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Pathological plants

Tackling crop diseases

Science Enhancement Programme

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The cover image shows a crop of poinsettias growing at a commercial nursery in Baden-Württemberg, Germany – see the article on pages 1-3. (Photo: D. Pfleiderer)

Contents

Hidden life

Perhaps your home featured a poinsettia at Christmas. They are a popular winter houseplant, but did you know that they owe their form and colour to the presence of a plant pest, a phytoplasma, living in their tissues? This is not just a 'fascinating fact'. Phytoplasmas can wreak havoc in commercial crops such as coconuts. On pages 1-3, Melanie Tuffen explains how scientists are tackling the problem.

There's more hidden life in the Big Picture (pages 10-11) where Gary Skinner shows a few of the myriad life forms you may find when turning over a fallen log. And on pages 6-9, Gary shows that there's much more to fieldwork in Biology than simply cataloguing species (although that is demanding enough). Fieldwork involves collecting and analysing data, devising explanations for the patterns found, and finding ways of testing the explanations.

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Melanie Tuffen

Phytoplasmas: friend or foe?

Christmas may be over for another year, but did you know a deadly pathogen may have been lurking amongst your festive decorations? ***Melanie Tuffen*** *explains.*

The deadly Christmas decoration?

Go to any supermarket in the weeks before Christmas, and you'll see neat rows of poinsettia plants *(Euphorbia pulcherrima)* on the shelves, their scarlet bracts (modified leaves) glowing. Four million poinsettias are sold in the UK every Christmas, and 75 million are sold in the US. They're such big business, there are farms devoted to growing nothing else. But would the people throwing the plants into their shopping trolleys be as keen to buy them if they knew the secret the poinsettias hide?

The poinsettias we see in the shops are very different from the ones found in the wild, in Mexico and Central America. Wild poinsettias are often taller than a human and perhaps only produce a single flower – hardly suitable as a house plant.

When, in the 1920s, plant breeders discovered a new variety of poinsettia, covered in flowers and small enough to sit on a table, they thought they had a winner. But these traits couldn't be bred. The only way to produce the compact plants was a method called grafting, where the tissues of two different plants are fused together. The result was that the recipient poinsettias took on the characteristics of the donor plant. This had the effect of transforming the straggly wild plant into the beginnings of an industry worth hundreds of millions of pounds every year. Breeders knew the secret must be in the sap of the grafted plant, but they had no idea what it could be.

Wild poinsettias growing by the side of the road in Mexico.

Key words
phytoplasma
plant disease
vector
gene expression

Bodie Pennisi, University of Georgia, Bugwood.org

Poinsettias are an important greenhouse crop, particularly for the Christmas market.

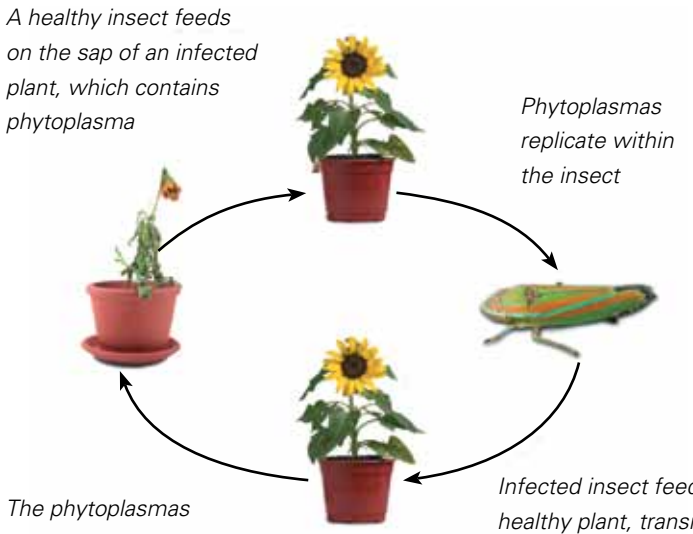
Phytoplasmas: The real Christmas star

It wasn't until 1997 that scientists discovered the secret of the poinsettia's transformation: those cheery poinsettias are actually all sick. Within the sap of the plants were phytoplasmas, a type of specialised bacteria that infects plant phloem, and damages the host plant. Phytoplasmas are normally transmitted by insects (known as vectors) that feed on plant sap. The grafted poinsettias were transmitting the phytoplasmas from the infected plant to the healthy plant through their sap.

(The phrase 'plant sap' is commonly used. Plants have two plumbing systems, the xylem, whiuch carries water, and the phloem which carries sugar solutions. The watery liquids in each can be called sap, but the sap referred to here is phloem sap.)

The diagram below shows the typical infection cycle of phytoplasmas. Insects (known as **vectors**) feed on the sap of an infected plant, also ingesting phytoplasmas. The phytoplasmas then begin to multiply in the insect salivary glands, so that when it feeds on a healthy plant, it passes the phytoplasmas to that plant causing it to become infected.

The phytoplasma infection cycle



The darker nature of phytoplasmas

Phytoplasma in poinsettias creates prettier plants perfect for our homes. But phytoplasma diseases threaten millions of people across the world, by devastating crops and leaving people hungry.

As well as the symptoms we see in poinsettia of stunting and increased branching, phytoplasmas may also cause little or no flowering (which in crop plants means no seeds, grains or fruit), can reduce leaf size, interfere in the ability to photosynthesise and can eventually kill the plant entirely.

Phytoplasmas are known to release proteins into the plant cell that enter the plant nucleus, where it is believed that they are able to change plant gene expression to cause the symptoms seen.

What does 'gene expression' mean? All genes do just one thing—they instruct the asembly of chains of amino acids, which form polypeptides, which then fold to make proteins. These proteins may act as enzymes, antibiotics, membrane proteins and many more. Genes do not always instruct amino acid assembly, they only do so when they are switched on (expressed). The switching on and off of genes is essential in the development and functioining of organisms.

A leafhopper – one example of a phytoplasma vector

Biologische Bundesanstalt für Land- und Forstwirtschaft, Bugwood.org

Grapes are an important crop which can be affected by phytoplasma diseases. Here, discoloured grapes result from the phytoplasma disease flavescence dorée.

Coconut-infecting phytoplasmas

Across the world, coconuts are a major food crop and cash crop for farmers. In Ghana, for example, coconuts are a major source of income. However, coconut palms are particularly threatened by phytoplasma diseases, which have already destroyed coconut plantations across the world. One particularly severe disease, Coconut Lethal Yellowing, causes the leaves to yellow, and the tree to die within a year, leaving just the 'telegraph poles' of dead tree trunks.

The trunks of coconut palms killed by phytoplasma disease resemble telegraph poles.

So why is the disease causing such devastation? Normally, phytoplasmas are controlled by using insecticides against the vector (the insect transmitter) of the disease. In West Africa the vector for coconut lethal yellowing is still unknown, so it cannot be controlled.

The nature of coconut farming in Africa does not help matters. Coconut farmers are smallholders and not large companies – they do not own many trees and cannot afford to cut them down even if they become infected. This gives the disease further opportunity to spread.

Phytoplasma research in the field

Phytoplasma disease is a problem in many countries across the globe, and scientists are working together to try and address this.

Collaboration includes creating links between labs in Africa, Europe, America and South East Asia – all regions where phytoplasma disease occurs. Scientists go out into the field to examine infected plants, and to help and advise farmers affected by disease.

Ndede Yankey from Ghana's Coconut Research programme with Dr Philip Swarbrick from the University of Nottingham in the field examining diseased trees.

Phytoplasma research in the lab

Very little is actually known about phytoplasmas, and how they cause disease in plants. There is no current cure, and though antibiotics can be used to treat bacterial infections in plants just as in humans, they do not kill phytoplasmas; the disease is only slowed in response to treatment. Many farmers in developing world countries can not afford to use antibiotics on their plants.

Scientists are working on tackling phytoplasma disease on multiple fronts. Some are trying to breed resistant plants, studying the genetics of plants in the field which survive when their neighbours succumb to the disease. Other scientific groups are trying to discover what phytoplasmas actually do to the plant – do they secrete toxins? Interfere with the plant hormones? Or are the plants weakened because the bacteria are using up the sugar it makes during photosynthesis?

They might produce beautiful plants for our home at Christmas, but sadly phytoplasma infection in poinsettias is the only example of phytoplasmas being beneficial to us. So perhaps when you see poinsettias next Christmas, you'll remember their dark secret, and if you bring one home make sure you look after it – after all, it is a bit poorly!

Melanie Tuffen is researching phytoplasmas at the University of Nottingham.

Vicky Wong

The Chemistry of the Noble Gases

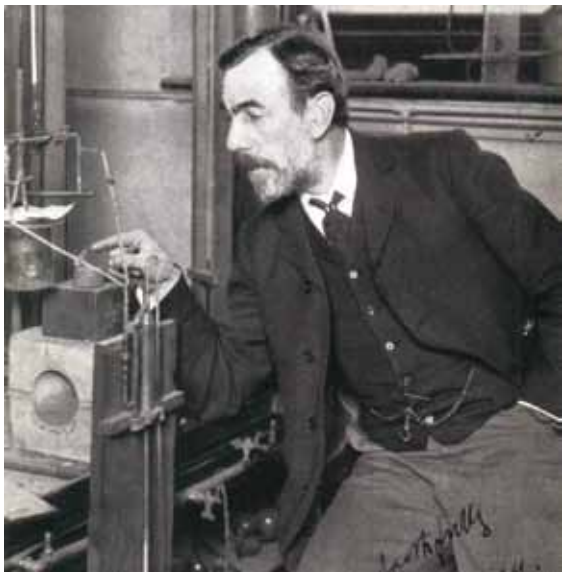
1	2											3	4	5	6	7	0
							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
N	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg							

Alkali metals *Halogens*
Transition metals *Noble gases*

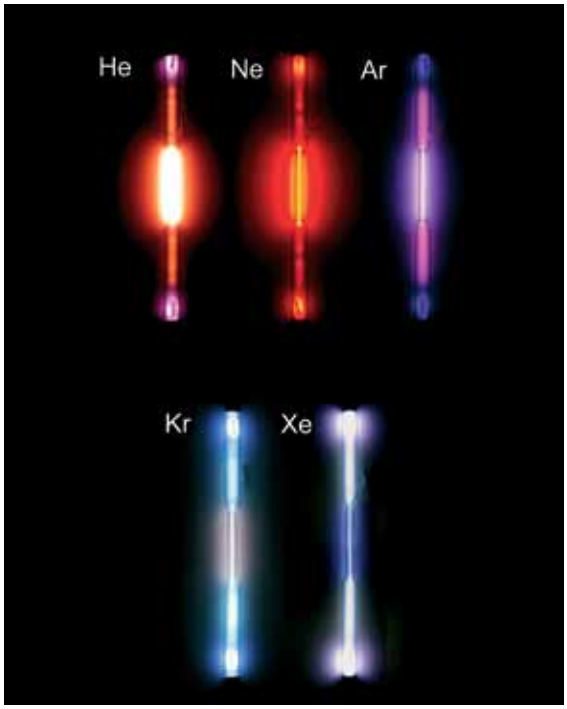
Group 0 or 8 of the periodic table contains the Noble gases: helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). This group was the last of the periodic table to be discovered due to their unreactivity.

Nobel prizes are awarded each year for physics, chemistry, physiology or medicine, literature and for peace. They are very prestigious international awards.

The periodic table had not allowed for a group of elements between the halogens and the alkali metals so their discovery came as a complete surprise. The first to be found was argon, in 1895 by William Ramsay and Lord Rayleigh. This was so unexpected that it was suggested by a number of eminent scientists, including Mendeleev, that it was a new sort of nitrogen, N_3. Within three years, Ramsay and his co-workers had also found helium, neon, krypton and xenon by using fractional distillation to separate out liquid air into several components. They showed that these gases are monatomic (consist of only one atom) and unreactive. Ramsay and Lord Rayleigh were both awarded Nobel prizes for their discoveries.

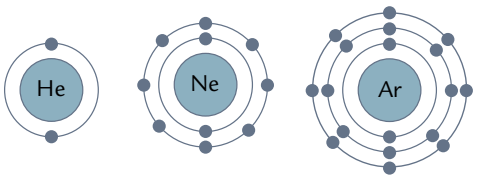


William Ramsay



When an electric current is passed through the noble gases, each glows with a distinctive spectrum of colours.

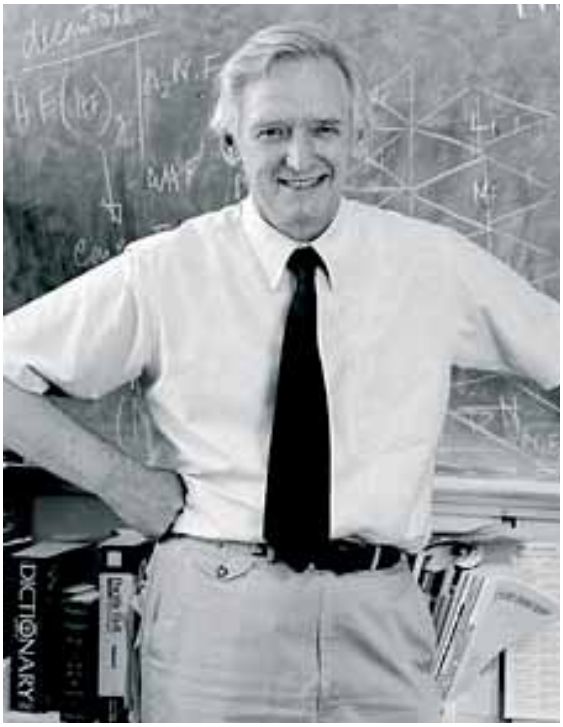
In 1913, Rutherford and Bohr published their theories on the structure of the atom and electronic configurations. We still use these theories today to explain the chemical properties of elements. It was noted early on that the noble gases were especially stable and this was linked to their electron configurations. Chemical properties of other atoms were related to the gain or loss of electrons from the configuration of the nearest monatomic gas. These theories were incredibly successful in predicting and explaining patterns of chemical behaviour. But partly as a result of them, the noble gases came to be thought of as completely inert and unreactive – chemists thought that they could *not* react.



Electron configurations of the first 3 elements of group 0 or 8

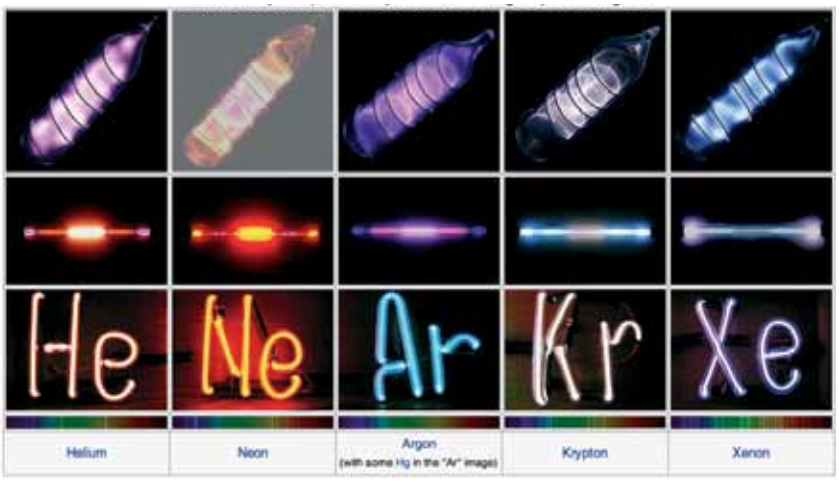
Changing ideas

However, even as early as 1916, it was noted that xenon was the most likely to chemically combine and that it would probably be with fluorine or oxygen. A few attempts were made to react xenon and fluorine, but without success. Chemists generally held that all noble gases were completely inert to chemical combination.

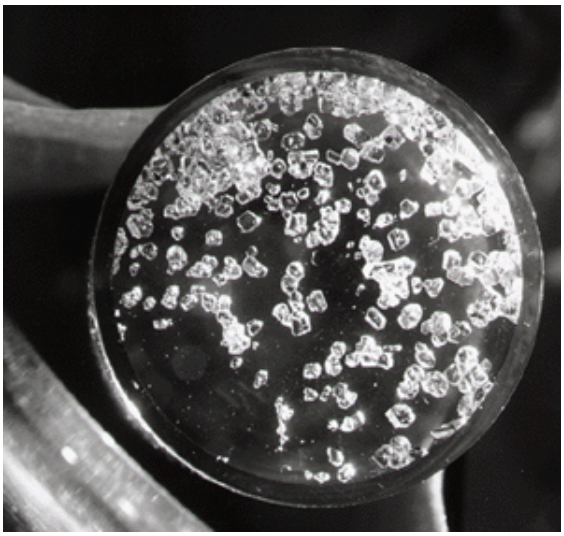


Neil Bartlett, professor of chemistry at the University of California, Berkeley.

That changed when a chemist called Neil Bartlett, who was originally from England but was working in Canada, tried something different. He had been working on compounds of platinum and fluorine and speculated that these may be reactive enough to combine with xenon. He was right. In 1962 he announced that he had made the first compound of xenon – with platinum and fluorine. Its chemical formula was complex and he had probably made a mixture rather than a pure compound – but he had offered the first proof that compounds could be prepared from a noble gas. Since he showed that it could be done, more than 100 compounds of xenon have been prepared including oxides, acids and salts. Even compounds with xenon bonded to hydrogen, sulfur and gold have been made, although most are stable only at very low temperatures.



Colours and spectra (bottom row) of electric discharge in noble gases



Crystals of xenon tetrafluoride – this was the first compound of xenon in which it was combined with only one other element.

Following Neil Bartlett's success, other compounds of noble gases followed; radon fluoride in 1962 and krypton difluoride in 1963. In spite of the success in forming compounds of three of the noble gases, opinion remained among chemists that the other gases were inert and would not form compounds.

It took until 2000 before the first compound of argon was announced. It has the formula HArF and is called argon fluorohydride. It was made by a team of Finnish chemists by freezing a mixture of argon and hydrogen fluoride onto caesium iodide at -265°C and exposing the mixture to UV radiation. They clearly identified the new compound and showed that the argon had formed bonds, but on warming it reverts back to argon and hydrogen fluoride.

At present, no compounds are known of neon or helium and they are considered to be completely inert and unreactive. However, this is what chemists thought of the other noble gases too – until they made compounds with them!

Vicky Wong is Chemistry editor of Catalyst.

Gary Skinner

Numbers from nature

Key words
ecology
fieldwork
collecting data
interpreting data

The usual image of a scientist many people have is of someone in a white coat in a rather comfortable laboratory. Not so the field ecologist. Their work goes on outside, in all weathers and often in some very challenging environments. In addition, to wrest information from the natural world in such places can take a very long time and be very dependent on the time of year. Despite these major difficulties, ecologists have learnt a lot about how living organisms live in the wild, and how they interact with each other and their environment. In this article ***Gary Skinner*** *tells the stories of two pieces of field ecology, one his own and the other from a Mexican botanist.*

Ants in my pants!

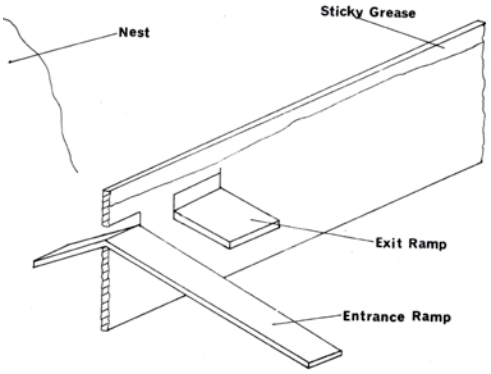
I must admit my first reaction when I finally got out to the woodland in which I was going to study the wood-ant *Formica rufa* for three years was one of horror. These centimetre-long creatures were there in their thousands and ran everywhere, including all over me! Although they do not sting, they have strong jaws which they nip with, and they spray pungent formic acid. I felt I could just about tolerate all this as long as they did not crawl up the inside of my trousers, so I spent the first few weeks wearing cycle clips.

A wood-ant (main picture), Formica rufa*, and the nest it shares with many other wood-ants (above).*

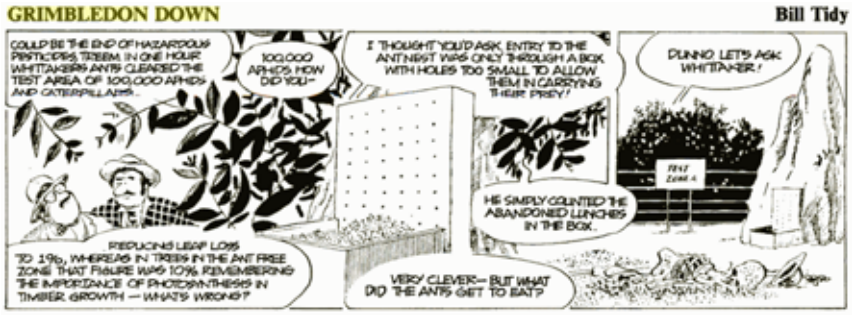
The original brief was to find out what effect these innumerable workers were having on the ecosystem and the route I decided to take was first to see what they were eating by watching what they brought back to the nest. Hours were spent sitting by one of their trails looking at the workers jaws, and occasionally taking what was there away from them. This, however, caused disturbance as a worker which had its prey taken away from it would spray formic acid, which is an alarm pheromone in these ants. So, the next frustration of studying animals in the field – the observer effect. The ants were behaving differently because I was watching them.

The solution was to put in place a permanent food collection device, which the ants became used to so that they settled down to normal activity. This device consisted of a sheet metal fence, smeared with grease which confined the ants to the nest, or to its outside. Holes were then cut in the fence

to give the ants a way in and out and equipment was set in place to collect their food from them. The way this works is perhaps best understood by looking at the cartoon strip that was drawn by Bill Tidy in *New Scientist* in 1984, just after the final paper on my work was published.



Wooden ramps installed to allow streams of ants in and out

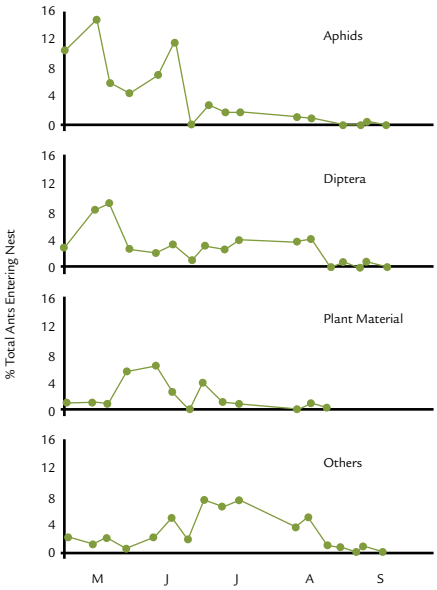


A cartoon from New Scientist*, based on Gary's work.*

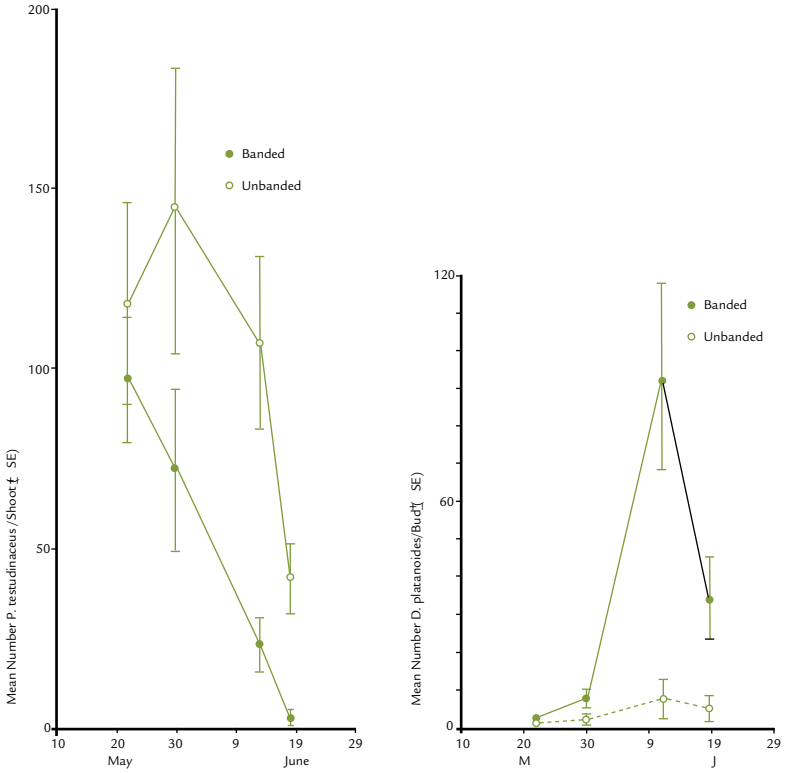
Once I had this information I was able to start thinking about the effect the ants have on the ecosystem. The data led me to focus on effects on aphids and caterpillars that live on oak trees. The results were surprising, at least for the aphids. Here I found that the ants ate one type on sycamore (the sycamore aphid, *Drepansosiphum platanoides*) but not another (called *Periphyllus testudinaceus*) from which it collects a sugary solution called honeydew. The effect of this is shown in the results of an experiment in which I excluded ants from some trees and not others by 'banding' the trees with grease. The aphids which are eaten by ants did better on banded trees where they were protected from ants; the honeydew aphids did better on unbanded trees. This put a big question mark over the practice in some other countries of using wood-ants to protect trees against caterpillar attack. This they may well do, but at the cost of encouraging some aphids which not only suck sap but transmit diseases to the trees too.

Representing data

The results were many but a flavour can be seen in the graphs which show the input of greenfly (aphids), two winged flies (diptera) and bits of plant material (which are not eaten but used to build the nest).



Numbers of prey taken into a wood ant nest over part of a year



Effect of excluding ants from colonies of aphids, one species of which is tended by ants for its honeydew (left) while the other is eaten by ants (right).

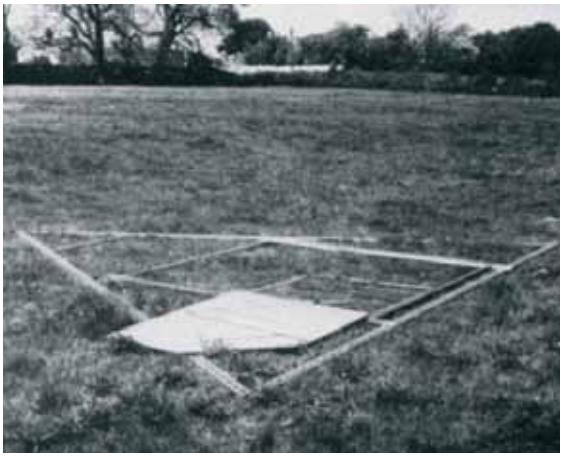
Dead interesting stuff!

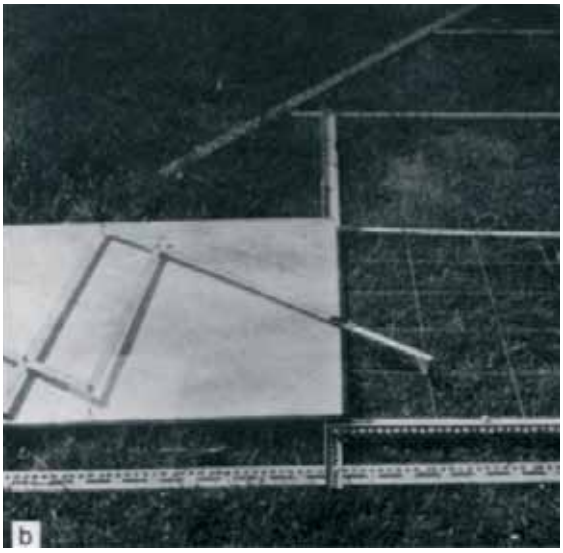
A very famous story amongst field ecologists is that of Mexican botanist Jose Sarukhan when he was doing his PhD at Bangor University in North Wales. This is how he tells it:

*My thesis research was on the population dynamics of three species of buttercups (*Ranunculus acris, R. repens *and* R. bulbosus*) which grow together in the same area but occupy different niches within it (Box 1)* – bulbosus *in the wettest spots,* acris *in the upper part of light 'humps' in the field and* repens *in intermediate conditions. They also differed in the way they reproduced:* acris *exclusively by seeds,* bulbosus *by germination of the little subterraneous bulb, and* repens *mostly by stolons, although also some seed, depending on the conditions that plants were in. They were a fantastic experimental model to make comparative studies on plant demography (population dynamics). Actually it became the first long-run comparative demographic study of plant populations.*

To do the work, I had to select populations in different places on the Henfaes field at the Aber field station of the University College of North Wales (now Bangor University), identify replicates of them and revisit these sites during three years.

The field in North Wales where Jose Sarukhan did his three year research project on buttercup populations



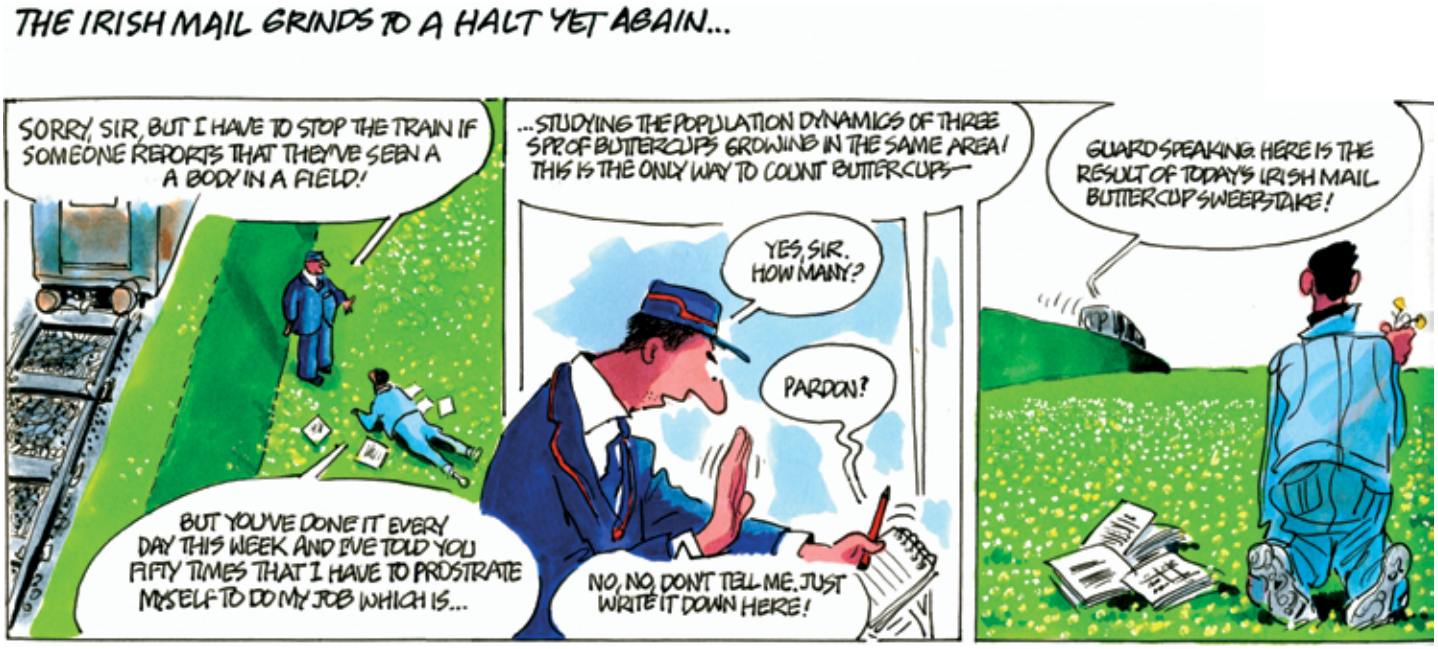


Jose Sarukhan's mapping device (a pantograph) which he used, often in the pouring rain under a greenhouse on wheels, to count all the buttercups in selected sites in the field

I had to adapt a pantograph mapping device for use on a low table that I used as a basis to record all the individuals every time I visited each site. I also had to design and build a portable 'greenhouse' (2×3 m) made of dexion, acrylic sheets and old pram wheels so I could roll it all over the field.

I then had to lie on the ground for long periods to check if every single plant I had recorded was still there, whether it was flowering, fruiting etc. I worked in the field mostly in late spring, summer and early autumn, which were the only relatively decent weather periods without gale force winds and rain.

Adjacent to the field ran the railway that connected Bangor to Holyhead and through which ran many local trains. On one of those occasions of field work, on a nice sunny day which did not require using the rollable greenhouse, during the late afternoon I was startled by someone who had carefully approached the site I was working in so I did not notice him until he was virtually on top of me. I almost jumped due to the surprise, and noticed a look of relief on the face of the person who was looking at me. He asked me what was I doing there on the ground. I said, "Counting buttercups." He questioned me as to what I was doing this for so I explained that I was



Bill Tidy's take on Jose Sarukhan's tale.

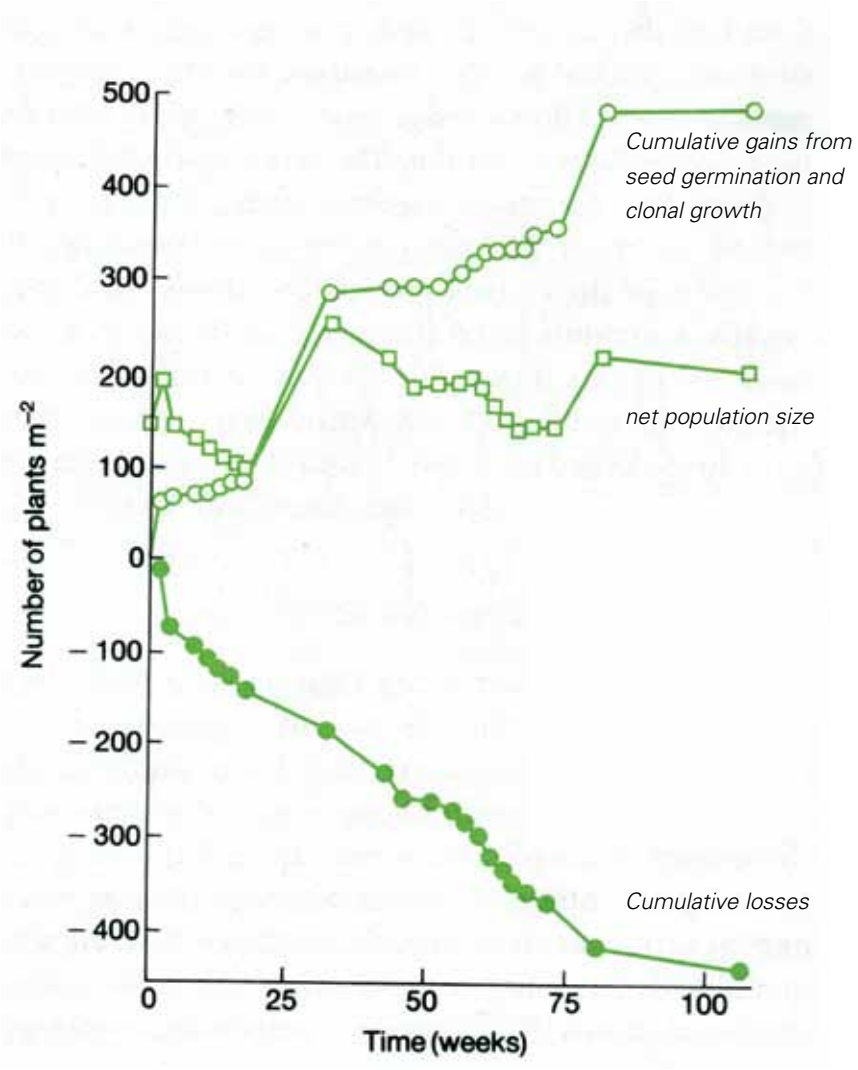
a graduate student, told him my research topic, etc. He then explained that he was the guard on the Irish Mail train. They had passed several hours before going towards Holyhead and they saw a body lying on the ground but did not think much of it; however on their return towards Bangor, they again saw the body and decided to stop the train. He jumped the fence and came to check what was happening. I did not know what to say, whether to apologize for having caused a disruption to the train's schedules or what. He was relieved that all was OK, shook my hand and left. In a small town like Bangor the story started running, reached the School of Plant Biology, and from there, it seems, to many parts of the world.

Jose Sarukhan's study was the first in which changes in populations in plants had been followed over time. As had been found in animals, the populations remain remarkably constant despite much reproduction and death.

Dr Sarukhan went on to be a professor of Ecology, and has worked in a range of institutions in his native Mexico and beyond. On his return to Mexico in 1972 he carried on work on demography, this time of tropical trees, work described by David Ackerly a professor at Stanford University as 'extraordinary and pioneering'. He then went on to found the Institute of Ecology at the National Autonomous University of Mexico (UNAM), described as one of the top five such institutes in the world. He is now president of UNAM with 28 000 staff and 260 000 students! During this time he founded the Mexican National Commission on Biodiversity.

So it was good for the world, ecology and the environment that he really was not dead in that field all those years ago!

Gary Skinner is Biology editor of Catalyst.



Some of Jose Sarukhan's results, showing changes in the population of the creeping buttercup, Ranunculus repens.

The log, returned to its original position after examination.

Black ants *Lasius niger*

Ants are warmth loving creatures and are found in abundance in the tropics. Entomologist EO Wilson said he found one tree in the rainforest with 52 species of ants living in it. There are only just about that many in the whole of Great Britain.

Snak
Tach

Anoth
under
on det
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Common slug *Arion ater* (Orange form)

Over 23% of all known marine animals belong to the phylum Mollusca, but there are many examples on land too, the slugs and snails being the most familiar.

Ground beetle *Harpalus a*

Asked what could be inferred about
study of His works, the British scient
have replied, "He has an inordinate
least 350 000 species on Earth and
these are ground beetles (Carabids)

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Life under a log

The damp ground under a fallen log provides a suitable environment for many invertebrates. Photographs: Gary Skinner.

ke millipede *ypodoiulus niger*

er millipede. They are common logs and stones because they feed ritus, which is abundant here, ey like damp paces.

Flat-backed millipede *Nanogona sp.*

There are two major groups of many legged invertebrates found under logs and stones, the Millipedes (seen here) and the Centipedes. Millipedes are quite slow moving and feed on detritus, centipedes by contrast are fast moving predators, some of which have venomous sting.

ffinis

the work of the Creator from a ist JBS Haldane is reported to fondness for beetles." There are at over 6000 in the UK. Over 300 of like this one.

Common slug *Arion ater* (Black form)

AJ Cain and MH Williamson said in a paper in 1958, "One of the most difficult problems in the systematics [naming] of British terrestrial molluscs is the proper assignment of all the colour varieties of the large slug Arion." Under this log there are least three which might look like different species. Why aren't they?

A glimpse through the basement window

Luccombe Down on the Isle of Wight

An idyllic country scene, like the one above, is well known to most of us. We can see the trees and some of the smaller plants, and fairly easily imagine birds, small mammals, butterflies and other insects out there. What is much less well known is the life beneath the scene, in the soil.

One of the simplest and most productive ways of having a look into the life of the soil is to search for it under logs and stones lying on its surface. The centre spread (pages 10-11) shows an overturned log and gives an idea of both the variety and abundance of life which can easily be seen here. Represented are slugs, ants, beetles and millipedes, and you might be able to see some other creatures if you look carefully at the photograph.

Also often found in this habitat are woodlice, centipedes, spiders, earthworms, earwigs, ants and even, on occasion, some vertebrates such as newts. If you go looking for animals under logs and stones, remember this is their temporary or even permanent home, so please put the log or stone back in place when you have finished.

Gary Skinner is Biology editor of Catalyst.

Woodlice *Porcellio scaber* with the ground beetle *Abax parallelepipedus*.

Many stones, especially flat ones, have ants' nests under them.

A centipede *Lithobius forficatus*, Very common under logs and stones.

Bob Ford/Nature Portfolio

The woodlouse-eating spider *Dysdera crocata*.

European newts spend most of their adult life on land, only breeding in water. Outside the breeding season (February to June) they are often found in damp places such as under logs and stones.

Artificial photosynthesis

Sarah Mackintosh

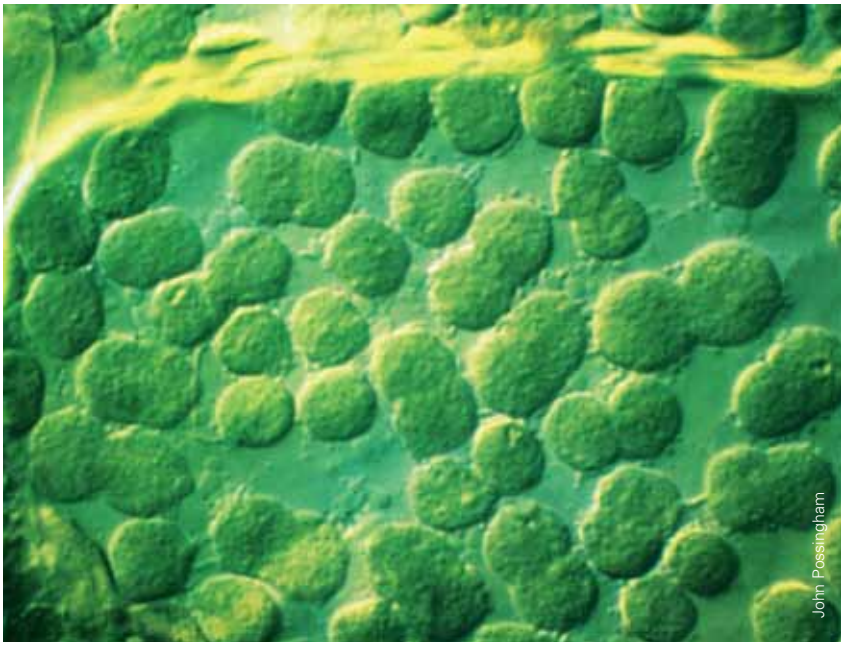
Key words
photosynthesis
chloroplast
photocatalyst
reduction

Trees and plants use sunlight to convert CO_2 and H_2O into sugars and O_2.

We are using up fossil fuels and emitting carbon dioxide into the atmosphere – these two problems combined are likely to cause increasing tension worldwide in the coming decades. Here, ***Sarah Mackintosh*** *describes one promising solution to both issues.*

After a cold winter, global warming may seem irrelevant, but there is no doubt that the climate is changing. This is primarily to do with the amount of carbon dioxide (CO_2) that we are emitting into the atmosphere causing an imbalance in the carbon cycle. The CO_2 level in the atmosphere has risen from a pre-industrial level of 270 ppm (parts per million) to the current level of 379 ppm.

At the same time, our fossil fuel supply is beginning to run short; this may be a good thing for our atmosphere, but it is bad for us. There are many solutions to these problems including using alternative sources of fuel or storing the CO_2 underground. However, as yet we have not found a renewable source to provide enough energy for the world and we have not been able to store 100% of CO_2. It looks as though we will be reliant on fossil fuel for some time to come and we will still need to try to deal with the amount of CO_2 emitted. One promising option to these problems is to 'recycle' the CO_2, by breaking the CO_2 molecule up into different fuels such as methane (CH_4) or methanol (CH_3OH).



Chloroplasts in the leaf of a green plant absorb light and use it to turn carbon dioxide into more complex and useful molecules. Some of these chloroplasts are dividing.

Photosynthesis

The idea of recycling CO_2 comes from nature. During the day, plants absorb CO_2 and produce O_2 through the process called photosynthesis. Plants utilise sunlight and a natural catalyst called chlorophyll to produce sugars and O_2 by oxidising H_2O and reducing CO_2. The reactions are:

$$6CO_2 + H_2O \text{ (+ light energy)} \longrightarrow C_6H_{12}O_6 + 6O_2$$

carbon dioxide + water (+ light energy) ⟶ glucose + oxygen

Reducing CO_2 means removing the oxygen from it.

Energy conversion efficiency is ratio of the useful energy output to the energy input. The higher the efficiency, the more energy is converted into a useful form.

However, the energy conversion efficiency of natural photosynthesis is relatively low. The efficiency limit of energy conversion is about 6%, but is usually as little as 0.8%. Scientists are looking into the use of artificial catalysts which are activated with sunlight (photocatalysts) to try to increase this level of efficiency.

Sounds good so why aren't we doing it?

CO_2 is a relatively inert and stable compound, and therefore it's very challenging to try to break up or reduce it. Semiconductors are the most suitable photocatalysts for CO_2 reduction because they are best able to reduce CO_2 into fuels such as methane or methanol. The equation below shows the reduction of CO_2 into methanol and oxygen. Unfortunately the reaction is not favourable, so even by utilising the catalyst the fuel yield is very low.

This equation shows the reduction of a single molecule of CO_2 . If you are not happy with the fraction 3/2, try multiplying each term by 2.

$$CO_2 + 2H_2O \xrightarrow{\text{light}} CH_3OH + \tfrac{3}{2} O_2$$

carbon dioxide + water $\xrightarrow{\text{light}}$ *methanol + oxygen*

If the fuel yield can be improved, the photocatalyst can be utilised in direct sunlight, thus keeping energy costs low. There are a number of different types of photocatalyst and whilst they are all activated by light, some are activated by the UV spectrum of light and some are activated by visible light.

Titanium dioxide-based photocatalysts have been used in much of the research for CO_2 reduction because they are widely available, low in cost, very chemically stable, have high photo-catalytic activity and are resistant to corrosion. A great deal of the research carried out in photocatalysis has been completed in Japan, Taiwan and here at Nottingham University.

Testing the reactions in a laboratory

In order to test and improve CO_2 reduction, experimental work is carried out in a laboratory. Small reactors are used to contain the photocatalyst and the CO_2. Artificial light sources are used in the laboratory so that the energy source, whether it is UV light or visible light, can be isolated, thus reducing the number of variables in an experiment. The fuel produced in the experiment is collected and analysed in a gas chromatograph.

Look here!

You can read Sarah Mackintosh's earlier article on carbon capture here:
http://www.sep.org.uk/catalyst/articles/catalyst_20_4_451.pdf

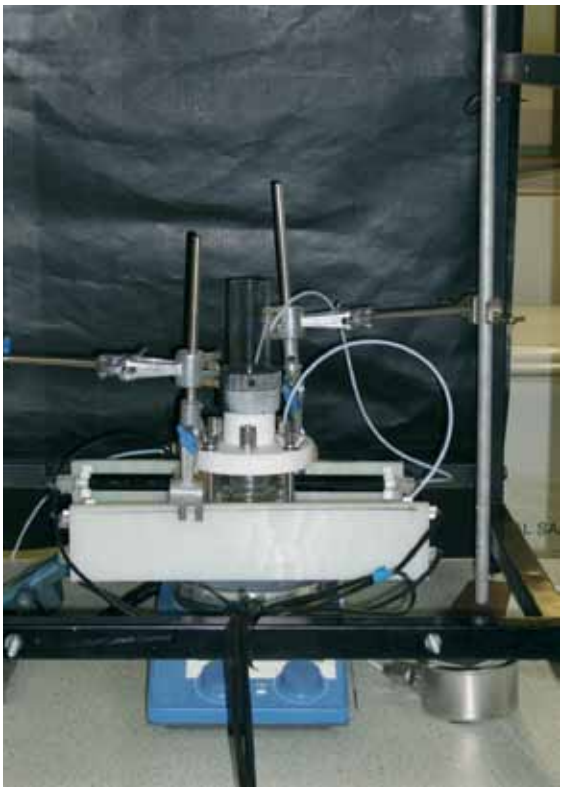
Find out more about the work of the National Centre for Carbon Capture and Storage at *www.ncccs.org.uk*

Current research

The activity of the photocatalyst can be enhanced by metal 'doping', which means that a metal is added to the surface of the catalyst to change its properties very slightly. A great deal of research has been carried out at Nottingham University to test different metals and different amounts of metal to enhance the process. These metals include copper, palladium and rhodium which have all been doped onto titanium dioxide. However yields are still low and although titanium dioxide is a good photocatalyst, it is activated by the UV spectrum of sunlight. Unfortunately, sunlight only contains approximately 3% UV light so now the research carried out is more focused towards catalysts which are driven by visible light in order to maximise the use of solar energy.

The type of reactor and the type of support used for the catalyst to carry out the photoreduction is also of vital importance in this process. Maximizing the surface of the catalyst for the CO_2 to react on is imperative to increase the fuel yield. Two-phase and three phase reactors are mainly used in CO_2 photo-reduction, including slurry, optical fibre and monolith reactors.

Much of the research which has been previously carried out at Nottingham has used a 'slurry reactor'. In this reactor, the catalyst is suspended in water in a glass reactor which is then pressurised with pure CO_2. However this reactor has limitations because the catalyst cannot be recycled and the light is not distributed evenly throughout the system.

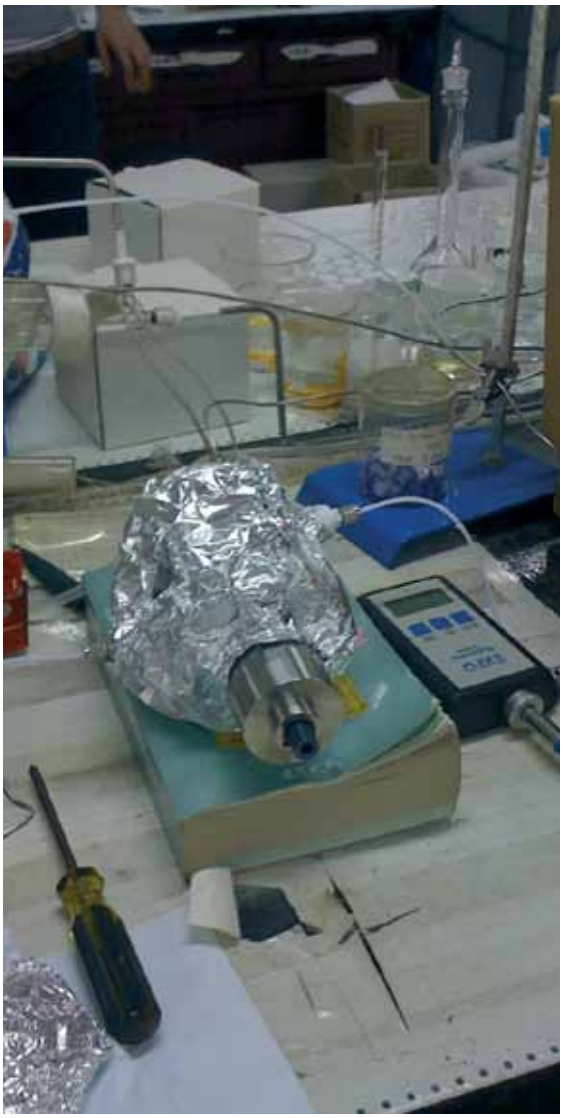


The reactor at Nottingham is surrounded with UV lights. Once the experiment is running all other light is shut out using the black curtains to minimise the variables in the experiment.

An optical fibre reactor incorporates optical fibres for providing light transmission and for the solid support of the photocatalyst. The optical fibres can deliver light uniformly to the photocatalyst surface and consequently increase the efficiency of conversion. However, their configuration does not effectively utilize the entire reactor volume and the catalyst-coated surface area is relatively low since the optical fibre is usually thin.

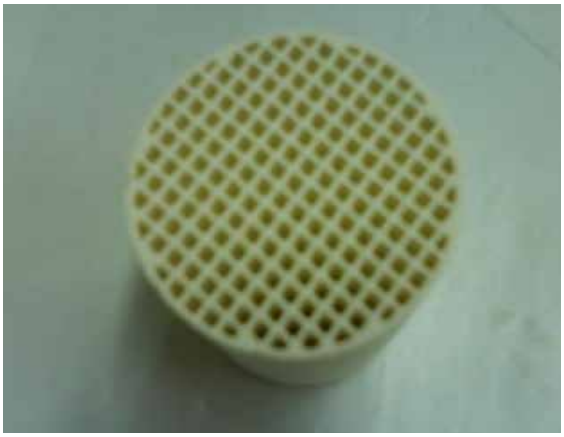
A trip to Taiwan

I recently went to the National Taiwan University to learn about a different reactor with which they have a lot of experience. It is called a monolith reactor. The photocatalyst is coated onto a monolith which is a tube with a honeycomb shape inside.



The monolith reactor is set up differently to the reactor at Nottingham but it can still be used with either UV light or visible light.

This reactor takes advantage of the fact that the monolith has a high surface to volume ratio. However, the efficiency of the monolith is hindered since limited light can penetrate through the cells of the honeycomb substrate so we push optical fibres through the monolith to carry the light to the catalyst.



The honeycomb monolith in which the reactants meet the catalyst.

As you can see, there are good points and bad points surrounding all of the different technologies currently in experiment. There is still much work to be done before CO_2 recycling becomes commercially viable but, once it is, the process will be a low energy option to combat climate change and provide us with fuel.

Dr Sarah Mackintosh is a research fellow in the Centre for Innovation in Carbon Capture and Storage at The University of Nottingham. She has a degree in Environmental Science.

NCCCS

The National Centre for Carbon Capture and Storage

Did you know?

- A semiconductor is a material that conducts electricity but which has a higher resistance than a good conductor such as a metal.
- Photocatalysts are used in many different applications including splitting water to obtain hydrogen, water treatment and in the decomposition of crude oil.
- Titanium dioxide is used in self-cleaning glass and in the disinfection of water.
- Gas chromatography works by using a flow-through narrow tube known as the *column*, through which different chemical constituents of a sample pass in a gas stream at different rates depending on their various chemical and physical properties and their interaction with a specific column filling. As the chemicals exit the end of the column, they are detected and identified electronically. This is a more complex version of paper chromatography, used to separate coloured inks and pigments.

Thomas Lewton

It's life, but much as we already know it

Mono Lake, home to the arsenic-tolerant bacteria. The strange rock formations are made of tufa, a form of limestone.

The controversial paper was published by the prestigious American journal *Science* in its rapid online version, *ScienceXpress*.

"It's life, but not as we know it" beckoned the Sun newspaper's headline last December following NASA's supposed discovery of a 'second form of life'. The scientific paper, published by the eminent journal Science, even created widespread speculation about the existence of extra-terrestrial life.

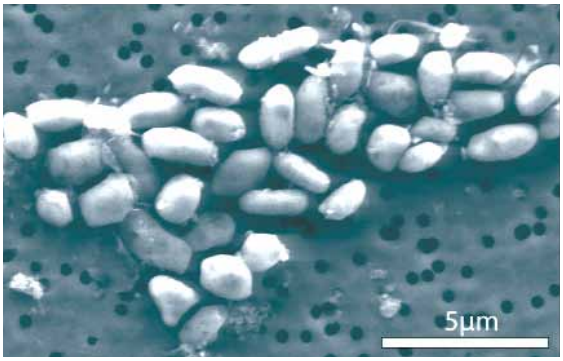
The findings turned out be rather less dramatic. If anything, scientists had discovered a new step in the order of life, rather than an entire new form of life. And that was before serious questions were raised about the scientists' methods.

Alien bacteria?

Researchers studied bacteria from Mono Lake in California, well known for its high concentrations of the poisonous chemical arsenic. Despite being highly toxic to most life, it was found that arsenic could be incorporated into the proteins and even the DNA of the bacteria. Arsenic was thought to be replacing the chemical phosphorus normally found in these molecules.

Life is mostly made up of six simple elements: carbon, hydrogen, oxygen, nitrogen, sulphur and phosphorus. Phosphorus forms the backbone of DNA molecules, the genetic blueprint of life, and is a vital component of the molecule ATP used for energy production in cells.

Arsenic has a similar atomic structure to phosphorus. Both elements lie in Group 5 of the periodic table, meaning they have the same number of electrons in their outer electron shells. This enables arsenic to be substituted for phosphorus in many chemical reactions. But the outer electrons in arsenic are more weakly attached, making molecules containing arsenic less stable than those that contain phosphorus.



A micrograph of bacteria from Mono Lake

Normally this instability stops molecules like DNA and ATP working when arsenic is substituted for phosphorus. This partly explains why arsenic is so poisonous. However, the bacteria in Lake Mono seem to have adapted to produce stable life molecules using arsenic.

The finding raised speculation about whether the unusual bacteria could be classified as a new form of life. Some people believe there could be whole communities of microbes that work using radically different molecular processes from traditional life. These are known as 'shadow biospheres' and could go unnoticed because we only go searching for life that works like our own.

Though the Mono Lake bacteria may use molecules surprisingly different from our own, they still prefer to use phosphorus when given the chance. It is only in the very extreme phosphorus-free, arsenic-rich laboratory settings that the bacteria are forced to use arsenic in their molecules. Rather than a new form of life existing in a shadow biosphere, the bacteria are just a cleverly adapted form of life from the same evolutionary tree as us.

Bad science?

While not exactly being ET, the Mono Lake bacteria were still a profound discovery. They questioned what it was possible for life to be and even extended the possibilities of what extra-terrestrial life could look like.

However, shortly after the publication of the scientific paper a number of prominent scientists spoke out against the findings. Critically, it is known that DNA with a backbone made of arsenic will split when put in water-it is not stable. The DNA of the Mono Lake bacteria was found to be stable in water, suggesting its backbone was actually made of phosphorus. It seems more research needs to be done to justify the claim that the bacteria can replace arsenic for phosphorus in their molecules.

The principal researcher on the project, Felisa Wolfe-Simon, tests sediment samples at Lake Mono.

Peer review – is it reliable?

The flaws in the science were all the more surprising because the paper was published in the well respected journal *Science*. Virtually all scientific research is published in a scientific journal. Before papers can be published they are put through a process known as peer review.

Peer review is a system used by scientists to decide which research should be published. Only research whose claims are supported by the data is meant to get published, but in the case of the Mono Lake bacteria it seems this wasn't wholly the case.

Evidently, peer review isn't a flawless process. It could be that reviewers at *Science,* over-excited about the potentially radical findings of the paper, didn't scrutinise the research enough in their haste to publish.

Felisa Wolfe-Simon (left) and her colleagues announced their findings at a NASA press conference, rather than at a scientific conference.

This isn't the only problem with peer review. Peer review doesn't check the actual scientific data on which the conclusions are based. Scientists are trusted to tell the truth about their measurements, and so peer review is unlikely to detect fraud.

Further, the reviewers of papers are often leading experts from that particular scientific field. It is suggested this could suppress ideas which disagree with mainstream scientific thinking. There is also evidence to show that reviewers are more critical of research that contradicts their own views compared to research that is in agreement.

Despite these problems, peer review does stop a lot of bad research getting through the net. The important point to recognise is that peer review is an imperfect process. Published science can be flawed, much like any other subject, and a critical eye should always be maintained.

Thomas Lewton is studying science communication at Imperial College London.

Eimear O'Carroll

Key words
sound waves
hearing loss
tinnitus
cochlea

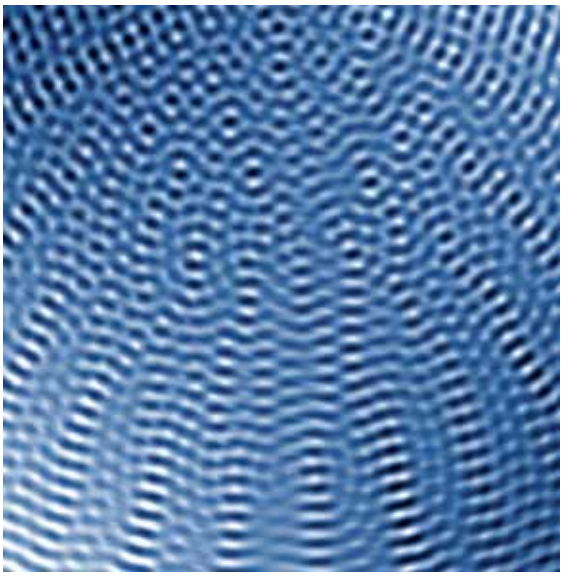
Can you hear me? I said, Can you hear me?

Loud music can be fun, but it can also be harmful.

Hearing loss is usually associated with the elderly, straining to hear the TV while turning up their hearing aid. As a teenager losing the ability to hear correctly seems decades away but hearing loss is increasingly becoming a problem for young adults and teenagers. ***Eimear O'Carroll*** *explains why.*

How many of your friends own an mp3 player? Or go to a club or disco every weekend? Or queue for hours to be right at the front when going to see their favourite band in concert? It is exactly these activities that are contributing to the rise in hearing loss and that may create a deaf generation in thirty years time. A study carried out at Children's Hospital Boston found that 1 in 5 teenagers in the USA now have mild hearing loss, a staggering figure for people so young. They also showed that this figure has risen by nearly 5% in the last 20 years as they tested from 1988-94 and again in 2005-06.

Hearing loss can occur in many different ways. At concerts the main factor involved, which most people know, is your proximity to the speakers. However there are other important issues like the interference of sound that is coming from multiple speakers, when the sound waves combine and either add or cancel each other. This creates loud and quiet patches in the room. And the rain is not the only thing to think about when going to an outdoor concert, the sound has no walls to reflect off, like it would indoors, so there are no reflected sound waves that would also add to the loud and quiet spots.



This image shows how sound waves from multiple sources interfere with each other to produce louder and softer regions.

Similarly the volume that you listen to music on your iPod or mp3 player at is one of the obvious factors that contribute to noise induced hearing loss but it is not the only one. Your headphones make a big difference too due to the varied levels of sound intensity. Sound played through inner ear headphones will do more damage to your hearing than the same volume through outer ear headphones. Intensity is a measure of the power per unit area and the more intense the sound the more harmful it is to the sensitive sound receptor cells in the inner ear.

In all cases, the length of time that you are exposed to the loud music is a critical factor in the damaging of your hearing. At a typical rock

concert the sound intensity is around 120 decibels, dB. This means that if you're about 20 metres away from the stage you can only stay there for two hours before your ears begin to be damaged. You may not feel like the music coming from your mp3 player is too loud but it may not be safe to listen at that volume for a long period of time.

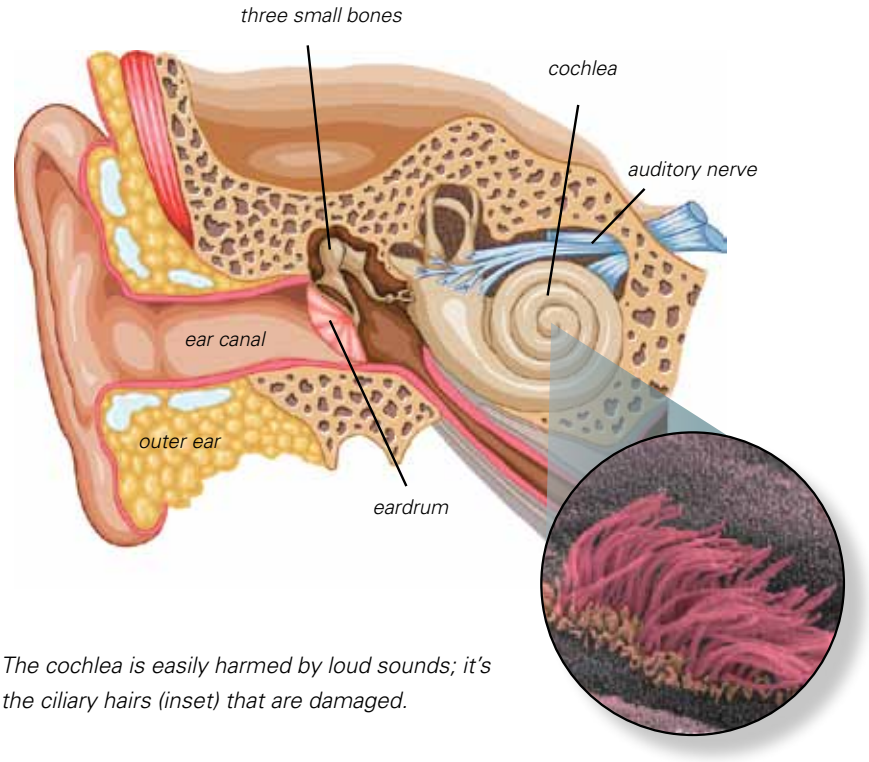
The problem of hearing loss has now entered the sporting world with the emergence of the vuvuzela at the South African World Cup in 2010. The growing phenomenon of the use of the vuvuzela horn at the World Cup and other sporting events around the globe, including football matches here in the UK, will see sports fans suffering from hearing loss and ringing in the ears in the same way concert goers currently do.

Playing a vuvuzela in Cape Town Stadium, June 2010

How the damage is done

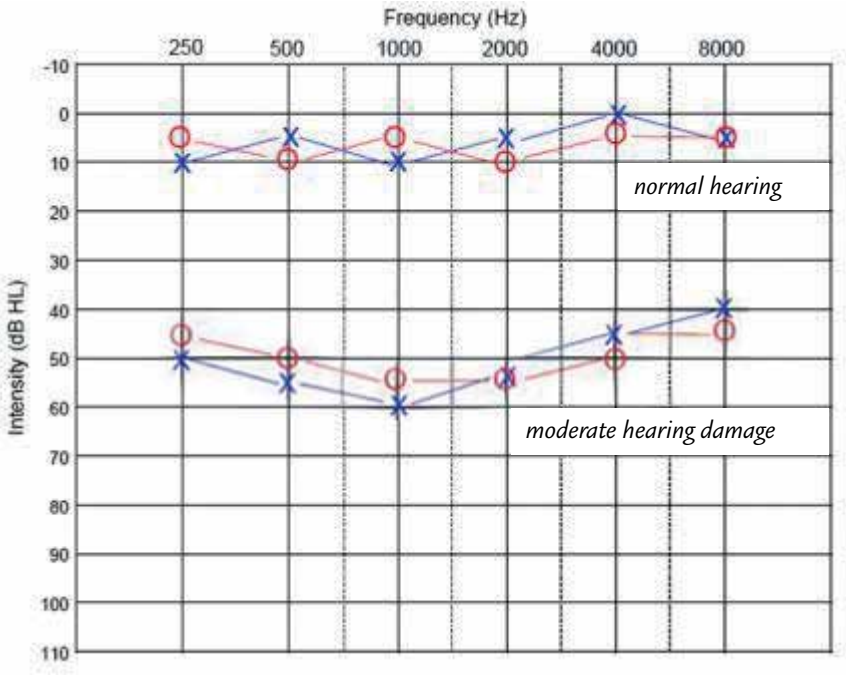
The cochlea in the inner ear contains the sound receptor cells that are like little hairs. These hairs move in response to sounds and their movements are converted to electrical signals and sent to the brain where they are interpreted as sound. When you listen to loud music or are in a noisy environment the cochlear hairs get bent or in extreme cases broken. These damaged cells cannot receive the sound as well as they usually would and they also interfere with each other.

This interference is interpreted by the brain as sound, even in the complete absence of sound, and frequently manifests itself as ringing in the ears. This ringing in the ears, called tinnitus, is one of the signs that you have done damage to your hearing. Tinnitus is one of the most common complaints of modern day living and it is regularly experienced after concerts, discos and listening to your mp3 player at high volumes. In 2008 I carried out a survey on 12–40-year-olds to discover their habits in relation to hearing and sound protection. 92% of them have experienced temporary tinnitus at some point after attending a noisy event like a concert or disco or working in a loud environment, a truly staggering figure.



The cochlea is easily harmed by loud sounds; it's the ciliary hairs (inset) that are damaged.

Along with ringing in the ears other signs that your hearing is not as good as it once was include not being able to hear high frequencies and finding speech difficult to comprehend. The normal range of human hearing is between 20 and 20 000 hertz, Hz. As people get older they lose the ability to hear the top portion of frequencies, this is usually 17 000 Hz and above but varies from person to person. Startlingly this loss of high frequencies is now being observed in teenagers and young adults. There has been no conclusive study done on this yet, but one of the strongest hypotheses is that the increased usage of mp3 players at high volumes is doing damage to teenagers' hearing.



Audiograms show how well people hear at different frequencies. X = left ear, O = right ear.

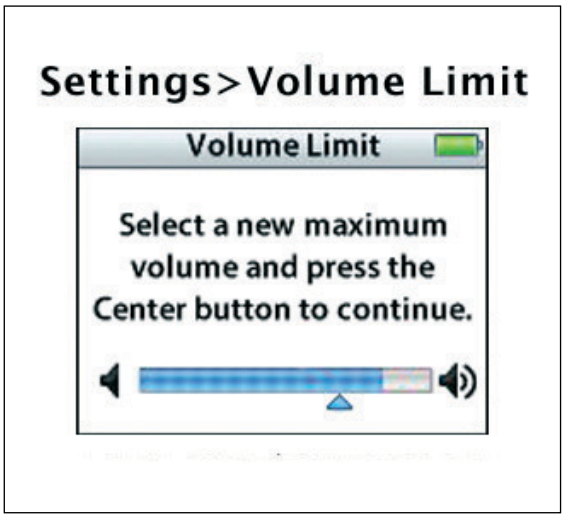
Caring for your hearing

Hearing loss can be prevented by taking a few simple steps towards protecting your ears. The safest option is to avoid loud noise entirely but this isn't always practical.

When attending concerts or discos it is a good idea to use a pair of earplugs. The music will still be loud enough for you to hear it but you won't incur the same levels of damage that you would without the protection. If you're trying to avoid ringing in your ears the next morning you won't want to be dancing beside the speakers when you're out at the weekend.

When using your mp3 player try not to listen at too high a volume. Try using the volume limiter, which is on most devices, to prevent you from turning up the volume beyond a safe level. Switching your headphones from inner ear headphones to outer ear headphones can reduce the sound intensity levels that your ears are subjected to.

Earbuds – more likely to cause damage than outer ear headphones.



Here's how to reduce the risk of hearing damage from an iPod.

If you work in a noisy environment it is the law that your employer must provide you with hearing protection depending on the intensity of the sound and the length of time for which you will be exposed. Even people who work in bars and clubs would also be advised to wear hearing protection if the music is particularly loud. Similarly if you play a musical instrument or are in a band you should use earplugs when performing – many classical musicians complain of hearing loss at an early age, it's not just the rockers that have all the fun!

Noise is a workplace hazard.

The recent publicity about hearing loss among teenagers provides some sobering facts about the decrease in auditory ability in young people. However by highlighting this issue and by informing young adults about the dangers of high intensity sound it is possible to change attitudes and form healthy hearing habits that you can carry into the future. Small and simple measures like wearing earplugs at a concert can make a big difference in both the short and long term. Our society seems only to be getting louder so by tackling the issue of hearing loss now we can aim to stop the deaf generation.

Eimear O'Carroll is studying Physics at Edinburgh University.

Look here!

You can read Eimear's previous article about temporary tinnitus and its cure here:

http://www.sep.org.uk/catalyst/articles/catalyst_20_4_455.pdf

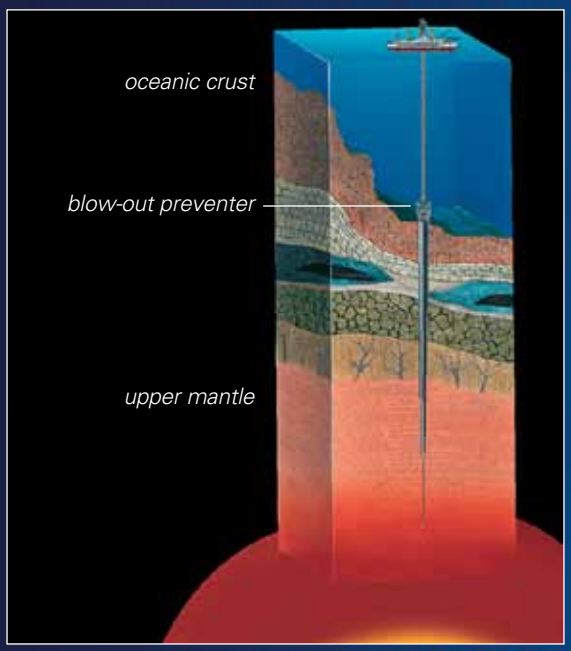
Representatives of the music industry have joined forces with the UK Health and Safety Executive to produce Sound Advice:

http://www.soundadvice.info

Drilling down
Inside the Earth

What's it like inside the Earth? From seismological evidence (mostly from earthquakes), we know the general structure of the Earth's interior. Now, geologists are excited by the first results from the Japanese drilling ship Chikyu.

Chikyu is capable of drilling down through the seabed, where the Earth's crust is thin, and into the mantle beneath. What's more, Chikyu is targeting areas where there is seismic activity. This may reveal more interesting data about the changes which lead up to an earthquake.



Chikyu can drill down through the Earth's crust, into the mantle, to a depth of 7 km below the seabed.

Analysing samples

Long samples or 'cores' are brought back to the surface and examined in a number of ways.

Core samples must be handled carefully to avoid contamination.

Close examination of a core can reveal the presence of microorganisms living deep inside the Earth's crust.

Cores can be studied using a CT X-ray scanner, similar to those used in hospitals.

These microbes were recovered by Chikyu from the Mariana Trench, the deepest point in all the Earth's oceans.

This core shows the exact point where a geological fault lies between two layers of rock.

At sea with Chikyu

The Japanese drilling ship Chikyu is part of an international project to investigate the Earth's crust and mantle.

The view from the top of the tower.

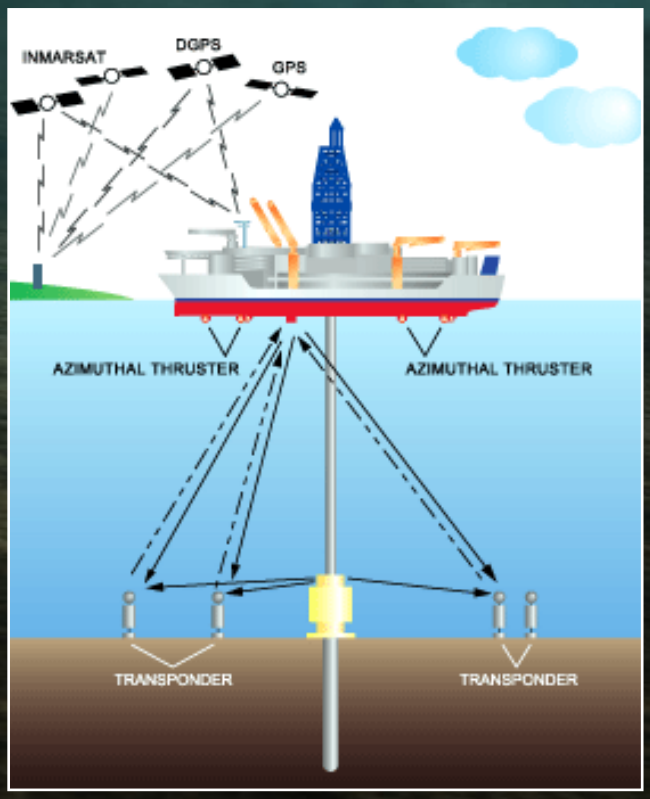
The central drilling tower is over 70 m high. It can raise a load of 1250 tons.

Over 200 people – crew, scientists and engineers – work on Chikyu. They can come and go by helicopter.

The drill pipe is made in sections which can make up a total length of 10 000 m.

Thrusters, capable of rotating through 360°, keep the ship in position.

The ship's position is monitored using signals from GPS satellites above and from transponders on the seabed.



Drill bits capable of boring through solid rock.

►►►►► Follow Chikyu's progress at *www.jamstec.go.jp/chikyu*