BBC OCEANS

The Open University

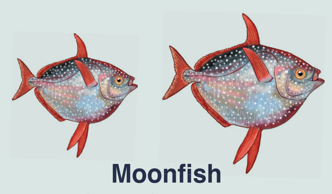
Our oceans dominate Earth's natural systems. They control the climate and the carbon cycle, produce half of all the oxygen we breathe and support an astounding diversity of life.

Diversity of life

Covering almost three-quarters of the Earth's surface, the world's great oceans are home to an incredibly diverse web of life. The World Register of Marine Species currently lists just under a quarter of a million species, with new ones being identified all the time. But even as we begin to discover the astonishing diversity of life and gain insight into their behaviour and physiology, human activity is becoming an increasing threat to the oceans and the life within them.

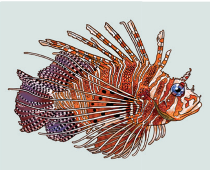
Dugong
Dugong dugon

Dugongs are more closely related to elephants than to marine mammals such as whales and dolphins. They belong to a group of African mammals known as the Afrotheria. This group contains the dugong, manatee, elephant, aardvark, hydrax, elephant shrew, golden mole and tenrec.



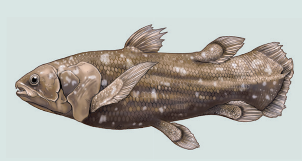
Moonfish
Lampris guttatus

Thought to be the first-known warm-blooded fish, the moonfish is able to keep its entire body core, including its heart, a constant 5˚C warmer than the surrounding water. This allows the fish to dive to great depths and remain there for long periods without having to return to the surface to warm up.



Red lionfish
Pterois volitans

Much about the venomous lionfish's appearance conveys a sense of danger – from its red and white zebra stripes to its long, elaborate pectoral fins. Its venom is delivered, for purely defensive purposes, via an array of needle-like dorsal fins. A sting is extremely painful to humans, but is rarely fatal.



Coelacanth
Latimeria chalumnae

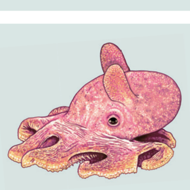
These primitive-looking fish were thought to have died out with the dinosaurs 66 million years ago. But scientists discovered these 'living fossils' in 1938, of which only two known species exist. Coelacanths represent an early step in the evolution of fish to land-based, four-legged animals like amphibians.

Sperm whale
Physeter macrocephalus

These giant mammals possess the largest brain of any animals that have ever lived on Earth. Their head contains an oily fluid (which hardens when cold) that regulates their buoyancy during diving and rising in search of food. They can dive to around 1 km depth by holding their breath for 90 minutes.

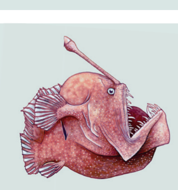
Gulper eel
Eurypharynx pelecanoides

The name of this bizarre looking eel derives from its abnormally large mouth, which is much larger than its body. Its jaw is loosely hinged, so it can open wide enough to swallow an animal much larger than itself. The eel also has a pink light-producing organ that it uses to lure prey towards its enormous mouth.



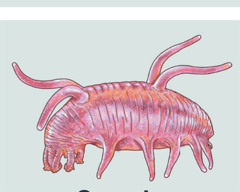
Dumbo octopus
Grimpoteuthis bathynectes

'Dumbo octopus' refers to an entire genus of deep-sea umbrella octopuses, comprising at least 15 species. Their name derives from their fins, which resemble the ears of Disney's Dumbo the elephant. All live at extreme depths of 3000 m to 7000 m making this group the deepest living of all known octopuses.



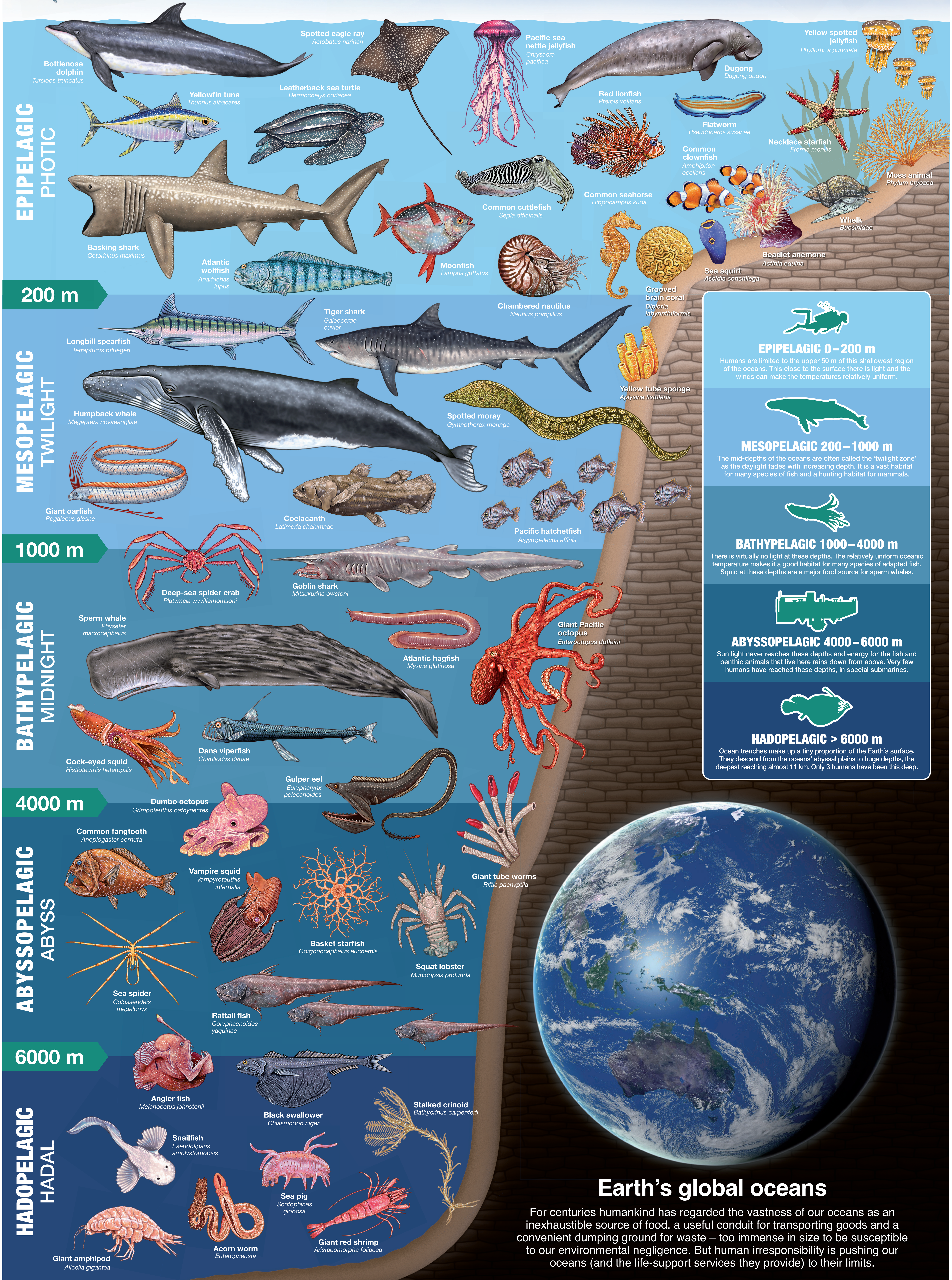
Angler fish
Melanocetus johnstonii

The female angler fish is recognised by a long spine resembling a fishing pole with a lit end, which is used to attract prey. Their large mouth and flexible body allow them to swallow prey twice their own size. A female may host up to six males on her body. The males eventually fuse with her after losing all their internal organs except testes.



Sea pig
Scotoplanes globosa

Sea pigs are a type of sea cucumber, and are restricted to deep, cold parts of the ocean where they are the dominant animals. They have five to seven pairs of enlarged tube feet that are hydraulically operated and serve as legs, allowing them to 'walk' along the sea floor.



EPIPELAGIC 0–200 m

Humans are limited to the upper 50 m of this shallowest region of the oceans. This close to the surface there is light and the winds can make the temperatures relatively uniform.

MESOPELAGIC 200–1000 m

The mid-depths of the oceans are often called the 'twilight zone' as the daylight fades with increasing depth. It is a vast habitat for many species of fish and a hunting habitat for mammals.

BATHYPELAGIC 1000–4000 m

There is virtually no light at these depths. The relatively uniform oceanic temperature makes it a good habitat for many species of adapted fish. Squid at these depths are a major food source for sperm whales.

ABYSSOPELAGIC 4000–6000 m

Sun light never reaches these depths and energy for the fish and benthic animals that live here rains down from above. Very few humans have reached these depths, in special submarines.

HADOPELAGIC > 6000 m

Ocean trenches make up a tiny proportion of the Earth's surface. They descend from the oceans' abyssal plains to huge depths, the deepest reaching almost 11 km. Only 3 humans have been this deep.

Earth's global oceans

For centuries humankind has regarded the vastness of our oceans as an inexhaustible source of food, a useful conduit for transporting goods and a convenient dumping ground for waste – too immense in size to be susceptible to our environmental negligence. But human irresponsibility is pushing our oceans (and the life-support services they provide) to their limits.

To discover more about oceans visit **www.open.edu/openlearn/blueplanet**

OCEANS

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PLASTIC OCEANS

The demand for plastic continues to grow but its durability – the key characteristic that makes plastic so popular – is also the reason why it is so widespread in the oceans. Plastic debris in our oceans is emerging as a new, truly global challenge and one that requires a response at local, regional and international levels.

THE CHALLENGE

Global production of plastics is rising – in 2015 global plastic production exceeded 320 million metric tons. A 2015 study estimated that 275 million metric tons of plastic waste was generated in 192 coastal countries in 2010, and between 4.8 and 12.7 million tons of it ended up in the ocean as a result of poor waste management. The study also predicted that, without waste management improvements, the quantity of plastic waste entering the ocean from land will increase by an order of magnitude by 2025, resulting in 1 ton of plastic for every 3 tons of fish.

Although there is substantial concern about macroplastic debris (comprising, among other things, fishing nets, plastic bags, and drinks containers), recent research highlights the growing presence and abundance of microplastics in marine environments. These plastic particles can be as small as a virus, and are now found worldwide, from the Arctic to the Antarctic, on beaches, in surface waters and in deep-sea sediments. It is estimated that, on average, every square kilometre of the world's oceans has 63,320 microplastic particles floating on the surface and in some places concentrations can be 27 times higher.

Where do microplastics come from?

Some microplastics in the ocean result from the incomplete degradation of larger plastic pieces. However there are several other sources. These include microbeads found in skin cleansers, toothpaste and shaving

cream; abrasives used to strip paint and/or remove rust from buildings, cars, ships and aircraft; fibres from synthetic fabrics (more than 1900 microplastic fibres are released from a single synthetic garment in just one wash); and the mechanical abrasion of car tyres on roads.

So why should we care?

Plastics adversely affect terrestrial and marine ecosystems at both the macro and micro scales. Nearly 700 marine species have been reported to either ingest and/or become entangled by plastic. This includes almost 50 per cent of all seabirds, sea snakes, sea turtles, penguins, seals, sea lions, manatees, sea otters, fish and crustaceans. The effects can be fatal but may also have sub-lethal consequences, compromising their ability to catch and digest food, escape from predators, maintain body condition and migrate. Plastics contain chemicals (added to increase their durability) that, when eaten, leach out and disrupt normal hormonal function. Microplastics also absorb a wide array of organic and inorganic pollutants from the surrounding environment. Their large surface-area-to-volume ratio means they concentrate organic pollutants and can be up to six orders of magnitude more contaminated than sea water. Ingestion of microplastics by marine zooplankton at the bottom of the food chain is magnified in organisms higher up the food chain, where toxins accumulate and concentration is increased.

OCEAN FACTS

Why do seabirds eat plastic?

Seabirds such as albatrosses, shearwaters and petrels are known as tube-nosed seabirds. They fly vast distances to find their food and mainly use smell to locate it. They feed on squid, fish and krill. Dimethyl sulphide (DMS) is a chemical that is released from the cells of marine alga when krill eat it. DMS therefore serves as an olfactory cue alerting the birds to the presence of krill.

A new study has shown that tube-nosed seabirds swallow large amounts of plastic compared to other birds because plastic debris coated with algae has a high level of DMS associated with it and so smells like food to the birds.

CLIMATE WARMING & OCEAN CIRCULATION

One of the most worrying and widely anticipated impacts of ongoing global warming is a weakening or collapse of the oceans' overturning circulation. This vast system of oceanic currents plays a major role in maintaining our regional climates and our oceans' biological productivity by transporting enormous volumes of heat, salt, nutrients and carbon around the planet.

POLAR SINKING

The Arctic Ocean between Greenland and Norway, and the Southern Ocean around Antarctica, are both areas where cooling and higher salinity make the seawater at the surface dense enough to sink into the abyss to form the descending currents of the oceans' global circulation system. Predictions are that global warming will cause surface ocean waters in these polar regions to become warmer and less dense (more 'buoyant') and thus less likely to sink. A stronger hydrological cycle, coupled with ice sheet melting, will lower the salinity of polar surface waters, which will also increase the buoyancy of surface waters. All these factors could weaken the oceans' overturning circulation or even make it collapse.

Ice sheet melting

Global warming is melting Earth's ice. Arctic sea ice is thinning dramatically and its geographic extent is shrinking too. The Greenland ice sheet is also shrinking, shedding nearly 300 billion tons of water a year into the North Atlantic. The West Antarctic ice sheet is also melting and showing signs of becoming increasingly unstable. As well as raising global sea levels, this melting will weaken deep ocean circulation by adding huge volumes of fresh water into the polar ocean surface, thus increasing its buoyancy and reducing its capacity to sink. While the Antarctic ice sheet is not experiencing as much net melting as Greenland, its surface waters are nevertheless becoming more buoyant

because of climate warming and a stronger hydrological cycle delivering more fresh water as rain.

Has ocean circulation already started to change?

Ocean circulation in the North Atlantic seems to have slowed in recent decades, but it is currently unclear whether this slowdown has been triggered by climate change or is just part of a normal cycle of faster and slower currents. It is also unclear whether circulation in the Southern Ocean, which circles the Antarctic continent, has started to change yet, although its surface waters have warmed substantially.

The past as a guide to the future

The big question is: when (or) will ocean circulation in the North Atlantic and Southern Ocean switch to new circulation patterns in response to ongoing global warming? We don't yet know. But if circulation does slow or change flow direction, it would have major consequences for regional climates and ocean ecosystems. The past offers us insights into what Earth would look like should the oceans' circulation change. Data from the geological past and computer models both show that if the North Atlantic circulation slows or shuts down, the entire Northern Hemisphere cools, Indian and Asian monsoon areas dry up, and less ocean mixing results in less plankton and other life in the ocean.

OCEAN FACTS

The hydrological cycle

The hydrological cycle describes the large-scale movement of water between Earth's major reservoirs: atmospheric water vapour (e.g. clouds), rain water, fresh water, ice sheets, sea ice and saline ocean water. The broad pattern on Earth is that ocean water is evaporated from the warm ocean surface in the tropics, is carried polewards by the major wind systems, and finally falls as rain (or snow) in polar regions. A warmer climate will strengthen this water cycle, causing more rainfall nearer the poles, and thus greater buoyancy in polar surface waters, reducing their sinking capability and potentially slowing down the deep ocean conveyor circulation.

FUTURE OF THE CARBON CYCLE

Concentrations of carbon dioxide (CO_2) in our atmosphere continue to rise at an astronomical rate. But even more disturbing is that the rate of change in CO_2 levels is entirely unprecedented in Earth's history. We therefore have little knowledge of how our planet, and our oceans in particular, will cope with this ever-increasing burden of greenhouse gas.

THE CO_2 PROBLEM

In the spring of 2014, for the first time in human history, and probably the first time in the last 2.5 million years, atmospheric levels of the greenhouse gas CO_2 exceeded 400 parts per million. This has been driven primarily by the burning of fossil fuels, with contributions from other industrial activities. Prior to the Industrial Revolution, CO_2 concentrations were about 270 parts per million, and had been consistently at that level for the 10,000 years of warm climate that humanity has experienced since the end of the last Ice Age. Yet, at 400 parts per million, we now find ourselves further from this average level for our warm climate of the last 10,000 years than this average level was from the depths of the last Ice Age. This underscores just how much we have already altered the greenhouse gas composition of our atmosphere, with major implications for our future climate and oceans.

Can the oceans bail us out?

Today, there is 60 times more carbon in the deep ocean than in the atmosphere. It is for this reason that one of the main controls on the CO_2 levels in the atmosphere is how much carbon is stored in the deep ocean. This huge reservoir of oceanic carbon means that the oceans may be able to help us out of our ever-worsening CO_2 problem. They have absorbed at least one-quarter of the excess CO_2 generated by human activities. But scientists think that the oceanic CO_2 sink may be slowing, partly because CO_2 has been accumulating in the upper ocean, which is now becoming saturated.

Rate of change is crucial

The rate at which CO_2 is released from fossil fuels will determine how much of this CO_2 can be absorbed by the oceans. Too fast a release and the oceans' natural CO_2 sinks will not be able to keep pace. Already the rate of release is overwhelming the capacity of upper ocean sinks to absorb it all. Over long timescales of 1000 years or more, our CO_2 pollution will gradually be transferred into the deep ocean, but this is a slow process as it occurs only in isolated polar regions where surface waters sink into the abyss, carrying their CO_2 burden with them. Eventually, over timescales of 1000 to 10,000 years, this excess CO_2 will be neutralised by reaction with abyssal sea-floor sediments. But can we wait that long?

Carbon capture

One solution to our CO_2 problem is obviously to burn less fossil fuels, but that doesn't seem likely to happen any time soon. Even if we could stop the burning of fossil fuels tomorrow, we still need to try to remove the CO_2 that we have already put into the atmosphere. Since the 1990s, scientists and engineers have been working on methods to remove CO_2 from the atmosphere and reduce the severity of future climate change. These methods involve using: (a) naturally occurring molecules, which react with CO_2 to form carbonate minerals that capture and store CO_2 in solid form; and (b) small devices termed 'CO_2 scrubbers', which aim to replicate the process by which CO_2 is removed from the air by leaves.

OCEAN FACTS

Where is the warming?

CO_2 is a powerful greenhouse gas in our atmosphere, meaning that it allows incoming sunlight to reach the Earth's surface, but blocks outgoing heat from escaping into space. Yet, if CO_2 is such a powerful greenhouse gas, where is the extreme warming that should have accompanied the extreme increase in recent CO_2 levels? The main reason that soaring CO_2 emissions have not caused air temperatures to warm more than 1°C thus far is that oceans have soaked up nine-tenths of the heat. But the oceans have a finite heat absorption capacity, so when this capacity becomes saturated, we may start to belatedly experience a level of atmospheric warming commensurate with our soaring CO_2 levels.

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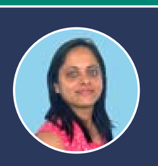

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OCEAN ACIDIFICATION

Our oceans are currently absorbing half of the carbon dioxide (CO_2) emitted by burning fossil fuels. This absorption is increasing ocean acidity, threatening the survival of marine organisms and their habitats, and affecting our oceans' health. If the continuing rise in emissions are not controlled, ocean acidity will reach 150 per cent by the next century.

THE OTHER CO_2 PROBLEM

Oceans are absorbing additional CO_2 emitted to the atmosphere from the burning of fossil fuels. The absorption of CO_2 increases the oceans' acidity through a series of chemical changes and reduces the availability of molecules essential for calcium carbonate shell formation. Also, oceans' ability to hold CO_2 is affected by temperature. Cold water holds more CO_2 than warm water, and because the oceans are warming rapidly, their ability to absorb CO_2 in the future is going to be severely hampered. As a result more CO_2 will remain in the atmosphere, further increasing Earth's temperature. In short, ocean acidification is caused by rising atmospheric CO_2, which increases oceans' acidity and reduction in essential ions required for shell formation, with potentially devastating consequences for marine ecosystems and our planet.

Dissolving shells

When carbon dioxide dissolves in the ocean it produces carbonic acid, which, in addition to making the ocean more acidic, also binds up with carbonate ions, essential building blocks for shell formation. The reduced availability of essential shell-forming ions means investment of more energy in shell formation at the expense of other essential activities, overall hampering growth in organisms such as corals, oysters, clams and mussels. Many species of plankton are making thinner carbonate shells and their fate is particularly important because they form the base of

marine food webs. Shell-forming marine creatures face two potential threats from ocean acidification: they are unable to build robust shells and their shells dissolve more readily as the ocean acidifies and becomes more corrosive.

Acidity and ecology

Continued ocean acidification will result in coral reefs corroding faster than they can be rebuilt, threatening their long-term viability and that of the estimated one million species that rely on them for survival. Other ecological impacts of acidification on marine organisms include reductions in the spawning and larval growth of fish, the oxygen-carrying capacity of blood in squid and predator-avoidance behaviour in sea urchins and fish. In contrast, plants and many algae (including seaweeds and sea grasses) may flourish in a high CO_2 world. However, future increases in coastal pollution may counteract this potential benefit.

Neutralising acidity

The current rise of atmospheric CO_2 and its impact on ocean acidity does not allow sufficient time for organisms and ecosystems to adapt. To alleviate this pressure, reduction in global CO_2 emissions and ocean acidity are required. Ideas being explored include addition of neutralisers to the oceans, and the capturing and safe storage of atmospheric CO_2. These positive steps are essential for saving our oceans, upon which we depend for food, natural resources and recreation.

OCEAN FACTS

Unprecedented change

Fifty-six million years ago the oceans became so acidic that many marine organisms died out, in particular organisms with carbonate shells. However, some surface-dwelling plankton species and other animals survived and the oceans slowly recovered over hundreds of thousands of years. So why should we be so concerned about the ocean acidification that is happening today? One big difference is that, back then, acidification of the ocean happened over a period of thousands to tens of thousands of years. This gave some organisms a chance to adapt and allowed ocean sediments to neutralise the extra acidity. Today's acidification rate is at least 10 times faster than 56 million years ago.

INVISIBLE PLANKTON

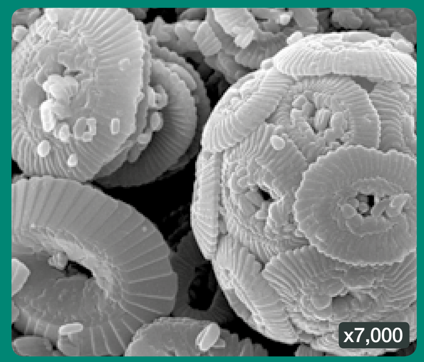
Marine phytoplankton are the foundation of oceanic biological productivity, supporting complex marine food webs, and are a vital component of life on Earth. Using energy from the sun, they absorb as much carbon as all the trees and other plants on land, through photosynthesis. They also produce half of all the oxygen that we breathe.

THE 'INVISIBLE PLANTS' OF THE OCEAN

Marine plankton consist of microscopic algae and bacteria (phytoplankton) and animals (zooplankton). Phytoplankton form the base of marine food webs. They are eaten by zooplankton – thousands of species of tiny animals, some of which are the larval forms of larger animals. Zooplankton, in turn, become meals for larger predators, ranging from small fish to enormous whales. Like land plants, phytoplankton have chlorophyll and, through photosynthesis, they use sunlight, nutrients and carbon dioxide to produce organic carbon compounds in the form of soft tissues, releasing oxygen as a by-product.

A biological pump

Organic matter and shells of calcifying plankton settle to the ocean floor when phytoplankton and calcifying plankton die. Organic matter is lighter than seawater so its vertical transport is through adsorption at the surface of other falling particles such as shell fragments, dust, sand and faecal matter. These falling particles of dead plankton and other organic materials are called marine snow because they resemble snowflakes falling from the upper ocean. The majority of marine snow disintegrates during the journey to the ocean floor, with only 1 per cent making it to the deep ocean where it provides food for many deep-sea creatures that filter it from the water or scavenge it from the ocean floor. The small percentage not consumed is incorporated into ocean floor sediments.



About three-quarters of the deep ocean floor is covered by sediment that can reach thicknesses of over a kilometre. In this way, marine snow transports carbon captured at the ocean surface into the deep and is part of a biological 'carbon pump'. If the pumped carbon dissolves in deep waters, it is locked away for hundreds or thousands of years, whereas if this carbon becomes buried in the sediment, it is locked away for millions of years.

Plankton in future oceans

Hundreds and thousands of species of phytoplankton live in Earth's oceans, each adapted to particular seawater conditions. Changes in water temperature, clarity, nutrient content and salinity affect both the diversity and abundance of phytoplankton communities. In response to trends in increasing ocean temperatures and acidity, the diversity of phytoplankton communities is also changing, becoming more diverse in the polar regions and less diverse in the tropics. Phytoplankton are also changing in abundance and hence productivity. As surface waters warm, there is less vertical mixing to recycle stored nutrients from deep waters back to the surface. The complex effects of these changes on marine food webs, carbon capture and oxygen production is not yet clear, but they could result in a cascade of negative consequences throughout the marine ecosystem that may ultimately threaten the abundance and diversity of all life in the ocean.

OCEAN FACTS

A vital role

Phytoplankton form the foundation of marine ecosystems and carry out half of all photosynthesis on Earth. Half of all the oxygen in our atmosphere comes from oceanic photosynthesis. In addition to providing us with oxygen, oceans remove a substantial amount of carbon dioxide created by human industrial activity, making them a crucial component in the battle to slow human-engineered climate change. Future warming of the oceans will not only threaten phytoplankton growth (due to limited availability of nutrients), but also risk the health of marine ecosystems, including our fisheries.

MARINE CONSERVATION

Today the oceans face many challenges from extensive human impacts. We have used the oceans for fishing, trade, communication and warfare and, as the Earth's population has increased from ~1 billion in 1800 to more than 7.5 billion today, so the pressures have increased – particularly on fishing.

FISHERIES

Fishing is often described as 'harvesting the oceans', but it is different from farming. What farmer would knowingly deplete his stock without ensuring there was a reliable supply of replacement animals? Fishing in the recent past has resembled the large-scale unsustainable slaughter of the herds of buffalo on the North American plains, and marine ecosystems worldwide are paying the price.

Human impacts on marine environments

As human population has increased, so has the pressure on fish stocks. Unfortunately, 'stocks' implies there are large supplies of available fish, and this is often not the case. Pressure on fish stocks has increased as humans have moved from fish traps thousands of years ago to factory ships today, which catch and process large quantities of fish while still at sea. The result has been significant overfishing of some species over the last century. For example cod, once abundant in the North Atlantic, has been so depleted that current fishing is heavily restricted. Another issue is so-called 'bycatch', when trawlers catch a species that they do not want. Historically, this bycatch was discarded and, because the fish were killed, there is an additional impact on the ecosystem. This impact includes the fish not being a food source for other species.

Managing fisheries

The UN Law of the Sea treaty determines where states can fish, but the treaty is not

binding on states that have not ratified or acceded to it, such as the USA. Fish are mobile and at different points in their life cycles they can pass through the legal responsibility of many states. This makes managing marine stocks challenging. Many states claim exclusive fishing rights to the full 200 nautical miles of their exclusive economic zone (or a line between them where states are closer than 200 nautical miles apart). Good management limits the amount of fish caught so that no species is over-exploited and the overall ecosystem does not decline. Today, many experts believe that in many cases we must aim to allow fish populations to rise, even if that means reducing our current exploitation rates.

Marine protected areas

We can restrict human activities, such as commercial fishing and mineral development, by using the laws. We can create marine protected areas (MPAs) to limit shipping and reduce both local pollution and acoustic noise. But do they work? Studies of MPA effectiveness have shown they consistently improve biodiversity (the number of species present), and fish numbers within them are higher too. How much human activity can be restricted depends on whether the MPA is in international waters, the exclusive economic zone or territorial sea. The largest MPA is currently an area of 1.5 million square kilometres of the Ross Sea in Antarctica (about 6 times the area of the United Kingdom). About 2 per cent of the oceans are protected by MPAs, and there are plans to expand this.

OCEAN FACTS

The United Nations Convention on the Law of the Sea (UNCLOS)

Coastal states have a territorial sea out to 12 nautical miles (1 nautical mile = 1.852 km) where they set and enforce laws and can use any resource. The measurement is from a notional base line. For a further 12 nautical miles, states can enforce a contiguous zone, which is important for immigration, pollution, customs and taxation. For 200 nautical miles from the baseline, states have an exclusive economic zone (EEZ) where they have rights over natural resources. Outside this are international waters (or high seas) where no state is in control. Where states are closer than 200 nautical miles apart, boundaries lie at the mid-point between them. This is called the median line.