About us

The Natural Environment Research Council (NERC) is the UK's main agency for funding research, training and knowledge exchange in environmental science. Our work tackles some of the most urgent and fascinating environmental issues we face, including climate change, natural hazards and sustainability.

NERC research covers the globe, from the deepest ocean trenches to the outer atmosphere, and our scientists work on everything from plankton to glaciers, volcanoes and air pollution – often alongside other UK and international researchers, policy-makers and businesses.

NERC is a non-departmental public body. Much of our funding comes from the Department for Business, Innovation and Skills but we work independently of government. Our projects range from ‘blue-skies’ research to long-term, multi-million-pound strategic programmes, coordinated by universities and our own research centres:

- British Antarctic Survey
- British Geological Survey
- Centre for Ecology & Hydrology
- National Oceanography Centre
- National Centre for Atmospheric Science
- National Centre for Earth Observation

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Planet Earth is NERC’s quarterly magazine, aimed at anyone interested in environmental science. It covers all aspects of NERC-funded work and most of the features are written by the researchers themselves.

For the latest environmental science news, features, blogs and the fortnightly Planet Earth Podcast, visit our website Planet Earth Online at www.planetearth.nerc.ac.uk.

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Compared to threats like volcanoes, earthquakes and flooding, soil degradation isn’t dramatic. But even if its slow, invisible progress doesn’t keep you up into the small hours with excitement, it may endanger at least as many lives and livelihoods – as several of this Planet Earth issue’s features show.

The way we raise our food is doing long-term damage to farmland soils, and this needs to stop if we’re going to feed a growing world population and stave off the risk of widespread and devastating famines. Learning to farm in a soil-friendly way is an enormous task that we’re only starting to grapple with in earnest; our interview with Professor Steve Banwart sets out some of the challenges of bringing soil science out of the lab and into the field, while other stories shed light on particular efforts to do this.

It’s not just farmland that needs attention, though. The world’s wild soils are also suffering, whether from ill-conceived drainage schemes, man-made pollution or poor land management. We need excellent science here too, whether it’s to help us understand what’s going on or to find solutions. Tom Roland describes his trip to the under-studied bogs of Patagonia, and Sorain Ramchunder explains his team’s research into how burning moorland to help support grouse for shooting affects wildlife.

But it’s not all soil, all the time. Jon Bennie describes his work on how wildlife can cope with a changing climate, while Bhavani Narayanaswamy argues we’re still a long way from getting an accurate handle on marine biodiversity. Finally, nobody disputes that the Earth provides a pretty fair environment for life, but Toby Tyrrell argues it might not be as good as it seems.

Europe’s first farmers used muck-spreading to keep their land fertile some eight millennia ago, according to new research. This revolution in agriculture may also have been vital for the genesis of violence between communities.

It seems people were manuring and watering their crops as long ago as 6000BC. Until recently, the consensus has held that this started much later, and that Neolithic farmers used slash-and-burn tactics. Researchers analysed charred pulses and cereals from 13 Neolithic sites around Europe, looking at the proportions of different forms of nitrogen, known as isotopes. They looked in particular at the abundance of the heavy nitrogen-15 isotope relative to the lighter nitrogen-14. The more muck has been spread on a field, the higher the N-15 to N-14 ratio climbs.

Clear evidence of muck-spreading at many of the sites shows these people understood how important the land’s fertility was and tried to preserve and increase it for the next generation. This involved long-term investments of time and effort.

This could have led to important social transformations: as farmers started to pass down fertile land to their children, early divisions between rich and poor might have started to emerge. If manuring had made one group’s land unusually fertile, their neighbours might have been tempted to resort to violence to get it.

‘The idea that farmland could be cared for by the same family for generations seems quite an advanced notion, but rich fertile land would have been viewed as extremely valuable for growing crops,’ says Dr Amy Bogaard of the University of Oxford, lead author of the Proceedings of the National Academy of Sciences paper. ‘We believe that as land was viewed as a commodity to be inherited, social differences in early European farming communities started to emerge between the haves and the have-nots.’
**Sharks stun prey with tail whip**

Thresher sharks hunt schools of sardines by whipping their tails over their heads to stun several fish at once, say scientists. It has long been thought the sharks use their tails when hunting for food, but we haven’t known exactly how.

The research, published in *PLoS ONE*, details how the sharks lunge towards a shoal of prey, then pull their pectoral fins in towards each other. This acts like a brake and causes their tail fins to flip up over their heads and slap both fish and water. The scientists clocked the quickest slap at nearly 48 miles per hour.

We know killer whales use their tails to stun fish by producing a shockwave through the water. The sharks probably use a similar technique. ‘The really forceful slaps resulted in dissolved gases coming out of the water, so we can hypothesise that the behaviour causes shockwaves in the water column that are powerful enough to stun the sardines,’ explains Dr Simon Oliver, who was a NERC PhD student when he led the research and founded The Thresher Shark Research and Conservation Project.

He made the discovery using video footage taken by divers off a small coral island in the Philippines. The 3.5m-long sharks regularly prey on large, dense shoals of fish called bait balls, and it seems whipping their tails is more efficient than chasing after individual fish.

**Feeding wild birds may harm breeding**

Feeding wild birds during the winter could harm the success of chicks born the next spring, says new research. Scientists spent three years monitoring nine sites across Cornwall, where they supplemented the blue tit population’s winter food with nothing, with balls of fat, or with fat enriched with vitamin E.

They checked nestboxes the following spring to assess how these handouts affected the number of eggs, and the size and success of chicks. The study, published in *Scientific Reports*, found that extra food made for smaller chicks with less chance of survival.

‘Our research questions the benefits of feeding wild birds over winter. Although the precise reasons why fed populations subsequently have reduced reproductive success are unclear, it would be valuable to assess whether birds would benefit from being fed all year round rather than only in winter,’ says Dr Jon Blount from the University of Exeter, who led the team.

Supplementing birds’ winter diet is common in the UK and USA, with more than half a million tonnes of commercial bird feed sold each year in the two countries. Previous studies have suggested that additional food can immediately benefit wild birds’ survival and improve future breeding success.

It’s possible the new results are because extra food helps birds who would not otherwise have survived to breed. These birds are in poor condition so can’t raise many chicks.

The study was funded by the Natural Environment Research Council along with the Royal Society, Gardman Ltd and the British Trust for Ornithology.
Magnetic rocks aid oil exploration

A new study has pinpointed the relationship between oil reservoirs and magnetic rocks, perhaps paving the way for more accurate oil exploration.

Previous research suggested a link between hydrocarbons – like natural gas and petroleum – and magnetism, but we didn’t understand how the two were connected. Researchers from Colombia, Venezuela and the UK wanted to change that.

Their paper in *Geochimica et Cosmochimica Acta* shows that as hydrocarbons push through the surrounding rock, they can cause it to gain magnetic properties. But over time bacteria enter the hydrocarbons and break them down, changing minerals like magnetite into less magnetic ones like haematite.

‘The invasion of hydrocarbons into rock appears to have a positive effect on the formation of magnetic minerals,’ explains Dr Stacey Emmerton, of Imperial College London, lead author of the study. ‘But the introduction of bacteria into the hydrocarbons can occur at any time, and this appears to have a negative effect on the magnetic signature.’

‘When there is more oil present or the oil is lower quality, then the amount of magnetisation decreases,’ she says.

When exploration companies find a possible source of petroleum using geological mapping of the rocks in the area, they have to run the risk that oil has migrated into the rock and become trapped there. Understanding the magnetic signatures of the rocks near hydrocarbons could help them map where reservoirs suitable for extraction might be, and determine the path migrating hydrocarbons have taken.

Traffic pollution – the problem’s not just exhaust

Vehicle exhausts are responsible for only a third of traffic pollution. A new study in *Atmospheric Environment* says nearly half of air pollution from road traffic comes from non-exhaust sources such as brake wear, road surface wear and particles whipped up from the road by vehicles.

Professor Ranjeet Sokhi, of the University of Hertfordshire, who led the study, is calling for greater control of non-exhaust pollution.

‘In terms of mass, non-exhaust sources can be more important than exhaust fumes, but legislation has focused on exhaust emissions,’ he says. ‘As exhaust regulations become stricter, non-exhaust sources become proportionately more important. Continuing to control exhaust emissions alone may not be enough to achieve legal air-quality standards.’

The team tested air from the Hatfield Tunnel on the A1 (M) in Hertfordshire for pollution particles less than ten millionths of a metre across. These particles, known as PM10, are linked with long-term health problems including heart disease.

‘Other studies have looked at non-exhaust components of PM10, but those have mostly been done in open-air locations,’ explains Sokhi. ‘We wanted to look at them in a more controlled environment, where the influence of the weather could be significantly reduced.’

In the lab, samples were separated out into their chemical components. It turns out that petrol and diesel exhausts are responsible for only 33 per cent of the particles. 27 per cent are whipped up from the road by vehicles, while brake and road surface wear account for 11 per cent each.

Road traffic is considered the most important source of air pollution in the UK. As well as the health effects, poor air quality is estimated to cost the UK economy up to £16 billion every year. Controlling non-exhaust emissions might need new approaches such as new materials for brakes and tyres, or a different approach to road-building.

The study was part of a PhD project undertaken by Samantha Lawrence. It was funded by the Natural Environment Research Council (NERC) and the British Oxygen Company (BOC).
Four of Greenland’s glaciers could contribute up to 5cm to sea-level rise if global temperatures increase by 4.5°C by the end of the 22nd century, say scientists.

Over the past decade, Greenland’s glaciers have been retreating at an accelerating rate. But without a better understanding of how icebergs form and whether the recent rise in calving – chunks of ice breaking off where the glacier meets the ocean – is due to climate change, they couldn’t accurately predict how much melting glaciers would add to sea-level rise in the future.

An international team of scientists created computer models of the four most important glaciers in Greenland, chosen because together they drain around 22 per cent of its ice sheet into the ocean. They used these models to predict the glaciers’ contribution to sea-level rise by 2200.

Published in Nature, their work shows that how fast a glacier retreats depends on shape and the landscape it flows over. While all four glaciers are retreating, because of their different shapes they accelerate at different rates and in different ways.

For these four glaciers, the study suggests their retreat is unlikely to continue accelerating at the same rate. Instead, under a mid-range climate scenario, where carbon emissions increase through the 21st century, causing global temperatures to rise by 2.8°C, the four glaciers could contribute up to 3cm to sea-level rise by 2200 – less than previous estimates based on current rates of retreat. But the researchers warn that other glaciers, which have not shown rapid changes yet, may start retreating.

‘It’s now clear that each glacier behaves differently depending on the geometry of land they sit on and whether they have an ice shelf or not,’ says Dr Faezah Nick, of the Université Libre de Bruxelles and the lead author of the paper. ‘So if we really want to understand how much sea-level rise will be in the next century we need to study each of the major outlet glaciers individually.’

Glacier impact on sea-level rise depends on shape

New research ship delivered

In July, shipbuilder CNP Freire SA handed over to NERC the new vessel that will serve UK marine science over the coming decades. The RRS Discovery represents a £75m investment in ocean science, and alongside the existing RRS James Cook will form one of the most modern research fleets anywhere in the world. Operated by the National Oceanography Centre at Southampton, the ship replaces a 50-year old vessel of the same name, which completed its final expedition last year. It will be formally named in October, and is expected to set out on its first science cruise in 2014 after trial voyages.

Planet Earth Online mobile

Our website Planet Earth Online has had a facelift. Rather than having a separate site for each of the different platforms people look at it on – there’s now just one website, and it smoothly reconfigures itself to suit whatever you happen to be browsing it on, whether that’s a tablet, a smartphone or a desktop PC. Check out www.planetearth.nerc.ac.uk for the latest environmental science news, features, podcasts and blogging – it includes the articles you can read in this magazine, and much more besides.

Contract signed for next-generation supercomputer

The Engineering and Physical Sciences Research Council and NERC have reached agreement with supercomputer manufacturer Cray on the UK’s next-generation academic high-performance computer system. Cray will supply an XC30 supercomputer as part of the new facility, known as Academic Resource Computer for High-End Research (ARCHER). Likely to be up and running by winter, ARCHER will have nearly four times the power of the UK’s current high-performance computing resource, HECToR, and will support innovative research in fields ranging from modelling ocean currents and hurricanes to predicting climate change and forecasting the spread of epidemics.
The disease Toxoplasmosis is widespread in animals in UK waterways, a new study shows. Humans could be at more risk than we’d thought.

The researchers examined dead otters – mostly road-kills – found around England and Wales to assess whether any of them contained antibodies for the disease, caused by the parasite Toxoplasma gondii.

‘40 per cent were carrying antibodies for the disease, although Toxoplasmosis was never shown to be the cause of death. This is higher than we might have expected given their mainly fish diet,’ says Dr Elizabeth Chadwick of Cardiff University, lead author of the study.

‘On the other hand, it may be that otters are being infected by cysts in the water containing a reproductive form of the parasite – the oocysts. If otters are picking it up directly from water it suggests there is an environmental risk to humans, as current screening and water treatments don’t get rid of oocysts.’

The parasite can complete its life cycle only when it is hosted by a cat. From there, the oocysts enter the cat’s faeces and eventually move into waterways, either when cat litter is flushed down toilets or when faecal matter drains off gardens and streets.

While around 30 per cent of humans carry the Toxoplasma gondii parasite, only 10-20 per cent of these – 3-6 per cent of the total population – show symptoms. These are flu-like, so most never realise they are infected. Once the initial illness ends, the parasite forms cysts in the body. Although largely inactive, these stay in the host’s tissues for life, and some think they may affect behaviour. Mice with the disease are known to take more risks, increasing the risk they’ll be eaten by a cat, letting the parasite complete its life cycle. While we aren’t likely to suffer this fate, there’s some evidence of greater risk-taking by humans with Toxoplasmosis – they seem to get into more road accidents, for instance. There are also links to psychiatric disorders like depression and schizophrenia.

Ozone can protect fruit from decay for weeks after exposure

Why does ozone treatment make fruit and veg last longer? Scientists have found out.

The study, published in Postharvest Biology and Technology, explored the impacts of ozone on the amounts of certain proteins present in a tomato fruit. The aim was to unravel why low levels of ozone gas can protect fruit and vegetables from disease and increase their shelf life.

‘Ozone has been used as an anti-spoilage agent for years, but while we know it works, we didn’t know why until this study,’ says co-author Professor Jeremy Barnes, of Newcastle University.

The team found that changes in the proteins observed when a tomato was treated with ozone after harvesting were associated with defence and signalling responses. They also showed that ozone protects stored fruit against pathogens for up to two weeks after it is removed from the ozone-enriched atmosphere.

They exposed the fruit to ozone and then introduced a pathogen, called Botrytis cinerea, which causes the grey mould you find on fruit in the bottom of your fruit bowl. The pathogen causes several proteins to increase, but once the fruit is removed from the ozone they slowly drop again.

The researchers had previously found that mimicking the ozone levels of a spring day in storage can suppress pathogens and increase shelf life of products like strawberries, avocado and asparagus by a few days.

Ozone has been used as an antimicrobial agent to treat drinking water since the 1800s. But these findings show that only very low levels are needed to get the benefit.

The scientists have now developed a range of commercial products to protect crops from spoiling when they are in storage or being transported. Their product range, developed by a company called biofresh, uses controlled environment chambers, including a battery-powered pallet which releases low levels of ozone and keeps crops fresh during transportation.
Wildlife losses now stabilising

Efforts to conserve biodiversity in the UK, Belgium and the Netherlands may be working, despite the widespread perception that wildlife is in terminal decline.

Many think we’ve failed abjectly to meet the 1992 Rio Earth Summit’s goal of slowing biodiversity loss by 2010. But taking a longer historical perspective shows that after plummeting for several decades, biodiversity has shown signs of improvement since 1990. A new report says conservation efforts and wildlife-friendly farming methods are a plausible explanation.

The authors looked at historical data on the diversity of plants and pollinating insects in the UK, Belgium and the Netherlands. Their results show that in the UK from the 1950s to 1980s, bumblebees, butterflies and wild plants were all becoming less varied and diverse, while hoverflies and solitary bees were holding steady.

Since 1990, most of those trends have improved. Wild plants have stopped their decline and bumblebees are declining more slowly – around a 10 per cent drop in UK species diversity, compared to 30 per cent from 1950 to 1980. Hoverflies are still stable and solitary bee diversity seems to be increasing – it’s up 10 per cent over the last two decades in the UK, and 7 per cent in the Netherlands.

This may well be because of greater efforts to conserve wildlife, seen in the uptake of agri-environmental schemes under which farmers are paid to do things like leaving field margins uncultivated to provide wildlife habitat. During the mid-twentieth century, the emphasis was on getting as much land under cultivation as possible; in the 1990s, this trend started to reverse.

And although local species diversity seems to have stabilised, wildlife is now less geographically varied. This trend was particularly evident in Belgium and the Netherlands, where differences between what lives in different areas have been almost completely erased.

The paper appears in Ecology Letters. It was mainly EU-funded but drew on data provided by bodies across Europe including the UK Biological Records Centre. Further support came from the UK Insect Pollinators Initiative.

Huge earthquakes possible near Arabian Sea

The risk of earthquakes south-west of Pakistan could be greater than previously thought, new evidence implies.

The research, published in Geophysical Research Letters, looked at the Makran subduction zone beneath the Arabian Sea – an area where two tectonic plates meet and one is pushed beneath the other into the mantle below, leading to higher risk of earthquakes and volcanic eruptions.

The area’s last major earthquake was in 1945. It registered 8.1 on the Moment magnitude scale, which measures the amount of energy released during the quake, and caused a tsunami that killed more than 4000 people. The lack of seismic activity since had convinced some people the zone was unlikely to produce very large quakes. But despite its potential danger, there was limited information available about this particular zone.

A team of scientists decided to find out just how dangerous it could be. The researchers, from the National Oceanography Centre in Southampton and the Pacific Geoscience Centre in Canada, used a 2-D computer model of the subduction zone to map out its potential to rupture and generate an earthquake.

They showed that, unlike most subduction zones where one plate plunges down quickly, the Makran is unusual because the Arabian plate pushes down at a shallow angle. This helps make the area capable of producing an earthquake up to 9.2 magnitude, and a tsunami to match, which could strike Pakistan, Iran, Oman, India and perhaps even further afield.

‘The shallow dip of the subducting plate is one of the key features of the Makran,’ says Gemma Smith, PhD student at the University of Southampton and the study’s lead author. ‘Because it’s so shallow the model produced quite a wide potential earthquake rupture zone, up to 350 kilometres, much wider compared to most other subduction zones which have been modelled in a similar way.’
Fungi are all around. Mostly you don’t see them, but under the microscope earth from almost anywhere in the world contains a tangle of branching, interwoven fungal filaments called mycelia. A kilo of soil contains 200km of these superfine threads; worldwide there’s an incredible 10,000 light years of them, mostly renewed several times a year. This isn’t just about big numbers though. Tom Marshall explains how NERC-funded science will be vital to feeding our hungry planet over the next century.

Mycelia are the nexus of a world-changing cooperation between fungi and plants. They attach to plants’ roots and supply them with essential soil nutrients in exchange for some of the carbon the plants make with photosynthesis. Without them, most plants couldn’t survive. The carbon ends up buried underground, some of it for long periods, so soils and the fungi they contain are a vital part of the carbon cycle.

‘Everyone takes soil for granted, but it’s amazing,’ says Professor Steve Banwart of the University of Sheffield, leader of a NERC project to investigate how fungi break down rock to help make this deceptively familiar growing medium. Banwart works alongside colleagues at Sheffield and the universities of Bristol and Leeds.

‘These fungi form a network of chemical energy that binds the trees to the soil and the rock below. If a tree is a photovoltaic cell, soil fungi are the national grid,’ Banwart adds. ‘They take energy and carbon from the roots and pump it underground, sometimes many metres away from the growing tree. So there’s this huge amount of biomass...’
The future of farming?

A big field can hold many different kinds of soil. Some places have more nutrients; some are at more risk from pests; some are wet and some are dry. Yet at the moment, most farmers apply similar amounts of fertiliser, pesticide and water across the whole field. What if they could draw on sophisticated environmental data to work out exactly what’s needed on every small patch of ground, and then use GPS-equipped precision farm machinery to apply only this much?

That’s the idea behind precision agriculture, and it’s taking off fast. Farmers save cash on unnecessary spraying; the environment benefits because there are fewer chemicals to run off into waterways and less energy is spent producing chemicals and pumping water in the first place. If we’re to move to a truly sustainable food system, techniques like this will be essential.

One possibility is combining data from tiny soil-moisture sensors all over a field with weather forecasts and atmospheric information to control irrigation pumps. Water is applied where it’s needed and nowhere else.

Satellite imagery is becoming commonplace; drones have attracted such military demand that their prices are plunging. Police are already adopting the technology for things like monitoring traffic or catching wildlife poachers; farmers could soon start using drones to monitor the health of crops and tell them when pesticides or irrigation are needed.

The next step could be using nanotechnology to move from bulk applications of dumb chemicals to tiny amounts of ‘smart’ ones, engineered to be taken up only by particular crops. A shift from the status quo would have economic benefits for countries like the UK beyond farming itself. Making such chemicals is now dominated by large economies like Brazil and China, but producing more valuable and sophisticated chemicals might be viable in high-wage smaller countries like the UK.

Another approach is no-till farming – growing food without ploughing, which disrupts the soil’s structure and fungal networks, and can contribute to soil loss and desertification. Growing crops without turning the land can be challenging, but in many areas it could be a vital step towards sustainably higher yields. This could involve steps like growing two or three crops to a field at the same time, or combining plants and animals in new ways, or combining traditional crops with forestry. None of these are new ideas, but until recently they’ve received limited interest in mainstream farming.

out there, pervading the soil beneath our feet. Until recently it got very little attention, but we are now realising it plays an essential part in the Earth’s chemical cycles.’

Banwart’s team estimates around 12 per cent of all the land-based carbon cycle passes through these fungi, known as mycorrhiza. Alongside forests, peat bogs and the ocean, soil fungi provide one of the most important routes by which carbon is transported and transformed.

So soil is critical for carbon cycling. It does a lot more than that, though; it takes care of everything from growing our food to helping filter our water. Recent research even showed some plants can communicate underground to warn of impending aphid attack. But if soil’s an underappreciated resource, it’s also increasingly under threat. Unsustainable farming techniques, deforestation and changes in weather patterns all help to strip topsoil up to 100 times faster than it’s created.

If we’re to feed a fast-growing global population by sharply increasing crop yields while also reducing the harm done to the environment – the challenge of ‘sustainable intensification’ – this can’t continue. We don’t only need to stem current soil degradation; we also want to reverse losses so that we start to accumulate an ever-increasing stock of this vital natural capital.

All this means soil science is central to a sustainable future for industries from farming and forestry to bioenergy production. If we can somehow boost fungi’s natural carbon-absorbing capabilities, it may even help slow climate change.
**Science to save soils**

All this was on the agenda at a meeting organised by NERC, the Royal Society of Chemistry, the Technology Strategy Board Environmental Knowledge Transfer Network and the University of Sheffield, which brought together attendees from a huge variety of fields including chemists and biologists, engineers, hydrologists, agronomists, business managers, farmers and farm suppliers, as well as officials from Defra, the European Commission and the research councils. Rather than just setting general research priorities, the meeting set out to identify concrete areas that scientists can profitably start investigating now.

Banwart himself gave a presentation on his group’s work illuminating exactly how mycelia break down rock into soil and sequester carbon from plants underground. We’ve known for a while that this happens, but the exact mechanisms have been a mystery until recently. Speakers presented results from other directly applicable research on the next generation of farming techniques and how they could help us manage the land more sustainably.

Major agribusiness firms like Yara and Syngenta talked about their interest in innovations like precision agriculture, which involves using real-time environmental information and GPS-equipped farm machinery to apply seeds, water, fertilisers and pesticides exactly where and when they’re needed rather than indiscriminately applying them across whole fields. This is already saving farmers and agribusinesses lots of money on expensive crop inputs. And the environmental impact of the crops drops sharply; we can grow the same amount for less energy and with fewer chemicals to cause problems elsewhere. (See ‘The future of farming’ to find out more about precision agriculture and other emerging techniques.)

As well as the need for practical research into how farmers can put these new ideas to work, Banwart stresses the importance of ‘critical zone observatories’ doing long-term monitoring of, and experimentation on, the soil, rock, water and organisms – including crops – in different places. Named after the thin envelope between the treetops and the bedrock that sustains most of the planet’s terrestrial life, these are field research facilities that are covered with instruments and monitored to support experimental design over the long term. They are often at nested scales of observation from a soil profile, to a small stream’s catchment, to a whole river basin; Banwart and his collaborators work with data from such sites around the world including ones operated in the UK by the Centre for Ecology & Hydrology. NERC is committed to supporting soil science over the long term. It recently joined forces with the Biotechnology and Biological Sciences Research Council to offer £4.5m for research into soil ecosystems and their impact on farming and food production through the joint Global Food Security programme. The money will support new work on the complex interactions between plants, microbes, animals, nutrients and water within the soil, as well as how agricultural ecosystems respond to changes in management and the environment.

‘There’s a vision emerging of how soil science and critical zone research can contribute to truly sustainable agriculture,’ says Banwart. ‘Meeting this challenge will drive lots of technological innovation and business development, and at the moment the challenge seems quite daunting. But I’ve no doubt we can get there. It’s what we need if we’re going to feed the world while coping with the impacts of still-increasing land degradation, the prospect of climate change and competition for scarce water resources.’

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**MORE INFORMATION**

- Securing soils for sustainable agriculture – Royal Society of Chemistry report
  [www.rsc.org/images/081203%20OSCAR%20web_tcm18-222767.pdf](www.rsc.org/images/081203%20OSCAR%20web_tcm18-222767.pdf)
- Benefits of soil carbon – an international rapid assessment project
  [www.soilcarbon.org.uk](www.soilcarbon.org.uk)
- mySoil smartphone app from the British Geological Survey and Centre for Ecology & Hydrology
  [www.bgs.ac.uk/mysoil/](www.bgs.ac.uk/mysoil/)
- Global Food Security programme
  [www.foodsecurity.ac.uk](www.foodsecurity.ac.uk)
The idea came about when Beth was talking to Will Rawling, Chair of the Cumbrian Farmer Network, about her planned research on the carbon and nitrogen content of the soil at Will’s farm, Hollins. Will commented that he had been to several events on the importance of soil carbon storage, but nobody had ever told him about the science behind it.

So Beth did her best to explain, and in return Will shared some knowledge about how farmers make silage. They both got so much out of the conversation that they began to plan an event specifically to bring farmers and scientists together to talk about something they were both deeply interested in – soil.

Just a few months later Hollins hosted a group of more than 30 researchers, farmers and farming advisors, who gathered together on different parts of the farm to share their knowledge. One group of researchers described their work on soil compaction in the Eden Valley, and how compaction and intense rainfall combined can lead to flooding. This is a familiar problem for many farmers in the area, and the group talked about things they could do differently to reduce the risk – such as reducing stock levels and farm traffic, or introducing species-rich pasture to improve soil structure.

The researchers were able to give farmers a better insight into the whole scientific process, explaining how carbon and nitrogen emissions are measured both in the field and in the lab (a length of drainpipe hammered into the ground being particularly helpful for the latter). Processes like photosynthesis and respiration occur above and below ground with soil microbes playing a huge role, and much of the discussion focused on the significance of nitrogen and carbon storage and leaching on things like soil quality, grassland productivity and resilience to drought.

They also talked about how plant traits, such as root length and leaf size, affect carbon and nitrogen retention underground, and how this links to the activities of soil microbes. Beth’s own research looks at the potential for using satellite images to analyse vegetation and estimate below-ground processes.

It turned out that fieldwork wasn’t just the preserve of the scientists; one farmer described an experiment he is running on his dairy farm comparing how quickly silage fields and sheep pasture absorb water. Local farmers Duncan Ellwood and Sam Rawling talked about a monitoring scheme on nearby Kinnerside Common – a collaboration with Natural England – which aims to increase vegetation diversity on the common. Farmers are trained in plant identification and surveying – with the aid of a GPS, good eyes and a handbook – and paid for submitting information regularly.

‘It is really important that farmers have a better understanding of how soils and everything that is stored in them work,’ said host Will. ‘Much of what was discussed at the meeting was actually about good farming practice, and if it helps to reduce damage to the planet then we all win.’

Farmers say it takes too long for scientific understanding to filter through to them, and many rely on advisors, who also feel they have limited access to useful information. Most believe that stronger bonds between farmers, advisors, scientists and policymakers can only be a good thing – and this kind of event is definitely a step in the right direction.

MORE INFORMATION
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http://tinyurl.com/lfwvv4q
The way Earth’s vast oceans support human life is so complex we are only just beginning to understand it. They regulate our climate and weather systems, absorb carbon dioxide from our atmosphere, supply half of our oxygen and are fundamental to primary productivity – the base of the world’s marine food chain. Our oceans provide us with roughly 20 per cent of the animal protein eaten around the world, support industries from fisheries and aquaculture, to oil and gas, sport and transport, and provide us with recreational, cultural and spiritual services which are so fundamental to us we are barely aware of them.

Yet despite our intertwined existence, the marine environment continues to puzzle us. We have been exploring the oceans for centuries, trying to understand the diversity of marine life and how the marine ecosystem works – initially out of curiosity but increasingly so we can harness and manage our critical marine resources responsibly.

In 1872, the UK government converted HMS Challenger into a survey ship for a 130,000km journey to investigate marine life. This four-year mission identified 4417 new marine species from as far down as 5km. This was a massive step forward in our understanding of the sea, but it would take decades of technological advances for us to discover, let alone investigate, the numerous complex habitats such as trenches, including the Marianas which is around 11km deep, or seamounts of which more than 30,000 are thought to exist.

Humans have long had a great fascination with the sea. The mystery of our oceans has inspired scientific investigation since the 3rd century BC. But even after many centuries of study, Bhavani Narayanaswamy asks, how much do we really know about what lies beneath?

What really lies beneath?
or hydrothermal vents where superheated water is released from the Earth’s crust.

With every new study it becomes clear that our current knowledge of marine life is merely a drop in the ocean.

In 2000, a ten-year global Census of Marine Life was launched to formally assess the diversity, distribution and abundance of marine life. The census catalogued life forms from whales to microbes, discovering over 6000 potential new species. In 2011, NERC funded a three-year research project to assess the seafloor biodiversity of some of the world’s least-studied marine habitats — seamounts in the south-west Indian Ocean. This ongoing project has already revealed such a rich array of life at these features that two have been proposed to the Convention on Biological Diversity for designation as Ecologically or Biologically Marine Significant Areas.

As well as discovering new species, research projects are increasingly highlighting the complex interaction of human activity and the marine environment. From resource extraction to fishing and waste disposal, human activities are undoubtedly having an impact on the oceans. There is even evidence of human impact as far out as the Indian Ocean seamounts, particularly from the fishing industry, and this is an area we have only just started to explore.

Across these and other marine areas there is clear evidence of habitat destruction, an increase in harmful algal blooms, changing nutrient contents in seawater and even the introduction of invasive ‘alien’ species.

Maintaining the biodiversity of life in all its forms is fundamental to the health of our planet. Its importance is recognised by European leaders, and the Marine Framework Strategy Directive aims to ensure European seas achieve and maintain good environmental health. But to maintain that status we need to understand the current state of our seas.

Without a complete picture of the marine environment we can’t be sure we fully understand the impact we are having and the long-term consequences for our oceans. Quantifying impact on an environment we know relatively little about is a major challenge. European seas have been exploited in one way or another for centuries, so working out a baseline picture of what marine environments were like before human impact is difficult.

But with more and more industries such as mining turning to the oceans for future operations, it is a challenge we must address.

Marine biodiversity and ecosystem function is at the very heart of much of the research we do at the Scottish Association for Marine Science (SAMS), with projects investigating the relationship of diversity and function in organisms ranging from microbes to mammals. Evidence from SAMS projects is used by UK government advisors to help us achieve ‘Good Environmental Status’ for our seas, to determine the best locations for Marine Protected Areas, and to feed into the EU-led Marine Strategy Framework Directive. Our knowledge is also contributing to the first UN World Ocean Assessment, which aims to provide sound scientific evidence for the global management of our oceans and seas. Such assessments are critical to ensure the security of our seas and sustain the life forms (many still undiscovered) within them.

So the answer to the question ‘what really lies beneath?’ is ‘more than we know’!

The oceans are vast areas, with many species undiscovered and the lives of many known species still a mystery to us. Different marine habitats will respond differently to human impact, yet despite the work done to assess marine life globally, we don’t fully understand the links between marine life and human activity in any single habitat. A step-by-step approach, concentrating on individual regions or habitats, may give us the best chance of tackling the massive challenge of protecting our oceans. It will take an army of trained scientists but it also calls for widespread appreciation of the need to understand the links between marine life and human activity for sustaining our seas.

MORE INFORMATION
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Feeling the heat from peatland vegetation burning

There are more than 1.5 million hectares of peatlands in the UK, covering 17.2 per cent of the land surface. Upland moorlands face a range of management pressures in the UK, and recent research shows vegetation burning in peatlands has altered the biodiversity of their rivers. Sorain Ramchunder explains the issues.
Peat is dead plant material that has built up over thousands of years under waterlogged conditions. Blanket peatlands cover much of the UK uplands and are important stores of carbon. Yet these areas have been heavily exploited for water collection, agriculture, commercial forestry, sport, tourism and windfarms. These can cause the peat to release sediment and carbon into watercourses, with knock-on effects on river wildlife and on atmospheric carbon.

Over the last 150 years, many upland landscapes have been subjected to controlled rotational burning regimes to increase red grouse populations. This involves burning patches of land (up to around 5000m²) in cycles of up to 25 years. This means the catchment of an individual river will comprise dozens of burning patches of different ages, creating a rather messy-looking checkerboard effect.

Burning removes the ageing growth of dwarf shrubs and allows younger, more palatable shoots to regenerate. The aim is to provide older grouse with shelter in the taller, dense heather, while the regrowing heather supplies more nutritious shoots for feeding.

Other scientists have highlighted an increase in the area being burned and how often this happens over recent decades, and some national assessments suggest large areas of upland Sites of Special Scientific Interest in England are in an unfavourable condition partly due to rotational burning.

Some work has been done on the effects of burning on carbon storage and release from peat, but we decided to look for the first time at its impact on river macro-invertebrates. These are invertebrates retained by a 0.25mm mesh, and include various groups of insect larvae, adult beetles, gastropods and amphipods. They are an important ecological link between algae and other organic substances and the amphibians, fish and birds that depend on them.

**Fire and water**

We investigated ten peatland rivers – five affected by burning and five unburned. Rivers draining burned catchments in particular had more suspended sediment and deposited peat material than those in unburned catchments. Burned rivers had fewer herbivores and predators. There was also a decrease in the abundance of some mayflies, stoneflies and caddisflies, but increases in non-biting midge and blackfly larvae.

There could be several reasons for these changes. Fine sediment can limit the availability of oxygen by reducing the exchange of water between coarser river bed sediments, and impede the movement of macro-invertebrates in the sediment. The increase in sediment concentrations can also smother periphyton – the mixture of algae, bacteria and other microbes that cling to underwater surfaces – so less food is available for herbivores. Yet the increase in fine peat in the water increased the abundance of non-biting midge and blackfly larvae, which feed by filtering particles from the river water.

In many upland regions, the range of plants and animals living in rivers has been affected by various catchment management strategies, including rotational vegetation burning of peatlands. To understand whether our findings from this study apply more generally, we need more routine monitoring of upland river systems, in the same way as lowland systems are monitored for water quality purposes. Further long-term monitoring will allow us to characterise the effects of land management such as burning, and to find out whether rivers will recover if or when changes are made to how uplands are managed.

Though there have been no other published studies investigating effects of vegetation burning on river ecosystems, researchers at the University of Leeds are finalising a NERC-funded project, EMBER, which examines the effects of burning on soil hydrology and chemistry as well as looking in more depth at river chemistry and macro-invertebrates. The first set of published results from the project detail how burning leads to changes in soil hydrology by reducing rates of water movement in the uppermost peat layers. This means that when there is very heavy rainfall, more of it might flow over the surface of the peat, potentially leading to higher river flows.

Macro-invertebrates are an important part of animal life within freshwaters and are integral to the structure and functioning of these ecosystems. The structural changes we observed in macro-invertebrate communities can also influence ecosystem processes such as the production of algae or the decomposition of organic matter. This study suggests that upland managers may need to consider ways of reducing the extent or frequency of burning to limit effects on river ecosystems.

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**More Information**

Dr Sorain Ramchunder carried out the river ecosystem work described here while at the University of Leeds.

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EMBER was a three-year NERC-funded project, which finished in June 2013. For further details, contact the principal investigator, Dr Lee Brown.

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To the casual visitor, it might not look like the Lake District National Park’s carbon emissions need much management. Splendid vistas, rolling uplands and the odd brooding crag, fine. Heavy industry and power generation? Not so much.

For all its beauty, though, this is a working landscape. The activities of the people who work it emit greenhouse gases that add to climate change. And not only by burning fossil fuels; changes to how we use the land itself can have an even bigger effect, releasing carbon that’s been stored for centuries or millennia in woodlands and peat soils.

It’s a global problem; there’s more carbon in soil and vegetation worldwide than in the whole atmosphere, so even marginal changes can make a big difference. The Lake District itself is estimated to hold the equivalent of 84 million tonnes of CO₂ in peat, which underlies some 40 per cent of the park, and some 13 million more in woodlands.

The Lake District National Park Authority decided to take action on emissions, collaborating with the University of Cumbria on a Knowledge Transfer Partnership (KTP), funded by NERC and the Technology Strategy Board. Aimed at getting scientific expertise to where it’s needed, KTPs involve scientists acting as information conduits between researchers and those who could put that research to work.

In this case that’s Sam Hagon, a geographer whose job over the last three years has been to develop and implement a plan for landscape carbon management across the national park. This has involved a lot of conversations with everyone involved – from farmers and park rangers to water companies, landowners and bodies like the National Trust, Environment Agency and Forestry Commission.

‘The National Park Authority aims to be a leader in addressing climate change, and there’s a growing awareness that long-term decisions about land management need to take carbon into account,’ she says. ‘So they knew they had to do something, but weren’t sure exactly what. My job has been to find out.’

The park emits around 2.3m tonnes of CO₂ a year. (For comparison, total UK greenhouse gas emissions are around 550 million tonnes a year.) The Authority and its partners have agreed to cut this by one per cent every year for the long term. The KTP has helped provide the information needed to maximise carbon savings from land management, contributing to this reduction target.

Hagon’s first job was to meet the different groups who manage and use the park. ‘We wanted to learn where they are now, where they’d like to be and how to get there,’ she explains. ‘Their knowledge of the issues turned out to be mixed. Some doubted climate change is even happening. Others were concerned about it – unsurprisingly, given the weather’s impact on their work – but didn’t realise that how they manage the land could make a difference.

Once the first phase had revealed this serious information deficit, Hagon moved on to designing ways to plug the knowledge gap and help the park’s users understand practical steps they could take to help.

‘If we wanted to engage with individual farmers and land managers, we knew we needed to explain the science in a relevant
way – things like expressing the carbon emissions per acre of land in terms of the equivalent number of plane flights,’ Hagon says. ‘You can’t expect busy farmers to read long scientific reports; they want clear guidance on things they should and shouldn’t do.’

Launched in June 2013, Hagon’s ‘information toolkit’ has three main parts. She created a booklet that explains the basics of land-based carbon and how it’s affected by land management in a way that’s accessible to readers with no scientific background. It sets out things to consider when managing different habitats. So if a farmer’s land contains large areas of bracken, say, they can easily find out that they should avoid soil erosion on these sites, which often sit on deep soils and so can contain substantial quantities of underground carbon that soil erosion will release to the atmosphere.

For recently-drained bogs, on the other hand, they could think about blocking drainage ditches to re-wet the peat. This should mean no more peat carbon is lost to the atmosphere, and eventually peat may start forming again. The booklet sets out the key points about each possible action, with guidance on how to find out more.

The second is an interactive carbon map of the park, drawing on satellite data to show exactly how much carbon is contained in soil and vegetation in different places. And Hagon has also created detailed case studies of particular farms, looking at how much carbon they contain, which good practices are already happening and what further changes could be made. The case studies look at cheap options, like tweaking how the farmer tills the land, and more ambitious ones like planting new woodland to absorb more carbon.

The information isn’t aimed only at those directly managing the land; it’s also designed to be used by those who advise them – park rangers and bodies like Natural England and the Forestry Commission.

The KTP recently ended, but the carbon-management programme continues. As new Environmental Stewardship Agreements take effect, farmers, foresters and estate managers sign up to five or ten-year plans for how they’ll make sure their land absorbs as much carbon, and emits as little, as possible.

And while the early consultation showed more information was needed, the picture wasn’t all bleak. Those managing the land agree they’re well placed to help with managing its emissions – after all, they know it best. But many didn’t feel they could afford to do much without outside support. ‘They’re trying to run a business; you can’t ask them to spend lots of money for purely altruistic reasons,’ Hagon says.

Funding is available, though, from various agri-environmental schemes already in place. Three quarters of the Park’s farmers are already involved with such schemes in some way, and although most of them were intended primarily to protect wildlife, many also have carbon benefits. For example, low fertiliser inputs and hedgerow maintenance both deliver carbon benefits. More recently, money is available for woodland creation from private businesses wanting to support UK climate-change projects, and Hagon has been trying to spread word of the opportunity to farmers.

Her project’s overall goal is to bring all these different considerations together so they can be tackled holistically. ‘Peat is good for biodiversity, for the climate, for water quality and for flood reduction,’ she says. ‘Or with grassland, increasing soil organic matter both helps from a carbon perspective and improves productivity, which is good for farmers – it’s win-win.’

The National Park and its partners also hope to use the knowledge gained from the KTP to set up an innovative carbon brokerage facility, which will put farmers looking for money for such carbon-friendly projects in touch with companies that want to finance them to demonstrate their corporate social responsibility.

Other problems are harder to solve – the answer to overgrazing is generally to graze less, which farmers don’t like. But in general, addressing environmental problems doesn’t have to be bad for business. ‘We want to work in partnership with the people who are using the land, not just dictate to them,’ Hagon says. ‘The KTP is over, but our goal all along has been to build something that lasts much longer.’
Bristling with potential

In an orchard near Sheffield city centre a symbiotic relationship is blossoming between Sheffield University and Heineken. It seems they have a mutual interest in a fungus which could benefit the cider industry and UK biodiversity. Richard Hollingham talks to scientists Duncan Cameron, Karl Evans and Despina Berdeni to find out how.
Richard Hollingham: Now Duncan, these 160 trees here – only one-and-a-half metres high at the moment – are cider apple trees?

Duncan Cameron: Yes, these are varieties we’ve identified with our industrial partner, Heineken, which owns Bulmers cider. We’re looking at how the condition of the soil helps us grow cider apples that are more disease-resistant and ultimately produce more fruit for cider.

Most plant species live in symbiosis with fungi in the soil. During photosynthesis plants turn carbon dioxide into sugar which moves to the plant roots where it’s taken up by this mycorrhizal fungi. A fungus’s thread-like filaments can explore much further into the soil than plant roots, so they transport nutrients back to the plant in return for sugar. It’s a mutualistic symbiosis – both partners are benefiting.

Richard Hollingham: And does the logic go that the more fungi the better the plant – in this case the better the cider apple?

Duncan Cameron: More fungi are potentially beneficial, but it’s often down to the type of fungus. We know there are thousands of species of mycorrhizal fungus and some of them appear to be better at transporting nutrients than others. So as well as the amount we’re interested in the diversity – the number of species that are associating with the apple trees.

Richard Hollingham: How is Heineken involved?

Karl Evans: Heineken is co-sponsoring all the apple trees growing here and all the work that Despina, Duncan and I are doing. We’re expanding the work to explore the relationship between fungal diversity and plant growth in real apple orchards. We are sampling a wide range of orchard production systems – conventional, organic and ones that vary in the amount of pesticide and fertilizer use – because we have some preliminary evidence that the current farming practices in orchards could actually be reducing the diversity of mycorrhizae, which would have negative impacts on plant production.

If we can demonstrate a strong benefit of mycorrhizal diversity we may be able to improve cider production systems, so they need fewer inputs which in turn will reduce the environmental impact through things like fertiliser run-off into freshwater systems. It would also improve the cost-effectiveness of farming – why pay for inputs if fungi can do the job for free?

Richard Hollingham: So there’s a double benefit here: the cider makers benefit and so does the science?

Karl Evans: It’s actually three-way: Heineken benefits from improved profits; science benefits from the pure scientific advances we hope to make; and if our research can be rolled out to a larger scale, UK biodiversity will benefit.

Richard Hollingham: Despina, you planted all these trees – why are they in pots?

Despina Berdeni: This experiment has been set up to investigate whether mycorrhizal associations can improve the health of these trees, so we’ve got different treatments here. In some the trees have been inoculated with fungi, in others not; and we’ve got different nutrient treatments to see whether these inputs will affect the relationship between the fungus and the trees, and whether the mycorrhizae alone will be able to improve tree health.

Richard Hollingham: How will you tell? Will it be the number or quality of the apples? Or the quality of the cider you produce from the apples?

Despina Berdeni: We’re measuring a number of things – the growth and health of the trees above and below ground, and the quality and quantity of the produce from the tree. And things like the instance of pathogens and pests, to see if there are differences in their occurrence and in the trees’ resistance to them.

Richard Hollingham: Duncan, there are some fundamental scientific questions underlying this aren’t there?

Duncan Cameron: Yes, we’ve certainly seen in other cropping systems, such as in wheat, maize and corn, that mycorrhizae have huge benefits for yield, not only the quantity but in terms of the amount of nutrients, the amount of protein, that you find in these seed crops. But crop breeding processes potentially limit the ability of various crops to associate with mycorrhizae and to reap the benefits of this symbiotic association.

Apples may seem a strange crop to be using but there are some fundamental questions about long-lived species like apples compared to these much shorter-lived annual crops. Understanding the biology of the symbiosis across a range of crops has really important applications for food security research in Europe over the next ten years.

Richard Hollingham: So this could have benefits for many more crops and not just cider apples?

Duncan Cameron: Absolutely – this is the beginning really. We’re using cider apples to start with to try and understand mycorrhizal fungi association with perennial long-lived species, but of course there are lots of long-lived species in horticulture, like citrus. So as our cropping system starts to change in the UK, we’re hoping this research can be applied to new types of crop that will start being produced in the UK in the coming years.

Mycorrhizae are never going to be a magic bullet, but our research indicates they can form part of an integrated strategy for lower-input, more sustainable agriculture.
I f you’ve thought about why there’s life on our planet at all, you have probably encountered James Lovelock’s Gaia hypothesis. This proposes that the biota – the collection of life on Earth – helped shape the Earth environment to make it and keep it especially hospitable for life.

Early in my career, as I studied nutrient cycles in the ocean and their effect on phytoplankton growth, I did not at first see the links to Gaia. But a research fellowship from NERC provided a welcome opportunity to think more deeply about the wider implications of my work.

I had long been intrigued by the Redfield ratio. This is the observation, first made by Alfred Redfield in the 1930s, of a puzzling similarity between the ratio of nitrogen and phosphorus found in plankton with that dissolved in seawater as nitrate and phosphate: in both cases it’s roughly 16:1. When deep waters upwell to the surface they are rich in nutrients, and proliferating phytoplankton take up nitrate and phosphate in the ratio of ~16:1 until one or the other, or both, become exhausted.

Redfield found that they nearly always run out together – suggesting that the levels of these nutrients in the sea are perfectly matched to the needs of phytoplankton growth. As he put it: ‘That two compounds of such great importance in the synthesis of living matter are so exactly balanced in the marine environment is a unique fact and one which calls for some explanation, if it is not to be regarded as a mere coincidence.’
I developed a simple computer model of nitrogen and phosphorus cycling which reproduced the match, stabilising at a nitrogen:phosphorus ratio for seawater similar to that of phytoplankton. This model (others have since obtained similar results) showed that the similarity is not a coincidence but rather is brought about by a complex negative feedback in the nitrogen cycle, which effectively restores the seawater ratio to 16:1 if it changes away from that value. Redfield’s puzzle had been solved.

That wasn’t the end of the story for me though. This match might seem ideal for the plankton, but really they would be better off facing one scarce nutrient rather than two. It also dawned on me that there’s an even greater mystery here, which is why nitrogen limitation occurs at all.

Death or incapacitation through nitrogen starvation is widespread, not just at sea but also on land where herbivores such as caterpillars often struggle to get enough nitrogen from the leaves they eat. It’s also a problem in agriculture, with prodigious quantities of nitrogenous fertilizers having to be applied worldwide to maximise crop yields.

Yet nitrogen is exceptionally abundant in the environment, it makes up 78 per cent of air, as dinitrogen (N$_2$). N$_2$ is also much more plentiful in seawater than other dissolved forms of nitrogen. The problem is that only organisms possessing the enzyme nitrogenase (organisms known as nitrogen-fixers) can actually use N$_2$, and there aren’t very many of them. This is obviously a less than ideal arrangement for most living things. It is also unnecessary. Nitrogen starvation wouldn’t happen if just a small fraction of the nitrogen locked up in N$_2$ was available in other forms that can be used by all organisms; yet biological processes taking place in the sea keep nearly all that nitrogen as N$_2$. If you think about what is best for life on Earth and what that life can theoretically accomplish, nitrogen starvation is wholly preventable.

This realisation led me to wonder what other aspects of the Earth environment might be less than perfect for life. What about temperature? We know that ice forming inside cells causes them to burst and that icy landscapes, although exquisite to the eye, are relatively devoid of life. We can also see that ice ages – the predominant climate state of the last few million years – are rather unfortunate for life as a whole. Much more land was covered by ice sheets, permafrost and tundra, all biologically impoverished habitats, during the ice ages, while the area of productive shelf seas was only about a quarter of what it is today. Global surveys of fossil pollen, leaves and other plant remains clearly show that vegetation and soil carbon more than doubled when the last ice age came to an end, primarily due to a great increase in the area covered by forests.

Although the cycle of ice ages and interglacials is beyond life’s control, the average temperature of our planet – and hence the coldness of the ice ages – is primarily determined by the amount of CO$_2$ in the atmosphere. As this is potentially under biological control it looks like another example of a less than perfect outcome of the interactions between life on Earth and its environment.

Look further and you find still more examples. The scarcity of light at ground level in rainforests inhibits growth of all but the most shade-tolerant plants. There’s only really enough light for most plants at canopy height, often 20 to 40 metres up, or below temporary gaps in the canopy. The intensity of direct sunlight does not increase the higher you go, so having the bulk of photosynthesis taking place at such heights brings no great advantage to the forest as a whole. Rather the contrary, trees are forced to invest large amounts of resources in building tall enough trunks to have the chance of a place in the sun. This arrangement is hard to understand if you expect the environment to be arranged for biological convenience, but is easily understood as an outcome of plants competing for resources.

During the course of my career, these – and other – conclusions about Earth’s habitability led me to examine the whole Gaia hypothesis with a much more critical eye. The Earth is indeed a wondrous place, and home to many millions of species including ourselves – but in my view it’s by no means perfect.
The potential of the peatlands of southern South America as sources of information about past climates has been neglected compared to those of the Northern Hemisphere. Tom Roland describes weeks tramping through the bogs of Tierra del Fuego in an effort to redress the balance.

‘We’ll be walking in Charles Darwin’s footsteps,’ I announced grandly at London Heathrow, a few days into the New Year. Patagonia, my destination, has always held a mysterious fascination for explorers, travellers and those following la ruta del fin del mundo – the road to the end of the world. It wasn’t just Darwin we’d be following, but Ferdinand Magellan, Bruce Chatwin and any number of hopeful nineteenth-century gold prospectors!

Thirty-six hours, four flights and over 8000 miles later, I find myself squelching across some of the world’s most pristine peatlands. The snow-capped Southern Andes rise steeply on either side, and the bright red Sphagnum magellanicum, the moss species so characteristic of these bogs, contrasts sharply with the blue sky of an unseasonably warm austral summer.

Writing in The Voyage of the Beagle, Darwin was clearly in awe of the landscape around him as he landed on the Isla Grande de Tierra del Fuego, at the southernmost tip of Patagonia.

‘A single glance at the landscape was sufficient to show me how widely different it was from anything I had ever beheld.’

Some 180 years later, the region still evokes a feeling of wilderness that is hard to imagine anywhere else. As we trudge further up the valley, it very quickly becomes clear that the peatlands of southern South America themselves are also unique, not just in their geographical distribution, but also their surface vegetation and topography. Despite having visited numerous bogs across Europe and North America, none of us had seen anything quite like this!

So what is so special about the region’s bogs – why have we travelled halfway across the world to visit them? The answer is simple: the NERC-funded PATAGON project aims to explore the potential of the region’s exceptional peatlands for palaeoclimatic reconstruction.

Peatlands occupy about three per cent of the Earth’s land surface, but this distribution is heavily skewed towards the north. In fact, recent estimates suggest that, outside the tropics, bogs in the Southern Hemisphere represent just over...
one per cent of the world’s peatlands, and are largely limited to southern Patagonia. Despite these figures, the region’s bogs possess a wealth of scientific interest, but a historic bias towards sites in the Northern Hemisphere has left the South comparatively underrepresented in terms of palaeoclimate studies. This hampers our ability to examine where climate change has happened, and is happening, and to evaluate the predictions of climate models.

The PATAGON project also presents an excellent opportunity to examine peatlands in their natural state, as many northern bogs have been heavily modified by humans – in some cases as long ago as Roman times. Sadly, southern bogs too are coming under increasing environmental pressures, largely at the hands of those wishing to exploit the peat for fuel and fertilizer – this makes their examination even more timely.

The project involves academics and research staff from Aberdeen, Southampton, Swansea and Plymouth universities. It aims to apply techniques to learn about past climates by analysing peat, which were largely honed in the Northern Hemisphere, to the remote bogs of southern South America.

The project’s study sites are ideal for research into past climatic variability in the Southern Hemisphere, owing to their position in the path of the Southern Westerlies, a major circulatory component in a complex region of the Earth’s climate system, which also includes the Southern Annular Mode – a shifting pattern in the atmospheric pressure gradient between Antarctica and the southern mid-latitudes – and the El Niño-Southern Oscillation.

One of the keys to unravelling past climate changes is the vegetation that
SO WHAT IS SO SPECIAL ABOUT THE REGION’S BOGS – WHY HAVE WE TRAVELLED HALF WAY ACROSS THE WORLD TO VISIT THEM?

Rostkovia magellanica, a species native to South American bogs.
A team led by researchers at the University of Oxford has revealed the evolutionary history of the deep-sea yeti crab, nicknamed ‘the Hoff’ because of its hairy chest. The crab lives around hydrothermal vents on the deep ocean floor; it turns out that it evolved relatively recently to adapt to this extreme environment, surrounded by noxious chemicals at temperatures of some 380°C. The study in *Proceedings of the Royal Society B* argues that the recently-discovered crabs – still not formally described – split off from their nearest relatives just 40 million years ago. They survive by effectively farming bacteria on their chest hair, then using special comb-like mouthparts to strain off and eat them.
In the next century, our planet’s climate system is expected to experience continued man-made warming at a rate not seen in thousands of years. As with past changes in climate, we are likely to see major shifts in the global distribution of plants and animals.

For many species, climate change will cause population declines and ultimately extinction. For others, it may provide opportunities to colonise new habitats and expand into new regions. In many cases the difference between survival and extinction for a species will depend on its ability to disperse to regions of newly-suitable climate. To keep pace with climate change, it must found new populations as those within its old range dwindle and die out.

This situation is a serious challenge to biodiversity conservation in the 21st century; how do we manage habitats and landscapes to encourage species to make the most of emerging opportunities, while still trying to minimise the losses as their historical ranges become climatically less suitable?

The solution is complicated because beneath the global maps and seasonal and regional averages, climate is inherently patchy and variable. The evidence for a global increase in temperature is unequivocal, yet any particular place on Earth may still experience an unusually cold season one year and a heatwave the next.

In the UK, where talking about the weather is a national obsession, statistics showing decades of average warming are easily forgotten after front-page newspaper coverage of a disappointingly cool, wet summer bank holiday or a heavy spring snowfall. For wildlife too, the signal of climate change may seem to be swamped by the variation in weather.

Understanding and managing how species respond to climate change may mean paying more attention to the variability and extremes of weather and microclimates which drive ecological processes. Most species are small; they sample their environment at a fine resolution. They also undergo seasonal cycles of reproduction, development and activity throughout the year, and can be particularly sensitive to climate at specific times of the year.

Certain weather conditions, times of day and seasons of the year can create many variations of microclimate. South-facing slopes may be considerably warmer than north-facing ones; short vegetation...
is warmer than tall vegetation during the day and cooler at night; regions near the sea, lakes and wetlands may be protected from extremes of temperature, and small depressions and valley bottoms can trap cold air and become several degrees cooler than their surroundings. Even the difference between sunlit and shaded leaves or the southern and northern sides of a tree trunk can provide a contrast of several degrees. Many species use these microclimates at specific stages in their life cycles to provide the conditions they need to survive.

**Climate change – winners and losers**

As an example of how species expand their range in a warming, but highly variable, climate we studied the spread of a butterfly, the silver-spotted skipper, over 27 years at the north-western margin of its range in south-east England. In the early 1980s, habitat fragmentation and changing agricultural practices had restricted this butterfly to a handful of British sites; however, in the three decades since, it has expanded its range considerably, aided by both conservation efforts and warmer summers.

The butterfly spends the winter as an egg, matures as a caterpillar through spring and early summer and flies as an adult butterfly for just a few weeks in August. During this brief adult life, the daytime temperature is critical to allow successful reproduction; butterflies are less active and females lay few eggs when the temperature in their grassland habitat falls below 26°C.

It’s a risky strategy in the unpredictable British climate. If butterflies emerge from their pupae during a period of hot weather they may breed successfully and boost numbers for the following year, but in cool, wet seasons their numbers dwindle. Our study period included the three warmest Augusts on record in England, but interspersed between these summer heatwaves were seasons at or slightly below the 20th-century average temperature.

We modelled the microclimate of individual patches of grassland in each year and the probabilities that each will be colonised by a new population, or that its existing population will go extinct. This let us reproduce the shifting patterns of colonisation and population explosion and limited decline that we observed in field surveys from 1982 to 2009.

Our models and observations of the silver-spotted skipper teach us two important lessons. Firstly, as the species has spread out from refuge populations as the climate becomes warmer, this expansion has mostly happened in exceptionally warm flight seasons. In cooler seasons, more populations go extinct than new ones are established, and some of these advances are lost. The amount of variability – extreme hot seasons above the warming trend and cool seasons below it – determines the pattern of expansion.

Secondly, the newly-established populations that survive are most likely to be in the warmest parts of the landscape – on south- and west-facing slopes capturing the afternoon sun, which can raise the temperature by over ten degrees and significantly boost the chances that a population of butterflies will persist. These local microclimates may act as sources for the next wave of expansion during a warm period, and are critical for rapid expansion.

Insights like these for a single species may be useful in planning for conservation. For example, they could help us choose the best sites to reintroduce plants and animals that have gone locally extinct, or to introduce them into new areas for the first time. They can help us decide how to manage the habitat in places that have not yet been colonised by a species, but may be key staging posts for its future expansion.

Managing for conservation of many species when faced with an uncertain, variable climate is hard. One strategy is to pay particular attention to conserving the range of habitat structures and features in the landscape that create a diversity of microclimates.

Many traditional management practices – coppicing woodlands, grazing pastures, controlled burning of moorland and cutting haymeadows, for example – are already widely used as tools for conservation, as they create varied microclimates and promote species diversity. Can we adapt these practices to meet the new challenges of biodiversity conservation in the 21st century? At a landscape scale, we need to keep space for wildlife along the full range of microclimatic conditions available – from icy mountain tops, snow beds and frost hollows to south-facing sun-traps, from valley-bottom wetlands to steep slopes with drought-prone thin soils. By managing for microclimatic diversity we can protect plants and animals from the worst effects of extreme climate.

**THE SIGNAL OF CLIMATE CHANGE CAN BE SWAMMED BY THE VARIATION IN WEATHER...**

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**MORE INFORMATION**

Dr Jonathan Bennie is a postdoctoral researcher at the University of Exeter’s Environment and Sustainability Institute.

Email: j.j.bennie@exeter.ac.uk.

Many ideas were contributed by the organisers and attendees of a NERC-funded workshop ‘Managing for Microclimate’ held at the Institute for Physics in November 2012, organised by Dr Jenny Hodgson at the University of Liverpool.
An environmental science PhD doesn’t only lead to a career in the lab. Alison Smith and Valerie Nadeau found that people with NERC-funded doctorates turn up in the most unexpected places.

**ANDY YOUNG**
Founder and managing director of Wallingford HydroSolutions, a consultancy spun out from the Centre for Ecology & Hydrology – provides software for assessing flood risk, managing water resources and planning hydropower schemes.

‘We’d been talking about setting up a spin-out company in the pub for about ten years. My line manager and I were always very outwards looking – focused on applied research, which academics often consider second rate – but I think it is more challenging than pure research because you don’t have the luxury of designing your own experiments. You have to deal with the data you’ve got, and produce a real answer for your client.’

**JANE FRANCIS** (left)
Professor of palaeoclimatology at the University of Leeds – studies fossil plants to help understand ancient polar climates.

‘I was in the field one day, and I hammered open a piece of rock, and in it there were remains of fossil plants that I absolutely had not expected to find. From that moment on, my research changed direction. If I hadn’t split open that rock, I don’t think I would be where I am today.’

**SARAH WATSON**
Consultant, Quintessa – assesses the safety of nuclear-waste disposal facilities.

‘People can argue all they like about nuclear new build, but we’ve got rather a lot of waste sitting at Sellafield in unsatisfactory facilities, or sitting at power stations – thousands and thousands of tonnes, and we need to make sure it is disposed of safely. What we do isn’t the sort of thing that’s taught on university courses. We often write our own software to address unique problems, rather than just using existing tools.’

**SIMON QUINN**
Principal hydrogeologist, AMEC – helps protect and manage groundwater resources, which supply 75 per cent of the water used in south-east England.

‘We advise the Environment Agency how to protect groundwater from the pressures on it – nitrate pollution from fertilisers, increased abstraction, the effects of climate change and so on. We help water companies predict how much groundwater will be available so they can plan for the future. As a result, over the last 20 years the heath of our rivers in the UK has increased a lot because of tighter regulations and better management of water catchment areas.’
NICOLA RANGER
Scientific advisor, Department for International Development – uses her knowledge of atmospheric science to contribute to international climate-change policy.

‘I always wanted to be a scientific advisor in government. That was my dream. I enjoy working on important questions and being able to identify the relevant science, feed it in at key points in the process and then see the impact on policy.’

GAVIN BROAD
Senior curator of Hymenoptera (wasps), Natural History Museum – looks after a collection of 75,000 species.

‘My job involves going through thousands of drawers full of pinned insects and thousands of tubes full of insects in alcohol, and making sure they’re safely housed and correctly identified. What might put a lot of people off is the scale of the collections, but that’s what I like. You can start on a drawer and you never know what you’re going to find in there.’

JILL CROSSMAN

‘For my fieldwork in Alaska I received wilderness survival training. I had about 20 bear encounters, and one of them charged. You just have to stand there and wave your arms and shout really loudly, and make sure the person you are with doesn’t run away. The bear got to within about ten feet before it stopped.’
Back issues

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