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Polychaete worm *Pelagobia longicirrata*

Pelagobia worms belong to a genus of holoplanktonic polychaetes. Polychaetes are annelid worms characterized by many bristle-like extensions called chaetae poking out of the body. *Pelagobia longicirrata* is the more common species and is found in all the world's oceans. All are small, slender worms that spend their whole lives in the water column.

Pelagobia are filter feeders and survive by sifting food particles of all kinds—mostly microbes and waste—from the water using feathery antennae. The mouthpart is then everted (turned inside out) to slurp up items from these feelers. The mouthpart can also be used to actively target food in the water. *Pelagobia* worms are an important part of the marine food web, being eaten by a variety of animals, including fish, crabs, and seabirds.

Body plan

As annelids, the worms are divided into multiple repeating body sections, with a head at one end with a mouth and sensory organs. The body is covered with small, overlapping scales. Although they are worms, polychaetes do look as if they have legs. However, these are unjointed, soft extensions of each body segment, called parapodia (which roughly translates as "beside feet" or "almost feet"). The adult worms have between 15 and 18 segments, each with a pair of parapodia. The appendages are fringed with chaetae which enlarge their surface area so they can function as oar-like swimming limbs. Similar paddle-like appendages are developed by benthic worms so they can swim up to the surface to spawn during the breeding season.

OPPOSITE | A dorsal (top-down) view of a *Pelagobia longicirrata*, showing the parapodia extending from the body's many segments.

Stages to adulthood

It is likely that the holoplanktonic species evolved a life cycle where they never needed to return to the seabed. The life cycle has multiple stages. Eggs are fertilized externally in the water. The larval worm starts out as a single head segment, but the body elongates as more segments are added in six developmental stages before reaching the adult form.

FAMILY:	Lopadorrhynchidae
DISTRIBUTION:	Worldwide
HABITAT:	Open water
FEEDING HABITS:	Filter feeder
NOTES:	The worms have symbiotic bacteria living in their digestive tract. These helpful germs break down the cellulose in the cell walls of phytoplankton, which is otherwise unavailable using animal enzymes.
SIZE:	3/16 in (4 mm)

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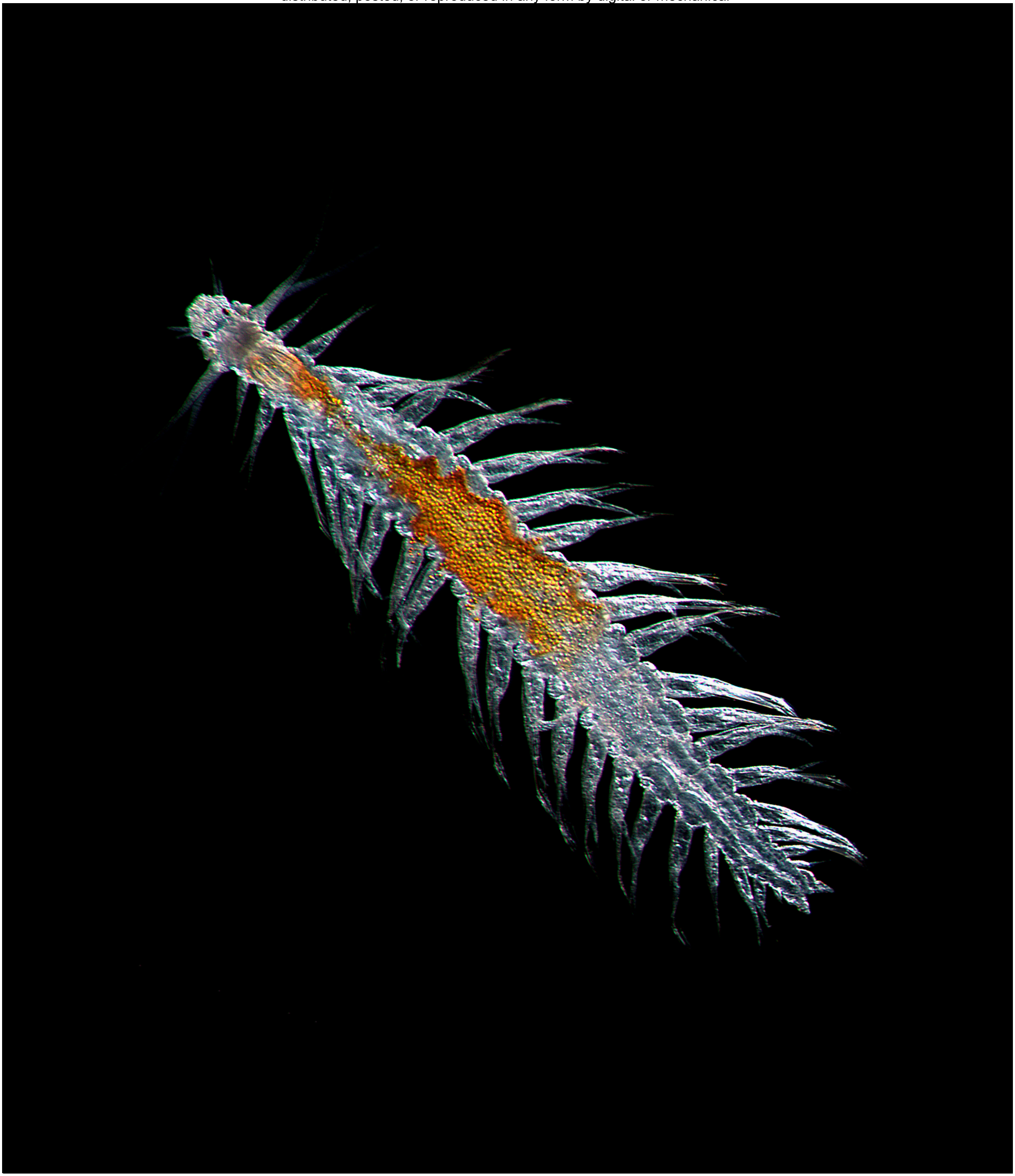

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Rotifer *Conochilus unicornis*

Rotifers are minute aquatic animals that belong to a separate phylum, Rotifera. With some being as small as 50 µm across, they are among the smallest multicellular animals of all. A typical body is made of just 1,000 cells. Most rotifers can only be seen with a powerful microscope, although a few giant species reach ⅛ in (3 mm) across and are visible to the naked eye. Even so, that is easier said than done. Rotifers are transparent, and only the digestive tract, which is tinted with food, is immediately obvious.

The name rotifer is derived from the Latin word for "wheel" because many of these creatures have round bodies. A colloquial name for them is wheel animals, although many are more bell-shaped. The rounded body is fringed by a "crown" of cilia at the front end, which forms a loosely defined head section. The most visible feature of the head are the tiny red eyespots, which are sensitive to light but cannot form images.

The cilia are at once used for locomotion through the water and for drawing a current through the crown from which food is filtered out. The digestive system is inside the trunk section of the body, and there is a rear section, known as a foot, which is much reduced in planktonic species to a tail-like spike.

Wide-ranging habitat

Being so small it is difficult to grasp just how widespread these tiny creatures are. They are primarily water animals, but do persist in damp soils and foliage on land as well. They are even found frozen in permafrost. Rotifers live in all freshwater and marine habitats and are often bottom feeders that are anchored to the seabed and form microscopic colonies. However, a large number are planktonic, and rotifers are a significant feature of freshwater plankton communities.

Parthenogenetic reproduction

Rotifers are able to reproduce both sexually and asexually. The asexual process is parthenogenetic, whereby females lay eggs without needing to mate with a male. The egg hatches into a miniature version of the adult and is always female. Male rotifers are produced occasionally. They have a limited life cycle and only exist to fertilize the eggs produced by other rotifers with their sperm, thus boosting the genetic diversity of the population.

OPPOSITE | A colony of rotifers, *Conochilus unicornis*, use their tail-like feet to cling to a central collective mass of mucus.

FAMILY:	Conochilidae
DISTRIBUTION:	Worldwide
HABITAT:	Marine and fresh water, as well as damp, terrestrial habitats.
FEEDING HABITS:	Filter feeder
NOTES:	Rotifers can even survive when trapped in ice.
SIZE:	0.01 in (250 µm)

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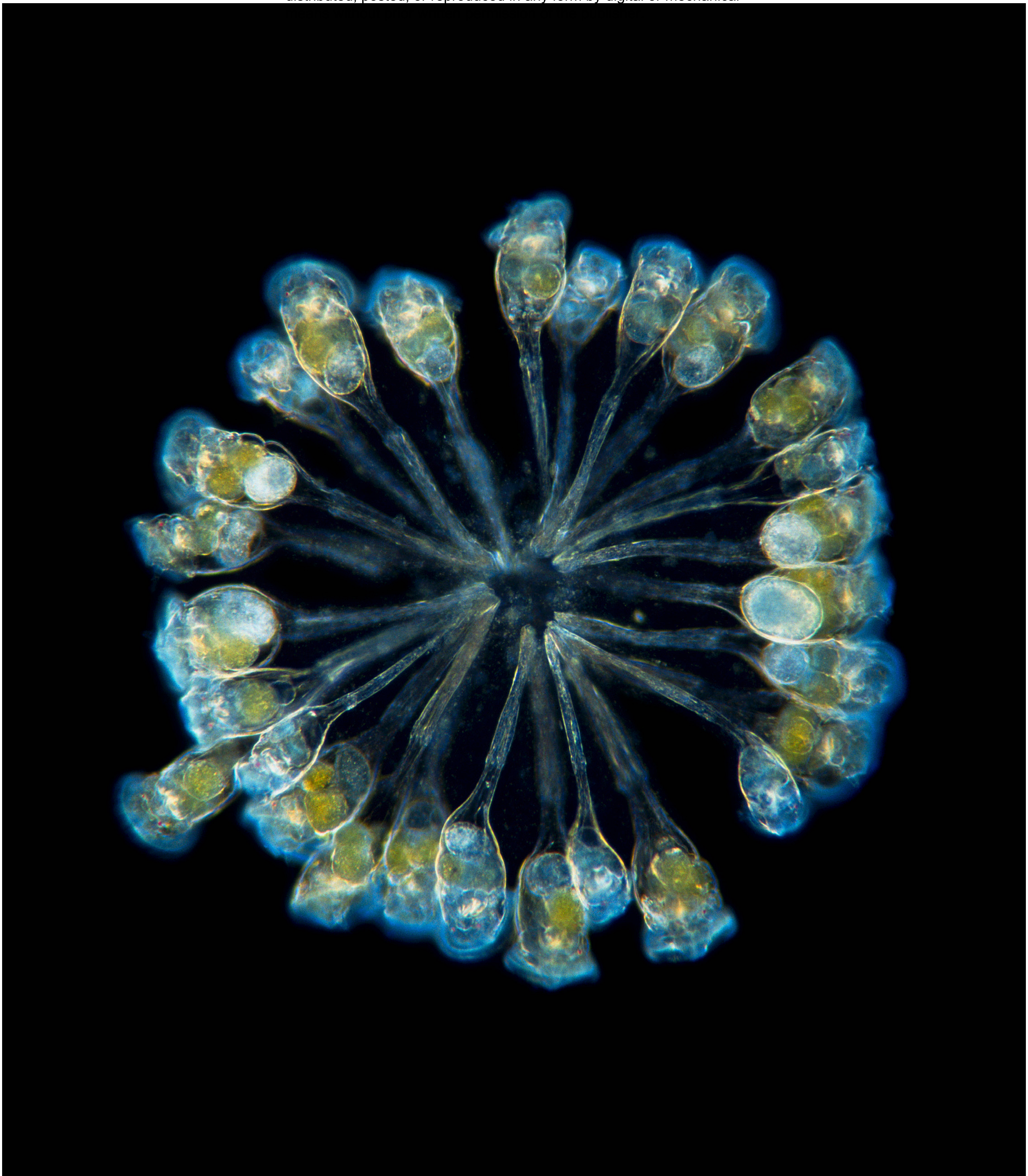

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Diatom *Coscinodiscus* sp.

Diatoms are phytoplankton and make up an important part of the marine food web. They are eaten by a variety of animals, including zooplankton such as copepods, krill, and jellyfish, as well as planktivorous fish like the basking shark.

Coscinodiscus is a common genus of diatoms found in seawater. It contains more than 100 species that make up part of the plankton throughout the world's oceans. *Coscinodiscus* diatoms are centric diatoms, which means they have a circular shape. This form comes from the outer covering called a frustule, which is made up of two overlapping sections, or valves. The valves are highly patterned with a variety of pits, ridges, and spines.

There are, however, around 200,000 species of diatom as a whole. Some have boat-shaped, pennate forms instead of a centric anatomy. The frustules are made of silica, which creates beautiful optical effects. Diatoms are sometimes called golden larvae as well as more lyrical names such as "jewels of the sea" or "living opals."

Value in oceanography

Coscinodiscus is one of the must abundant genera of diatoms in the sea and provides an important source of data for oceanographers. The size, shape, and markings of *Coscinodiscus* valves identifies individual species, and the abundance of different species can be used to track changes in the environment. A bloom of these diatoms can produce damaging quantities of mucilage that clog the gills of fish and other marine life.

Reproduction

Diatoms are able to reproduce both sexually and asexually. The latter system is the most common, with individual diatoms dividing into two. Each daughter cell inherits one valve from the parent. In a fully grown diatom, the top valve always fits neatly over the lower one. When new cells form, the inherited valve is promoted so it is always the top valve and a smaller lower valve grows to fit perfectly inside it. As a result, one of the daughter cells—the one using the smaller lower valve—will always be smaller than its parent, a process that continues down the generations.

OPPOSITE | A dorsal (top-down) view of the diatom *Coscinodiscus jonesianus*. The epitheca, or upper valve, of the frustule can be seen here. The lower valve, or hypotheca, fits underneath.

FAMILY:	Coscinodiscaceae
DISTRIBUTION:	Worldwide
HABITAT:	Sunlit oceans
FEEDING HABITS:	Photosynthetic
NOTES:	Some species release harmful toxins that can reach dangerous levels during a bloom.
SIZE:	0.008 in (200 μm)

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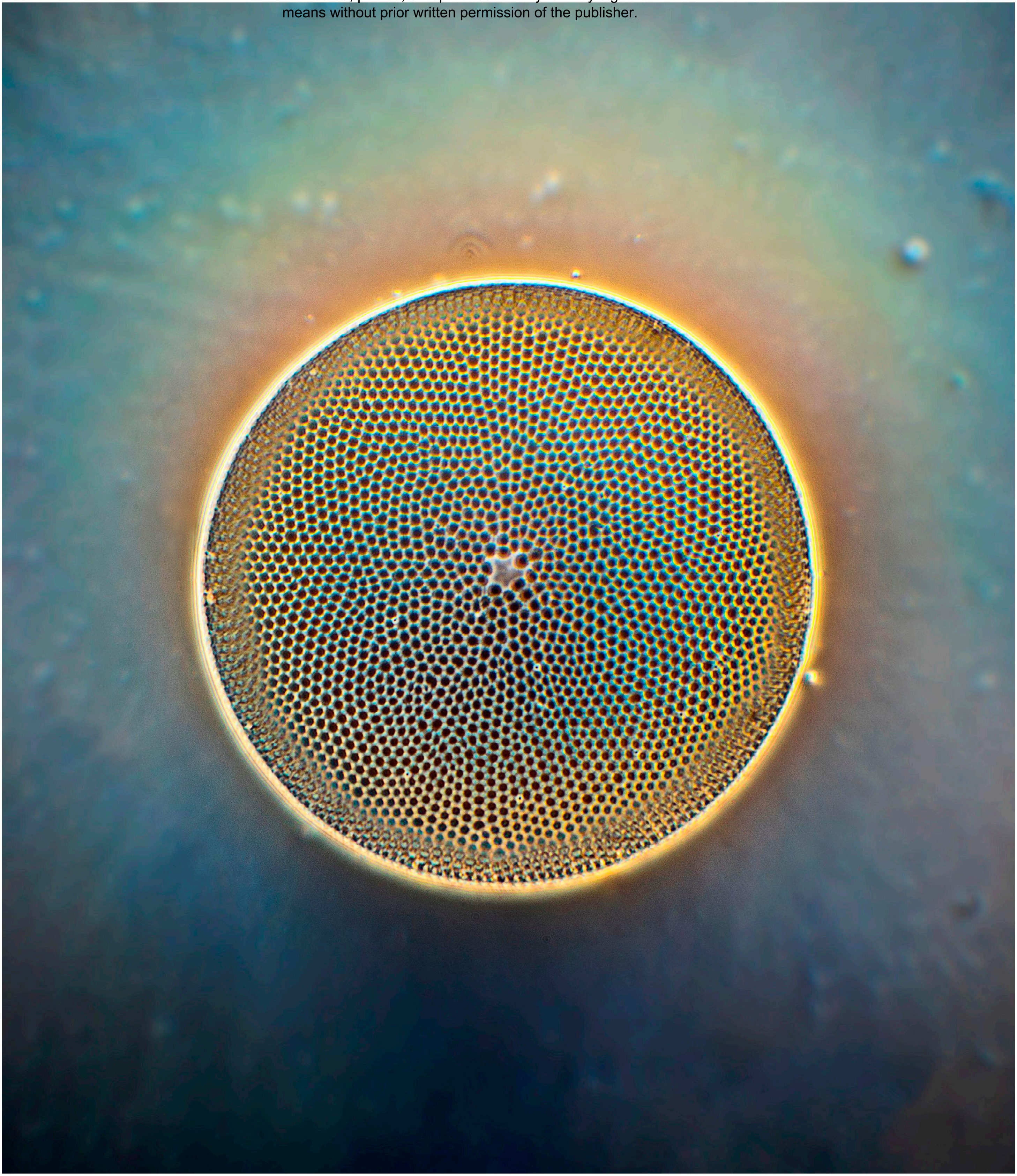

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Dinoflagellate *Tripos muelleri*

This species of marine dinoflagellate is characterized by its distinctive shape. In common with the other 100-plus species of the *Tripos* genus, it has a long, slender cell body that is tapered at both ends. The cells have a distinct top—the apex, or apical horn—and two antapical horns at the lower end. The U-shaped antapical horns in this species are curved upward compared to the central axis set by the apex. Other members of the genus have straighter horns or another distinctive shape.

The cell body is surrounded by a two-part shell, or frustule. The frustule is made up of upper and lower valves that are joined together at the midline by a girdle section, seen here as a faint double line. Dinoflagellates are by definition organisms with two flagella. The first is connected via a lateral groove between the valves, while the second is located near the antapex (in this case, the lowest point where the horns curve out and up).

In keeping with all dinoflagellates, *Tripos muelleri* is a photosynthetic organism. As one of the larger examples of a dinoflagellate, this species is mostly found in coastal waters. Smaller dinoflagellates are more common out in deeper open waters, where nutrients are more sparse. Researchers are finding that many members of the *Tripos* genus are mixotrophic, meaning that as well as photosynthesizing, they also consume food particles, mostly bacteria, by engulfing them with their cell body.

Red tides

Tripos species have a complex life cycle. Most of the reproduction is asexual, where a single cell divides into four or eight cells. To achieve that, the cell must first escape from its shell. During the sexual phase, two cells merge to create a temporary form which then divides, releasing offspring called swarmers. Dinoflagellates also form inactive cyst forms, which can sink to the seabed and lie dormant for a period.

Tripos dinoflagellates are one of the types of plankton that are responsible for red tides, where the population explodes in such vast numbers that the color of the water changes—as well as red, it can also be brown and green. These plankton produce toxins in quantities that threaten fish.

OPPOSITE | The orientation of the three horns indicates that this is a species of *Tripos*.

FAMILY:	Ceratiaceae
DISTRIBUTION:	Worldwide
HABITAT:	Mostly coastal seas
FEEDING HABITS:	Photosynthetic
NOTES:	Named for the German naturalist Johann Adam Müller (1769–1832).
SIZE:	0.008 in (200 μm)

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Coccolithophore *Emiliania huxleyi*

Emiliania huxleyi is a species of coccolithophore, a type of marine protist. It is one of the most abundant and widespread species of coccolithophore, and it can be found in all the world's oceans. This species is especially widespread because it is able to withstand water temperatures ranging from 34–86°F (1–30°C). It is especially well represented in non-polar seas.

E. huxleyi is a flagellated phytoplankton, although the term flagellate simply refers to the presence of the whip-like appendage and holds no particular taxonomic value. Indeed, in this species the flagellum is only present for a short sexual phase of the life cycle. Most of the time, there is no flagellum at all.

Porous skeleton

As a coccolithophore, *E. huxleyi* is more defined by the calcium carbonate plates, known as coccoliths, which encase its body. Together the coccoliths form a porous skeleton called a coccosphere. The stark white of these structural materials makes these organisms look like tiny snowflakes. Chalk, the soft form of limestone, is a rock constructed of an immeasurable quantity of coccospheres of long-dead plankton. The heyday of the coccolithophores was about 100 million years ago, in the Late Cretaceous Period. This period is best known for witnessing the rise and fall of the dinosaurs, but is really named after all the chalk beds created at the time by coccolithophores.

Huge blooms

E. huxleyi is most evident in summer when it forms blooms that cover hundreds of thousands of square kilometers. Blooms are stimulated in part by warmer waters, and a climate feedback mechanism has been identified. As climate change heats the oceans, blooms of coccolithophores become larger and more frequent. The blooms form by vegetative growth—another term for asexual reproduction—which occurs when the coccolithophore has its white skeleton in place. The pale bloom increases the reflectivity of the surface water, pushing heat and light back into the atmosphere (and space). The end result is that deeper waters become cool. The long-term effects of this apparent climate mechanism are still being investigated.

OPPOSITE | A colorized scanning electron micrograph of *Emiliana huxleyi*, showing the skeleton, or coccosphere, of calcium carbonate plates, the coccoliths.

FAMILY:	Noelaerhabdaceae
DISTRIBUTION:	Worldwide
HABITAT:	Sunlit oceans
FEEDING HABITS:	Photosynthetic
NOTES:	Named for Thomas Henry Huxley (1825–1895), an English biologist.
SIZE:	0.0004 in (10 μm)

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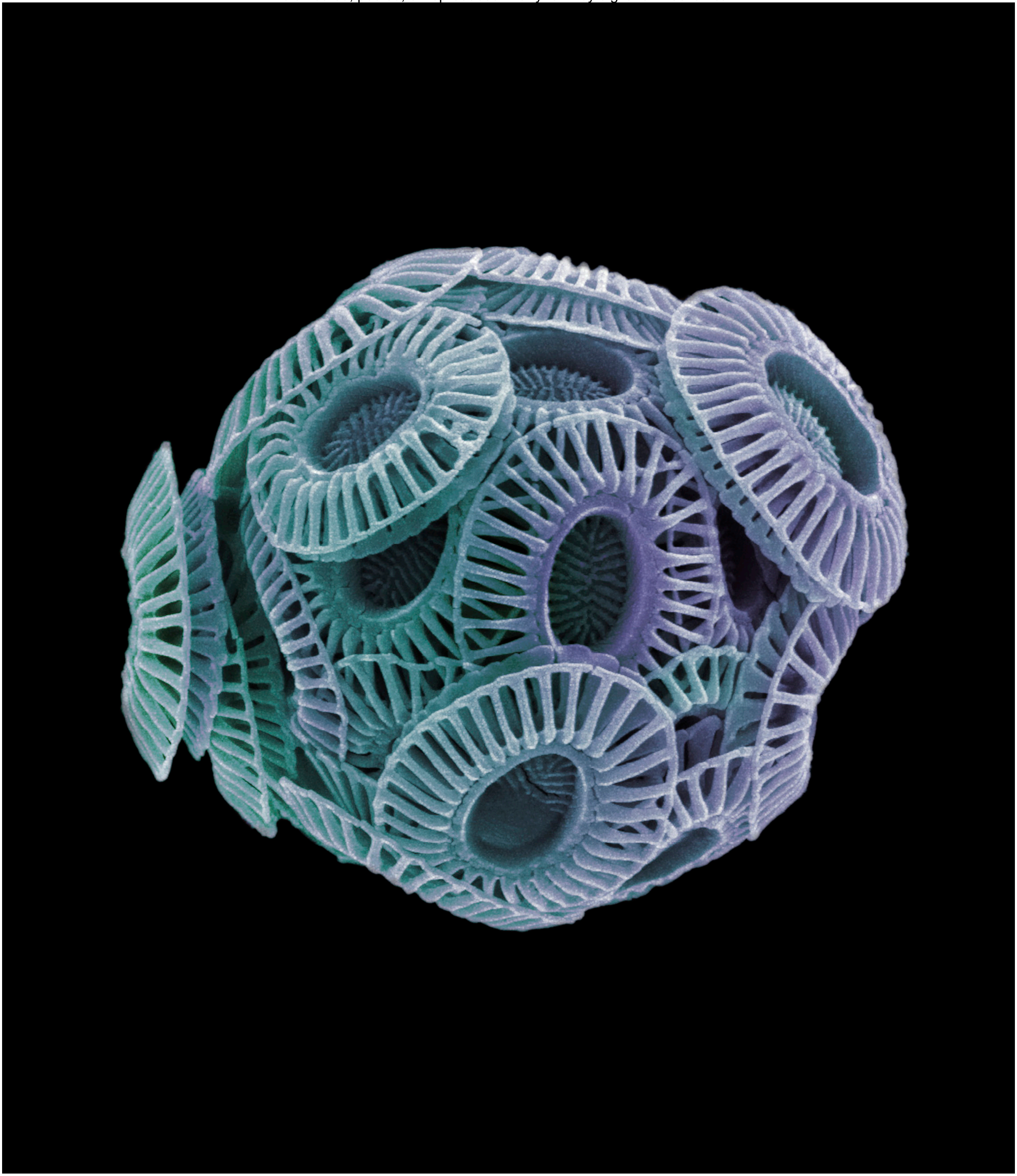

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Hydrozoan jellyfish *Aequorea victoria*

Aequorea victoria, also known as the crystal jelly, is a small hydrozoan jellyfish from the Pacific Ocean. It is most abundant along the cold-water coastlines of North America, from the edge of the Arctic Ocean to Central America. Seen here is the adult planktonic medusa, a form with the tentacles hanging from a bell. Sexually mature individuals will have a bell above 1¼ in (3 cm) in diameter. The largest specimens are 2 in (5 cm) across. Larval forms of this species, in common with most hydrozoans, start out as seafloor creatures. At this stage they take a polyp form, where the tentacles reach up from the body in an inverse orientation to the medusa.

Bioluminescence

The bell is transparent and decorated with blue or green spots. *A. victoria* is also bioluminescent, meaning that it can produce its own light. The light is created by a protein called aequorin, which is activated inside cells by calcium ions. When the calcium ions bind to aequorin, a flash of blue light is released. That blue light can then be converted to green by another protein called GFP (somewhat uninspiredly short for green fluorescent protein).

A. victoria uses its light for communication, mostly to attract mates in dark waters. Flashing lights also have a defensive function by startling predators and suggesting that the animal is much larger than is the case. In twilight environments where light is twinkling down from the surface, the light show can create a camouflage, helping the jellyfish to blend in with the shimmering surroundings.

The protein aequorin has been used in a variety of scientific studies, not least into the nature of bioluminescence itself. This research has led to a burgeoning of artificial fluorescent proteins, which are used in a variety of applications, including cell biology and medical imaging. In 2008, Osamu Shimomura, Roger Tsien, and Martin Chalfie were awarded the Nobel Prize in Chemistry for their work on aequorin and GFP.

FAMILY:	Aequoreidae
DISTRIBUTION:	Eastern Pacific
HABITAT:	Coastal waters
FEEDING HABITS:	Predators
NOTES:	A source of fluorescent proteins.
SIZE:	1¼ in (3 cm)

OPPOSITE | The crystal jelly (*Aequorea victoria*), like many pelagic organisms, has an ability to produce bioluminescence.

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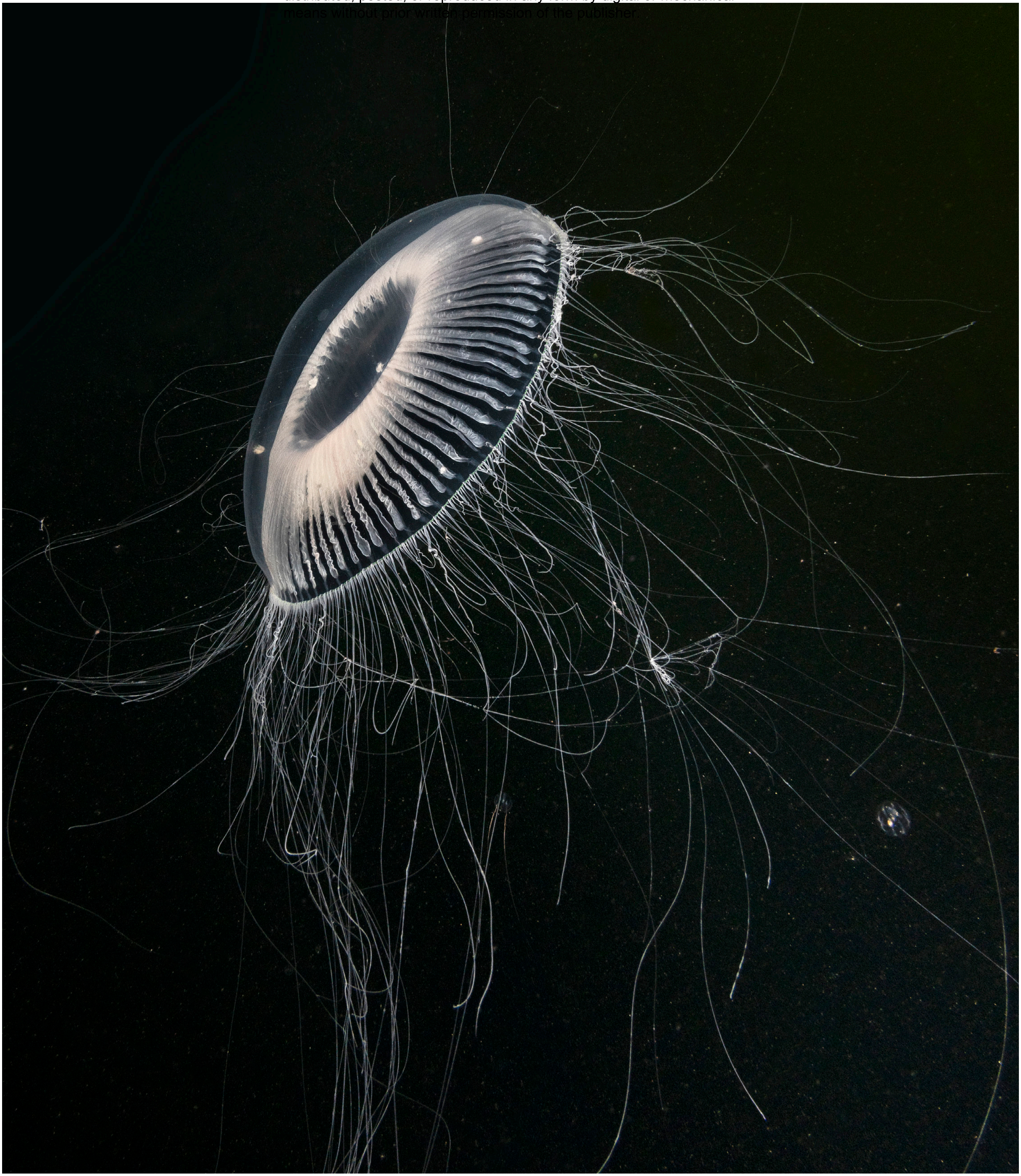

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European eel *Anguilla anguilla*

When adult, this snake-shaped fish lives in the freshwater rivers of western and northern Europe. However, that is just a single phase of one of nature's most incredible life cycles, and one that even now we do not fully understand. In a turnabout from the more familiar breeding pattern, such as that used by salmon where young fish swim down river to the sea and then return as adults to breed, European eels do it the other way around. They spawn in the middle of the ocean, and then spend their larval stage, seen here and known as a leptocephalus, as marine plankton slowing drifting their way to freshwater habitats.

To the Sargasso Sea

The story begins in the inland waters of Europe where sturdy, meter-long eels spend up to 20 years, using their sense of smell to find worms and aquatic insect larvae to eat. They then head down river and out to sea using that same sense of smell to swim fast and deep to the Sargasso Sea. Deep in these waters, no one is quite sure where, the eels spawn and die.

The next generation emerge from the eggs as tiny, transparent larvae called leptocephali, which are about 0.04 in (1 mm) long. They have flattened, leaflike bodies and swim weakly, meaning they can only drift in the water. The larval eels feed on smaller planktonic organisms, such as copepods, rotifers, and microscopic jellyfish, as they move in the gyre of the Sargasso. A gyre is a swirl of warm currents that corrals a vast patch of floating *Sargassum* seaweeds.

The current spreads out the tiny eels until they are caught in the Gulf Stream, which takes them northeast across the ocean to the shores of Europe. Once in the stream, the leptocephali take about 300 days to make the crossing. After reaching neritic, or coastal, waters, the changing smells of the water stimulate the flimsy planktonic larvae to metamorphose into sturdier glass eels, or elvers, which enter the freshwater system for the first time.

Sadly, the amazing European eel is now critically endangered due to overfishing of juvenile elvers as they swim into rivers. These juvenile eels are then raised in farms. Eel farmers are currently unable to breed their own stock due to the species' unique life cycle and so rely on fishing. As a result, very few wild eels remain.

FAMILY:	Anguillidae
DISTRIBUTION:	Sargasso Sea and the Gulf Stream
HABITAT:	Open ocean
FEEDING HABITS:	Prey on zooplankton
NOTES:	Critically endangered due to overfishing.
SIZE:	0.04 in (1 mm)

OPPOSITE | The leptocephali of a European eel (*Anguilla anguilla*) head for fresh water.

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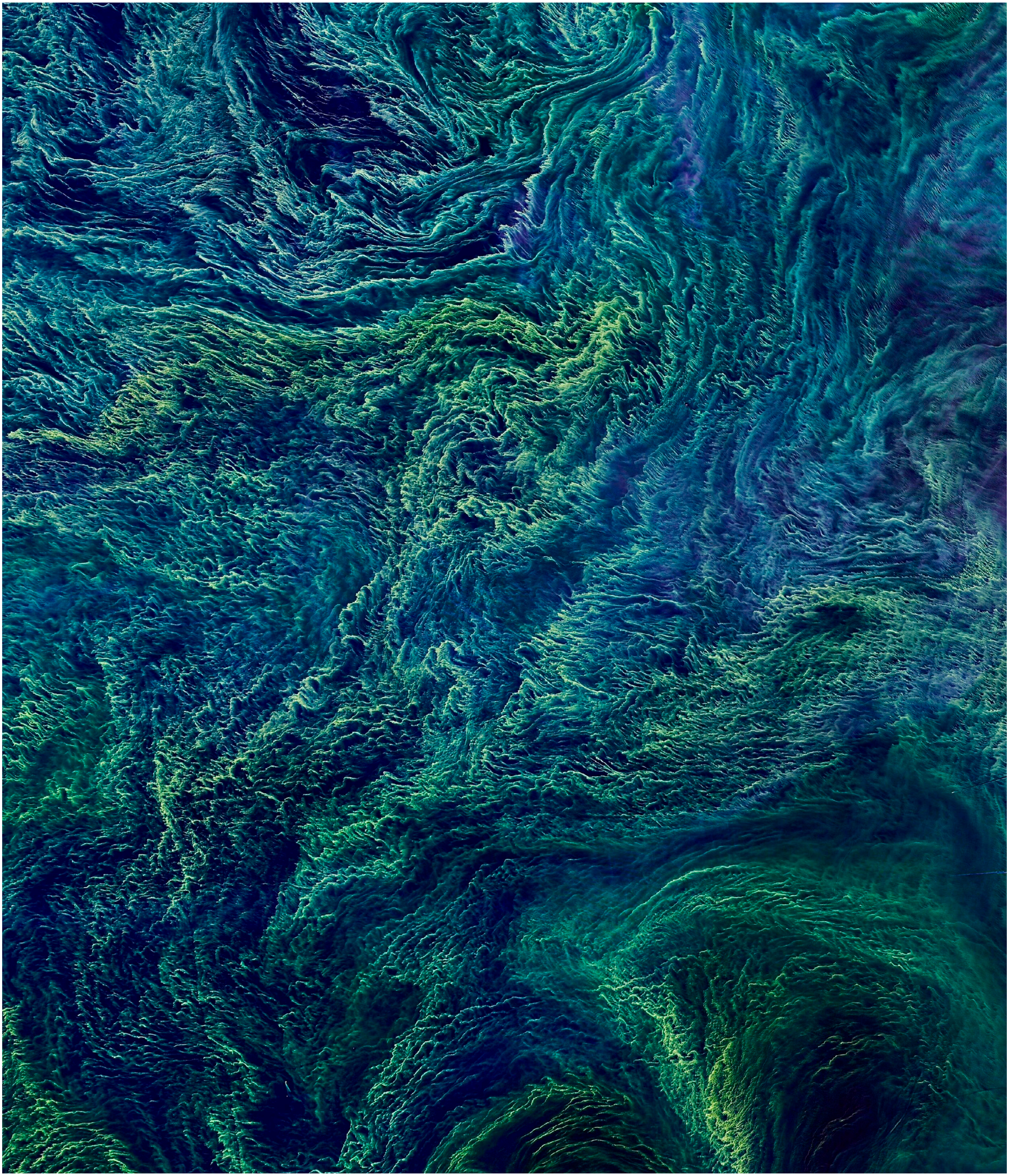

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CHAPTER 2

LIFESTYLES AND ADAPTATIONS

Earth has a lot of room for plankton, with the oceans covering more than 70 percent of the surface of the globe. Almost 90 percent of that ocean is more than 3,200 ft (1,000 m) deep and generally a lot deeper than this. All that water makes up more than 99 percent of the world's habitable space where life can persist. Nevertheless, the oceans are barren compared to land, harboring only an estimated 15 percent of the planet's species. Even so, the oceans are very diverse, with a wider array of phyla represented despite fewer total species than on land.

Despite the apparent simplicity of their lifestyle, plankton are by no means a ubiquitous feature of the oceans. They are not spread evenly, either geographically or by depth. Researchers still have much to learn about why plankton communities thrive in some places but not others. Such knowledge will be crucial in a world subject to climate change and ecological damage.

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FORCES AT WORK

Plankton all share one ability: they stay afloat. This may be an intrinsic fact based purely on the size of the organism. Other plankton are adapted to this floating lifestyle, with simple features like gas vacuoles inside the cell body that act as tiny life preservers to reduce the density of the whole cell to below that of the surrounding seawater. Larger plankton have entire gas bladders or air bags that do the same job, while less clean-cut adaptations rely on strings of mucus splaying though the water to spread the weight and reduce the effects of gravity. Others are suspended by active swimming. They will sink when they don't swim, so swim they must just to stay where they are.

Archimedes did not have a working knowledge of plankton, nor as far as we can tell did he care much for marine biology, but he was the first to articulate the way forces work to create floating and sinking. All plankton have a weight and this all adds up. It is estimated that the cumulative mass of the world's cyanobacteria alone is about a billion tons. But a single bacteria cell has a negligible weight of one picogram—or a trillionth of a gram. In life plankton do not sink, but once dead they cannot counter gravity and down they must go.

Sinking and floating is all down to the size of the buoyant force, which is the push of all the surrounding water molecules. Archimedes might have put it in these terms: A plankton displaces its volume in water, and if it weighs less than that volume of water, it will float. This is because the force of gravity on the plankton is weaker than the buoyant force. If it is considerably weaker, then the plankton will rise to the surface. (It could even float off into the air if released from the water's surface tension by wind-blown sprays. Like balloons, aeroplankton float in the air due to the buoyant force of the surrounding gases.) A more general case is that plankton are close to the density of water, being largely composed of water, so they achieve a neutral buoyancy, more or less staying at the same depth until the water is churned by waves and currents.

RIGHT | A bloom of moon jellyfish (*Aurelia aurita*).

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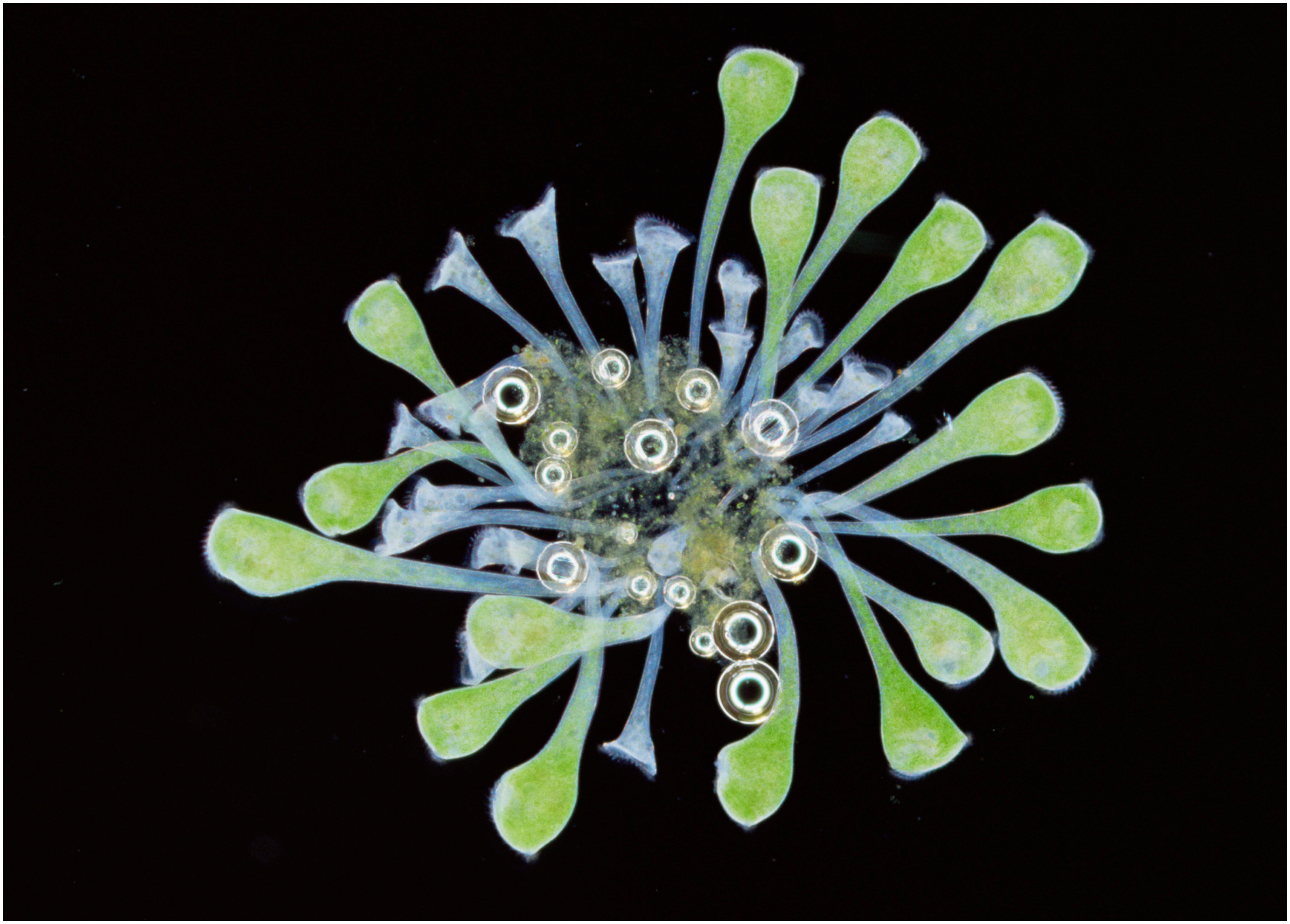

Sizing up

Buoyancy is obviously not a function of size, but the vast majority of plankton are small organisms. It is perhaps instructive that megaplankton, the biggest subset, refers to anything over 8 in (20 cm) wide. This group is dominated by the jellyfish but also includes less common creatures like the salps and other free-floating tunicates. Less than 8 in (20 cm) wide but larger than ¾ in (2 cm) are the macroplankton, which again are visible to the naked eye—if, that is, you can get a good enough look in the water. This group includes the larger crustaceans, like shrimp and krill, plus some comb jellies.

Below ¾ in (2 cm), we enter the domain of the mesoplankton. This is where the community really starts to expand in diversity and sheer quantity. Mesoplankton is still dominated by animals, like the previous groupings, and this time includes the planktonic larval forms of nektonic animals. (Nekton refers to sea animals that can swim and move independently of the currents.) On top of that, the list is filled with many of the biggest hitters of the zooplankton community, such as the copepods, arrow worms, and water fleas.

Smaller still are the microplankton, which occupy a size between 20 and 200 micrometers (µm, or a millionth of a meter). At this size, the single-celled protists begin to appear, including organisms like ciliates and foraminifera. There are also tiny animals, such as rotifers and the numerous larvae of copepods. Next come the nanoplankton, which are between

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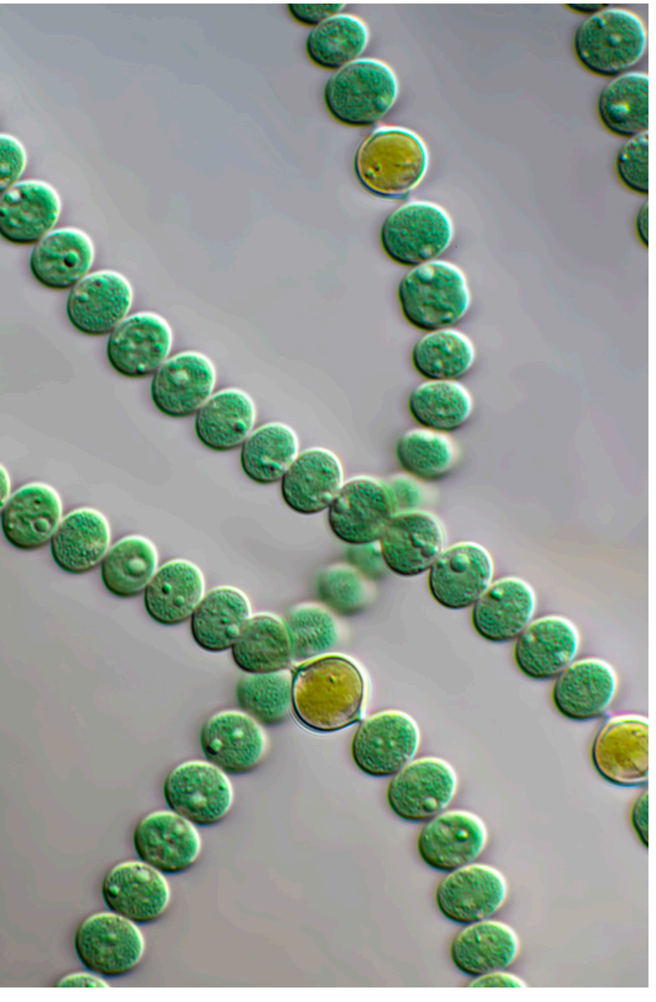


OPPOSITE | Floating colonies of ciliate protozoa, a species of *Stantor*, showing the gas bubbles used to lift colonies.

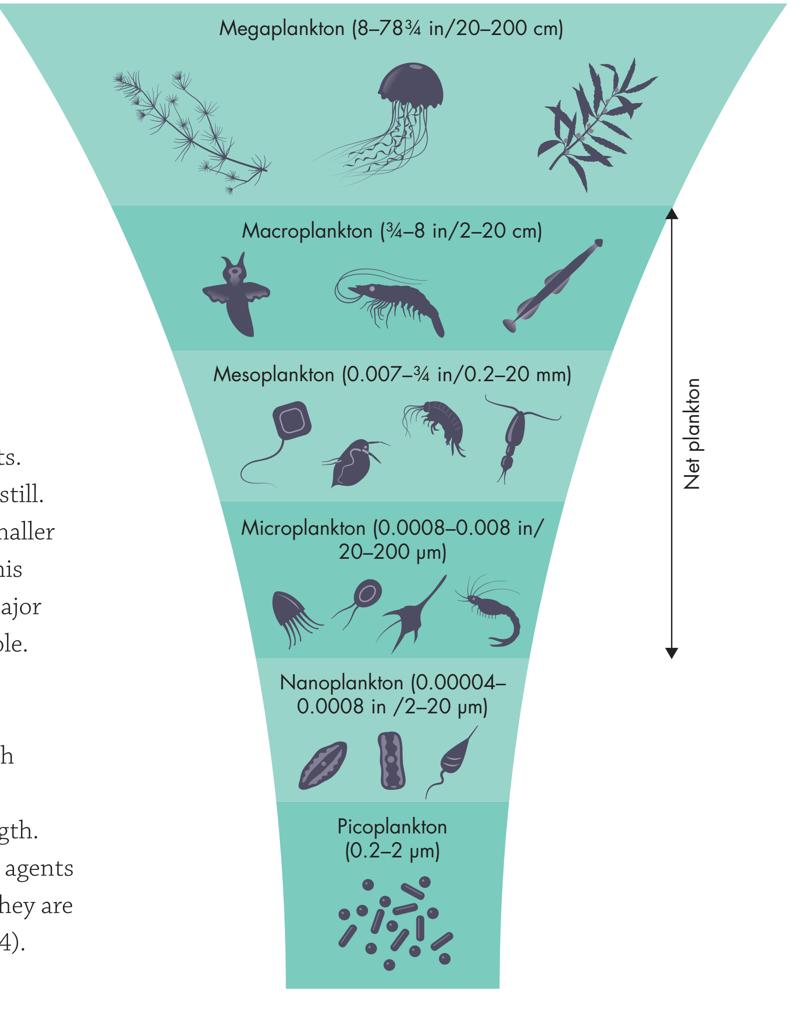
LEFT | A chain of *Anabaena* cyanobacteria. The slightly larger and darker cells are heterocysts, which convert nitrogen from the water into nitrate.

BELOW | A diagram showing the relative sizes of plankton.

2 and 20 μm. This size group is dominated by the protists. There are no animals this small and bacteria are smaller still.

Bacteria occupy the picoplankton group, which are smaller than 2 μm. Despite their tiny stature, the members of this group, dominated as they are by cyanobacteria, play a major role in the ecology of the oceans and the planet as a whole. Additionally, bacteria are the only kind of planktonic organisms found consistently at all depths (although in diminishing concentrations). Plankton does not end with bacteria, however. The femtoplankton contains marine viruses, which are only a fraction of a micrometer in length. As discussed in Chapter 1, viruses are biologically active agents that have a major ecological impact on marine life, but they are not really living things in the accepted sense (see page 34).

Plankton size categories



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VERTICAL ZONES

The living conditions in the ocean are by no means uniform, varying according to depth, latitude, and numerous other factors. In most places, life in the ocean is hard, but wherever one looks, there will be some plankton. The surface layers of the ocean are bathed in sunlight by day, and in certain places visibly teem with life. But with depth comes darkness, cold, and a rapid increase in water pressure that would kill an unprotected human diver still within view of the surface. Due to the variables, oceanographers divide the oceans into zones based on depth. The defining factors for these ocean zones are firstly light and, secondly, the location and topography of the seafloor beneath.

The sunlit zone

The upper layer of sea is the euphotic zone, better understood as the sunlit zone. As one might expect, this upper zone is bathed in sunlight by day. However, light and water do not mix well. At most, the brightness of the sun beams will be reduced to 1 percent of their original intensity by a depth of 650 ft (200 m), and that is in the clearest waters. In turbid waters churned up with sediment, the light barely makes it 33 ft (10 m) down.

The euphotic zone is where all the action is. An approximate 90 percent of all marine life lives here. It is impossible for phytoplankton, those organisms that rely on photosynthesis as their primary source of nutrition, to live in any other part of the water column for long periods. Zooplankton and sea animals in general flock to this zone to join the food chain that starts with those phytoplankton.

Into the gloom: the twilight zone

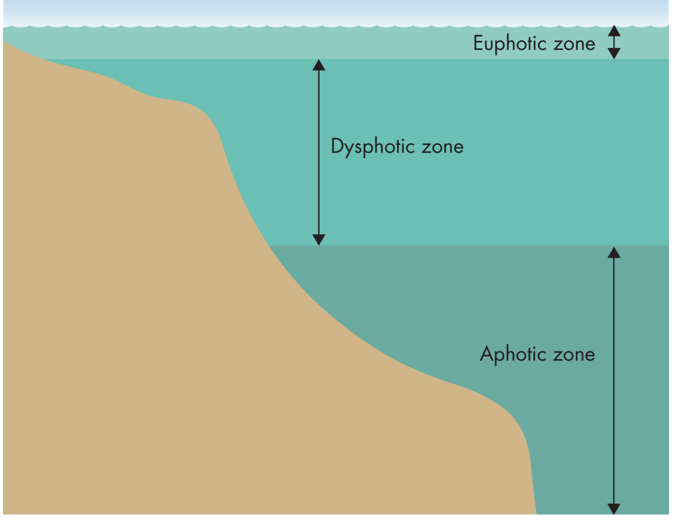
Below the sunlit waters, deeper than 650 ft (200 m), we enter the dysphotic zone, again perhaps better termed as the twilight zone. Here light arrives from the surface but not strongly enough to be used for photosynthesis and it never gets above a deep gloom. Nevertheless, the twilight zone is something of a haven for animal life, including many of the biggest shoals and swarms of zooplankton.

The dark zone provides a refuge for the zooplankton, mostly in the mesoplankton groups, and also many nektonic species, from where they launch assaults on the communities of phytoplankton and zooplankton in the euphotic zone. This results in the largest mass movement of life on the planet,

OPPOSITE | Tropical fish, including the Bengal snapper (*Lutjanus bengalensis*) and bannerfish (*Heniochus diphreutes*) dive toward a coral reef in order to avoid predators, North Ari Atoll, the Maldives, in the Indian Ocean.

RIGHT | The oceanic zones are delineated by the light environment.

Ocean light zones



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known as the diel (or diurnal) vertical migration (DVM). Chapter 4 gives a more in-depth look at the DVM (see page 134), but in a nutshell, zooplankton lurk in the twilight zone until the sun sets at the surface, thus plunging the euphotic zone into darkness. Under the cover of this darkness, the zooplankton, such as copepods and krill, rise up to feed on the phytoplankton. They cannot risk foraging by day lest they are targeted by visual predators in the euphotic zone.

Fish and a host of other marine animals follow the night-time marauders up to the surface. (Lanternfish famously have their own lights to guide them as they feast in vast night-time shoals). By contrast, a few other zooplankton head to deeper waters at night to get away from this upsurge of predatory activity. They will swim back to the light come morning. In those species that show reverse DVM, this may allow them to avoid the predators that are following the DVM of their prey.

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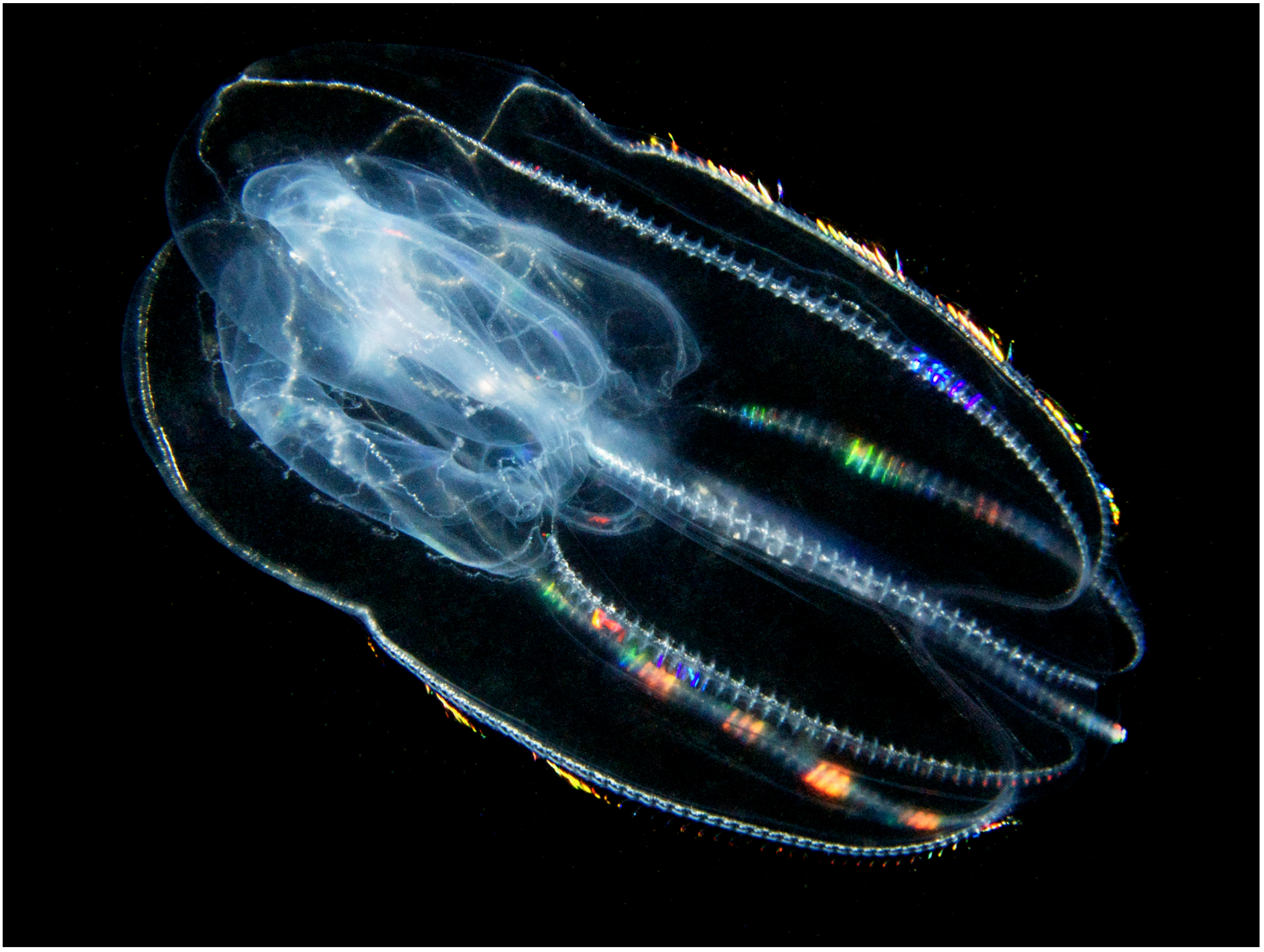
Into the midnight zone

No light ever reaches below about 3,200 ft (1,000 m). From here the water is in the aphotic zone, more commonly described as the midnight zone. It is completely dark 24 hours a day, no matter what the sunlight conditions at the surface. This zone continues all the way to the seabed. Life has thinned out somewhat in these dark waters, but it is still there. In terms of plankton, the ecology of the midnight zone limits them. Many have arrived here by mistake, churned in surface water by storm winds and ocean currents, and doomed never to get back to the surface. As such, these plankton become part of the marine snow (see page 100), which is a perpetual shower of organic—and mostly dead—material that sinks from the more productive zones nearer the surface. It is the ultimate source of nutrients for most of the food chains that exist in the deep ocean and on the seafloor.

OPPOSITE | This dorsal (top-down) view of a copepod shows the antennae on the head are covered in setae. These hair-like structures are used to detect the tiniest motions of prey in the water, and help them forage.

BELOW | *Bolinopsis infundibulum* comb jelly in the twilight zone.



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EVADING DETECTION

Marine life uses a variety of tricks to evade capture by predators, whether this is the countershading displayed by dolphins and penguins, the reflective scales of fish, or being transparent, as is the case for some plankton.

These clever tricks make use of the optical properties of water, which are quite distinct from those of air. This distinction has a profound effect on the vision of marine creatures, especially the oceanic ones, which spend their days in the endless vastness of deep, open oceans. That in turn impacts the strategies used by marine life, including plankton, to stay out of sight.

The difference is clear

One way to experience the different visual ecology of water for oneself is to dive a few meters under clear water on a sunny day and take a look at Snell's Window. This is a bright patch on the surface above you. You can see through it and make out features above the water, although the full 180-degree field of view is compressed and distorted into just over 90 degrees. It is not something human eyes are good at interpreting, but this is all that marine life can ever see from below the surface.

Snell's Window is a product of refraction, and is named for the Dutch Renaissance astronomer who described the way refraction works. Refraction alters the direction of light beams as they move from one transparent medium to another, such as from air to water. The refractive properties of water focus all light that gets through from the air into this narrow window. The end result is that wherever you look up at the surface, you see an opaquely illuminated boundary, not a detailed image of what lies beyond. Look down, and there is no source of light, only a descending darkness.

One obvious product of this marine light environment is the countershading that is a feature of many big sea creatures, from dolphins and whales to sharks and penguins. The idea is that the top of the body is dark and this transitions to a paler underside. When viewed from above, the dark surface blends in with the darkness emanating from the deep. Seen from below, the pale underbelly is hard to make out against a background of bright light entering Snell's Window. In smaller creatures like plankton, this shading may be reversed, as is the case with the violet sea snail (*Janthina janthina*; see page 80), which hangs upside down from the surface of the water and so has a shell that is paler on top and a bluish purple underneath.

Big blue

The major factor for smaller animals is that water is blue. This is the color of the substance, just as table salt is white and charcoal is black, although the blueness of water is only apparent when observed in large quantities. Meanwhile, air is colorless (a blue sky is an optical effect, not the color of the gases). So in some senses, blue is more akin to the green in a forest. If an organism wants to blend in, that is the color it needs to be—little forest animals are more likely to be green for this reason.

However, it does not quite work like this in water. A green tree frog appears that color because its skin reflects the green fraction of sunlight and absorbs the red and blue parts. In the ocean, the water has already absorbed the red and green light and is transmitting a little blue light, which illuminates the objects swimming or floating in it. To appear the same color as the water around it, an object must reflect all the light that hits it. This is why fish have mirror-like scales. The scales reflect the light between the fish and the observer, which is identical to the light coming from behind the fish. Thus, the fish disappears behind a cloak of invisibility. At least that is the plan, and for eyes that are attuned to pick out three colors like ours, it can work well. But fish themselves are less easily

OPPOSITE ABOVE | An oceanic whitetip shark (*Carcharhinus longimanus*) in the Red Sea, seen swimming below Snell's Window.

OPPOSITE BELOW LEFT | A flock of king penguins (*Aptenodytes patagonicus*) reveal their countershaded bodies while swimming off Macquarie Island, near Antarctica.

OPPOSITE BELOW RIGHT | The mirror scales of these fusiliers, *Caesio lunaris*, make them hard to see in the blue waters of Palau, in Micronesia.

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fooled. They have dichromatic vision, which is tuned to visualizing shapes against the background of water. Fish that hunt by sight, such as sardines or anchovies, scan the water for the shapes of zooplankton.

To minimize detection, therefore, many zooplankton species, including copepods, use a simple trick: the best way to stay unseen in water is to have a largely transparent body. The elaborate colorings used for camouflage on land are of no use here. So the light passes straight through the plankton, leaving no tell-tale silhouette that can be spotted by predatory fish. The internal structures of the plankton, its digestive tract especially, will show up but offer less of a target for predators.

Of course, as with all biological adaptation, adopting transparency involves a trade-off. Pigments are inherently useful in that they absorb the nasty, high-energy rays of ultraviolet light, which could otherwise disrupt the cell chemistry of plankton. In lakes where fish predators are less of a threat, plankton are more pigmented for this very reason.

Staying alive

Inevitably plankton cannot evade detection forever. Therefore they have a last line of defense. This may be an escape response where zooplankton flick an appendage to dart off in a random direction at high speed. Copepods make impressive "jumps" by delivering determined strokes with their cephalic appendages, the limb-like body parts on the head. This provides acceleration through the water of 500 body lengths per second, exceeding the equivalent acceleration of an F16 fighter jet.

Another strategy to avoid being eaten is to grow a lot of protective jelly. Both phytoplankton and zooplankton of various kinds have developed gelatinous bodies. It allows them to grow to a large size very quickly and without expending too many resources. Predators tend to view the ball of jelly as a less-than-perfect meal.

RIGHT | The bioluminescence from a dinoflagellate bloom lights up the water in spectacular fashion along the beach at Jervis Bay, in Australia (right) and the Maldives (far right).

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Bioluminescence

In the dark oceans, organisms make their own light in a process called bioluminescence. Many types of plankton do this, from bacteria and dinoflagellates to jellyfish. Why plankton bioluminesce is not always clear. It may be that the light is a signal to other members of the species to attract mates or even communicate in more advanced ways. In turn, the light may be a trick, designed to fool prey into thinking they are seeing friendly relatives but instead drawing them closer to their foe. Bioluminescence creates a cold light, which means no other energy, such as heat, is emitted with it. The light is produced by a chemical process. The color is not chemical but structural, which means the different hues are produced by the way the same chemicals (known as luciferins) are arranged in the light-emitting organs.

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SEAFLOOR PROFILE

As well as depth, plankton communities are also affected by the undersea topography, the ups and mostly downs of the seabed. Areas of oceans near the coast are called neritic, while farther out from land the waters are described as oceanic. Neritic waters are mostly shallow because they overlay a continental shelf.

Continental shelves

A continental shelf is the lower lip of a landmass, the part of the continental crust that is below sea level. The water here is only a few tens of meters deep and so is, in effect, completely contained within the euphotic zone.

Continental slopes

Eventually, the shelf gives way to a steep drop called a continental slope, which plunges thousands of meters to the deep seafloor. This marks the transition from the thick continental crust to the thinner and lower-lying oceanic crust. The continental slopes form the walls around the vast oceanic basins, which hold Earth's surface water. Beyond the slope the waters are oceanic.

Continental rises

The continental slope meets a continental rise, a less steep slope that descends more gently to the abyssal plain. The continental rise is built from materials that flow over the rim of the continental shelf, including gargantuan undersea mudslides that can create tsunamis. All the debris piles up at the base, forming a transitional zone between the physical materials and the chemical signatures derived from the continental crust and those made from the oceanic crust beyond.

Abyssal plains

An abyssal plain is well named. Compared to land it is mainly flat, with areas of low hills. It is also largely empty of life, with barely ⅛ oz (4 g) of living material for every square meter. (Although, interestingly, that doubles on the abyssal hills.) Compare that with the biomass density of ¾ oz (20 g) per square meter in a desert or 88 lb (40 kg) in a rainforest.

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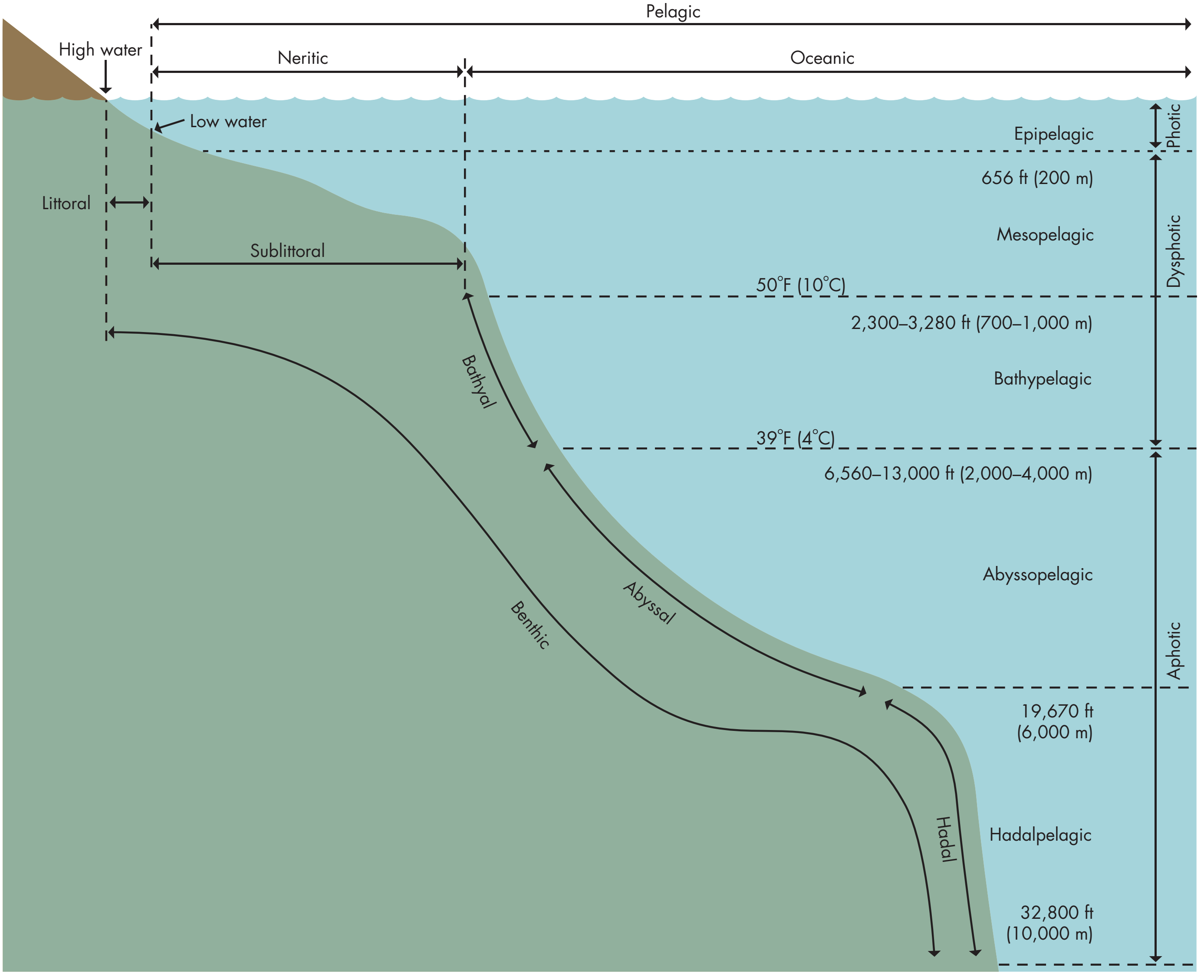
Ocean depth zones



Ocean zones

The oceanic waters above the abyssal plain are divided into zones that correspond to the seafloor topography. The epipelagic region corresponds with the euphotic zone. The dysphotic waters are the mesopelagic region. Below this we enter the aphotic zone. The open waters down to the depth of the bottom of the continental slope or thereabouts are described as bathypelagic. Below this depth the water is uniformly cold. It is at its densest around 39°F (4°C), and water of this temperature accumulates below around 13,000 ft (4,000 m) down, creating an eerily still layer known as the abyssopelagic realm. However, the ocean does not end there. There is deeper water still.

OPPOSITE | A deep submarine canyon plunges through the continental shelf just off the shore of Monterey, California. This connection to deep water means this area of sea is full of life.

ABOVE | A diagram outlining the profile of the seafloor as it extends out and down from the coast, as well as the zones of water above.

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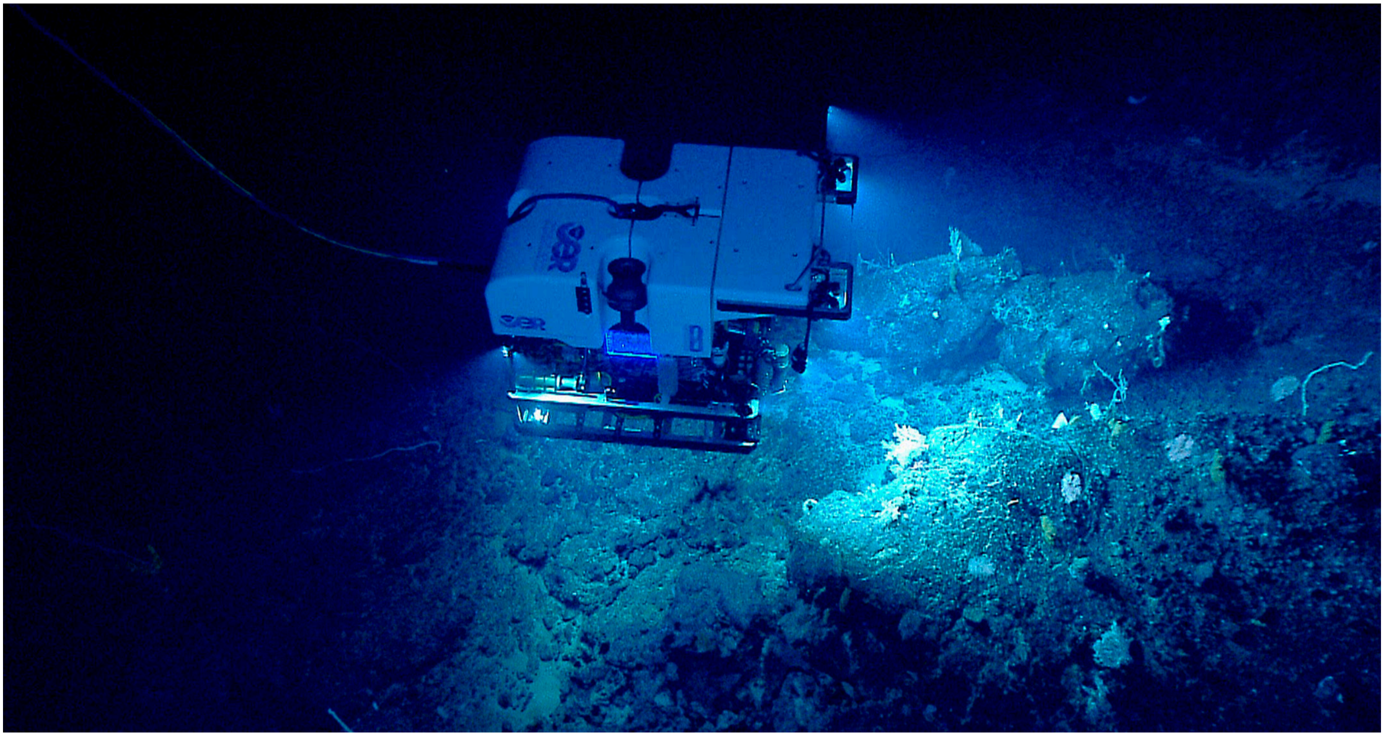

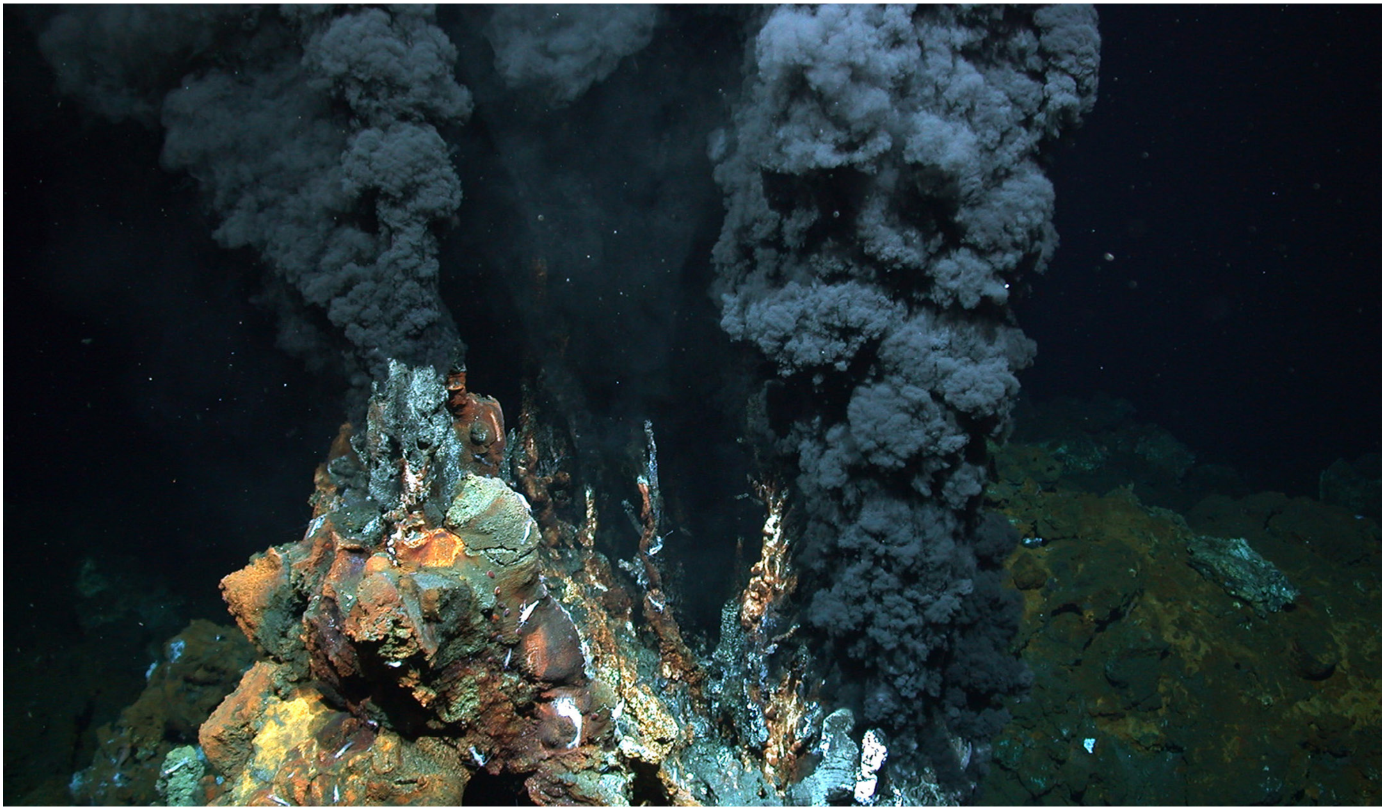

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