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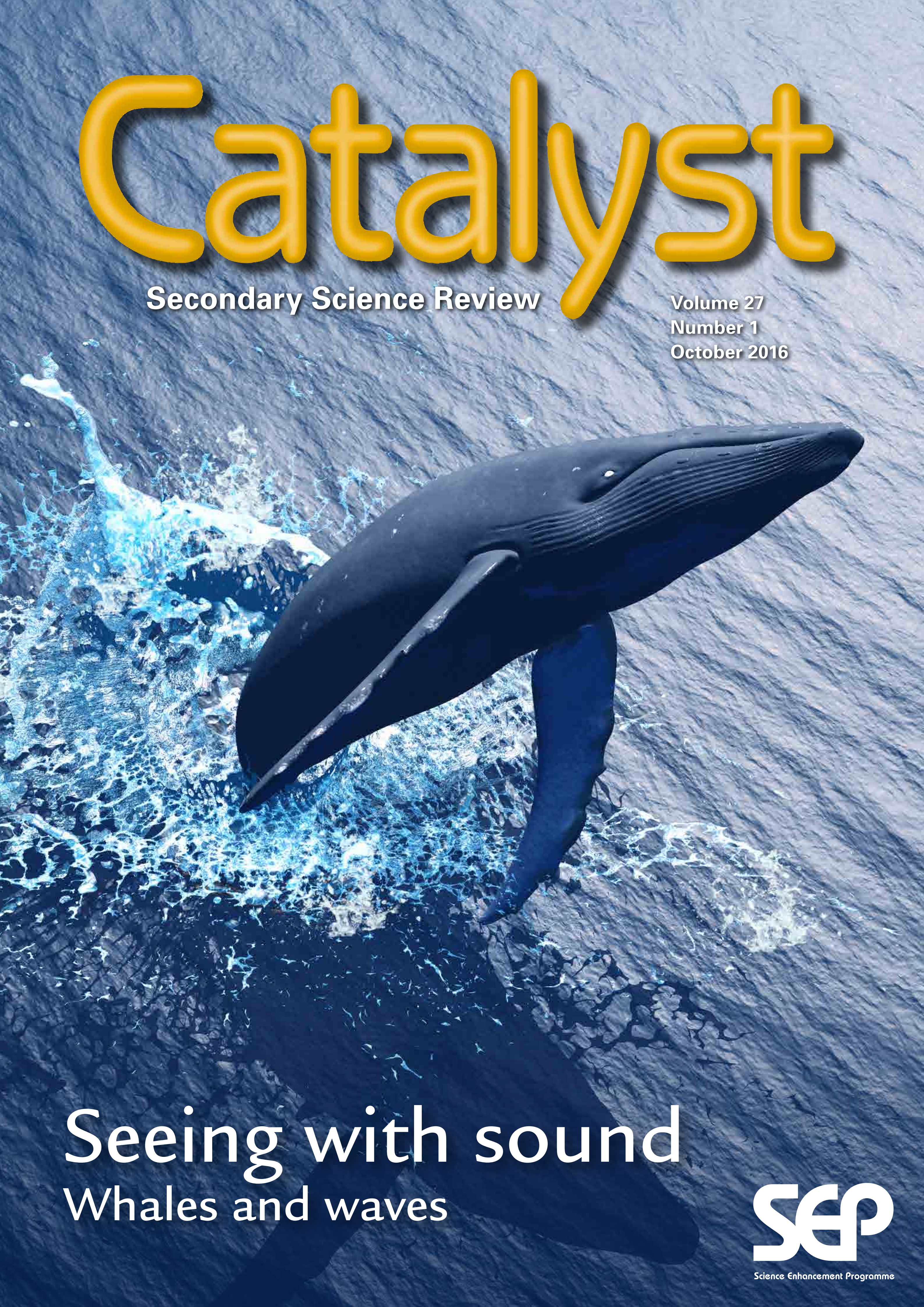

Seeing with sound
Whales and waves

SEP
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Catalyst

Volume 27 Number 1 October 2016

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The cover image shows a whale leaping from the ocean. Sperm whales dive to great depths where light cannot penetrate, so they must use sound to detect their prey and each other. (Photo: 1971yes/Bigstock)

All at sea

Whales are fascinating creatures. We are only gradually coming to understand how they use sound to communicate with each other and to detect their surroundings in the ocean depths. As Russell Arnott describes on pages 1-3, noise pollution has radically changed the environment in which whales swim.

Another form of pollution is building up in the sea – plastic waste. Polymer beads are increasingly being used in commercial products including cleaning materials and cosmetics. Vicky Wong describes how this problem is being tackled on pages 16-18.

Alien species can also damage an ecosystem. Over 750 non-native plant species have been recorded on the Galápagos Islands. The impact of one, the hill raspberry, is explained on pages 19-21.

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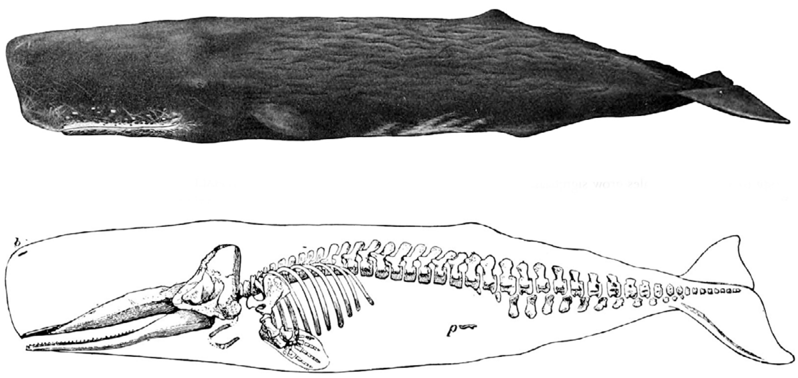
Russell Arnott

Key words
whales
electromagnetic waves
sound waves
decibels

Whales and waves

Humans use waves for all kinds of things. The waves that we are most familiar with are light and sound. Since humans evolved, we have used **visible light** to see (as this is the wavelength of light that penetrates furthest through our atmosphere) and **sound waves** to talk to and listen to each other. As our scientific knowledge has advanced, we have gone on to discover the entire **electromagnetic spectrum** of light. When Heinrich Hertz discovered radio waves in 1887, he stated of his discovery, "*It's of no use whatsoever.*" Of course we now use radio waves and microwaves to send information all over the globe at the press of a button.

But what if it was possible to talk to another person on the other side of the planet without needing a mobile phone or the internet? As the loudest creatures on Earth, this is what sperm whales can do.



This illustration, drawn by Richard Lydecker in 1894, shows how the sperm whale's skeleton fits inside its body.

Despite having a name that incites awkward laughter in teenagers across the world, sperm whales are not named after the amount of semen that they produce. When one was caught by an American whaling boat in 1712, the crew opened its head to find 500 gallons of 'sperm-like' spermaceti oil which they then believed to be its 'seed'. For over a hundred years, almost every light on Earth was lit using this whale oil until we discovered how to distil crude oil in the 1860s.

Seeing in the dark

So why do sperm whales have this vast amount of oil inside their heads? It is thought to be used for two purposes: firstly, as a means to alter the whale's buoyancy, helping it dive to depths of 2500 m and return to the surface to breathe; secondly, the spermaceti organ acts as a vast resonance chamber allowing the whale to send and receive sound waves for **echo-location**.

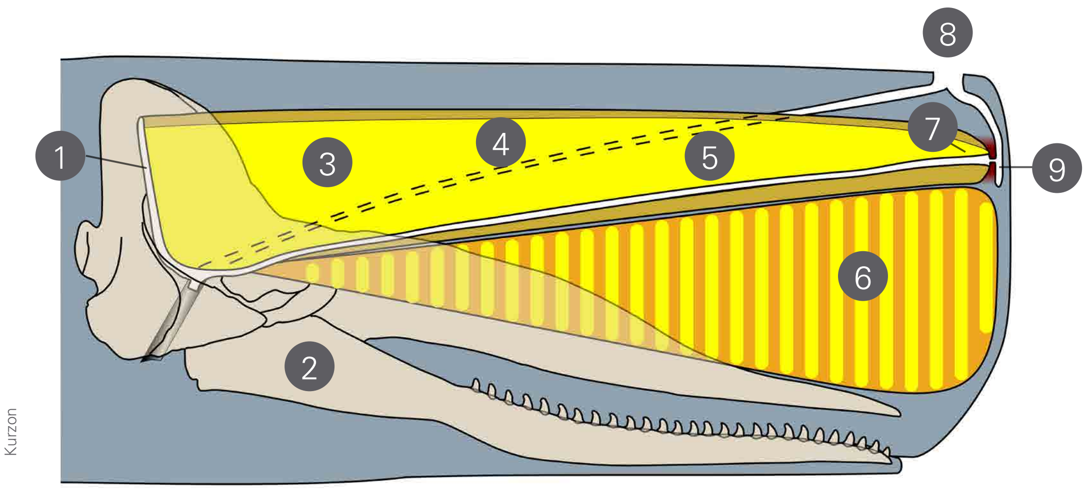
At just 100 m under water, 99% of the surface light has been absorbed. There is next to no light at depths of 2500 m where sperm whales hunt. As such, they have evolved to see in sound as well. The whale emits a pulse of sound into the water. When this sound hits an object, it is reflected back to the whale. Highly intelligent, the whale can work out how far away the object is by timing how long the sound pulse took to reach the object and return. If an object is close to the whale, the timing of this echo will be small; if an object is far away, the sound will take longer to reach it so the echo will be longer also.

Steve Backshall, naturalist and adventurer, gets close to a sperm whale.

Not only can whales use sound to work out how far away an object is but they can also tell what an object is made from, what shape it is, how fast it is moving and in what direction! New research from the DAREWIN Institute postulates that once a whale has obtained an image of an object using sound, it can then send a holographic image of what they saw to another whale using sound. That's like sending a 3D-picture to your friend using only your face.

Sperm whales also have one of the largest frequency ranges out of any animal on Earth. The hearing range of a human is limited to 20 Hz up to 20 000 Hz. Humans are unable to hear any sound outside of this range so frequencies under 20 Hz are classed as **infrasound** ('*below sound*') and any frequency above 20 000 Hz is known as **ultrasound** ('*above sound*'). By comparison, sperm whales have a vocalisation and hearing range as low as 0.2 Hz and up to 32 000 Hz. So just as medical professionals use high-frequency ultrasound to view inside the human body, divers who swim with sperm whales have reported instances where they have been 'probed' by sound as the whales view inside them using sound to work out whether they are worth eating (luckily they weren't)!

1 frontal sac	6 junk (melon)
2 lower jaw	7 phonic lips
3 spermaceti organ	8 blowhole
4 left nasal passage	9 distal sac
5 right nasal passage	



The sperm whale produces clicks using its phonic lips (7). The sound travels back through the spermaceti organ (3) and then reflects forwards through the melon (6), an organ which focuses the pulses of sound into a narrow beam. Reflected pulses are detected by the lower jaw (2) which connects to the whale's hearing organ.

Increasing noise from human activities including shipping has interfered with whales' ability to communicate with each other over long distances.

Louder and louder

But we still haven't even touched on how *loud* sperm whales are. Sound energy is measured in **decibels (dB)**. The more energy that is carried by a sound, the higher the decibel level. Normal human conversation clocks in at around 65 dB while noisy roadworks can be as high as 95 dB (the level at which you may start to experience damage to your hearing). If you've ever been to a loud rock concert or club night, you will have been exposed to around 115 dB and probably had ringing in your ears (tinnitus) the next day. At 125 dB pain begins and the scale keeps going up to 194 dB, the loudest sound possible in air. Any louder than this then the sound becomes so distorted that it becomes a pressure wave. However, because water is **denser** than air, it is capable of allowing louder sounds to propagate through it. Sperm whale clicks as loud as 236 dB have been recorded; this is louder than a ton of dynamite exploding or a rocket taking off. In fact, sperm whales have the potential to produce a sound so loud that it would not only completely blow your ear drums but could in fact vibrate your body to death. It is not unheard of for divers to have been knocked unconscious by sperm whale clicks.

A sperm whale and a diver investigate each other.

But despite having these amazing sonic abilities, whales and dolphins around the world are becoming victim to ocean noise pollution. Ships' motors, drilling for oil, naval testing, military SONAR, and oil and gas exploration all add up to produce a cacophony of man-made sounds that interfere with the ability of cetaceans (the collective name for whales, dolphins and porpoises) to use sound. At the very least, the noise acts as an irritant causing them to behave unnaturally, driving them away from feeding areas. Louder sounds can not only cause entire pods to strand on beaches but can also physically harm whales and dolphins. Sound pulses produced from seismic surveying are amplified inside whale and dolphin skulls which can result in permanent brain damage.

As mankind continues to explore our oceans, it is important to be mindful of the other creatures that we share the ocean with. With the largest brain on Earth, it has been suggested that sperm whales are at least as intelligent as humans and have a culture as complex as ours to match. Still recovering from the onslaught of whaling where 60% of the global sperm whale population was destroyed, it would be a shame if our continued actions resulted in their demise when we have only just started learning about these amazing animals.

Russell Arnott is Outreach Officer for WhaleFest

Look here!

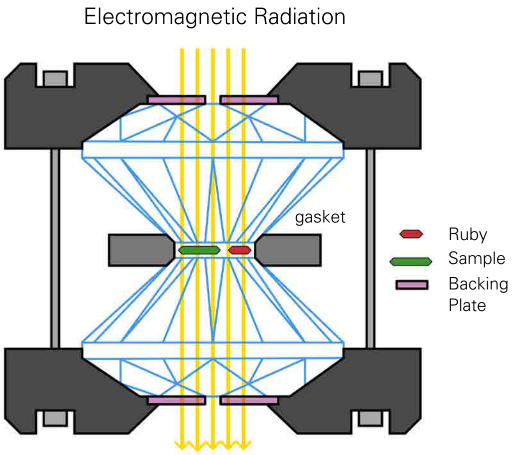
WhaleFest is the largest marine festival on Earth. Last year, it attracted over 15 000 people a day. Incredible Oceans is the educational outreach part of WhaleFest. It aims to teach people of all ages about the marine environment by visiting schools and events across the country: www.*incredibleoceans.org*

Vicky Wong

The bizarre world of high pressure chemistry

Sodium metal is pale grey and shiny when first cut.

What would happen if you put some sodium, normally a soft, pale grey metal, under extremely high pressures? When chemists tried this the results were not as they expected and as yet cannot be fully explained.



A diamond anvil cell; the sample is held between two diamonds; there is also a ruby which is used to indicate the pressure.

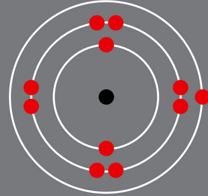
The research was done using a piece of apparatus called a diamond anvil cell. It contains two diamonds and as the screws are tightened it is in between these that the high pressure is created. The pressure between the diamond tips can reach 1000 gigapascals, which is about 10 million times atmospheric pressure. Electromagnetic rays can be passed through the sample chamber to allow measurements to be taken of what is inside.

Using the diamond anvil cell to produce high pressures has allowed chemists to create some new materials including superconductors. They have also allowed some geochemical processes to be examined and have allowed scientists to study what happens to the materials believed to be in the Earth's mantle at the high pressures found there. It is not possible to access the mantle directly so there are few other ways of studying this. Two of the iron oxides in the mantle, Fe_2O_3 and Fe_3O_4, were found to decompose at the high pressures releasing oxygen and forming the very unusual Fe_5O_7 and $Fe_{25}O_{32}$.

When sodium is squeezed to 190 gigapascals it turns from being a pale grey metal to being transparent, with see-through crystals. It also loses another property of metals and instead of being a conductor is now an insulator. The change in properties shows that there is a change in the structure and bonding of the sodium, but the current models used by scientists (like the one in the Box: **Bonding**) are not able to predict what will happen to the bonding when chemicals are subjected to these high pressures. Chemists are now working to try to improve their models, with the hope that they will allow the prediction of possibly useful properties.

Vicky Wong is Chemistry editor of Catalyst.

Bonding



Sodium at room temperature and pressure has a metallic structure. How does this relate to its atomic structure?

Sodium atoms have 11 electrons. Two of these fit into the first energy level, eight into the second energy level with the last in the third energy level. These outer shell electrons are delocalised and can move about in metallic sodium, allowing it to conduct electricity.

Insulating ice cream How to make Baked Alaska

Baked Alaska is an unusual pudding because it contains ice cream which is put into a hot oven. If you follow the recipe carefully then the ice cream does not melt as it is insulated by sponge cake and meringue, allowing it to remain frozen

You will need:

- a sponge cake approx 20 cm in diameter and 2.5 cm thick
- 2-3 tablespoons of jam
- about ½ litre of ice cream
- 3 egg whites
- 175g caster sugar
- ice cream scoop
- tray or dish which can go in the freezer
- oven dish about the same size as the cake
- bowl
- whisk – an electric one is easier
- table spoon and knife
- access to a freezer and an oven

What to do:

Heat the oven to 200°C/gas mark 6.

Allow the ice cream to thaw slightly then put scoops of it into the tray and put it back into the freezer to harden up for about 10 minutes.

Put the cake into the oven dish. Spread jam over the cake with the knife.

Separate the eggs and put the egg whites into a bowl. It is very important that the bowl is clean and dry and that there are no bits of yolk in with the whites or they will not whisk up well.

Begin whisking the egg whites. When they have turned white and puffed up and will stay standing begin to add the sugar. Add a spoonful at a time and whisk in each spoonful before adding another. The egg whites should now be white and glossy. This is the meringue.

This next bit needs to be done quickly. Remove the ice cream from the freezer and put the scoops onto the cake, adding more if you think it is needed. Leave about a 2 cm gap all around the edge of the cake. Cover the ice cream thoroughly with the beaten egg mixture ensuring that there are no gaps at all. If you wish you can swirl a pattern in the meringue, but be quick.

Beaten eggs contain lots of tiny air bubbles which insulate the ice cream.

Place the dish into the oven and leave for 10 minutes. The meringue should be just turning golden.

Serve immediately. When you cut it open you should find the ice cream is still frozen inside the hot meringue.

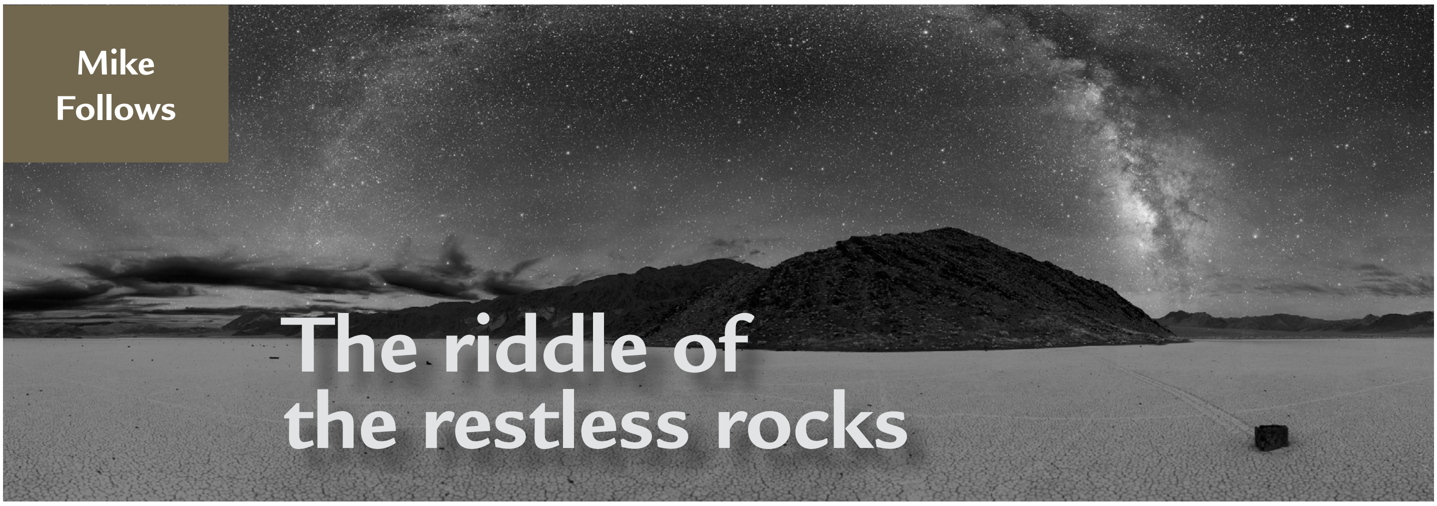
How it works:

When you beat the egg whites, air becomes trapped. You have made a foam, with many tiny air bubbles surrounded by the egg protein. The sugar strengthens the foam. Sponge cake also contains a lot of air. Air is a good thermal insulator – it is a poor conductor of heat.

As you bake the meringue, the ice cream is insulated by both the meringue and the sponge, so the heat from the oven does not have time to reach it.

Vicky Wong is Chemistry editor of Catalyst.

Mike Follows

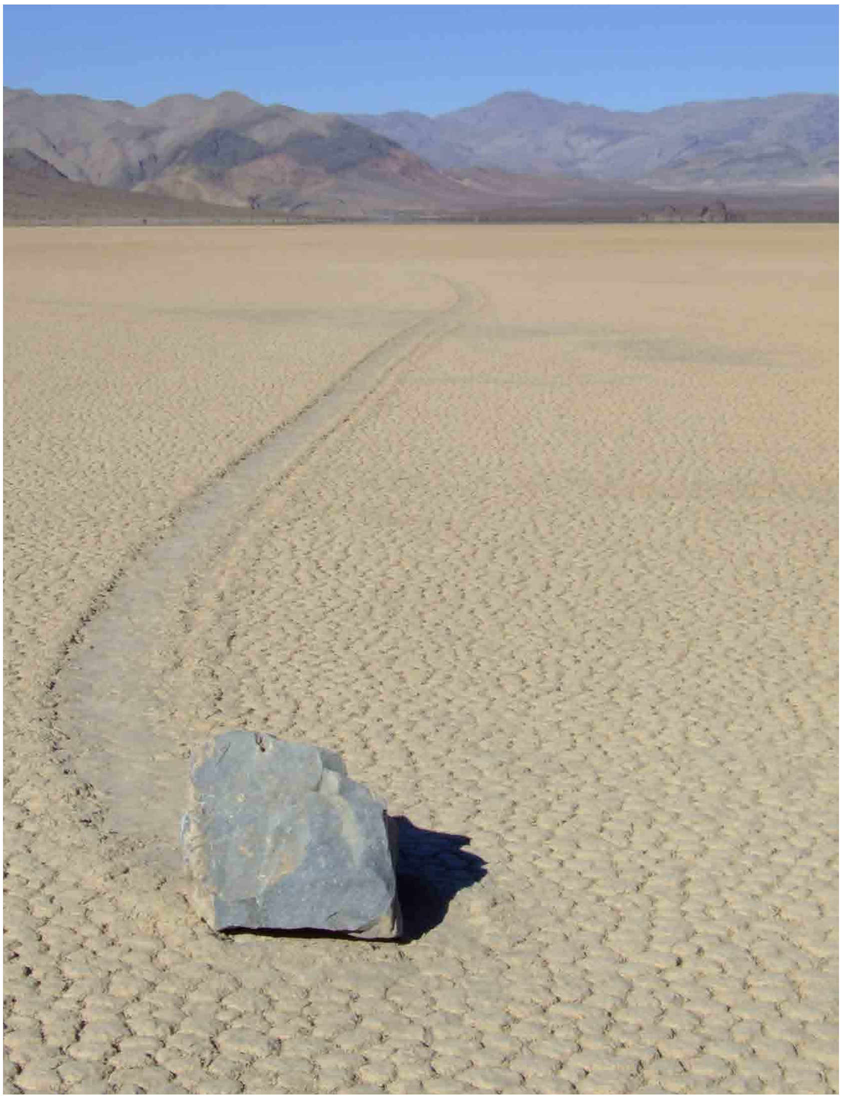


The riddle of the restless rocks

Racetrack Playa seen below the night sky

Key words
weight
upthrust
density
hypothesis

Racetrack Playa in Death Valley National Park, California, is a dry lakebed, very flat and level. It gets its name from the tracks of moving rocks which have slid across its surface. These rocks might have been overlooked except that they show up dark against the very uniform beige-coloured playa and often appear at the end of long furrows ploughed into the playa surface.



This rock has left a clear track as it has moved across the playa.

Racetrack's 'sailing stones' are usually cobbles or small boulders but some have masses of hundreds of kilograms. The dark rocks originate from the ancient dolomite cliffs at the playa's southern end, where frost shattering causes pieces to break away and crash to the ground below, where they embark on their northward journey.

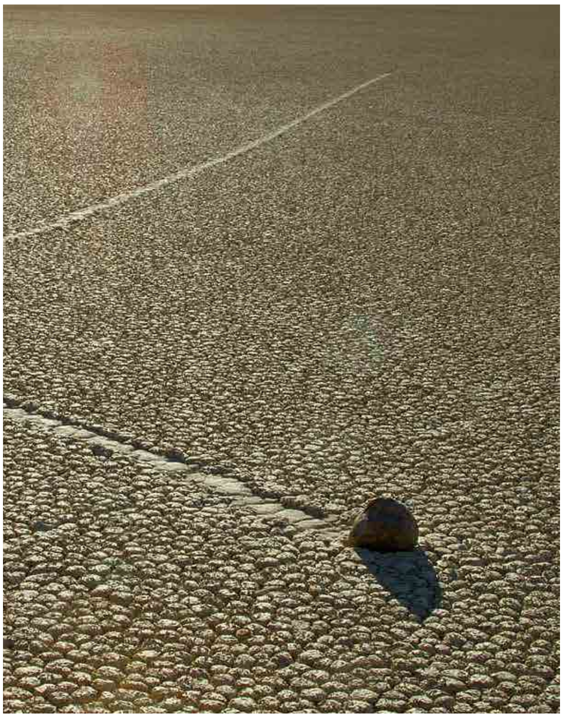
Racetrack Playa is 1130 m above sea-level, where snowstorms are common. The snow melts to produce a shallow pond. This periodic wetting of the surface clay helps explain its extreme flatness, with only a few centimetres of relief across its entire 2 km by 4.5 km area. A prospector named Joseph Crook was the first to witness the movement of the stones when he visited the site in 1915.

Racetrack Playa seen from space

Competing hypotheses

So how do these rocks move? Calculations show that winds at Racetrack are not strong enough on their own to shift them, so people have suggested that friction between the rocks and the ground could be reduced by the growth of slippery algae when the playa is wet. Others have blamed aliens or dismissed the phenomenon as a prank by university students.

In 1955 George Stanley, a geologist at California State University, suggested the rocks might get frozen into large ice rafts which act like big 'sails'. As the air blows over the ice, friction between the air and the ice (known as skin friction) pushes the floating ice along. This is why floating on an inflatable at the beach can be dangerous – a small breeze can push you out to sea.



Did the wind change direction as this stone was sliding?

Laboratory experiments

Ralph Lorenz, a NASA scientist, investigated the 'ice raft' idea in more detail. He suggested that water freezes around the rocks, forming collars of ice that float the rocks off the ground. Reducing the friction between the rocks and the ground, this would allow the rocks to be blown along by light winds.

He tested his idea by pouring a bed of sand into a plastic container. He placed a rock onto the sand and added water until the rock was almost completely submerged. He then placed the container in the freezer. Once the water was frozen, he took out the container and allowed the ice to partially thaw. When he ended up with a small raft of floating ice with the rock embedded in it, he gently blew across the container so that the rock was dragged across the sand, reproducing the furrows observed at Racetrack. But is this model supported by observation?

A student studies the track of a sliding rock.

Field observations

Given that the rocks so seldom move, it wasn't practical to have scientists observing the rocks around the clock. Instead they deployed remote sensing equipment. Ralph Lorenz joined forces with two cousins, James and Richard Norris, who received funding for their Slithering Stones Research Initiative in 2011. They drilled holes into 15 test rocks in order to insert motion-activated GPS receivers. The receivers revealed the speed and direction of the rocks, which could be compared to data recorded by their nearby weather station. As well as temperature and rainfall, wind speed and direction data was collected at one-second intervals. By the end of 2013 they added wind-triggered time-lapse photography. The cousins happened to be present at Racetrack on 20 December 2013 when they actually observed more than 60 rocks moving. Some rocks moved a staggering 224 metres between December 2013 and January 2014.

A GPS receiver being installed in a rock

Results

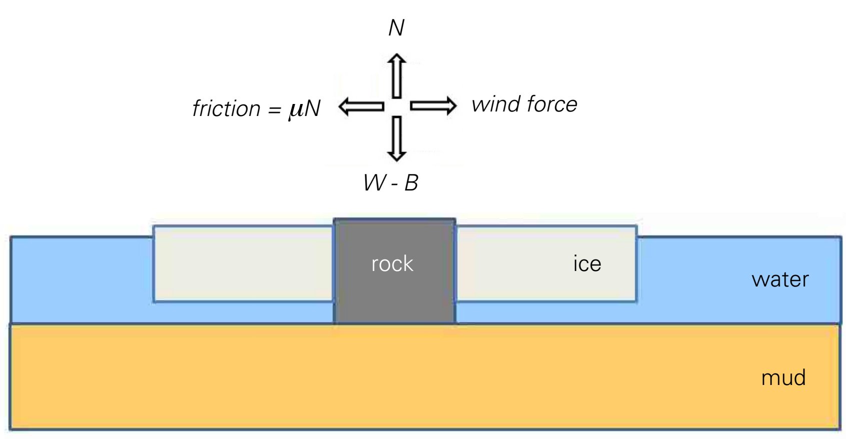
Moving the rocks requires a rare combination of events. First, snow melts to flood the playa to a depth of 7 cm. This freezes to form 'windowpane' ice less than 5 mm thick. On a sunny day this ice melts and breaks up to form large floating panels. Light winds of about 3 to 5 m/s (10 miles per hour) push the panels and these shove the rocks in front of them, much as a bulldozer would, leaving trails in the soft clay beneath. A large mass of ice, even if it is not moving very quickly, can have a large momentum (as momentum = mass × velocity).

The work done by moving ice should not be underestimated. After all, an ice shove event in 1952 uprooted enough telephone poles at a lake in Nevada to break a transcontinental telephone line. Researchers also observed rock-less trails formed by grounding ice panels – features that the Park Service had previously suspected were the result of tourists stealing the 'sailing stones'.

Observations do not yet support the model proposed by Stanley and developed by Lorenz. But it might still work for small cobbles being carried at night. For example, a cube of rock with sides of 10 cm would have a mass of 2.7 kg and weigh 27 N. Even for such a small rock, 'window pane' ice that is only 5 mm thick would need to be more than 2 m across to provide sufficient buoyancy. Moreover, once the Sun comes up, the dark rocks will absorb solar radiation and melt the ice in contact with the rock so that the rock will no longer be buoyed up by the ice.

The model

The ice raft can be represented as a free-body diagram – see the figure below. The weight W of the rock and ice acts downwards while the reaction force N of the mud pushes back upwards. As a result of Archimedes' Principle, there is also a buoyant force B acting upwards, equal to the weight of the water displaced. (When you go for a swim, you experience the buoyant force of water pushing up on you.) This displacement of water reduces the reaction so that $N = W - B$. If the weight and buoyant forces were equal, N would be zero and the ice raft would just float off the playa surface.



The forces on an ice-encrusted rock surrounded by water.

It turns out that the rock can be floated by about 20 times its volume of ice as shown in the Box: Forces on an icy rock. If the ice raft were nearly as thick as the rock then the raft need only be about five rock diameters across.

It is not necessary for the rock to be lifted completely off the bottom of the playa surface. Indeed it is important that the some weight is still exerted in order for the furrows to be created. As the weight of the raft is reduced so is the reaction force, N, which reduces the force of friction between the rock and playa surface, given by the equation $F = \mu N$, where m is the coefficient of friction. The coefficient of friction depends on the surfaces in contact. For example, it is easy to slide on ice because the coefficient of friction between the sole of your shoe and ice is close to zero. The coefficient of friction between the rock and the playa surface has been measured to be around 0.5. For the ice raft to move, the wind must have enough puff to exceed this force of friction.

Mike Follows teaches Physics.

Box: Forces on an icy rock

A rock sinks in water but ice floats. So how much ice does it take to make a rock float?

Imagine a cubic metre of rock of density 2700 kg/m^3. We have
mass = density × volume and weight = mass × gravitational field strength, so

- weight = density × volume × gravitational field strength

So, for a cubic metre of rock, weight W = 2700 kg/m^3 × 1 m^3 × 10 N/kg = 27 000 N

The upthrust on the rock is equal to the weight of water displaced (i.e. of 1 m^3 of water).

- upthrust U = 1000 kg/m^3 × 1 m^3 × 10 N/kg = 10 000 N

Thus when the rock is submerged in water there is a net downward force on it of 17 000 N.

Now think about 1 m^3 of ice immersed in water. Ice is less dense than water (density = 9170 kg/m^3) so there is a net force of $W - B$ = 9170 N – 10 000 N = -830 N.

Notice the minus sign; this means that the force is upwards, a buoyant force. (This is why ice floats with part of its volume above the surface.)

So 1 m^3 of ice can provide 830 N of upthrust to help float a rock. In order to float 1 m^3 of rock, there needs to be about 20 cubic metres of ice (because 20 × -830 N is opposite and roughly equal to 17 000 N).

Philip Henry Gosse
Brilliant naturalist, disastrous theologian

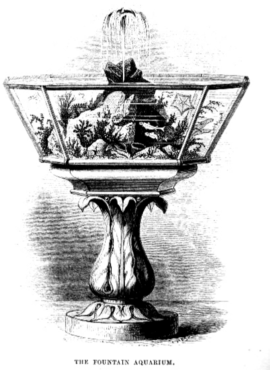
Philip Henry Gosse was born in 1810 and lived most of his early life in Poole on the south coast of England. His aunt taught him to draw and introduced him to the study of natural history.

Philip Henry Gosse, photographed in 1855

As an adult, work took him to Canada and Jamaica. Here, in his spare time, he made systematic studies of insects and birds. His published works on the birdlife of Jamaica led to him being known as 'the father of Jamaican ornithology'.

Aquarium

The early Victorian period was a time of great public interest in natural history. People collected specimens and read popular books on the subject. Gosse published several. One of his great interests was marine biology – little was known about the wildlife around the coasts of the British Isles.



A 'fountain aquarium', as designed by Philip Henry Gosse

In 1854 he published *The Aquarium: An Unveiling of the Wonders of the Deep Sea* in which he described how anyone could set up a seawater aquarium and use it to display sea creatures collected on visits to the coast. It isn't easy to maintain suitable conditions for marine life in a tank but Gosse's detailed instructions made it a possibility for Victorian enthusiasts. (Gosse invented the word 'aquarium' as the name for such a tank.)

Nature devastated

The story of the invention of the marine aquarium has a sad ending. Some years after Gosse published his book he revisited many of the sites he recommended to collectors in his book. He found that the local communities of sea creatures had been devastated; pools cleared of their inhabitants, rocks smashed by collectors' hammers. When marine biologists visit these sites today they have still not returned to how they were before the aquarium craze of the 1850s.

One of Gosse's exquisite drawings of sea anemones – people were surprised to learn that such exotic creatures lived in British waters.

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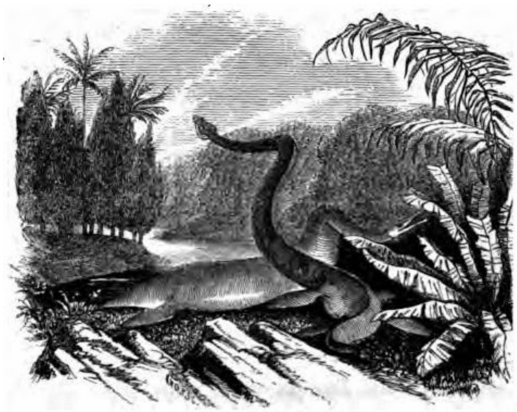
A colour plate from Philip Henry Gosse's book on British sea anemones, published in 1860

Religious life

At the age of 22, Philip Henry Gosse declared a strong Christian faith. He became a regular preacher, first with the Methodists and then with the Plymouth Brethren. He chose these non-conformist denominations because they allowed lay members to preach – the Church of England allowed only ordained ministers to preach.

In the 1830s and 40s there was increasing conflict between scientific theories and literal interpretations of the Bible. In particular, scientists such as Charles Lyell suggested that the Earth was many millions of years old, as evidenced by the time required to lay down the sequence of rocks which geologists had identified. Many biologists believed that such long periods of time were needed for the evolution of the many species of plants and animals found in nature and in the fossil record. All this was seen to contradict the biblical account in the Book of Genesis.

To support his theory of the Creation, Gosse published Omphalos, *complete with his own illustrations of how he imagined fossil creatures might have looked, such as these snake-necked lizards.*



SNAKE-NECKED MARINE LIZARDS.
Plesiosaurus dolichodeirus and *P. macrocephalus.*

Resolution and rejection

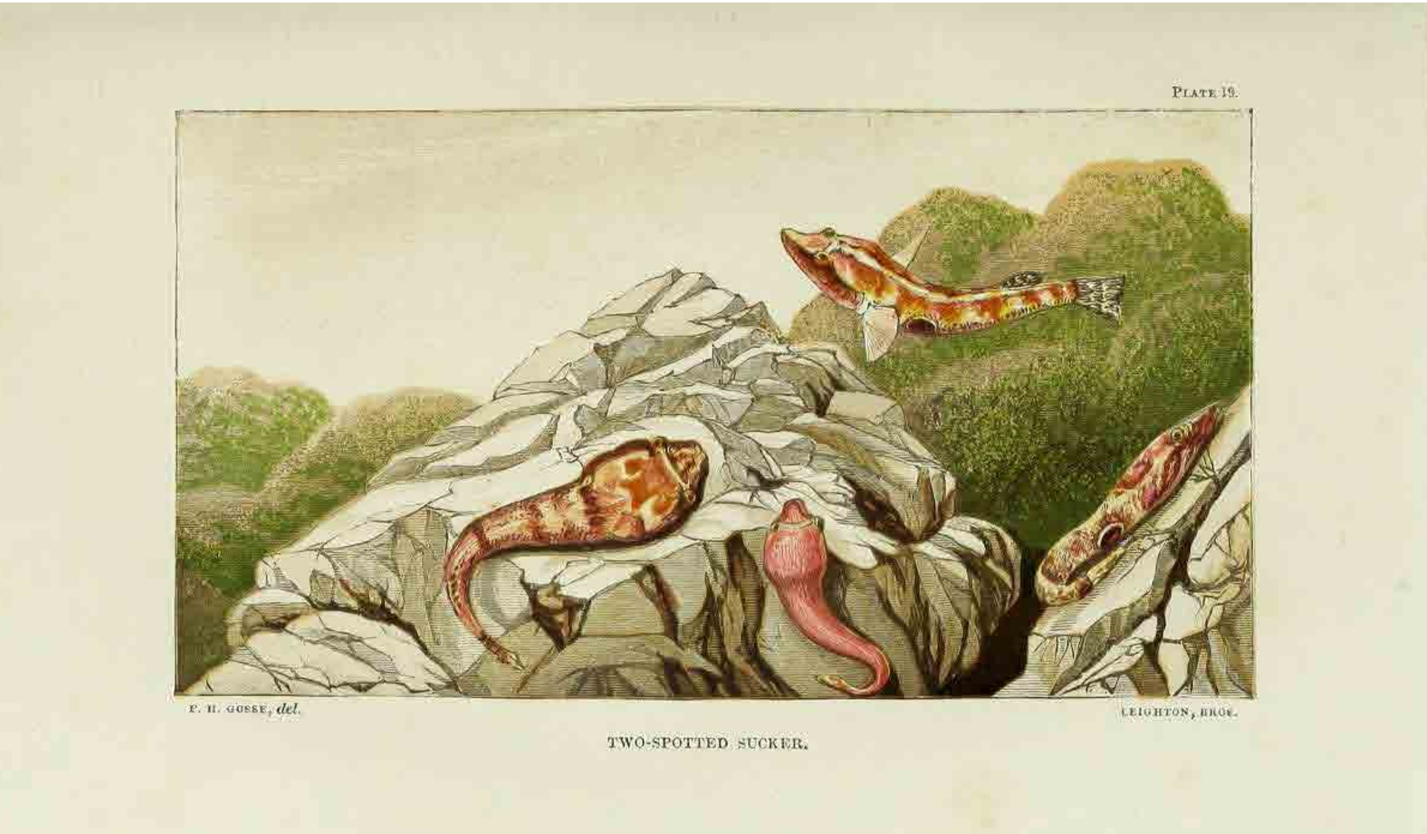
In 1857 Gosse published a book containing his resolution of this conflict. In *Omphalos: An Attempt to Untie the Geological Knot* he set out a remarkable theory. He noted that organisms show signs of their individual histories. Trees have tree rings, people have navels, and so on. He argued that, at the time of the Creation roughly 6000 years ago, God would have decided to create living organisms just like those of today – for example, trees with tree rings even though they were newly created. Adam would have had a navel even though he had never been in the womb bvecause every human has one ('omphalos' is Greek for navel). And rocks would have been created complete with fossils.

If Gosse had published his theory a century earlier it might have been accepted, at least for a time. Sadly for him, both scientists and theologians rejected it. Would God really have created a fossil record that might lead us to think that the Earth was vastly older than Genesis suggests? His book was variously condemned and mocked and eventually the unsold copies were pulped.

Gosse continued his work as a natural historian, publishing scientific papers and popular books until he died in 1888.

David Sang is Physics editor of Catalyst.

An illustration from Gosse's A Year at the Shore, *published in 1865* ▼



The healing of the ozone layer

Vicky Wong

Key words

ozone layer

CFCs

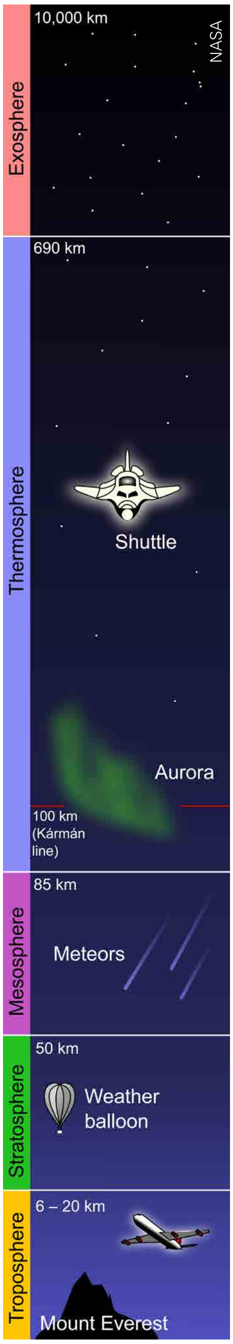
international cooperation

The Ellsworth mountain range in Antarctica; the thinning of the ozone layer is greatest above the poles.

*In 1974, the chemists **Mario Molina** and **Sherwood Rowland** showed that ozone can be destroyed by chlorine atoms produced when chlorofluorocarbons (CFCs) are decomposed by sunlight. **Susan Solomon** showed that these manufactured chemicals were causing a hole in the ozone layer. International cooperation led to the banning of CFCs and research carried out by **Susan Solomon** in 2016 showed that the ozone hole is reducing.*

Chlorofluorocarbons are molecules with a chain of carbons, each of which is bonded to chlorine and fluorine atoms. There are a huge variety of these such as CF_2Cl_2 and $CFCl_2$-$CFCl_2$. They are gases and were used widely in refrigerators and as propellants in aerosols as they are have low reactivity, low flammability and low toxicity so were thought to be ideal, safe chemicals for use in a variety of applications. As they are not reactive, they do not react when released into the atmosphere and so can stay around for a long time, in some cases up to 50-100 years. However, when sunlight hits them they can break apart to release a chlorine atom. This has a single unpaired electron and is very reactive, but there is not much for it to react with in the atmosphere.

Ozone is a form (allotrope) of oxygen. Unlike most oxygen, which has a chemical formula of O_2, ozone is O_3 and is far less stable than O_2. It has a much lower concentration in the atmosphere than oxygen, only 0.6 parts per million. It does, however, have a very important role. There is a part of the stratosphere which has a higher concentration of ozone, from 2 to 8 parts per million, which is called the ozone layer. It absorbs ultraviolet light, preventing too much ultraviolet from reaching the Earth's surface, where it can damage plants and animals. More ultraviolet light (UV) would increase the effects that UV has on human health including positive effects such as enabling people to produce more vitamin D and negative effects including sunburn and skin cancer. The effects may not be only on humans. In 2010 scientists at the Institute of Zoology in London found that whales off the coast of California have shown a sharp rise in sun damage, and these scientists feared that the thinning ozone layer was to blame.



The layers of the atmosphere; the ozone layer is in the stratosphere, roughly 25 km above the Earth's surface.

Mario Molina

In 1995 Mario Molina became the first person born in Mexico to receive the Nobel Prize for Chemistry, which he shared with Sherwood Rowland, for showing how CFCs can destroy ozone. Molina continues to serve on various national and international scientific and environmental boards and committees. In 2013, President Obama gave him the highest civil award in the United States, the Presidential Medal of Freedom, calling him 'a visionary chemist and environmental scientist'.

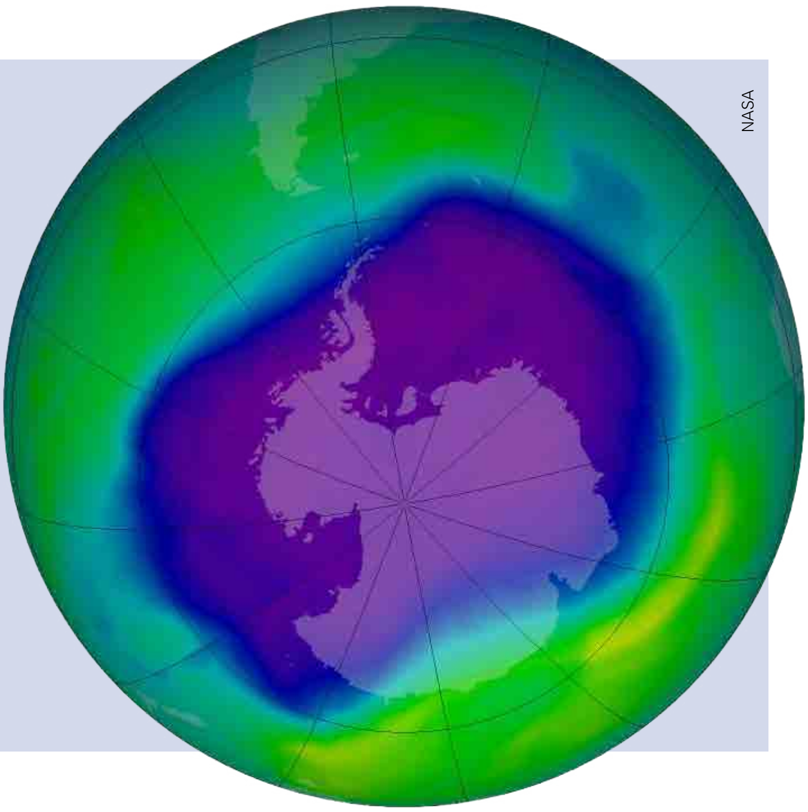
CFCs destroy ozone

Molina and Sherwood showed in the mid-1970s that the chlorine atoms produced from CFCs can act as catalysts and destroy ozone, but nobody was very interested at first. The trouble with the chlorine atoms being catalysts is that they could destroy very large numbers of ozone molecules without being used up themselves. In the mid-1980s satellite data from NASA confirmed that there was a hole in the ozone layer over Antarctica and that it was getting bigger. Some pressure groups from industry claimed that ozone depletion was a natural process and it was nothing to do with manufactured chemicals.

Susan Solomon led two expeditions to Antarctica in 1986 and 1987 and these showed that it was manufactured chemicals which were causing the problem and it was not the result of natural processes.

As many countries were using and manufacturing CFCs because they were useful in such a wide range of applications, individual countries acting to reduce their use of CFCs would not have the effect needed, international action was needed. In 1987 an international treaty, the Montreal Protocol, was signed which agreed to protect the ozone layer by phasing out the production of the numerous substances that are responsible for ozone depletion. This treaty has been ratified by 197 parties, 196 different international states and the European Union, and is the first universally ratified treaty in United Nations history. It is remarkable because it only took 14 years from the scientific research discovery by Molina and Sherwood to the signing of the national agreement. When compared to the difficulties with establishing international policy on climate change it is particularly impressive. But would phasing out CFCs work to reduce the hole in the ozone layer?

Refrigerators must have the CFCs removed from their cooling systems when dumped.



In September 2006, the Antarctic ozone hole was one of the largest recorded at 10.6 million square miles (27.5 million square kilometres). Satellite instruments monitor the ozone layer, and NASA uses their data to create these images that depict the amount of ozone. The blue and purple colours are where there is the least ozone, and the greens and yellows are where there is more ozone.

A NASA balloon is prepared for launch in McMurdo Station, Antarctica. McMurdo is where Susan Solomon conducted her research in the 1980s to show that manufactured CFCs are the cause of ozone depletion.

Susan Solomon

In 1986 and 1987, chemist Susan Solomon served as the Head Project Scientist of the National Ozone Expedition at McMurdo Station, Antarctica, and made some of the first measurements there that pointed towards chlorofluorocarbons (CFCs) as the cause of the ozone hole. She was the only woman on the team. In 1994, an Antarctic glacier was named in her honour in recognition of that work. In 1999 she was awarded the US National Medal of Science and in 2004 the Blue Planet Prize which recognizes outstanding efforts in scientific research or applications of science that contribute to solving global environmental problems. In 2008 Time magazine elected her as one of the top 100 most influential people in the world.

Antarctic spring

The holes in the ozone layer open up during the polar spring. During the cold, dark, winter nitric acid and water condense out of the atmosphere and form wispy clouds. The surfaces of the cloud particles host chemical reactions that release chlorine that came from CFCs. The chlorine, in turn, goes on to destroy ozone—but only in the presence of light. That is why, over Antarctica, the destruction of ozone really gets going in September, the beginning of the southern spring, when light returns to the pole.

Susan Solomon, who had shown that it is manufactured chemicals causing the depletion of ozone, has continued to study ozone levels over Antarctica. In June 2016, using a combination of measurements from satellites, ground-based instruments and weather balloons her team found that, since 2000, the September hole has shrunk by 4 million square kilometres—an area bigger than India.

They have used a 3D atmospheric model to show that it is a decline in pollutants which is the reason for the recovery and the healing of the ozone hole. Although it will not be fully restored until at least 2050, for Solomon there are reasons for optimism: “The fact that we’ve made a global choice to do something different and the planet has responded to our choice can’t help but be uplifting,” she says.

Vicky Wong is Chemistry editor of Catalyst.

Vicky Wong

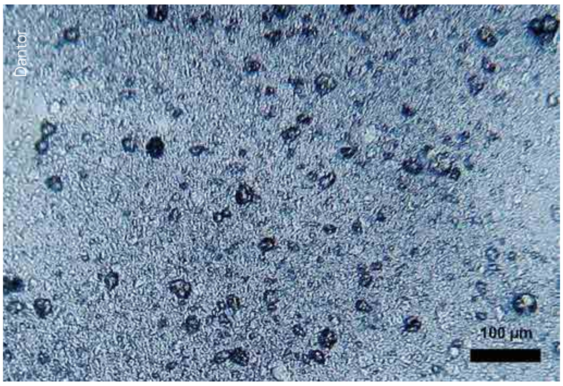
Microplastics and the oceans

Plastic rubbish on the beach

Key words
polymers
microbeads
pollution
marine environment

Have you used a soap or cleanser recently which contained small bits of solid? These are known as microbeads and are usually made from plastic. When you rinse them down the drain they are too small to be filtered out by water treatment works and so end up in rivers, lakes and ultimately the ocean.

A typical household product such as a facewash or toothpaste can contain millions of microbeads. Up to 86 tons of microbeads are washed into the water supply from the UK alone each year. According to the United Nations, the build-up of these and other small plastic particles known as microplastics is a growing threat to the health of humans and other organisms.



Polythene based microparticles in toothpaste

Microplastics are particles of plastic with a diameter of less than 5 mm. Microbeads from household products are relatively straightforward to stop using and although cosmetic companies are unwilling to admit when they began to put microbeads into their products, most have now agreed to remove them from their formulations as it becomes apparent the scale of the damage they could cause. They are far from the only source of microplastics in the oceans, however.

Thrown away plastic

According to the United Nations, between 2004 and 2014 the amount of plastic produced worldwide rose by 38 per cent – this plastic has to end up somewhere and for some of it this is in the oceans. By one estimate, in 2010 between 4.8 million and 12.7 million tons of plastic was washed into the seas including plastic bags, plastic drink bottles, take away containers and fishing gear. The larger pieces of plastic waste get broken down by the action of the seas and in time become tiny pieces of microplastics. Another major source is from washing machines. As clothes made of synthetic fibres like fleece and polyester are washed they release tiny fibres which also end up in waste water. Like the microbeads these are too small to be filtered out by water treatment works and so end up in the world's waters.

Many cosmetic products contain microbeads which can get into the oceans.

Trillions of tiny pieces of plastic are accumulating in the world's oceans, lakes and estuaries, harming marine life and entering the food chain. The microbeads in scrubs, shower gels and toothpastes are an avoidable part of this plastic pollution problem. A single shower can result in 100 000 plastic particles entering the ocean. One study estimated that there are 5 trillion pieces of plastic in the ocean, over 90% of them microplastics. They are spread throughout the world, with plastics reported in a remote Mongolian lake and in the deep sea sediments. They are not spread evenly, with larger concentrations in parts of the Pacific Ocean and with the seas round Japan having up to 27 times the world average.

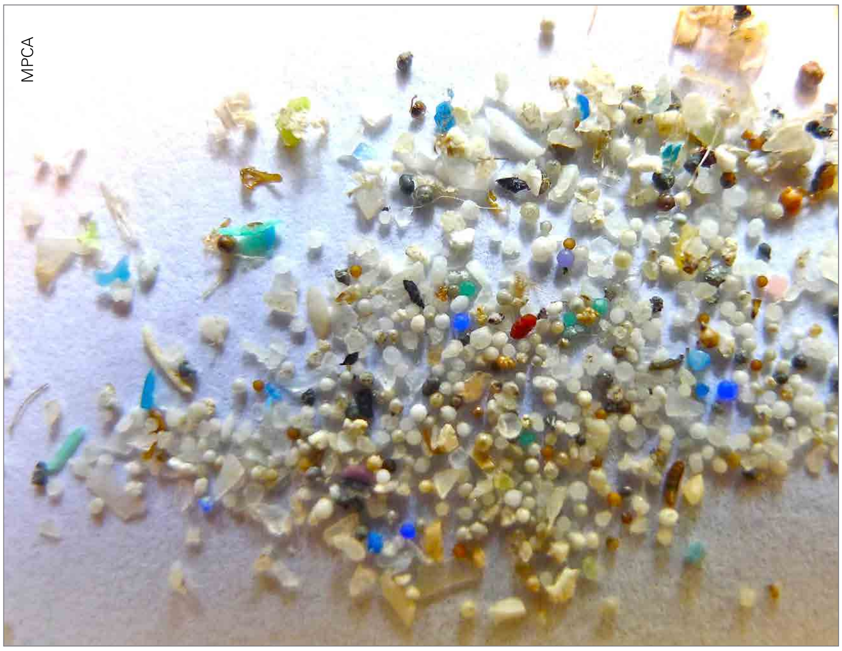
A krill – these organisms sometimes ingest microplastics. When they themselves are eaten the microplastics may move up the food chain.

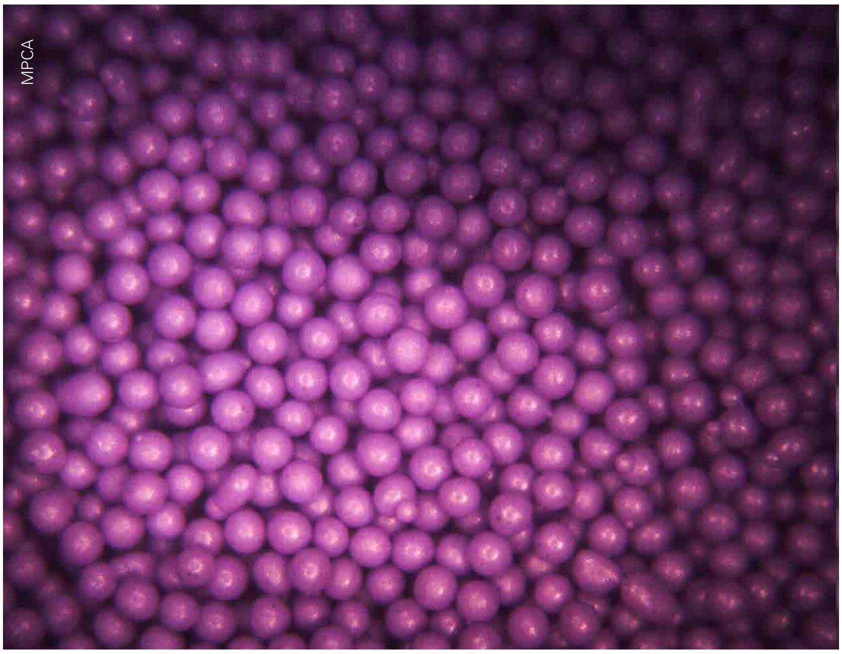
The thought of the oceans filling up with pieces of plastic is obviously unappealing, but why does the United Nations consider it such a threat? The pieces of plastic can be eaten by plankton such as krill, whales, fish and other marine life as they look like their normal food sources. A recent study analysed fish for sale in markets in California and Indonesia and found that a quarter of them contained plastics. When these are eaten by people the plastic can be ingested by them too.

Consuming plastics is potentially harmful for a number of reasons. One is that the tiny pieces could cause physical harm in the organism. Another is that many contain additives such as colours, UV stabilisers or plasticisers which are harmful or toxic. If enough is eaten these might cause poisoning, infertility or genetic disruption. In addition, microplastics can act like little chemical sponges so other toxic chemicals in the environment may attach themselves to plastics, meaning that even more harm can be caused by eating them. Once they have been eaten the chemicals may come off the microplastic to cause harm to the organism.

Future research

There have also been very few studies into how much plastics humans and other organisms are actually consuming or how much harm is caused by their doing so. Fresh water treatment plants are thought to have filters small enough to filter out microplastics, but one study of 24 brands of German beer found microplastics in every bottle, which the researchers thought probably came from the water used to make the beer. A Chinese study in 2015 found that 15 brands of lake, rock and sea salt were contaminated with microplastics.





Microbeads can be very regular in size and shape (above) but they end up as part of a mixture in the environment (below).

Rich Carey

Volunteers clear plastic waste from a beach in Malaysia

It is possible to predict how various plastics will behave in fresh and salty water from the density of the polymer. Polythene, polypropylene and expanded polystyrene will all float; polyvinyl chloride and nylon will sink. In the environment, however, it is not so simple. For one thing the various plastics may contain additives which change their density. Biofilms, from algae and other organisms, can form on them and make them heavier. This difficulty in predicting how plastics will behave means that we have very little idea how much plastic is in various parts of the ocean. It is relatively easy to see how much is on the surface, but it is not known how much more there is deeper down and how much is in various marine organisms.

Action

Although there are many unanswered questions about microplastics and far more research is needed, many scientists believe that there is sufficient evidence that they do harm to require action. The best way to reduce the amount of microplastics and other plastics in the seas is to prevent further plastics from entering the water supply. Banning microbeads is a start, but it will not of itself solve the problem. Coastal clean ups happen around the world and these are a great way to make a difference – in the UK the *Two minute beach clean* campaign encourages people to take two minutes to clean rubbish off beaches. Plastic rubbish taken from the beach is plastic which does not become microplastics in the seas. There is project called *The ocean clean-up* which is a larger version of a beach clean-up where nets are used to try to remove plastics from the oceans.

Better than removing plastics once they are in oceans is preventing them from getting there in the first place. This requires an increase in the amount of recycling which actually takes place. At present many items which are labelled as recyclable are not recycled in practice. As much as 40% of the plastics which are produced each year are only for using once – for example in packaging. This could be designed differently to reduce the amount and to ensure that it is worthwhile recycling after it has been used. Reducing the amount of plastics that we use is also possible. England's carrier bag usage has dropped a huge 86% since the 5p charge for a bag was introduced, a reduction of 6 billion plastic bags per year. The other UK nations have seen similar falls in plastic bag use. This shows that it is possible to encourage people to use less plastic.

Most environmental scientists are not suggesting that we should stop using plastics altogether. They are very useful materials in a variety of applications. But the build-up of plastics in the oceans shows that we need to think very carefully about what we use plastic for, avoiding it where we can, and consider how we deal with plastic products when we have finished with them.

Vicky Wong is Chemistry editor of Catalyst.

Look here!

More about the two minute beach clean: *http://beachclean.net*


Stella Bogdanic

Dan Wright Sarmiento
Clare Simm
Jenny Vidler

Raspberry invasion

How a berry can destroy an ecosystem

The Galápagos Archipelago is a collection of 13 main islands and more than 100 volcanic islets located in the Pacific Ocean. Galápagos inspired Charles Darwin's momentous Theory of Evolution by Natural Selection, and is a haven for terrestrial and marine wildlife including the famous giant tortoises.


Galápagos Conservation Trust

The Galápagos Islands are home to a range of endemic plant and animal species, including giant tortoises.

For over 400 years, people have been visiting the islands but multiple attempts at setting up permanent colonies have failed. In the 20th century, new technology and a re-kindled frontier spirit amongst Europeans and South Americans led people back to the Galápagos Islands, this time to set up colonies that would remain and thrive. They brought their cats and dogs, their pigs and other livestock. They brought seeds for the crops that would one day feed them. They tried to surround themselves with familiar animals and plants, unaware of the impact that certain species would have on the delicate Galápagos ecosystem that had remained almost completely isolated for millions of years.


Stephanie Foote

Invasive species, including dogs, have damaged the delicate ecosystem of the Galápagos Islands.

Invasive species are present across the globe. The word 'invasive' describes an alien animal or plant, moved to a new site, which then thrives within the new site, challenging and damaging the native species. In some cases, invasive species cause little damage to the local species, but in other areas of the world, local species may suffer almost irreversibly.

Key words
invasive species
alien plants
ecosystem
biological control

The hill raspberry, Rubus niveus, *was originally planted by settlers in Galápagos for its berries.*

Introduction of mora to Galápagos

No-one thought that household cats left to fend for themselves would turn to hunting endemic marine iguanas. No-one considered that feral pigs could one day feast on the eggs of giant tortoises. Certainly no-one suspected that a raspberry would become one of the leading threats to biodiversity in this unique environment.

The flora of Galápagos was changed during the 1970s due to the introduction of the hill raspberry, *Rubus niveus*, which is known locally as 'mora'. Mora is native to a large area of Southern Asia and it is understood that the inhabitants of Galápagos at the time brought seeds over from the continent in order to cultivate the tasty berries that this species produces.

The settlers soon found that Galápagos had the perfect climate for mora. Good news for the settler's pantry, bad news for the existing wildlife and plant life of the Islands. Mora outcompeted other native and endemic species. It grew rapidly, spread quickly, and the thousands of seeds produced by each plant were easily transported. Mora has now become one of the leading threats to biodiversity in this unique environment.

Why is mora a problem?

Several studies have been undertaken looking at the impact of mora on the delicate Galápagos ecosystem, and how best to eradicate it. Mora grows into dense, thorny thickets that can reach up to 4.5 metres in height. As it grows, it becomes more and more impenetrable, starving any other species of plant of light and nutrients and becoming an impassable obstacle for ground-based organisms. Each plant is capable of producing thousands of seeds each year which can then be dispersed over long distances by the organisms that have feasted on the sweet berries including birds, humans and even giant tortoises.

Mora thickets can become extremely dense, causing issues for native plant and animal species.

Once seeds have been dispersed to a suitable patch of soil, approximately 80% of seeds will germinate. If the conditions are not ideal, the seeds can stay dormant for up to 10 years. With this level of resilience before the seed has even taken root, the plant proves very hardy and immensely tricky to control. Incredibly, within just six months of germinating, mora plants are able to produce fruit and the cycle of seed dispersal continues.

Understanding and tackling mora

When considering all methods to remove the damaging mora, it is important to find a solution that will effectively remove this alien species while causing the least amount of damage to other existing species.

Removing mora by hand, also known as mechanical management, has a number of drawbacks. Given the rapid growth of the thickets and the restrictions on heavy machinery in the protected national park zone, wellington boots and machetes are often the go-to management strategy. Unfortunately, hacking away at the brambles is not enough to effectively deal with the alien plants. It will also take a number of years to clear a thicket, as it only takes an astonishing six months for any dropped seeds to grow into a plant which can re-seed. Repeat visits are necessary and time consuming.

An alternative mechanical approach would be to remove the plant at the roots and dispose of it carefully. This approach is effective but also time-consuming and not entirely guaranteed; seeds could be accidentally dropped along the disposal route, leading to further plants growing.

We can also try to remove mora by swapping our machetes for barrels of herbicide. Like cutting the mora down, spreading the herbicide is hard work and will take a large number of people to cover an overgrown area. There are various herbicides that have been shown to be effective in managing mora, such as those containing picloram and 2,4-D. However, introducing chemicals into fragile ecosystems can also have negative impacts which may be even more drastic.

If chemicals have drawbacks, what about biological controls to fight the invasive mora? Biological management would involve introducing another species to the ecosystem, perhaps one that feeds on mora. A good example of how this works in practice is when the Australian ladybug (*Rodalia cardinalis*) was introduced to the Galápagos in order to manage the population of invasive cottony cushion scale (*Icerya purchasi*), another Australian native that was threatening over 60 endemic and native plant species on the Islands.

It took over six years of research to assess whether it would be safe to release the Australian ladybug, and to date the introduction of this species has not negatively impacted native and endemic species. The potential for using fungal pathogens to control mora is currently being explored and researched.

So what's the answer?

With its capacity for rapid growth and the difficulties surrounding its removal, it would seem that total eradication of mora from Galápagos is an impossible task. However, whilst eliminating mora from the environment is the ideal goal, a study from 2012 suggests that this is not necessary to maintain a healthy ecosystem. It was found that reducing the amount of mora to just 40% of the cover in an area could achieve the balance needed for native plants to thrive. While this does rely on ongoing management, it does suggest that there is a long-term solution in the battle against mora.

Anne Parr

Unspoiled Galápagos landscape

Look here!

The Galápagos Islands are a microcosm with lessons for the world. Biologists are on the frontline of conservation for the islands and are dedicated to protecting this treasure. To learn more about invasive species, the endemic wildlife, the fascinating history and the amazing geography of Galápagos together with lots of free resources, visit discoveringgalapagos.org.uk.

The Galápagos Conservation Trust is the only UK charity working solely for the conservation of the Islands. For more information, visit *Galápagosconservation.org.uk*

The authors all work for the Galápagos Conservation Trust. Dan Wright Sarmiento *is the Sustainability and Projects Officer and coordinates their bilingual educational programme.* Clare Simm *is Communications and Marketing Officer.* Jenny Vidler *is Communications and Membership Assistant, having previously volunteered for several months.*

Turn to the back page for more about the wildlife of the Galápagos.

Endemic, native, alien

The wildlife of the Galápagos

Like everywhere, the Galápagos Islands have three kinds of species: native, endemic and alien. A troublesome alien is the hill raspberry or mora – see the article on pp19-21.

*The **Nazca booby** is a native species, one which lives on the Galápagos but also elsewhere.*

All photographs by Gary Skinner.

*One of the very important features of the Galápagos is the high number of endemic species, those which are found only there. The **Gálapagos large ground finch** is an example, one of the species sometimes called Darwin's finches.*

*The Islands have many endemic bird species, including the **Galápagos penguin, hawk** and **albatross**.*

*The **swallowtail gull** is an example of a 'near endemic' species, almost entirely confined to the Galápagos Islands. It is also the only nocturnal seabird in the world. It specialises in feeding on squid which come to the surface at night.*

*The **Galápagos sea lion** is one of several endemic animal species.*