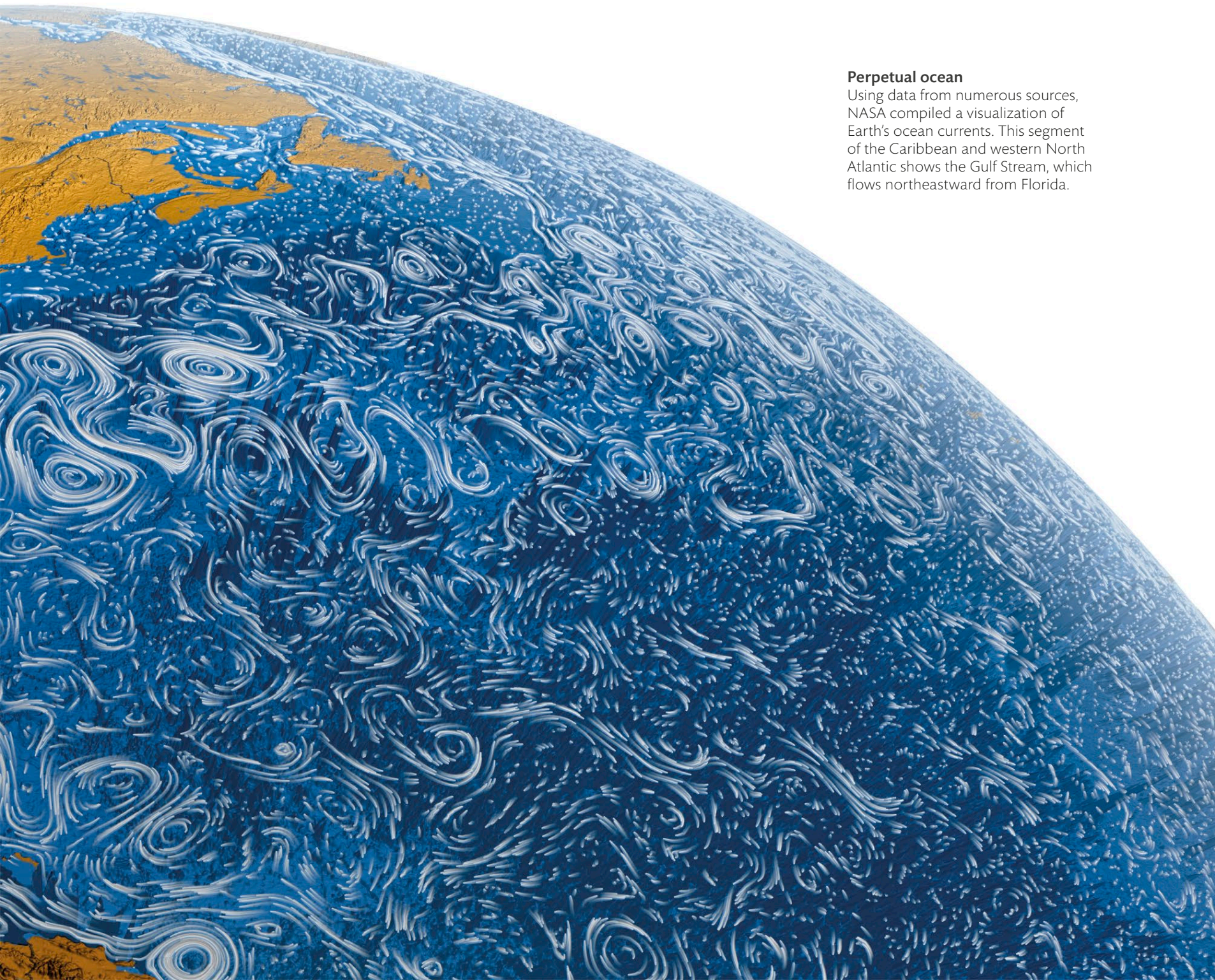
THE CORIOLIS EFFECT

Like all moving objects that are not rigidly attached to Earth's surface, ocean currents are affected by Earth's rotation. This is known as the Coriolis effect (after the French scientist Gaspard-Gustave de Coriolis, who first described it). This effect causes ocean currents in the Northern Hemisphere to deviate to the right and those in the Southern Hemisphere to deviate to the left. Because the speed of rotation is faster at the equator than at higher latitudes, the effect is greatest at lower latitudes.



Perpetual ocean

Using data from numerous sources, NASA compiled a visualization of Earth's ocean currents. This segment of the Caribbean and western North Atlantic shows the Gulf Stream, which flows northeastward from Florida.



great white shark

An oceanic apex predator, the great white shark (*Carcharodon carcharias*), also known as the white shark, can be more than 20 ft (6 m) long and weighs several tons. Great white sharks were once feared by humans, yet attacks are rare and humans pose the greatest threat to this officially vulnerable species.

Although increasingly rare, great white sharks have one of the widest geographic ranges of any marine animal and can be found in all cold, temperate, and tropical waters. This slow-growing shark takes up to 16 years to reach maturity, and females only give birth every 2 to 3 years. Humans hunting for sharks' jaws, fins, and teeth and attempts to reduce numbers near beaches have exacted a heavy toll on their population. However, the great white shark possesses remarkable characteristics that make it a formidable hunter, increasing its chances of survival.

It is partially endothermic, or warm-blooded, so it is able to maintain its brain, swimming muscles, and stomach at a temperature higher than its ocean habitat. This not only keeps the animal highly active but also helps power astonishing bursts of speed of up to 37 mph (60 kph) when hunting. The great white shark also

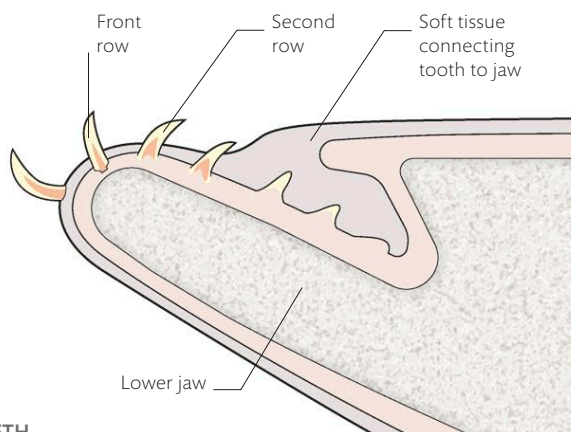
has a streamlined body and excellent color vision, as well as the largest scent-processing organs of any shark. Highly sensitive electroreceptors on its head can detect even the slightest of prey-generated electrical fields. In spite of this, the great white shark often relies on ambush tactics when hunting. It typically swims slowly beneath potential prey, which are outlined against the ocean's surface. However, the prey cannot see their predator because the shark's dark upper body blends in with the murky depths. When attacking from below, a shark makes a near-vertical strike, often leaping 26 ft (8 m) clear of the water.

Tools of the trade

This shark has narrow bottom teeth to hold its kill and large upper ones to tear flesh. It favors high-calorie prey such as seals or dolphins, but it eats squid, turtles, fish, and other sharks, too.

REPLACEMENT TEETH

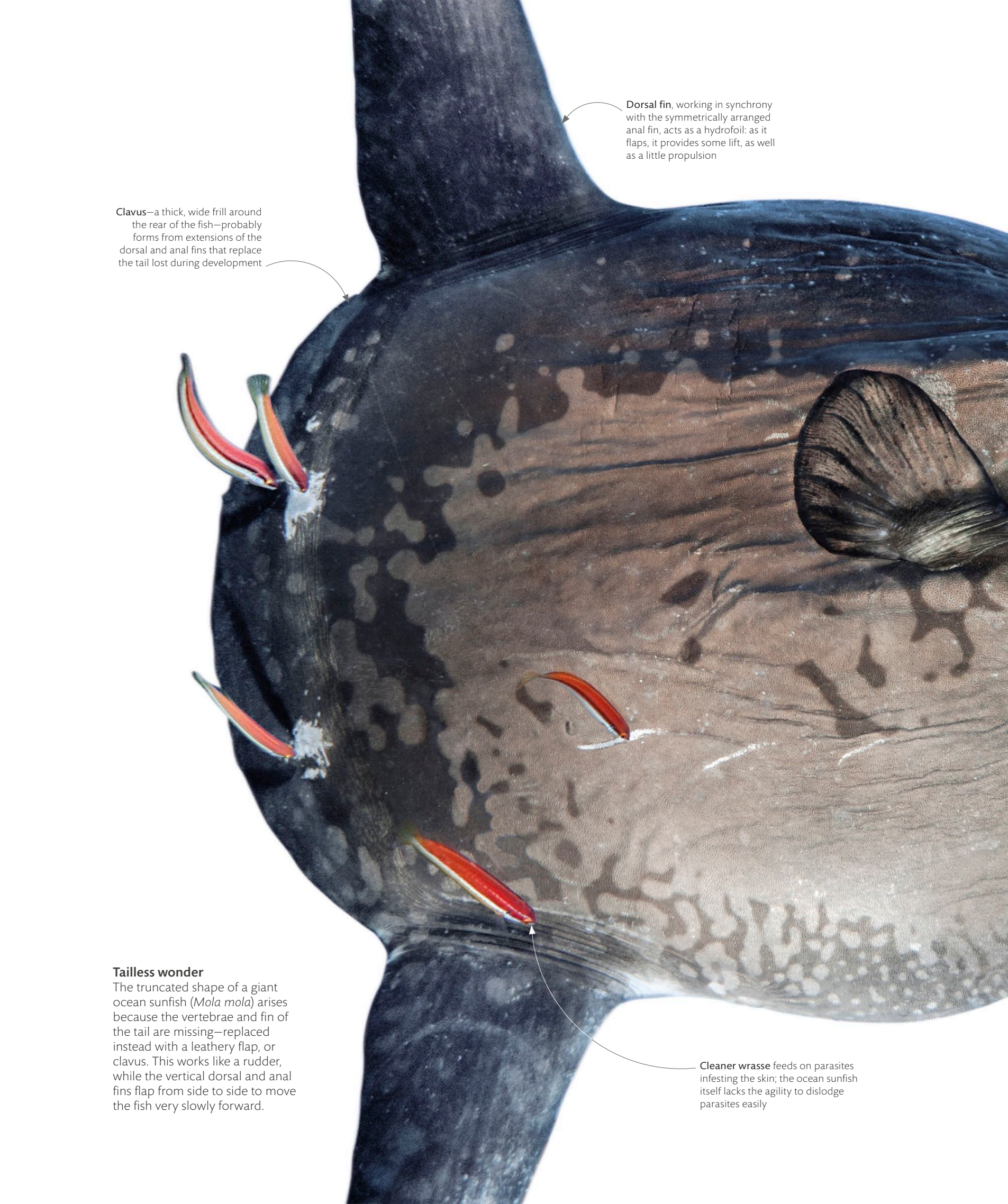
Adult great white sharks may have up to 300 retractable teeth, arranged in up to seven rows, at any one time. Attached to the jaws only by soft tissues, not sockets, the teeth are frequently lost due to pressure exerted when the shark bites its prey. When this happens, a tooth from the row behind moves forward to replace it. A great white shark can go through 20,000 or more teeth in its lifetime.



LOWER JAW WITH ROWS OF TEETH







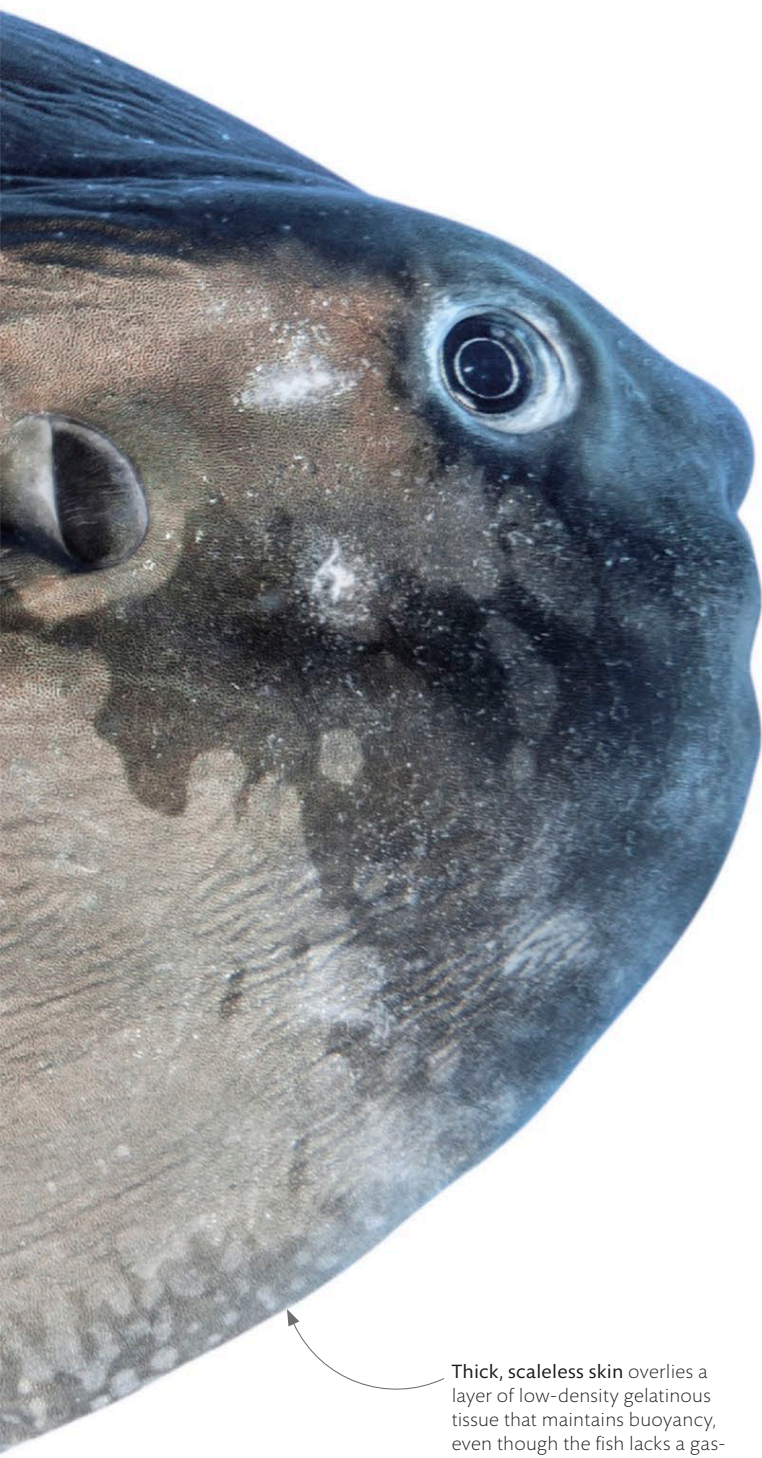
Clavus—a thick, wide frill around the rear of the fish—probably forms from extensions of the dorsal and anal fins that replace the tail lost during development

Dorsal fin, working in synchrony with the symmetrically arranged anal fin, acts as a hydrofoil: as it flaps, it provides some lift, as well as a little propulsion

Tailless wonder

The truncated shape of a giant ocean sunfish (*Mola mola*) arises because the vertebrae and fin of the tail are missing—replaced instead with a leathery flap, or clavus. This works like a rudder, while the vertical dorsal and anal fins flap from side to side to move the fish very slowly forward.

Cleaner wrasse feeds on parasites infesting the skin; the ocean sunfish itself lacks the agility to dislodge parasites easily



Thick, scaleless skin overlies a layer of low-density gelatinous tissue that maintains buoyancy, even though the fish lacks a gas-filled swim bladder

Spiny beginnings

The protective spiny skin of ocean sunfish fry is reminiscent of pufferfish, their close relatives. Ocean sunfish fry hatch from eggs with a working tail, which shrinks as they develop.



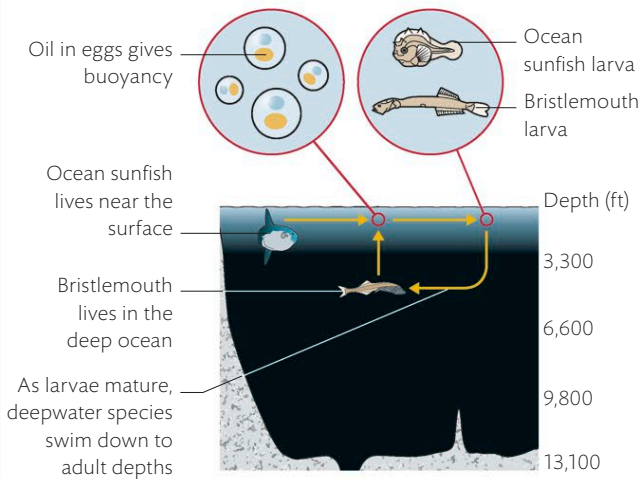
Wide pectoral fins, which stabilize the body, are retained into adulthood

slow giant

Plankton are organisms that drift in water because they lack the strength to swim against currents. Most are tiny, but some much larger animals have such weak powers of propulsion that they may sometimes move like plankton. They include the heaviest bony fish: ocean sunfish. Weighing as much as a rhinoceros, they lack any trace of the sweeping tail most other fish use to generate thrust.

FLOATING EGGS

Pelagic (open-ocean) fish are adapted to live at different depths, but most produce buoyant eggs that rise to the surface. Here, they hatch into fry that spend their infancy feeding on the microscopic, Sun-fueled plankton. Producing many eggs increases the chance that some will survive. A single ocean sunfish may release 300 million eggs—a record among vertebrates.



EGG, LARVAL, AND ADULT DEPTHS OF PELAGIC FISH



Carta Marina (1539)

The largest and most accurate map of Scandinavia of its time was produced by exiled Catholic priest Olaus Magnus, whose mission was to share the history, culture, and natural wonders of the north with the rest of Europe. It was printed from nine carved wooden blocks and shows Nordic lands and seas teeming with life, including the monsters described to Magnus by fishermen and sailors.



New Map of the Whole World (1648)

One of the great works of the Dutch Golden Age of cartography, Joan Blaeu's breakthrough map *Nova totius terrarum orbis tabula* is part of a huge atlas showing the discovered world fairly accurately, with northwest America and Australasia indicated in incomplete outlines.



the ocean in art

mapping the seas

Since modern humans first carved designs into rocks up to 40,000 years ago, people have used their cognitive spatial skills to map themselves in relation to their environment. By the 15th century's Age of Exploration, an increasing number of maps from around the world emerged as Europeans recorded territories they traveled to in pursuit of trade and colonization.

Primitive maps carved in stone or wood or created in 3D reliefs from sand and clay were superseded over time by woodblock printing, then copperplate printing in the 16th century and lithography in the 19th century. Medieval map-makers based the proportions of countries on their relative wealth and power. However, this changed in the 14th century, when the works of the Greek geographer and astronomer Ptolemy (c.100–c.170 CE) were rediscovered and translated into Latin. His calculations of the size and proportions of Earth changed western cartography forever, although they later proved to be incorrect.

In 1539, Swedish priest Olaus Magnus produced a map of Scandinavia (see left)—an attempt to correct Ptolemy's

vague rendering of northern Europe produced in distant Mediterranean climes. The geography is immediately recognizable, and even the whorls in the ocean may represent known currents and fronts, but what enchants is the detail. The everyday lives of the Scandinavians—driving sleighs, milking reindeer, and spearing seals—are played out in a natural world teeming with real and fantasy beasts. None more so than in the seas, where a dragon wrestles with a giant crayfish, ships anchor mistakenly on tusked whales, and a red sea serpent is described in the map's key as “a worm 200 feet long wrapping itself around a big ship and destroying it.”

A century later, Dutch cartographer Joan Blaeu's remarkable map of the world (see above) showcases the great copperplate engraving skills of the Dutch Golden Age. It also reflects the nation's prowess in seafaring and the artist's considerable scientific knowledge. The work features the five known planets in personified form with the Sun at their center, endorsing Copernicus's controversial heliocentric theory that Earth orbits the Sun.

“Inside this broad expanse of fluid Ocean ... a conglomeration of monsters may be found.”

OLAUS MAGNUS, A DESCRIPTION OF THE NORTHERN PEOPLES (VOLUME III), 1555



Blue photophores
emit light downward

Light signals

The lanternfish *Lepidophanes guentheri*, a deep-sea Atlantic species, has paired light-producing cells (photophores) along its sides and on its head. These lights are used in communication and courtship.

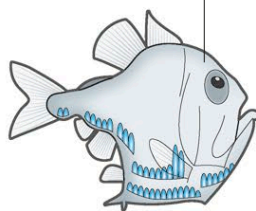
lights in the dark

Bioluminescence, a process in which living organisms produce their own light (see pp.192–193), is particularly common in the unlit waters of the deep oceans. Deepwater fish may use bioluminescence for several purposes. For predatory fish, such as some anglerfish, attracting prey with a luminous lure on a chin barbel or suspended on a structure like a fishing rod can be an energy-efficient way to hunt. Other species use light to disguise their outline (see below), confuse predators, or attract a mate.

LIGHT AS CAMOUFLAGE

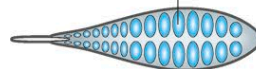
Some fish, such as the hatchetfish (shown here), have light-emitting photophores on their underside. These help disguise the fish's silhouette when viewed from below—a camouflage method known as counter-illumination. The fish can control the intensity of the light that it produces to match that of sunlight filtering down from above, making the fish less visible to predators.

Body covered
in silvery,
reflective scales



SIDE VIEW

Blue-emitting
photophores
on the underside



VIEW FROM BELOW



Retina is sensitive to red light, which most other deep-sea fish cannot detect

Photophore behind eye glows blue

Photophores in front of and below the eye produce blue light, but a fluorescent protein makes it appear red (see p.193)

Highly flexible jaw opens 100° when fully extended to engulf prey up to half the fish's own size

Seeing red

Most deep-sea bioluminescence produces blue light, which penetrates farther in water than other colors. One group of dragonfish, called loosejaws—which includes the small-tooth dragonfish (*Pachystomius microdon*) shown here—also has red photophores. Since red light is not visible to most other deep-sea animals, it may help the loosejaws see prey or predators without being seen themselves.

Slender barbel bears blue photophores and is sensitive to touch

Huge, sail-like dorsal fin, which extends almost the length of the body, is raised for hunting

Tail sweeps rapidly from side to side, helping maximize thrust and minimize drag

Trunk is streamlined and muscular, helping sailfish reach top speeds when swimming

Cornering at speed

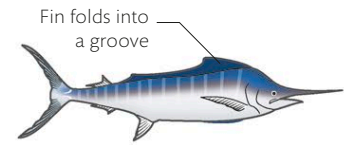
When hunting, the sailfish (*Istiophorus platypterus*) raises its large dorsal fin, which aids maneuverability and provides stability so the fish can improve its aim. It hunts by probing schools of smaller fish with its long, sharp bill, then swiping suddenly sideways, often stunning or maiming several prey at a time.



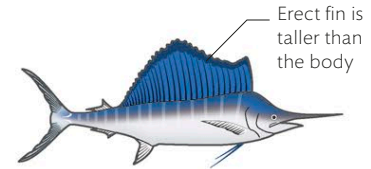


SPECIALIST FINS

The dorsal fin of the sailfish is usually retracted, but when the fish hunts, it raises its fin as much or as little as necessary to stabilize a maneuver, such as herding schools of small fish to make them easier to catch. The crescent-shaped tail generates maximum thrust and reduces drag, allowing great speed over a long distance.



RETRACTED FIN



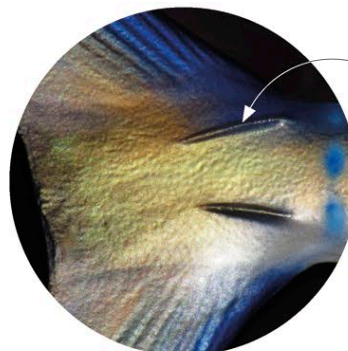
RAISED FIN

Elongated, bony bill is an extension of the snout

Long pectoral fins can help generate lift when extended

built for speed

Billfish, such as sailfish, marlin, and swordfish, benefit from two key weapons: a long, serrated bill and the ability to swim at great speed. Their bodies are highly streamlined and packed with muscle for both rapid acceleration and endurance. The sailfish is one of the fastest fish, with a top speed of about 22 mph (35 kph) in short bursts.



Torpedo-shaped keel directs flow of water over the tail

Tail keels

Small, horny ridges (keels) on the sailfish's tailstock make swimming more streamlined and provide stability. The tail beats side to side up to eight times a second.



spotlight species

wandering albatross

One of the world's largest flying birds, the wandering albatross (*Diomedea exulans*) can be 4 ft 3 in (1.3 m) long and weigh as much as 26 lb (12 kg). This species is found mainly in the circumpolar region of the Southern, or Antarctic, Ocean and has a lifespan of 50 years or more.



Elaborate courtship

The albatross's display includes wing-spreading, head-waving, bill-rapping, and a distinctive braying call.



The wandering albatross has the longest wingspan—up to 11 ft 6 in (3.5 m)—of any bird. It is a consummate glider that flies vast distances in search of squid and other cephalopods. A bird can cover up to 6,200 miles (10,000 km) in 10 to 20 days. It often soars for several hours without flapping its wings by gliding on thermals and allowing winds to push it along. An albatross spends most of its life at sea; during its first 6 years, it may never touch land, although it might rest on the ocean occasionally to digest a heavy meal or

when there is not enough wind to fly. It can drink seawater, as it secretes excess salt via a gland above the nasal passage.

Sexually mature at around the age of 11, albatrosses mate for life, but they breed only once every 2 years. The female lays one egg in a nest of mud and grass, usually on subantarctic islands, and the parents take turns sitting on the nest.

Unfortunately, human fishing equipment kills thousands of these birds each year, placing the survival of all albatross species in jeopardy.

Soaring across the waves

Albatrosses can cover 620 miles (1,000 km) per day, and they have been recorded reaching speeds of 67 mph (108 kph), yet they consume only slightly more energy in flight than when sitting on their nests.

Beneficial feeder

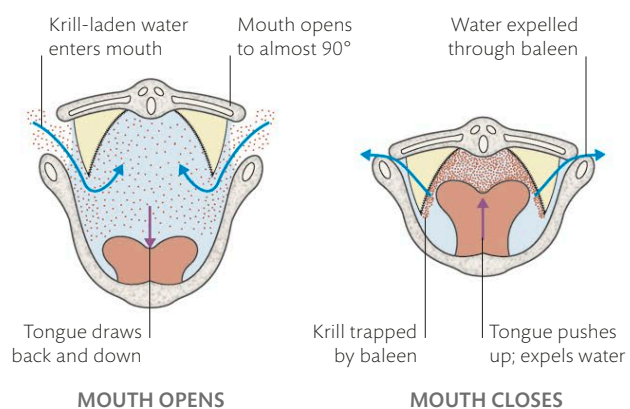
The recovery of great whale populations, including that of the endangered blue whale (here, off the coast of Mexico), may play a key role in averting climate change. Their feces are rich in iron, which is released from krill during digestion. This boosts the growth of phytoplankton, which in turn absorb and store vast quantities of carbon.

bulk feeding

There are two main types of whale: toothed whales and baleen whales, which are filter feeders and have baleen plates instead of teeth. The blue whale (*Balaenoptera musculus*), the largest animal ever to have lived on Earth, belongs to the family of baleen whales known as rorquals, distinguished by the grooves or pleats on their throat, which expand to accommodate vast volumes of food-laden seawater. When swallowing a dense swarm of krill, a blue whale can engulf 53,000 gallons (200,000 liters) of water and almost half a million food calories.

HOW BALEEN WORKS

Baleen whales have hundreds of baleen plates hanging from their upper jaw. These plates are fringed with stiff hairs, which form a "curtain" that prevents food, mainly shrimplike krill, from escaping with seawater as it is squeezed out of the closing mouth.





Ancient activity

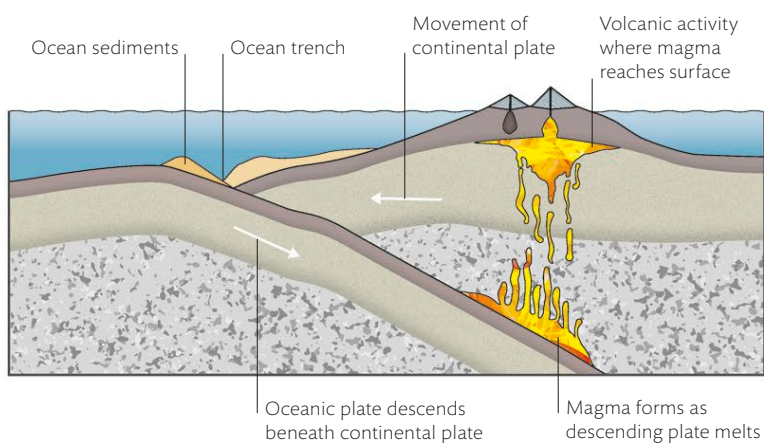
The Tao-Rusyr caldera off Onkoten Island, Kamchatka, was formed by volcanic activity that occurred in the northwestern sector of the Pacific Ring of Fire over 9,000 years ago.

destruction of the oceans

Earth's outer layers are divided into huge, mobile fragments called plates. The zones where plates collide, called subduction zones, are the world's largest recycling plants. Here, old rocks in Earth's outermost layer, or crust, are drawn back down into the interior. Newer seafloor is produced at the same rate elsewhere, at mid-ocean ridges (see pp.264–265). Subduction zones encircle the Pacific Ocean, consuming the ocean floor at rates of up to 6 in (15 cm) per year. These are regions of great heat and pressure, and produce deep-seated earthquakes and volcanic eruptions in a band called the Ring of Fire. When they occur under the ocean, earthquakes and landslides can trigger devastating tsunamis (see pp.76–77).

COLLIDING PLATES

Where two plates collide, such as an oceanic plate and a continental plate, the pressure forces the older one, which has a cooler, denser crust, beneath the younger plate. A deep ocean trench is formed where seafloor sediments are dragged downward. As the plates grind past one another, enormous frictional strain is generated. The energy is released by periodic violent earthquakes, while the intense heat created begins to melt the rocks, and this molten magma pierces upward to form a line of volcanic seamounts known as an island arc.







orca

One of Earth's largest living predators, the orca (*Orcinus orca*) is also one of the fastest marine mammals, reaching speeds of about 34 mph (55 kph). Often called the “killer whale,” at up to 33 ft (10 m) long, it is actually the largest member of the dolphin family—and one of the most intelligent.

Found in every ocean, orcas have the widest distribution of any sea mammal on the planet. Striking black-and-white markings make orcas easy to spot, particularly as adult males bear the largest dorsal fin of any cetacean, with some reaching up to 6 ft (1.8 m) high.

The orcas' success is due in part to their range of sophisticated hunting techniques, which are taught to juveniles by adults. These include coordinated attacks on large whales, herding fish before stunning them with powerful tail strikes, and “wave washing” seals off ice

floes. Orcas are the only cetaceans that regularly eat other marine mammals—including other dolphins.

Sea lions, octopuses, sea otters, rays, sea turtles, squid, and penguins are part of the orca's diet, but what individuals eat depends largely on what population type they belong to. “Resident” orcas, which form the largest pods (or groups), mostly hunt fish, squid, and octopuses; “transient” orcas feed almost exclusively on marine mammals; and “offshore” orcas mainly hunt fish, especially sharks.

Pods range from just a few animals to groups of 50 or more and usually consist of a mature female and her female offspring and relations. Orcas can mate year round, but most matings occur during late spring and summer. Following a gestation period of around 17 months, the female gives birth to a single calf, which is usually born tail-first.

Keeping in touch

Pod members communicate with each other via a sophisticated series of high-frequency clicks and whistles, as well as “pulsed calls,” which, to human ears, sound like screams.



Wave washing

Working together, several orcas swim underneath an ice floe to create a large wave that will knock the seal off into the water.



the polar oceans

Low temperatures in the polar oceans slow the movement and growth of plants and animals. Yet the water is rich in oxygen and nutrients, enabling marine life to thrive in this extreme environment.



sea butterfly

A tiny zooplanktonic sea snail sporting twin translucent winglike appendages, the sea butterfly (*Limacina helicina*) is critical to the ecology of the Arctic seas. It feeds on zooplankton and phytoplankton, which it traps by casting a net of mucus.

Sea butterflies are pteropods, or free-swimming marine gastropods, that propel themselves with elegant parapodia (or “wings”) adapted from a modified foot. Their $\frac{1}{25}$ – $\frac{1}{2}$ in (1–14 mm) thick shells are formed from aragonite, a type of calcium carbonate absorbed from seawater.

At the bottom of the Arctic food chain, sea butterflies create huge swarms in the upper reaches of open Arctic waters, where they consume plankton—even other sea butterflies. They, in turn, are eaten by whales and seals, which can be prey for polar bears.

Weighty armor

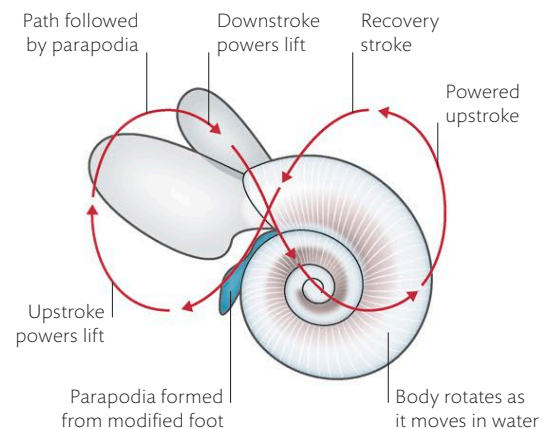
Sea butterflies are normally protected by their dense aragonite shells. However, their shells are heavy, and the animals sink rapidly if not actively swimming or hanging from their mucus feeding webs.

These minute animals have a short, 1-year life cycle and, when they die, their shells fall to the seabed. This creates an effective carbon “sink” that keeps tons of carbon dioxide (CO₂) out of the atmosphere and helps slow the rate of global warming. However, oceans absorb more than 25 percent of the rising CO₂ emissions, which raises acidity levels (lowers their pH). Ocean acidification hinders the sea butterflies’ ability to build their protective armor by reducing the speed at which their shells grow and the availability of aragonite. While a damaged or nonexistent shell does not necessarily kill sea butterflies, it does leave them vulnerable to predators and disease. The size and health of the sea butterfly population is therefore a key indicator of how much ocean ecosystems are being affected by global warming.

FLYING THROUGH WATER

Sea butterflies swim by moving their parapodia, or “wings,” in the same figure-eight pattern seen with the wings of flying insects. Both animals generate lift on up- and downstrokes by peeling their wings apart at the start of each downstroke and rotating each wing slightly during the upstroke.

“WING” MOVEMENT MADE BY A SEA BUTTERFLY



Intricate patterns

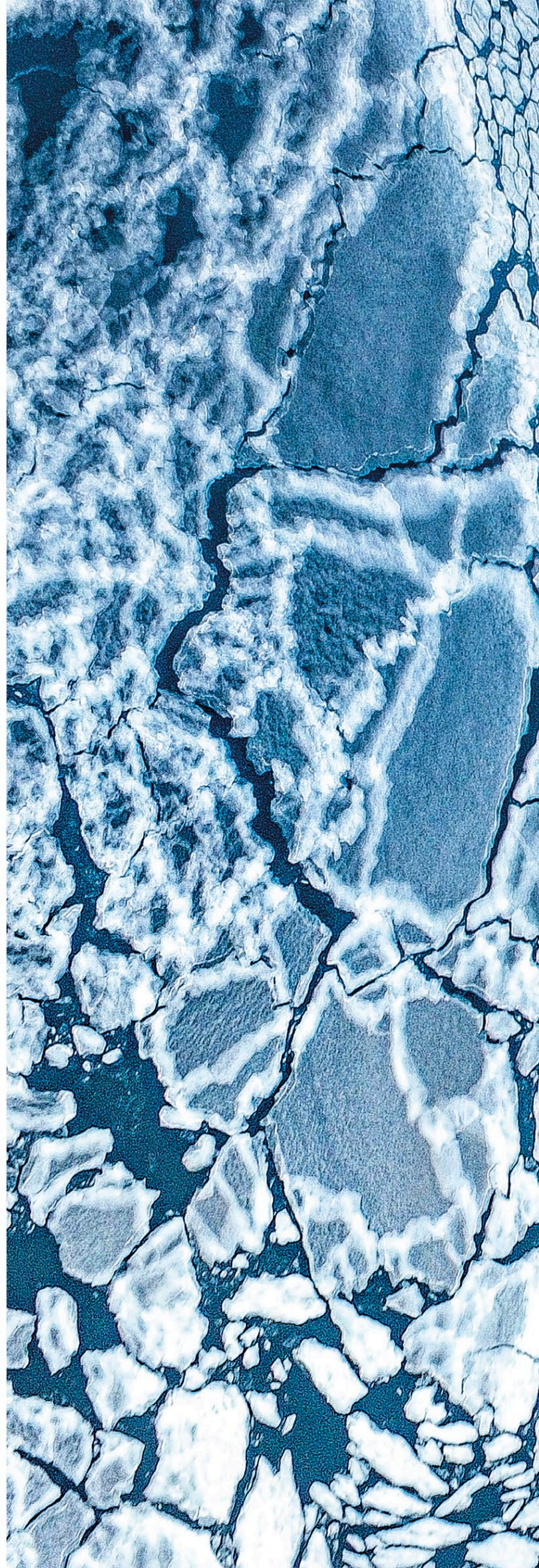
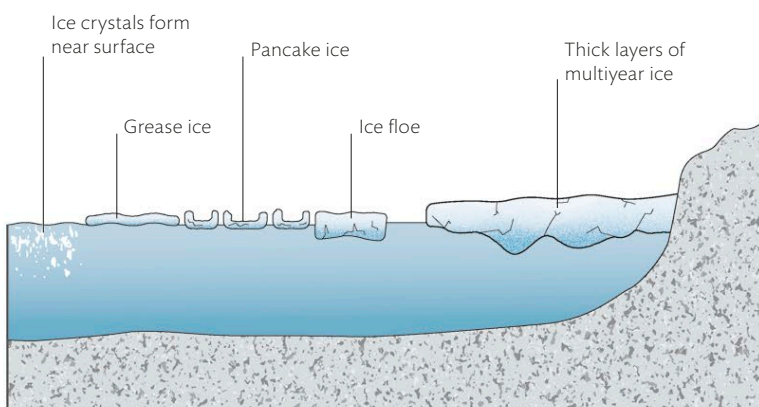
This aerial view of sea ice off the Icelandic coast shows small segments of sea ice (right) formed offshore combining to produce larger expanses of ice (left) in the shallower waters near the coast.

sea ice

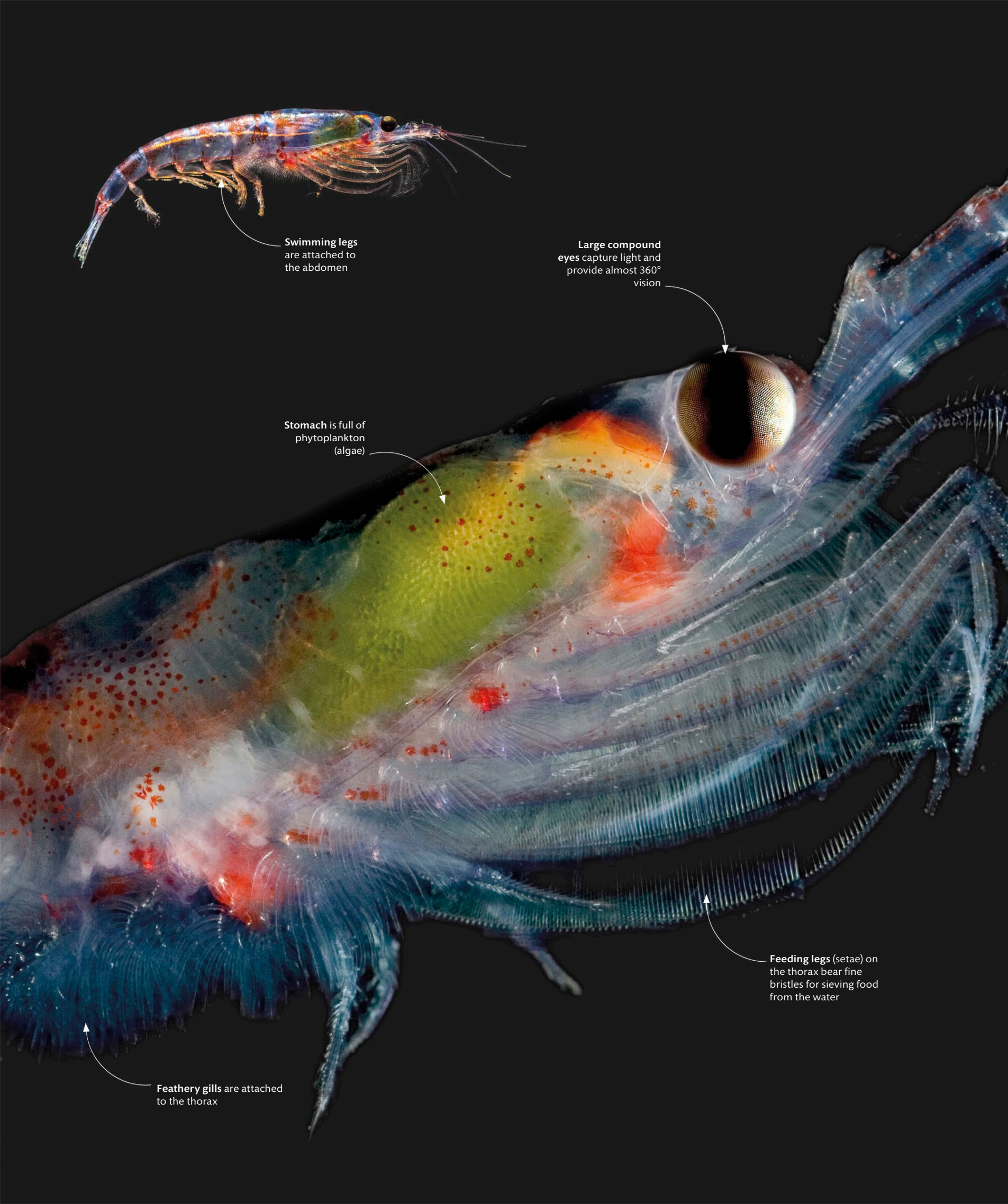
The water in the ice-cold polar oceans freezes and thaws in an annual cycle. During the winter months of 24-hour darkness, temperatures can drop to to -30°C (-22°F) so that the sea freezes over to form sea ice. When water freezes, it is less dense than it is as a liquid. Consequently, the ice that is formed floats. Each year, this sea ice covers a remarkable 15 million square miles (40 million square km) of frozen ocean, which is equivalent to the area of Russia, China, and the US combined. In summer, 60–80 percent melts back into the ocean, with no net effect on sea level. Any ice that remains frozen through the summer grows thicker year-on-year and drifts in the ocean currents, but the area of permanent sea ice is fast diminishing as the global climate warms.

HOW THE SEA FREEZES

Freezing winds across the ocean surface cause ice crystals to grow in the polar waters. These lock together to form a slushy surface layer known as grease ice, which hardens and thickens into a continuous sheet. Wind and waves may break the cover into pieces that jostle and bump to form separate platterlike shapes of solid ice called pancake ice. These eventually fuse into larger sheets up to 7 ft (2 m) thick, which continually separate into ice floes and then freeze together again. Near the shore, thick layers of ice that endure for many years may form.







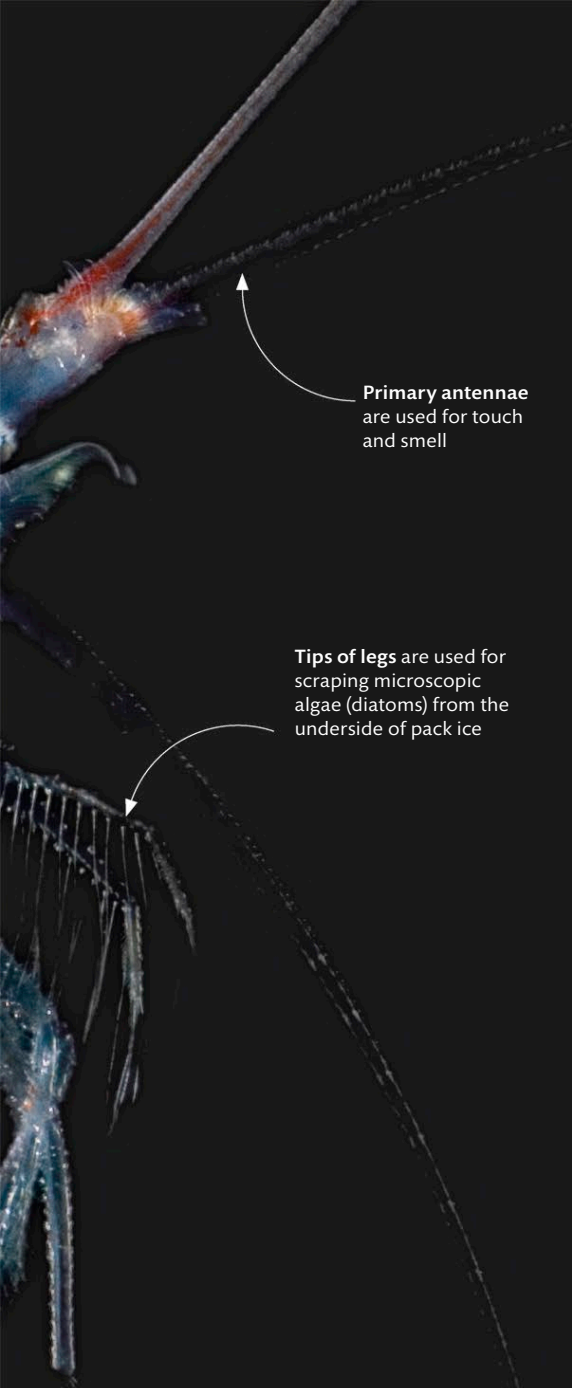
Swimming legs are attached to the abdomen

Large compound eyes capture light and provide almost 360° vision

Stomach is full of phytoplankton (algae)

Feeding legs (setae) on the thorax bear fine bristles for sieving food from the water

Feathery gills are attached to the thorax

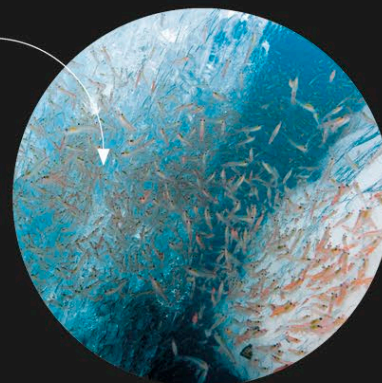


Primary antennae are used for touch and smell

Tips of legs are used for scraping microscopic algae (diatoms) from the underside of pack ice

Secondary antennae are longer and more whiplike than primary antennae

Underside of pack ice is often covered with "lawns" of algae on which krill graze



Seasonal plenty

Antarctic krill (*Euphausia superba*) grow to 2-2½ in (5-6 cm) long on a diet of mostly single-celled algae such as diatoms. They feed by filtering algae from the water using their bristly legs and by raking algae from the underside of pack ice. During winter food shortages, they can reduce body size to limit the chance of starvation.

Marine biomass

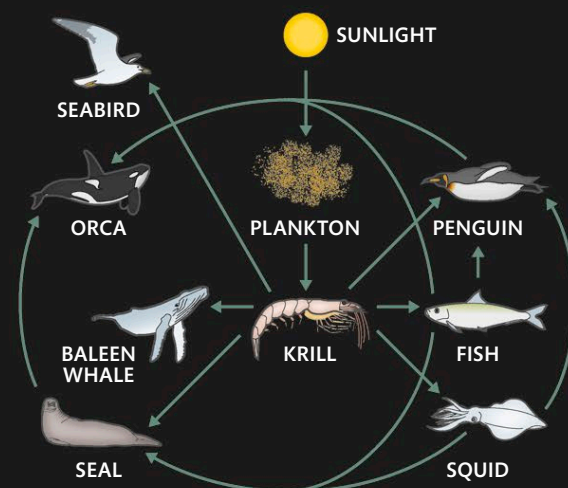
Krill are among the most numerous animals in the ocean, with some swarms of krill having more than 10,000 individuals per 35 cubic feet (cubic meter). Whales, seals, seabirds, fish, and squid consume up to 330 million tons (300 million tonnes) of Antarctic krill a year.

polar swarms

The angle at which Earth tilts as it circles the Sun results in extreme seasonal variation in the amount of light reaching the polar regions. In summer, extended daylight hours create a massive boom in the growth and reproduction of marine phytoplankton (mainly single-celled algae) and consequently also in the animals that feed on them. These include small, shrimplike crustaceans known collectively as krill, which constitute one of the most abundant life forms and food sources on the planet.

MARINE FOOD WEB

Phytoplankton live on the surface of the ocean, where they can capture the Sun's energy, which is needed for photosynthesis. As the primary producers, they form the base of the marine food web. In the Antarctic, the phytoplankton are then eaten by krill, which are the primary consumers and hold a critical position in the food web because of the sheer variety of other animals that feed on them. In the Arctic, copepods replace krill as the primary consumers.



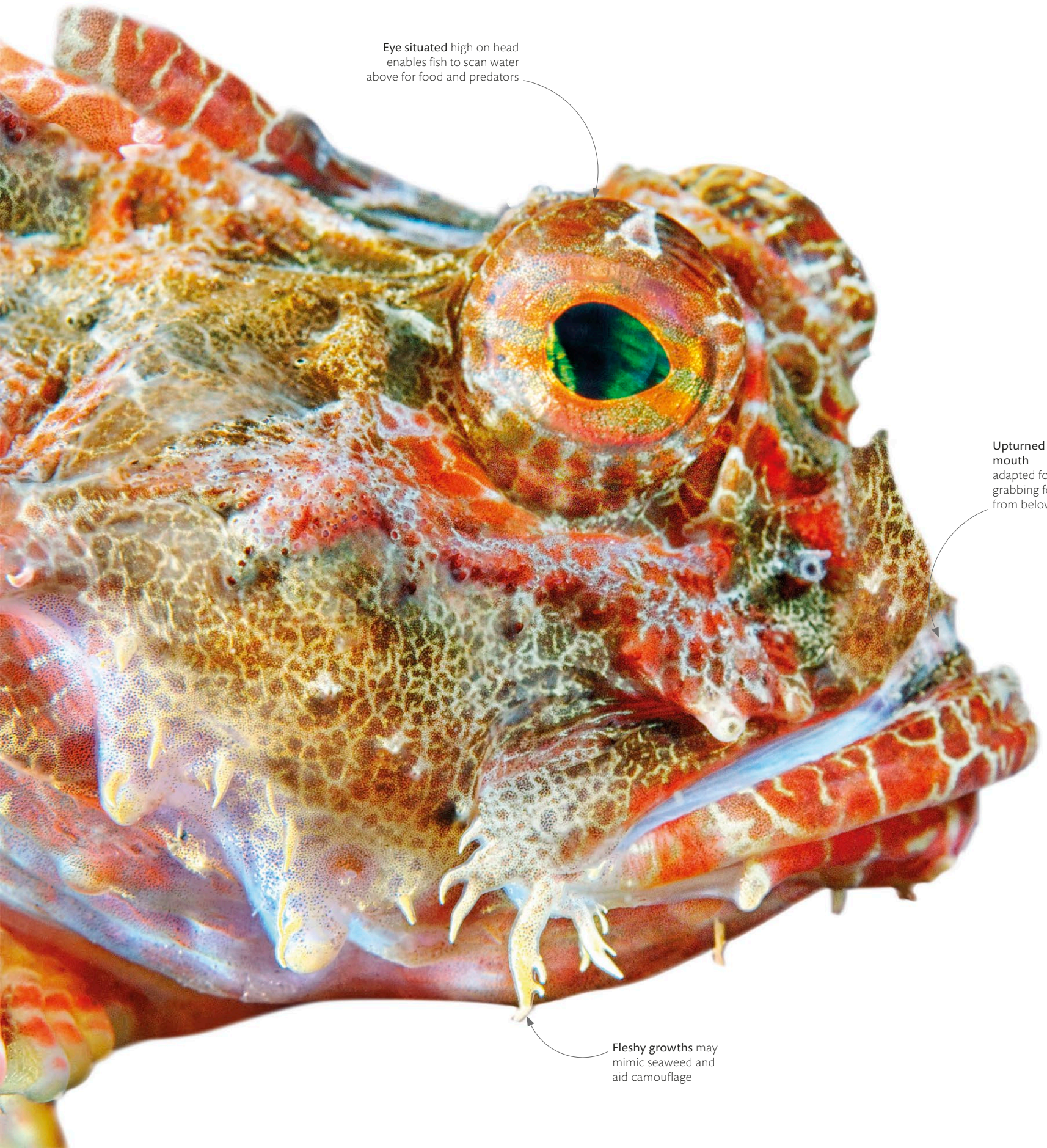
Arctic specialist

The sculpins are a family of small fish that are common in the icy seas of high northern latitudes. The antlered sculpin (*Enophrys diceraus*), native to seas around Alaska and Siberia, shows some of the highest levels of blood antifreeze protein known in any fish.

Eye situated high on head
enables fish to scan water
above for food and predators

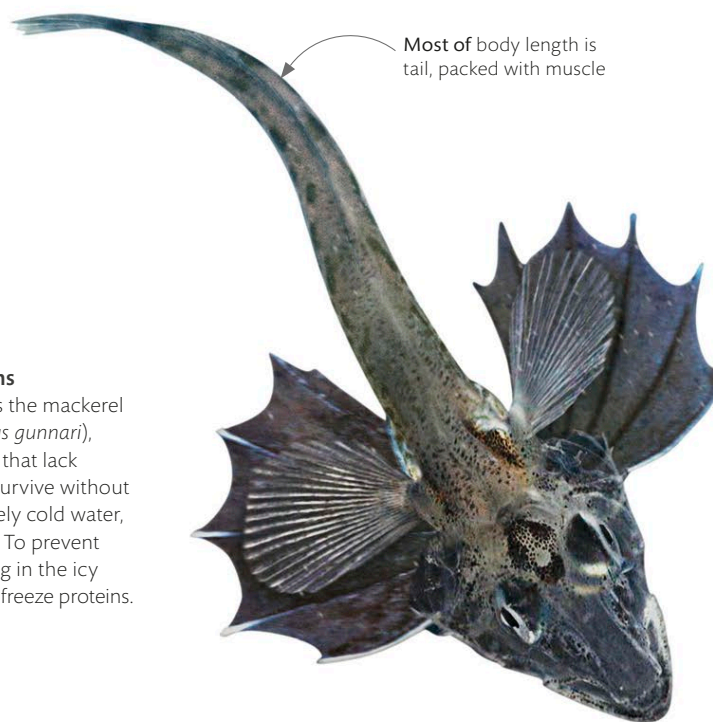
Upturned
mouth
adapted for
grabbing food
from below

Fleshy growths may
mimic seaweed and
aid camouflage



Cold-water adaptations

Antarctic icefish, such as the mackerel icefish (*Champsocephalus gunnari*), are the only vertebrates that lack hemoglobin. They can survive without it, as they live in extremely cold water, which is high in oxygen. To prevent their blood from freezing in the icy ocean, they produce antifreeze proteins.

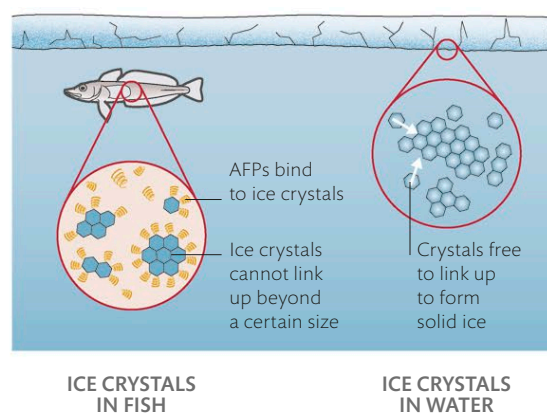


antifreeze in fish

Because water expands when it turns to ice, freezing can be lethal to living organisms, causing cells to rupture. Seawater remains liquid to about 28°F (-2°C), and organisms living in sub-zero conditions have evolved to cope. While mammals and birds burn sugars and fat to keep warm, many fish produce antifreeze proteins that inhibit ice formation.

ANTIFREEZE PROTEINS

Many fish living in polar waters produce proteins in their blood-stream that prevent the fish from freezing. These antifreeze proteins (AFPs) bind to the corners of tiny ice crystals in the blood and prevent the crystals from linking up. As a result, provided there are enough AFPs in the fish's body, ice crystals do not grow large enough for the blood to freeze.



zooplankton

Animals that drift with ocean currents because they cannot swim or are very weak swimmers are known as zooplankton. They include some of the tiniest animals in the oceans, which, together with phytoplankton (see pp.258–259), form the base of marine food webs. For these creatures, the viscosity of water can make forward progress the equivalent of a human moving through syrup, so they depend on the currents for dispersal. Some are the larvae of animals that are free-swimming as adults, others live out their lives as plankton.

Meroplankton

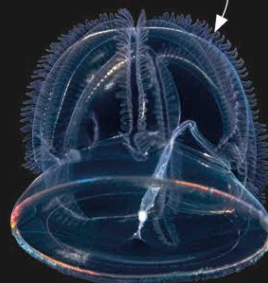
This group of zooplankton are plankton for part of their lives only, usually the larval stage, and many bear little or no resemblance to their final adult form. They feed on other plankton or may live off the yolk of the egg from which they hatched. As adults, they may either move to the benthic (deeper ocean) waters or stay in open water.



Tail-like abdomen folds underneath the adult crab during metamorphosis

MEGALOPA STAGE BOX CRAB
Calappidae

Convolved bands of microscopic beating hairs (cilia) aid propulsion



TORNARIA LARVA
Ptychodera flava

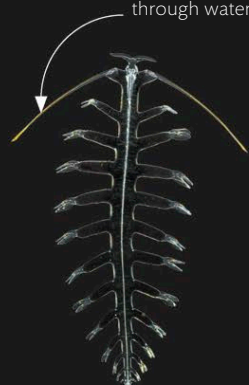
Transparent mantle contains pigment-containing cells (chromatophores) that form early in development



WONDERPUS OCTOPUS LARVA
Wunderpus photogenicus

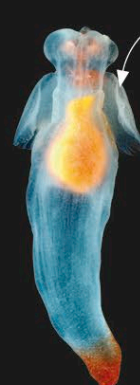
Holoplankton

Animals that remain as plankton for their entire life cycle are known as holoplankton. They live in the open (pelagic) water column, and, like meroplankton, most are transparent. They vary in shape and size and are equipped with a variety of adaptations, from body shape to gas-filled floats, to assist survival.



Spindly, antennalike appendages twitch, so they appear to jump through water

BRISTLEWORM
Tomopteris helgolandica



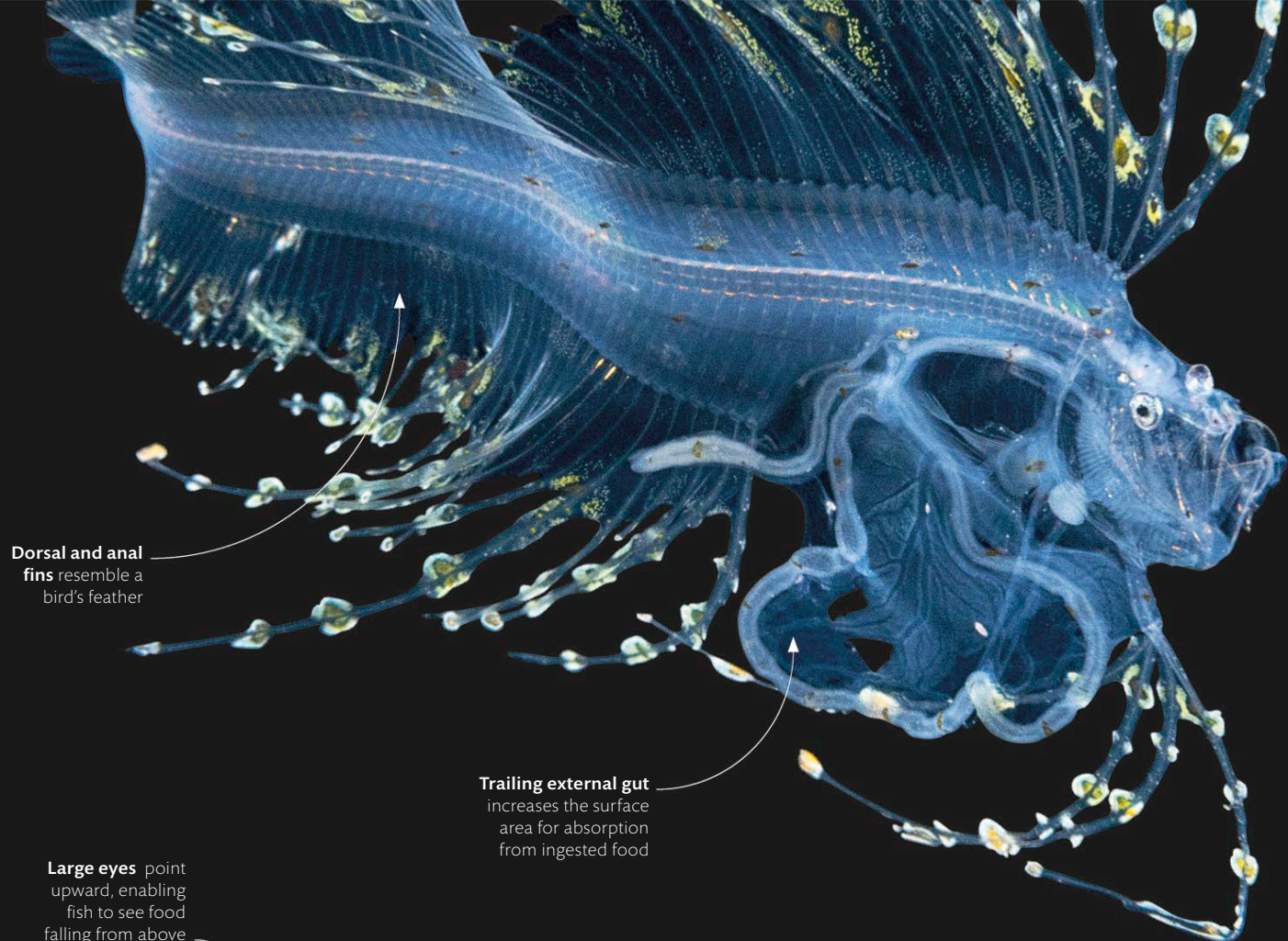
Fleshy, winglike flaps (parapodia) help sea slug propel body through water

SEA ANGEL
Clio limacina



Flat-shelled snail that can be up to 1¼ in (3 cm) long

SEA BUTTERFLY
Clio recurva



Dorsal and anal fins resemble a bird's feather

Trailing external gut increases the surface area for absorption from ingested food

Large eyes point upward, enabling fish to see food falling from above



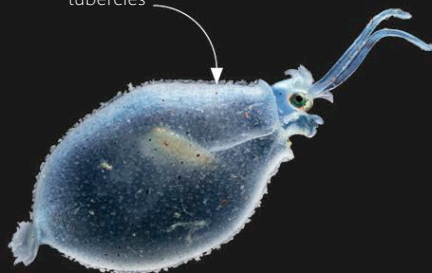
JUVENILE DEEP-SEA HATCHETFISH
Argyropelecus olfersii



Larva has an eye on either side of its head and swims vertically

LEFTEYE FLOUNDER LARVA
Engyprosopon xenandrus

Surface is covered with cartilaginous tubercles



GLASS SQUID
Cranchia scabra

Mirrorlike eyes are used by this crustacean to locate small animal prey



OSTRACOD
Gigantocypris muelleri

Full intestine visible through transparent swimming body of this snail



SEA ELEPHANT
Cardiapoda placenta





Chicks huddle together in groups from the age of three months while the adults hunt for food



Contrast in appearance

Covered in brown fluffy down for the first year of their lives, king penguin chicks bear little resemblance to their parents—so much so that they were once thought to be a completely different species.

spotlight species

king penguin

These birds are found mainly on subantarctic islands in the southern Atlantic and Indian oceans. There are more than 2.2 million king penguins (*Aptenodytes patagonicus*) around the world, and the largest concentration is on the island of South Georgia.

At up to 3 ft (1 m) tall and weighing up to 35 lb (16 kg), the king penguin is second in size only to its closest relative, the emperor penguin (*A. forsteri*). Its colonies are usually established with close access to the sea, where nests can be built on flat beaches or in tussock grass free of snow and ice.

At 13–16 months, including the adults' premolting period, king penguins have a much longer breeding cycle than any other penguin. They do not build nests. Females lay one egg between November and April, which they pass to their mates, then they return to the sea to hunt. The

males carry the eggs (and later, the new chicks) on their feet and cover them with a brood pouch. Males can lose up to 30 percent of their body weight as they wait for the females to come back. Later, groups of chicks huddle together while both parents go to sea in search of food; feeding sessions are up to 3 months apart, so they, too, rely on fat reserves to survive. The adults can swim up to 300 miles (500 km) before finding enough fish and squid. There are signs that shifts in the Antarctic Polar Front might increase this distance even further as the penguin's prey moves in response.

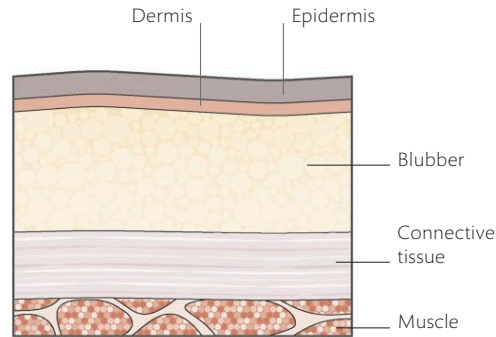
A king penguin's eyes are adapted to extreme differences in light conditions. In sunlight, their pupils constrict to a pin-sized opening, but in low light—for example, when diving to depths of 1,000 ft (300 m)—they expand by 300 times, the widest alteration of pupil size in any bird.

Group dynamics

King penguins are highly sociable. Even in the largest colonies, where adults stand flipper to flipper, fighting is rare. However, breeding adults tend to remain separate from nonbreeding birds.

BLUBBER

The blubber of cetaceans and pinnipeds is a thick, relatively firm layer of fatty tissue lying under the skin (made up of the epidermis and dermis). In addition to the adipose (fat) cells, the blubber contains abundant collagen fibers, which stabilize the fat layer, and it is bonded tightly to the underlying muscle by a layer of connective tissue. Blubber thickness ranges from $\frac{3}{4}$ in (2 cm) in a small seal or a porpoise to about 12 in (30 cm) in large whales.



CETACEAN SKIN AND BLUBBER

Dispensing with fur

The walrus (*Odobenus rosmarus*) has a thin coat of fur, but by adulthood, it often becomes virtually bald, except for a mustache of massive, bristly whiskers. These thick, touch-sensitive hairs are a vital aid to hunting prey, such as clams, in soft sediments.

insulating layers

For mammals living in cold seas, heat loss can be a constant challenge. Cetaceans (whales, dolphins, and porpoises) and pinnipeds (seals, sea lions, and walruses) rely on a thick layer of fat under the skin, known as blubber, for their survival. The blubber prevents body heat escaping through the skin and also stores energy, including proteins and fats. The thickness and fat content of blubber can be adjusted seasonally, and the blood supply is restricted during dives to minimize heat loss.

Flexible protection

The skin of a male walrus is anything up to 2½ in (6 cm) thick, overlying a layer of blubber at least as thick again. In addition to insulation, this full body padding provides significant protection and serves as a kind of soft armor when fighting.



Scars on skin of males are evidence of "tusking"

Short, sparse hair may
be retained on the head,
even after body hair has
been shed

Nostril linings are the
thinnest part of the skin;
walruses have a well-
developed sense
of smell in air



spotlight species

southern elephant seal

The world's largest seal, the southern elephant seal (*Mirounga leonina*), is named for its size and the trunklike inflatable proboscis seen on mature males, or bulls. These animals exhibit the greatest gender-related size and weight disparity of all mammals.

Found in cold Antarctic and subantarctic waters, elephant seals feed only at sea and can spend up to 10 months a year in their search for fish and squid. They typically dive for 20–30 minutes, although they can remain underwater for up to 2 hours and reach depths of 6,500 ft (2,000 m) or more. To achieve this, they exhale before diving to eliminate gases that could cause sickness. To ensure a constant oxygen supply, they have twice the amount of oxygen-carrying hemoglobin in their red blood cells as land animals of similar sizes and store more oxygen in their muscles. Their heart rate can slow to 5–15 beats a minute, so blood flows only to vital organs.

Although elephant seals see poorly in daylight, their vision is adapted to hunting in deep, dark water. Their eyes are highly sensitive to the wavelengths of light (see pp. 258–259) given off by bioluminescent lanternfish, a main source of food.

Their extended feeding periods ensure these seals accumulate enough fat, or blubber, to see them through two lengthy periods of time on land: a month-long molt between January and February and the breeding season, which starts around mid-August. The seals return to the same place on land every year. Bulls can spend weeks, or months fighting for control of harems of females, then breeding with them. The largest bulls acquire vast harems of 50 females or more.

Coming ashore for breeding

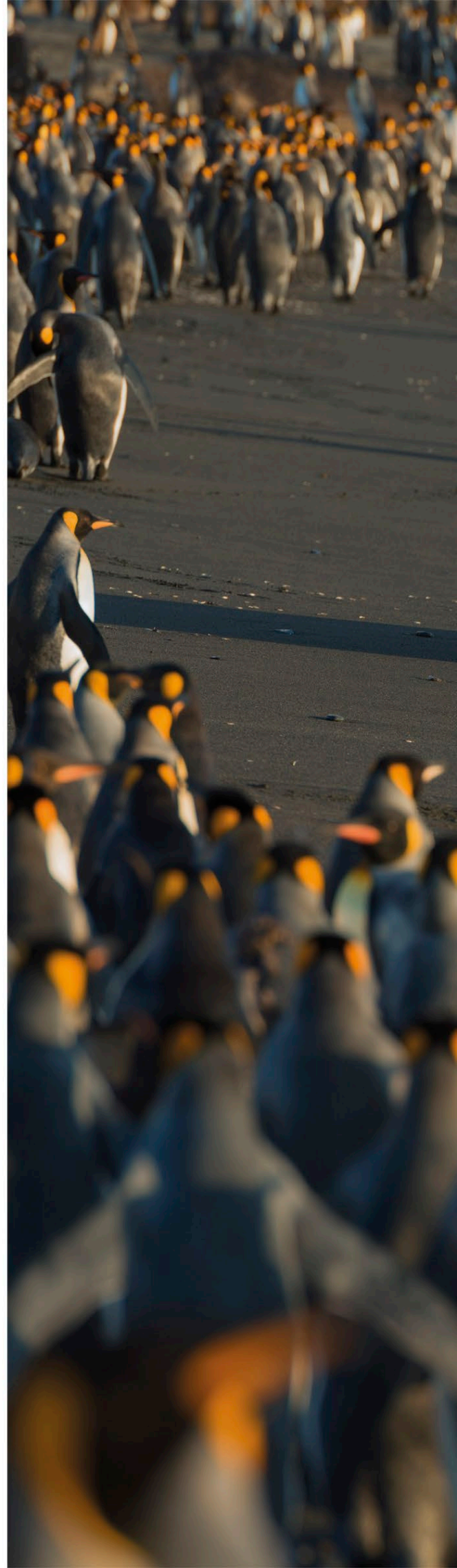
A male southern elephant seal hauls himself out on the island of South Georgia, also the site of a vast king penguin breeding colony. More than 50 percent of the global population of these seals come to breed here.

Size difference

Sexual dimorphism—when males and females of a species show marked contrast in appearance—is extreme in these seals. Males can weigh up to 6,000 lb (3 tonnes); females weigh just 1,300–1,800 lb (600–800 kg).

Huge males can be up to 10 times larger than females

Females mate again a few days after their pups are weaned



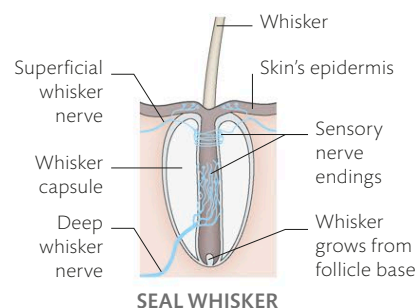


sensitive whiskers

Mammalian hair serves multiple purposes. In seals, it provides individually unique patterning, waterproofing, insulation, and vital sensory information. Seals have long, stiff, highly sensitive whiskers (or vibrissae), which grow from hair follicles that detect the slightest vibration and transmit the information along sensory nerves to the brain. This enables seals to navigate in murky water and pick up on prey or predator movement and helps them assess the size of breathing and access holes in the ice.

THE WHISKER SENSORY SYSTEM

Seal whisker follicles are packed with blood vessels and nerve fibers, which process sensory data and relay information about the physical environment to the brain via the trigeminal nerve.

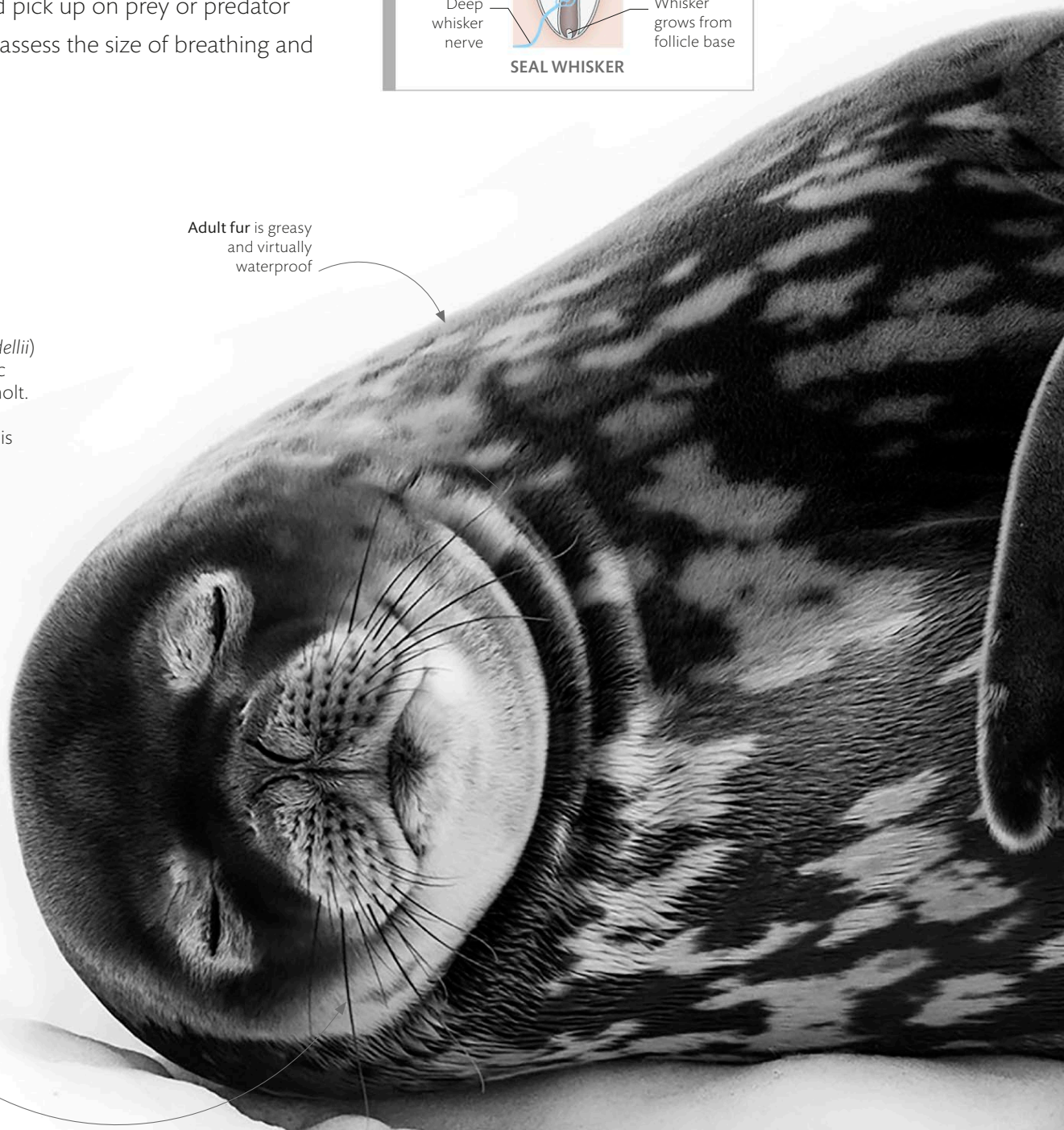


Summer bask

Weddell seals (*Leptonychotes weddellii*) leave the sea in the short Antarctic summer to give birth, bask, and molt. Unlike the whiskers, which grow throughout the year, the seal's fur is shed and replaced annually.

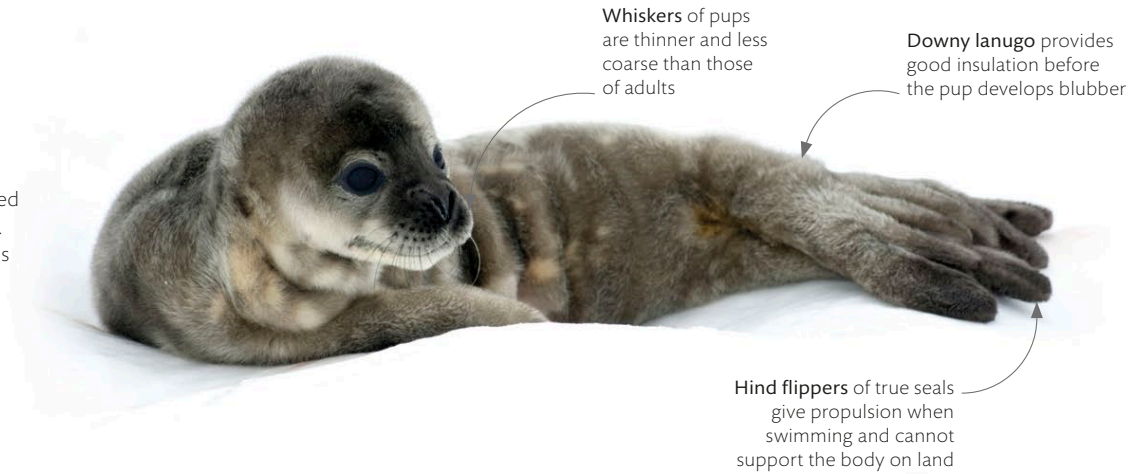
Adult fur is greasy and virtually waterproof

Coarse, stiff whiskers enable seal to detect prey up to 590 ft (180 m) away



Seal pup

The Weddell seal is born with whiskers and is covered in lanugo, a fine, dense fur. After 4 weeks, the lanugo is replaced by the more waterproof adult coat.



Whiskers of pups are thinner and less coarse than those of adults

Downy lanugo provides good insulation before the pup develops blubber

Hind flippers of true seals give propulsion when swimming and cannot support the body on land



Front flippers are used for steering and adjusting speed when swimming; hind flippers provide propulsion

Fantastic forms

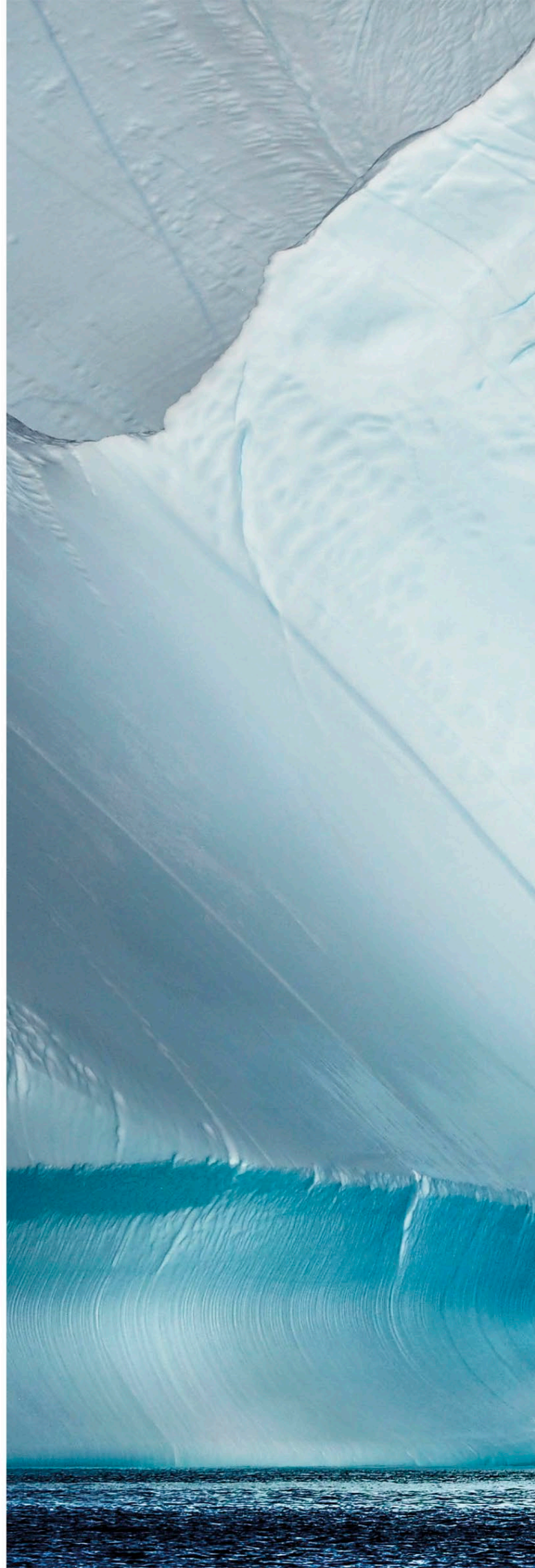
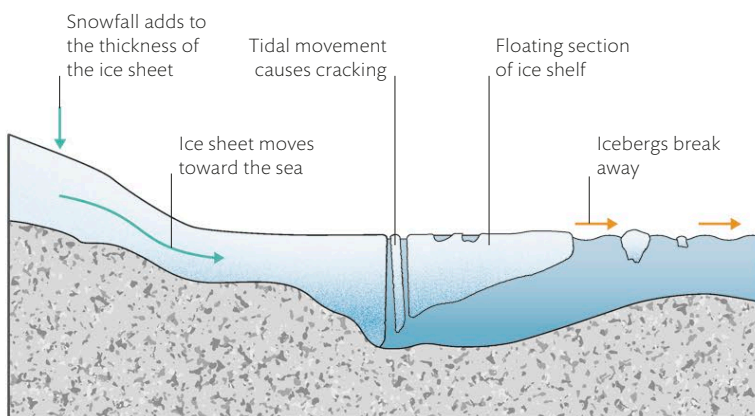
This immense iceberg was formed in Disko Bay, western Greenland, where the Ilulissat Icefjord flows into the sea. Ten percent of the ice that fragments from Greenland's glaciers comes from this glacier.

ice shelves and icebergs

Ice sheets and glaciers lock up huge volumes of water over the landmasses of the polar regions. In coastal areas of Antarctica and Greenland, ice sheets and glaciers extend over the sea as vast ice shelves that can form towering cliffs up to 160 ft (50 m) high. Ice shelves are composed of dense ice that has accumulated over hundreds of years and are often a vivid blue, because all the tiny white air bubbles have been squeezed out. Marine algae frozen into the ice may give parts of ice shelves a vivid green coloration. An iceberg is a section of an ice shelf that has broken away from the main body of ice. Ice shelves in both the north and south polar regions are diminishing in size due to global warming, releasing massive volumes of water into the world's oceans.

ICEBERG FORMATION

Ice shelves and glaciers are grounded on land, while the outer parts float on the sea. The movement of the floating section with the rise and fall of the tides causes great strain, especially where crevices are already present. Huge cracks open up and chunks of ice break away, which crash into the sea as icebergs—a process known as calving. Some icebergs can be as large as a small country. More than 50,000 large icebergs are calved from Greenland alone each year.





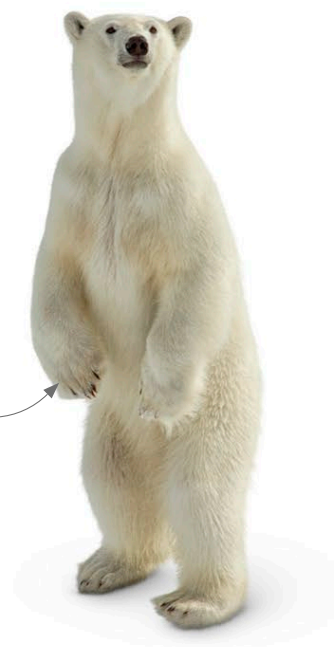




Sea bear

The polar bear lives, hunts, and breeds on sea ice or in water, coming ashore only when forced by melting ice. The fur loses a large proportion of its insulating properties in water, but the dense underfur still provides some benefit by trapping body heat, ensuring the bear stays warm.

Huge paws act as shovels, snow shoes, and powerful paddles when swimming



Arctic giant

An adult male polar bear on two legs stands over 10ft (3m) tall and can weigh over half a ton (tonne). Along with the bear's fur and a layer of blubber, huge size is an adaptation to cope with extreme cold.

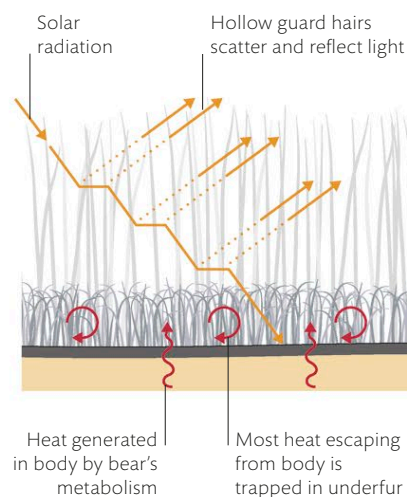
multipurpose fur

Many polar mammals protect themselves from extreme cold by having a coat of fur, but the insulation provided by the fur of different animals varies greatly. The fur of the polar bear is highly effective. It has two layers: a water-repellent outer coat, consisting of long guard hairs, and a dense underfur that keeps the bear warm. The guard hairs are tapered and hollow, making the coat lighter and more buoyant than it would otherwise be. Although polar bears look white and blend into their Arctic surroundings of snow and ice, their skin is black and their hair is colorless.

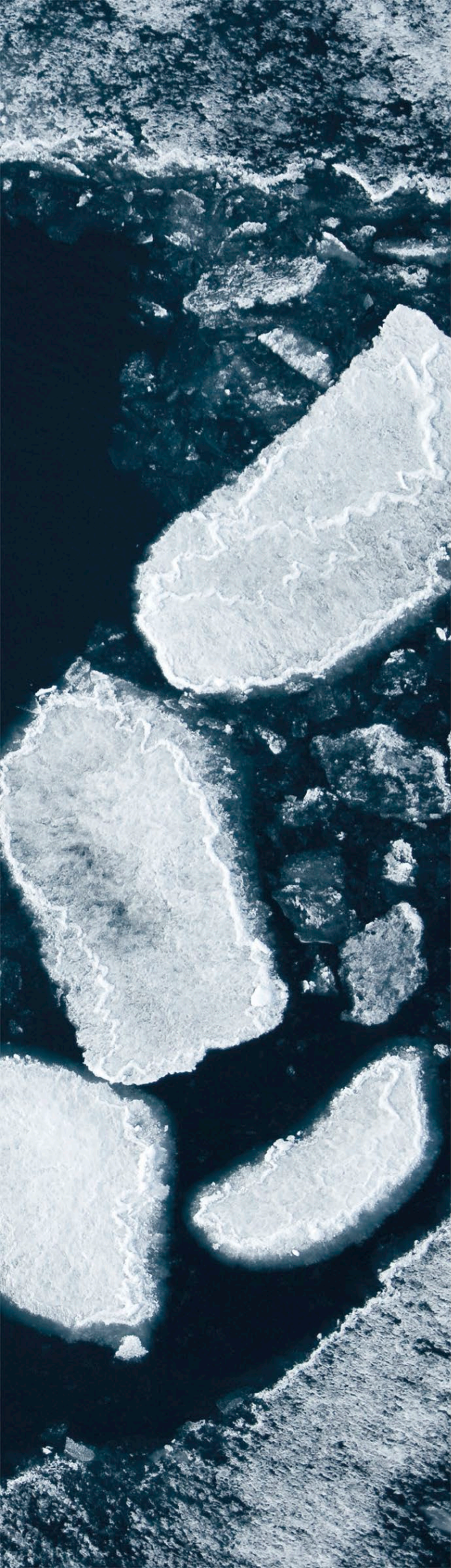
COLOR AND WARMTH

The guard hairs of the polar bear's coat are transparent. Light falling on them is scattered and reflected so that the bear appears white. Like all fur-coated mammals, a polar bear's metabolism generates heat to keep the body warm and functioning. Most of the insulation is provided by the bear's underfur, where air trapped between the densely packed hairs helps to stop heat escaping from the body on moving currents of air.

POLAR BEAR FUR AND SKIN







spotlight species

narwhal

The narwhal (*Monodon monoceros*) can be easily identified by the impressive tusk that gives rise to its nickname: the “unicorn of the sea.” The tusk is in fact a sensitive, elongated tooth that erupts from the side of the animal’s upper jaw.

Narwhals are classed as toothed whales, but the one or sometimes two tusks they grow are their only teeth. The tusks are highly flexible, “inside-out” teeth—soft on the outside, hard and dense toward the core—with millions of nerve endings near the surface. Found mainly in males (only around 3 percent of females have them), they grow in a counterclockwise spiral throughout an animal’s life. It was once thought that a narwhal used its tusk only for defense, but studies show that it is also a sensory organ. Its nerves detect information from the water, helping the

animal “read” its environment for the presence of food or mates and measure water salinity. A narwhal does not use its tusk to spear food; instead, it uses it to tap and stun its prey, which it swallows whole.

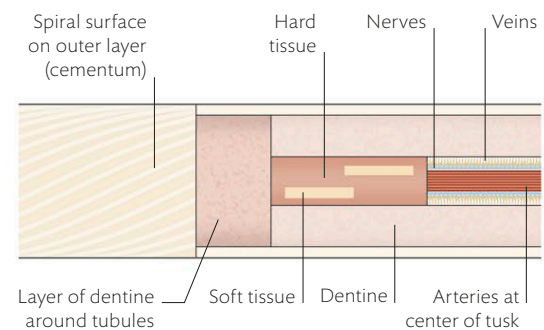
Male narwhals become sexually mature around the age of 9 years (females mature at 6 to 7 years), when they reach 13–15 ft (4–4.5 m) long and weigh 2,200–3,500 lb (1,000–1,600 kg). The animals live in the Arctic waters of Russia, Norway, Greenland, and Canada. Around 75 percent of the world’s population inhabit the biologically rich waters of Baffin Bay and the Davis Strait, between Canada and Greenland. In winter, when the sea turns to pack ice, they can dive up to 3,600 ft (1,100 m) to hunt for deepwater fish such as halibut before coming to surface at cracks or holes in the ice to breathe.

Coming up for air

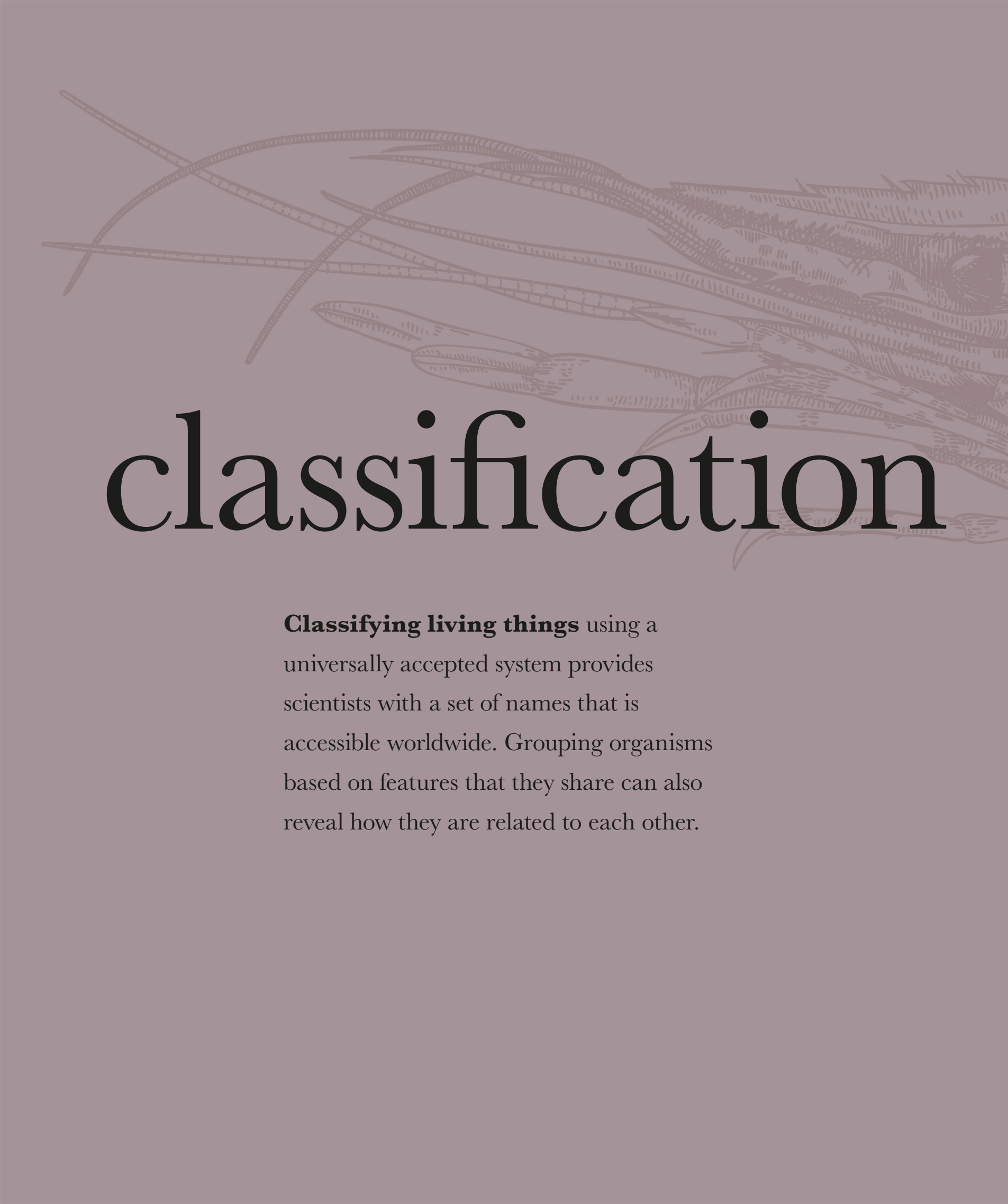
In winter, narwhals congregate, usually in pods of 2 to 20, in areas of Arctic pack ice. When they surface, like these males at Nunavut, Canada, they are vulnerable to predators such as polar bears.

THE NARWHAL TUSK

Nerves deep within the core of the narwhal’s tooth, or tusk, are connected to tiny pores in its outer surface, or cementum, via an estimated 10 million tubules that lie in the dentine layer. When seawater washes through these tubules, specialized cells at their base detect changes in water composition, pressure, and temperature and relay the information to the brain via the tusk’s nerve cells.



NARWHAL TUSK ANATOMY



classification

Classifying living things using a universally accepted system provides scientists with a set of names that is accessible worldwide. Grouping organisms based on features that they share can also reveal how they are related to each other.

classifying living things

Scientists need names for living species that mean the same everywhere so they can talk about them accurately. They also need ways of grouping these species together to understand how they are related. Eighteenth-century Swedish naturalist Carl Linnaeus made a great advance with his binomial (two-word) system for naming species. The first word in these Latinized names is the genus, which is often the same for several related species. The second word narrows the name down to a specific species. These binomial names are written in italics, and the genus name is capitalized. Greatly expanded, this same system is still in use today.

There are scientific names for larger groupings of organisms as well. At the top are kingdoms: all animals are one kingdom, and there are four or five others, depending on the classification system chosen. Modern classification tries to group living things into how closely related they are by evolution.



A species named

Linnaeus placed all turtles and tortoises in a single genus, *Testudo*, and named the hawksbill turtle *Testudo imbricata* in 1766. Austrian zoologist Leopold Fitzinger gave the species its own genus name, *Eretmochelys*, in 1843.

The pattern of head scales is unique to this species

HAWKSBILL TURTLE
Eretmochelys imbricata

CLASSIFYING A TURTLE

The hawksbill turtle, like every species, is classified within a hierarchy of different levels, each of increasing size. Genera are placed in families, families gathered into orders, and so on. These different levels are a way of expressing the position of a species in the family tree of life.

phylum (plural: phyla)

Within the animal kingdom, there are around 30 top-level groupings called phyla. The phylum that contains turtles is called Chordata and includes all animals with backbones, as well as some invertebrate groups.

class

Turtles are classified in the class Reptilia, which also includes lizards, snakes, crocodiles, and the extinct dinosaurs.

order

All turtles and land tortoises are classified in the order Testudines, which includes around 350 living species.

family

The seven species of sea turtles are classified into two families. One family contains only the leatherback turtle, while the second, the Cheloniidae, contains the other six species, including the hawksbill turtle.

genus (plural: genera)

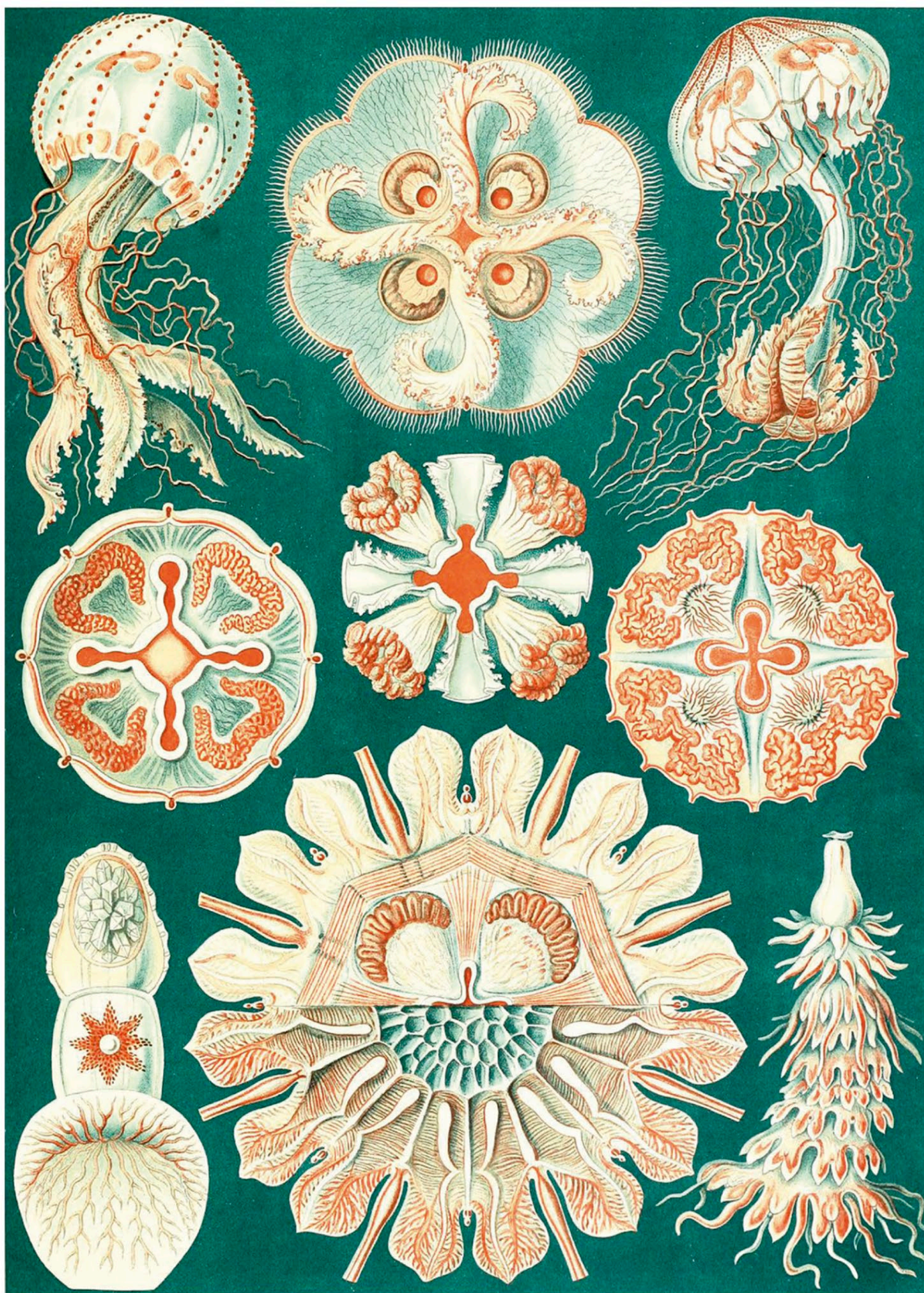
The genus *Eretmochelys* contains only a single species, the hawksbill turtle. This means that none of the other sea turtles are very closely related to it.

species

A species, such as *Eretmochelys imbricata*, is often defined by its individuals being able to mate with each other to produce fertile offspring.

Nature into art

In 1904, German biologist Ernst Haeckel completed an illustrated book, originally issued in several parts, called *Kunstformen der Natur* (Art Forms of Nature), which drew attention to the beautiful and intricate body forms of many lesser-known living organisms, such as these jellyfish.



cyanobacteria

PHYLUM: Cyanobacteria **KINGDOM:** Bacteria

Cyanobacteria, formerly called blue-green algae, are the smallest organisms that photosynthesize (create food using the Sun's energy). They live as single cells or tangled filaments in plankton or attach to rocks. Their tiny cells do not contain distinct nuclei, unlike the cells of most other organisms. By combining atmospheric nitrogen into compounds usable by other organisms, many cyanobacteria help fertilize the oceans and are important in marine photosynthesis, especially in warmer, nutrient-poor regions. In one sense, they led to photosynthesis on Earth: cyanobacterial cells are believed to have been engulfed by larger, nucleated cells and integrated into them. Such cyanobacteria eventually turned into the chloroplasts found in all living plant and algal cells today.



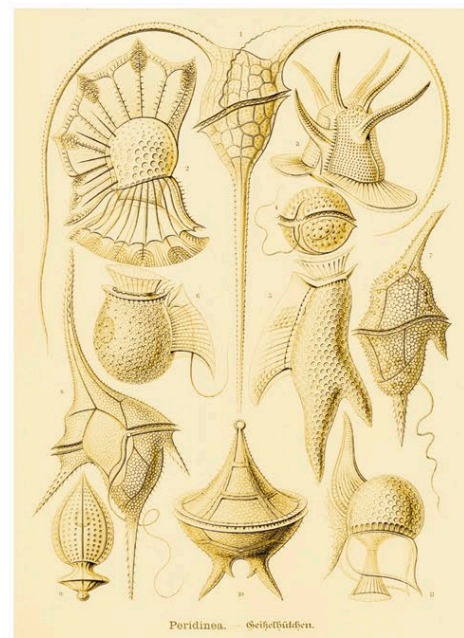
Cyanobacteria

This illustration shows microscopic images of various cyanobacteria. The shapes they form are a result of cells that stay attached as they multiply to form filaments or colonies.

dinoflagellates

INFRAPHYLUM: Dinoflagellata **PHYLUM:** Myzozoa **KINGDOM:** Chromista

Dinoflagellates are single-celled, planktonic organisms that are major photosynthesizers in the oceans. Typical free-living forms have a cell of two halves with a groove around the middle containing a beating flagellum, while a second flagellum stretches behind them. The organism can corkscrew through the water using these flagella. Many species also have elaborate protective armor. Dinoflagellates can act like tiny animals by catching and absorbing other plankton; for species without chloroplasts (which carry out photosynthesis), this is the only source of food. Large dinoflagellate blooms may occur in the oceans, leading to toxic phenomena called “red tides.” Dinoflagellates are usually called zooxanthellae for their symbiosis with corals, where they provide the corals with food.



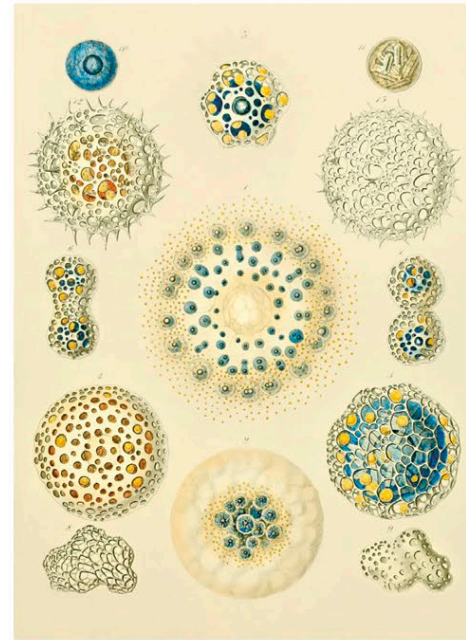
Dinoflagellate variety

Dinoflagellates exist in many shapes and sizes. The two wavy flagella, typical of members of this group, can be seen in several drawings of this illustration.

radiolarians

PHYLUM: Radiozoa **KINGDOM:** Chromista

Radiolarians are single-celled organisms that are abundant in ocean plankton. They have intricate silica skeletons, the main part of which forms a perforated case that contains the central living part of the cell. This case can be in a variety of shapes, including spherical or rodlike. Long rays called pseudopods stretch out from pores in the skeletal case, sometimes accompanied by spines growing from the skeleton. Radiolarians act like tiny animals by using the pseudopods to capture food floating in the plankton. Many kinds can also obtain food from symbiotic green algae and dinoflagellates in their cells. Radiolarians can adjust their buoyancy to rise and sink in the water. After death, their skeletons sink to the seabed, accumulating as sediments called “radiolarian ooze.”



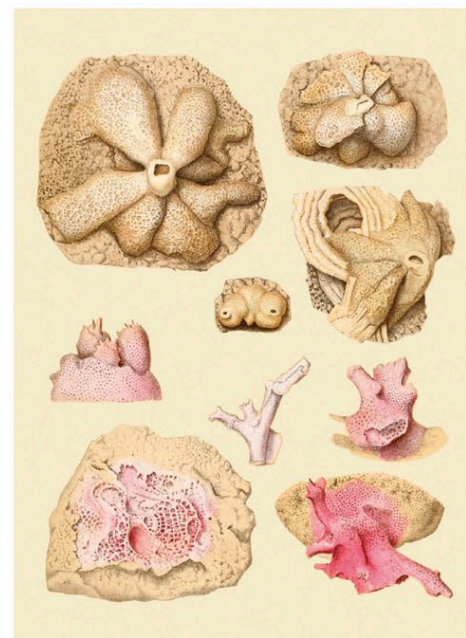
Perforated skeletons

This 19th-century illustration shows several radiolarian skeletons. The pores through which raylike pseudopods would extend in life are clearly visible.

foraminiferans

PHYLUM: Foraminifera **KINGDOM:** Chromista

Foraminiferans are single-celled organisms that are similar to radiolarians; they have hard skeletons and use long pseudopods to capture food items. However, nearly all species live on the seafloor and have skeletons made of calcium carbonate, although some can be of sand grains or organic material. The skeleton grows as a series of chambers, each bigger than the last, the cell occupying more and more chambers as it grows. The resulting shape is variable, depending on the species. Individuals can crawl along the seafloor using their pseudopods. Some foraminiferans can reach 8 in (20 cm) across, which is enormous for a single cell. Like radiolarians, foraminiferans sometimes contain symbiotic algae, and their skeletons contribute to the ooze of the deep oceans.



Deep-sea foraminiferans

This 1884 illustration of deep-sea foraminiferans shows the irregular-shaped skeletons that some species form. Many other kinds grow snail-like skeletons.

coccolithophores

CLASS: Prymnesiophyceae **PHYLUM:** Haptophyta **KINGDOM:** Chromista

These microscopic planktonic life forms are single-celled and create their own food by photosynthesis. Spherical in shape, they have a hard covering of disk-shaped plates called coccoliths, made mainly of calcium carbonate. Once they die, the coccoliths sink to the seafloor, where they are often preserved: chalk is mainly composed of coccoliths. The living organisms flourish under a wide range of temperature and nutrient conditions. Their coccoliths act like tiny mirrors and reflect sunlight, so the water can appear milky. This phenomenon, called white water, is visible both at the ocean surface and from satellites. Collectively, these organisms have the ability to absorb net carbon dioxide, and they have been studied in relation to their possible effects on climate change.



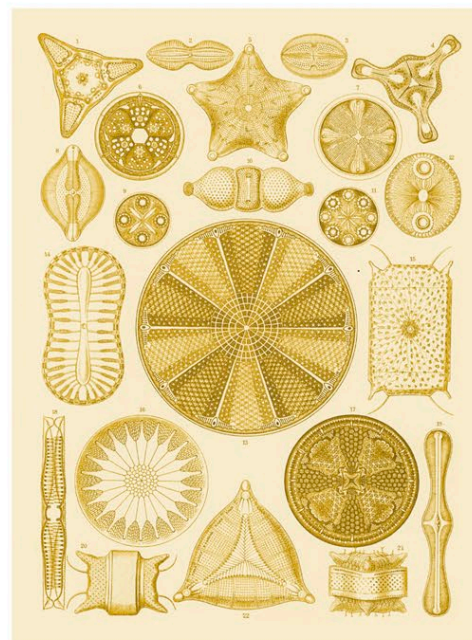
Fossil coccoliths

This illustration shows magnified individual fossil coccoliths. In life, each coccolithophorid cell has a number of these disk-shaped structures covering its outer surface.

diatoms

CLASS: Bacillariophyceae **PHYLUM:** Ochrophyta **KINGDOM:** Chromista

Diatoms are one of the most important groups of photosynthetic organisms in the plankton and form the basis of many marine food chains. Thousands of species of these microscopic single-celled organisms are known, usually growing as separate cells but sometimes as chains of individuals. Each individual cell is protected by a box of silica called a frustule, comprising two overlapping halves that fit together and are often intricately ornamented. When a cell splits during asexual reproduction, each “daughter” receives one half of the frustule and grows a smaller half inside it. This means diatom cells gradually shrink over generations and must form shell-less stages, which produce two new valves, to restore their size.



Symmetric skeletons

Diatom skeletons grow in symmetric shapes that may be elongated, disklike, square, or even triangular, as shown in this plate from Ernst Haeckel's *Kunstformen der Natur* (1904).

brown seaweeds

CLASS: Phaeophyceae **PHYLUM:** Ochrophyta **KINGDOM:** Chromista

The 2,000 or so species of brown seaweeds include the giant kelp of coastal Pacific regions that can grow at least 100 ft (30 m) long. Like all seaweeds, brown seaweeds have a simpler structure than land plants, attaching to surfaces using a holdfast rather than a true nutrient-absorbing root. Their tissues contain chlorophyll but also other light-absorbing pigments, resulting in their typical yellow–brown coloration. Brown seaweeds flourish on and below shorelines, particularly in cooler regions of the world.

As well as giant kelp, the kelp family includes smaller but still sizable oar-shaped or ribbon-shaped forms, growing mainly below the waterline at low tide. Another common group, the wracks, are more tolerant of exposure and often cover rocky seashores in sheltered areas. Their fronds are usually branched and sometimes have gas-filled floats to help raise them in the water. Slimy mucus helps them slip past each other in the water and protects them from drying out. Wracks also include the free-floating sargassum weed that forms habitats in some open oceans. There are also numerous families of smaller brown seaweeds of varied shapes.



Giant kelp

This herbarium specimen of fronds from the giant kelp (*Macrocystis pyrifera*) was collected in South Africa and is held by the Natural History Museum, London.



Sea oak
Halidrys siliquosa



Thongweed
Himanthalia elongata



Common kelp
Ecklonia radiata



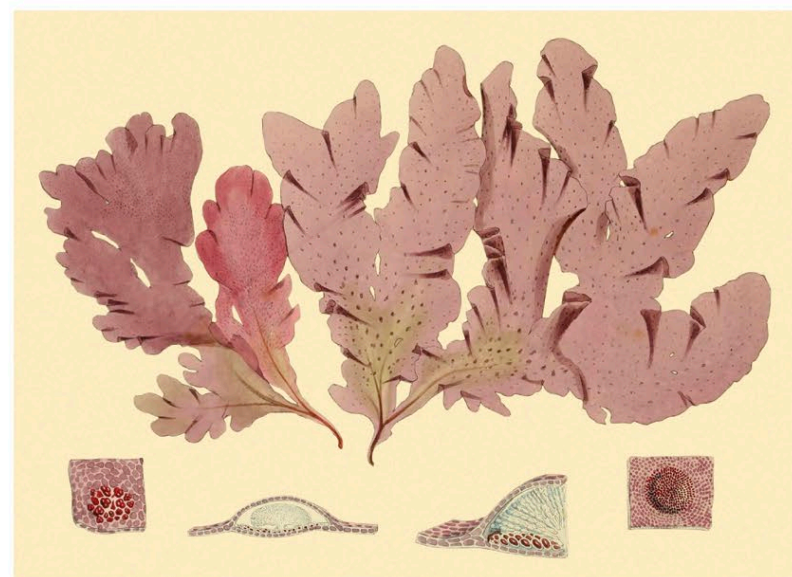
Wireweed
Sargassum muticum

red seaweeds

PHYLUM: Rhodophyta **KINGDOM:** Plantae

Red seaweeds are the most diverse group of seaweeds, with over 7,000 species worldwide. They are usually pink or red in color due to phycobiliprotein, a pigment that helps them absorb more light for photosynthesis and allows many of them to grow in deeper waters. Red seaweeds are small and delicate compared to brown seaweeds but are very varied in form. Most cannot survive long exposure to air, so they are found either in rock pools or below the low-tide line, often growing on other seaweeds. Some temperate species are annual and die back in the winter. Many red seaweeds are harvested to extract agar, a substance used for gelling food and in laboratories, while some, including laver, are collected for eating.

There are also many “coralline” red seaweeds, which have deposits of calcium carbonate in their tissues that give them a hard structure. These include the beautiful feathery coral weed, found worldwide, and the paintweeds, which resemble pink stains on rocks. This group also includes maerl, which grows as hard, branching nodules lying unattached on sandy seafloors and forms a habitat for other organisms.



Red seaweed

Now known as *Myriogramme livida*, this delicate red seaweed is native to the Southern Ocean, where the specimen shown here was collected.



Irish moss
Mastocarpus stellatus



Coral weed
Corallina officinalis



Laver
Porphyra umbilicalis

green seaweeds and microalgae

PHYLUM: Chlorophyta **KINGDOM:** Plantae

Green seaweeds are the nearest seaweed relatives of land plants. Many are small and delicate and grow in the shelter of larger brown seaweeds (see p.327). They come in a variety of forms. Some consist of a single giant cell and have been studied by scientists interested in cell function. Others thrive on soft seafloors, spreading using horizontal runners and anchoring themselves with rootlike rhizoids. One such soft-floor species from the tropics, *Caulerpa cylindracea*, has become invasive in the Mediterranean Sea. The sea lettuce, a widespread edible species, is one of many tolerant of fresh water and often grows where a stream crosses a beach.

Green seaweeds show further diversity in tropical waters. “Cactus” seaweeds accumulate calcium carbonate in their tissues, which crumbles to form coral sand when they die. Other types look like feather dusters, mushrooms, or even shiny green globes. Single-celled chlorophyte microalgae are diverse in the plankton, especially in nutrient-rich waters. Some of these live symbiotically inside sea anemones and other marine creatures, where they are termed zoochlorellae.



Green seaweeds

This illustration shows a selection of green seaweeds, including seagrapes, *Caulerpa racemosa* (fig. 1), and *Acetabularia acetabulum* (fig. 10). Both are giant single cells, although seagrapes contains many nuclei.



Sea lettuce
Ulva lactuca



Velvet horn
Codium tomentosum



Sailor's eyeball
Valonia ventricosa



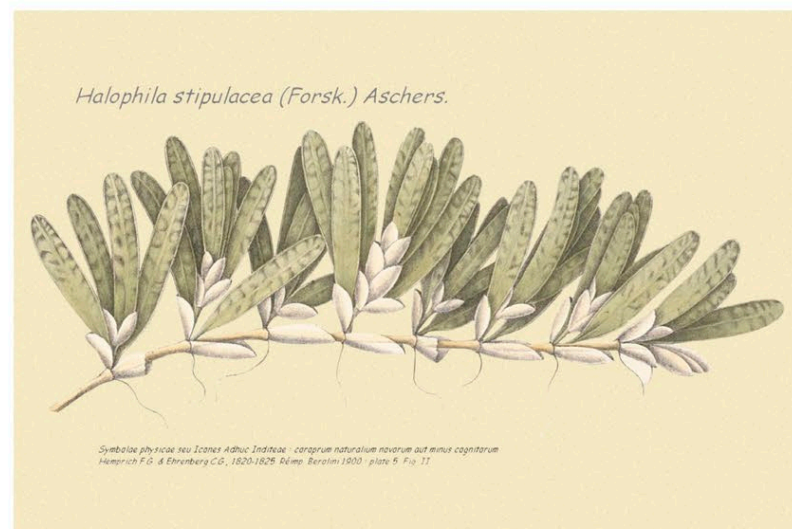
Mermaid's wineglass
Acetabularia acetabulum

seagrasses

ORDER: Alismatales **CLASS:** Magnoliopsida **PHYLUM:** Tracheophyta

Seagrasses are true flowering plants that live completely submerged in the sea. They form extensive “meadows” in sheltered shallow waters of temperate and tropical regions. Seagrass beds are important habitats for young fish, seahorses, and other marine animals; dugongs, manatees, and green turtles graze on beds in warmer latitudes.

Seagrasses belong to many different families in the order Alismatales. Although they are not true grasses, many have long, grasslike leaves; the broad-leaved species of the genus *Halophila* are the main exception. They spread using horizontal stems called rhizomes buried in the seafloor sediment and require clear waters to thrive. The rhizomes store food and are long-lived—some beds of neptune grass in the Mediterranean have been estimated to be thousands of years old. In most seagrasses, male and female flowers appear on separate plants. Male pollen is either released under water, drifting until it finds a submerged female flower, or in some species the flowers are at the surface and the pollen floats. Seeds vary greatly in size between species. Seagrasses also reproduce asexually by releasing small plantlets or simply by plant fragments breaking off.



Halophila stipulacea

This broad-leaved seagrass, native to the Indian Ocean, has become an invasive species in the Mediterranean and Caribbean Seas.



Common eelgrass
Zostera marina



Tape seagrass
Enhalus acoroides



Paddle weed
Halophila ovalis



Neptune grass
Posidonia oceanica

mangroves

FAMILIES: Acanthaceae, Rhizophoraceae, and others **CLASS:** Magnoliopsida

Mangroves are saltwater-tolerant trees that form intertidal forests on sheltered shorelines in warmer parts of the world. They are important for terrestrial and marine life, especially for juvenile fish that find shelter among their roots (see pp.106–107). Trees from several different plant families have evolved to become mangroves.

In the mangrove ecosystems of Florida and the Caribbean, three species predominate. The red mangrove, *Rhizophora mangle*, grows at the seaward boundary, propping itself up with arched roots growing from high up on its stems. The upper parts of these roots absorb oxygen, which is passed on to the parts buried in the mud below. The seeds germinate into long, pointed seedlings while still on the tree; when they fall, they often spear themselves into the mud and start growing immediately. Black mangroves, *Avicennia germinans*, grow landward of red mangroves. Their buried roots produce peglike structures called pneumatophores that grow vertically upward into the air to obtain oxygen. The white mangrove, *Laguncularia racemosa*, grows farther inland. The Indo-Pacific region has similar, although more species-rich, mangrove forests.



***Rhizophora* seedlings**

This illustration shows how the long, spearlike *Rhizophora* seedlings grow while still attached to the tree before they drop and leave the empty fruits behind.



Black mangrove
Avicennia germinans



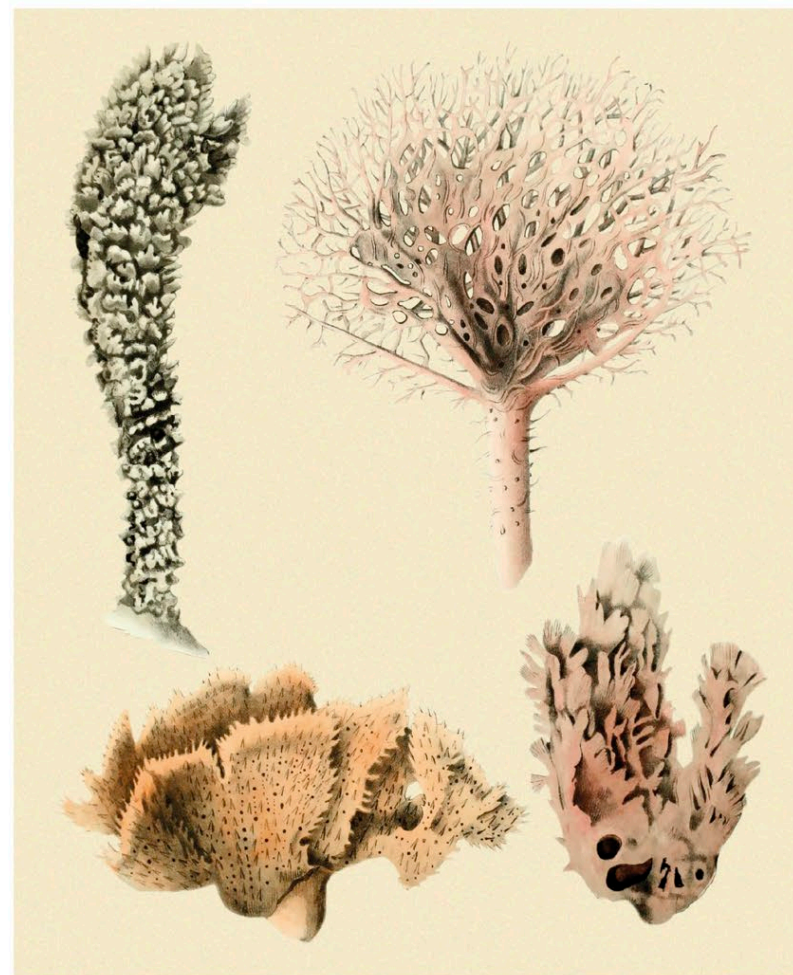
Red mangrove
Rhizophora mangle

sponges

PHYLUM: Porifera **KINGDOM:** Animalia

Sponges are multicellular animals with very simple structures. They live attached to one spot on the seafloor, and many colorful species are commonly found on coral reefs. Although sometimes large in size, sponges do not have a nervous system or specialized organs. The simplest species are shaped like a hollow cup or vase. They take in water through small pores in their sides and force it out through a larger hole at the top of the body, sifting out small food particles in the process. The water current is created by tiny beating hairs (flagella) on thousands of cells in the body wall. Some sponges have a more complicated structure with internal chambers and channels. In some species, the individuals merge together to form colonies.

Sponges' bodies are supported by various structural elements. Demosponges, the most common subgroup, have bodies supported by a tough protein called collagen. In calcareous species, tiny skeletal units called spicules made of calcium carbonate form the skeleton. The deep-sea glass sponges also have spicules but made of silica. Spicules come in many geometric shapes and are used to identify species.

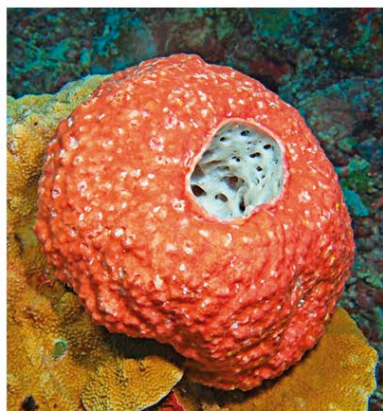


Varied forms

This plate from an 1864 French book on Caribbean sponges shows some of the many growth forms of different sponge species.



Calcareous sponge
Callyspongia plicifera



Demosponge
Class Demospongiae



Demosponge
Clathrinidae family



Glass sponge
Class Hexactinellida

sea anemones and stony corals

SUBCLASS: Hexacorallia **CLASS:** Anthozoa **PHYLUM:** Cnidaria

These animals, along with others such as jellyfish, belong to the Cnidaria, a phylum noted for the stinging cells on their body surfaces. The body, known as a polyp, is cup-shaped, with a single stretchable, slitlike mouth surrounded by tentacles. Sea anemones grab shrimp and small fish with their tentacles or in some cases feed on plankton. They have no head or brain, and their movements are slow—they typically stay anchored to a rock or half-buried in sediment. However, they can be surprisingly mobile when avoiding predators. Some tropical species can reach 3ft (1 m) across.

The stony corals are relatives of sea anemones. A few are solitary, but most species are colonial. Small individual polyps multiply by budding and remaining connected together, resulting in a continuous tissue of thousands of individuals. Coral polyps build a permanent growing support by laying down a chalky skeleton below their bodies, the shape of which depends on the species. Stony corals are the main creators of reefs such as the Great Barrier Reef. Although corals are animals, many shallow-water species contain symbiotic algae (zooxanthellae) that contribute to their food supply.



Sea anemones

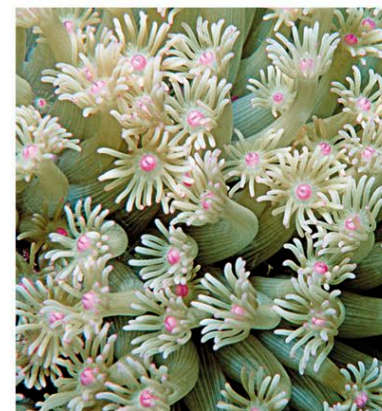
As well as showing sea anemones' shape and variety, this plate shows their typical slitlike mouth (fig. 7) and their appearance when the tentacles are withdrawn (fig. 9).



Northern red anemone
Urticina felina



Magnificent sea anemone
Heteractis magnifica



Flowerpot coral
Genus *Goniopora*

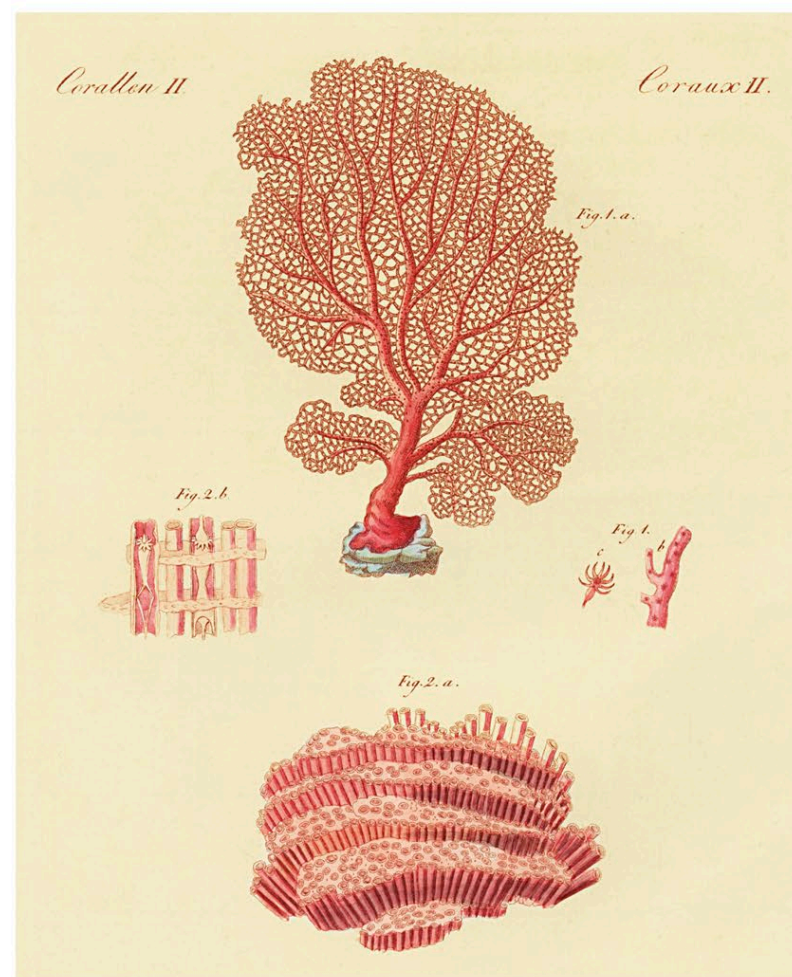


Boulder brain coral
Colpophyllia natans

soft corals, sea fans, and sea pens

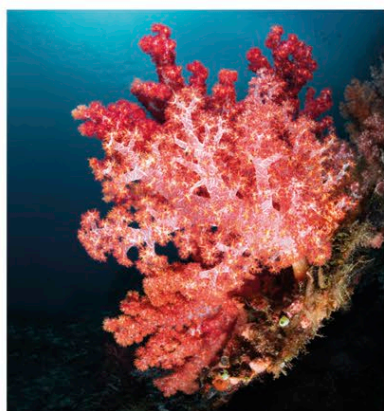
SUBCLASS: Octocorallia **CLASS:** Anthozoa **PHYLUM:** Cnidaria

Known as octocorals, these marine animals form colonies of small polyps. Unlike stony corals (see p.333), the polyps have only eight tentacles, each with short side branches that give them a feathery appearance when seen up close. The polyps usually withdraw into the colony body if threatened. There are a great variety of octocorals. They mainly feed on small organisms and drifting algae, and their stinging cells are not dangerous. The colonies live attached to underwater surfaces, but their swimming larvae allow them to disperse to other locations. The skeletons of octocorals lie within their tissues rather than outside and below their bodies as in stony corals. Some species, such as dead man's fingers, are soft to the touch when the polyps are extended. Other colonies are stiffened by small, hard particles called sclerites, or have a continuous branching skeleton of horny protein called gorgonin. Sea fans and sea whips have a continuous skeleton. They are common on coral reefs and sift food particles from water currents. A few species, such as blue coral and organ pipe coral, resemble stony corals. Sea pens and sea pansies live on soft sediments, using an enlarged burrowing polyp to anchor their colonies.



Fans and pipes

This illustration from Friedrich Bertuch's *Bilderbuch für Kinder* shows an organ pipe coral (bottom) and a sea fan (top). The small polyps (enlarged) can retreat into the skeletons for protection.



Common soft coral
Dendronephthya hemprichi



Orange sea pen
Ptilosarcus gurneyi



Venus sea fan
Gorgonia flabellum



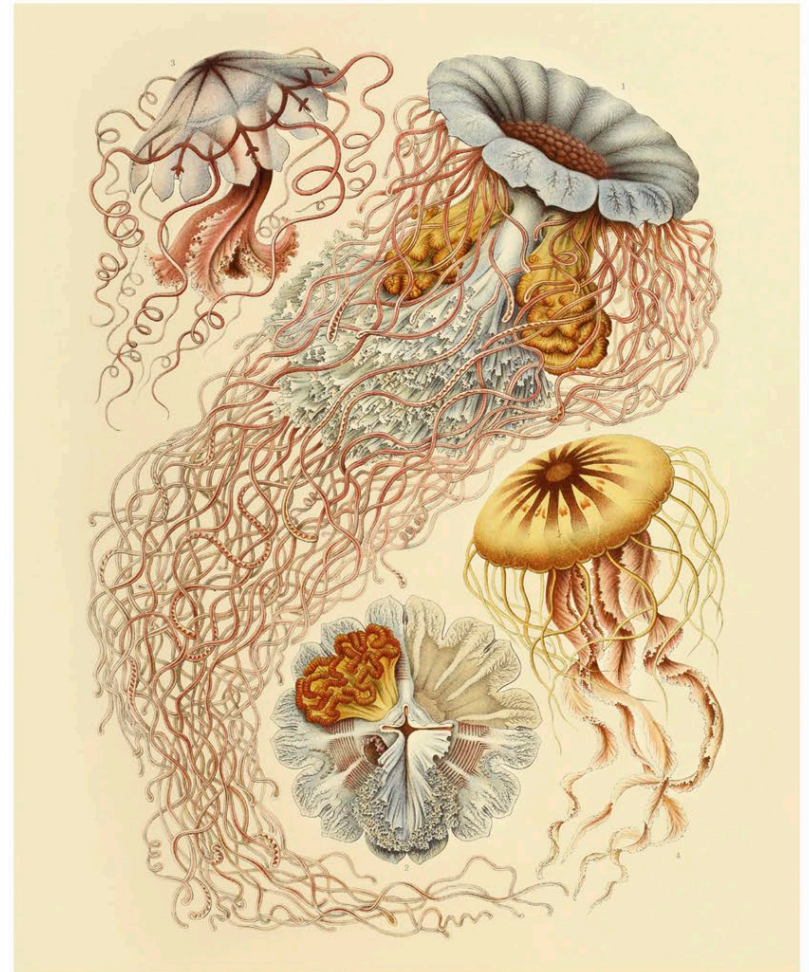
Red whip coral
Ellisella cercidia

jellyfish

CLASS: Scyphozoa **PHYLUM:** Cnidaria

Jellyfish are a little like upside-down sea anemones (see p.333). Their body form is called a medusa and is shaped like a bell. The mouth is on the underside, with four or eight frilly “arms” dangling from it, and there are usually stinging tentacles around the edge of the body. Depending on the species, jellyfish stings can be dangerous to humans. There is no hard skeleton, but the upper part of the body contains a stiff, jellylike layer of tissue called mesoglea. Jellyfish swim by contracting the muscles around the rim of their bell, which also contains sensory pits to detect light and body angle. Most jellyfish are predators of fish and other large prey. The sexes are usually separate, and the eggs hatch into tiny, swimming larvae. In most shallow-water species, the larvae settle on undersea surfaces and grow into small polyps, which eventually transform or split into miniature swimming medusae.

Rhizostome jellyfish have eight finely subdivided arms, which are partly fused together, but no tentacles. They trap planktonic organisms in mucus and ingest them through the many “micro mouths” on their arms. Deep-sea jellyfish have taller bells and fewer, stiffer tentacles.



Arms and tentacles

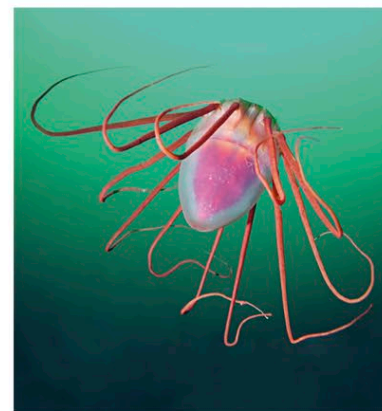
This illustration from Ernst Haeckel's *Kunstformen der Natur* (1904) shows the outer tentacles and long, frilly arms dangling from the mouths of these jellyfish.



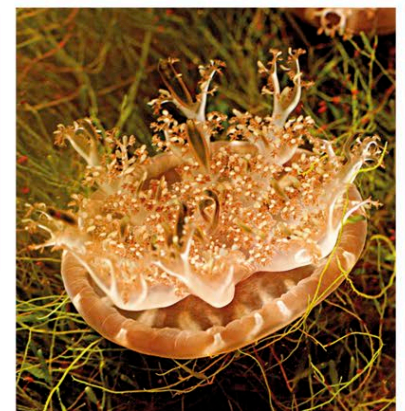
Mauve stinger jellyfish
Pelagia noctiluca



Moon jelly
Aurelia aurita



Helmet jellyfish
Periphylla periphylla



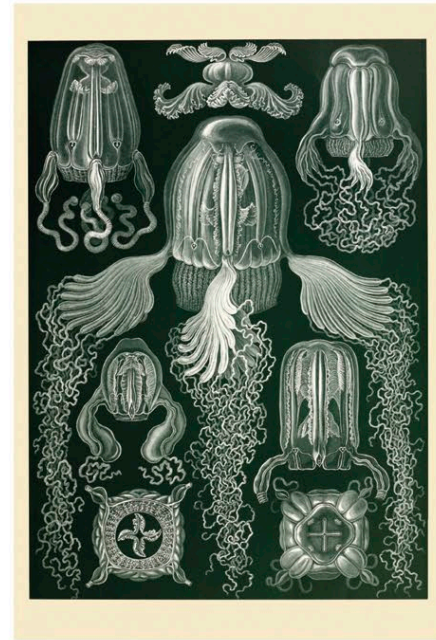
Upside-down jellyfish
Cassiopea ornata

box jellyfish

CLASS: Cubozoa **PHYLUM:** Cnidaria

Box jellyfish are named for the cubelike shape of their bell; one or several tentacles grow from each corner of the bell rim. They are mainly found in warmer seas and are notorious for the excruciating pain, sometimes death, that the stings of certain species inflict on humans. The largest species, with tentacles up to 10 ft (3 m) long, is called the sea wasp for this reason. Much smaller transparent species, collectively called irukandji jellyfish, are also extremely venomous and deadly.

Box jellyfish are most abundant in tropical Australian and east Asian waters. They can swim much faster than ordinary jellyfish (see p.335) and actively seek prey, aided by special-purpose eyes on the sides of their bodies that help in hunting and dodging obstacles.



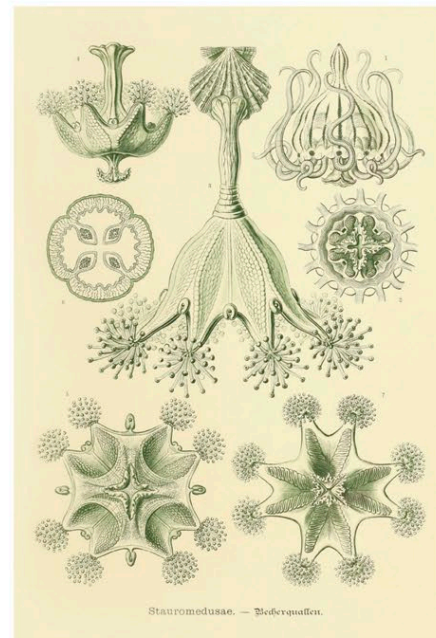
Box jellyfish

This plate from Ernst Haeckel's *Kunstformen der Natur* (1904) illustrates how the tentacles of box jellyfish grow from the corners of their bells.

stalked jellyfish

CLASS: Staurozoa **PHYLUM:** Cnidaria

Growing to only a few inches high, these small, funnel-shaped marine animals attach to seaweed or other surfaces using a muscular stalk. They are mostly found in cooler regions of the world. The adults have eight clusters of short, stinging tentacles around the bell rim, which they use to subdue prey such as small invertebrates. They can change position by detaching their stalk and “somersaulting.” Stalked jellyfish have no swimming stage in their life cycles: eggs hatch into tiny larvae that settle on a surface and grow into polyps with eight long tentacles. The polyps then transform into the medusalike adults. Recent research indicates that stalked jellyfish evolved before present-day swimming jellyfish and have not descended from them as was previously thought.



Stalked jellyfish

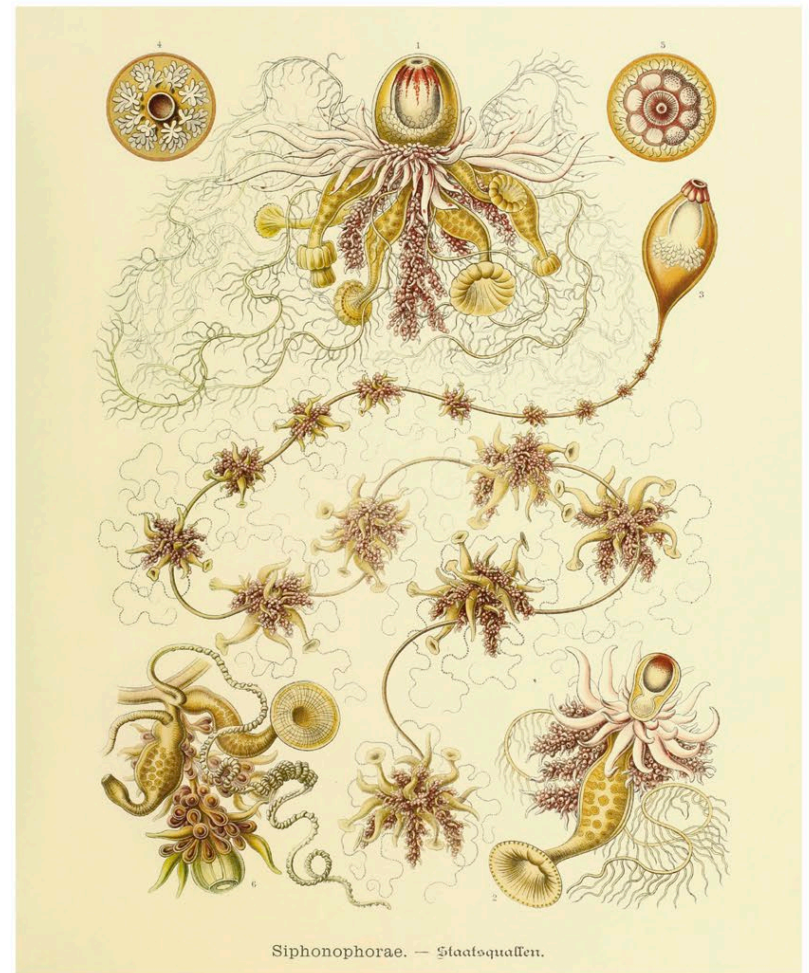
This illustration from *Kunstformen der Natur* shows the trumpet-shaped body and eight bunches of tentacles of a stalked jellyfish.

hydrozoans

CLASS: Hydrozoa **PHYLUM:** Cnidaria

Hydrozoans are mainly colonial cnidarians with complex life cycles that alternate between a fixed polyp stage and a swimming medusa stage, although some species have only one or the other. Those termed hydroids grow as small anchored colonies of tiny polyps, typically branched and with a tough coating. All polyps are connected by a continuous internal cavity, which helps in sharing of food. The colonies are sometimes mistaken for small seaweeds. Most of the polyps are for feeding, but others are specialized for defense or reproduction. The last of these usually give rise to small swimming medusae.

The siphonophores are even more specialized. The Portuguese man o' war is a colonial organism with one polyp enlarged as a gas-filled float and other smaller, stinging and reproductive polyps clustered in tentacles below it. Other species may form chains that are several feet long and include polyps specialized as swimming bells. The widespread floating "by-the-wind sailor" and "blue button," although not siphonophores, are also colonies of polyps. In contrast, the tropical fire corals are coral-like hydrozoans that can deliver a painful sting.



Siphonophore shapes

These complex colonial hydrozoans consist of groups of polyps specialized for feeding, reproduction, propulsion, and buoyancy.



Blue button
Porpita porpita



Cypress sea-fern
Aglaophenia cupressina



Portuguese man o' war
Physalia physalis

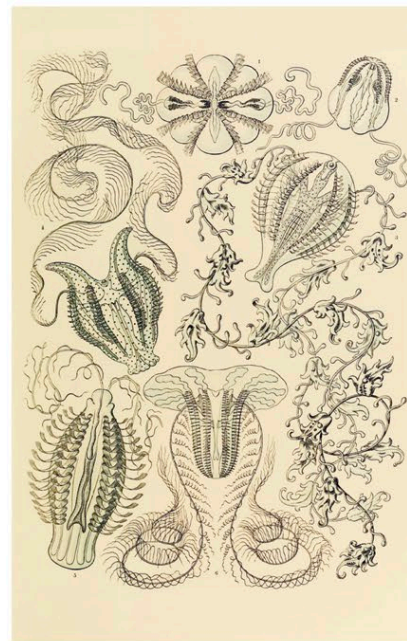


Ringed tubularia
Ectopleura larynx

comb jellies

PHYLUM: Ctenophora **KINGDOM:** Animalia

Comb jellies are free-floating marine animals that look similar to jellyfish but are not closely related. They have transparent bodies that are usually oval-shaped but are sometimes long and beltlike. Comb jellies have eight bands running down the outer surface of their bodies, each comprising comblike rows of beating microscopic hairs that enable them to swim—ctenophore literally means “comb-bearer.” They are predators that mainly eat small animals in the plankton, but some species eat other comb jellies. Most have a pair of long, branched, retractable tentacles that can grab and stick onto their prey. Many comb jellies are bioluminescent and can produce their own light. There are a few specialized types that live on the seafloor.



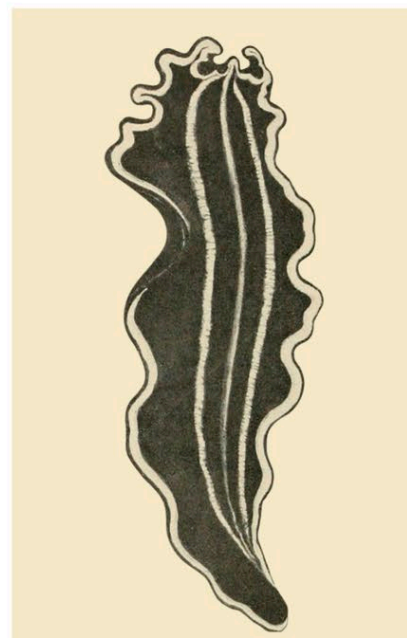
Adult ctenophores

This plate from Ernst Haeckel's *Kunstformen der Natur* (1904) shows a variety of comb jellies with their “comb rows” and two long tentacles.

flatworms

PHYLUM: Platyhelminthes **KINGDOM:** Animalia

Flatworms live in many habitats in the oceans, fresh water, and damp places on land. Due to their flat shape, they can get enough oxygen without needing specialized gills. Unlike ctenophores and cnidarians, but like most other animals, they have a left and a right side and a head and a tail. Flatworms are mostly predators and have a tubelike mouth on their underside, which also acts as the anus. They crawl along using muscles or tiny beating hairs; some species can swim. The most prominent marine flatworms are the colorful polyclads, commonly found on coral reefs. They are typically oval in shape with frilly margins and are sometimes mistaken for sea slugs but are much flatter. Tapeworms are the longest flatworms and are parasites of vertebrates.



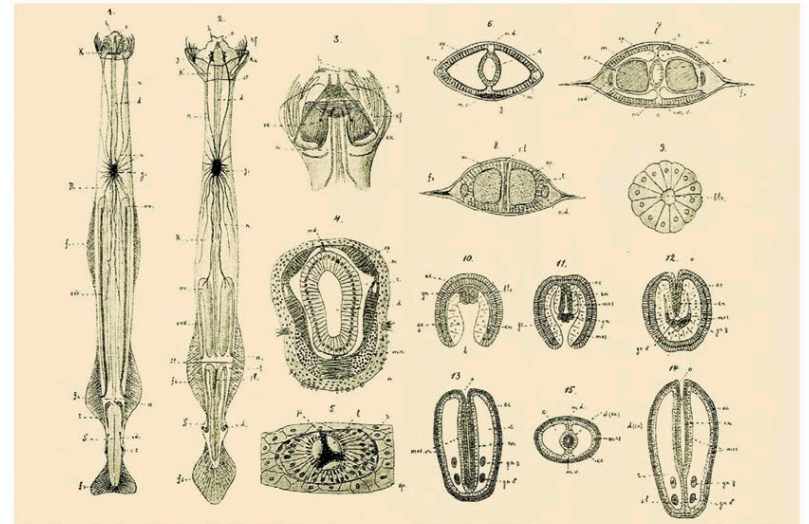
Philippine flatworm

This black-and-white image from a work on the polyclad flatworms of the Philippines shows the “pseudo-tentacles” polyclads create by making folds at the end of the head.

arrow worms

PHYLUM: Chaetognatha **KINGDOM:** Animalia

Arrow worms are small, dart-shaped predators that exist in large numbers in the plankton and on the seabed, forming an important part of the marine food chain. Over 100 species have been described, growing up to 5 in (12 cm). They are hermaphrodites (individuals have both male and female reproductive organs), and the eggs develop directly into miniature adults. Arrow worms have stiff but flexible transparent bodies equipped with fins. On detecting prey, such as a copepod or fish larva, an arrow worm darts forward with flicks of its tail and grasps the prey with tough mouth bristles, sometimes injecting venom. Some species follow their prey by rising to the surface at night and sinking down during the daytime. Arrow worms in turn are food for many other animals, such as jellyfish and manta rays.



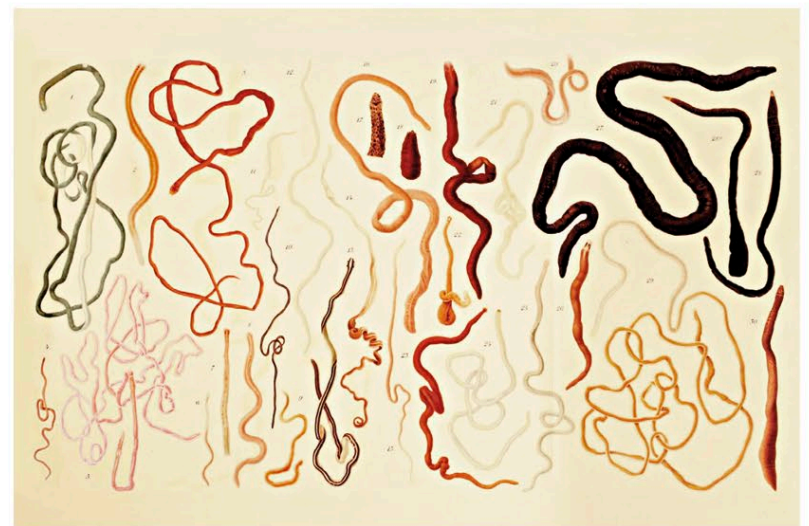
Bristle-jawed worms

This illustration shows the dartlike shapes of arrow worms. Chaetognatha, meaning "bristle-jaws," describes the bristles in their mouth, visible in fig 3.

ribbon worms

PHYLUM: Nemertea **KINGDOM:** Animalia

Ribbon worms are an unusual phylum of predatory worms that mainly crawl on the ocean floor, although some can swim. Typically long, slow-moving, and narrow-bodied, they have soft, mucus-covered skin and hunt using a unique proboscis. This tubelike structure, sometimes equipped with a spine, can be shot out from the head or mouth to grab prey such as other worms and subdue them with toxins. Ribbon worms are also scavengers and may live with other animals, either as a parasite or by sharing their food. Some species have bright colors and patterns. The bootlace worm, *Lineus longissimus*, is probably the world's longest animal, growing to an incredible 100 ft (30m) or more. It feeds partly by absorbing dissolved organic substances through its skin.



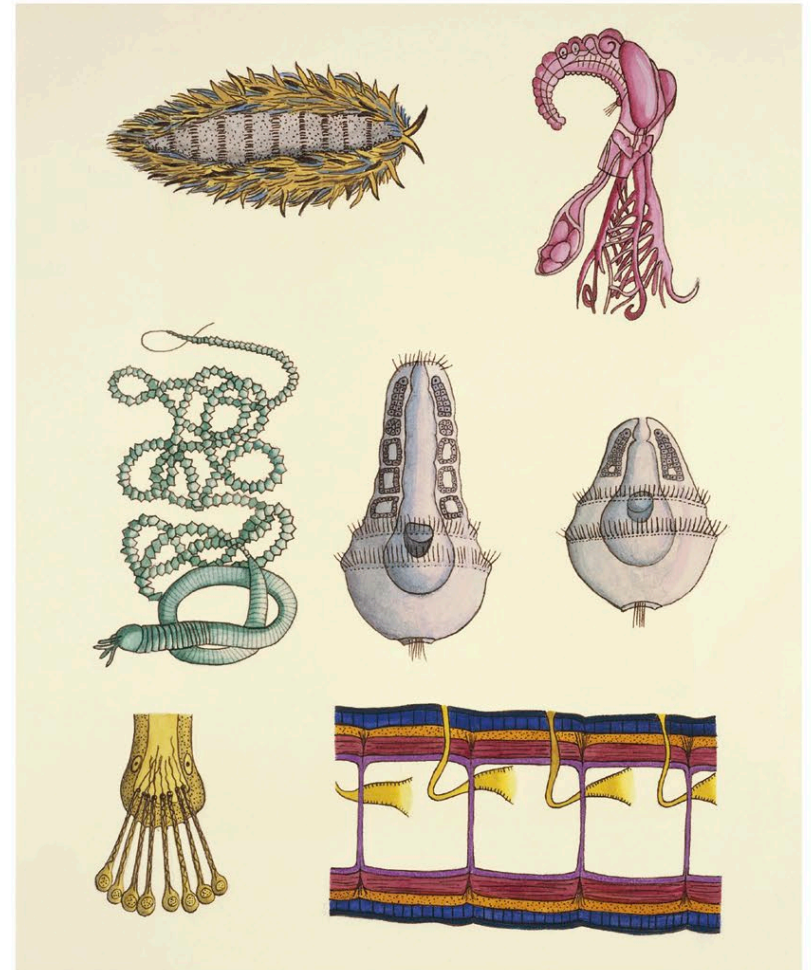
Ribbon worm variety

This illustration, from a work on the marine ribbon worms of the Gulf of Naples in Italy, shows the varied colors and elongated shapes of these worms.

segmented worms

PHYLUM: Annelida **KINGDOM:** Animalia

Segmented worms, or annelids, include thousands of species of marine worms, as well as earthworms and leeches that live on land. Most marine annelids belong to a group called the polychaetes, which means “many bristles” and reflects the fact that polychaetes often have bristly, leglike protrusions down the sides of their bodies. Internally, their bodies are partitioned into segments, often marked by rings on the outside. A majority of polychaetes live on or in the seafloor, although some swim in the plankton. Many live in burrows or create permanent protective tubes for themselves. The latter includes fan worms, whose elaborate fans spread out to filter tiny food particles but can quickly withdraw if danger threatens. Some polychaetes, such as ragworms, have sharp jaws and are active predators that crawl or swim toward their prey. Lugworms, common in muddy estuaries, swallow mud to extract nutrients. Polychaetes release sperm and eggs separately into the sea; after fertilization, the eggs turn into free-swimming larvae. Some relatives of earthworms and leeches are also marine, although most live in fresh water or on land.

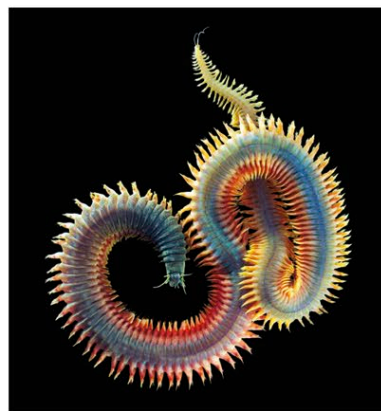


Aphrodita aculeata

This image shows various features of the sea mouse (shown top left), including two stages of its swimming larva (center and center right).



Christmas tree worm
Spirobranchus giganteus



King ragworm
Alitta virens



Magnificent feather duster
Sabellastarte magnifica



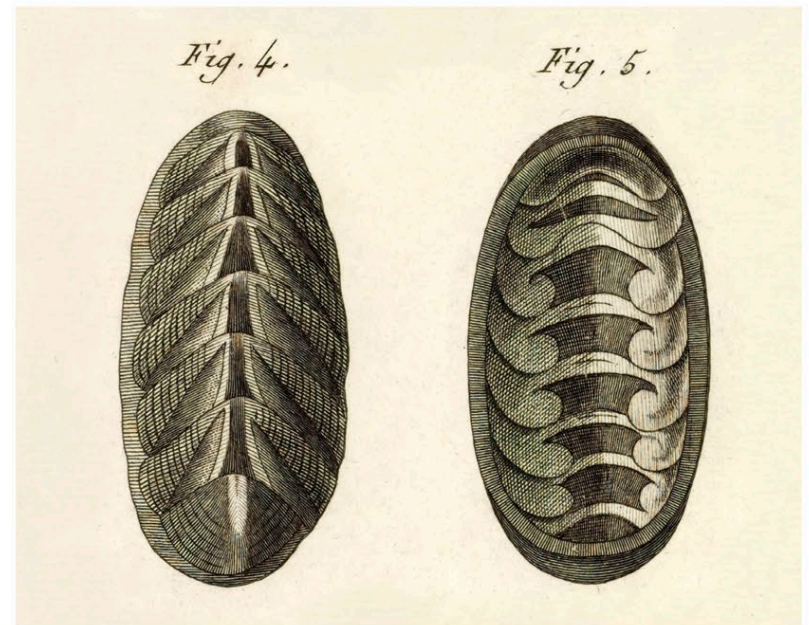
Sea mouse
Aphrodita aculeata

chitons

CLASS: Polyplacophora **PHYLUM:** Mollusca

Chitons are primitive members of the phylum Mollusca, which also includes snails, bivalves, squid, and octopuses. They display many anatomic features that are probably ancestral to mollusks. They crawl along slowly on a muscular “foot” and typically cling to underwater rocks or seaweed. They have a rasping, tonguelike structure called a radula, which is armed with tiny, sharp teeth for scraping food. A fleshy structure called the mantle covers the animal’s back, overlaps its sides, and secretes a chalky shell for protection. The protective shell consists of eight interlocking plates that are arranged in a line from front to back. The mantle projects out from around the shell to form a girdle, the upper surface of which is often colored or decorated with hair.

Chitons are mainly found in shallow seas and most graze on tiny algae, although some eat nonmoving animals such as sponges. Chiton eggs, like those of most mollusks, hatch into tiny, free-swimming larvae called trochophores, which later settle down and turn into adult forms. The largest species of chitons can be 12in (30cm) long, but most are a lot smaller.



Polyplacophora

Unlike other mollusks, the shell of a chiton is made up of eight separate sections. The scientific name for chitons is Polyplacophora, meaning “bearing many plates.”



West Indian fuzzy chiton
Acanthopleura granulata



Bristled chiton
Acanthochitona fascicularis



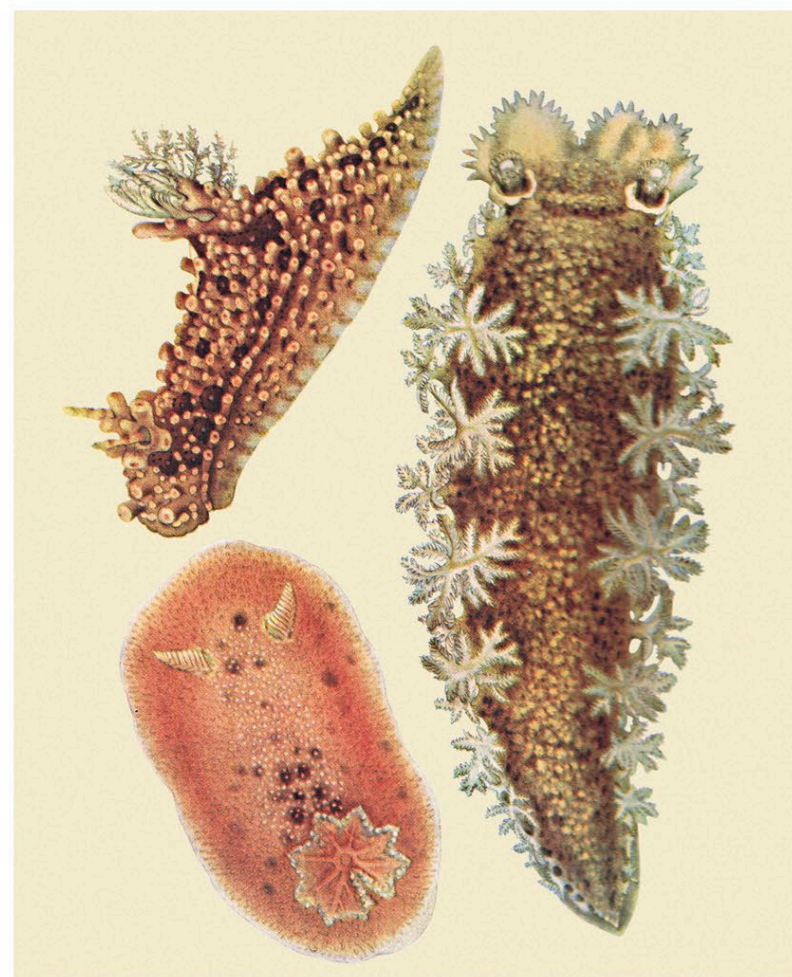
Lined chiton
Tonicella lineata

snails and sea slugs

CLASS: Gastropoda **PHYLUM:** Mollusca

Snails and slugs (gastropods), both marine and land types, are the largest class of mollusks in terms of species. Like chitons (see p.341), they have a crawling foot, a radula, and a mantle that secretes the shell, but they are more active and have a definite head, generally equipped with eyes and tentacles. The shell is usually coiled, and the animal can withdraw into it, often protected by a hard “door” called an operculum. Some gastropods such as limpets graze algae, while others are carnivorous or eat dead material. In whelks and cone shells, which belong to the subgroup Neogastropoda, the mouth and radula are on the end of a proboscis and can be pushed into the prey’s flesh. Some whelks can drill holes in bivalve shells, while cone shells use their proboscis as a harpoon, injecting venom in fish and other prey.

Sea slugs either have no shell or have a small one hidden in their bodies. Most are not related to land slugs. The colorful nudibranchs that are common on coral reefs are carnivorous, but there are other species that graze algae. There are also many swimming gastropods, especially the sea butterflies and the sea angels.



Nudibranchs

This 19th-century illustration shows three nudibranch sea slugs. Nudibranch means “naked gill” and describes the gills on their bodies, visible as tufted structures on the sides and back.



Flamingo tongue snail
Cyphoma gibbosum



Red-lined bubble snail
Bullina lineata



Magnificent chromodoris nudibranch
Chromodoris magnifica



Tiger cowrie
Cypraea tigris

bivalves

CLASS: Bivalvia **PHYLUM:** Mollusca

This group of mollusks includes oysters, mussels, scallops, and clams. About two-thirds of bivalves are marine, while the remainder live in fresh water. All species have two half-shells or “valves,” one on each side of the body, with a hinge between them that is anatomically positioned on the upper (dorsal) surface. In most species, the valves can shut together tightly for protection when necessary. Bivalves have no head and a greatly reduced brain. Most are sedentary animals that burrow in ocean sediments or attach themselves to hard surfaces. Some, such as shipworms, burrow into sunken wood or bore into stone to create secure habitats. Bivalves have a foot, which is not used for gliding along but may be long and pointed for burrowing or to create sticky threads for attaching to rocks. Most bivalves filter-feed using large, specially modified gills under their shells. Burrowing species extend tubes called siphons into the open water: one draws in water and food particles, while the other expels water and waste material. The largest bivalve, the giant clam, obtains food from the microscopic algae in its tissues.



Oyster shells

This illustration from an 1853 work depicts oyster shells from different angles. Oysters cement onto rocks and develop thick, irregular-shaped shells that show annual growth rings.



Zebra mussel
Dreissena polymorpha



Cockscomb oyster
Lopha cristagalli



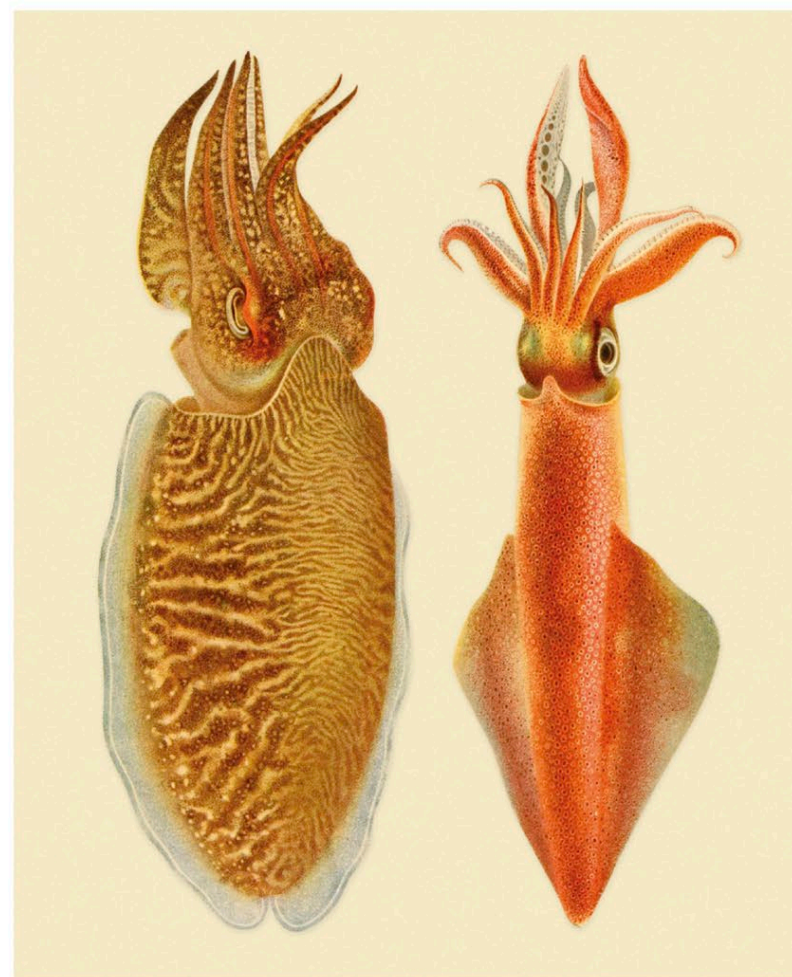
Fluted giant clam
Tridacna squamosa

squid and cuttlefish

SUPERORDER: Decapodiformes **CLASS:** Cephalopoda **PHYLUM:** Mollusca

These carnivorous animals, along with their octopus relatives, have bodies in which the original molluscan foot has become the front body, equipped with grasping arms. Squid and cuttlefish have large brains, excellent eyesight, and a mouth with a hard, parrotlike beak. They have two long tentacles and eight arms, all bearing suckers that usually (except in cuttlefish) feature a circle of sharp “teeth” or pointed hooks. There are many deepwater squid, including the two largest species, the giant squid (the longest including the tentacles) and the colossal squid (with a larger, more muscular body). Most squid are fast-moving predators, propelling themselves partly by squirting water out of a flexible tube (siphon), and some species can shoot themselves into the air like flying fish. Cuttlefish are slower, using their fins for movement.

Squid have an internal stiffening rod called a pen, while cuttlefish have a larger, porous “cuttlebone” that they use to adjust their buoyancy. Masters of camouflage, both squid and cuttlefish can confuse predators by squirting out a cloud of ink. Their eggs typically develop into miniature adults, not larvae.



Large predators

The broad body of a European cuttlefish (left) contrasts with that of a streamlined squid (right). The unusual w-shaped eye pupil of cuttlefish can also be seen.



Giant cuttlefish
Sepia apama



Broadclub cuttlefish
Sepia latimanus



Bigfin reef squid
Sepioteuthis lessoniana



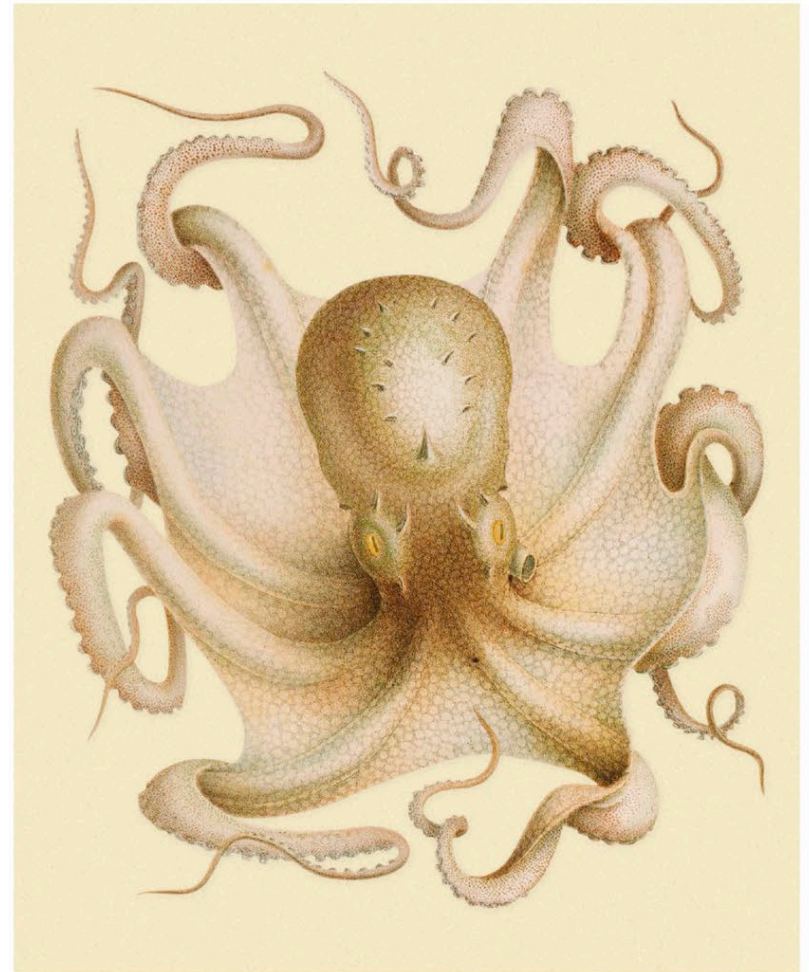
Hummingbird bobtail squid
Euprymna berryi

octopuses

SUPERORDER: Octopodiformes **CLASS:** Cephalopoda **PHYLUM:** Mollusca

Octopuses are intelligent marine animals. They are similar to squid in that they possess eight suckered arms, a horny beak, and jet-propulsion ability, but they do not have a pair of longer tentacles, and their suckers lack hooks or “teeth.” Their bodies are devoid of an internal stiffening rod, enabling them to squeeze through narrow spaces. The “typical” octopuses of shallow seas live on the seafloor, hunting prey such as crabs and mollusks, crawling along using their arms. They often choose a retreat or den to shelter in. Just like squid, octopuses usually die after breeding once; however, the females guard and care for their eggs, even though they starve themselves.

Many octopuses live in open water. Those near the surface of the ocean include the argonauts, whose females secrete delicate, chalky shells with their arms to protect their eggs. There are also species that swim and hunt in the twilight and dark zones. Thought to be more primitive in evolutionary terms, many of these deepwater species have tentacles connected by a web of tissue and swim in a similar way to jellyfish.



Common octopus

This species, *Octopus vulgaris*, is common in the north Atlantic. Its propulsive siphon can be seen in the image below its left eye.



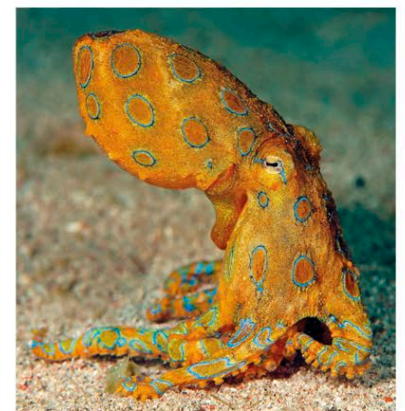
Knobbed argonaut
Argonauta nodosa



Common octopus
Octopus vulgaris



Day octopus
Octopus cyanea

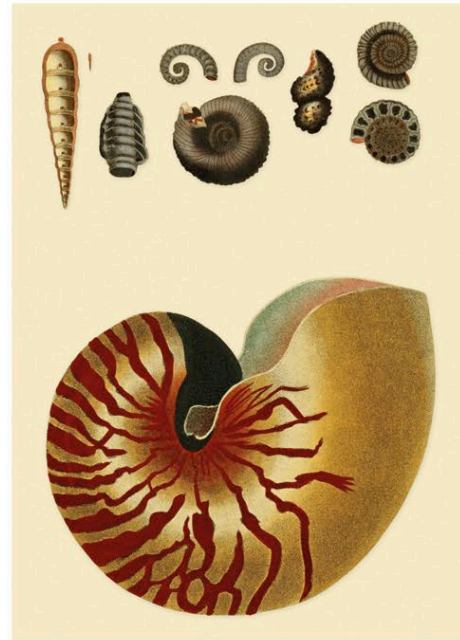


Greater blue-ringed octopus
Hapalochlaena lunulata

nautilus

SUBCLASS: Nautiloidea **CLASS:** Cephalopoda **PHYLUM:** Mollusca

Nautilus are an ancient group of shelled cephalopods with only five living species, all from the western Pacific. They swim slowly and hunt near the ocean floor at depths of 330 ft (100m) or more, feeding on animals such as crabs and dead fish. Nautilus have a horny beak like other cephalopods and up to 90 suckerless arms. Their coiled shell is divided into separate airtight chambers, with new ones being created as the animal grows. The body of the organism occupies the end chamber, while other chambers contain air or water, which can be adjusted to alter the animal's buoyancy. Nautilus can live for 20 years or more and can breed repeatedly. They lay only a few large eggs each time, which hatch to produce shelled juveniles that are miniatures of their parents.



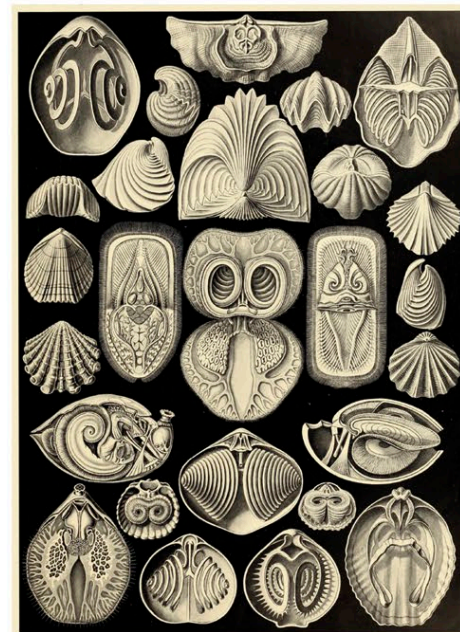
Shelled organisms

This plate from 1810 shows a nautilus shell in the main image alongside other shells for comparison, including fossil ammonoids, nautilus' extinct relatives.

lamp shells

PHYLUM: Brachiopoda **KINGDOM:** Animalia

Lamp shells, or brachiopods, are two-shelled invertebrates that resemble bivalve mollusks (see p.343) on the outside but have a completely different body structure. Their shells are of unequal sizes and represent the top and bottom (not the left and right sides as in the case of bivalves) of the animal, which usually attaches to the seafloor via a muscular stalk. The main body lies toward the back, between the shells near the stalk, while the front space is occupied by a lophophore—a coiled, U-shaped filtering organ with tentacles. When the shells open, the animal draws water through the lophophore and extracts food particles. There are more than 400 living species of brachiopods. Most are small; the largest have shells up to 4 in (10 cm) long.



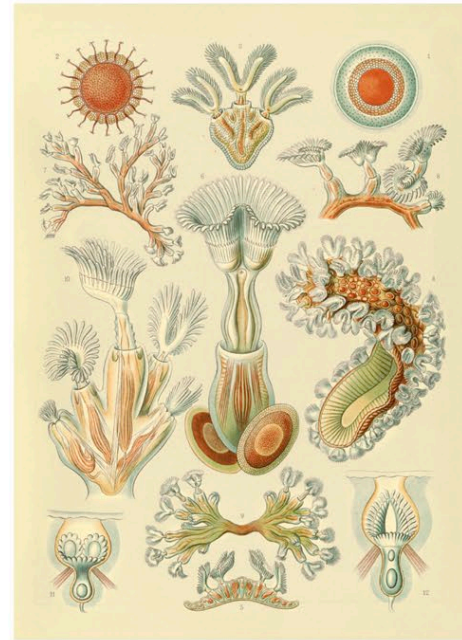
Unique anatomy

This illustration from Ernst Haeckel's *Kunstformen der Natur* (1904) shows the structure of brachiopod shells, as well as cutaway views of the animals inside.

moss animals

PHYLUM: Bryozoa **KINGDOM:** Animalia

Moss animals, or bryozoans, are related to lamp shells, and like them, they filter feed using a lophophore. However, they are very different in appearance. Bryozoans grow as colonies of connected, genetically identical individuals called zooids, each zooid being only around 0.5 mm across. In that respect, they resemble cnidarian colonies, but bryozoans are more anatomically complex, with each zooid having a two-ended digestive system. They grow as mats on top of seaweed fronds or form branched structures up to a few inches high on undersea surfaces. Each zooid is protected by a tough or chalky box, and some are specialized for defense, reproduction, or storing nutrients. There are about 6,000 living species and about the same number of fossil ones.



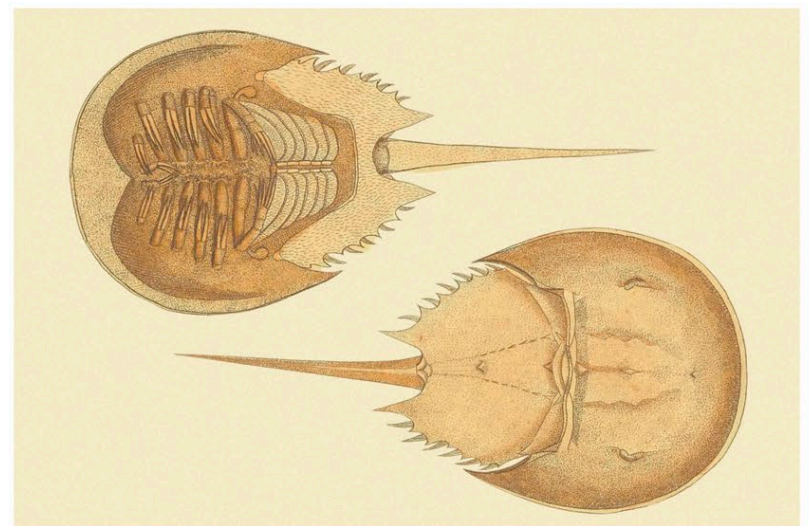
Moss animals

This illustration from *Kunstformen der Natur* depicts a variety of moss animals. They are shown with their feeding structures (lophophores) extended.

horseshoe crabs

CLASS: Merostomata **SUBPHYLUM:** Chelicerata **PHYLUM:** Arthropoda

Named after their horseshoe-shaped headshield (carapace), horseshoe crabs are primitive arthropods—jointed-legged animals that also include crustaceans, spiders, and insects. They are not true crabs but an ancient group of marine animals more closely related to spiders. Only a few species of horseshoe crabs are alive today. They have five pairs of walking legs underneath the carapace and a movable spine at the rear end that they use to rotate themselves if turned upside down. Horseshoe crabs are seafloor animals that feed on a wide variety of food, both living and dead. They assemble in large numbers on sandy shorelines during the breeding season to mate, after which the females bury their eggs for protection until they hatch.



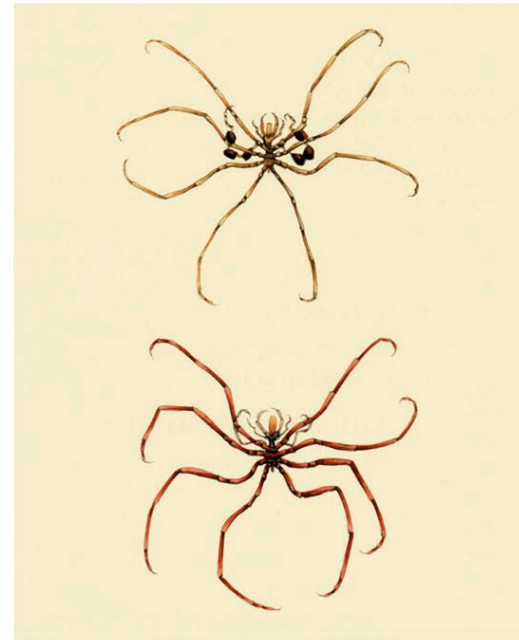
Limulus polyphemus

This illustration shows the exoskeleton and the underside (top) of the Atlantic horseshoe crab. Pincerlike appendages (chelicerae) near the mouth are used for capturing and consuming prey.

sea spiders

CLASS: Pycnogonida **SUBPHYLUM:** Chelicerata **PHYLUM:** Arthropoda

Sea spiders are marine arthropods that live in seafloor habitats throughout the world. They have an unusual body shape—their main body is tiny in comparison to their legs, and some of their body systems, such as the digestive and reproductive systems, extend into the legs. Sea spiders usually have four pairs of walking legs, but some species have five or six. Most are small, but the largest species can have leg spans of up to 30 in (75 cm). Although usually classified in the same subphylum as land spiders (Chelicerata), the two groups are distinctly different. Sea spiders are predators that mainly feed on nonmoving animals such as corals and sponges. Their mouthparts include a pair of small claws called chelifores and a tubular proboscis for sucking up food.



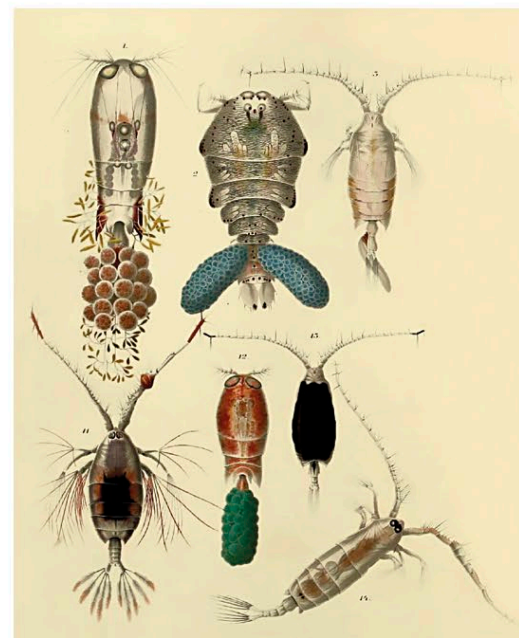
Male brooding

After mating, male sea spiders glue the female's eggs together into batches and carry them on modified legs called ovigers until they hatch.

copepods

CLASS: Copepoda **SUBPHYLUM:** Crustacea **PHYLUM:** Arthropoda

Copepods, like shrimp and crabs, are crustaceans, the largest group of arthropods found in the oceans. Free-swimming copepods exist in large numbers in the plankton and are a vital part of the marine food chain. Typically only 1–2 mm long, they have distinctive long antennae and feed by filtering tiny phytoplankton from the water with sievelike mouthparts, as well as by attacking other small animals. Many copepods undergo daily “vertical migration,” retreating to deeper water during the day to avoid predators and rising to the surface at night. Some live on the seafloor, while many others are parasites of fish and of other invertebrates. Parasitic copepods can grow as long as 12 in (30 cm) and often have body shapes that are completely different from their free-living relatives.



Copepod collection

This illustration shows a variety of open-water copepods displaying their typical long antennae, as well as the egg sacs that are typically carried by females before hatching.

barnacles

CLASS: Cirripedia **SUBPHYLUM:** Crustacea **PHYLUM:** Arthropoda

Barnacles are often mistaken for mollusks rather than crustaceans, because they live anchored to one spot and protect themselves by secreting chalky plates around their bodies. The shrimplike organism lives inside, capturing food particles from seawater by extending its feathery legs. Barnacles mainly come in two shapes: goose-necked barnacles, which are larger and have a flattened body that sits on top of a muscular stalk; and acorn barnacles, in which the body cements directly onto rocks or other surfaces and resembles a tiny volcano. Although adult barnacles cannot move around, the larvae can swim and select new sites to settle on. Some barnacle species are parasitic and look completely unlike the free-living types.



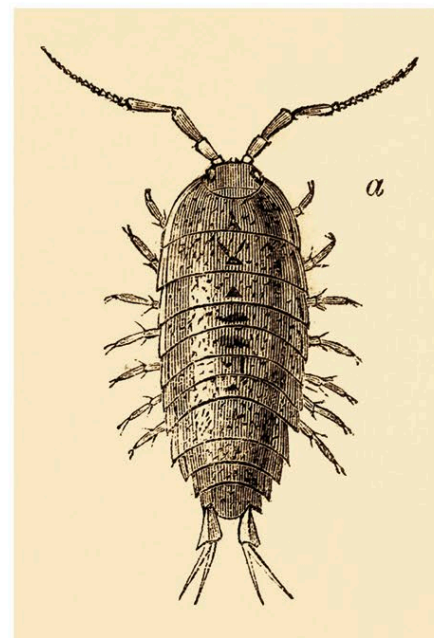
Megabalanus tintinnabulum

This large species of acorn barnacle is often found on ships' hulls and man-made structures worldwide.

sea slaters and relatives

ORDER: Isopoda **SUBPHYLUM:** Crustacea **PHYLUM:** Arthropoda

Isopods include the land-living woodlice, as well as thousands of marine species. They typically have flattened bodies protected by a series of horny plates. The sea slaters of the shoreline can survive above or (temporarily) below water, but most marine isopods are fully aquatic, crawling or burrowing on the seafloor. They usually feed on dead material or algae, with the exception of one subgroup that are parasites of other crustaceans. One notorious species, the gribble, destroys timber pilings by tunneling into the wood and eating it. Female isopods have brood pouches on their underside to protect their eggs, which hatch into miniature adults and not free-swimming larvae like other crustaceans. Most isopods are small, but giant species from the deep sea can reach up to 20in (50cm) long.



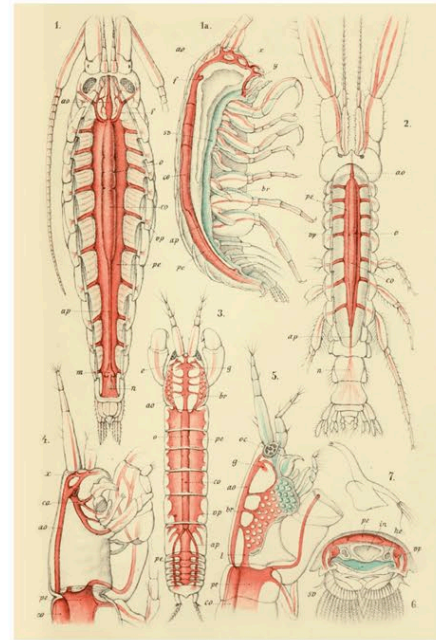
Ligia oceanica

This sea slater is a common shoreline species of the north Atlantic. It emerges from hiding at night to feed on dead seaweed.

sandhoppers and relatives

ORDER: Amphipoda **SUBPHYLUM:** Crustacea **PHYLUM:** Arthropoda

Amphipods are relatives of isopods (see p.349), but their bodies are usually flattened from side to side rather than top to bottom. Many species crawl or burrow on the seafloor, where they eat dead material—some even build “houses” of cemented sand grains that they pull around with them. The sandhoppers of the shoreline feed on rotting seaweed and can leap into the air to avoid predators such as shore birds and small fish. The spindly “skeleton shrimp” climb among seaweed and hydroids and are often carnivorous. Some amphipods live in the plankton associated with jellyfish and salps, while the specialized flat-bodied “whale lice” make a living on the skin of whales. The largest deep-sea amphipods can reach a length of 12 in (30 cm).



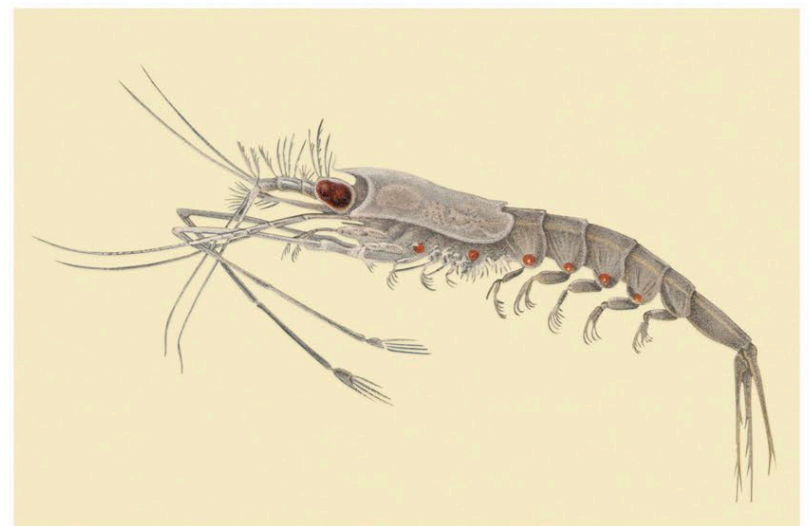
Amphipod anatomy

This illustration shows the typical body form of an amphipod and the variety of appendages it uses for different purposes, such as burrowing, swimming, and jumping.

krill

ORDER: Euphausiacea **SUBPHYLUM:** Crustacea **PHYLUM:** Arthropoda

Krill are shrimplike crustaceans that swim and feed among the plankton of the open ocean. Although there are fewer than 100 species, this group includes Antarctic krill, which are one of the most abundant animals on the planet. They form huge swarms in the Southern Ocean, sometimes dense enough to turn the water pink. Despite being several inches long, Antarctic krill can capture the tiniest phytoplankton using a basketlike filtering apparatus formed by their legs. In turn, they provide staple food for whales, seals, and other large animals. Most krill species are filter feeders, although some are predators of small planktonic animals. All species have light-producing photophores on their bodies, except one species that lives in deeper water.



Northern krill

This species, *Meganyctiphanes norvegica*, lives in the north Atlantic. Its protective carapace extends only partway down its sides, a characteristic common to all krill.

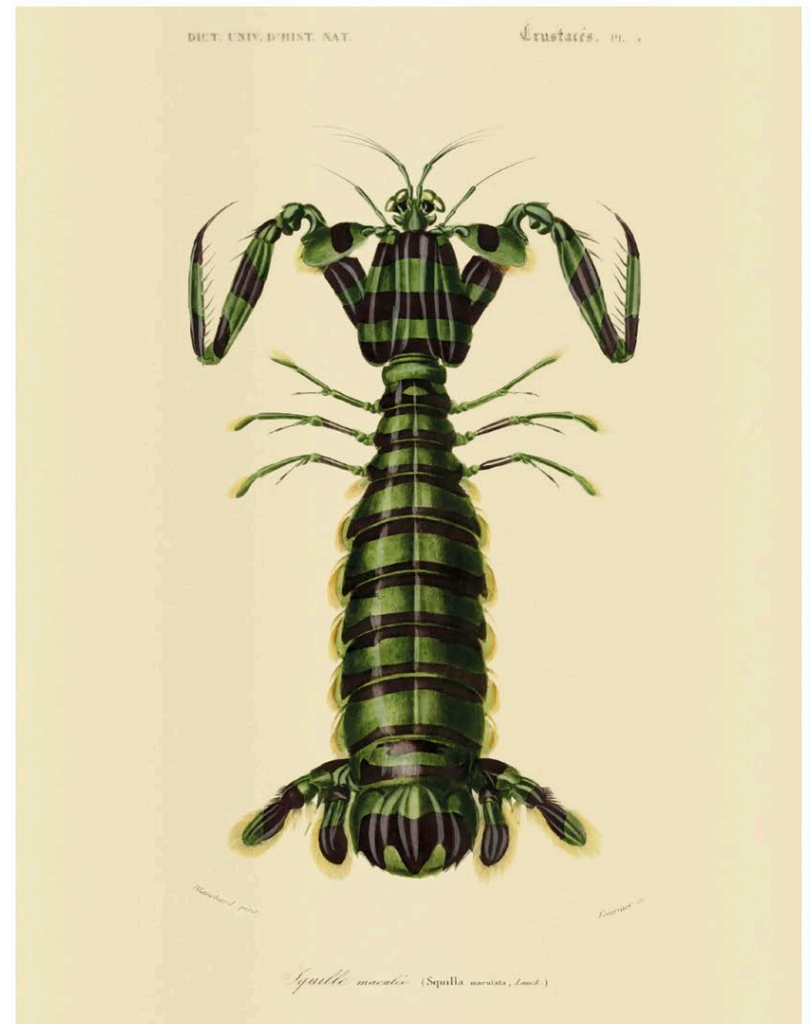
mantis shrimp

ORDER: Stomatopoda **SUBPHYLUM:** Crustacea **PHYLUM:** Arthropoda

Mantis shrimp are predatory crustaceans that live on the seafloor, mainly in warm, shallow waters, including coral reefs. There are more than 400 species, ranging in size from 2 to 16 in (5 to 40 cm). They have an elongated, flexible body and stalked, compound eyes—eyes made up of many facets. Often brightly colored and patterned, these arthropods live in burrows or rocky crevices, ready to ambush prey or, in some cases, to swim swiftly after it.

Mantis shrimp have an enlarged second pair of legs, or raptorial appendages, that are powerful weapons. These appendages can unfold in an instant, stretching out just like the front legs of a praying mantis to attack prey. In some species (“spearers”), the spiny end of the final leg section is the main weapon, while in others (“smashers”), its thickened base acts as a club and can smash open the toughest shells of prey with lightning speed.

Mantis shrimp are notable for their remarkable eyesight. They can detect polarized light and can perceive more colors than any other animal, including humans. Each of their two stalked eyes can see in three dimensions by itself, independent of the other.



Zebra mantis shrimp

Lysiosquilla maculata, a “spearer,” is the largest species of mantis shrimp. It is found in the Indian and Pacific Oceans.



Pink-eared mantis shrimp
Odontodactylus latirostris



Zebra mantis shrimp
Lysiosquilla maculata



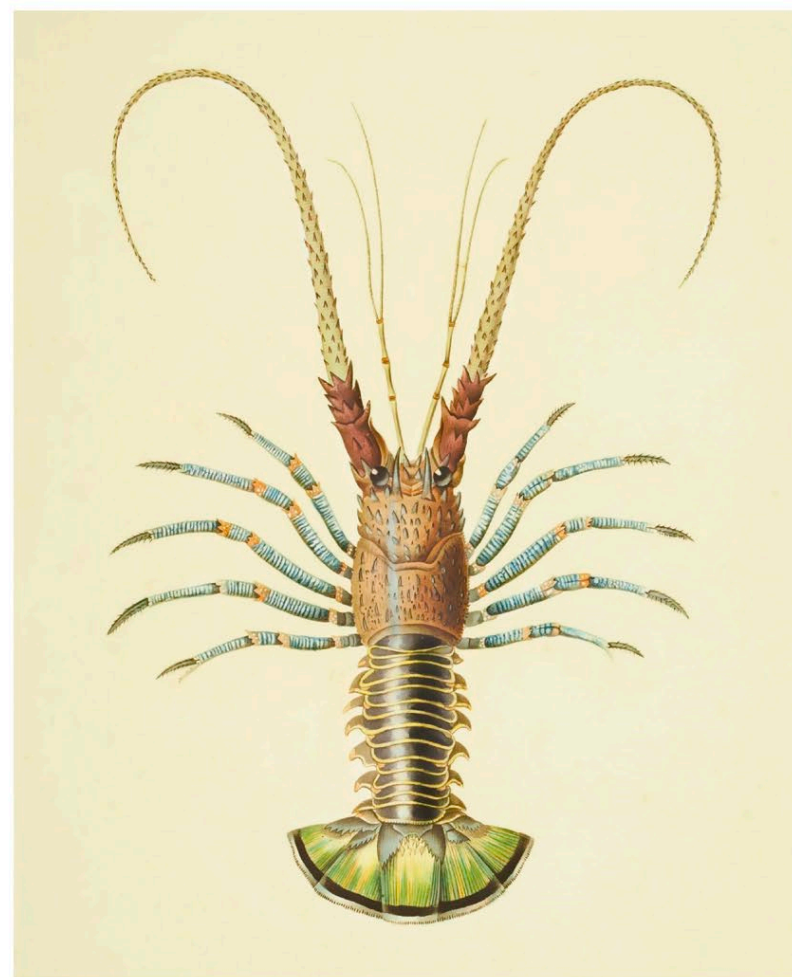
Peacock mantis shrimp
Odontodactylus scyllarus

lobsters, shrimp, and crabs

ORDER: Decapoda **SUBPHYLUM:** Crustacea **PHYLUM:** Arthropoda

This order includes most of the largest crustaceans. The name Decapoda means 10 legs, a characteristic of the group, although the first pair of legs are often modified into heavy claws. Like other crustaceans, decapods have an outer skeleton that they molt regularly to grow in size—a difficult and sometimes fatal challenge for an animal such as the lobster, which may die in the process.

Decapods have varied lifestyles. Smaller species, such as shrimp, can swim, although even these tend to live close to surfaces such as coral reefs. Decapod shrimp are sometimes called “true shrimp” to distinguish them from other crustaceans with “shrimp” in their name, such as mantis shrimp (see p.351). Many decapods live in the homes of other marine animals, helping themselves to scraps. Lobsters lumber across the ocean floor at night, seizing prey, such as mollusks, with their huge claws—one for crushing and one for snipping. Hermit crabs have soft abdomens and use empty snail shells as protection. True crabs have short, wide bodies, with a tiny abdomen that is tucked underneath, out of sight. The Japanese spider crab is the largest living arthropod, with a leg span of 18ft (5.5m).



Spiny lobsters

Unlike true lobsters, spiny lobsters lack a claw on their first pair of walking legs. Spiny lobsters also have extremely long antennae.



Japanese spider crab
Macrocheira kaempferi



Spotted porcelain crab
Neopetrolisthes maculatus



European lobster
Homarus gammarus



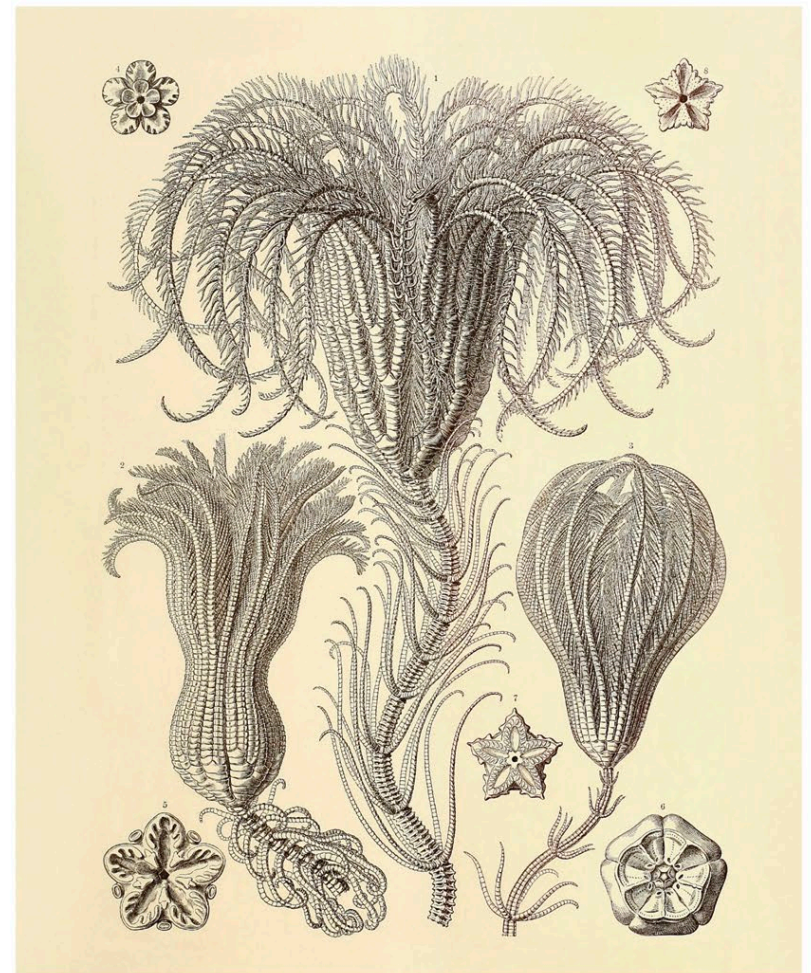
Marbled shrimp
Saron marmoratus

sea lilies and feather stars

CLASS: Crinoidea **PHYLUM:** Echinodermata

Sea lilies are the most ancient living members of the phylum Echinodermata, which also includes starfish, sea urchins, and sea cucumbers. Most are found in deeper waters, where they attach to the seafloor by a stalk. Their arms—covered with thousands of flexible projections called tube feet—trap food particles, which are then moved toward the central mouth. Sea lilies display many features of echinoderms, including a five-fold body symmetry and a skeleton made of chalky units called ossicles. They have a hydraulic system of water-filled tubes, called a water-vascular system, that operates the tube feet on their arms. Their tiny, free-swimming larvae have a left and right side, like most animals, later transforming into the radial symmetry of the adult.

Feather stars are more common than their relatives, the sea lilies, and feed in the same way, but lose their stalks before adulthood. These often colorful, night-feeding animals perch themselves on surfaces such as heads of coral to catch food. They can swim slowly by beating their arms, which in most species are subdivided into branches lined with appendages called pinnules.



Stalked sea lilies

Some sea lilies can uproot themselves and crawl to a new location using the movable projections (cirri) on their stalks, visible in this illustration.



Orange feather star
Davidaster rubiginosus



Bennett's feather star
Anneissia bennetti



Red feather star
Himerometra robustipinna

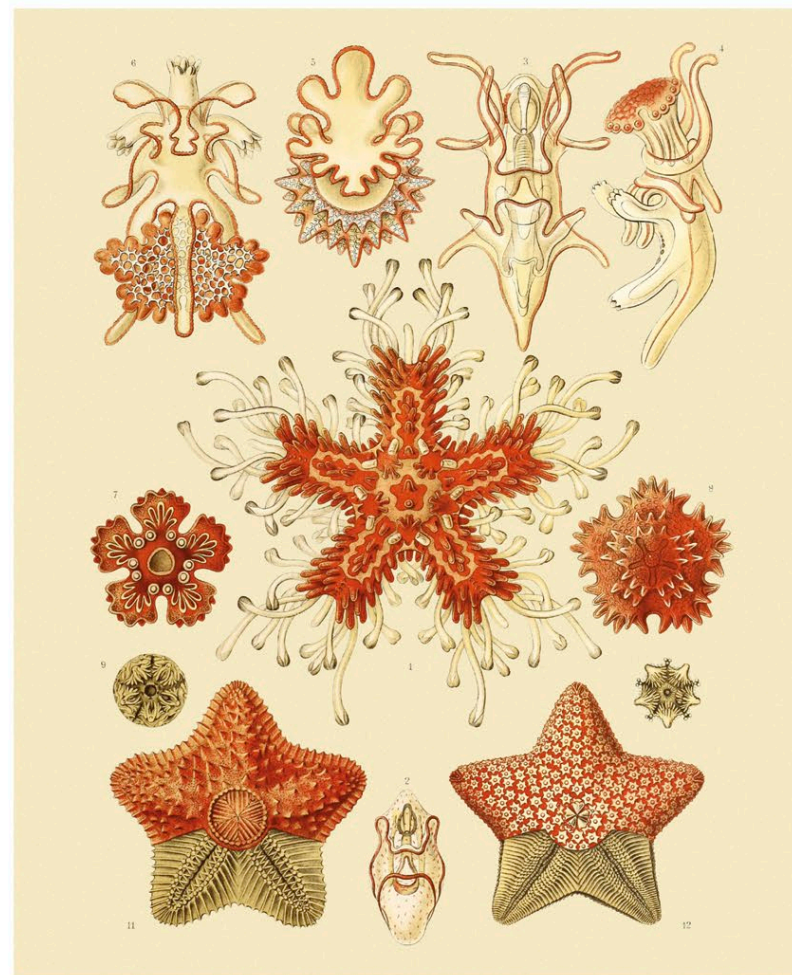


Elegant feather star
Tropiometra carinata

starfish

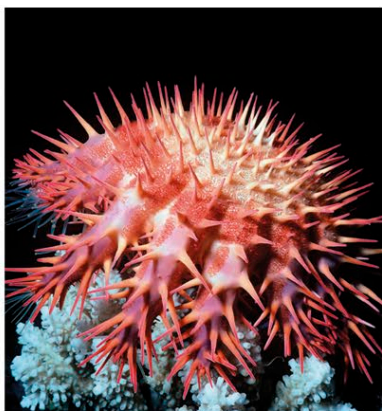
CLASS: Asteroidea **PHYLUM:** Echinodermata

Starfish, or sea stars, have no head or brain, but are successful predators of the ocean floor, with the largest species growing up to 3 ft (1 m) across. They usually have five arms, but some species have many more. Species lacking arms or having very short arms are called cushion stars. The mouth of a starfish is on the underside and can often stretch to swallow slow-moving prey, such as mollusks and other echinoderms. Some starfish can extend their stomach over prey, digesting it externally. Typical starfish have flexible arms with thousands of suckered tube feet for walking, gripping, and pulling prey apart. Other species have stiffer arms and burrow in sand or mud to either seek buried prey or feed on smaller particles. The tube feet of burrowing species lack suckers and are used for digging. One family of starfish, the brisingids, resemble brittle stars and hold their arms up to filter feed. Like other echinoderms, most starfish release eggs and sperm into the sea, which turn into swimming larvae after fertilization. Starfish also have tiny pincers, called pedicellariae, on their surface that help keep their skin free of small animals.



Biological transformation

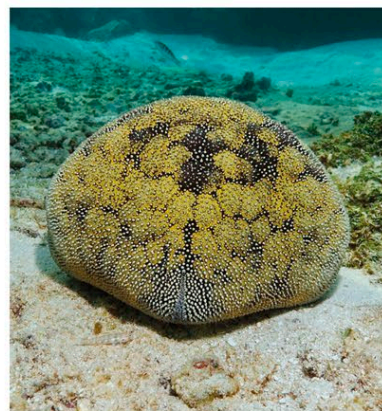
The top four drawings of this 1904 illustration from *Kunstformen der Natur* depict a young adult starfish developing from the body of its transparent swimming larva.



Crown-of-thorns starfish
Acanthaster planci



Common starfish
Asterias rubens



Cushion star
Culcita novaeguineae



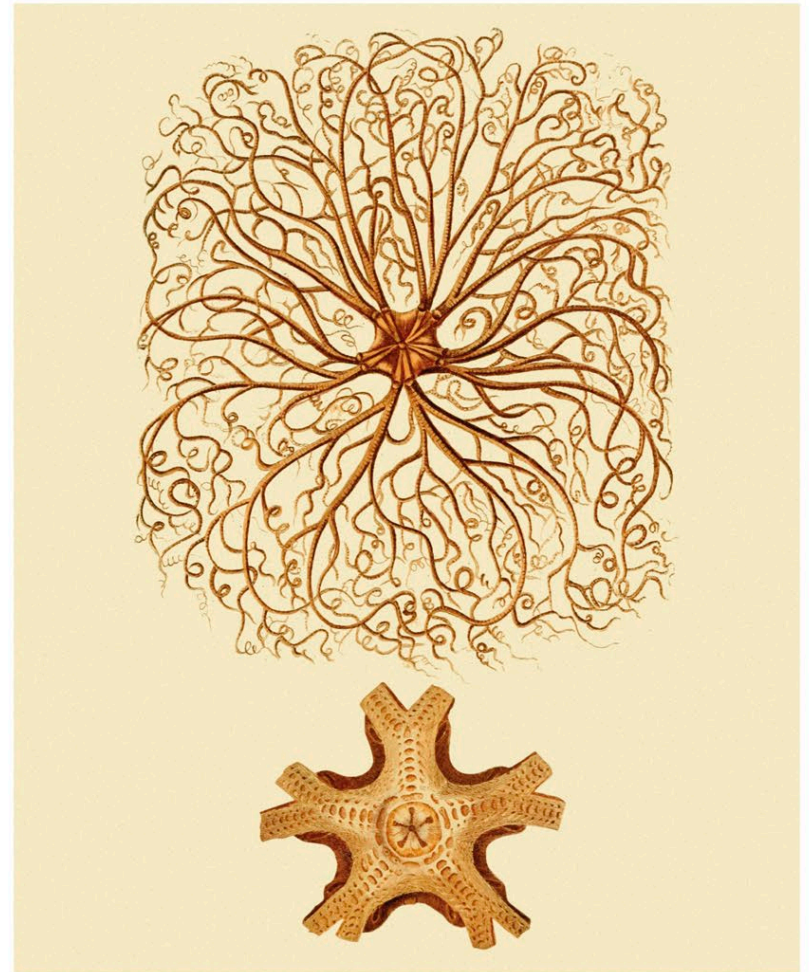
Purple sea star
Pisaster ochraceus

brittle stars

CLASS: Ophiuroidea **PHYLUM:** Echinodermata

Like starfish (but unlike feather stars), brittle stars typically have five arms, but their bodies are structured differently. Their thin, flexible, often spiny arms are clearly marked off from the small central body, and their suckerless podia are not used for walking but for feeding, probing, and sensing. They “walk” along the seafloor with sweeping motions of their arms, each of which is strengthened by bonelike ossicles that function like a miniature backbone. Brittle stars filter small food particles from the water, often at night, raising their arms and using their podia, spines, and mucus secretions as traps. Huge numbers of feeding brittle stars can sometimes carpet the seafloor. Some species can catch larger prey, such as shrimp and small fish, or burrow in mud for food.

Typical brittle stars are only a few inches across, but a subgroup called basket stars can grow much bigger, the largest approaching 3 ft (1 m) in diameter. Their arms are finely divided and resemble ferns or a tangle of snakes, depending on the species. They often cling on to corals to feed—as do serpent stars, their flexible-armed relatives.



Basket star

Basket stars spread out their branched arms at night to catch prey, such as shrimp. Their arms bend to bring the prey to the mouth, which is located in the center of the body.



Black brittle star
Ophiocomina nigra



Gorgon's head basket star
Gorgonocephalus caputmedusae



Common brittle star
Ophiothrix fragilis

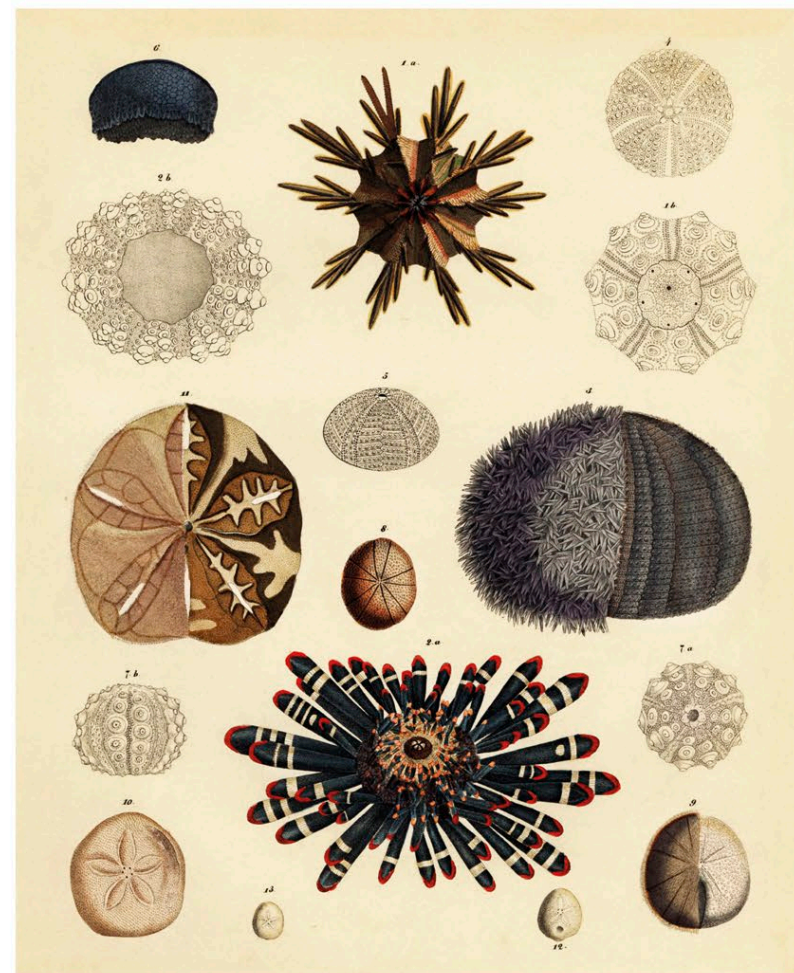


Sponge brittle star
Ophiothrix suensoni

sea urchins

CLASS: Echinoidea **PHYLUM:** Echinodermata

The body structure of a sea urchin resembles a starfish whose arms have been curled up until they meet at the top. Round and spiny-skinned, sea urchins have rigid bodies made of small units called ossicles and five bands of tube feet running down their sides, which are used for clinging, climbing, and sometimes walking. Their downward-facing mouth has chisel-like teeth. Many sea urchins graze algae from rocks, while others extract food from muddy ocean floors. The latter includes the largest species, the leather urchins, mainly deep-sea dwellers that collapse when taken out of water. Urchins with extra-large, thick spines are known as slate pencil urchins. Some urchin species can inject venom with their spines. Typical sea urchins have symmetric bodies, but some species have lost that symmetry and have a “front” and a “back.” These include heart urchins, or sea potatoes, burrowing species with soft spines that tunnel slowly through mud, extracting food from sediments and the water currents they create. Similarly, the flat sand dollars live buried or half-buried in sand, filtering food particles using a dense covering of short spines.

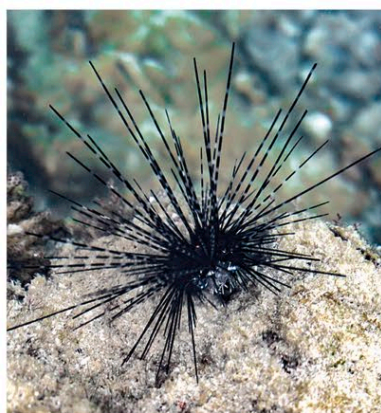


Spineless exterior

A few drawings in this illustration show the hard casings (tests) of sea urchins; these are best seen with the spines removed. The raised knobs on their bodies are attachment points for larger spines.



Sand dollar
Clypeaster humilis



Long-spined sea urchin
Diadema setosum



Edible sea urchin
Echinus esculentus



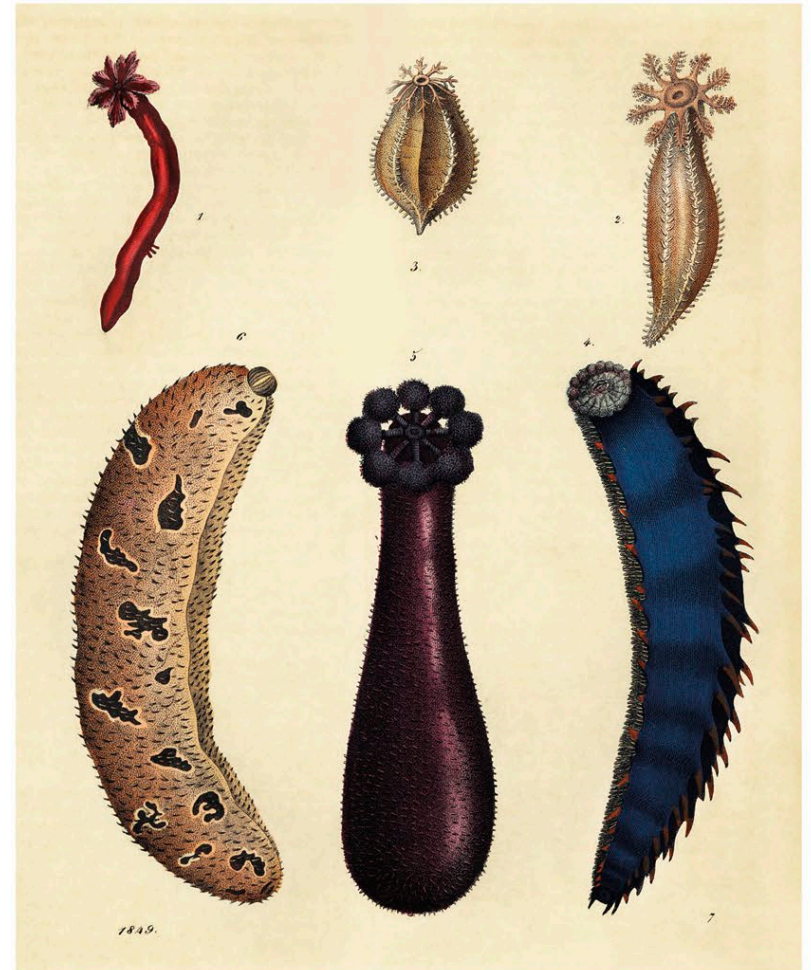
Purple sea urchin
Strongylocentrotus purpuratus

sea cucumbers

CLASS: Holothuroidea **PHYLUM:** Echinodermata

Sea cucumbers are a diverse class of echinoderms that anatomically somewhat resemble sea urchins that have been stretched vertically and laid out on their sides, with the mouth now at the front end. The larger species can reach up to 6.5 ft (2 m) long. The “classic” sea cucumber looks more like a pickle, with rough skin dotted with knobs and protuberances. Tube feet for walking and gripping are typically found only on the underside. The body color varies, but it often contrasts with the environment. This may be because sea cucumbers have few predators, possibly because of the toxins in the bodies of some species. Branched tentacles surround their mouths and help them filter feed or collect and swallow sediment.

Some deep-sea cucumbers have fins and “sails” on their bodies, enabling them to swim, and they touch down only to eat. Others, called sea pigs, have large leglike podia and move like herds of cattle on the seafloor as they consume muddy sediment. Some species are wormlike and do not have tube feet. Sea cucumbers show an array of unusual features—some species can eject some of their internal organs if disturbed and grow a new set.



Diverse anatomy

This illustration from Carl Hoffmann's *Book of the World* shows typical sea cucumbers (figs. 4 and 6), drawn with their suckered undersides facing inward. Fig. 1 shows a wormlike species.



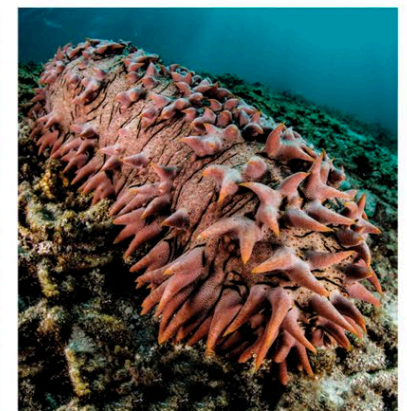
Sea apple cucumber
Pseudocolochirus violaceus



Yellow sea cucumber
Colochirus robustus



Edible sea cucumber
Holothuria edulis



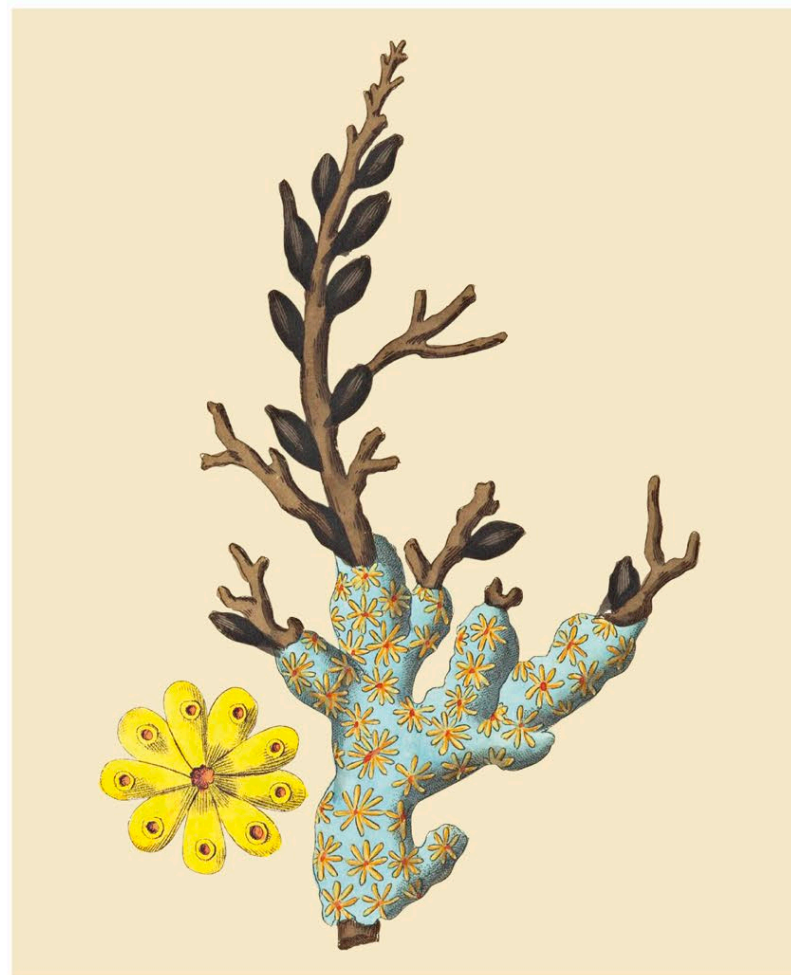
Prickly redfish
Thelenota ananas

tunicates and lancelets

SUBPHYLA: Tunicata and Cephalochordata **PHYLUM:** Chordata

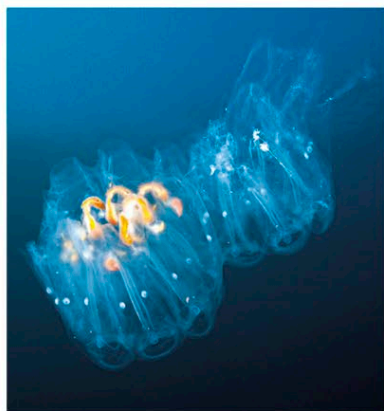
Tunicates and lancelets are invertebrates that belong to the same phylum (the chordates) as the vertebrates. All chordate bodies feature a stiffening rod called a notochord, at least in the larvae or embryos. In vertebrates, the backbone replaces the notochord. The best-known tunicates are the sea squirts. Their larvae are free-swimming, but the adults attach themselves to undersea surfaces and filter food just like sponges (see p.332). However, their bodies are more complex and are covered by a tough protective layer called the tunic. Sea squirts have a tubelike siphon to draw seawater in and another to expel it. Individuals often merge together to form colonies. Some colonial tunicates, such as salps and pyrosomes, float or swim in the plankton, and their colonies can reach several feet in length.

Lancelets (cephalochordates) live half-buried in soft seafloors, filtering food from the water through gill-like openings on the sides of their bodies. They look like small fish and can swim away in a fishlike manner if disturbed. Lancelets have long been studied for clues as to what the ancestors of vertebrates may have been like.



Colonial sea squirt

This illustration shows a golden star tunicate, *Botryllus schlosseri*, growing on seaweed. The stars are formed by groups of individuals that share a single siphon for expelling water.



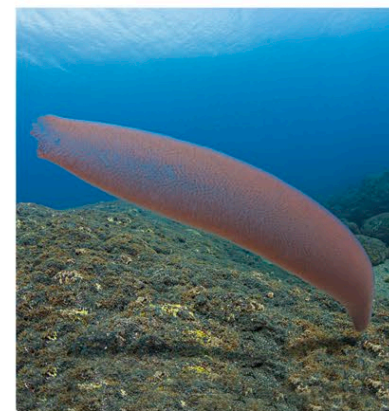
Salp
Salpidae family



European lancelet
Branchiostoma lanceolatum



Blue club tunicate
Rhopalaea crassa

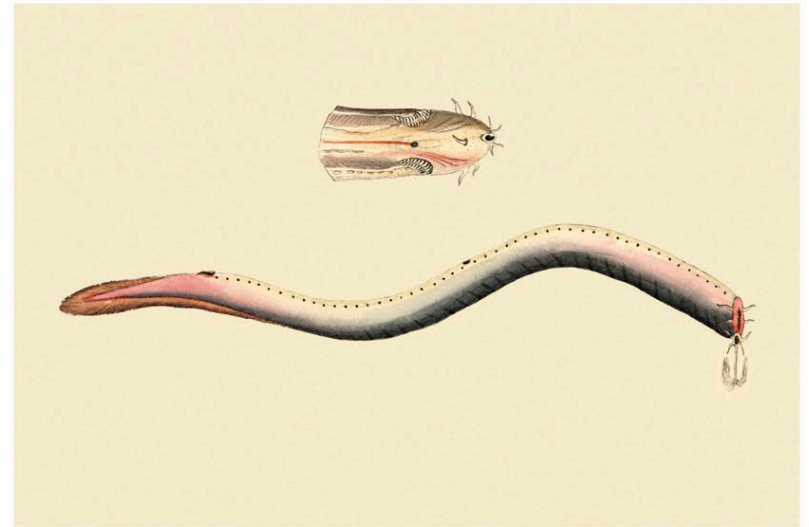


Pyrosome
Pyrosoma species

hagfish

CLASS: Myxini **SUBPHYLUM:** Vertebrata

Hagfish look like but are not related to eels. They are living representatives of the ancient jawless fish, many species of which swam in the world's oceans before fish with jaws evolved. Hagfish have rudimentary eyes and no true fins. They live on the ocean floor and feed on various invertebrates, as well as the dead bodies of large animals such as whales. The classification of hagfish as vertebrates has been debated—they have a skull made of cartilage, but their body is stiffened by a flexible notochord rather than a vertebral column. Their slitlike mouth contains a tongue equipped with horny teeth and is surrounded by sensory barbels. A line of pores runs down their bodies, discharging substances that combine with seawater to create huge amounts of thick slime, used for defense.



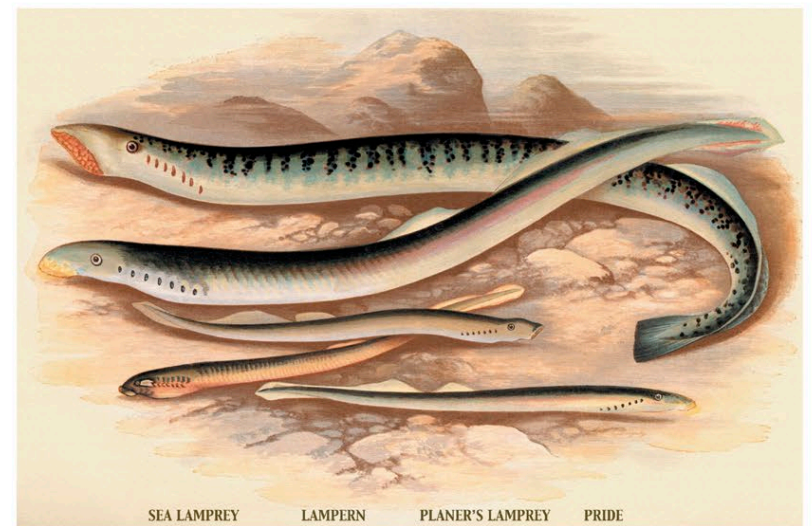
Atlantic hagfish

These drawings of the Atlantic hagfish, *Myxine glutinosa*, show the barbels around its mouth (top) and the slime-producing pores that run down its body.

lampreys

CLASS: Petromyzontida **SUBPHYLUM:** Vertebrata

Like hagfish, lampreys are also jawless fish, but with dorsal fins, a rudimentary vertebral column, and fully functioning eyes. All species spawn in fresh water, but around a quarter of them move to the oceans as adults. The larvae, called ammocoetes, live half-buried in river sediments, living off small food particles, until they transform into the eel-like adults. In species such as the sea lamprey of the north Atlantic, young adults head downstream to the ocean, where they live as parasites of fish. They use the rasping teeth on their suckerlike mouths to attach themselves to their hosts before journeying back to fresh waters to breed. Many lamprey species never leave fresh water, and some do not feed as adults but simply breed and die.



Lamprey selection

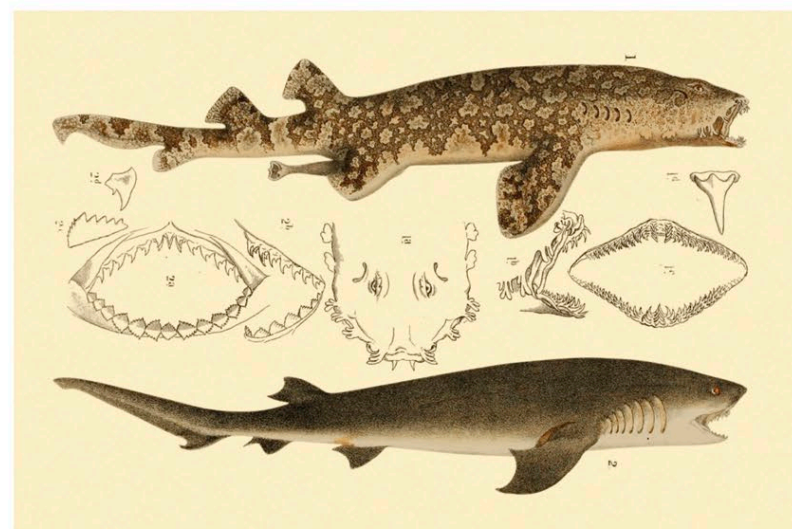
The top two images in this illustration show the sea lamprey and the lampern, both seagoing north Atlantic species, with their jawless rasping mouths.

sharks

INFRACLASS: Selachii **CLASS:** Chondrichthyes **SUBPHYLUM:** Vertebrata

Sharks differ from other jawed fish in having a skeleton of cartilage, not bone, although this is often hardened by mineral deposits. There are only around 500 species of sharks, compared to about 30,000 bony fish, but they include many top ocean predators. A shark's body design has several significant features, such as protruding jaws with replaceable, razor-sharp teeth in some species; robust, fleshy fins; tough skin covered with spiny scales; and highly developed senses, including an electro-sense that detects tiny electric currents given off by prey. Hammerhead sharks migrate long distances, like many large sharks. They have wide heads that may help with 3D perception of sight and smell. Unlike bony fish, sharks copulate, and fertilization is internal. Females either produce large, yolky egg capsules, which can be attached to seaweed and other surfaces, or give birth to live young.

Not all sharks are fast, streamlined open-ocean predators. Many smaller ones feed on the ocean floor; some have flat-topped molar teeth for crushing shellfish. Angelsharks are highly flattened and often lie half-buried in the seafloor, waiting to ambush prey. The largest sharks, the whale shark and the basking shark, are slow-moving and feed on plankton.



Bottom-dwelling sharks

The two bottom-dwelling sharks illustrated here are a carpet shark, or wobbegong of the genus *Orectolobus* (top), and a broadnose sevengill shark, *Notorynchus cepedianus* (bottom).



Bull shark
Carcharhinus leucas



Horn shark
Heterodontus francisci



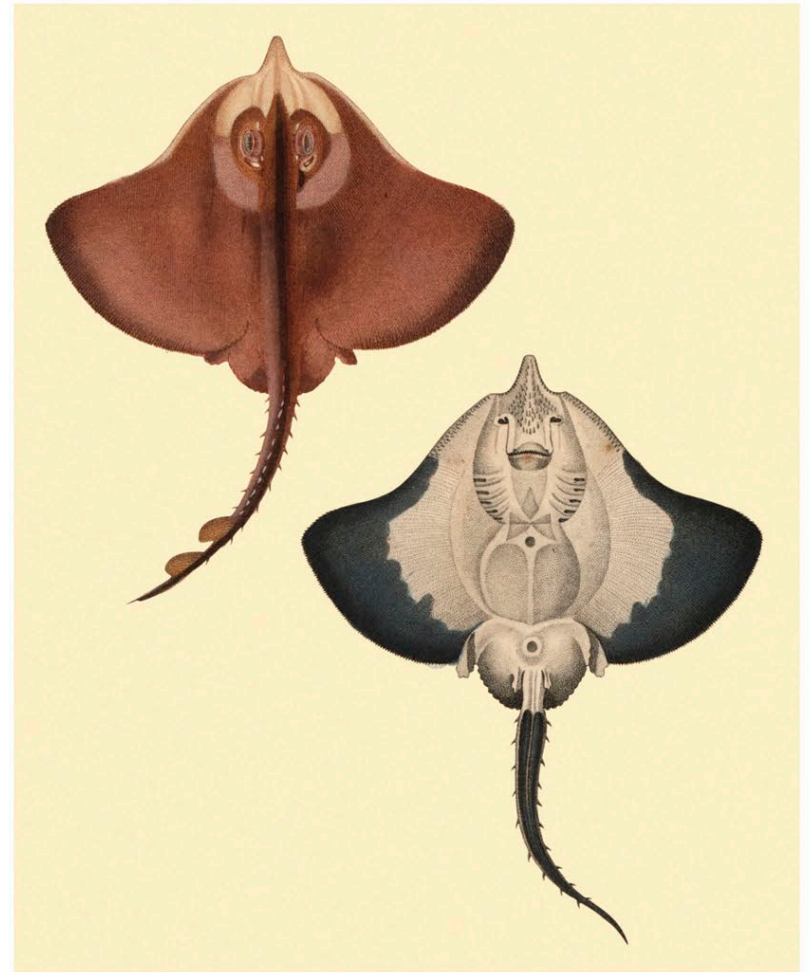
Eastern angelshark
Squatina albipunctata

rays

INFRACLASS: Batoidea **CLASS:** Chondrichthyes **SUBPHYLUM:** Vertebrata

Rays are flat-bodied relatives of sharks that usually live close to the seafloor, often lying half concealed in sand and mud. They swim using their expansive pectoral fins and most have broad, flat-topped teeth for crushing hard-shelled prey. Unlike sharks, their gill slits are underneath the body, and they have holes called spiracles behind their eyes to take in water in order to breathe.

Rays are classified into four orders. Members of the largest order, which includes the skates, lay yolky eggs and have a fleshy tail with dorsal fins and a tail fin. These are the most common rays in cooler oceans. Members of the stingray order are more common in warmer waters and give birth to live young. Their whiplike tails are finless and have one or more large, venomous spines. They include the open-water eagle rays and the filter-feeding manta rays. A third order contains sawfish, guitarfish, and banjofish—longer-bodied fish that superficially look like flattened sharks. The sawfish's long “saw” contains electro-receptors and is used as a weapon. The fourth order, which includes torpedofish and numbfish, comprises rays with a rounded outline that can generate powerful electric shocks for attack and defense.



Skates

This illustration shows the top view and underside of a skate. Members of this group of rays have pointed snouts and fleshy tails with fins.



Brown guitarfish
Rhinobatos schlegelii



Round ribbontail ray
Taeniura meyeni



Reticulate whipray
Himantura uarnak



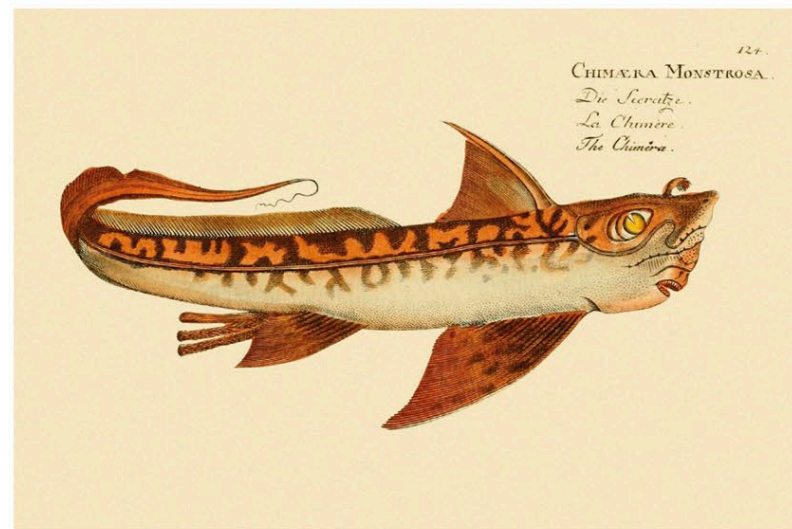
Leopard torpedo
Torpedo panthera

chimaeras

SUBCLASS: Holocephali **CLASS:** Chondrichthyes **SUBPHYLUM:** Vertebrata

The chimaeras, comprising 55 or so species, live close to the ocean floor, mainly in deeper waters, so they are relatively unstudied. Related to sharks and rays (see pp.360–361), they have large heads; long, tapering bodies; a dorsal fin spine; and platelike teeth, which grow continually. The largest species can be more than 5 ft (1.5 m) in length. Chimaeras swim slowly using their pectoral fins and feed mainly on invertebrates. They have large eyes and a sensitive electrical sense. Fertilization is internal as in sharks, and the females lay large, yolky eggs protected by capsules.

Chimaeras comprise three families. The largest of these, the shortnose chimaeras, includes a few shallow-water species. Their tail often tapers to a slender filament, earning them the name ratfish. They are also called rabbit fish because of their large teeth and the shape of their head. Members of the ploughnose, or elephant-fish, family have remarkable protuberances on their noses that may be used to dig up prey. Their tails are more sharklike than those of shortnose chimaeras. The third family, the long-nosed chimaeras or spookfish, are less well known, although species occur widely in deeper waters.



Rabbit fish

This illustration from 1796 is of the species *Chimaera monstrosa* from the northeast Atlantic. It shows the large eyes and tapering tail typical of members of the shortnose chimaera family.



Pacific spookfish
Rhinochimaera pacifica



Spotted ratfish
Hydrolagus colliei



Rabbit fish
Chimaera monstrosa

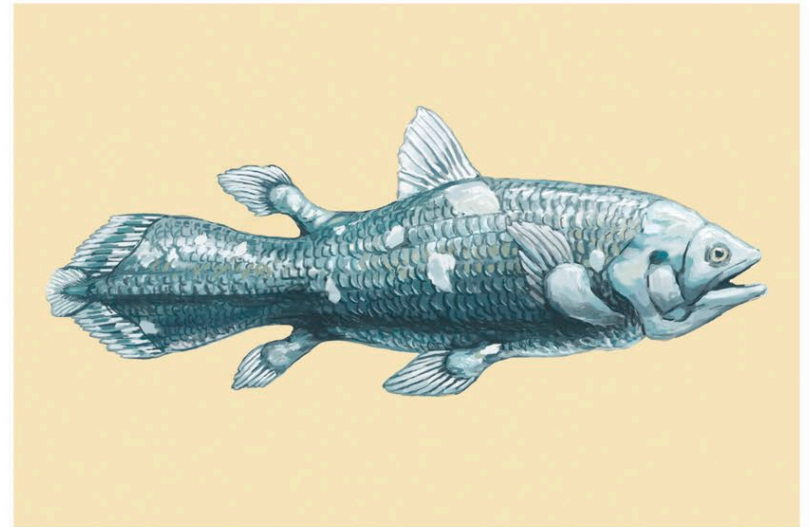


Australian ghostshark
Callorhynchus milii

lobe-finned fish

CLASS: Sarcopterygii **SUBPHYLUM:** Vertebrata

Along with ray-finned fish (class Actinopterygii), described in the following pages, the Sarcopterygii are bony fish, but the two groups are very different. The pectoral and pelvic fins of lobe-finned fish have a fleshy base and contain small bones equivalent to those in human arms and legs. In fact, all land vertebrates are believed to have evolved from sarcopterygian ancestors. Only eight species remain alive today: six species of freshwater lungfish and two marine coelacanths. Thought to be extinct until a living specimen was identified in South Africa in 1938, coelacanths are slow-moving fish. They live in relatively deep water, favoring areas with rocky underwater caves where they can hide. Coelacanths grow up to 6.5 ft (2 m) long, and their skin is protected by thick, bony scales. One species lives in the western Indian Ocean and the other, discovered only in 1997, in Indonesia. Dissection of coelacanths has shown that their diet consists mainly of smaller fish and cephalopods. Females produce large eggs, which they hatch in their bodies, giving birth to live young. Although coelacanths have now been filmed from submersibles, much remains to be learned about their biology.



Fleshy fins

This illustration of a coelacanth shows the fleshy bases that form part of the pectoral, pelvic, anal, and second dorsal fins.



West Indian Ocean coelacanth
Latimeria chalumnae

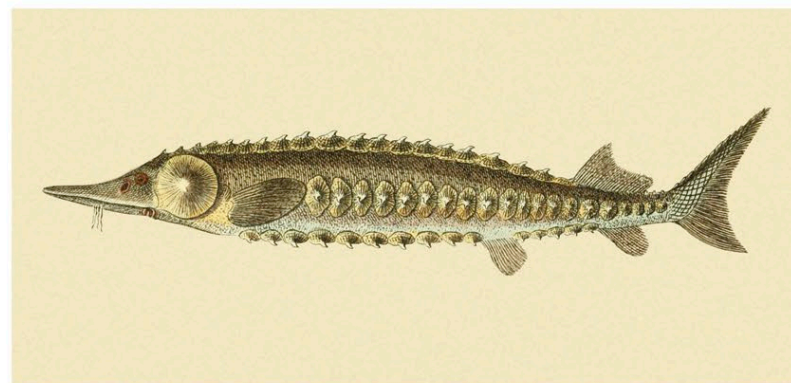


Indonesian coelacanth
Latimeria menadoensis

sturgeons

ORDER: Acipenseriformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Apart from one freshwater-only group, the bichirs, sturgeons represent the most ancient living order among the ray-finned fish (Actinopterygii). There are over 20 species, mainly living in coastal waters but entering rivers to breed. Some North American species are known to migrate and winter in deeper parts of the continental shelf. Most sturgeons are now endangered due to disruption of river systems and hunting for their prized roe (caviar). Some species can be enormous—the beluga of eastern European river basins can grow up to 16ft (5m) in length and live over 100 years. Sturgeons have sharklike tails and five rows of large plates (scutes) on their bodies instead of regular scales. Their downward-facing, toothless mouths, aided by fleshy barbels (feelers), help them root in muddy seafloors for food.



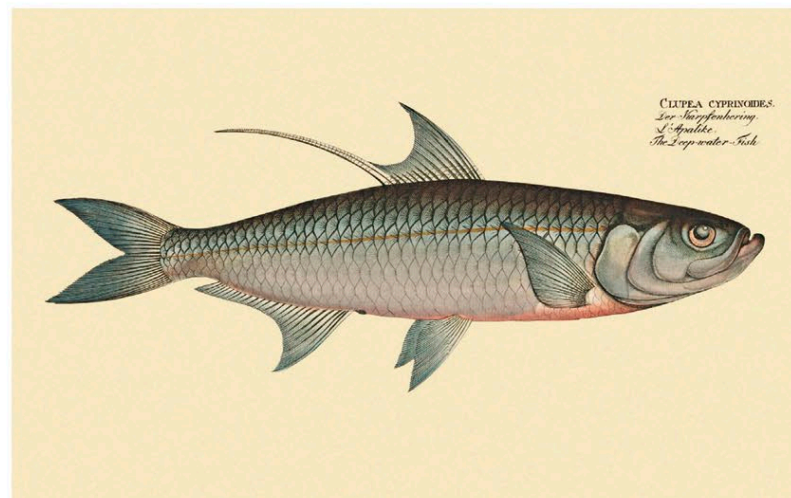
Distinctive shape

This illustration shows a sturgeon's unmistakable appearance, which includes a long snout with barbels underneath, an asymmetric tail, and rows of scutes running down the body.

tarpons and ladyfish

ORDER: Elopiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This small order of two families includes the tarpons and the ladyfish, or tenpounders, both found mainly in warmer waters. The Atlantic tarpon, a well-known game fish, has distinctive large, silvery scales and a long “pennant” on its dorsal fin. It can reach up to 8ft (2.5m) in length. Individuals move freely between salt- and fresh water but spawn in the sea. Their swim bladder is connected to the esophagus, so they can supplement their air supply by coming to the surface and gulping air, which gives them an advantage in stagnant freshwater habitats. Adults are carnivorous. Ladyfish have similar habits but are smaller. All members of this order have leaflike larvae similar to those of eels. Many fossil species are also part of this order.



Indo-Pacific tarpon

Now named *Megalops cyprinoides*, this species is similar to the Atlantic tarpon, though smaller. It is shown here in a plate from a German work of the late 1700s.

eels

ORDER: Anguilliformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This diverse order is made up of 19 families of long-bodied predatory and scavenging fish. Mainly nocturnal, they usually burrow or hide in crevices when not hunting. The dorsal, tail, and anal fins are usually merged into one continuous strip; some species have no fins at all. Their slippery skin lacks or has inconspicuous scales. The heavily built European conger eel, as well as the longest of the 200 or so species of moray eels, can grow up to 10 ft (3 m) or more. Moray eels live in rocky areas and reefs in warmer regions. They have bright patterns, and most have fierce-looking fangs for capturing other fish. The slender snake-eels are sometimes patterned to imitate venomous sea snakes. The gulper and swallower eels that swim in the ocean depths have enormous mouths and can catch prey bigger than themselves.

The familiar river eels of Europe and North America swim all the way to the deep ocean to breed. Their eggs, and those of other eels, develop into transparent, leaf-shaped larvae called leptocephali that live in the plankton and look nothing like the adults. There are also other fish with “eel” in their name, but these are not true eels.

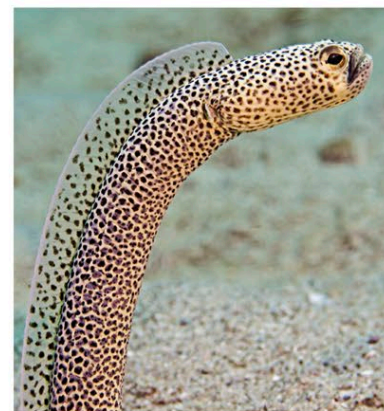


European eel

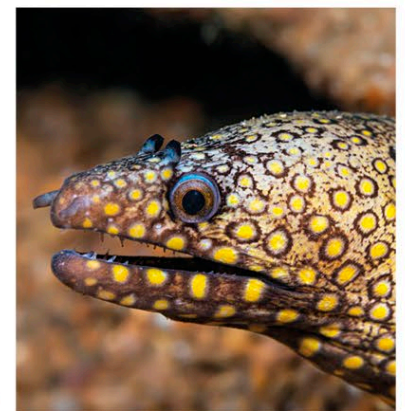
This species, *Anguilla anguilla*, lives in European rivers but migrates to the Sargasso Sea to breed. A close relative performs a similar migration from North American rivers.



European eel
Anguilla anguilla



Japanese garden eel
Gorgasia japonica



Jewel moray
Muraena lentiginosa

herrings and relatives

ORDER: Clupeiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

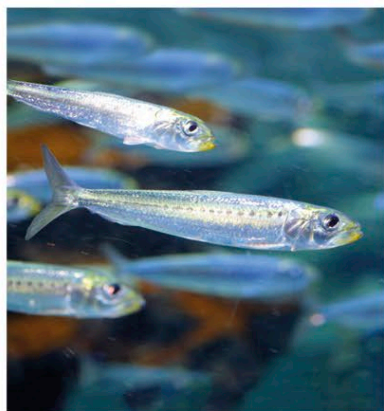
Members of this order of silvery, smooth-scaled fish nearly all feed on plankton, straining their food out of the water using structures in their gills called gill rakers. The main family, with around 200 species, includes herrings (genus *Clupea*), as well as sprats and shads. The names pilchard and sardine are also used for members of this family but can refer to different fish in different parts of the world. True herrings, of which there are Atlantic and Pacific species, can reach a length of 18 in (45 cm) as adults. Preying mostly on copepods, they are capable of forming vast schools and have been fished intensively for centuries. Populations migrate to shallow waters and estuaries to spawn, their eggs sinking to the seafloor before hatching. In contrast, the shads, from the subfamily Alosinae, swim up rivers to spawn in fresh water.

The second largest family comprises the anchovies, which are smaller than herrings but found worldwide. They are also important as food fish. Among the remaining families, the wolf herrings are predators of other fish and have large, sharp teeth. There are two species of wolf herrings, which can reach 3 ft (1 m) in length.



Wingfin anchovy

This anchovy, *Pterengraulis atherinoides*, from South American Atlantic coastal waters and rivers is not a filter-feeder but hunts small fish and shrimp.



Japanese anchovy
Engraulis japonicus



Pacific herring
Clupea pallasii



South American pilchard
Sardinops sagax



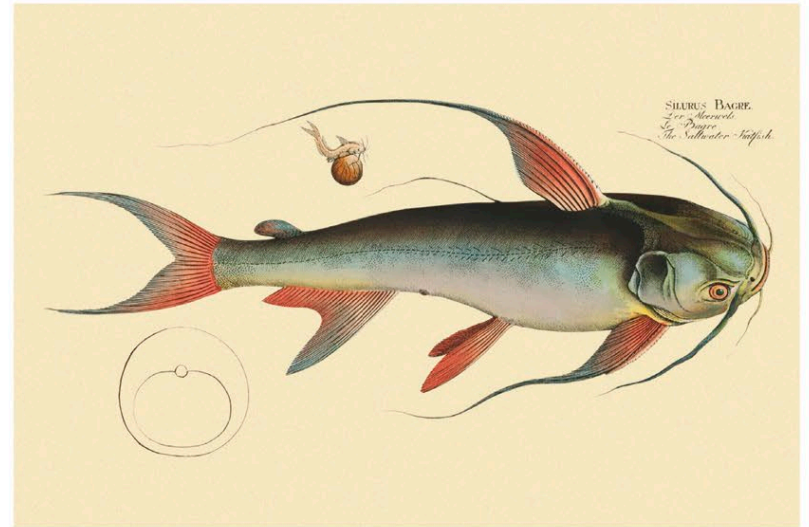
Twaite shad
Alosa fallax

catfish

ORDER: Siluriformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

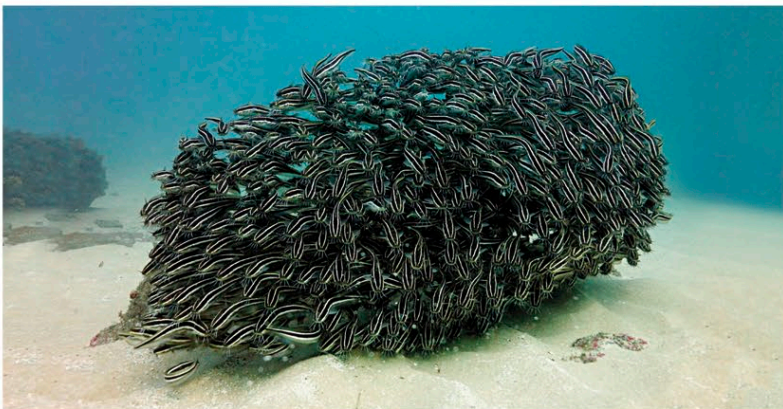
Catfish get their name from the whiskery barbels around their mouths, which help them detect food in sandy or muddy habitats. Most of the 3,000 or more species live in fresh water, but two families, the Ariidae and the Plotosidae, include marine species. These tend to live in coastal waters and use estuaries or other shallow-water areas as breeding sites.

The Ariidae have an unusual breeding system. The males brood the fertilized eggs, and sometimes the newly hatched young, in their mouths and refrain from eating during this period. Two well-known Ariidae species from the Atlantic coast of the Americas are the hardhead catfish and the gafftopsail catfish. The Plotosidae, or eeltail catfish, are unusual in appearance because their second dorsal, tail, and anal fins run together, similar to those of eels (see p.365). Of the marine species, only one—the striped eel catfish—lives on coral reefs, where juveniles are often obvious as they swim in large shoals near the reef floor. Members of both families have a long and sometimes highly venomous spine on the first dorsal fin and on each of the pectoral fins.



Coco sea catfish

Now known as *Bagre bagre*, this sea-living catfish from the family Ariidae is found on Atlantic and Caribbean coasts of South America, where it is caught for food.



Striped eel catfish
Plotosus lineatus



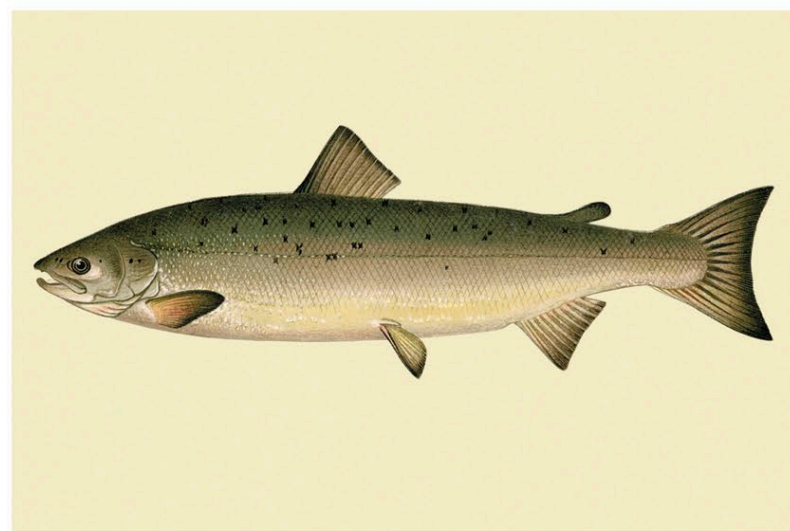
Tete sea catfish
Ariopsis seemanni

salmon, trout, and relatives

ORDER: Salmoniformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This order of more than 200 species of carnivorous fish consists of a single family, the Salmonidae, that is native to cooler parts of the Northern Hemisphere. All species lay their eggs in fresh water, and most spend their entire lives there. Only two salmonid genera, *Salmo* in the Atlantic and *Oncorhynchus* in the Pacific, have members whose life cycles take them out to the open ocean. These include some of the world's most important commercial fish.

In both *Salmo* and *Oncorhynchus*, the larger, more seagoing species are called salmon and the smaller species trout. The Atlantic salmon, *Salmo salar*, spawns in the fast-flowing headwaters of rivers, and the females cover the eggs with gravel for protection. The young stay in fresh water for 1–4 years before migrating to the ocean. After years hunting at sea, adult salmon migrate back to rivers to spawn, often choosing the same stream where they hatched. The six species of Pacific salmon—including chinook, sockeye, and coho—have similar life cycles, and adults usually die after breeding once. Male salmon change their appearance at spawning time, and sockeyes are notable for the bright red coloration that the males develop. Salmon are also raised commercially on fish farms.



Salmo salar

The Atlantic salmon ascends European and North American rivers to breed. Unlike the Pacific salmon, it may survive to return again in future years.



Atlantic salmon
Salmo salar



Arctic char
Salvelinus alpinus



Chinook salmon
Oncorhynchus tshawytscha

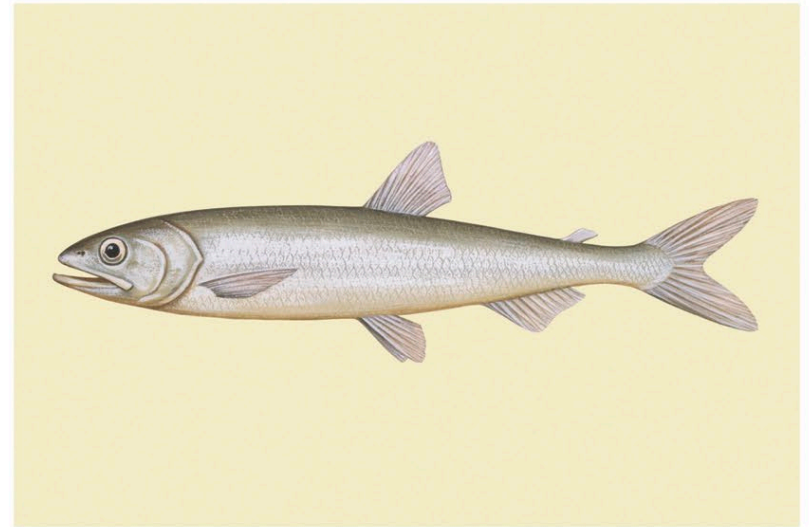


Sockeye salmon
Oncorhynchus nerka

smelts

ORDER: Osmeriformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Smelts are relatively small fish that are similar to salmon and trout, although they are more closely related to dragonfish. The best studied are the typical smelts from the family Osmeridae, found in the Northern Hemisphere. They include the European smelt, *Osmerus eperlanus*, which has been fished for hundreds of years. Both “*Osmerus*” and “smelt” refer to the odor of this species, which is like cucumber. Members of the Osmeridae have silvery scales, sometimes showing iridescent colors. Sea-dwelling smelts swim in large schools, eating other fish and zooplankton, and many, including the European smelt and its North American relatives, ascend rivers to spawn. The species capelin is a major part of the food chain in the Arctic. There are four or five other families in the order, including one confined to the Southern Hemisphere.



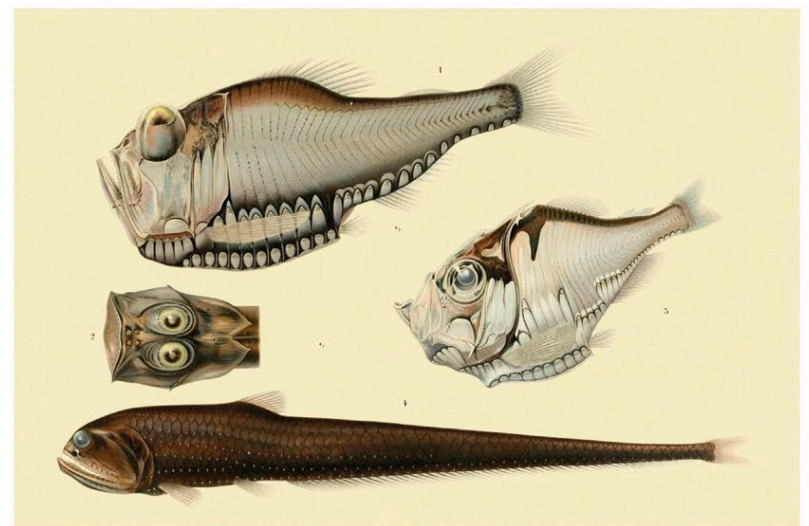
European smelt

A popular food fish in some northern European countries, this species, *Osmerus eperlanus*, is traditionally caught using nets or baskets, although it is under pressure due to overfishing.

dragonfish

ORDER: Stomiiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

These small but fearsome-looking predators have large mouths filled with fanglike teeth and are common in the deep ocean. The body shape varies between the four families, from slender viperfish up to 16 in (40 cm) long to deep-bodied, silvery hatchetfish. Most dragonfish are dark-bodied to help hide in the ocean depths, although many move upward at night following their prey. Other names for members of this order include bristlemouths, lightfish, and fangjaws. They use photophores (light-producing organs) to attract or confuse prey, to disguise their shadows when seen from below, and possibly for communication. The stoplight loosejaw and related species have red photophores under their eyes that they use like a torch to illuminate prey, which mainly cannot see red light.



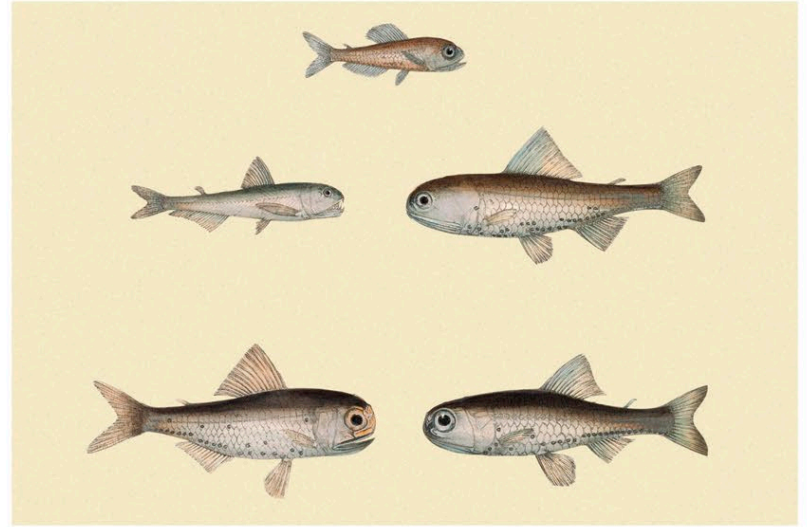
Dragonfish

This illustration shows two species of hatchetfish, with the upward-pointing eyes in one of them (fig. 2), and a bristlemouth (fig. 4).

lanternfish

ORDER: Myctophiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This order of deepwater fish contains around 250 species and includes lanternfish, as well as a much smaller family called the blackchins. Unlike dragonfish (see p.369), all lanternfish are similar in shape, and it can be difficult to distinguish between species. They are usually up to 6 in (15 cm) long. Lanternfish stay in the depths of the ocean by day but rise up at night to feed on plankton. In turn, they are food for many other fish. Lanternfish occur throughout the world's oceans and have been estimated to be the most abundant fish in the world. They have silvery scales and many light-emitting photophores on their bodies. Photophore patterns vary between species and sometimes between the sexes and are probably used for identification and communication.



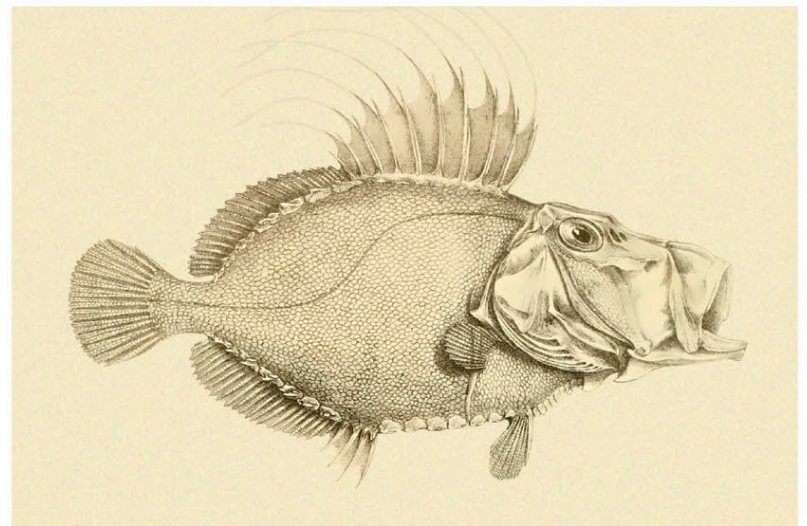
Lanternfish

This image of five species of lanternfish shows the similar body form shared by the different species of this very abundant order.

dories

ORDER: Zeiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Dories are a small group of aquatic vertebrates that contain 33 species of narrow, deep-bodied fish. The best known, the John Dory, is a widespread edible species that grows up to 35 in (90 cm) long and is found in shallow waters in Europe, Africa, and Asia. Its distinctive appearance includes long spines on the pelvic and first dorsal fins and eyes near the front of the head that provide binocular vision. Living near the seafloor, this species stalks prey with slow movements, disguised by its narrow shape, before shooting out a large, extendible mouth to capture it. Dories often have silvery skin and scales and are classified under six families in the order. One family that lives in deeper water is called tinselfish because of its members' silvery appearance.



John Dory

This illustration of a John Dory, *Zeus faber*, comes from a 19th-century account of a voyage of exploration to the seas of Australasia and Antarctica.

cod and relatives

ORDER: Gadiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Members of this large group live and feed near the seabed and often swim in large shoals, seeking anything they can find to eat. There are up to 13 families in this order, including the Gadidae—the family to which the cod belongs. Gadidae species have up to three dorsal fins and typically one or more barbels on their chin. The Atlantic cod has long been fished for food. As a result, and despite the millions of eggs a female produces, populations have drastically declined and the average size of the fish has reduced. Other significant food fish in this family include haddock, Alaskan pollock, and whiting.

Species of a related family, the Lotidae, are typically more slender-bodied than the Gadidae. They include the ling, which can grow up to 6 ft (2 m) long, and smaller shore species called rocklings. Some families in this order are little known and only include a few species. However, the grenadier family (Macrouridae), with around 400 species, represents an important part of the deepwater fauna. Grenadiers have large eyes and long, tapering tails. They can grow up to 3 ft (1 m) in length and have been found at depths of 20,000 ft (6,000 m).



Gadus morhua

This illustration of an Atlantic cod shows the three dorsal fins and single chin barbel that are characteristic of this species and some of its relatives.



Atlantic cod
Gadus morhua



Pouting, or bib
Trisopterus luscus



Mediterranean grenadier
Coryphaenoides mediterraneus



Shore rockling
Gaidropsarus mediterraneus

opahs and ribbonfish

ORDER: Lampriformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Opahs are large, deep-bodied fish that range throughout the world's oceans and are believed to feed mainly on squid and swimming crustaceans. They are strikingly colored, with orange-red fins and jaws and white-spotted bodies that are tinged with blue or violet. Fossil evidence indicates that the original members of this small order were like the opah in shape, but four out of the six families living today consist of elongated, ribbonlike fish. These sometimes have crests behind their heads, formed by extended dorsal fin rays. One of these species, the giant oarfish, is the world's longest bony fish, growing to at least 36 ft (11 m) in length. Not often caught or filmed, it has a long, red dorsal fin, as well as pelvic fins that contain a single long ray with an expanded end.



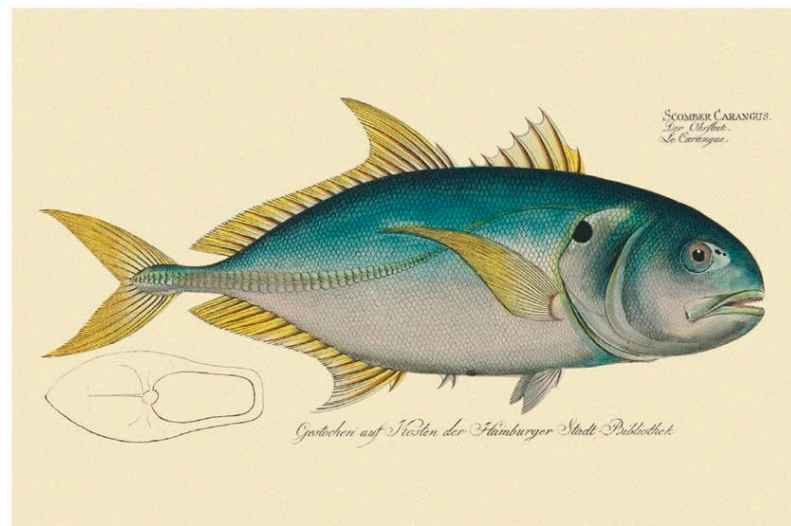
Lampris guttatus

This illustration of *Lampris guttatus* shows a specimen from the Mediterranean Sea. Little is known about the open-ocean lifestyle of this species.

jacks and relatives

ORDER: Carangiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This order is named after the Carangidae, a family of fast-swimming, predatory fish, with lengths up to 6 ft (2 m). Members of this group go by various names, including jacks, trevallies, pompanos, and scads. The Carangiformes, and all the other fish orders described on the following pages, are part of a huge superorder called the Acanthopterygii (spiny-finned fish). Species in this superorder often have a spiny first dorsal fin in front of a softer-rayed second dorsal fin. Jacks are common reef fish, and the giant trevally can even leap out of water to catch seabirds. Other fish in the Carangiformes include the colorful, open-ocean dolphinfish, or dorado, and the remoras. In order to move around, remoras, or sharksuckers, attach themselves to the bodies of sharks, turtles, and occasionally human divers.



Crevalle jack

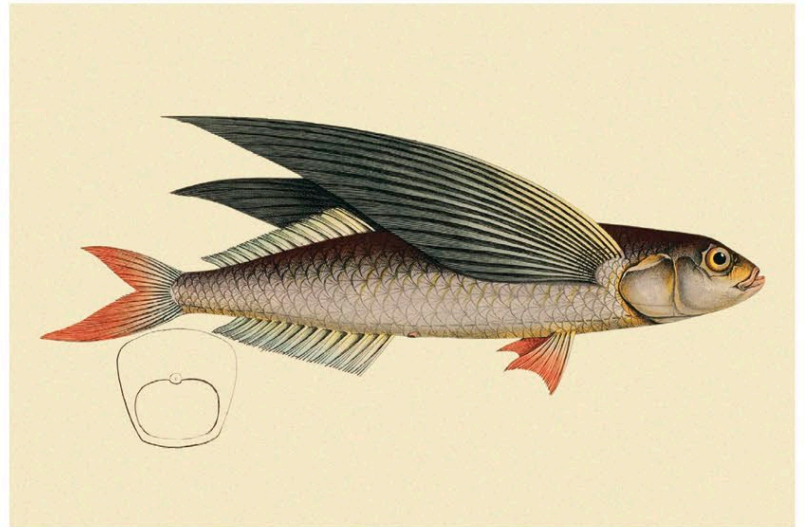
This common species of jack, now known as *Caranx hippos*, is found on both sides of the Atlantic Ocean and can grow over 3 ft (1 m) long.

needlefish and flying fish

ORDER: Beloniformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Flying fish grow up to 12 in (30 cm) long and hunt plankton in the surface layers of the oceans in warmer regions throughout the world. Members of this family can launch themselves into the air, with their huge pectoral fins locked into position like wings, and glide up to 330 ft (100 m) to escape predators. Their stiff body makes them aerodynamic, and the enlarged lower lobe of their tail fin stays in contact with the water at takeoff, helping propel them. The species belonging to two of the genera are sometimes called four-winged flying fish because the enlarged pelvic fins also spread out to create lift.

This order also contains five other families of mainly long, thin fish, including the needlefish, halfbeaks, and sauries, which are found in fresh water, as well as the ocean. Although these fish cannot glide, they have the habit of jumping out of water. The largest, the needlefish, are fish-eaters and grow to over 3 ft (1 m) in length. They have caused injuries and deaths by leaping over small boats and impaling themselves on the human occupants. Sauries resemble small needlefish, while halfbeaks, as their name suggests, have an extended lower jaw that is much longer than the upper one.



Tropical two-wing flying fish

This common species, now called *Exocoetus volitans*, is found in warmer oceans. It has a long lower tail lobe that is used in launching its flight.



Atlantic flying fish
Cheilopogon melanurus



Sailfin flying fish
Parexocoetus brachypterus



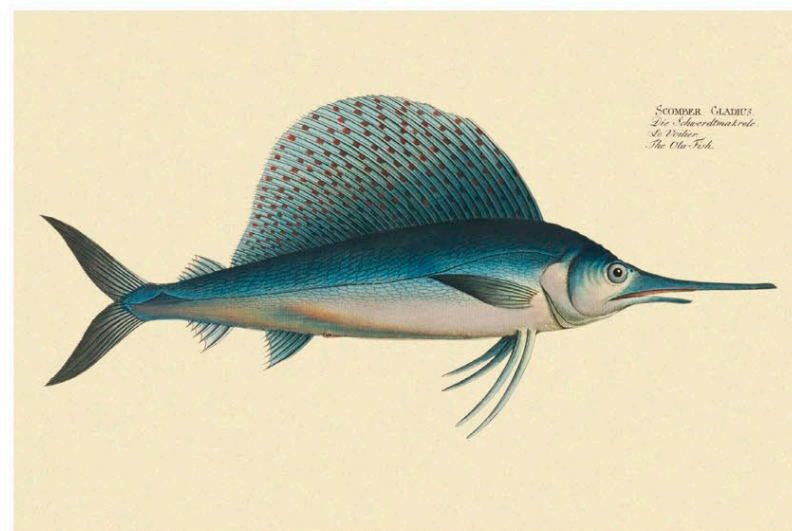
Houndfish, or crocodile needlefish
Tylosurus crocodilus

marlins, swordfish, and barracudas

ORDER: Istiophoriformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Members of the marlin family, Istiophoridae, are fast-swimming, open-water predators that range widely across warmer oceans. The blue marlin can grow up to 16 ft (5 m) long. Smaller marlin species are known as spearfish, and the family includes the distinctive sailfish with its huge dorsal fin. Together with the swordfish (family Xiphiidae), they are often called “billfish,” the bill being the extended upper jaw. Marlins have conical bills, while those of swordfish are longer and flatter. The bills are used to slash around in dense schools of smaller fish, injuring them—sailfish are known to do this cooperatively. The prey is probably swallowed whole, as marlins have small teeth and adult swordfish lack them altogether.

Although disputed, a recent classification places the barracuda family in the same order as billfish. Barracudas are long, narrow predatory fish that hunt mainly by sight. They are common in shallow, warm waters and on reefs. There are nearly 30 species, the largest of which can reach 6 ft (2 m) in length. Barracudas have a large mouth full of sharp teeth. They lurk almost motionless before dashing forward to attack their fish prey.

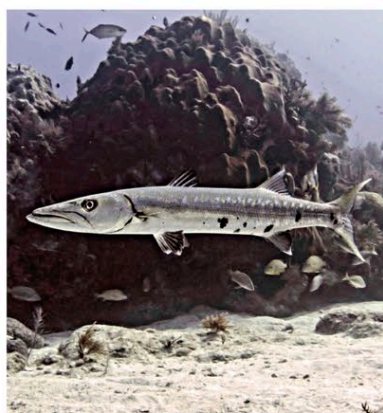


Sailfish

This 18th-century illustration of a sailfish portrays its large “sail” as being rounder than it would be in reality.



Atlantic blue marlin
Makaira nigricans



Great barracuda
Sphyræna barracuda



Swordfish
Xiphias gladius



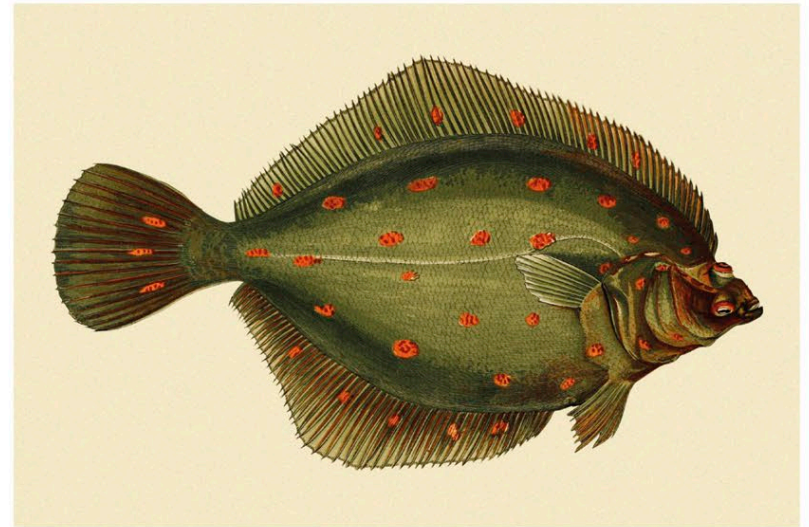
Sailfish
Genus *Istiophorus*

flatfish

ORDER: Pleuronectiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Flatfish are a large, distinctive order of fish with flattened bodies. The adults are asymmetric and lie on what is anatomically the side of the fish. Either the left or the right side faces upward, depending on the family, species, and even the individual within a species. Newly hatched flatfish are symmetric like other fish, but as they grow, one of their eyes migrates around to join the other on what becomes the upper surface of the fish.

Flatfish live on the seafloor and are often nocturnal, feeding mainly on invertebrates. The underside is usually white, but the upper side is typically camouflaged to match the fish's background. Often, the slightly raised eyes are the only visible part of a motionless flatfish, the rest being buried in sand or mud. The Pleuronectidae, or right-eyed flounder family, contains many species that are fished commercially in the north Atlantic, including plaice, lemon sole, and halibut—although these names may refer to different fish in different parts of the world. The Atlantic halibut is the world's largest flatfish, reaching 10 ft (3 m) or longer. Some tropical flatfish, such as whiteblotched sole, are brightly colored, and their juveniles can mimic the colors of poisonous flatworms.



European plaice

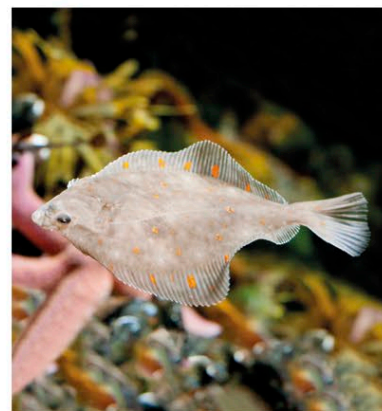
Pleuronectes platessa lives on seafloors in the northeast Atlantic, migrating to shallow waters to spawn.



Atlantic halibut
Hippoglossus hippoglossus



Common, or Dover, sole
Solea solea



European plaice
Pleuronectes platessa



Turbot
Scophthalmus maximus

seahorses, pipefish, and relatives

ORDER: Syngnathiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

The seahorse and pipefish family, Syngnathidae, is one of the most unusual families of fish. Its members have knobby rings of bony armor under their skin, so they cannot flex their bodies and have to use their fins to swim; seahorses use their dorsal fin for propulsion. Syngnathids have a long, thin snout with a tiny mouth at the end, which can suck up small prey at lightning speed. In addition, the males brood the eggs, either in a brood pouch on the belly, as in the case of seahorses, or in other locations such as at the base of the tail. Seahorses and some pipefish have individually swiveling eyes and finless, prehensile tails. Typical pipefish are like straightened-out seahorses, but there are some partly bent forms called pipehorses. Some species called seadragons have leaflike body extensions. There are seven other families in this order with various shapes and sizes, but they mostly have a long, tubular snout. Ghost pipefish have strange, spiny bodies, while the trumpetfish and cornetfish are like large pipefish in shape; some cornetfish grow as long as 6 ft (2 m). Snipefish have deeper bodies, similar to typical fish, but still feature a long snout.



Armored bodies and long snouts

This illustration compares a common seadragon, *Phyllopteryx taeniolatus* (left), with a seahorse species, both native to the coasts of Victoria, Australia.



Chinese trumpetfish
Aulostomus chinensis



Common seahorse
Hippocampus kuda



Leafy, or Glaucert's, seadragon
Phycodurus eques

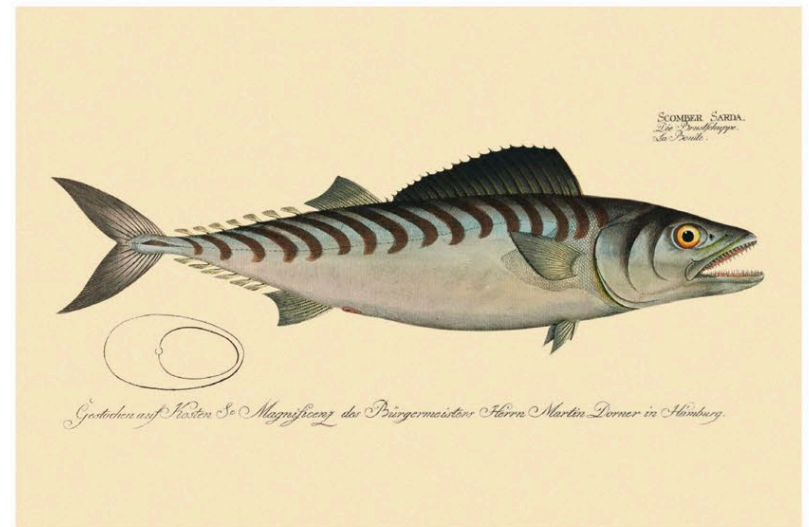


Pygmy, or Bargibant's, seahorse
Hippocampus bargibanti

tuna, mackerel, and relatives

ORDER: Scombriformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This order is named after its main family, the Scombridae, which includes tuna, mackerel, and bonitos. The fish in this family are fast-swimming, streamlined, open-water predators that swim in large schools and migrate long distances in search of prey or spawning grounds. Distinctive finlets behind their dorsal and anal fins aid their passage through water. Tuna are medium-sized to very large in size; the Atlantic bluefin tuna is the largest, growing up to 15 ft (4.5 m) long. They feed mainly on other fish, such as herrings and flying fish. Tuna can maintain parts of their body at a higher temperature than their surroundings, which enables them to live in cooler waters. They can even fold some of their fins into “slots” to further streamline their body. Several species have been overfished, and their populations are now in danger. Mackerel, such as the Atlantic mackerel, are smaller. They feed on plankton and small fish. Members of this family migrate to traditional spawning grounds, usually in shallower water, to lay their eggs. Other families in this order include the long, thin cutlassfish and the deep-bodied, shiny butterfish.



Atlantic bonito

This 18th-century illustration shows the series of rear finlets characteristic of the family Scombridae. This species is now known as *Sarda sarda*.



Atlantic bluefin tuna
Thunnus thynnus



Atlantic bonito
Sarda sarda



Indian mackerel
Rastrelliger kanagurta



Yellowfin tuna
Thunnus albacares

wrasses and parrotfish

ORDER: Labriformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This group comprises the wrasse and parrotfish families and one smaller family. Often brightly colored, these fish swim mainly by moving their pectoral fins rather than waving their tails. They live and feed near the seafloor in shallow seas, including coral reefs, and are mainly active by day, often sleeping in sheltered areas by night. Labriforms have complex sexual systems: they often start out as females before switching to become males, and their body changes color at the same time. Some species have a dominant male who defends a harem of females.

There are at least 500 species of wrasse, most being 8–12 in (20–30 cm) long or less. Diet varies considerably between species. Some wrasse are “cleaner fish,” removing parasites from other fish. Nearly all of the 80-plus species of parrotfish live on coral reefs. They are mainly herbivores and use their parrotlike beak (made of fused teeth) to eat seagrasses, algae, and dead coral. The largest wrasse, the dullish-colored humphead or Napoleon wrasse, measures up to 6.5 ft (2 m), and the largest parrotfish, the green humphead parrotfish, is 5 ft (1.5 m) long. They look superficially similar, although they are not closely related.



Wrasse

This 18th-century illustration probably shows the pastel-green wrasse, *Halichoeres chloropterus*, a Pacific species that lives on coral reefs.



Mediterranean parrotfish
Sparisoma cretense



Bluestreak cleaner wrasse
Labroides dimidiatus



Harlequin tuskfish
Choerodon fasciatus



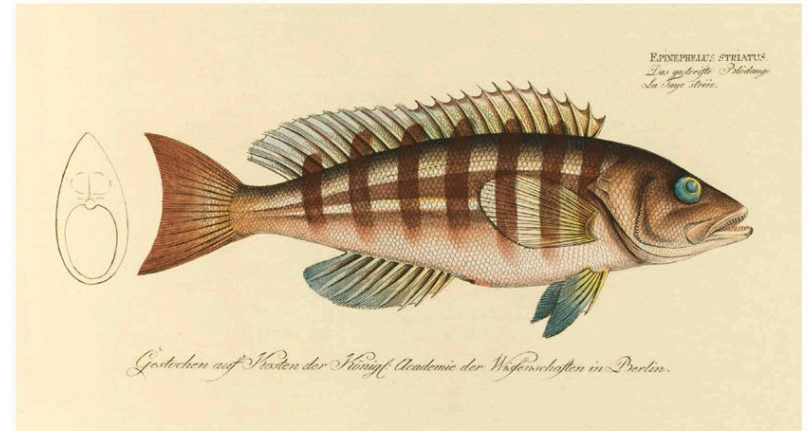
Cuckoo wrasse
Labrus mixtus

perches and relatives

ORDER: Perciformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Traditionally, this order used to be a huge grouping that included most of the spiny-finned fish. In recent years, however, many former species, including wrasses, marlins, and tunas, have been reclassified into their own separate orders. Debates about classification continue, but even with some groups removed, the Perciformes remains the largest fish order, with numerous different families.

The perch itself is a small freshwater fish, but most perciforms are marine. The large family Serranidae includes commercially fished sea basses, as well as groupers and anthias. Groupers are bulky, slow-moving fish that can reach over 8 ft (2.5 m) long, while shoals of anthias are common on tropical reefs. Other reef-living families include the colorful butterflyfish and angelfish. These narrow-bodied fish have small mouths for picking small invertebrates off the reef surface. Similar to wrasses, many species change color and sex as they grow. Perciforms also include families that generate sounds, possibly for communication, and are called grunts, drums, and croakers. Icefish are dominant on the continental shelf around Antarctica and have proteins that act like antifreeze in their blood to cope with the icy surroundings.



Nassau grouper

This endangered grouper is native to shallow reefs in the western north Atlantic. It can grow to over 3 ft (1 m) long.



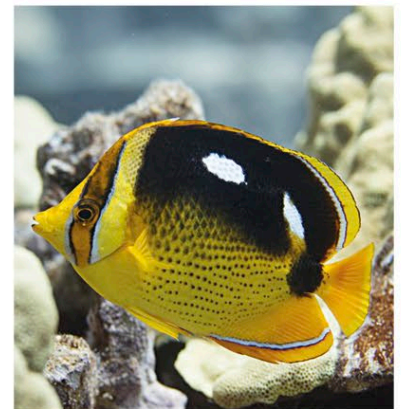
Blackfin icefish
Chaenocephalus aceratus



Painted comber
Serranus scriba



Malabar grouper
Epinephelus malabaricus



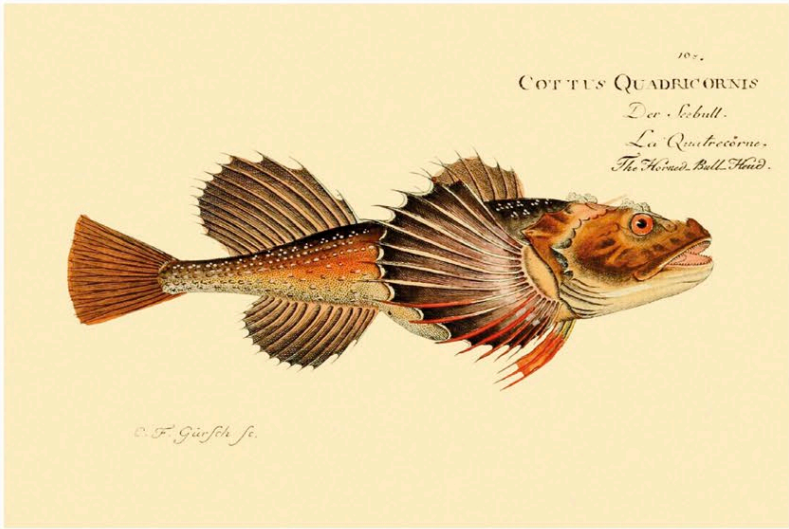
Fourspot butterflyfish
Chaetodon quadrimaculatus

scorpionfish and relatives

ORDER: Scorpaeniformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This large order includes over 1,600 species of spiny-finned, bony-plated fish that mainly hunt on the seafloor. They typically have big heads and large, rounded pectoral fins. Scorpionfish (family Scorpaenidae) have spines that inject potent venom if they are attacked or trodden on. Stonefish are particularly lethal, and their venom can kill a person. These odd-shaped, camouflaged fish lurk in ambush among rocks and are very difficult to see. In contrast, lionfish species advertise their venomous nature with bold stripes and markings. They hunt on coral reefs, cornering their prey with large, fanlike fins.

There are many other families in this order, generally nonvenomous but with unusual and varied shapes. The large group called sculpins, or bullheads, often have spines on the underside of their fins to grip surfaces. Gurnards, or sea robins, use their pectoral fin spines to “walk” along the ocean floor and stir up hidden prey. Flatheads have heads that resemble miniature crocodiles, while lumpsuckers (lumpfish) resist waves by clinging to rocks with a sucker on their underside. Larger species include the wolffish, which have teeth adapted for crushing hard-shelled prey.



Fourhorn sculpin
Now known as *Myoxocephalus quadricornis*, this member of the sculpin family lives close to the seafloor in cooler parts of the Northern Hemisphere.



Common lionfish
Pterois miles



Spotted scorpionfish
Scorpaena plumieri



Streaked gurnard
Chelidonichthys lastoviza



Reef stonefish
Synanceia verrucosa

anglerfish

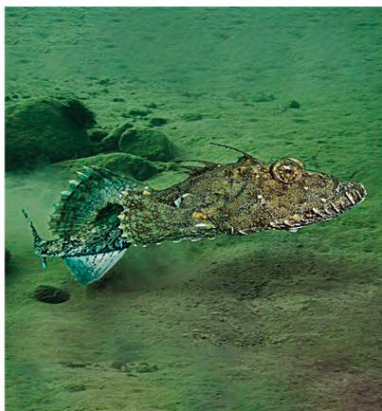
ORDER: Lophiiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

Ambush predators, anglerfish have a modified fin spine that can be dangled over their mouth to act as a lure to prey, who think they have spotted a morsel of food. Shallow-water anglers of the genus *Lophius*, also called goosefish or monkfish, have flattened bodies that appear to be “all head,” equipped with a wide mouth full of sharp teeth. Growing to over 3 ft (1 m) long, they camouflage themselves on the seafloor until prey moves close enough to capture. There are separate American and European species in the north Atlantic. Many other anglerfish species live in the twilight and dark zones of the open ocean. These free-swimming types have rounder bodies and use light-emitting lures to attract prey, sometimes having a luminous barbel under their chins as well. In these species, males are often tiny compared to females and may latch on to the female for life, living as parasites. This order also includes the frogfish and batfish families, which mainly live in coral reefs and other tropical shallow waters. These small fish use their fins as legs to walk along the seafloor; though often colorful, their strange shapes help disguise them.



Sargassum fish

Now named *Histrio histrio*, this well-camouflaged species of frogfish lives among rafts of floating sargassum seaweed in warmer oceans worldwide.



Goosefish
Lophius piscatorius



Giant frogfish
Antennarius commerson



Polka-dot batfish
Ogcocephalus cubifrons

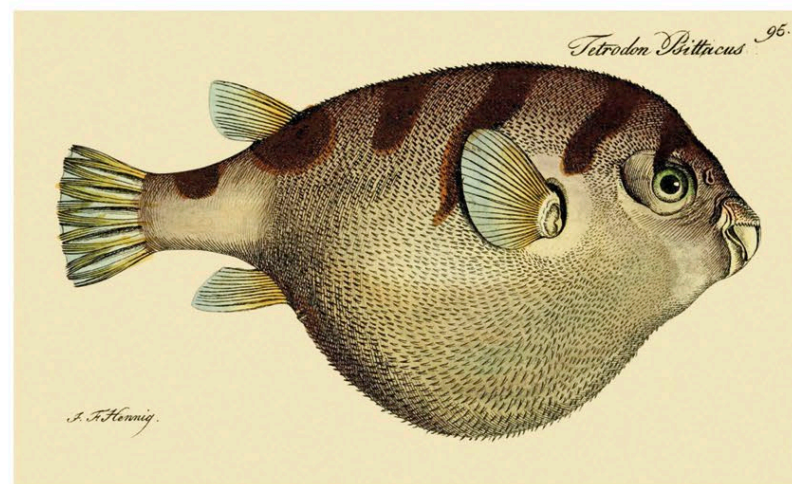


Sargassum fish
Histrio histrio

pufferfish and relatives

ORDER: Tetraodontiformes **CLASS:** Actinopterygii **SUBPHYLUM:** Vertebrata

This order contains 10 families of mainly slow-swimming fish with unusual body shapes. Apart from the large ocean sunfish, they are generally small and live close to the seafloor in shallow, warm waters, especially on coral reefs. Their few large teeth are usually fused together to form a hard beak for crushing invertebrate prey, although some also eat algae. Many species deter predators with poisonous flesh or skin secretions. Pufferfish, a group of around 200 species, swallow water when threatened, swelling up into a prickly ball. Porcupinefish are similar, but with longer spines that are visible even when the fish is not inflated. Boxfish, or trunkfish, are protected by a rigid casing of fused scales and swim using their fins alone. This group includes cowfish, which have horns above their eyes. The triggerfish have deeper, colorful, more flexible bodies, with spines on their backs that are erected by a triggerlike mechanism. The related filefish are similar but smaller. In contrast, the five species of ocean sunfish, or molas, from the family Molidae include the largest bony fish on the planet, weighing over 2.2 tons (2 tonnes). These tough-skinned, slow-swimming giants eat jellyfish and other invertebrates.



Banded puffer
Now known as *Colomesus psittacus*, this species of pufferfish is widespread down the Atlantic coast of South America and is tolerant of fresh water.



Titan triggerfish
Balistoides viridescens



Ocean sunfish
Mola mola



Scrawled filefish
Aluterus scriptus



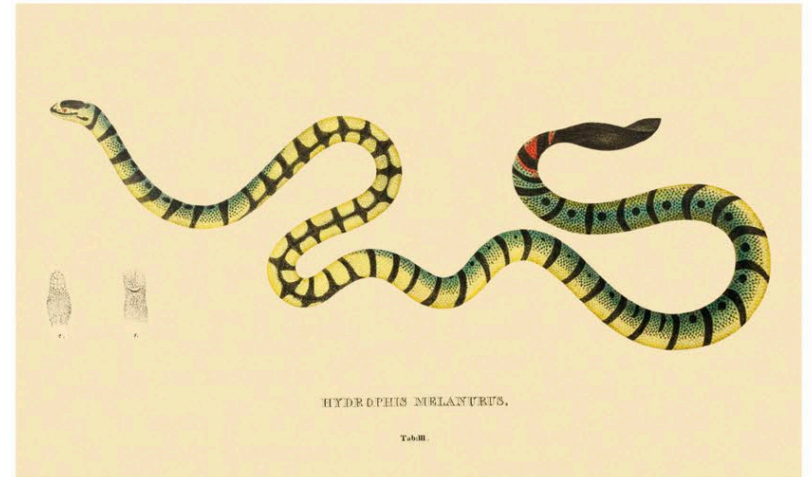
Yellow boxfish
Ostracion cubicus

sea snakes and lizards

ORDER: Squamata **CLASS:** Reptilia **SUBPHYLUM:** Vertebrata

The 70 or so species of sea snakes belong to the venomous cobra family. They fall into two subgroups. The seven species of sea kraits return to land to lay eggs and have large scales on their undersides similar to land snakes. The remaining “true” sea snakes give birth to live young in the water and are helpless on land. Like all marine reptiles, they need to visit the surface regularly to breathe, although they have an extra-large lung that probably also helps regulate buoyancy. In addition, they can take in oxygen through their skin. Sea snakes typically hunt in reefs and other rocky areas, seeking small fish hiding in crevices. They are confined to tropical waters of the west Pacific and Indian Oceans, with the exception of the yellow-bellied sea snake, an open-ocean species that can be found up to American Pacific coasts.

The marine iguana of the Galápagos Islands is the only completely sea-dependent lizard and obtains some of its food by diving for underwater seaweed. It needs to return to land periodically to bask on rocks and raise its temperature. Some tropical members of the monitor lizard family also enter the sea to seek fish and crustacean prey.



Yellow sea snake

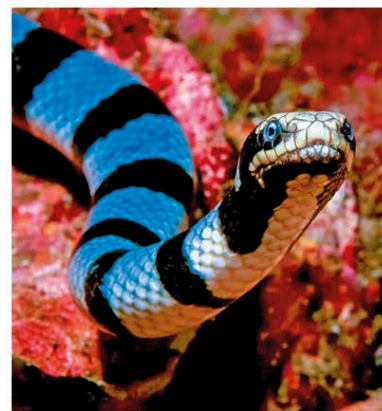
This large species of sea snake, now named *Hydrophis spiralis*, is native to the tropical Indian Ocean and western Pacific.



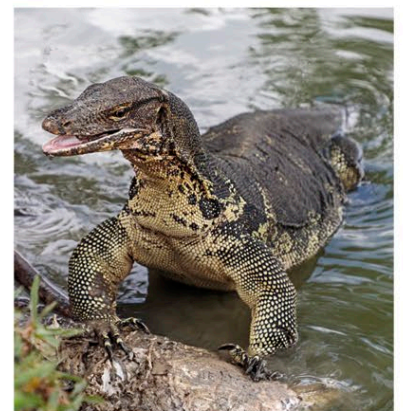
Yellow-bellied sea snake
Hydrophis platurus



Galapagos marine iguana
Amblyrhynchus cristatus



Yellow-lipped sea krait
Laticauda colubrina



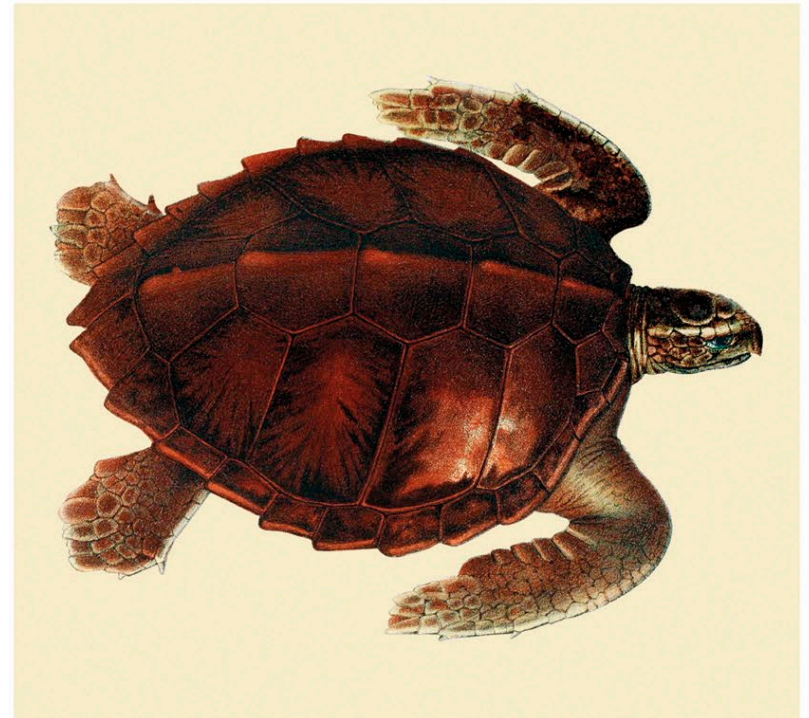
Common water monitor
Varanus salvator

turtles

ORDER: Testudines **CLASS:** Reptilia **SUBPHYLUM:** Vertebrata

Only seven of the world's 300 or so turtle species live in the open oceans, and almost all are under threat. They have streamlined shells and powerful front flippers for long-distance swimming. Like other reptiles, they breathe air, but only the females ever visit land, crawling up chosen beaches to dig holes and lay their eggs. They may travel thousands of miles to reach these egg-laying grounds. The hatchlings dig themselves out and run the gauntlet of predators as they head toward the water.

There are two families of sea turtles, one of which only contains the leatherback turtle, which can raise its body temperature to survive in cooler seas. Its ridged, leathery upper shell (carapace) lacks the horny scutes of other turtles. It feeds largely on jellyfish, sometimes mistaking floating plastic bags for its prey. The other six species are found only in warmer waters. Their diet varies across species: the adult green sea turtle only eats plants, especially seagrasses, while the hawksbill turtle mainly eats sponges. The remaining species, including the loggerhead turtle, have a broader carnivorous diet that includes hard-shelled mollusks and crustaceans.



Shell structure

Turtles' shells have two parts: the carapace (upper shell) and the plastron (lower shell). Both are constructed of flat, fused bones and covered by horny plates called scutes.



Hawksbill sea turtle
Eretmochelys imbricata



Green sea turtle
Chelonia mydas



Loggerhead sea turtle
Caretta caretta



Leatherback sea turtle
Dermochelys coriacea

crocodiles

ORDER: Crocodilia **CLASS:** Reptilia **SUBPHYLUM:** Vertebrata

Crocodiles are semiaquatic predators that have webbed feet, nostrils that can be closed, a valve in the mouth that allows breathing underwater if the nostrils are above the surface, and salt-secreting glands on the tongue. Most species of crocodile are confined to rivers and lakes. Only two species occur regularly at sea: the saltwater crocodile of Australian and Indo-Pacific waters and the American crocodile. Both live in coastal areas, including river mouths, but their willingness to swim across the open ocean means they are widely spread across their respective regions.

The saltwater crocodile or “salties” is the world’s largest crocodile. It mainly breeds in river mouths and creeks during the wet season. The females create a moundlike nest for their eggs above the waterline and guard them till they hatch, helping the young crawl down to the water afterward. Males are territorial, and young crocodiles may be forced out to sea to avoid being killed. Saltwater crocodiles eat virtually any animal they can catch, including humans. American crocodiles have similar lifestyles to saltwater crocodiles, but they are smaller and less dangerous.



American crocodile

Crocodylus acutus is found on Atlantic and Pacific coasts from Florida and Mexico to Peru. It is at the very edge of its range in southern Florida, as it cannot survive in colder weather further north.



American crocodile
Crocodylus acutus



Saltwater crocodile
Crocodylus porosus

waterfowl

ORDER: Anseriformes **CLASS:** Aves **SUBPHYLUM:** Vertebrata

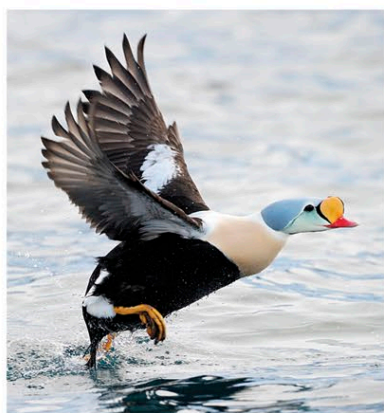
Waterfowl include geese, ducks, and swans. They all have webbed feet; waterproof plumage; and a broad, flattened bill. The members of this group vary in size from small teals that are 14 in (35 cm) long to swans that measure up to 5 ft (1.6 m). The sexes are almost alike in swans and geese; they differ in most ducks, but the males resemble females for a few weeks in summer, when they molt and become flightless.

Swans, geese, and many ducks eat grass, seeds, and shoots or are filter feeders, sifting food from water, but have no connection with the open sea. Except when nesting, some ducks (colorful eiders and black scoters) do live on the sea, often in sheltered, sandy bays and inlets. They feed by diving from the surface to catch mollusks and crustaceans on the seabed, using their webbed feet for propulsion. Sawbills, or mergansers, dive for food in shallow waters. Their hooked bills with serrated cutting edges help grasp prey. These marine ducks nest close to the shore (eiders) or on remote freshwater lakes (scoters), where downy ducklings quickly take to the water but are vulnerable to predators.

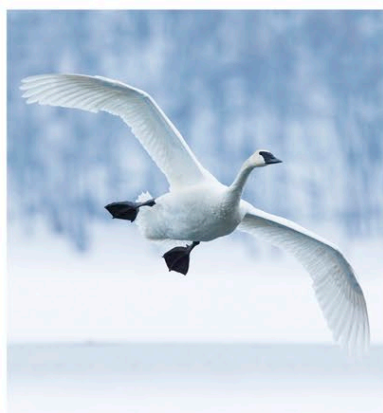


Gadwall

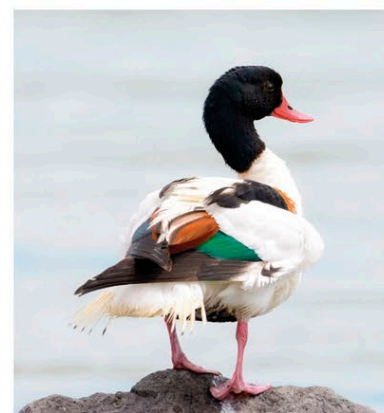
Mareca strepera is a dull-colored but exquisitely patterned, surface-feeding duck. It has an extremely wide range in areas with shallow fresh water and is sometimes seen along sheltered coasts.



King eider
Somateria spectabilis



Trumpeter swan
Cygnus buccinator



Common shelduck
Tadorna tadorna



Egyptian goose
Alopochen aegyptiaca

albatrosses, shearwaters, and petrels

ORDER: Procellariiformes **CLASS:** Aves **SUBPHYLUM:** Vertebrata

This group includes petrels, as little as 6 in (15 cm) long, to huge albatrosses, with wingspans of 11.5 ft (3.5 m). These web-footed birds are characterized by small, tubelike nostrils, which excrete excess salt (the birds rarely drink fresh water) and also assist in finding food and, in some species, nesting burrows. In larger species, an unusually long humerus gives an extended wingspan. By exploiting air currents over wavetops and banking steeply against the wind to gain speed, they cover huge distances without effort. Shearwaters have faster wingbeats between shorter glides, and small petrels have a more fluttering action that is less dependent on wind. Some shearwaters and petrels breed in southern ocean archipelagos and migrate far into Northern Hemisphere seas, with extraordinary powers of navigation, but the still air in calm tropical regions prevents albatrosses from going farther north. Shearwaters catch fish and squid in shallow dives, while petrels mostly pick smaller food from the surface, pattering with their feet. Albatrosses can stand and nest on open ground, but shearwaters and petrels merely shuffle on land and nest in holes, arriving and departing only after dark to avoid predators.



Shy albatross

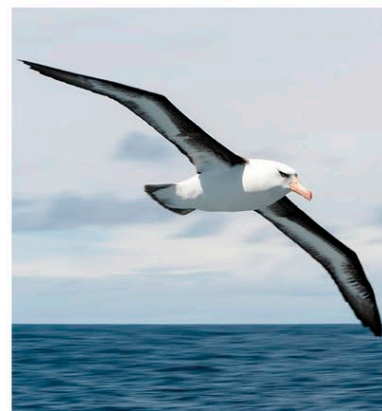
Thalassarche cauta is native to the islands of Australia. Even though it is one of the smaller albatrosses, or “mollymawks,” it still has a wingspan of 8 ft (2.5 m).



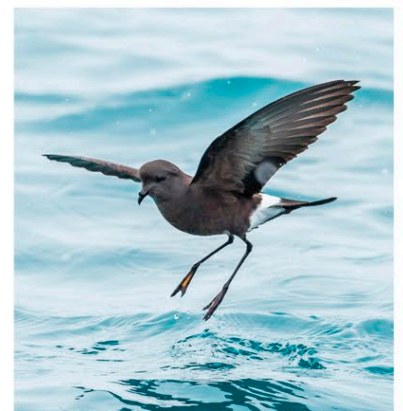
Great shearwater
Ardenna gravis



Northern fulmar
Fulmarus glacialis



Black-browed albatross
Thalassarche melanophris

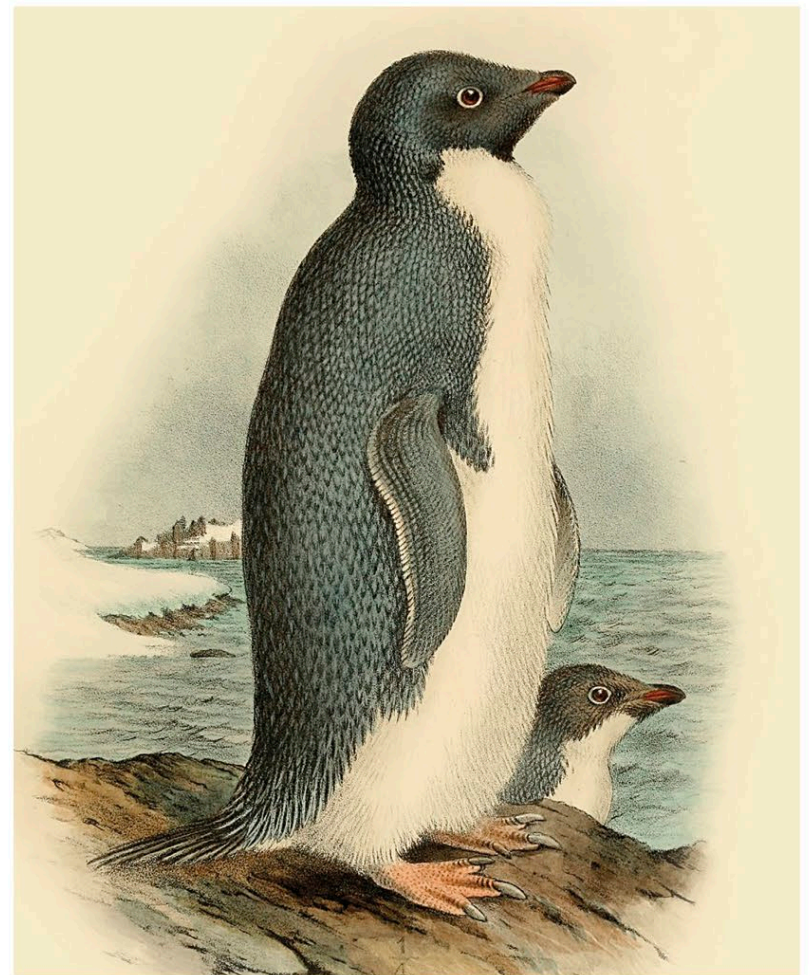


Wilson's storm petrel
Oceanites oceanicus

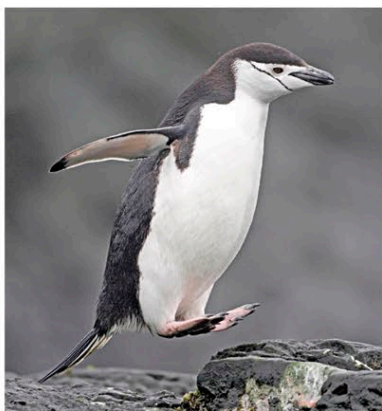
penguins

ORDER: Sphenisciformes **CLASS:** Aves **SUBPHYLUM:** Vertebrata

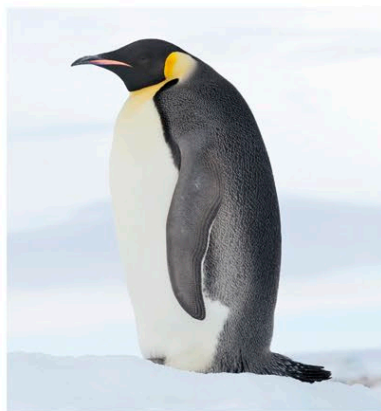
Penguins are found in the Southern Hemisphere, although the Galapagos penguin breeds on the equator. Most are temperate or subantarctic species, but the emperor penguin can endure severe weather conditions better than any other animal in the far south. Penguins have barrel-shaped bodies and short tails, with short legs near the tail that give them an upright stance, and wings reduced to narrow, flipperlike appendages. The bill is short, stubby, and blunt or slim and pointed. Stiff, narrow feathers create a dense, furlike plumage, which is normally immaculate but becomes untidy and clumped during molting. Males and females are alike, dark above and white below for camouflage when swimming; some species have decorative head plumes. Penguins feed on fish and marine invertebrates, such as krill (see p.350), using their wings to propel themselves underwater. Larger species dive deep; emperor penguins can reach 1,640 ft (500 m), staying underwater for 20–30 minutes. Breeding penguins stay close to their colonies but swim far away from land at other times, often within reach of sea ice.



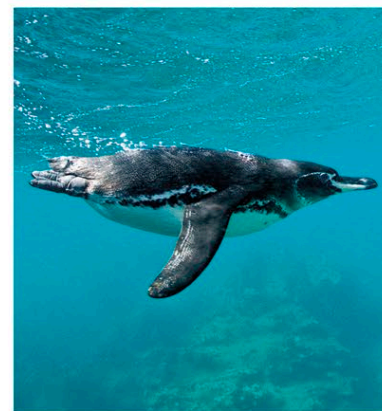
Adélie penguin
The medium-sized Adélie penguin, *Pygoscelis adeliae*, is one of the most widespread and southerly of the penguins, found all around the Antarctic Ocean.



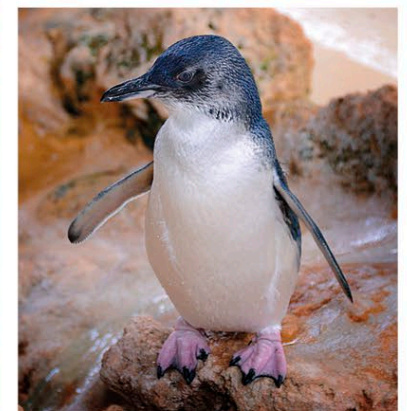
Chinstrap penguin
Pygoscelis antarcticus



Emperor penguin
Aptenodytes forsteri



Galapagos penguin
Spheniscus mendiculus



Little penguin
Eudyptula minor

gannets, boobies, cormorants, and frigatebirds

ORDER: Suliformes **CLASS:** Aves **SUBPHYLUM:** Vertebrata

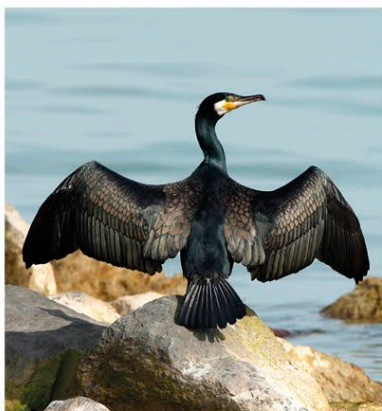
Birds in this group have webs between all four toes and bare, flexible skin at the base of the bill. Gannets, with broad, pointed bills, and cormorants, with slender, hooked bills, can extend this skin to swallow large fish. Gannets and boobies, with forward-facing eyes and heads protected by air sacs, plunge headlong from the air using their wings and feet to chase fish underwater.

Cormorants dive from the surface, powering the dives with their feet. Some flush fish from rocks and reefs, while others feed in more open water. They frequently rest ashore with their wings spread out to dry—their feathers are inadequately waterproofed, which makes them heavier and aids diving—and possibly to aid digestion. All cormorants are social breeders, some forming huge colonies on cliffs and offshore islands, characterized by a “whitewash” of droppings. Some cormorants and boobies nest in trees. Frigatebirds do not dive and rarely settle on water but fly far over the open sea. Their extremely long wings and tails give them speed and agility for catching flying fish or forcing other seabirds to disgorge food.



Great cormorant

This illustration shows a colony of great cormorants, *Phalacrocorax carbo*. They have white head plumes and thigh patches during the breeding season, and they nest in trees inland, as well as on coastal cliffs.



Great cormorant
Phalacrocorax carbo



Northern gannet
Morus bassanus



Blue-footed booby
Sula nebouxii



Magnificent frigatebird
Fregata magnificens

pelicans and herons

ORDER: Pelecaniformes **CLASS:** Aves **SUBPHYLUM:** Vertebrata

This diverse group of birds is often linked with the Suliformes (see p.389). It includes herons, ranging from 12 in (30 cm) to 5 ft (1.5 m) tall, and pelicans with wingspans of 11.5 ft (3.5 m). This group also includes ibises and spoonbills. Herons and egrets include many species that feed on tidelines worldwide, but a few pelican species are regularly seen at sea. Males and females are similar in appearance, but males are slightly larger; there is little seasonal change other than brighter bill, facial skin, and leg colors at the start of the breeding season, when herons also grow longer plumes on the head and back.

Pelicans have a large, flexible pouch under the bill that they use to scoop up fish and other aquatic prey while swimming. Brown pelicans are the most marine and typically plunge-dive like gannets. They scoop up water and prey and then, upon surfacing, expel excess water before swallowing the prey. The long wings, short tail, and heavy body make pelicans look ungainly, but they are skilled fliers once airborne, exploiting warm air currents over land like birds of prey. Without such assistance, they cannot fly far over water, hence migrating flocks fly around seas or cross at the narrowest points.



American white pelican

This illustration from Audubon's *Birds of America* shows the American white pelican, *Pelecanus erythrorhynchos*. In addition to the fleshy pouch, the bill has a "horn" on the top.



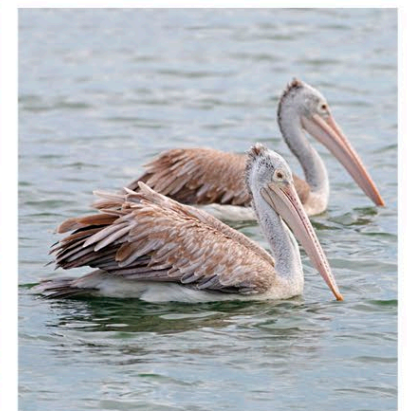
Green heron
Butorides virescens



Gray heron
Ardea cinerea



Black-crowned night heron
Nycticorax nycticorax

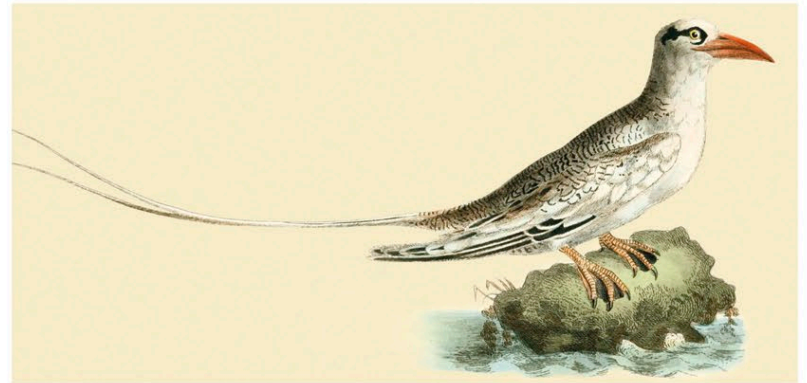


Spot-billed pelican
Pelecanus philippensis

tropicbirds

ORDER: Phaethontiformes **CLASS:** Aves **SUBPHYLUM:** Vertebrata

Tropicbirds are slim and elegant, mostly white birds with long wings and elongated tail feathers that form a thin “spike.” The three species existing today range in length from 30 in (75 cm) to 3 ft (1 m). They have webs between all four toes and cannot easily walk on land. Tropicbirds feed by hovering over water and plunging to catch fish and squid. Food is scarce near land and, like many tropical seabirds, tropicbirds must forage widely to feed, but fish may be abundant in localized areas. They form breeding colonies on remote islands, where females lay a single egg in crevices or shallow holes in the ground. The chicks grow slowly, an adaptation to an irregular but sometimes abundant supply of food.



Red-billed tropicbird

The largest tropicbird, the red-billed tropicbird, *Phaethon aethereus*, breeds across the eastern Pacific, Caribbean, and eastern Atlantic, with separate populations in the tropical Atlantic and Indian Oceans.

eagles, hawks, and relatives

ORDER: Carthartiformes, Accipitriformes, Falconiformes **CLASS:** Aves **SUBPHYLUM:** Vertebrata

This group of birds of prey includes the osprey, eagles, hawks, and their relatives. While it includes some coastal species, it has none that are truly oceanic. Northern Hemisphere sea- or fish-eagles grab prey from the surface using their talons and feed on dead fish washed ashore. In the south, Andean condors and smaller caracaras scavenge on carcasses of whales and dolphins. None of these birds can fly far from land, as they rely on air currents and warm air rising over land for soaring and gliding. Powerful as they are, they soon become exhausted over open water due to constant flapping of wings. Peregrine falcons take seabirds near breeding colonies on cliffs and wildfowl on estuaries, while Eleonora’s falcons specialize in catching migrant songbirds crossing the Mediterranean Sea.



White-tailed eagle

With a heavy, hooked bill, short tail, and bare legs equipped with sharp, curved claws, the massive white-tailed eagle (*Haliaeetus albicilla*) is a typical sea eagle. It takes fish from the surface and marine creatures washed up on the shore.

shorebirds

ORDER: Charadriiformes **CLASS:** Aves **SUBPHYLUM:** Vertebrata

Shorebirds are a diverse group, many of which feed on coasts. They include waders such as plovers, curlews, oystercatchers, and sandpipers, as well as gulls and terns, which include many coastal species and a few (such as the kittiwakes) that are more strictly marine when not breeding. Skuas wander widely over the oceans, as do most of the auks (such as puffins), which visit land only when nesting. Of the waders, only two of the three species of phalaropes are truly oceanic, living at sea for much of the year. Many northern-hemisphere waders breed on northern tundra, islands, moorland or high plateaux, visiting coasts in winter or on migration. Estuarine mudflats are especially rich in food, allowing birds to refuel on their long migratory journeys. Some are solitary, while others form large flocks outside the breeding season. Many shorebirds have long legs in proportion to their bodies, enabling them to wade in shallow water. Some members of this group are among the world's greatest travelers and may use fat deposits and deplete body tissues on their long flights. American golden plovers migrate 20,000 miles (32,000 km) each year, while some bar-tailed godwits fly nonstop for 7,000 miles (11,000 km).

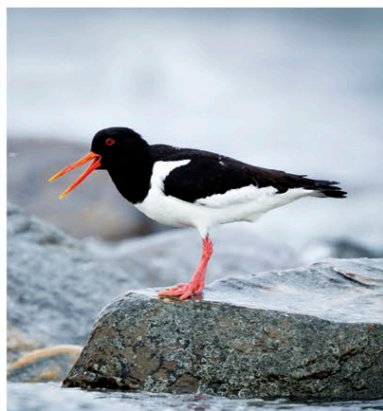


Common sandpiper

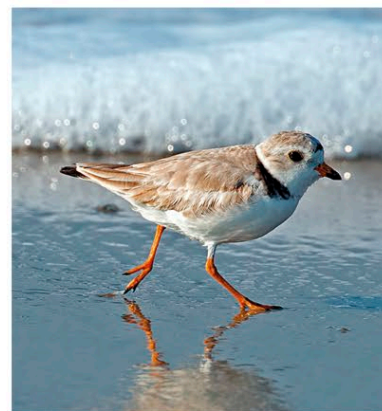
Delicate and subtly colored, the common sandpiper, *Actitis hypoleucos*, has a characteristic springy bob of its head and tail as it walks, half-crouched, on the shore.



Solitary sandpiper
Tringa solitaria



Eurasian oystercatcher
Haematopus ostralegus



Piping plover
Charadrius melodus



Eurasian curlew
Numenius arquata

dugongs and manatees

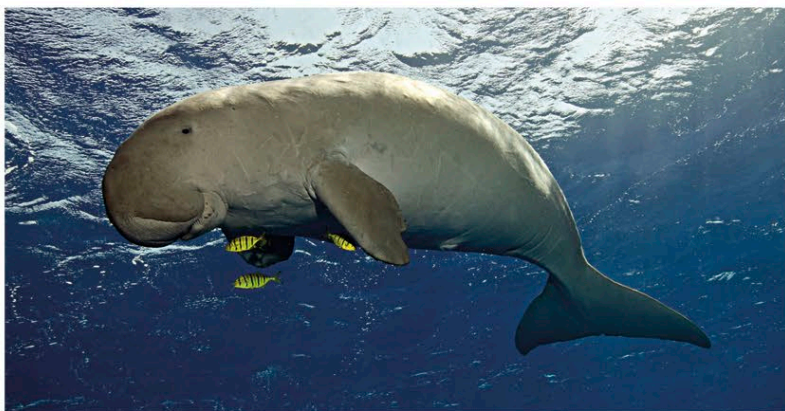
ORDER: Sirenia **CLASS:** Mammalia **SUBPHYLUM:** Vertebrata

The order Sirenia contains a single species of dugong and three manatees. All resemble rounded, bulky seals or dolphins and can reach up to 13 ft (4m) in length. They have horizontal tails; the dugong's tail is forked, while manatees have a broad, rounded "paddle." Their exceptionally dense, fused bones reduce buoyancy, but elongated lungs help control position underwater. Sirenians have massive heads, flipperlike forelimbs, and no external hindlimbs. They rarely dive deep, raising their high-set nostrils to the surface to breathe every few minutes when feeding. However, much of their life is spent asleep underwater, surfacing to breathe every 20 minutes. All species replace teeth at the back of their jaws as they wear out in a lifelong, continuous succession. Male and older female dugongs have short tusks. The West Indian manatee and the dugong are the most marine species, preferring estuaries and sheltered bays. Herds move slowly, grazing on dense underwater swards of seagrass. The dugong's massive muzzle is angled downward, while manatees have a more mobile upper lip for active foraging. Manatees may live for 60 years. The females rear a single calf every 2 years.

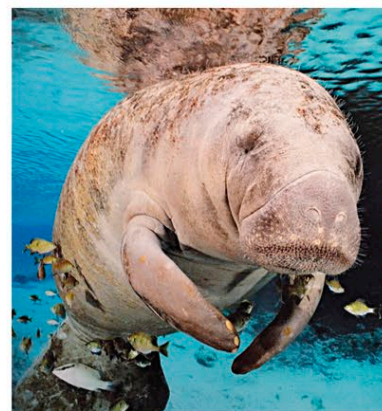


Manatee

While feeding, a manatee may use its flippers to hold vegetation while maintaining position by resting its broad tail against the ground.



Dugong
Dugong dugon



African manatee
Trichechus senegalensis



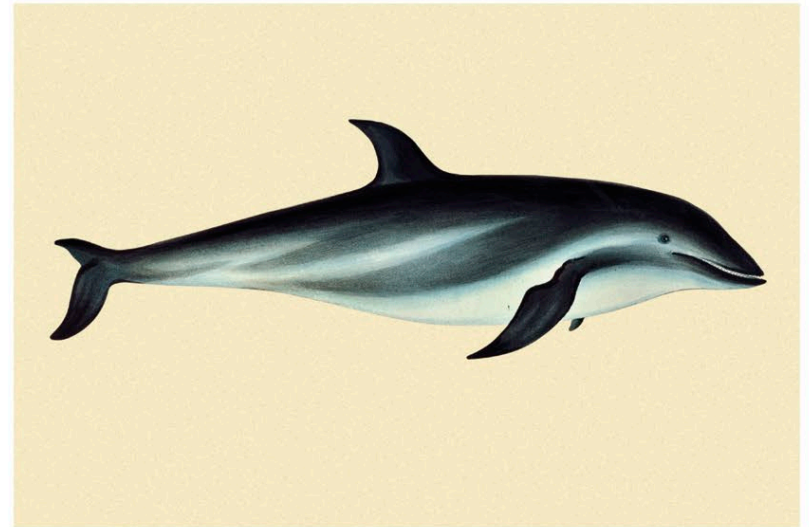
Florida manatee
Trichechus manatus latirostris

toothed whales

PARVORDER: Odontoceti **INFRAORDER:** Cetacea

Toothed whales include dolphins, orcas, porpoises, white whales, sperm whales, and beaked whales. They can reach up to 65 ft (20m) in length and 55 tons (50 tonnes) in weight; dolphins are typically 6–10 ft (2–3 m) long. All have conical teeth; in some, “beaked” mandibles extend into a snout. Most have inflexible, “neckless” bodies and range from round-headed to the extraordinary square head and slim lower jaw of the sperm whale. The large tail fin is set horizontally, and many have a curved back fin. The forelimbs are replaced by powerful flippers, while the hindlimbs are internal and therefore invisible. They breathe from a blowhole on top of the head. Orcas are cooperative predators of seals, but most species eat fish and squid. Larger species dive deep—sperm whales dive to depths of 2,600 ft (800m). Toothed whales use a variety of sounds to communicate and to find prey by echolocation.

The group is widespread, but many species are restricted in range: apart from a few river species, dolphins are ocean dwellers. Many are social, with some dolphins forming groups that are tens to hundreds strong. Males mate with several females annually, but females give birth to a single calf every 2 or 3 years.

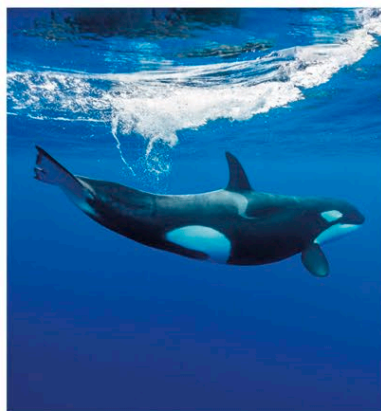


Dusky dolphin

Dolphins are dynamic, efficiently streamlined, and remarkably intelligent oceanic mammals. This illustration shows the dusky dolphin, *Lagenorhynchus obscurus*.



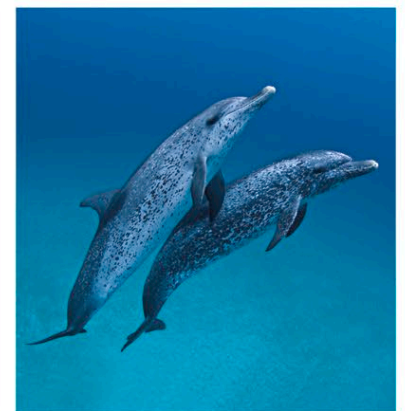
Short-beaked common dolphin
Delphinus delphis



Orca
Orcinus orca



Sperm whale
Physeter macrocephalus



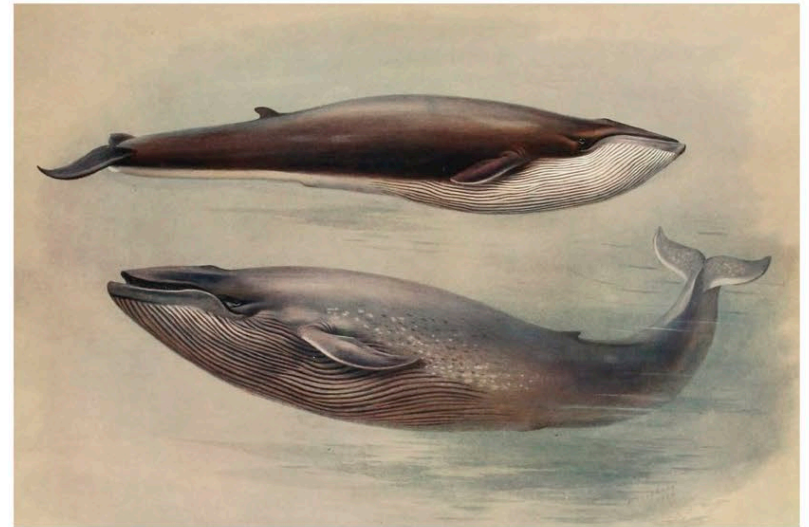
Atlantic spotted dolphin
Stenella frontalis

baleen whales

PARVORDER: Mysticeti **INFRAORDER:** Cetacea

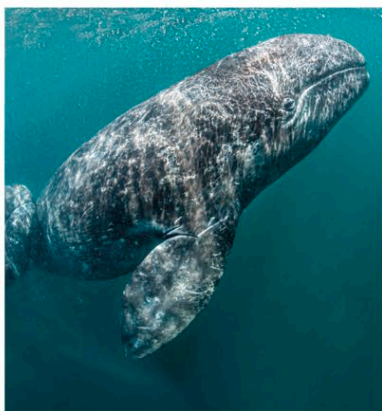
This widespread group includes massive whales ranging from 20 ft (6 m) long to the gigantic blue whale, which measures up to 100 ft (30 m) and weighs 200 tons (180 tonnes). All have baleen filaments, made from the protein keratin, attached to the upper jaw, forming two curtains that are used for filtering food. Gray whales are bottom-feeders, taking crustaceans, while rorquals are faster, streamlined “lunge-feeders” that chase krill or fish. Right whales swim open-mouthed and take in vast amounts of water, sieving plankton as they go. The rorquals have pleated tough skin around the throat, which expands to take in a volume of water greater than the volume of the whale’s own body. This works most efficiently when the whale dashes into a dense ball of prey.

Most species are long-distance migrants; some gray whales travel 12,000 miles (20,000 km) each year. Such movements exploit massive plankton “blooms” in cold northern seas in summer. In winter, the whales return to warm, tropical waters, where the females give birth to thin-skinned calves. Baleen whales detect prey by “taste” and communicate with extremely loud, low-frequency “songs” that can be detected over hundreds of miles.



Fin whale and blue whale

Baleen whales include the world’s two largest mammals—the slender, elegant fin whale, *Balaenoptera physalus* (top), and the magnificent blue whale, *Balaenoptera musculus* (bottom).



Gray whale
Eschrichtius robustus



Southern right whale
Eubalaena australis



Common minke whale
Balaenoptera acutorostrata

seals

FAMILY: Phocidae **ORDER:** Carnivora **CLASS:** Mammalia **SUBPHYLUM:** Vertebrata

True seals, eared seals, and the walrus (see p.398) all belong to the pinniped group. True seals (phocids) lack external ears and can only rest or shuffle on their bellies, as their flipperlike forelimbs and short, flippers “tail” are too weak to provide support. They have thick fur and a layer of fat (blubber) for insulation and sharp teeth to catch and tear prey. Unlike whales, which live entirely at sea, seals have to come to land to rest and breed. Although less oceanic, they have greater flexibility than dolphins and can be elegant and agile underwater. Most prey on fish, squid and other mollusks, and crustaceans. Seals are shallow divers, but Weddell seals reach depths of 3,000 ft (1,000 m). Northern elephant seals migrate vast distances between feeding areas in the Gulf of Alaska and breeding sites in Mexico, traveling up to 13,000 miles (21,000 km). Occasionally, they may dive to 5,200 ft (1,600 m). Seals prefer cooler currents in tropical seas and in subpolar regions may feed under ice, maintaining breathing holes. Most seals breed on open shores and islands where suitable beaches become crowded, but some breed on ice. Males try to mate with as many females as possible but take little interest in rearing their offspring.



Hooded seal and harbor seal

Seals, while sharing a consistent basic form, range from the 4.4-ton (4-tonne) hooded seal, *Cystophora cristata*, to small species such as the 130-lb (60-kg) harbor seal, *Phoca vitulina*.



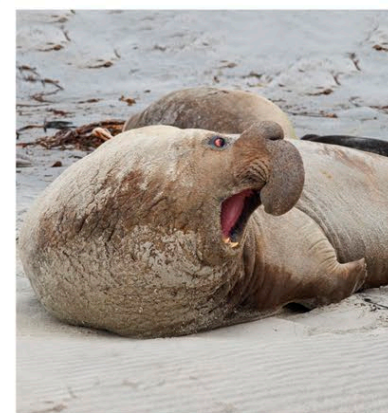
Leopard seal
Hydrurga leptonyx



Bearded seal
Erignathus barbatus



Hooded seal
Cystophora cristata



Southern elephant seal
Mirounga leonina

sea lions and fur seals

FAMILY: Otariidae **ORDER:** Carnivora **CLASS:** Mammalia **SUBPHYLUM:** Vertebrata

Also known as otariids or eared seals, these animals have tiny ears, strong forelimbs, and hind flippers that can be angled forward. This gives them a rudimentary four-footed, waddling walk on land, unlike the true seals, which merely lay on their bellies. The sea lions comprise six species, all with short fur and rounded snouts, while the nine species of fur seals have longer, thicker fur and pointed snouts. Eared seals are opportunistic feeders, taking fish, squid, birds, and other prey as the chance presents itself, being much more agile underwater than on land. Males, which are larger and more heavily maned than the sleek females, arrive early at breeding sites called rookeries. The appearance of females stimulates territorial fighting. The most powerful males, territorial at 9–13 years old, mate with more females. Females raise a single pup with no assistance from the males. Resting animals drift in water with half the brain awake and aware of potential predators, but on land, they sleep normally. The otariids range from tropical to subarctic seas. Among the best-known and most easily seen is the California sea lion, a species typically up to 8 ft (2.4 m) long and 660 lb (300 kg) in weight.

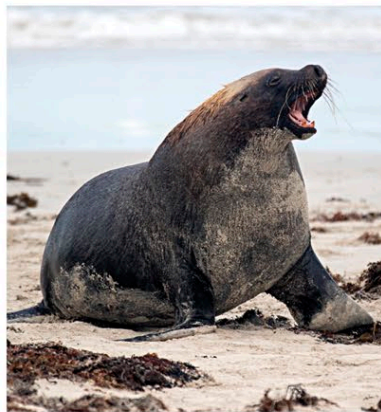


South American sea lions

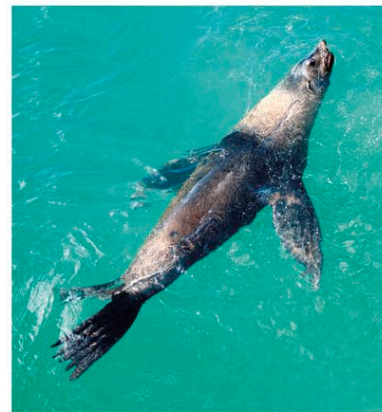
Male South American sea lions, *Otaria byronia*, are almost twice as heavy as females. The pups are born with a dark brown coat that turns lighter as they reach maturity.



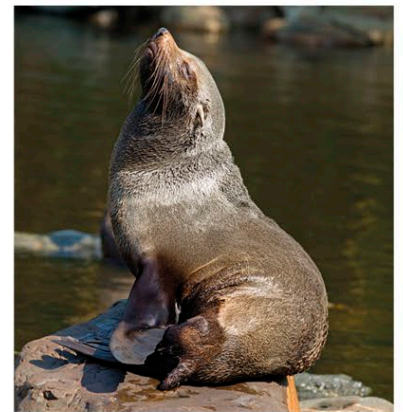
California sea lions
Zalophus californianus



Australian sea lion
Neophoca cinerea



Afro-Australian fur seal
Arctocephalus pusillus



South American fur seal
Arctocephalus australis

walruses

FAMILY: Odobenidae **ORDER:** Carnivora **CLASS:** Mammalia **SUBPHYLUM:** Vertebrata

There are two subspecies of walrus: the Atlantic walrus and the Pacific walrus. This massive pinniped of the Arctic seas ripples with soft blubber under its almost-bare pink skin, which becomes deeply fissured and calloused in older males. Walruses have a small head with a broad muzzle and a sparse, stiff, bristly “mustache” above two long, straight ivory tusks. The large, angled fore-flippers can scarcely support the weight of this 12-ft (3.5-m) long animal on land, where it rolls and shuffles with its hind flippers lifted and curled clear of the ground. Males can be almost 2.2 tons (2 tonnes) in weight. Highly social, walruses crowd together on land or sea ice and feed in groups, rolling on the surface before diving into the water. The tusks rake into soft mud, which is “pumped” and dug out with the enlarged upper lips and flippers, so the animal progresses slowly in a cloud of swirling sediment. Walruses typically feed on large bivalve mollusks such as clams. On the surface, often only the top of their head is visible, with an occasional whalelike “spout” of breath from the nostrils. Calves are born in spring after a gestation of 15 months. They are weaned after a year or more and may remain with the mother for 5 years.



Atlantic walrus

This illustration of *Odobenus rosmarus* shows its characteristic tusks at their greatest extent, reaching around 3 ft (1 m) long in adult males.



Atlantic walrus
Odobenus rosmarus rosmarus



Pacific walrus
Odobenus rosmarus divergens

bears

FAMILY: Ursidae **ORDER:** Carnivora **CLASS:** Mammalia **SUBPHYLUM:** Vertebrata

Polar bears spend most of their lives around Arctic seas and are seriously threatened by the accelerating loss of ice around their habitat. They have become scavengers around human settlements in some areas but still maintain their natural role as predators of seals, which they catch at breathing holes in ice. Few seals are caught on land or at sea, but bears will stalk the ones resting on ice. Formidable animals, the males weigh 1,550 lb (700 kg), double the weight of females, and rear up to an impressive height of 10 ft (3 m). They can swim for several days at a stretch to reach ice fields and sprint on land at a speed of 25 mph (40 kph). The females dig dens in snow to give birth to cubs, which are weaned after 2 years or more.



Ursus maritimus

A polar bear's large teeth and massive neck, shoulders, and front legs give it the immense power needed to pull a heavy seal from water onto ice.

otters

FAMILY: Mustelidae **ORDER:** Carnivora **CLASS:** Mammalia **SUBPHYLUM:** Vertebrata

Otters are sleek, elongated mammals with long tails and short legs, streamlined for a life in water. Some live on the coast and catch saltwater fish, but only the sea otter of the northeast Pacific has a fully marine life. Sea otters may be up to 4.5 ft (1.4 m) long. They can walk on land, but usually remain at sea. Groups rest in kelp, keeping afloat and insulated by exceptionally dense fur, which is constantly groomed. Otters dive to turn over loose rocks in search of sea urchins, fish, and shellfish. They use small stones both to dislodge shellfish from rocks and to break open shells, a rare example of tool use among mammals. Females may give birth to a single cub in any month and care for it with great affection for a year or more.



Sea otter

J.J. Audubon pictured this sea otter with a salmon, but it feeds mostly on clams, mussels, and sea snails such as abalones, which are brought to the surface and broken open on the otter's chest, with a rock held in the forefeet.

glossary

ABDOMEN The hind part of the body of a vertebrate or arthropod.	ANEMONE See <i>Sea Anemone</i> .	BEAK The horny, toothless jaws of a bird, turtle, or cephalopod.	ocean plants such as mangroves, seaweeds, and seagrasses.
ABORAL On the opposite side of the body from the mouth; used especially with reference to animals that have radial symmetry, such as jellyfish and echinoderms. See also <i>Radial symmetry</i> .	ANTENNA (pl. ANTENNAE) One of a pair, or in some groups two pairs, of long, thin sensory structures on the heads of arthropods. Antennae are sometimes called “feelers” because of this sensory characteristic.	BENTHIC Relating to an object or organism living on the seafloor.	BONY FISH The class of vertebrates that includes all living fish except hagfish, lampreys, and sharks and their relatives. These fish have an internal skeleton, which in almost all species is made of bone. See also <i>Cartilaginous fish</i> .
ABYSSAL A term applied to the depths of the ocean. The abyssal plain is the almost flat plain of the deep ocean floor beyond the continental margin. The abyssal zone is the zone of water between 13,000 and 20,000 ft (4,000 and 6,000 m) deep. See also <i>Hadal zone</i> .	ARTHROPODS The phylum of jointed-legged invertebrates, including crustaceans, insects, and spiders.	BILATERAL SYMMETRY Body symmetry in which there is a left and right side, a head, and a tail. See also <i>Radial symmetry</i> .	BREAKWATER A long, solid structure built into the sea to protect a harbor from rough ocean conditions.
ADIPOSE FIN A small, fleshy fin between the dorsal and tail fins in some bony fish.	ASEXUAL REPRODUCTION Any form of reproduction that does not involve the fusion of sex cells to create a new individual. An example of this is the budding off of new individuals from a parent, which can occur in marine invertebrates, such as some corals.	BINOCULAR VISION A type of vision in which objects are viewed from two eyes simultaneously, which allows perception of depth and distance.	CALCAREOUS Containing or made of calcium carbonate.
AERIAL ROOT A root that grows from or reaches a point above ground level, as in many mangrove trees. See also <i>Mangroves</i> .	BACKSHORE The part of the shore lying above the normal high-tide line, reached by the sea only under exceptional conditions.	BIOELECTROGENESIS The creation of electric fields by living organisms, including some fish. Weak electric fields can be used as a form of echolocation, while strong ones can be used to “shock” other organisms, either in attack or in defense.	CALYX In zoology, the cuplike structure of a sea lily or feather star.
ALGA (pl. ALGAE) Any organism that photosynthesizes but is not a true plant, including seaweeds and many microscopic forms. Cyanobacteria are usually now excluded from the definition. See also <i>Cyanobacteria</i> .	BACKWASH The flow of water back to the sea after a wave has broken. See also <i>Swash</i> .	BIOLUMINESCENCE Production of light by living organisms. Sometimes the light is produced by the organism’s own cells, and in other cases by light-producing bacteria.	CAMOUFLAGE Features of an organism that make it difficult to detect visually against its natural background, including color patterns and aspects of body shape.
AMPHIPODS An order of mainly small crustaceans that includes sandhoppers and their marine and freshwater relatives.	BALEEN A horny material that grows in the mouths of many whales. It takes the form of plates with hairlike fringes that are used in filter feeding.	BIOME Any group of large-scale ecosystems across the world that display similar features due to shared climatic conditions. The concept is most commonly applied to land ecosystems.	CARAPACE The protective shield covering the upper surface of a turtle, crustacean, or horseshoe crab.
AMPULLAE OF LORENZINI The sensory receptors in the skin of sharks and relatives located around the head region. They can detect weak electric fields such as those produced by the muscle movements of potential prey.	BANK In oceanography, a submerged shallow region or plateau of seafloor surrounded by deeper water.	BIVALVES A class of mollusks that features a pair of hinged shells. Bivalves include clams, mussels, scallops, oysters, and relatives.	CARRION Animal matter that is dead or decaying.
ANADROMOUS Having a life cycle that involves migrating from the sea to fresh water in order to breed, such as in some species of salmon. See also <i>Catadromous</i> .	BARBEL A fleshy, sensitive feeler or a longer projection found near the mouth in some fish, such as catfish and dragonfish.	BLACK SMOKER A type of hydrothermal vent in which the hot water is colored dark by sulfide minerals. See also <i>Hydrothermal vent</i> .	CARTILAGINOUS FISH A class of fish whose skeleton is made of cartilage, not bone. It includes sharks, rays, and chimaeras.
ANAL FIN A single fin on the underside of many fish, near the tail.	BARNACLES A class of filter-feeding marine crustaceans that live attached to surfaces and have bodies protected by chalky plates.	BLOWHOLE The nostrils of a whale or dolphin, found on the top of the head. The blowhole may be single or double depending on the species.	CATADROMOUS Having a life cycle that involves migrating from fresh water to the sea in order to breed. See also <i>Anadromous</i> .
	BARRAGE A low dam with sluices (gates for water) built across a river or estuary. A tidal barrage is designed to trap water at high tide and obtain hydropower when the water is let out.	BLUE CARBON Carbon that is removed from the atmosphere by	CAUDAL FIN The tail fin of a fish.
			CELLULOSE A fibrous carbohydrate that is the main structural substance of plants, many algae, and also tunicates. Animals that consume cellulose through eating plant matter can normally only digest it with the aid of symbiotic bacteria in their gut. See also <i>Symbiosis</i> , <i>Tunicates</i> .

CEPHALOPODS A class of tentacled mollusks that includes squid, cuttlefish, octopuses, and nautilus.	CIGUATERA Poisoning from eating toxic sea food, often caused by consuming fish that have eaten toxic dinoflagellates. See also <i>Dinoflagellates</i>.	CONTINENTAL RISE The region where the deep ocean seabed begins to get shallower at the edge of a continental margin.	water in one direction; also a smaller flow of water near the shoreline.
CEPHALOTHORAX The fused head and thorax of a crustacean or a spider.	CILIA (sing. CILIUM) Microscopic beating hairs on the surface of some cells, found on animals such as fan worms. These hairs are used for locomotion or to generate currents.	CONTINENTAL SHELF The relatively flat and shallow seafloor surrounding a continent, which is geologically part of that continent.	CYANOBACTERIA An abundant group of microscopic photosynthesizing bacteria, formerly called blue-green algae. Their tiny cells lack nuclei, as do those of other bacteria. See also <i>Alga</i>, <i>Protists</i>.
CHELA A pincer, especially one belonging to an arthropod such as a crab. A chelate leg is a leg with a pincer at the end of it.	CIRRI (sing. CIRRUS) Small, stiff, hairlike projections in some animals, often used for grasping or movement. They are found, for example, in sea lilies and feather stars.	CONTINENTAL SLOPE The sloping seabed that leads from the edge of a continental shelf down to the continental rise.	CYANOPHORE A blue chromatophore. See also <i>Chromatophore</i>.
CHEMOSYNTHESIS The process by which an organism can grow and multiply using the energy stored in simple chemicals such as hydrogen sulfide or methane. Chemosynthesis functions in contrast to photosynthesis, which depends on energy coming from the Sun. Many bacteria can carry out chemosynthesis, notably those living around hydrothermal vents. See also <i>Hydrothermal vent</i>, <i>Photosynthesis</i>.	CLASPERS In sharks and their relatives, the modified pelvic fins of the male that transfer sperm to the female's body during copulation. See also <i>Pelvic fins</i>.	CONVECTION Circulating movements in a fluid caused by heat being applied to parts of it. This results in warmer and therefore less dense fluid rising upward, which drives the circulation.	DEPOSIT FEEDER An animal that feeds by extracting food particles from mud or sand.
CHITIN A nitrogen-containing carbohydrate material that forms the skeletal parts of some animals, including the exoskeletons of arthropods. It usually mixes other materials to increase its hardness and strength. See also <i>Exoskeleton</i>.	CLASS A category in biological classification. It is above an order and below a phylum. See also <i>Order</i>, <i>Phylum</i>.	COPEPODS A class of small swimming crustaceans that form an important part of the plankton.	DETRITIVORE An animal whose food consists of small fragments of dead material (detritus).
CHLOROPHYLL The green pigment that plants, algae, and some other organisms, including cyanobacteria, use to trap the Sun's energy for use in photosynthesis. There are several different types of chlorophyll. See also <i>Cyanobacteria</i>, <i>Photosynthesis</i>.	CLOACA A combined body outlet for urinary products, feces, and reproductive cells, found in most fish and birds.	CORALLITE The cup-shaped skeleton of aragonite below the body of an individual coral polyp.	DIATOMS A group of microscopic single-celled organisms featuring an ornamented, boxlike protective covering. Most are photosynthesizers and live near the water surface as plankton, where they form an important part of many marine food chains. See also <i>Photosynthesis</i>, <i>Phytoplankton</i>, <i>Plankton</i>.
CHORDATES A phylum of animals that includes all the vertebrates, as well as some invertebrate relatives, including tunicates. See also <i>Tunicates</i>.	CNIDARIANS A phylum of invertebrate animals with stinging tentacles that includes sea anemones, corals, jellyfish, and relatives.	COUNTERSHADING Coloration of an animal's body that helps disguise it by counteracting the effect of shadows, usually by being lighter on the underside of the body.	DINOFLAGELLATES A group of microscopic single-celled organisms with two flagella that help them move, many of which are photosynthetic and live near the surface as plankton. See also <i>Flagellum</i>, <i>Photosynthesis</i>, <i>Plankton</i>.
CHROMATOPHORE A pigment-containing cell or group of cells in the skin of many animals. Different types of chromatophores display different colors. Animals with chromatophores can adjust the distribution of pigments within individual cells, altering their overall appearance. See also <i>Cyanophore</i>, <i>Iridophore</i>.	COAST See <i>Emergent coast</i>, <i>Erosional coast</i>, <i>Submergent coast</i>.	CRUSTACEANS A subphylum of arthropods, including crabs, lobsters, shrimp, barnacles, and copepods.	DORSAL Relating to the upper side or back of an animal. See also <i>Ventral</i>.
	COMPOUND EYE An eye consisting of many small individual facets packed together. Compound eyes are a common type of eye in arthropods.	CRYPSIS Features or behaviors that allow an animal to avoid detection. Crypsis includes concealed habitats, camouflage, or nocturnal behavior.	DORSAL FIN A fin situated on the back of a fish or whale.
	CONTINENTAL CRUST The part of Earth's crust that forms the continents. It is less dense and thicker than oceanic crust. See also <i>Oceanic crust</i>.	CRYPTIC COLORATION See <i>Camouflage</i>, <i>Crypsis</i>.	DOWNWELLING The sinking down of water from the surface of the ocean. Large-scale downwelling in certain regions gives rise to a process known as thermohaline circulation. See also <i>Thermohaline circulation</i>, <i>Upwelling</i>.
	CONTINENTAL MARGIN The region of seafloor surrounding a continent, including the continental shelf, continental slope, and continental rise.	CTENOPHORES A jellyfishlike phylum of floating carnivorous animals, also called comb jellies.	DRIFT A large-scale flow of surface water that is broader and slower-moving than a current.
		CURRENT A regular large-scale horizontal or vertical flow of ocean	

DUNE A mound of sand formed by the action of winds blowing toward coastal land.	FAST ICE Sea ice that is frozen on to the coast or land-formed ice at its landward edge. See also <i>Sea ice</i> .	a species and below a family. The scientific name of a species consists of two words: a genus name and a species epithet. For example, <i>Ursus maritimus</i> , the polar bear, is a species in the genus <i>Ursus</i> , which also includes other bears. See also <i>Family</i> , <i>Species</i> .	chemicals issues from the rock at high temperatures.
ECHINODERMS A marine invertebrate phylum that includes starfish, sea urchins, sea cucumbers, and relatives. These animals feature tube feet that enable some of them to walk. See also <i>Tube feet</i> .	FILTER FEEDER An animal that feeds by filtering small food particles from its environment, through the baleen in the case of some whales. Filter feeders are a type of suspension feeder. See also <i>Baleen</i> , <i>Suspension feeder</i> .	GILL A structure for absorbing oxygen from water, often found in fish, mollusks, and crustaceans. Gills can also have other functions, such as sieving small food particles.	HYDROZOANS A class of mainly colonial cnidarians that includes hydroids, siphonophores, and some small jellyfish. See also <i>Cnidarians</i> , <i>Hydroids</i> , <i>Jellyfish</i> , <i>Siphonophores</i> .
ECHOLOCATION A method of detecting and locating objects, which is used by dolphins and some other animals. Sound waves are emitted, and their echoes are then gathered and interpreted. See also <i>Melon</i> .	FJORD An inlet of the sea once occupied by a glacier. Fjords are often deep and steep-sided, with a shallower sill at their mouth. See also <i>Glacier</i> .	GLACIER A “river” of ice that flows slowly downhill from an ice cap or mountainous region.	ICE SHEET A very large area of ice that permanently covers a land area, as in Antarctica or Greenland.
EMERGENT COAST A coast where the land has risen relative to the current sea level. See also <i>Submergent coast</i> .	FLAGELLUM (pl. FLAGELLA) A long, microscopic whiplike structure used by some single-celled organisms, such as dinoflagellates, for locomotion. See also <i>Dinoflagellates</i> .	GUYOT A seamount with a flat top. See also <i>Seamount</i> .	ICE SHELF A floating extension of an ice sheet or glacier over the ocean.
ENDOPARASITE A parasite that lives inside the body of another organism. See also <i>Parasite</i> .	FLIPPER A limb used for swimming—for example, in whales, seals, penguins, and turtles.	GYRE A large system of ocean currents circulating round a center point. There are five major ocean gyres.	INTERNAL FERTILIZATION Fertilization where the eggs and the sperm meet and fuse inside the body of an animal. See also <i>External fertilization</i> .
ENDOSKELETON A skeleton that is inside the body rather than on the surface, such as the skeletons of vertebrates and echinoderms.	FLUKE Either of the two flattened sides of a whale’s tail.	HADAL ZONE The deepest zone of ocean water, below 20,000 ft (6,000 m), which occurs only in ocean trenches. See also <i>Abyssal</i> .	INTERTIDAL Between the high and low water marks of a shoreline.
EPITHELIUM A layer of living cells on the surface of an animal’s body or of an internal organ.	FORAMINIFERANS Single-celled organisms that mainly live on the seafloor, protected by chalky shells, and feed on other small organisms.	HERMAPHRODITE An animal that is both male and female. A simultaneous hermaphrodite is male and female at the same time, while a sequential hermaphrodite changes from one sex to the other, either once or repeatedly.	INVERTEBRATE Any animal other than a vertebrate without a backbone, such as tunicates and arthropods. See also <i>Vertebrates</i> .
EROSIONAL COAST A coastline that is gradually being eroded by the sea.	FRAZIL ICE Ice that forms in cold water and consists of thousands of tiny crystals. It is an early stage in the development of sea ice and in turbulent waters, it can form pancake ice. See also <i>Pancake ice</i> , <i>Sea ice</i> .	HOLDFAST The structure that holds a seaweed to the seafloor. It is not a true root because it does not absorb substances for use in the rest of the body.	IRIDOPHORE A reflective or iridescent kind of chromatophore. See also <i>Chromatophore</i> .
EURYHALINE Able to survive in water of a wide range of salinities. See also <i>Salinity</i> , <i>Stenohaline</i> .	FROND A flattened, leaflike structure found in many seaweeds. Unlike the leaves of land plants, seaweed fronds do not contain specialized transport vessels to interchange materials with the rest of the organism.	HOST Any organism on which a given parasite regularly feeds.	ISOPODS An order of mainly small crustaceans that includes woodlice, sea slaters, and many marine species.
EXOSKELETON A skeleton on the outside of the body, such as the skeletons of arthropods.	GASTROPODS The largest class of mollusks, which includes all snails and slugs.	HYDROIDS A subgroup of hydrozoans that usually grow as small, plantlike colonies of connected individuals. See also <i>Hydrozoans</i> .	JELLYFISH Members of the cnidarian class Scyphozoa, whose adults drift or swim slowly in the ocean and use stinging cells to subdue prey. The deadly “box jellyfish” are a separate but related class, and the word can also be used for the small medusas of hydrozoans. Despite their name, jellyfish are not in fact fish. See also <i>Cnidarians</i> , <i>Hydrozoans</i> , <i>Medusa</i> .
EXTERNAL FERTILIZATION Fertilization in which egg and sperm combine outside the body, usually in seawater. See also <i>Internal fertilization</i> .	GENUS (pl. GENERA) A category in biological classification. It is above	HYDROTHERMAL VENT A fissure in a volcanically active area of the ocean floor, where water rich in	KERATIN A tough protein that forms the substance of claws, nails, and hair.
FAMILY A category in biological classification. It is above a genus and below an order. See also <i>Genus</i> , <i>Order</i> .			KINGDOM The highest category in traditional biological classification.

KRILL An order of shrimplike planktonic crustaceans that form a major part of ocean food chains, especially in the Southern Ocean. See also <i>Plankton</i>.	MANTLE The fleshy covering on the outside of the body of mollusks and brachiopods that secretes the shell. Mantle can also refer to the rocky layer of Earth between the crust and the core.	NEMATOCYST The stinging cell of a cnidarian that acts like a tiny harpoon. It is usually charged with venom. See also <i>Cnidarians</i>.	a snail's shell when the animal withdraws its body inside.
LAGOON An enclosed area of coastal water almost cut off from the sea by a barrier, or the sea area within the ring of an atoll.	MEDUSA One of the main body forms of cnidarian animals. A medusa is a floating, usually saucer-shaped body form with a central mouth on the underside and tentacles. Jellyfish are medusas. See also <i>Cnidarians</i>, <i>Polyp</i>.	NEUROMAST One of the small sensory structures that form part of the lateral line system in aquatic vertebrates. See also <i>Lateral line system</i>.	OPISTHOSOMA The hind part of the body of a horseshoe crab or spider.
LARVA The young stage of an animal when it is very different in structure from an adult.	MELON A structure containing fatty tissue, found in the head of dolphins and other toothed whales, that plays a role in emitting sound for communication and echolocation. See also <i>Echolocation</i>.	NOTOCHORD A stiffening rod that runs the length of the body in chordate animals. In most vertebrates, it is replaced by the backbone early in embryonic development. See also <i>Chordates</i>.	ORDER A category in biological classification. It is above a family and below a class. See also <i>Class</i>, <i>Family</i>.
LATERAL LINE SYSTEM A sensory system that runs along the sides of the body in fish and some other aquatic vertebrates. It is used to detect movement and pressure changes in the surrounding water.	METAMORPHOSIS A major rearrangement of body structures that occurs during the development of some animals.	NUTRIENTS Chemicals, especially salts of elements such as nitrogen, phosphorus, and iron, that are essential for living organisms to grow.	OSSICLES The tiny calcareous units that connect together to form the skeleton of an echinoderm.
LICHEN A “double organism” in which a fungus's body is combined with algal cells. Although essentially land organisms, some lichens are tolerant of sea spray and thrive on higher levels of rocky shores.	MID-OCEAN RIDGE An undersea mountain range running along the deep ocean floor where new oceanic crust is created.	OCEAN One of the huge bodies of salt water that between them cover almost 70 percent of Earth's surface. They are normally listed as the Atlantic, Pacific, Indian, Arctic, and Southern (or Antarctic) Oceans, but as they are all connected, they are also sometimes referred to as the World Ocean.	PACK ICE Floating sea ice that is not attached to land. It may be fused together in a single mass or consist of separate ice floes.
LONGSHORE DRIFT Process by which sediments such as sand and mud are transported along the coastline as a result of sea waves breaking at an oblique angle to the shore.	MIMICRY A detailed resemblance between an animal and something else, especially another animal, for the purposes of disguise or deception. See also <i>Camouflage</i>.	OCEAN ACIDIFICATION An increase in the acidity of ocean waters, especially as a result of dissolved carbon dioxide as a consequence of human activities.	PALPS In arthropods and some other invertebrates, palps are paired, jointed structures near the mouth, typically with a sensory function. In bivalves, they are a pair of fleshy structures close to the mouth.
MAMMALS A class of warm-blooded vertebrates that almost all give birth to live young and nourish them using milk produced by the female. Marine mammals include seals, whales, manatees, and sea otters.	MOLLUSKS A major phylum of soft-bodied but usually hard-shelled invertebrate animals that includes gastropods, bivalves, and cephalopods.	OCEAN BASIN A region occupied by a deep ocean or part of one, consisting of low-lying oceanic crust surrounded by shallower water or land.	PANCAKE ICE A stage in the formation of sea ice in turbulent waters consisting of separate floating plates. Pancake ice plates have raised, rounded edges as a result of colliding with other plates. See also <i>Sea ice</i>.
MANDIBLE The lower jaw of vertebrates, or the biting or crushing mouthparts of many arthropods. See also <i>Arthropods</i>.	MUTUALISM An association between members of two different animal species in which both benefit. The association between cleaner shrimp and moray eels is an example of this. See also <i>Symbiosis</i>.	OCEANIC CRUST Earth's crust under the deep oceans, which is thinner and denser than the crust of the continents. See also <i>Continental crust</i>.	PARASITE An organism that lives on or in another larger organism and feeds from it for an extended period of time.
MANGROVES Salt-tolerant trees that grow in sheltered intertidal zones in warmer regions and whose roots are regularly covered by seawater. The term “mangroves” can also refer to the ecosystems and forests that feature such trees.	NEKTON Organisms that live in open water and swim strongly enough to move directionally rather than being at the mercy of currents. See also <i>Plankton</i>.	OMMATIDIA (sing. OMMATIDIUM) The individual eye facets in a compound eye. See also <i>Compound eye</i>.	PECTORAL FINS A pair of fins attached to the chest, toward the front of a fish, behind the gills, one on each side.
		OPERCULUM The external covering of a gill of a bony fish. It can also refer to a hard disk that seals the opening of	PELVIC FINS A pair of fins in fish, attached to the abdomen, farther back and lower down than the pectoral fins.
			PHOTOPHORE A light-producing organ found in some fish, cephalopods, and other animals. Complex photophores may feature lenses and color filters. See also <i>Bioluminescence</i>.

PHOTOSYNTHESIS The process by which plants, algae, and cyanobacteria use the Sun’s energy to convert water and carbon dioxide into carbohydrates, as a first step to building up their body structure and trapping energy for cell processes. See also *Chemosynthesis*.

PHYLUM (pl. **PHYLA**) A category in biological classification, above a class and below a kingdom. Examples of phyla include cnidarians, mollusks, arthropods, and chordates. See also *Class*, *Kingdom*.

PHYTOPLANKTON Planktonic organisms that photosynthesize, mainly microscopic algae and cyanobacteria. See also *Alga*, *Cyanobacteria*, *Plankton*.

PINCER A claw or similar structure for grasping objects and for attack and defense.

PLANKTON All the life forms that drift in the open ocean and are carried along by ocean currents. See also *Nekton*.

PLATE BOUNDARY A boundary between two of Earth’s tectonic plates. A constructive (or divergent) boundary is where two plates are being pushed apart by new molten rock rising between them, as at mid-ocean ridges. At a destructive (convergent) boundary, two plates are pushed together, often with one being subducted beneath the other. See also *Subduction*.

PLATE TECTONICS All the processes relating to the movement and collision of the enormous tectonic plates into which Earth’s crust and upper mantle are divided. See also *Mid-ocean ridge*, *Subduction*.

PNEUMATOPHORE Part of a mangrove plant root that is exposed above the ground and can absorb air. Siphonophores, such as the Portuguese

man o’ war, have a gas-filled float that is also known as the pneumatophore. See also *Siphonophore*.

PODIA (sing. **PODIUM**) Small hydraulically operated structures on the surface of echinoderms, used for respiration or movement. Podia for walking and grasping usually have suckered ends and are called tube feet. See also *Tube feet*, *Water-vascular system*.

POLYP One of the main body forms of cnidarians, consisting of an attached cup-shaped body with a mouth on the top surface surrounded by tentacles. A sea anemone is a polyp. See also *Cnidarians*, *Medusa*.

PREDATOR An animal that catches and eats other animals.

PREY Animals that are food for a given predator within a food chain.

PROSOMA A word for cephalothorax, especially in horseshoe crabs and spiders. See also *Cephalothorax*.

PROTANDRY A form of hermaphroditism where an organism is first male, then female. See also *Hermaphrodite*, *Protogyny*.

PROTISTS A broad category covering organisms that are not classified as animals, plants, or fungi. Most are microscopic, although traditionally seaweeds are also included. Protists all have cells with nuclei and so do not include cyanobacteria. See also *Cyanobacteria*.

PROTOGYNY A form of hermaphroditism where an organism is first female, then male. See also *Hermaphrodite*, *Protandry*.

RADIAL SYMMETRY The form of symmetry exhibited by a star-shape, as opposed to one with left and right sides. Sea anemones, starfish, and sea urchins have radial symmetry. See also *Bilateral symmetry*.

RADIOLARIANS A group of single-celled organisms that float in the plankton and act like tiny animals, feeding on other small life forms. They have elaborate skeletons of silica, often spherical in shape.

RADULA A belt-shaped rasping organ found in the mouths of many mollusks and equipped with horny teeth.

REFRACTION The change of direction of waves, including light waves, when they pass from one medium to another, and water waves when they reach shallow water.

RHIZOME A horizontal underground stem of a plant.

RHIZOSPHERE The region of soil or mud around a root that is influenced by the root’s activities and metabolism.

ROOKERY A breeding colony of penguins, and sometimes of other seabirds or seals.

SALINITY The degree of saltiness of seawater.

SALPS Free-floating colonial tunicates that consume phytoplankton. See also *Phytoplankton*, *Tunicates*.

SALT MARSH An ecosystem that may develop on the upper intertidal zone of sheltered, muddy coastlines, mainly in cooler parts of the world, and consists of a community of small, salt-tolerant land plants. In the tropics, mangrove forests generally grow in similar situations. See also *Intertidal*, *Mangroves*

SCALES Small, often overlapping protective structures on the skin of fish, reptiles, and some invertebrates.

SEA Sometimes used as another word for ocean, but can also refer to a relatively small, often shallower region of an ocean partly marked off by land, such as the North Sea.

SEA ANEMONES An order of solitary soft-bodied cnidarians that have only a polyp stage, also referred to simply as “anemones.” See also *Polyp*.

SEA ICE Ice formed directly on the sea, unlike icebergs and ice shelves, which originally formed on land before entering the sea.

SEAGRASS One of many flowering grasslike plants in the order. Alismatales that have become adapted to live under saline water.

SEAMOUNT An undersea mountain, usually formed by volcanic activity. See also *Guyot*.

SEAWEEDS Any of several groups of relatively large marine, plantlike organisms traditionally classified as multicellular algae. One group, the green seaweeds, is closely related to land plants.

SEDIMENT Particles carried in water that are capable of settling out under the force of gravity, or deposits formed by such particles, including sand, silt, or mud.

SEXUAL REPRODUCTION Reproduction involving the fusion of two sex cells (typically an egg and sperm) followed by development of a new individual from the fertilized egg. See also *Asexual reproduction*.

SHELL The hard protective covering of animals such as mollusks, brachiopods, and turtles. Also, the outer covering of an egg.

SIPHON A tubelike structure that draws in or expels water. Bivalve mollusks and tunicates have a pair of siphons that are used for filter feeding, as well as for obtaining oxygen from the water.

SIPHONOPHORES An order of floating colonial hydrozoans resembling jellyfish, that includes the

Portuguese man o’ war. See also *Hydrozoans*, *Jellyfish*.

SPAWN Masses of small eggs released by many marine animals. “To spawn” is to release these eggs.

SPECIES A particular kind of organism, such as a polar bear or an emperor penguin. If a species reproduces sexually, it can be defined as comprising individuals that are able to breed with each other to produce fertile offspring that resemble their parents. See also *Genus*.

SPICULE One of the small skeletal units embedded in the bodies of many sponges and some cnidarians. Spicules come in many shapes and sizes and are important in sponge classification.

SPIRACLE One of the openings behind the eyes of a ray through which water for the gills enters. The term is also applied to other structures, such as the breathing holes of insects.

SPIRALIANS A large group of invertebrate phyla all thought to be related, named after the spiral pattern of early cell divisions in their fertilized eggs. Spiralians include mollusks, lamp shells, segmented worms, ribbon worms, and others.

SPONGES A phylum of simple-bodied slow-moving animals that live by straining food particles from the water.

STENOHALINE Able to tolerate only a narrow range of salinities. See also *Euryhaline*, *Salinity*.

SUBDUCTION The process in which the oceanic crust of one tectonic plate is slowly forced under the edge of another plate. See also *Oceanic crust*, *Plate tectonics*, *Trench*.

SUBMERGENT COAST A coast where the land surface has become lower relative to the current sea level. See also *Emergent coast*.

SUBTIDAL Below the lowest level of the tides on a shoreline.

SUCKER A structure used by an animal to attach to a surface.

SURFACE CURRENT A current at the ocean surface, usually driven by wind.

SUSPENSION FEEDER An animal that feeds by extracting small food particles suspended in the water. Filter feeding is a form of suspension feeding. See also *Filter feeder*.

SWASH Moving of turbulent water up a shoreline after a wave breaks.

SWIM BLADDER A gas-filled structure in most bony fish that regulates the buoyancy of the fish and stabilizes it in the water.

SYMBIOSIS The close association between two kinds of animal. When this is mutually beneficial, it is called mutualism. See also *Mutualism*.

TAGMA (pl. TAGMATA) One of the main sections into which the bodies of arthropods and some segmented worms are divided.

TELSON The hindmost segment of an arthropod. In crustaceans such as lobsters and some crabs, it forms the central part of the tail fan.

TENTACLE A long, fleshy structure used for capturing food or other purposes. Many marine invertebrates have multiple tentacles.

THERMOCLINE Any layer at a particular depth in an ocean where the average temperature changes rapidly with depth. Thermoclines can also occur in the atmosphere.

THERMOHALINE CIRCULATION A worldwide circulation of deepwater currents driven by differences in temperature and salinity between different water masses.

THORAX The chest region of a vertebrate, or the central region of the body of an arthropod.

TIDE The regular variation in the height of the ocean surface at a given point, caused by the gravitational attraction of the Moon and Sun combined with Earth’s rotation. In coastal regions, it results in horizontal movements of water.

TISSUE An assemblage of cells of a particular type in the body, such as nervous tissue or muscle tissue. Organs are formed of different types of tissue combined together.

TRENCH A large-scale, naturally forming chasm on the ocean floor where the ocean is deepest and one tectonic plate is forced under another. The deepest is the Mariana Trench in the Pacific Ocean. See also *Subduction*.

TROPICAL CYCLONE A large-scale circulating weather system in tropical and subtropical regions, powered by warm ocean water and producing violent winds and heavy rain. Also known as hurricanes, typhoons, or simply as cyclones depending on which part of the world they occur in.

TSUNAMI A large, fast-moving ocean wave generated by an undersea earthquake or a large coastal landslide.

TUBE FEET Another name for the podia of echinoderms, especially when they have suckered ends and are used for walking or clinging. See also *Podia*, *Water-vascular system*.

TUNICATES A subphylum of invertebrate animals that are related to vertebrates and include the sea squirts and salps. See also *Chordates*.

TUSK An enlarged tooth of a mammal such as a walrus or narwhal.

UPWELLING The rising of deep ocean water to the surface. It can be caused

by wind blowing parallel to a coastline or by an underwater obstruction such as a seamount interrupting a deep-sea current. Upwelled water often enriches the surface of the ocean with nutrients. See also *Downwelling*.

VALVE Either of the two hinged shells of a bivalve mollusk.

VENTRAL Relating to the front or underside of an animal. See also *Dorsal*, *Invertebrate*.

VERTEBRATE A backboned animal. Forming a subphylum of the phylum Chordata, vertebrates include fish, amphibians, reptiles, birds, and mammals. See also *Chordates*.

WARNING COLORATION The coloration of an animal signaling to predators that the animal is poisonous or venomous.

WATER-VASCULAR SYSTEM The hydraulic system of echinoderms, which operates their tube feet (podia). See also *Podia*, *Tube feet*.

WHISKER A stiff, modified hair on the face of a mammal. The “whiskers” of catfish are actually long, thin barbels. See also *Barbel*.

ZOOID An individual unit of a colonial invertebrate animal that is physically connected by strands of tissue to other individuals. The term is used in connection with moss animals and tunicates but not cnidarians.

ZOOPLANKTON Animals and animal-like organisms living in the plankton. See also *Plankton*, *Protists*.

ZOOXANTHELLAE Symbiotic dinoflagellates that live in the bodies of many corals and some other animals and create food for them by photosynthesis. See also *Dinoflagellates*.

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Jenny E. Ross / www.jennyross.com.: (br). **56 Nat Geo Image Collection:** Klaus Nigge (bl). **56-57 Rebecca Nason Photography.** **58-59 Nat Geo Image Collection:** Thomas P. Peschak. **58 Alamy Stock Photo:** Arco Images GmbH / C. Kutschenreiter (tr). **60-61 Shutterstock.com:** Andrey Oleynik. **62 Alamy Stock Photo:** Blickwinkel / H. Schulz (tl). **62-63 Science Photo Library:** Gerd Guenther. **64-65 Courtesy of the artist Zaria Forman.** **64 Bridgeman Images:** Mr. and Mrs. Jake L. Hamon Fund / Ocean Surface (First State), 1983, Drypoint on Rives BFK paper, Image size: 19.8 x 25 cm, Paper size: 66 x 50.8 cm, Edition of 75, Printed by Doris Simmelink, Published by Gemini G.E.L., Los Angeles, CA. / Vija Celmins (tc). **66-67 Getty Images:** Cyndi Monaghan / Moment Open. **67 Dreamstime.com:** Mirror Images (cr). **68-69 Nat Geo Image Collection:** George Steinmetz. **70-71 Alamy Stock Photo:** Art Heritage. **71 Alamy Stock Photo:** Classicpaintings (tr). **72-73 Antonio Pastrana.** **74-75 Alamy Stock Photo:** Phototrip. **75 Simon Grove:** (tl). **Image from the Biodiversity Heritage Library:** The Birds of Australia By John Gould (cra). **76-77 Getty Images:** The AGE / Fairfax Media. **78-79 Alamy Stock Photo:** World History Archive. **80-81 Dreamstime.com:** Yodsawaj Suriyasirisin. **80 Alamy Stock Photo:** Natural Visions / Heather Angel (tr). **82-83 Fortunato Gatto / Fortunato Photography.** **84-85 Andy Deutsch Photography.** **84 Andy Deutsch Photography:** (cl); **naturepl.com:** Shane Gross (tr). **85 Andy Deutsch Photography:** (tr). **86 Alamy Stock Photo:** Helmut Corneli (bc). **86-87 Wesley Jay Oosthuizen.** **88-89 Science Photo Library:** Sandra J. Raredon, National Museum Of Natural History, Smithsonian Institution. **88 Rex by Shutterstock:** Rob Griffith / AP (clb). **90 SuperStock:** Jelger Herder / Buiten-beeld / Minden Pictures (cra). **90-91 Alamy Stock Photo:** Design Pics Inc. **92-93 Nat Geo Image Collection:** Joel Sartore - National Geographic Photo Ark. **92 Alamy Stock Photo:** Buiten-Beeld / Astrid Kant (clb). **94 Alamy Stock Photo:** The Picture Art Collection (tl). **94-95 Amsterdam Museum:** SA 5611. **96-97 Pedro Jarque Krebs.** **97 Alamy Stock Photo:** Harry Collins (tr). **98 Taiwanese Photographer Wilson Chen.** **99 Taiwanese Photographer Wilson Chen.** **100-101 iStockphoto.com:** Ilbusca / Digitalvision Vectors. **102 Black Diamond Images:** (tr). **102-103 Ke Guo.** **104-105 Phil’s 1stPix.** **105 SuperStock:** Christian Ziegler / Minden Pictures (tr). **106 Rex by Shutterstock:** Auscape / UIG (tr). **106-107 SuperStock:** Kevin Schafer / Minden Pictures. **108-109 Nat Geo Image Collection:** David Liittschwager. **109 Nat Geo Image Collection:** David Liittschwager (tr). **111 Alamy Stock Photo:** Florilegius (br). **Ariane Müller:** (cb). **112-113 Getty Images:** Ruslan Kalnitsky / 500px. **114 iStockphoto.com:** McCluremr (t); McCluremr (b). **115 iStockphoto.com:** McCluremr (bc). **116 naturepl.com:** Kim

Taylor (tr). **116-117 Dreamstime.com:** Marcel De Grijns (ca). **118-119 Alamy Stock Photo:** Heritage Image Partnership Ltd. **118 Alamy Stock Photo:** Peter Horree (tl). **120-121 Getty Images:** Paul Starosta / Stone. **121 Getty Images:** Jay Fleming / Corbis Documentary (crb). **122-123 Dreamstime.com:** Jeneses Imre. **124 Science Photo Library:** Alexander Semenov. **125 Alamy Stock Photo:** Wolfgang Pölzer (crb); World History Archive (cla); Stocktrek Images, Inc. / Brook Peterson (cr). **128-129 Tom Shlesinger.** **128 New World Publications Inc:** Ned DeLoach (tr). **131 Alamy Stock Photo:** Florilegius (cra). **132-133 BioQuest Studios.** **132 Science Photo Library:** Alexander Semenov (tl). **134 123RF.com:** Ten Theeralerttham / Rawangtak (cr). **Getty Images:** Auscape / Universal Images Group (tc). **naturepl.com:** Alex Mustard (tr). **Alexander Semenov:** (c). **135 Alamy Stock Photo:** John Anderson (tc). **Getty Images:** Wild Horizon / Universal Images Group (tr). **naturepl.com:** Georgette Douwma (cl); Norbert Wu (tl); Jurgén Freund (c); David Shale (cr); Georgette Douwma (fcr). **Bo Pardau:** (ftr). **136-137 Alamy Stock Photo:** Pete Niesen. **136 Getty Images:** Oxford Scientific (tc). **138 Science Photo Library:** Andrew J. Martinez (tl). **140-141 Yen-Yi Lee, Taiwan.** **142-143 BioQuest Studios.** **144-145 Maurizio Angelo Pasi.** **145 Alamy Stock Photo:** Nature Photographers Ltd / Paul R. Sterry (tr). **146-147 Getty Images:** BigBlueFun / 500px. **147 Kunstformen der Natur by Ernst Haeckel:** (tc). **148 Alamy Stock Photo:** Blickwinkel / W. Layer (tl). **148-149 Nat Geo Image Collection:** David Doubilet. **150-151 Alamy Stock Photo:** David Fleetham. **151 Salty Black Photography by Ernie Black:** (tr). **152 Alamy Stock Photo:** Agefotostock. **153 123RF.com:** Antonio Abrignani (tr). **Kunstformen der Natur by Ernst Haeckel.** **154 Alamy Stock Photo:** Reinhard Dirscherl (tr). **155 Image from the Biodiversity Heritage Library:** Atlas Ichthyologique Des Indes Orientales Néerlandaises : Publié Sous Les Auspices Du Gouvernement Colonial Néerlandais (tc). **158-159 © Arthur Anker.** **158 Alamy Stock Photo:** Stephen Frink Collection (br). **162 Dreamstime.com:** Isselee (clb); Isselee (bc, crb). **163 Dreamstime.com:** Izanbar. **164 Getty Images:** DEA / N. Cirani / De Agostini. **165 Alamy Stock Photo:** Heritage Image Partnership Ltd / Werner Forman Archive / Art Gallery of New South Wales, Sydney (tl); Heritage Image Partnership Ltd / Werner Forman Archive / Private Collection, Prague (cl). **167 Getty Images:** Giordano Cipriani / The Image Bank (crb). **168-169 Dreamstime.com:** Isselee. **168 Getty Images:** Hal Beral / Corbis (tr). **169 Dreamstime.com:** Isselee (b). **170 Alamy Stock Photo:** Jane Gould (bl). **174 iStockphoto.com:** Marrio31 (cr). **Minden Pictures:** Becca Saunders (tl). **Nat Geo Image Collection:** Joel Sartore - National Geographic Photo Ark (tr). **naturepl.com:** Georgette Douwma (cl); Alex Mustard (tc); Alex Mustard (c); Georgette Douwma (bl); Linda Pitkin (br). **175 Alamy Stock**

Photo: Reinhard Dirscherl (cl); Andrey Nekrasov (bl). **naturepl.com:** Fred Bavendam (c); Alex Mustard (tl). **176-177 Alamy Stock Photo:** Blue Planet Archive. **176 Getty Images:** Michael Aw / Stockbyte (bc). **177 Getty Images:** Giordano Cipriani / The Image Bank (tr). **180 Getty Images:** DEA / Archivio J. Lange / De Agostini. **181 Alamy Stock Photo:** Azoor Travel Photo (tr); The History Collection (cl). **182-183 François Libert | flickr.com/photos/zsispeo/:** (b). **182 Alamy Stock Photo:** David Fleetham (t). **183 Alamy Stock Photo:** David Fleetham (tr). **184-185 iStockphoto.com:** Ilbusca. **186-187 Getty Images:** Aukid Phumsirichat / EyeEm. **187 Alamy Stock Photo:** NZ Collection (bc). **188-189 Getty Images:** Brent Durand / Moment. **189 Alamy Stock Photo:** Mauritius Images GmbH (bc). **190 Alamy Stock Photo:** The History Collection (tr). **190-191 Nat Geo Image Collection:** Cristina Mittermeier. **192 Science Photo Library:** Alexander Semenov (c). **193 Ocean Wise Conservation Association:** Neil Fisher / Vancouver Aquarium (bc). **Science Photo Library:** Alexander Semenov (t). **194 Kunstformen der Natur by Ernst Haeckel.** **195 Science Photo Library:** Alexander Semenov (bc); Alexander Semenov (br). **196-197 Rijksmuseum, Amsterdam:** Gift of Mr and Mrs Dissevelt-van Vloten. **197 Alamy Stock Photo:** The History Collection (tr). **199 Alamy Stock Photo:** Nature Picture Library / Richard Robinson (tr). **200-201 BioQuest Studios.** **201 Dr. Karen Osborn:** (tr). **202-203 David Moynahan.** **202 Alamy Stock Photo:** David Fleetham (c). **204 Ramiro Gonzalez:** (bc). **204-205 Todd Aki / https://www.flickr.com/photos/90966819@N00/albums.** **205 Alamy Stock Photo:** StellaPhotography (tc). **Science Photo Library:** Power And Syred (tr). **206-207 ESA:** NASA / A.Gerst. **208-209 Science Photo Library:** Alexander Semenov (t); Alexander Semenov (c). **208 Getty Images:** Wild Horizon / Universal Images Group (br). **210 Alamy Stock Photo:** Stocktrek Images, Inc. / Ethan Daniels (fbr). **naturepl.com:** Alex Mustard (c, cr, fcr, bc, br). **211 Alamy Stock Photo:** Nature Picture Library / Franco Banfi (cr). **Getty Images:** Antonio Camacho / Moment Open (cl). **naturepl.com:** Franco Banfi (bc); Alex Mustard (c); Solvin Zankl (bl); Norbert Wu (br). **Alexander Semenov:** (t). **212 Alamy Stock Photo:** Blickwinkel (tl). **212-213 Getty Images:** Maarten Wouters / Stone. **215 Alamy Stock Photo:** Brandon Cole Marine Photography (bc). **216-217 Getty Images:** Fine Art / Corbis Historical. **217 Alamy Stock Photo:** Antiquarian Images (tl). **220-221 Alexander Semenov.** **221 naturepl.com:** Sue Daly (tc). **222 Alamy Stock Photo:** Pulsar Imagens (tr); WaterFrame (cr). **iStockphoto.com:** Searsie (bc). **Museums Victoria:** Chris Rowley / CC BY 4.0 (cl). **Nat Geo Image Collection:** Joel Sartore - National Geographic Photo Ark (br). **naturepl.com:** Sue Daly (tl); Georgette Douwma (tc); Visuals Unlimited (c); Lynn M. Stone (bl). **223 iStockphoto.com:** Tac208 (tl).

naturepl.com: Georgette Douwma (br); Norbert Wu (cl); David Shale (bl). **224 Alamy Stock Photo:** Panther Media GmbH / Jolanta WĄtjickica (bc). **226-227 Edwar Herreno.** **226 James Ferrara:** (b). **228-229 Jorge Cervera Hauser / Pelagic Fleet.** **229 Dreamstime.com:** Sergey Uryadnikov (tc). **230-231 SuperStock:** Minden Pictures. **232 Science Photo Library:** Alex Mustard / Nature Picture Library. **233 Alamy Stock Photo:** Imagebroker (br); Andrey Nekrasov (cb). **naturepl.com:** Visuals Unlimited (cra). **234-235 Getty Images:** Yuichi Sahacha / 500Px Plus. **238-239 Davide Lopresti.** **239 iStockphoto.com:** Clintscholz / E+ (tr). **240-241 Malcolm Thornton Photography.** **240 Getty Images:** Wei Hao Ho / Moment (clb). **242 National Audubon Society:** (bc). **naturepl.com:** Alan Murphy / BIA (t); Tui De Roy (br). **243 Alamy Stock Photo:** Paul Barnes. **244-245 Alamy Stock Photo:** Design Pics Inc / Tom Soucek. **245 Science Photo Library:** Thomas & Pat Leeson (tr). **246-247 Sheila Smart Photography.** **247 iStockphoto.com:** Cinoby / E+ (bc). **248-249 Gabriel Barathieu:** underwater-landscape.com. **250-251 NASA:** Image By Norman Kuring, Nasa's Ocean Color Web. **252 Alamy Stock Photo:** Imagebroker (b). **252-253 naturepl.com:** Brandon Cole. **254-255 iStockphoto.com:** Bitter. **256-257 Science Photo Library:** Alexander Semenov. **256 NOAA:** Kevin Raskoff, Cal State Monterey / Hidden Ocean Expedition 2005 / NOAA / OAR / OER (ca). **258 Alamy Stock Photo:** Science History Images / Eric Grave (tc). **Science Photo Library:** Wim Van Egmond (tl, cl, cr); Raul Gonzalez (tr); Marek Mis (c). **259 Alamy Stock Photo:** Scenics & Science (tr). **Jan van IJken Photography & Film:** (br). **Science Photo Library:** Wim Van Egmond (tl, tc, cl); Marek Mis (fll); M. I. Walker (fcl). **260-261 Science Photo Library:** Alexander Semenov. **261 Alamy Stock Photo:** Nature Photographers Ltd / Paul R. Sterry (tr). **262 naturepl.com:** David Shale (crb, cl). **262-263 naturepl.com:** David Fleetham. **263 Nat Geo Image Collection:** Emory Kristof (tr). **264-265 Alamy Stock Photo:** Nature Picture Library / Alex Mustard. **266 Alamy Stock Photo:** Nature Picture Library / Solvin Zankl. **267 Alamy Stock Photo:** Chronicle (bc); Nature Picture Library / Solvin Zankl (tr). **268 Dreamstime.com:** Aleksey Solodov (tl). **Jonathan Lavan | Underpressure Nature Photography:** (br). **269 Alamy Stock Photo:** Artmedia. **270 Alamy Stock Photo:** Jeff Mondragon (bc); Visual&Written Sl / Kelvin Aitken (cr); Andrey Nekrasov (bl). **naturepl.com:** Gary Bell / Oceanwide (tr); David Shale (tl); Jurgen Freund (cl); Doug Perrine (c). **Science Photo Library:** Andrew J. Martinez (br). **Alexander Semenov:** (tc). **271 Science Photo Library:** Alexander Semenov (tl, tr, c). **Alexander Semenov:** (tc). **272-273 Jorge Cervera Hauser / Pelagic Fleet.** **273 Getty Images:** Torstenvelden (tc). **274-275 NASA:** Goddard Space Flight Center Scientific Visualization Studio. **276-277 Getty Images:** Benjamin Lowy / The Image

Bank. **278-279 © Jordi Chias Pujol.** **279 Alamy Stock Photo:** Minden Pictures / Norbert Wu (tr). **280-281 Getty Images:** Fine Art / Corbis Historical. **281 Alamy Stock Photo:** Art Collection 2 (tr). **282 Alamy Stock Photo:** Solvin Zankl (t). **283 Getty Images:** E. Widder / HBOI. **284-285 Shawn Heinrichs.** **285 Taxidermy by Kevin Halle:** (bc). **286 Alamy Stock Photo:** David Tipling Photo Library (br). **286-287 Paul Cottis.** **288-289 naturepl.com:** Doc White. **290-291 NASA:** Earth Observatory image created by Robert Simmon, using EO-1 ALI data provided courtesy of the NASA EO-1 team. **292-293 Jorge Cervera Hauser / Pelagic Fleet.** **293 naturepl.com:** Doug Allan (bc). **294-295 iStockphoto.com:** Zu_09 / Digitalvision Vectors. **296 Alexander Semenov:** (tl, tc, bl, bc). **297 Alexander Semenov:** (tl, bl). **298-299 Florian Ledoux Photography.** **300 Nat Geo Image Collection:** Keith Ladzinski (tl). **300-301 naturepl.com:** Ingo Arndt. **301 Alamy Stock Photo:** National Geographic Image Collection / Paul Nicklen (tr). **302 Alamy Stock Photo:** Andrey Nekrasov. **303 Alamy Stock Photo:** Paulo Oliveira (tr). **304 naturepl.com:** Shane Gross (fcr); Solvin Zankl (cl); Doug Perrine (cr); Solvin Zankl / Geomar (bc); David Shale (br); Solvin Zankl (fbr). **305 Alamy Stock Photo:** Nature Picture Library / Doug Perrine (t). **naturepl.com:** Doug Perrine (c); Solvin Zankl (cl); Solvin Zankl (bl); Solvin Zankl (bc); Solvin Zankl (br). **306-307 Daisy Gilardini Photography.** **307 Getty Images:** Richard McManus / Moment (tr). **308 Alamy Stock Photo:** Agefotostock / Eric Baccega (b). **309 Valter Bernardeschi.** **310-311 Mike Reyfman Photography.** **310 naturepl.com:** Sylvain Cordier (b). **312-313 © Rasch-Photography | Ralf Schneider.** **313 Dreamstime.com:** Tarpan (t). **314-315 Alamy Stock Photo:** National Geographic Image Collection / Marcín Dobas. **316-317 Getty Images:** Sergei Gladyshev / 500px Plus. **317 Alamy Stock Photo:** Steve Davey Photography (tr). **318-319 Nat Geo Image Collection:** Paul Nicklen. **320-321 Dreamstime.com:** Andrii Oliinyk. **322 Getty Images:** Robert Mallon / Moment. **323 Image from the Biodiversity Heritage Library:** Kunstformen der Natur by Ernst Haeckel. **324 Getty Images:** De Agostini Picture Library (cra). **Kunstformen der Natur by Ernst Haeckel:** (bc). **325 Image from the Biodiversity Heritage Library:** Die Radiolarien (Rhizopoda radiaria) (cra); H.M.S. Challenger reports 1873-76 (bc). **326 Alamy Stock Photo:** Interfoto (bc); The Natural History Museum, London (cra). **327 Alamy Stock Photo:** Daniel Poloha Underwater (bc); The Natural History Museum, London (cr); Nature Picture Library / Sue Daly (bl); Nature Picture Library / Sue Daly (bc/ Himantalia). **iStockphoto.com:** DaCILD (br). **328 Alamy Stock Photo:** Nature Picture Library / Sue Daly (br); Premaphotos (bl); Premaphotos (bc). **Image from the Biodiversity Heritage Library:** The Botany Of The Antarctic Voyage Of H.m. Discovery Ships Erebus

And Terror In The Years 1839-1843. (cra). **329 Alamy Stock Photo:** Nature Picture Library / Nick Upton (bl); Nature Picture Library / Sue Daly (bc/Codium). **Dreamstime.com:** Seadam (bc). **iStockphoto.com:** Ashish Kumar (br). **Kunstformen der Natur by Ernst Haeckel:** (cr). **330 Alamy Stock Photo:** The History Collection (cra); Steve. Trehwella (bl); Nature Picture Library / Constantinos Petrinos (bc/Enhalus); Nature Picture Library / Jurgen Freund (bc). **Dreamstime.com:** Seadam (br). **331 Alamy Stock Photo:** Blickwinkel (br); The Natural History Museum (cra); Juergen Freund (bl). **332 Alamy Stock Photo:** John Anderson (bl); Daniel L. Geiger / SNAP (bc). **Dreamstime.com:** Alexander Ogurtsov (bc/Demosponge). **Image from the Biodiversity Heritage Library:** Spongiaires de la mer Caraï'be (cr). **imagequestmarine.com:** Jez Tryner (br). **333 Alamy Stock Photo:** Blue Planet Archive (bl); Science History Images (cr); Mark Conlin (bc). **Getty Images:** Wild Horizon / Universal Images Group (br). **iStockphoto.com:** Placebo365 (bc/ Heteractis magnifica). **334 Alamy Stock Photo:** Avalon / Photoshot License / Oceans Image (br); Florilegius (cr); Biosphoto / Bruno Guenard (bc/Orange sea pen). **Getty Images:** The Image Bank / Giordano Cipriani (bc). **iStockphoto.com:** E+ / Michael Zeigler (bl). **335 Alamy Stock Photo:** Cultura Creative Ltd / George Karbus Photography (bc/Moon jelly); Naturepix (br). **Getty Images:** ullstein bild / Reinhard Dirscherl (bl). **imagequestmarine.com:** Kî're Telnes (bc). **Kunstformen der Natur by Ernst Haeckel:** (cr). **336 Kunstformen der Natur by Ernst Haeckel:** (cra, bc). **337 Alamy Stock Photo:** Nature Photographers Ltd / Paul R. Sterry (bc); WaterFrame (bc/Stinging hydrozoan). **Getty Images:** Cultura RF / Alexander Semenov (br); DEA Picture Library / De Agostini (bl). **Kunstformen der Natur by Ernst Haeckel:** (cr). **338 Alamy Stock Photo:** AF Fotografie (cra); Book Worm (bc). **339 Alamy Stock Photo:** AAA Collection (crb); Archive PL (cra). **340 Alamy Stock Photo:** Frank Hecker (br); Image Source / Alexander Semenov (bc/ Ragworm). **Getty Images:** De Agostini Picture Library (cr); George Grall / National Geographic Image Collection (bl). **iStockphoto.com:** Damocan (bc). **341 Alamy Stock Photo:** Artokoloro (cra); National Geographic Image Collection / Joel Sartore (br). **Dreamstime.com:** Velikanpiter (bl). **Getty Images:** Joao Pedro Silva / Moment Open (bc). **342 Alamy Stock Photo:** Biosphoto / Mathieu Foulquie (bc). **Bridgeman Images:** (cr). **Dreamstime.com:** Francofirpo (br); Toby Gibson (bl). **iStockphoto.com:** S.Rohrlach (bc/Bullina lineata). **343 Alamy Stock Photo:** Blickwinkel (bl); Chronicle (cr); Martin Habluetzel (br). **Shutterstock.com:** tank200bar (bc). **344 Alamy Stock Photo:** Reinhard Dirscherl (bc); Z4 Collection (cr); Genevieve Vallee (bl); Imagebroker (br). **iStockphoto.com:** Michael Zeigler (bc/Sepia latimanus). **345 Alamy Stock Photo:** Imagebroker / T. Eidenweil (br); UtCon Collection (cr); WaterFrame (bc). **Dreamstime.com:**

Wrangel (bc/Common octopus). **naturepl.com:** Fred Bavendam (bl). **346 Image from the Biodiversity Heritage Library:** Encyclopaedia londinensis, or, Universal dictionary of arts, sciences, and literature (cra). **Kunstformen der Natur by Ernst Haeckel:** (bc). **347 Alamy Stock Photo:** Alpha Stock (cra). **Image from the Biodiversity Heritage Library:** The Naturalist's Miscellany, Or Coloured Figures Of Natural Objects. (crb). **348 Alamy Stock Photo:** Florilegius (cra); Historic Collection (bc). **349 Alamy Stock Photo:** Artokoloro (bc); The Natural History Museum (cra). **350 Alamy Stock Photo:** Actep Burstov (cr). **iStockphoto.com:** ZU_09 / DigitalVision Vectors (br). **351 Alamy Stock Photo:** Helmut Corneli (br); Juniors Bildarchiv GmbH (bl); Imagebroker (bc). **Image from the Biodiversity Heritage Library:** Dictionnaire universel d'histoire naturelle. v. 3 1849 - Atlas (Zoologie-Botanique) (cr). **352 Alamy Stock Photo:** Helmut Corneli (bc/Spotted porcelain crab); Nature Picture Library / Sue Daly (bc); SeaTops (br). **Dreamstime.com:** Kateryna Levchenko (bl). **Image from the Biodiversity Heritage Library:** Voyage Autour Du Monde (cr). **353 Alamy Stock Photo:** Pete Niesen (bc); Heiko der Urlauber (bc/Anneissia benneti). **Dreamstime.com:** Toby Gibson (bl); Toui2001 (br). **Kunstformen der Natur by Ernst Haeckel:** (cr). **354 Alamy Stock Photo:** Nature Picture Library / Alex Mustard (br); Jeff Rotman (bl). **Dreamstime.com:** Robertlasalle (bc/Asterias rubens); Seadam (bc). **Kunstformen der Natur by Ernst Haeckel:** (cr). **355 Alamy Stock Photo:** blickwinkel / F. Hecker (bl); The Protected Art Archive (cr); Solvin Zankl (bc/Gorgon's head basket star). **Dreamstime.com:** Seadam (br). **Getty Images:** De Agostini Picture Library (bc). **356 Alamy Stock Photo:** Blickwinkel (bc); Florilegius (cr); Helmut Corneli (bl). **Dreamstime.com:** Kelpfish (br); Ashish Kumar (bc/Diadema). **357 Alamy Stock Photo:** Blickwinkel (bc); Florilegius (cr); Erik Schlogl (bc/Colochirus). **Dreamstime.com:** Ethan Daniels (bl); Ethan Daniels (br). **358 Alamy Stock Photo:** Reinhard Dirscherl (bl); Paulo Oliveira (bc/European lancelet); Imagebroker (bc). **Getty Images:** Antonio Camacho / Moment (br). **Image from the Biodiversity Heritage Library:** The Naturalist's Miscellany, Or Coloured Figures Of Natural Objects. (cr). **359 Alamy Stock Photo:** Florilegius (cra); A.F. Lydon (crb). **360 Alamy Stock Photo:** Kelvin Aitken / VWPics (br); Mark Conlin (bc). **Image from the Biodiversity Heritage Library:** Natural history of Victoria. Prodrumus of the zoology of Victoria (cra). **iStockphoto.com:** June Jacobsen (bl). **361 Alamy Stock Photo:** Reinhard Dirscherl (bc/Taeniura meyni); Florilegius (cr); Imagebroker (bc). **Depositphotos Inc:** Lilithlita (br). **Dreamstime.com:** Roman Vintonyak (bl). **362 Alamy Stock Photo:** Kelvin Aitken / VWPics (bl); Imagebroker (bc/Rabbit fish); Minden Pictures / Norbert Wu (br). **Image from the Biodiversity Heritage Library:** Ichthyology, Berlin, Chez l'auteur, 1796 (cra). **iStockphoto.**

com: Wrangel (bc). **363 Alamy Stock Photo:** Science History Images (cra). **iStockphoto.com:** Christophe Sirabella (bl). **SuperStock:** Hoberman Collection (br). **364 Image from the Biodiversity Heritage Library:** D. Marcus Elieser Bloch's, Ausübenden Arztes Zu Berlin (crb); Gemeinnützige Naturgeschichte Des Thierreichs Bd. 4 Plates (cra). **365 Alamy Stock Photo:** Imagebroker / Christian Guy (bl); WaterFrame (br). **Getty Images:** De Agostini Picture Library (cra). **iStockphoto.com:** Scubaluna (bc). **366 Alamy Stock Photo:** Arco Images GmbH / G. Lacz (bc); Paulo Oliveira (br); National Geographic Image Collection / Ian Mcallister (bc/Pacific herring). **Image from the Biodiversity Heritage Library:** D. Marcus Elieser Bloch's, Ausübenden Arztes Zu Berlin (cra). **iStockphoto.com:** Feathercollector (bl). **367 Dreamstime.com:** Irko Van Der Heide (bl); Wrangel (br). **Image from the Biodiversity Heritage Library:** D. Marcus Elieser Bloch's, Ausübenden Arztes Zu Berlin (cra). **368 Alamy Stock Photo:** Blickwinkel (bl); Blickwinkel (bc/Arctic char); Bill Brooks (bc); Nature Picture Library / Alex Mustard (br). **Getty Images:** GraphicaArtis / Archive Photos (cra). **369 Getty Images:** De Agostini Picture Library (cra). **Image from the Biodiversity Heritage Library:** Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition auf dem Dampfer "Valdivia" 1898-1899 (crb). **370 artscult.com:** (cra). **Image from the Biodiversity Heritage Library:** The Zoology Of The Voyage Of The H.m.s. Erebus & Terror, Under The Command Of Captain Sir James Clark Ross, During The Years 1839 To 1843. (crb). **371 Alamy Stock Photo:** Frank Hecker (bc/Pouting); Paulo Oliveira (bc). **Dreamstime.com:** Serg_dibrova (br); Slowmotiongli (bl). **Image from the Biodiversity Heritage Library:** Ichthyology, Berlin, Chez l'auteur, 1796 (cra). **372 Alamy Stock Photo:** Artokoloro (cra). **Image from the Biodiversity Heritage Library:** D. Marcus Elieser Bloch's, Ausübenden Arztes Zu Berlin (crb). **373 Alamy Stock Photo:** Anthony Pierce (bl); Anthony Pierce (bc). **Image from the Biodiversity Heritage Library:** D. Marcus Elieser Bloch's, Ausübenden Arztes Zu Berlin (cra). **iStockphoto.com:** Hansgertbroeder (br). **374 Alamy Stock Photo:** Paulo Oliveira (bc); WaterFrame (bl). **Getty Images:** Alastair Pollock Photography / Moment (br). **Image from the Biodiversity Heritage Library:** D. Marcus Elieser Bloch's, Ausübenden Arztes Zu Berlin (cra). **iStockphoto.com:** Swimwitdafishes (bc/Great barracuda). **375 Alamy Stock Photo:** Blickwinkel (bl); Nature Picture Library / Sue Daly (bc/Solea solea); Niels Poulsen (bc). **Dreamstime.com:** Slowmotiongli (br). **Image from the Biodiversity Heritage Library:** A History Of The Fishes Of The British Islands (cra). **376 Alamy Stock Photo:** Imagebroker / David & Micha Sheldon (bc/Common seahorse). **Image from the Biodiversity Heritage Library:** Natural history of Victoria : Prodrumus of the zoology of

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