Catalyst

Secondary Science Review

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Testing the ice
Persistent pollutants in the Arctic

SEP
Science Enhancement Programme

Catalyst

Volume 25 Number 3 February 2015

The cover image shows Melinda Webster of the University of Washington, USA, walking on sea ice near Barrow, Alaska in March 2012. Her probe tests the thickness of snow covering the ice; her backpack holds electronics that power the probe and record the data. Photo: Chris Linder / Univ. of Washington

Contents

The environment issue

This issue of Catalyst includes several articles on an environment theme. Human influences are causing rapid change and it is scientists who can help us to detect these changes and suggest ways in which they can be mitigated.

Organic substances used in agriculture and industry turn up in the Arctic (pages 1-3). The demand for palm oil, used in processed foods, leads to the destruction of tropical forests (pages 4-5). Extraction of natural gas can release poisonous mercury, but ionic liquids have provided a means to remove the hazard (pages 9-11). Farming in temperate zones can alter the intricate relationships that make up a food web (pages 20-22).

In each of these articles, professional scientists describe their work and show how a detailed understanding of biology and chemistry can help us understand and improve the environment.

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The Catalyst archive

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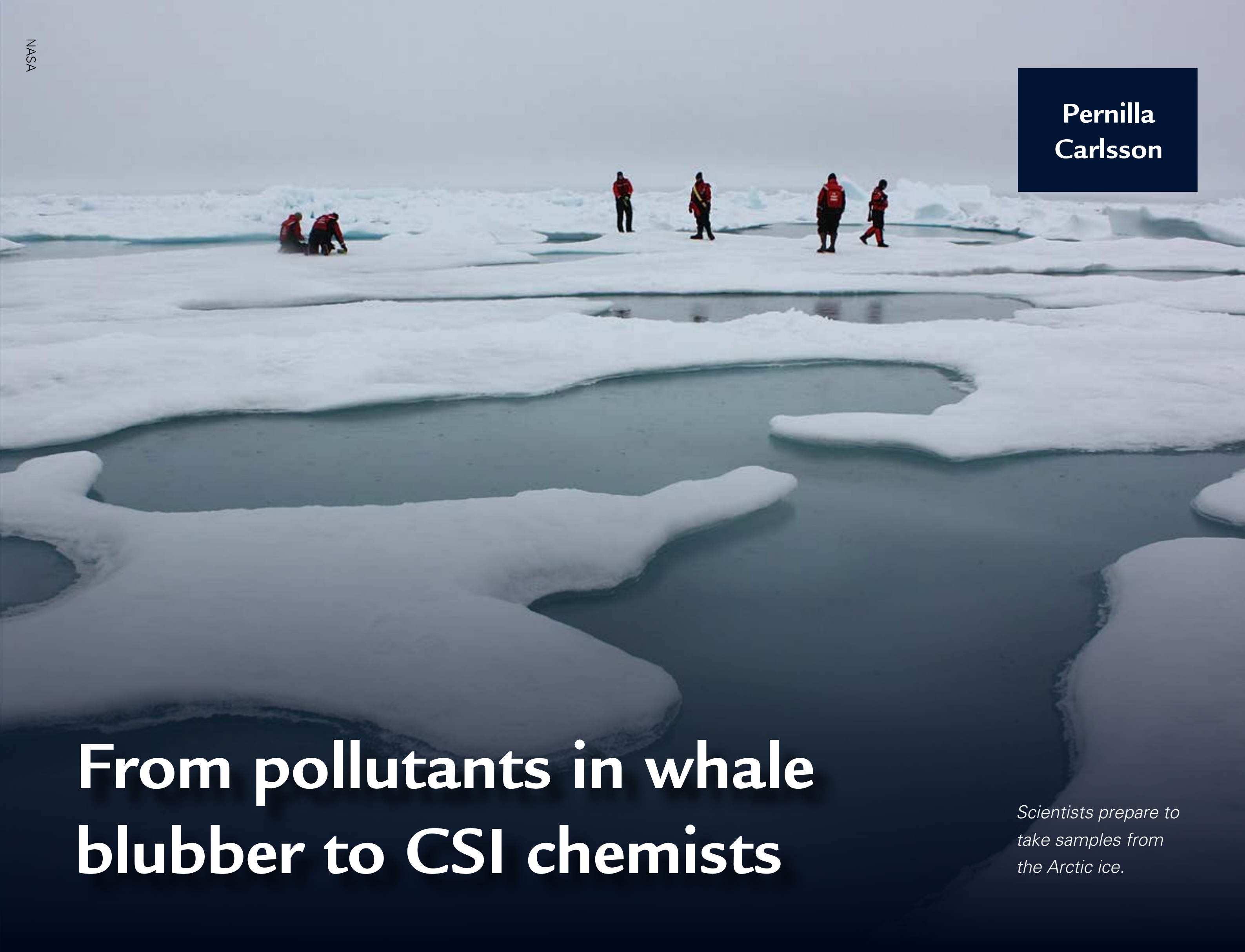

NASA

Pernilla Carlsson

From pollutants in whale blubber to CSI chemists

Scientists prepare to take samples from the Arctic ice.

Key words
pollution
organic compounds
food chain
Arctic

Do you eat a lot of whale blubber? Probably not, but if you lived in northern Canada or in Greenland, you would probably have answered 'yes' to this question. In Inuit communities, whale blubber is well known for its health benefits. Today, local food such as whale, seals, fish and seabirds contributes about 20% of the Greenlandic everyday cuisine. Back in the days when it was very expensive and difficult to get fresh vegetables and fruits to Greenland, they had to get vitamins and minerals from somewhere else. Many glands in animals are rich in vitamin C; the testicles can be around 70 mg/100 g, while adrenal glands may contain up to 130 mg/100 g. For comparison, oranges have about 50 mg vitamin C per 100 g fruit.


Jai Mansson

Blubber from a beluga whale, hung to dry in Alaska

Many Greenlanders were very healthy during the early 20th century. Scurvy was not present, and neither was diabetes. However, during recent decades, more and more Greenlanders have accessed Western food, and not only fruit and vegetables, but also soda, chips and sweets. In addition, environmental chemists have begun to discover high concentrations of heavy metals and persistent organic pollutants (POPs) in fatty food from high up in the food chain. So, not only did people get access to sugar-rich food, they also became aware of recent risks with their traditional diet.

Persistent organic pollutants

POPs are man-made, toxic and very stable molecules which accumulate in fatty tissues. This means that, once out in the environment, they stay there for a long time. POPs biomagnify in nature, meaning that the higher up in the food chain the higher the levels of POPs will be.

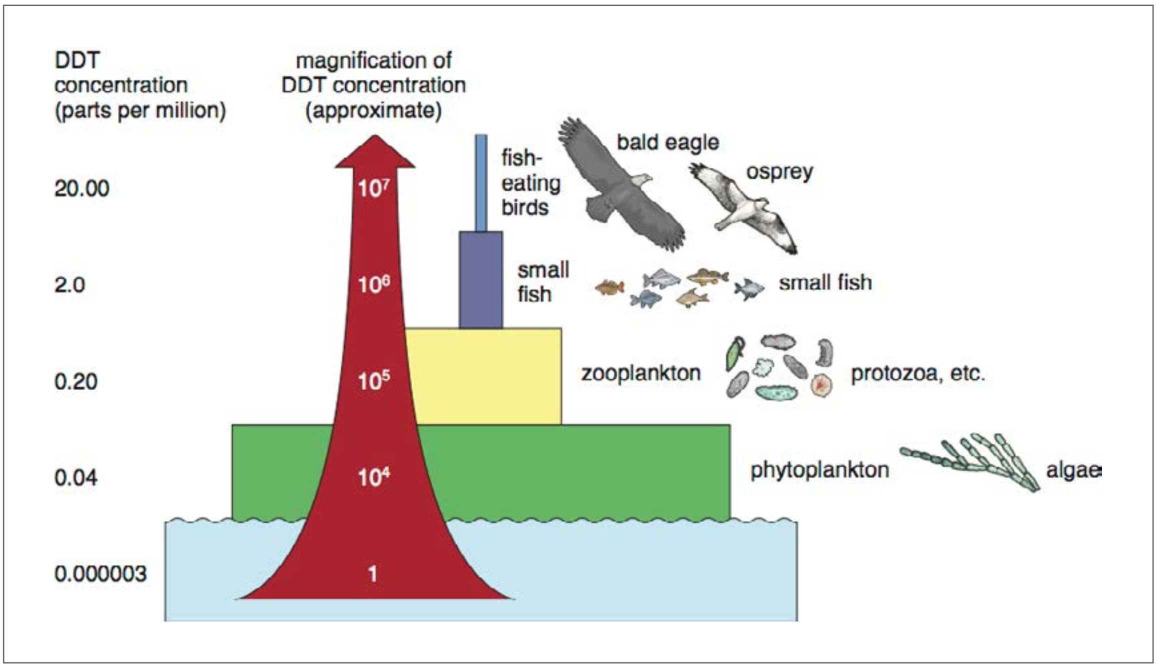
Some of these compounds were used as flame retardants or pesticides while others are by-products formed during combustion. In 2002, several countries signed the Stockholm Convention and promised to phase out these compounds and ban production. This was good news for everyone

– not only for those who ate lots of whale blubber and fish, but also for you and me, because we are exposed as well.

POPs are quite volatile and can be transported long distances. This means that POPs will evaporate from southern areas where they are used and move all the way up to the Arctic. The Arctic food web is very fatty – if you want to survive the cold, harsh conditions here, you had better have some extra insulation. This is perfect for the POPs and they will bioaccumulate in the fat of plankton, via fish to marine mammals and to humans. The molecular structure of POPs is similar to some of our hormones, and they can therefore disturb our hormone systems. Children and foetuses are especially vulnerable and since POPs stay in your body for a long time, so that young women who eventually want to give birth are vulnerable too.

biomagnify throughout the food web. In addition, old POPs are being replaced with several new chemicals. The world still needs flame retardants and insecticides. Several new compounds are now being found in Arctic air and in animals. Screening for new substances in Arctic animals reveals compounds from Gore-Tex jackets and frying pans in polar bears, and compounds from deodorants have been found in the air of the Arctic archipelago Svalbard at 79°N.

In addition climate change affects transport of POPs, both to and within the Arctic. Higher air temperature can lead to evaporation of heavier molecules than before. Run-off of melting water drains the soil and snowcaps of buried POPs and transports them out to the ocean. However, higher temperatures can also lead to increased degradation of these compounds.



Biomagnification of a pesticide (DDT) along a food chain from phytoplankton to eagles and ospreys. Tiny amounts which would be harmless to the birds are magnified to harmful levels. Source: SmartScience: KS3 Student's Book

Thanks to bans around the world, concentrations are decreasing in nature and so there are fewer restrictions on eating certain types of fish in countries such as Norway. Food advice in Greenland and northern Canada focuses not only on the risks associated with POPs in whale and seal blubber, but also on the benefits of nutrients and the social aspects of eating traditional food. Advice nowadays is to be a bit more careful with food items such as liver and blubber from marine mammals when you are young, pregnant or planning to have a baby, while if you are older, or a man, you can eat more of these food items.

Novel chemicals

Sadly, this is not the end of the story and environmental chemists are facing new challenges. POPs that were produced before the bans still leak from land to the marine environment, where they

To detect new compounds in the Arctic, chemists are using very sensitive instruments. We want to find out how these compounds behave in the environment, preferably before any environmental damages happen. The instruments can analyse trace levels and operate at the picogram scale (10^{-12} g). Samples have to be handled very carefully to avoid contamination because many of the new compounds are present in everyday life. This is why we go to remote areas to sample, wear gloves and leave our Gore-Tex jackets at home. To find out if, and how, chemical compounds accumulate in the Arctic marine food chain, we dive under the sea ice and collect plankton living there. Air samplers have been erected in remote areas, such as Zeppelin station in Ny-Ålesund, Svalbard, and we go to the local market to buy everyday food to find out how much POPs it contains.

Ice diving North of Svalbard on an research expedition with Norwegian Polar Institute

This map shows several bases used for scientific studies of the Arctic environment. Pernilla has worked on Svalbard, a Norwegian archipelago.

Students at UNIS (UNiversity Centre in Svalbard) putting out baits for amphipods (small, benthic crustaceans) that will be analysed for POPs)

Field data from my research showed that pesticides can be stored in snow packs and ice in the Arctic, but arethey will be washed out to the ocean when the snow melts. We could also use the distribution pattern of some pesticides in zooplankton to investigate relevant processes for uptake of POPs. The contribution of POPs from the air and ocean currents is important for the amount of POPs we find in zooplankton, but also what comes from land. Some POPs that are first buried in the sediment can be released some years later to the water again.

Finally, the levels of newer POPs, e.g. perfluorinated octane sulfonate (PFOS) and polybrominated diphenyl ethers (PBDE), were low in selected fish and marine mammals from the west coast of Greenland. So, you can keep on eating fish for dinner!

Pernilla Carlsson is an environmental and analytical chemist working at the Masaryk University, Brno, Czech Republic.

David Edwards
conservation biologist

Before I even went to school I was obsessed with wildlife. I was the weird kid in the playgroup who could identify all sorts of animals. I blame Sir David Attenborough for making me decide to pursue a degree in ecology (at the University of East Anglia). Those amazing wildlife shows made me want to get out to the tropics and amongst the animals. I took a year out first and worked so that I was able to spend the money I earned going to tropical countries each year during the university holidays. I visited Kenya, Uganda, Ecuador, Sumatra, Java, India, Borneo, India, Madagascar...all in my university holidays.

These experiences helped me to see the difficult situation in which tropical conservation sits and the poverty in which the local people live. When I was travelling in National Parks in Indonesia, people were shooting the wildlife and cutting the trees down even whilst I was there. I also had a number of experiences which you might say were ‘close to the wire’. I’ve been held up at gunpoint in the middle of the night whilst camping on Mount Kenya and was growled at by a tiger 10 metres away in the Sumatran bush. It’s one of the reasons for going – it’s wild and exciting!

Young researcher

After I graduated, I spent time working as a researcher analysing the migration of plaice in the North Sea – not related to the tropics, but it gave me skills in data analysis and made me want to do my own research project, rather than working for someone else. I ended up applying to do a PhD in Peruvian ant-plant mutualism – cooperation between ants and plants in the Peruvian Andes. This meant that I got to go to the Amazon quite a lot!

I then decided to make the jump from a tropical ecologist to a tropical conservation biologist. This took a year and a half of being nominally unemployed – taking the odd short term contract, the odd bit of teaching. Ultimately I did some voluntary work doing a month’s bird surveying in Borneo and this led to a research role looking at how logging impacts food webs, specifically birds. This then moved into studying the impacts of land-use change in rainforests on biodiversity in general.

The data we collect from the field is used to make models predicting how different land-use strategies will affect biodiversity in tropical regions. For instance, is it best to farm intensively over smaller land areas, sparing some wild forests for nature, or is it better to farm less intensively but over a larger area? We also try to consider how we can provide some economic benefit to local people and poor governments and take into account the profit that they could have had by cutting down their forest instead of not.

One solution might be carbon payments. In some areas, such as cattle pastures in the Colombian Andes, agriculture is not very profitable but the local people lack the financial means to move to cities and towns to get other jobs. Our work suggests that secondary forests provide a habitat for much biodiversity and can sequester a lot of carbon. So by paying them to grow carbon, instead of cows, we can help stop climate change and the extinction of biodiversity.

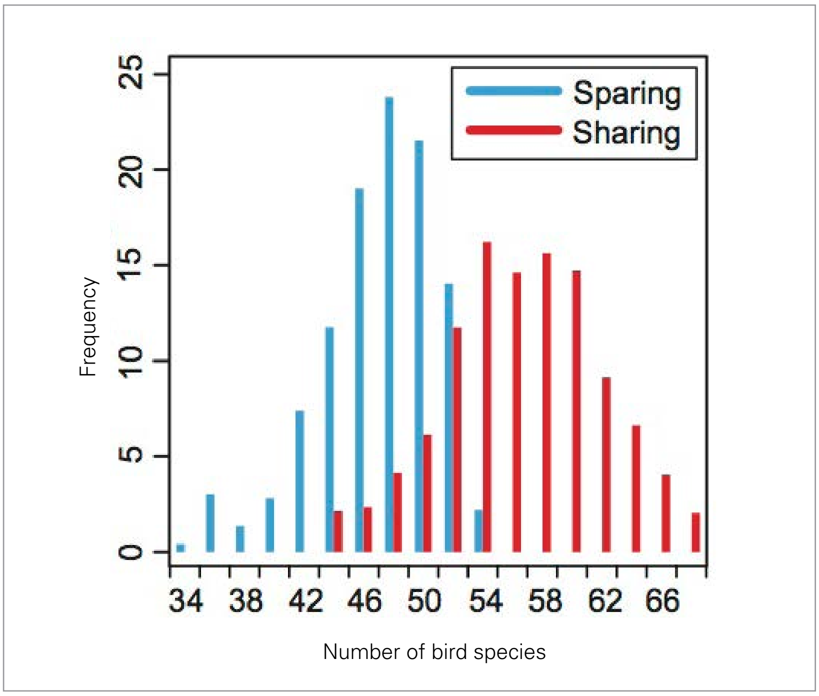
Making models

It takes 2-3 years to make a model. You start with an idea, then you have to get research permissions (which might take 6 months), before selecting your study sites and sampling the biodiversity there. We sample transects for birds, dung beetles, ants, etc. to generate species abundance data for plots in unlogged, lightly-logged and intensively-logged forest. These are used for computer simulations where we randomly extract 3 intensively-logged and 1 unlogged plot (equivalent to a 'land-sparing' strategy) and compare them with the species abundance of 4 lightly-logged plots (which represent 'land-sharing'). We can then total up the number and abundance of species in each simulation to ask whether land-sparing or sharing would be better for biodiversity.

The best part of my job is feeling that I can possibly make a difference to save the biodiversity in these wonderful places. My work has shown that lightly-logged tropical forests still retain much biodiversity and are extremely valuable for most species threatened with extinction, including orang-utans, elephants and birds. Given this fact, in Sabah, Borneo, they have recently protected 250 000 hectares of heavily- and lightly-logged tropical forest (an area roughly 70% the size of Essex).

Logging of tropical forest in Borneo prior to planting with oil palms.

Greenpeace celebrated when Nestlé agreed not to use products from deforested areas in the manufacture of KitKat bars.



Surveys show that there is greater diversity of bird life when farming is less intensive ('sharing') than when separate areas are set aside for wildlife ('sparing').

We have to accept that people will want to use natural resources and require land for food but this needs sensible land use management. Instead of cutting down more trees, we should look at enhancing our yields on existing croplands and placing croplands on areas which have very limited biodiversity.

Playing your part

Consumers *do* have a collective power to bring about change. The key is to aim at large companies – they are the biggest producers and own millions of hectares of former tropical forest in oilpalm, soil and cattle. They have the most to gain from being seen as green or the most to lose from being associated with deforestation. An example is the Greenpeace Nestlé campaign. In response to tens of thousands of people, Nestlé announced that they would no longer use palm oil from deforested areas in their foods. Many people think that these issues are too massive for them to be able to make a difference. But if we as consumers create a market for deforestation-free products, we remove the reason for companies to keep cutting down tropical forests.

To students interested in a career in conservation, I would advise going out and looking for birds, dragonflies or whatever you like, just for fun, speaking to people with similar interests, going on trips in Britain and abroad, volunteering at the local nature reserve – there are lots of things that can build your experience. You have to love what you're doing to work in tropical conservation. But the threats are so great that you know the work you are doing has great value.

Dr David Edwards is a lecturer in the Department of Animal and Plant Sciences at the University of Sheffield, UK.

Maggel Deetlefs
Ken Seddon

Making the world safer

Ionic liquids at work

Hycapure-Hg™ are beads coated with an ionic liquid which are used to capture mercury and its compounds

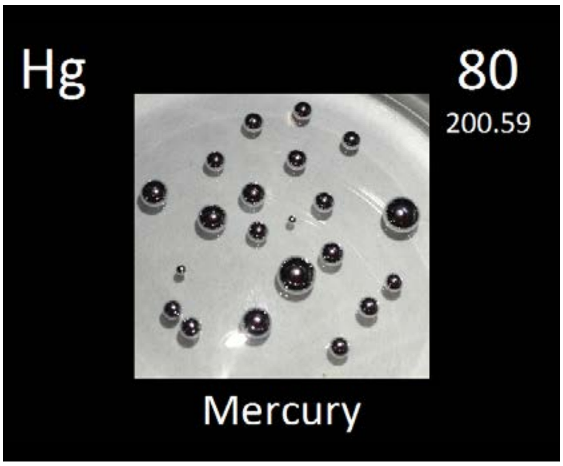
Key words
ionic liquids
mercury
pollution
natural gas

In the last issue of CATALYST, *we looked at the composition of ionic liquids and some of their uses. In this article, we describe how work at the Queen's University Ionic Liquid Laboratories (QUILL) in Belfast is reducing the amount of hazardous mercury entering the environment from the oil and gas industry.*

Natural gas remains an important source of energy. To keep up with our growing energy needs, new natural gas reservoirs need to be used, but they are often contaminated with toxic mercury. In a successful partnership, and in record time, QUILL have developed an innovative, ionic liquid-based technology to remove mercury safely from natural gas throughout the world.

Maddening mercury

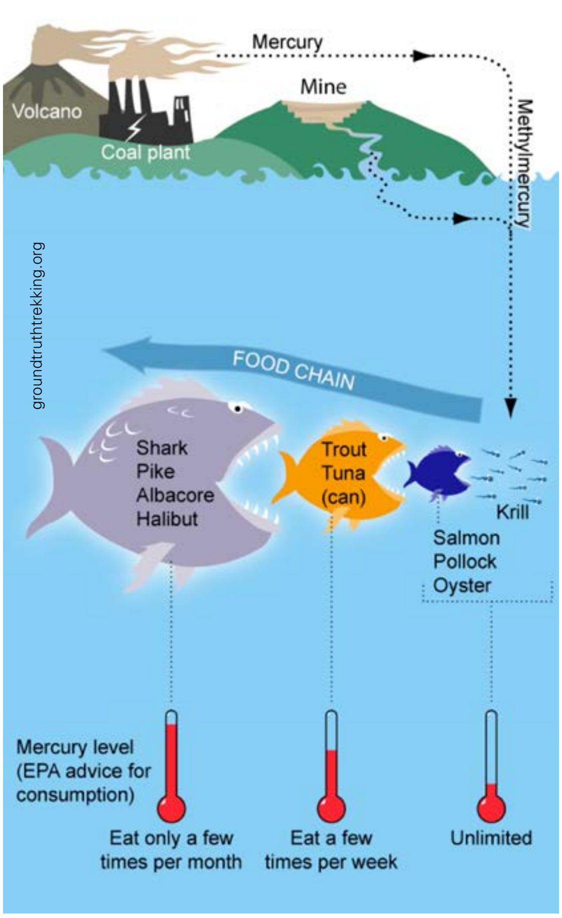
"Oh, you can't help that," said the Cat. "We're all mad here." – The Cheshire Cat in Alice's Adventures in Wonderland by Lewis Carroll



Of all the metals in the periodic table, the visual imagery of mercury is probably the most attractive and also the best known. It is a liquid under normal conditions and an important component of everyday items such as energy-saving light bulbs and laboratory thermometers.

But mercury has a dark side – it is an extremely toxic element in all its different forms. Mercury metal itself has a toxic vapour, but it can also chemically combine with other elements to form organic (carbon-containing) and inorganic (non-carbon-containing) compounds that are toxic too. In its metallic form, it causes 'madness'. Equally distressing, carbon-containing methylmercury found in fish and shellfish (see graphic opposite) causes Minamata disease, a neurological syndrome that affects the nervous system. Inorganic mercury compounds such as the salt mercury(II) chloride ($HgCl_2$) can be toxic to the kidney, stomach and intestines. The bottom line is that mercury, in all its forms, is extremely toxic and exposure to it must be reduced, or if possible, eliminated completely.

The Mad Hatter, as drawn by Sir John Teniel in Lewis Carroll's book Alice's Adventures in Wonderland. In the 19th Century hatters went 'mad' because they used mercury to add a shine to hats.



How methylmercury accumulates in fish.

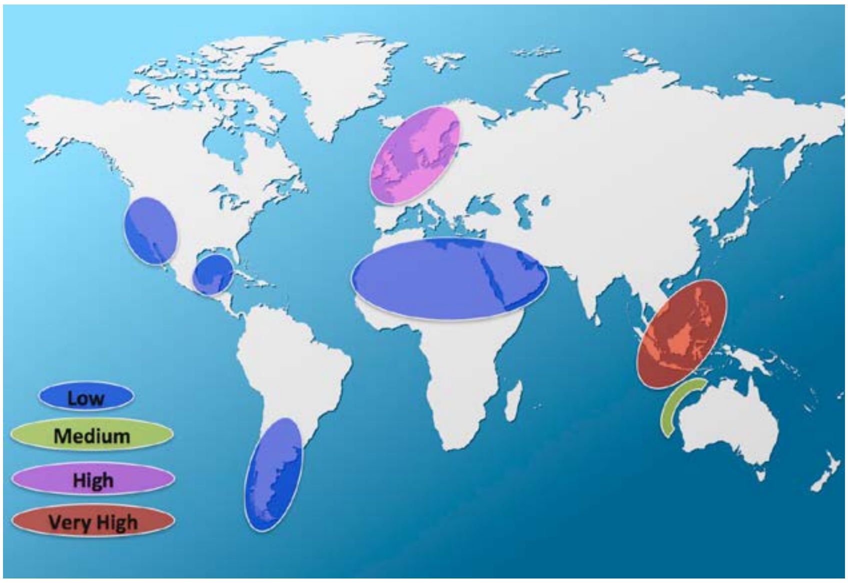
Mercury in natural gas

Alice: *"Would you tell me, please, which way I ought to go from here?" "That depends a good deal on where you want to get to,"* said the Cat.

A less well-known fact about mercury is that it occurs naturally in the Earth's crust – about 10% of all mercury emissions on Earth originate from environmental sources such as erupting volcanoes and natural gas reservoirs. Many different mercury compounds are found in natural gas reservoirs. These cause major health and safety problems for workers on plants, and can also severely damage plant equipment too.

A poignant example of the destructive result of mercury build-up occurred in Algeria in 2004 (see photo top right), when 27 people died in an explosion caused by mercury corrosion of the plant. So, because so many of us rely on natural gas as an energy source, ridding it of mercury is a vitally important global issue. The trouble is that this removal process has been fraught with difficulties and needed a better solution, especially in and around Malaysia, where mercury levels in gas fields can be extremely high (see map on right). Therefore, in a major industry/university team effort, PETRONAS (a national oil company based in Malaysia) and the Queen's University Ionic Liquid Laboratories (QUILL - based at the Queen's University of Belfast in Northern Ireland, UK) worked together to find an ionic liquid solution to remove mercury from natural gas feeds.

The Skikda liquefied natural gas plant in Algeria was destroyed by an explosion caused by mercury corrosion.



Maximum mercury levels in natural gas fields worldwide

Mercury capture using ionic liquids

"Nothing's impossible!" – The Doorknob

Ionic liquids are liquid salts – they consist only of positively-charged cations and negatively-charged anions (see the ionic liquids article in the previous issue). They are ideal for combatting pollution because they cannot evaporate and pollute the atmosphere, and also because they can be tailor-made to suit a wide variety of applications, including mercury capture.

Working closely together, QUILL and PETRONAS designed a new ionic liquid-containing material, now called Hycapure-Hg™, which can capture all species of mercury from 'raw' natural gas without any of the problems associated with older technologies. In less than four years, this material moved from first experiments in the laboratory on the gram scale to an industrial scale application on the ton scale, which has been producing clean gas continuously, in two mercury removal units, since November 2011 (see photos on next page).

The transformation of Hycapure-Hg™ technology from (a) laboratory scale, to (b) 100 g pilot plant scale, and to (c) 15 ton industrial scale

It normally takes about seven to ten years to get a process commercialised in the oil and gas industry. The speed at which our new process was deployed reflects both the simplicity of the process and the enthusiasm of PETRONAS to implement this green technology. Also, compared to other technologies for mercury removal from natural gas, our process absorbs mercury faster and more efficiently, and is also much safer and more economical to use. PETRONAS have recently made our new technology available for use worldwide in a business deal with a speciality chemical company, Clariant, which will make and sell Hycapure-Hg™. The consequence of this is that, globally, release of mercury into the environment from natural gas processing should reduce significantly.

An award-winning collaboration

"EVERYBODY has won, and all must have prizes." – The Dodo

The success of the PETRONAS/QUILL collaboration in developing our mercury removal technology has been recognised in the multiple awards it has won. These accolades include five Institute of Chemical Engineering (IChemE) awards in 2013 and 2014 – in the Institute's awards history, no other entry has achieved this before. We also won the Royal Society of Chemistry's 2014 'Teamwork in Innovation Award'. It is hoped that these accolades will increase the public awareness of the benefits of ionic liquids in general, and herald the way for more exciting developments in the near future.

Dr Maggel Deetlefs is CEO of QUILL and Prof Ken Seddon is Co-Director. QUILL is the Queen's University Ionic Liquid Laboratories in Belfast, Northern Ireland: quill.qub.ac.uk

Look here!

The previous Catalyst article by the same authors about ionic liquids:

http://www.catalyststudent.org.uk/cs/article/378

Mercury as art: Alexander Calder's mercury fountain at the Fundació Joan Miró in Barcelona. See it in operation: https://www.youtube.com/watch?v=Kv3XbKH3-lQ

Tom Lyons

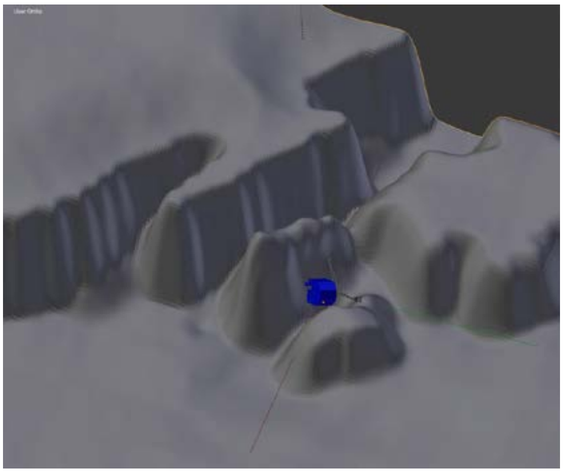
The landing
Philae touches down

In two recent issues of Catalyst, ***Tom Lyons*** *described how the Rosetta spacecraft travelled across the Solar System to rendez-vous with Comet 67P Churyumov-Gerasimenko, and how the landing craft Philae, carrying a payload of scientific instruments, was prepared to descend on to the comet's surface. Now the first results are in from this audacious mission.*

After a 10-year wait, on 12th November 2014, the Philae lander was dropped towards the surface of Comet 67P. Due to the very weak gravitational acceleration of the comet, release to landing took around 7 hours. Compared to a landing on Mars, which from orbit to surface takes nearer 7 minutes, the technology required is far more basic but just as fraught with uncertainties. Rather than being concerned about crashing into the surface, this landing was all about trying not to bounce off.

Anxious scientists await the first signals indicating that Philae has landed safely on the comet surface, 12th November 2014.

Philae had three mechanisms by which it should secure itself to the ground: boosters to prevent bouncing, harpoons to attach to the surface, and drills on its feet, as a final measure. Unfortunately, even before landing, the boosters had failed. Initially, scientists in the control room at Darmstadt announced a successful landing on the surface. After some time, however, it became clear that Philae had bounced. This was in fact a two hour bounce, which took it over 1 km from the landing site. A second, shorter bounce then took Philae to its final resting place, in a shadow at the edge of a crater, next to a cliff, lying on its side – or as some described it 'stuck between a rock and a hard place'.



(top) The Philae lander leaves the Rosetta spacecraft, heading for touchdown on Comet 67P; (left) Philae is awkwardly positioned in the shadow of an icy cliff.

There was then a race against time to collect as much data from Philae's instruments as possible before its batteries ran out of power. The team knew that they had around 60 hours before Philae would get so low on power that it would go into hibernation. The original plan was to try to increase this time by charging the battery from the solar cells, but in its final landing position this was not possible. It is hoped that Philae may awaken again as the comet gets closer to the Sun.

Comet surface

Despite the problems with attaching itself to the surface, the landing was a great success. Philae was able to record data and download this, via Rosetta, to Earth.

The ROLIS camera showed that the surface of the comet was made of pea-sized gravel with some larger pieces mixed in. The top layer appears to have very low strength – crumbling to dust when disturbed.

The surface of Comet 67P seen from just 40 m above the comet's surface. The large block at top right is 5 m across.

The composite photo on pages 10-11 shows the Philae lander as it approached its landing point at 0.5 m/s. You can see where it bounced at 15:43. Each square is 17 m across. Rosetta was 15 km above the comet surface when it took these photos.

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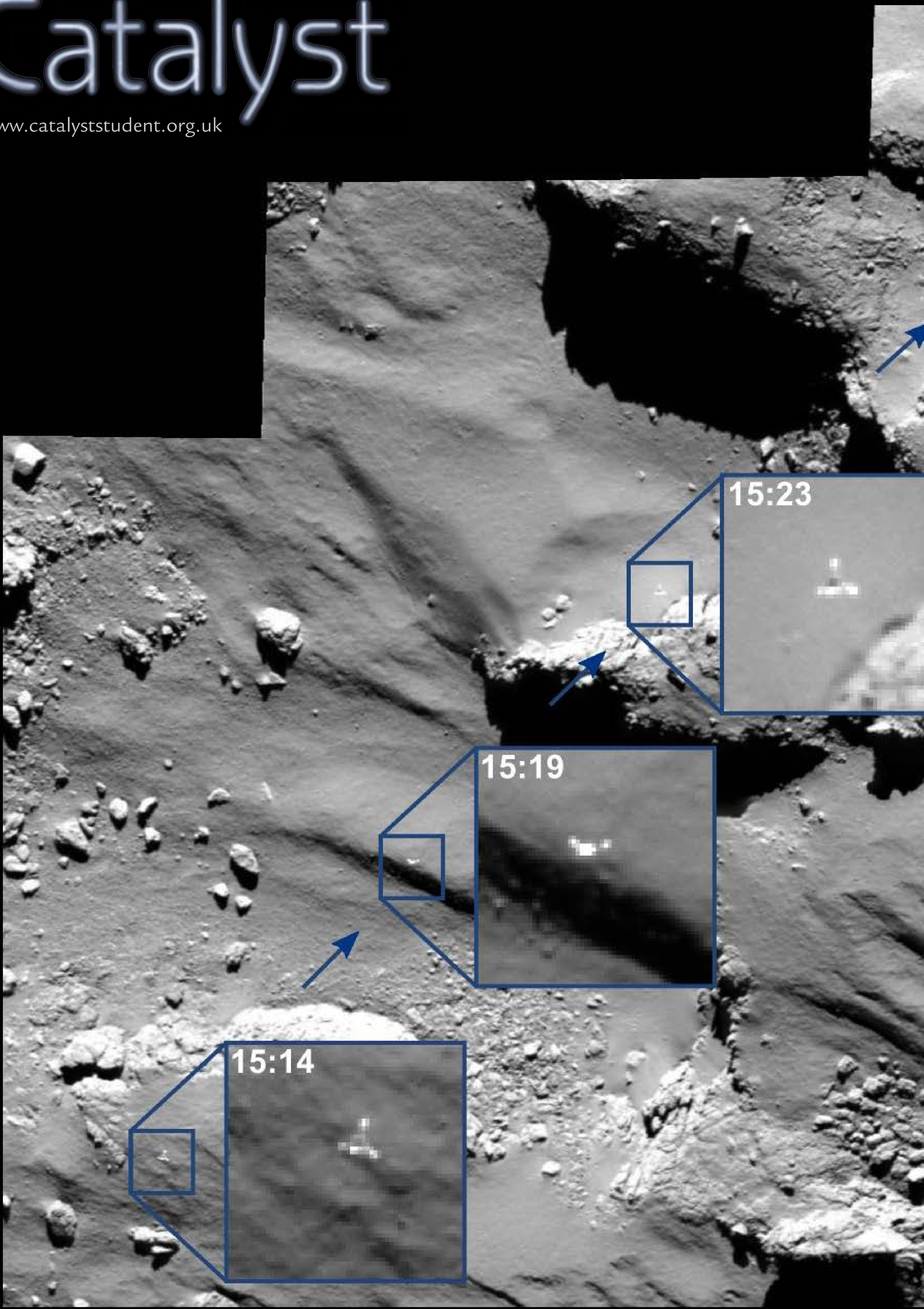
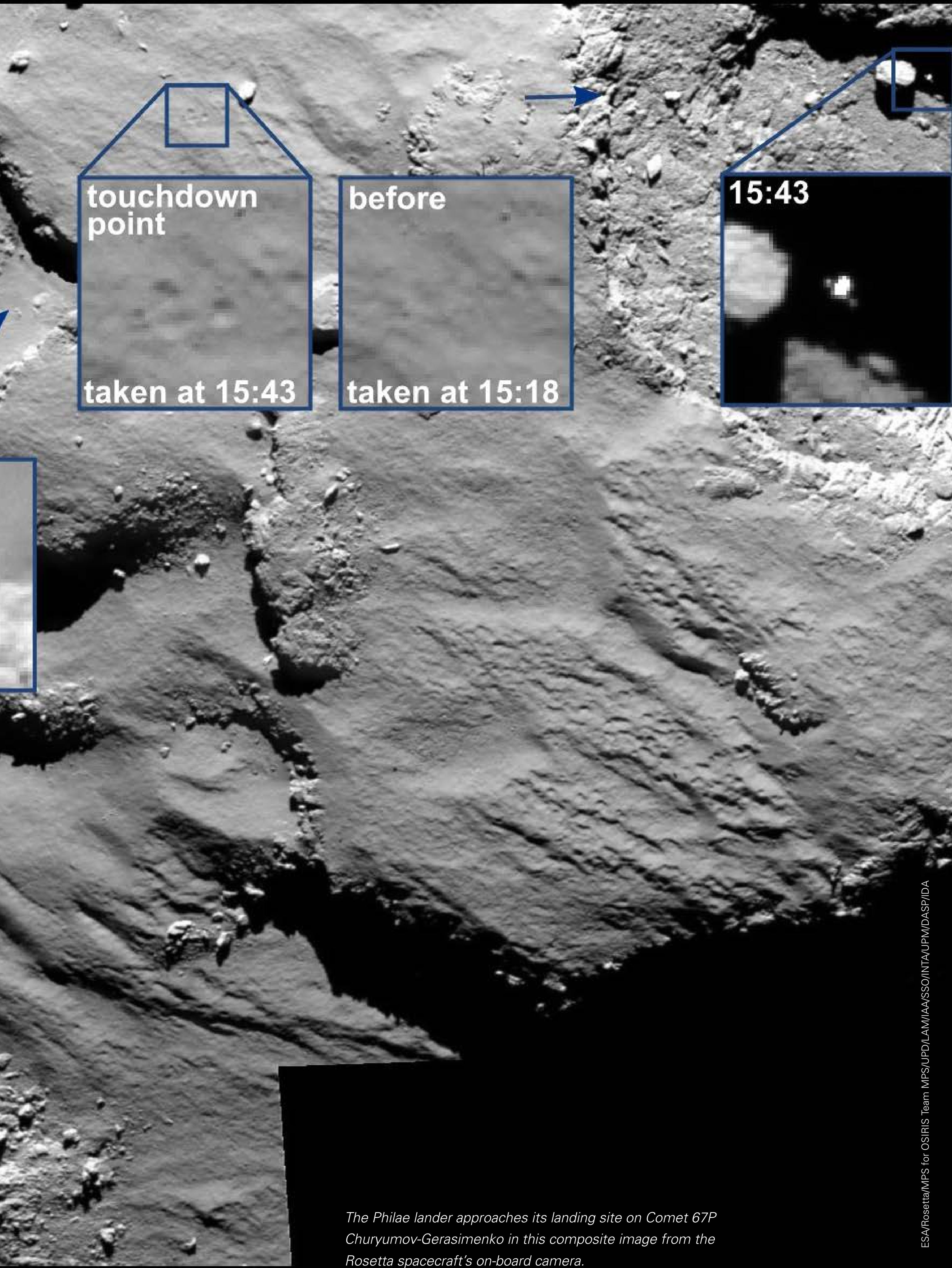




The Philae lander approaches its landing site on Comet 67P Churyumov-Gerasimenko in this composite image from the Rosetta spacecraft's on-board camera.

Analysing water vapour

Much of the data from Philae's time on the surface still requires further analysis but important results have already been found using instruments on board the Rosetta spacecraft. The Rosina instrument has provided the most significant science to date. It has tested the idea that most of the water on the surface of the Earth came originally from comets, but the data from Rosetta is casting doubt on this hypothesis. It has analysed water vapour coming from the comet, and found it to be to be significantly different to that found on Earth.

The ratio of deuterium to hydrogen within the water vapour provides the signature as to whether the water is the same type as on the Earth. Deuterium is an isotope of hydrogen – a deuterium atom is a hydrogen atom with an extra neutron in its nucleus. It is found in very small proportions in water on the Earth but several times more was found in the water coming from Comet 67P. Despite asteroids containing much less water than comets, it appears that their D/H ratio is much closer to that of the Earth, and they are therefore much better candidates for bringing water to our planet.

ROSINA is the Rosetta Orbiter Sensor for Ion and Neutral Analysis instrument and comprises two mass spectrometers: the double focusing mass spectrometer (DFMS) and the reflectron time of flight mass spectrometer (RTOF) – and the cometary pressure sensor (COPS). The measurements reported here were conducted with DFMS.

The future

Rosetta continues to orbit Comet 67P, its closest approach (186 million km) to the Sun occurring in August 2015. As the spacecraft gets closer to the Sun, the volume of gas and dust leaving the surface of the comet, known as the coma, will increase. This will enable more detailed measurements of the composition of the comet. The increased light level may also enable the lander Philae to come out of hibernation and take more in-situ data from the surface of the comet, presuming it survives the increasingly harsh environment around the comet.

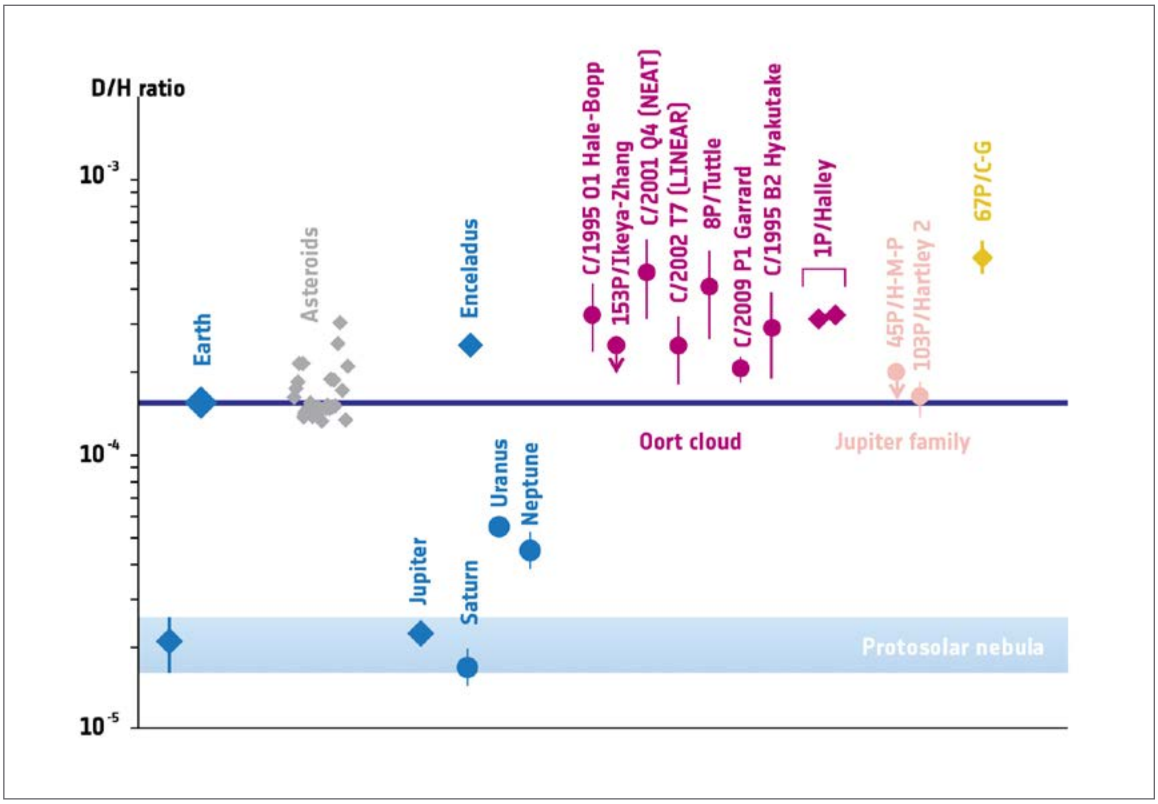
Rosetta's mission ends in December 2015, although data may still be coming from the satellite beyond this time. As ever, with complex space missions, the data from the satellite will be analysed for many years to come.

Tom Lyons has worked as an engineer on space satellite systems. He now works at the National STEM Centre in York.

Look here!

Find out how a mass spectrometer can distinguish between hydrogen and deuterium atoms: *http://stem.org.uk/rxbm6*

Rosetta-themed science resources for schools: *http://stem.org.uk/cx3yd*



The different values of the deuterium-to-hydrogen ratio (D/H) in water observed in various bodies in the Solar System. The data points are grouped by colour as planets and moons (blue), meteorites from the Asteroid Belt (grey), comets originating from the Oort cloud (purple) and Jupiter family comets (pink). Rosetta's Jupiter-family comet 97P is highlighted in yellow; its D/H ratio is more than 3 times that found in water from the Earth's oceans.

Sophie Harrington

Gardens in the sky

Growing plants in space

Thinking of space science conjures up images of planets, stars, and sleek spaceships cruising through the galaxy. But humans aren't the only life forms we're sending into space. As ***Sophie Harrington*** *explains, some of the most cutting edge plant-science research is being carried out hundreds of kilometres above our heads.*

Missing gravity

The presence of gravity is a given for life on Earth. It's no surprise that many organisms use this ever-present force to guide their growth and development. Plant growth is highly directed by gravity, as roots grow downwards while shoots reach up towards the sky, in the opposite direction. These are known respectively as *positive gravitropism* and *negative gravitropism*. This response to gravity is crucial in directing plant growth down on Earth, but up in the International Space Station (ISS) it's another story.

Key words

plants

tropisms

space travel

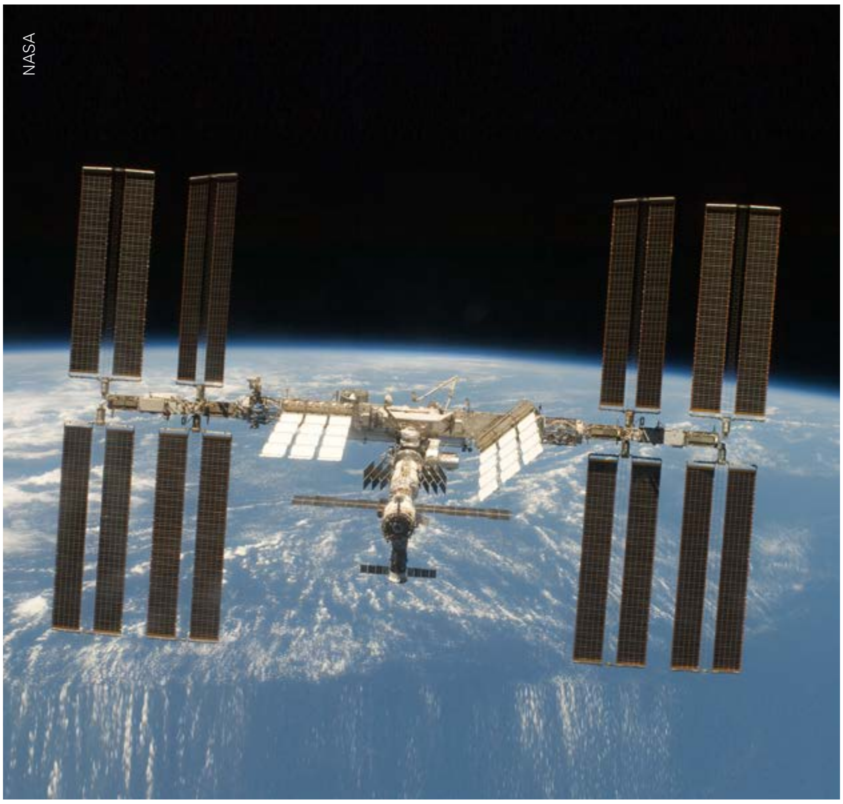
Mars

In orbit over 300 kilometres above the Earth, the ISS experiences only microgravity. The gravitational force from the Earth holds the station and its contents in orbit, so that everything inside experiences zero gravity (sometimes known as microgravity). But if gravity is so important, how do plants manage to grow properly on the ISS?

It turns out that plant responses to light, known as *phototropism*, may be just as important as gravity in determining how plants grow. Plant responses to light go in the opposite direction to gravity, with shoots growing towards the light (positive phototropism), while roots grow away (negative phototropism). It appears that on Earth both light and gravity play a role in directing plant growth. This also explains why, on Earth when seeds are germinated in a dark room, the shoot still grows up and the roots down. In that case, gravity is sufficient to determine the direction of plant growth.

Intriguingly, studies on the ISS suggest that the response of plants to different wavelengths of light may change in microgravity. Red light was found to promote plant growth on the ISS, while it doesn't back on Earth. It may be that the red-light response is suppressed on Earth by gravity, only appearing when plants don't perceive any gravitational force. This result was a big surprise to scientists who had originally thought that only blue light could direct plant response to light.

By studying plants in microgravity, researchers are able to remove gravity from the equation. Hopefully this will lead to even more discoveries about how light and other environmental cues interact with gravity (or the lack of it) to influence plant growth both on Earth and in space.

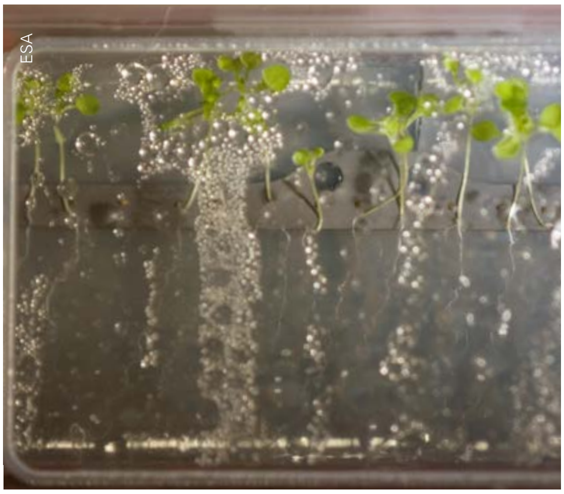


The International Space Station in orbit.

Growing up in space

Any plans to send humans into space for long periods of time will require the ability to grow plants to supplement the astronauts' diet. However, until recently, scientists weren't sure how microgravity might affect the life cycles of plants. It's not much good sending all sorts of seeds into space if they aren't going to grow properly.

Arabidopsis thaliana, a small garden weed, is the favoured plant for many scientists in part due to its short lifecycle. This makes it particularly suited for studying how life in space might affect its growth. Luckily for the astronauts, the little plants were able to grow quite normally in space. In fact, not only did their leaves, flowers, and fruit develop normally, but the leaves remained dark green for longer than they would on Earth. This suggests that microgravity may somehow influence leaf senescence, slowing plant ageing. Scientists still don't know what's behind this peculiar result, or if it also occurs in other plants. Even more intriguing is the question of whether humans and animals might also benefit from a visit to space. Perhaps the fountain of youth is actually in outer space.



Plants growing on the ISS need to use as little space as possible. Here Arabidopsis *seedlings are growing in a small dish, testing the effect of microgravity on root and shoot growth.*

The next step in growing plants sustainably in space is making sure they can produce seeds in space, and that these 'space seeds' can in turn germinate and grow themselves. A study by NASA attempted to grow *Arabidopsis* from seed to seed on the ISS. When the second generation seeds were sent back to Earth and germinated, the plants didn't show any visible abnormalities, boding well for the future.

Further work by Russian cosmonauts with pea plants showed that four generations of the plants could be grown on the ISS without any significant changes from the original. This suggests that microgravity and other space conditions do not affect the reproductive ability of at least some plants. It's looking more and more likely that astronauts will one day be able to significantly supplement their diet with home-grown vegetables and fruit.

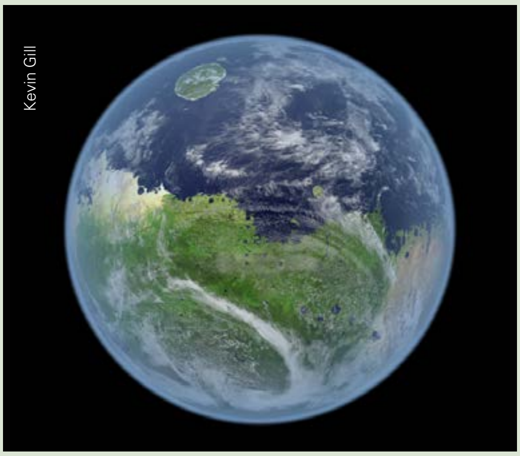
A green future for Martian exploration

Sending humans to Mars is a big operation, with public agencies like NASA and the European Space Agency as well as private groups such as Mars One working to make it a reality. But sending humans to Mars is going to need more than just a big rocket.

Feeding new colonists on the red planet will likely rely on easily-assembled greenhouses shipped with the astronauts to Mars. In these, colonists will be able to grow vegetables such as tomatoes and peppers to supplement their long-lasting, pre-packaged space food. Besides tasting good, these plants will provide needed nutrients to the colonists.

Future colonists on Mars will cultivate a variety of vegetables and fruits to supplement their diet. It will be a long time, though, before colonists can become self-sufficient. Early missions are likely to depend on biennial deliveries from Earth.

Most plans for colonies on Mars expect to use hydroponic systems to create their gardens. Some scientists, however, are exploring the ability of plants to grow on Martian soil. This would be crucial for an expanding colony, reducing the need for increasing greenhouse capacities. In fact, a recent paper suggested that many plants grow even better on Martian soil than they do on Earth soil. Perhaps the Red planet could one day be even greener than our own.



An artist's interpretation of how a fully terraformed Mars might look

In early plant experiments on the Mir space station, Russian cosmonauts found that their favourite time of day was tending to the plants. Gardening helped the astronauts unwind, with many becoming very attached to their plants. More recently, NASA astronaut Don Pettit (shown here) even started writing a blog from the point of view of the courgette plant he was tending to. That's dedication!

One small step for a plant

We know plants can grow in space, but what about on other planets? Researchers have been doing work simulating Martian and lunar conditions on Earth (see Box on left), but it's hard to study the Moon when we're stuck on Earth.

Luckily for us, NASA is about to send a miniature greenhouse to the Moon, filled with *Arabidopsis*, basil and turnip seeds. If all goes to plan, in late 2015 these will be the first plants to grow on a different world. Researchers will follow the growth of the plants for 5-10 days, comparing their growth to that of the Earth-based controls.

The Lunar Growth Module will hitchhike to the Moon on a rocket sent up by a private space company.

By sending these seeds to the Moon, scientists hope to discover whether plants would be able to germinate and respond appropriately with the different environmental signals on the Moon. While the first experiment will focus mainly on germination and phototropism, if all goes to plan more experiments will be flown to the Moon. As plant growth is studied for longer periods, the effect growing on the Moon has on sexual reproduction, dominant and recessive traits, and multi-generational growth amongst others can be studied.

Who knows – it might not be too long before all sorts of plants are growing on different worlds and in outer space.

Sophie Harrington is a final-year undergraduate at the University of Cambridge studying plant sciences

Mike Follows

Are airships making a comeback?

Hot air balloons over Quebec, Canada

When hot air balloons are propelled through the air rather than just being pushed along by the wind they are known as airships or dirigibles. The heyday of airships came to an abrupt end when the Hindenburg crashed dramatically in 1937. But, as ***Mike Follows*** *explains, modern airships may have a role in the future.*

Key words
density
forces
Newton's laws
aircraft

According to Archimedes' Principle, any object immersed in a fluid receives an upthrust equal to the weight of the fluid it displaces. This can be applied to lighter-than-air balloons: a balloon will descend if its weight exceeds that of the air displaced and rise if its weight is less.

We can also think of this in terms of density. A balloon will rise if its overall density (balloon + air inside) is less than the density of the surrounding air. In hot-air balloons, the volume is constant and the density of air is varied by changing its temperature. Heating the air inside the envelope using the open flame from a burner in the gondola suspended beneath causes the air to expand and escape out through the bottom of the envelope. The top of the balloon usually has a vent of some sort, enabling the pilot to release hot air to slow an ascent. Colder, denser air will enter through the hole at the bottom of the envelope.

Burning gas to give a hot air balloon greater lift

Airships of the past

Airships used lifting gas like helium because it is less dense than air. There are rigid, semi-rigid and non-rigid airships. A metal framework maintains the shape of rigid airships. Semi-rigid airships have a rigid hull but the envelope needs to be pressurised to maintain the overall shape of the airship. Non-rigid airships, or blimps, have their shape maintained solely by the pressure within the envelope. The envelope contains the lifting gas, often helium, and ballonets. Ballonets are volumes of pressurised air and, because air is heavier than the lifting gas, ballonets act like ballast tanks on a submarine, affecting altitude and pitch.

In the 1920s, Zeppelins regularly crossed the Atlantic and, by 1929, they were circumnavigating the globe in a little over 21 days. Designers wanted to use helium as the lifting gas because, unlike hydrogen, it is not flammable. But helium was scarce and the USA, with 80% of global production, banned its export under the Helium Control Act of 1927.

The Germans were forced to use hydrogen. The fact that no passengers had been killed or injured in a German airship led to the mistaken belief that Germany had mastered the safe use of hydrogen. This myth was shattered on 6 May 1937 when the Hindenburg burst into flames and crashed to the ground in just over half a minute killing 35 of the 97 passengers and crew, along with one member of the ground crew.

The dangers of using a flammable fuel – the Hindenburg disaster of 1937

Airships in the modern era

There is no way that airships can compete for passengers with aeroplanes partly because they cruise at less than 200 km h^{-1} compared to a passenger jet's speed of around 1000 km h^{-1}. However, there are now several innovative modern airships. One of them is the Airlander, designed and built in Britain by Hybrid Air Vehicles (HAV) for the US Army as a surveillance platform, intended for deployment over Afghanistan. But after US defence budget cuts led to cancellation of these LEMVs (Long Endurance Multi-intelligence Vehicles), HAV bought the airship back from the Americans and it now operates from the famous Number One shed at Cardington near Bedford, UK, where the doomed R101 airship was built.

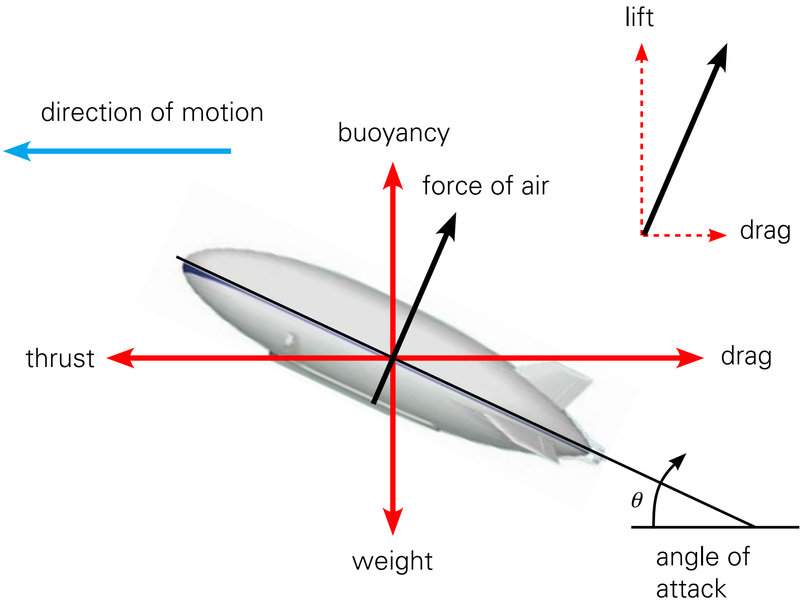
The Airlander, a modern hybrid airship

Airlander is 92 m long, 34 m wide and 26 m high and is known as a 'hybrid airship' because lift is provided by a combination of buoyancy and aerodynamics. The helium lifting gas provides 60 per cent of the lift and gives the blimp its shape. It looks like three cigars sewn together and this aerofoil shape means that it can also generate lift just as an aeroplane wing does.

Generating lift

Any aircraft requires lift, the upward force that acts against the downward force of gravity. To generate lift, an aircraft pushes downwards on the air so that the air pushes upwards on the aircraft. That's an example of Newton's Third Law of Motion. So how does a fixed-wing aircraft or an airship like the Airlander push down on the air?

The diagram on page 18 shows an airship which is moving to the left. It is tilted slightly upwards at the front; we say that there is an 'angle of attack', θ, between the longitudinal axis of the airship and the horizontal. As the airship moves forwards (propelled by its engines), the air it strikes is deflected downwards and forwards. The result is an equal and opposite force on the aircraft. You can see that this force has both upwards (lift) and backwards (drag) components.



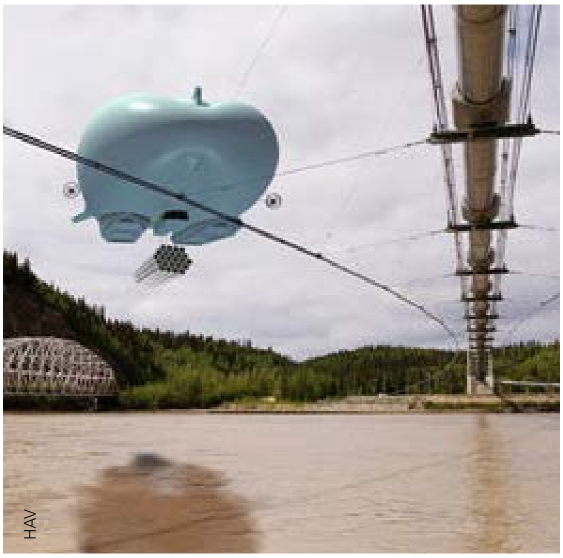
The forces on an airship as it moves horizontally: the airship's weight is balanced by the buoyancy of the balloon and also by the vertical (lift) component of the force created as the airship pushes air downwards. (The angle of attack is exaggerated in this diagram.)

Forward motion is needed to generate lift. As an aircraft slows down, the required angle of attack must increase to maintain lift. But increasing the angle of attack also increases drag, which slows the aircraft further, reducing lift. The stall speed is the speed at which increasing the angle of attack can no longer be used to generate lift, so the aircraft descends. But the Airlander has another trick up its sleeve. It can rotate its jet engines so that they provide downward thrust allowing the airship to hover and land just like a jump jet or helicopter.

Why heavier-than-air?

A drawback with traditional airships was the manpower required to 'dock' and handle them, with 1920s zeppelins needing more than 200 ground staff. Because it is heavier than air a large ground crew is not required for the Airlander and it can fly with only two aircrew. A true lighter-than-air craft relies solely on buoyancy to provide lift. This limits the load it can carry and creates problems with stability during loading and unloading because rapid changes in weight upset the craft's buoyancy if not counterbalanced. Hybrid airships are heavier, and therefore more stable in adverse conditions.

Airships offer the flexibility of a helicopter and the range of a fixed-wing aircraft, and have operating costs lower than both. They can transport goods all the way to the point of delivery because they do not require infrastructure like runways – the Airlander can land on any reasonably flat surface, including water. It is capable of vertical take-off and landing (VTOL) or hovering like a helicopter. It can stay in the same spot for 21 days at an altitude of up to 5 km to provide a stable platform for communications, geological survey, surveillance or filming. It can even fly over hostile territory because it can stay airborne even if its outer skin is riddled with bullet holes.



An Airlander airship can deliver heavy loads in difficult terrain.

Airships like Airlander are designed to carry up to 50 tonnes of equipment to any area in the world, making it ideal for disaster relief or delivering heavy equipment to remote corners of the world for oil or mining companies. Transport aircraft normally run out of space for cargo before their payload makes them too heavy to fly. This would not be an issue with the Airlander as the capacity of the gondola can be modified – unlike the fuselage of a fixed wing aircraft.

The Airlander is fitted with four turbine engines which together can deliver 8 MW of power. It has a range of about 5000 km so it could access many of the most remote locations on the planet.

But there are disadvantages. As already mentioned, airships are slow compared to jet aircraft and they suffer from the 'Hindenburg effect' – the perception that airships are dangerous, even though inert helium is usually used as a lift gas. There is unlikely to be a huge demand to carry regular freight as cargo ships already carry goods whose delivery is not time-critical and about half of airfreight is already transported as 'belly' freight in passenger aircraft.

Mike Follows teaches Physics.

Water movement in potatoes

Try this

What happens when water moves into and out of potato cells?

You will need

1 medium sized potato
knife and chopping board
2 glasses or beakers
sugar
spoon
kitchen paper
water

Note: Ideally you should use distilled water for this experiment. If you don't have any, tap water will work.

What you do

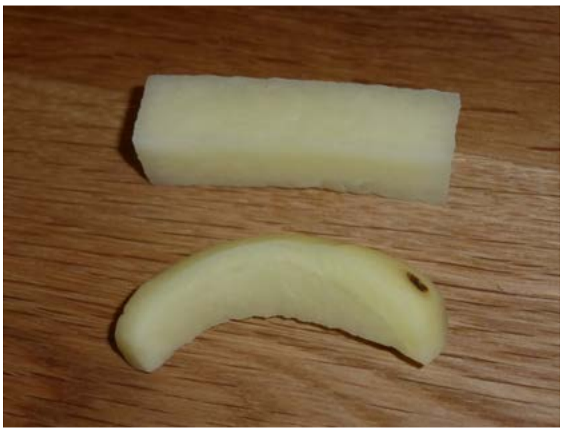
Cut at least 4 'chips' from the potato and remove any skin.

Put water into the glasses. Stir sugar into one of the glasses until you have a fairly concentrated solution.

Put two or three of your chips into each of the glasses. You may need to hold the potato into the sugar water with the spoon.

Leave the chips for about 40 minutes then remove from the solution and dry carefully with kitchen paper.

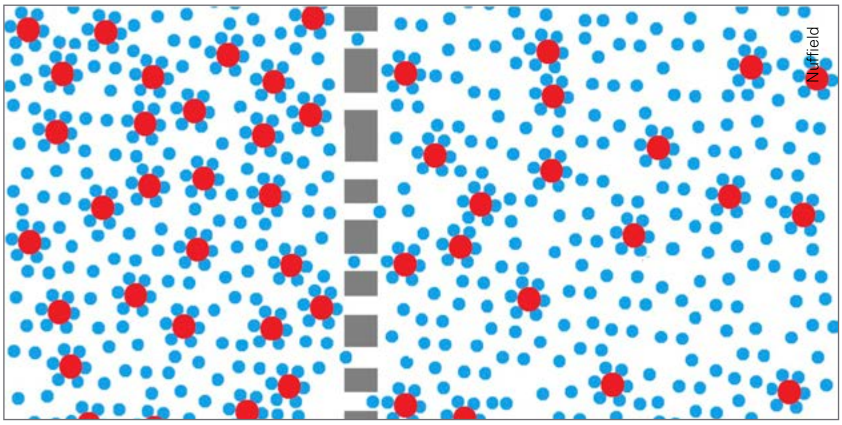
What do you notice about the potato chips from each solution?



The potato at the end. One has swelled up with water, one has lost so much that it is really flaccid. Which was in the sugar solution? Answer opposite.

What's going on?

This is a special case of diffusion called osmosis. Water moves by diffusion across the cell membrane. The pores in the cell membrane are big enough to allow the water molecules to cross but are too small for the sugar molecules so the membrane acts like a sieve.



The blue circles are water molecules, the red circles are sugar molecules. The dashed line is the cell membrane with the pores.

You can see the water molecules have clustered round the sugar. This is due to weak bonds which form between the sugar molecules and water molecules. These bonds make it harder for water to cross the membrane. Water molecules pass through the cell membrane in both directions, but water can pass more freely from a dilute solution to a concentrated solution. In this diagram, in which direction will water move? Which way will it move for your potato chips? What effect will that have on the potato?

Vicky Wong is Chemistry editor of CATALYST.

Answer: The flaccid potato chip was in the sugar solution, the one which has swelled was in distilled water.

A life in science

Michael Pocock

UK Ecologist

A burnet moth visiting a flower on one of the downland study sites

A couple of years ago I was doing some field work. The work was very weather-dependent, so I had to make the most of any sunny day that came. The weather was poor that particular summer so, if the weekend was sunny, I had to work then. So there I was, on a beautiful hillside in the sunshine, overlooking the incredible landscape of southern England, counting flowers and catching and identifying insects as part of a research project. To be honest I felt a bit down-in-the-dumps because I was working on a weekend, when I would much rather have been with my family doing something like... well... what I would ideally like to be doing is looking for insects on a sunny hillside in a beautiful landscape. Hmm, maybe this job isn't so bad after all!

My job is doing research in ecology. The incredible benefit of my job is that I get paid for doing something that I love – it is more of a vocation than 'work'. I also think what I do is important. Our environment is under threat from all sorts of pressures from people, such as habitat loss, agriculture, urban development and, of course, climate change. That is often bad for nature. And because we depend upon nature (for air, clean water, food, pollination, natural pest control and so on) then what is bad for nature is bad for us. And that is what I do research on. Maybe through my research I can do my bit to contribute to a better future for people and our environment.

Checking for fleas on a wood mouse by combing it with a toothbrush – not all science is hi-tech!

Michael being filmed talking about the Conker Tree Science project for BBC1's The One Show

Computing power

Recently, my work has involved a lot more analysis on the computer, but prior to this I used to do field work and lots of it! I would go out and sample insects, survey plants and monitor mammals. I've done research on all sorts of wildlife in Britain. (Many ecologists do field work abroad, but all of mine has been done in Britain. It's convenient but probably less exciting than going abroad!

Some of my research seems odd to other people, two fieldwork projects in particular. In one I was live-trapping house mice on farms, covering them in fluorescent powder and then returning at night with a special torch to follow the glowing trails to discover where and how far the mice moved. (They didn't move far at all, which has important implications for the spread of disease on farms.) The other one was spending many freezing cold winter mornings combing mice with a toothbrush to find what fleas they were carrying. (I wanted to discover whether the diversity of fleas on mice and voles was related to the farmland conditions they live in.) Yes, some of the field work might seem odd but it contributes to answering important questions and it is an incredible privilege to get hands-on (literally) with nature.

Webs and networks

Going back to the start of my story, when I was looking at insects visiting flowers, I was working on food webs. When you look at all the different insects visiting flowers, you have a big network of these interactions. One fun thing is that networks crop up in lots of different areas: Facebook forms a big network, as do computer servers, people spreading disease, subatomic particles interacting together, and bankers trading on stock markets. It means that I do analysis by learning from people who do research in physics, maths, geography or economics. Science can get really creative.

Once I have the data I'll then analyse it and write up the results of my research. This will be published in scientific journals for other scientists to read. Publishing results is important, but I also get excited about engaging ordinary people about nature and their environment. One of the most exciting ways is for them to get hands on with nature too and so with a friend I set up the Conker Tree Science project, so that ordinary people could get involved in real scientific research (which is known as 'citizen science'). I've even had opportunities to talk about my work on national television and radio. I have no desire to be a TV star, but doing this once in a while definitely adds to the variety of my work and is really enjoyable.

One of the incredible privileges of being a scientist is that it is up to me to come up with interesting ideas to research; in many areas of my work I am my own boss. It means I need to be really self-motivated and I have an incredible sense of freedom to do what I think is important and interesting (as long as I can get funding for it). One disadvantage is that funding for scientific work is very competitive (only about 1 in 5 ideas will get funded) – I've had to develop a really thick skin to cope with rejections and keep persevering to get funding for some ideas. It can be tough, but when it works out it is amazing!

Michael Pocock is an Ecologist at the Centre for Ecology and Hydrology. He also co-runs the Conker Tree Science project in which anyone, including school students in key stages 2, 3 and 4, can get involved in real scientific research.

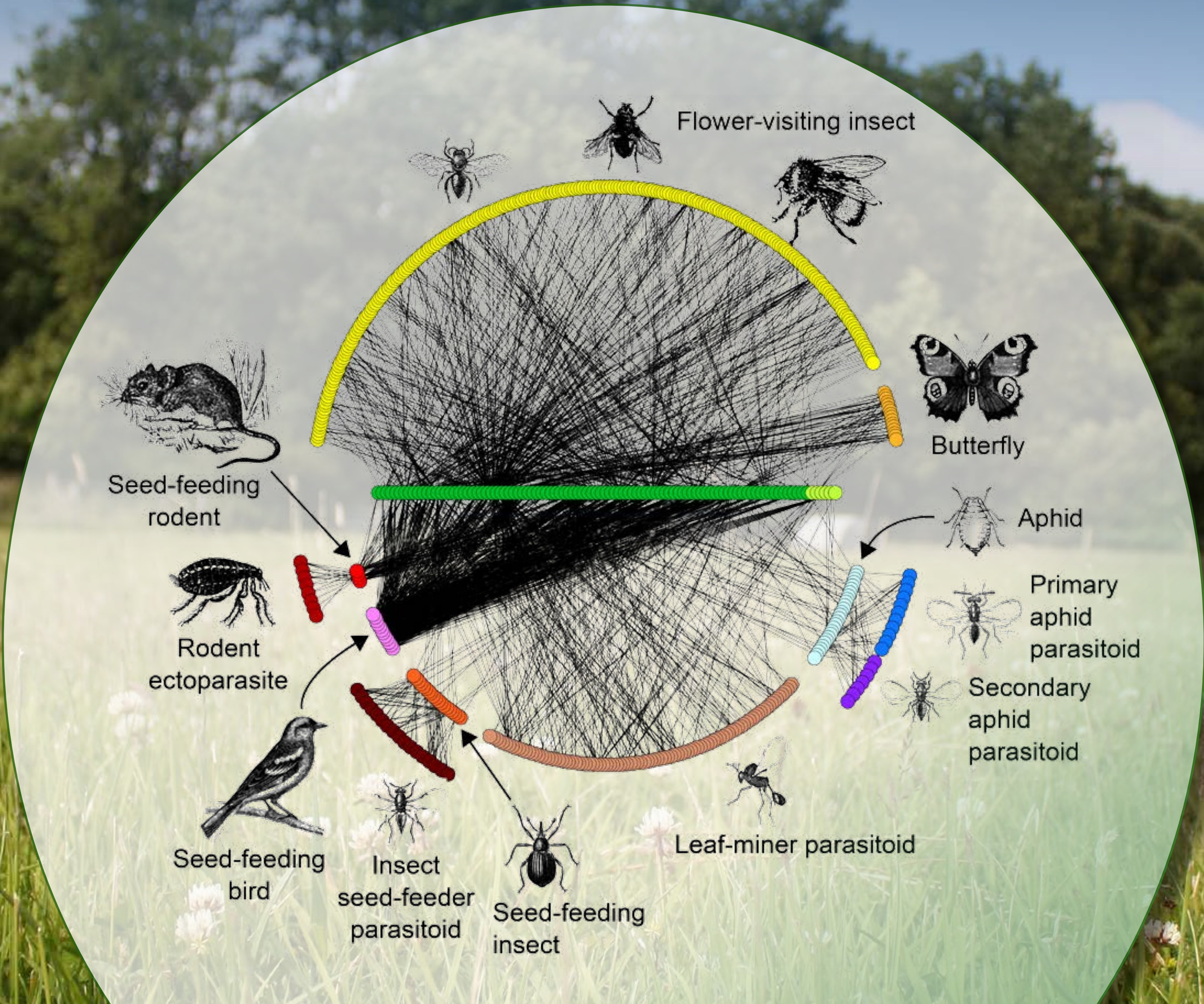
Look here!

Find out more about Michael's Conker Tree Science project here:
www.conkertreescience.org.uk/

The next page shows a typical food web resulting from a detailed survey of a single farmland habitat.

Food web

This food web, derived from Michael Pocock's survey data, shows the interactions between 560 different species on a single organic farm in Somerset.



In this web, each circle represents a different species sampled on the farm (green circles indicate plants, with the lighter green circles indicating crop plants). Even this incredibly complex food web represents just a sample of the interactions. If we had sampled predators, insectivorous animals, animals that eat decaying matter or fungi, the food web would have been far more complex!