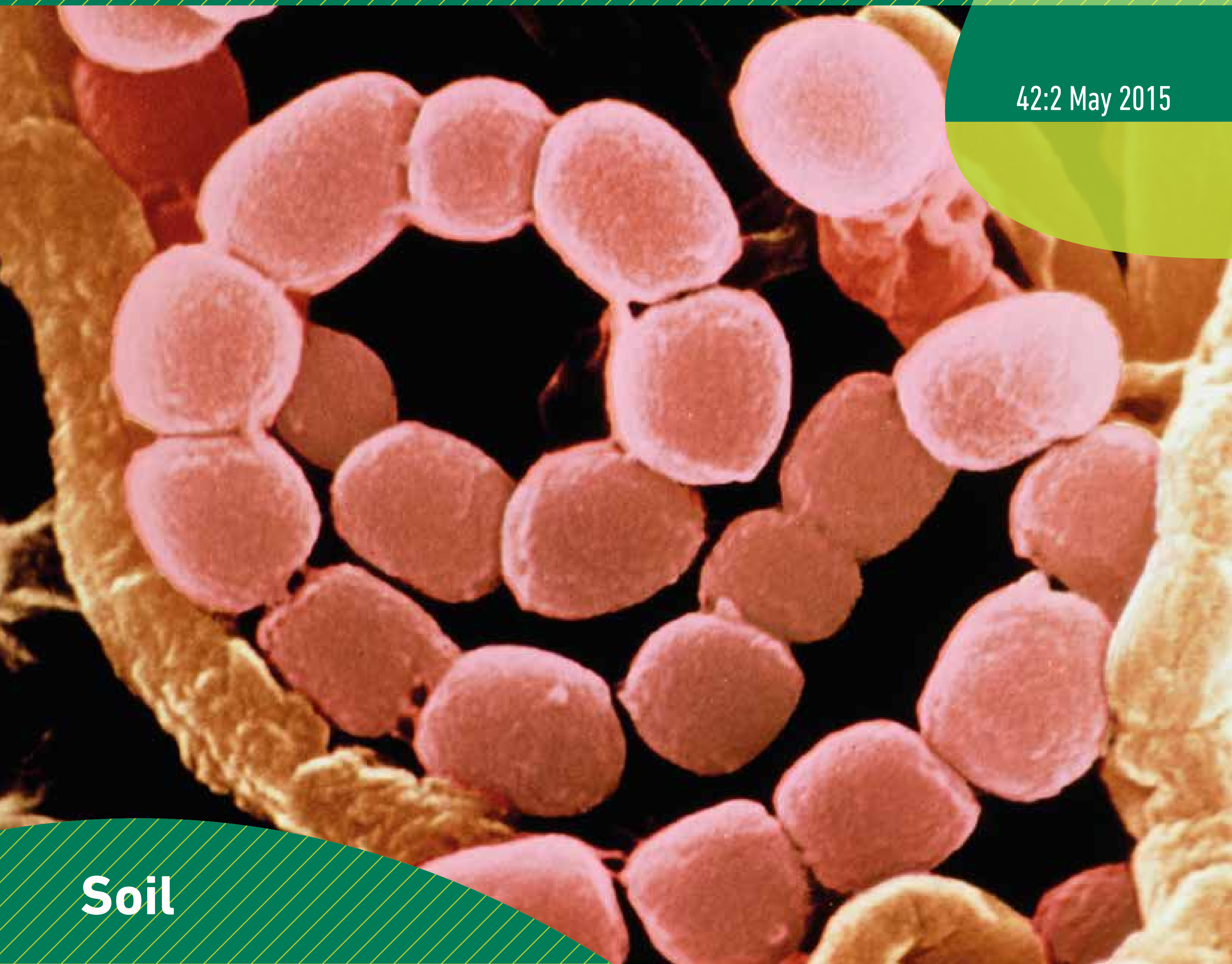
Microbiology TODAY

42:2 May 2015



Soil

The microbial world at our feet
Micro-organisms, -biomes and -networks
Soil ecosystem processes
The smell of the soil
Soil-borne human diseases

SOCIETY FOR GENERAL MICROBIOLOGY

Widely distributed throughout the body, including CSF[1]

Oral levels comparable to i.v. levels[2]

Rarely implicated with *C.difficile*[3]

CHLORAMPHENICOL

CAPSULES

PIP: 106-5796

AAH: CHL600B

ALLIANCE: 065995

MOVIANTO: CHL25060

Effective against serious infections including:

- *H. influenzae*[1,2]
- Typhoid[1,2]
- MRSA[4]
- VRSA[5]
- Neisseria[1,2]
- Legionella[1,2]
- Rickettsia[1,2]
- *C.difficile*[6-9]
- *E. coli*[1]

Abbreviated Prescribing Information
Chloramphenicol Capsules BP 250mg

Presentation: Hard Gelatin Capsules.
Indications: Typhoid fever and life-threatening infections, particularly those caused by *Haemophilus Influenzae*, where other antibiotics will not suffice.
Posology: For oral administration.
Adults and elderly: 50 mg/kg body weight daily in 4 divided doses. For severe infections (meningitis, septicaemia), this dose may be doubled initially, but must be reduced as soon as clinically possible. Children: Not recommended.
Contra-indications: Known hypersensitivity or toxic reaction to chloramphenicol or to any of the excipients. Should not be used for the prophylaxis or treatment of minor infections; during active immunisation; in porphyria patients; in patients taking drugs liable to depress bone marrow function; during pregnancy, labour or by breast-feeding mothers.
Special warnings and precautions for use: Use only if other treatments are ineffective. Use should be carefully monitored. Reduce dose and monitor plasma levels in hepatic or renal impairment; in the elderly; and in patients concurrently treated with interacting drugs.
Interactions: Chloramphenicol prolongs the elimination, increasing the blood levels of drugs including warfarin, phenytoin, sulphonylureas, tolbutamide. Doses of anticonvulsants and anticoagulants may need to be adjusted if given concurrently. Complex effects (increased/decreased plasma levels) requiring monitoring of chloramphenicol plasma levels have been reported with co-administration of penicillins and rifampicin. Paracetamol prolongs chloramphenicol half-life. Chloramphenicol may increase the plasma levels of calcineurin inhibitors e.g. ciclosporin and tacrolimus. Barbiturates such as phenobarbitone increase the metabolism of chloramphenicol, resulting in reduced plasma chloramphenicol concentrations. In addition, there may be a decrease in the metabolism of phenobarbitone with concomitant chloramphenicol use. There is a small risk that chloramphenicol may reduce the contraceptive effect of oestrogens. Chloramphenicol reduces the response to hydroxocobalamin. Chloramphenicol is contra-indicated in patients taking drugs liable to suppress bone marrow function e.g. carbamazepine, sulphonamides, phenylbutazone, penicillamine, cytotoxic agents, some antipsychotics including clozapine and particularly depot antipsychotics, procainamide, nucleoside reverse transcriptase inhibitors, propylthiouracil.
Pregnancy and Lactation: The use of chloramphenicol is contra-indicated as the drug crosses the placenta and is excreted in breast milk.
Effects on ability to drive and use machines: No significant effect on driving ability.
Undesirable Effects: Reversible dose related bone marrow depression, irreversible aplastic anaemia, increased bleeding time, hypersensitivity reactions including allergic skin reactions, optic neuritis leading to blindness, ototoxicity, acidotic cardiovascular collapse, nausea, vomiting, glossitis, stomatitis, diarrhoea, enterocolitis, Gray Baby Syndrome particularly in the newborn, which consists of abdominal distension, pallid cyanosis, vomiting, progressing to vasomotor collapse, irregular respiration and death within a few hours of the onset of symptoms.
Overdose: Stop chloramphenicol immediately if signs of adverse events develop. Treatment is mainly supportive. If an allergy develops, oral antihistamines may be used. In severe overdosage e.g. Gray Baby Syndrome, reduce plasma levels of chloramphenicol rapidly. Resin haemoperfusion (XAD-4) has been reported to substantially increase chloramphenicol clearance.
Pack size and Price: 60 capsules £377.00
Legal Category: POM.
Market Authorisation Number: PL17736/0075.
Market Authorisation Holder: Chemidex Pharma Limited, 7 Egham Business Village, Crabtree Road, Egham, Surrey TW20 8RB, UK.
Date of preparation: October 2014.
See Chloramphenicol Capsules Summary of Product Characteristics for full prescribing information.

EG/CH/JAN/2015/09

Adverse events should be reported. Reporting forms and information can be found at www.mhra.gov.uk/yellowcard. Adverse events should also be reported to Essential Generics on 01784 477167.

References:

1. Martindale: The Complete Drug Reference. Chloramphenicol. [Online]. Available from: http://www.medicinescomplete.com [Accessed 18th August 2014]. **2.** Fluit, A.C., Wielders, C.L.C., Verhoef, J., and Schmitz, F.J. Epidemiology and susceptibility of 3,051 Staphylococcus aureus isolates from 25 university hospitals participating in the European SENTRY Study. Journal of Clinical Microbiology. 2001; 39(10): 3727-3732. **3.** Weigel LM *et al.* High-level vancomycin-resistant Staphylococcus aureus (VRSA) associated with a polymicrobial biofilm. Antimicrobial Agents and Chemotherapy. Published online ahead of print on 30th October 2006. http://aac.asm.org/cgi/reprint/AAC.00576-06v1.pdf. (Accessed on 22nd August 2011). **4.** Kelly, C., LaMont, T. Patient information: Antibiotic-associated diarrhea (Clostridium difficile). www.uptodate.com. 2011. **5.** Feder. H, Chloramphenicol: What we have learned in the last decade. Southern Medical Journal. 1986; (79)9: 1129-34. **6.** Ensminger, P., Counter, F., Thomas, L., Lebbehuse, P. Susceptibility, resistance development, and synergy of antimicrobial combinations against Clostridium difficile. Current Microbiology. 1982; 7: 59-62. **7.** Poilane, I., Bert, F., Cruaud, P., Nicolas-Chanoine, MH., Collignon, A. Interest of the disk diffusion method for screening Clostridium difficile isolates with decreased susceptibility to antibiotics. Pathologie Biologie (Paris). 2007; 55(8-9): 429-33. **8.** Cattoir, V., Ould-Hocine, ZF., Legrand, P. Antimicrobial susceptibility of Clostridium difficile clinical isolates collected from 2001 to 2007 in a French university hospital. Pathologie Biologie (Paris). 2008; 56(7-8): 407-11. **9.** Brazier, JS., Levett, PN., Stannard, AJ., Phillips, KD., Willis, AT. Antibiotic susceptibility of clinical isolates of clostridia. Journal of Antimicrobial Chemotherapy. 1985; 15(2): 181-5.

ESSENTIAL GENERICS

For further information, please contact: Essential Generics, 7 Egham Business Village, Crabtree Road, Egham, Surrey TW20 8RB, UK

Editorial

Soil is a fundamental source of life. As such it is fitting and timely that 2015 has been declared the International Year of Soils by the 68th United Nations General Assembly. Among other reasons, it highlights a need to raise awareness of the importance of soils for food security and other essential eco-system functions.

I became aware of the importance of soil as a child living in Uganda. My father was a soil chemist who worked in the field of international development. He travelled the globe, often to remote, inaccessible and war-torn areas to collect data and soil samples to provide information for future crop use and agricultural practice. Our house was a repository for piles of books providing both historical and up-to-date accounts of soil studies; scientific instruments designed to gather, analyse and record soil samples; handwritten field notes; and tightly rolled, stained and soiled maps annotated with symbols and abbreviations. My father's passion for the earth was also centred around my childhood home on the east coast of Scotland. As children, my siblings and I learnt about our local geology of sandstone and sediments. We were shown how this translated into crop choice (mostly soft fruits and potatoes) and crop rotation, soil and soil fertility, local building materials and land use and our modern coastal landscape.

My father had an intuitive understanding of soil microbiology and its importance to the 'health' of the soil. He had an inherent belief that there were forces at work in the soil that scientists simply hadn't discovered and as technology improved our understanding would increase. The articles that we present in this edition lend weight to this belief.

Richard Burns describes soil as a massive and versatile repository of activities that are capable of responding to any number of chemical, physical and biological conditions. He discusses the catabolic potential of the microbial world and the likelihood that microbes will be used to break down pollutants and render them harmless thereby saving our soil. Robin Sen's article discusses the role of bacteria in the evolution of our soil on Earth. A complementary article by Geertje van Keulen and Ingrid Hallin describes the ecosystem processes sustained by microbial activity, which include nutrient cycling, and the breakdown of complex organic compounds from dead biomass to simple forms that can be used by the soil biosphere. Keith Chater's article focuses on the main odour component geosmin that was first studied scientifically towards the end of the 19th century and is responsible for the evocative smell of freshly disturbed or wetted soil. The article written by Simon Jeffery and Wim H. van der Putten outlines a different side to soil, namely the ecology of soil-borne human diseases.

In this edition the Comment section has been written by Gulnaz Javan and her team of microbial forensic scientists at Alabama State University. It describes how microbial activity on, in and around cadavers may potentially aid death scene investigations. Finally, we are highlighting the start of the Small World Initiative programme, an exciting project that was first organised by Yale University (http://smallworldinitiative.org) and is now being rolled out by the Society. More details about the programme will be released as it develops over the coming months.

If you look up 'soil' in any English dictionary, it is apparent that it can be used as both a verb and a noun. Interestingly, as a verb, 'soil' has been imbued with negative meanings and connotations and as a noun it fares little better. It is timely that 2015 is the International Year of Soils. Soil is not just dirt. This recognition will remind the wider world of the positive and essential role that soil and soil microbes share as part of our life here on Earth.

This edition is dedicated to my father, Alexander Ross McWalter, born 21 July 1926 and died 29 November 2013.

Laura Bowater
Editor
laura.bowater@uea.ac.uk

2015 International Year of Soils

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False-colour scanning electron micrograph of the soil bacterium *Streptomyces lividans*. Dr Jeremy Burgess / Science Photo Library

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Division of Immunity & Infection, University of Birmingham Medical School, Edgbaston, Birmingham B15 2QU; **i.r.henderson@bham.ac.uk**

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Faculty of Health and Life Sciences, Northumbria University, Northumberland Road, Newcastle-upon-Tyne NE1 8ST; **david.pearce@northumbria.ac.uk**

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From the President

2015 is the International Year of Soils, which provides the focus for this edition of *Microbiology Today*. Those of us who have worked on soil micro-organisms know what a complex and fascinating ecosystem they inhabit. Not only is soil microbiology of great academic interest, the micro-organisms are of crucial importance in determining the characteristics of the soil.

Photo Ian Atherton

Soil health and nutrient cycling was one of the nine research themes emphasised as important to feeding the planet in the Society's 2012 Position Statement on Food Security and Safety. In the same year the Society won a Silver Gilt Medal at the Chelsea Flower Show for our display on the role of micro-organisms in the health of soils and of crops entitled Can Microbes Feed the World?

Not only are soil micro-organisms of interest in maintaining a healthy soil and ensuring good productivity from land, they are important in many other areas. One of the more bizarre hypotheses I have come across is that the African veldt is so flat because of the action of micro-organisms, as opposed to the physical erosion, in leaching soils and thereby causing the soil to settle in a uniform fashion. As far as I am aware, any evidence for this entertaining hypothesis is totally lacking. However, the actions of micro-organisms on the mineral composition of soils are important and are of interest to the Geomicrobiology Network, a group supported by the Society in association with the Mineralogical Society, which brings together researchers from a variety of disciplines with an interest in the role of micro-organisms in geological processes. The Network will hold its next meeting on 24 June at the University of Leeds.

Another high-profile role of soil micro-organisms is in the production of antibiotics. Streptomycetes produce about two-thirds of the known natural antibiotics, for example. Given the concerns about the prospective increase in antibiotic resistance, with the prediction of an extra 10 million deaths by 2050 unless new antibiotics become available, I am delighted that the Society is proceeding with the Small World Initiative. This citizen science project will engage schoolchildren and the public in the search for antibiotic-producing micro-organisms in soil samples and will, we hope, allow new classes of antimicrobials to be discovered and developed for clinical and veterinary use. Further details of the Initiative are given in this edition.

Antimicrobial resistance was one of the sessions at our Annual Conference in Birmingham and this focus helps pull together the research and future opportunities in this area. This was again a highly successful conference. The Annual Conference is an opportunity to bring together microbiologists across the breadth of our discipline and across the range of experience from PhD students to senior industrial practitioners and geriatric professors (among whom I include myself). Our 2016 Conference returns to Liverpool and we already have a variety of excellent proposals for sessions at that meeting. It is never too soon to think about sessions for the 2017 Conference in Edinburgh; the deadline for proposals is 14 December 2015.

The Society continues to develop and expand its reach to our scientific community. The Annual Conference saw the launch of our new journal, *Microbial Genomics*, which complements our existing publications. I encourage colleagues to use the Society's journals for their publications. Our future as a learned society, our support of early-career researchers, our public engagement activities and our ability to influence opinion-formers all depend heavily on our journal income.

We are a membership organisation. As always, if you have suggestions for how the Society could better serve you, I am pleased to receive these by email.

Nigel Brown
President
president@sgm.ac.uk

From the Chief Executive

It was wonderful to meet so many of you at the Annual Conference and to listen to talks and discuss posters about the vast range of innovative science being conducted by members of the Society for General Microbiology. There were many highlights of the Conference but for me one of the most important was the launch of the Society's new journal, *Microbial Genomics*.

As well as developing our portfolio of publications, *Microbial Genomics* will publish research that allows us to explore the origins, evolution and drivers associated with historical and contemporary disease outbreaks, in addition to applications related to the environment, agriculture and the pharmaceutical industry.

As the Society reaches the milestone of its 70th birthday, it is worth remembering that the founders of the Society wanted to support networks and connections between microbiologists working in ostensibly different fields but whose research, when combined, could have a greater impact. In their words, the Society existed "for the establishment and extension of common ground between all forms of microbiology". That aim is as relevant today as it was seven decades ago, and *Microbial Genomics* is a very clear example of how biochemical techniques, used to reveal patterns in genetic information, can equally well be applied in a clinical setting or help to understand ecological and environmental processes.

This is typical of the output of the Society's journals, which collectively have a huge impact not only in the scientific world but in practical settings and in the public consciousness. One indication of that is the level of interest in the Society's blog, which, among many other subjects, runs a monthly round up of new species described in the *International Journal of Systematic and Evolutionary Microbiology*. In the last year, the number of readers of the blog has doubled. Recent papers in the journals have covered evolution in *Salmonella*, pathogenicity in *Actinobacillus*, dogs' susceptibility to human influenza, protein interactions in phages and medical reports about diseases as different as farmer's lung disease and diarrhoea in toddlers in the developing world. This is the tip of a massive iceberg; we know we are publishing some of the best microbiology research from around the world because more and more authors are submitting their work to the Society's journals. Well over 90% of the authors are based outside the UK or Ireland.

Sir David Baulcombe, who won this year's Prize Medal for his brilliant plant science work, did not start out as a virologist. He pointed out that when his research interests led him into the field, the Society for General Microbiology provided a platform for him to meet established virologists and develop his understanding and experience. One of the things he specifically mentioned as valuable was publishing in the *Journal of General Virology*. For example, he was part of the team that published the complete nucleotide sequence of tobacco rattle virus in 1987. Early career scientists take note – people who publish in the Society's journals can go on to great things, so start submitting to *Microbial Genomics*!

We want to keep the Society's journals at the forefront of scientific publishing, which is why we have invested in new technologies and partnerships this year, to provide the best service to authors, readers and referees, and why we are looking at how we can recognise the contributions that those referees are making to scientific progress.

As in all of the Society's work on behalf of the scientific community, we are keen to ensure that our scientific publishing operation is as closely aligned as possible with the needs and ambitions of microbiologists in universities and research institutes, industrial laboratories and hospitals. So please email me to let me know what you think about *Microbiology*, the *Journal of General Virology*, the *Journal of Medical Microbiology*, *JMM Case Reports* and the *International Journal of Systematic and Evolutionary Microbiology*.

Peter Cotgreave
Chief Executive
p.cotgreave@sgm.ac.uk

News

Second call for Prize Lecture nominations

The Society is reopening its call for nominations to our 2016 Prize Lectures and the 2017 Prize Medal. If you missed the opportunity to submit in the first wave, this is your chance to acknowledge the contribution of someone you know to microbiology. For all Prize Lecture criteria, process information and nomination forms please visit: **www.sgm.ac.uk/prizelectures**

Nominations will close **3 August 2015**. Members are reminded to consider the widest talent pool available when selecting candidates for nomination.

Microbiology policy challenges – members share their views

January saw the members of the Society for General Microbiology and Society for Applied Microbiology discuss the grand policy challenges most relevant to microbiology at a workshop in London. Following on from workshops held last year in Nottingham and Glasgow, members from a diverse range of backgrounds picked their top policy priorities and identified ways learned societies could help microbiologists make a difference. We will be combining the views from the workshop with 140 responses we received from our online survey to identify priorities for our policy work going forward. Thank you to all members that took part. Further information will be provided in the August issue of *Microbiology Today* including the results from the member survey.

Politicians and researchers discuss genetically modified insects

Earlier this month the Society co-sponsored an event at the House of Lords, which brought politicians and researchers together to discuss the promise and pitfalls of using genetically modified insects to control infectious diseases. The event was organised by Society member Dr Anusha Panjwani, a postdoctoral researcher at The Pirbright Institute, who wrote a policy briefing on this issue during a recent fellowship at the Parliamentary Office of Science and Technology. The event was co-sponsored through one of the Society's Education and Outreach Grants. For further information on the Society's grants programme visit: **www.sgm.ac.uk/grants**

Young microbiologists quiz politicians

Six of the Society's younger members got the chance to put their science policy questions to parliamentarians and policy-makers in March at Voice of the Future 2015. The event, which followed the format of a committee hearing in the House of Parliament, saw young scientists and engineers quiz witnesses including Sir Mark Walport, the Government's Chief Scientific Adviser, and Greg Clark, Minister of State for Universities, Science and Cities. Leah Fitzsimmons, Lorena Fernández-Martínez, Elaine Cloutman-Green, Ruth Nottingham, Kevin Maringer and Sarah Duxbury attended on behalf of the Society. Kevin asked Sir Mark about how vaccination uptake can be improved in the UK, while Ruth questioned Mr Clarke about what Conservative science policies set them apart from the other parties.

At the Voice of the Future 2015 event.

Federation of Infection Societies (FIS) 2015: Glasgow 21–23 November

Action on Infection – beyond 2015

FIS 2015 promises to be a vibrant meeting to address the issues of tackling infection beyond 2015 so that although the 'post-antimicrobial era' may remain a concern, it does not become a reality. International speakers who are leaders in their field will be discussing issues that will help tackle infection. All aspects of infection will be covered, from point of care diagnostics through to innovative treatment options. There will be 40+ interactive sessions and excellent networking opportunities. Up to 40% reduction will be available on 2014 registration prices. Go to **www.actiononinfection.com** to register.

2015 Focused Meetings

Two more international Focused Meetings are taking place in September; the first will focus on invasive fungal species and is held jointly with the British Mycological Society, the second is on arboviruses and their associated vectors. These events offer a defined programme on a specific microbiology topic to engage key researchers in the field. More details are available on page 82.

Irish Division Meeting 2015: Microbial Interfaces

To coincide with the 50th Anniversary of Microbiology at the National University of Ireland, Galway, the Irish Division has organised a meeting on 'Microbial Interfaces' which will take place on 17–19 June. For further information see page 82.

Equality & Diversity in the Society

Equality and Diversity will now be embedded across the Society's Council and Committees following a recommendation from the Society's Equality and Diversity Working Group, chaired by Professor Hillary Lapin-Scott. A member of each Committee and Council will be the Equality and Diversity Champion and the Champions will meet once a year to review Equality and Diversity across the Society. The Society for General Microbiology Council would like to thank all of the members of the Equality and Diversity Working Group for their work and input over the last 18 months.

Small World Initiative PhD studentship

We are delighted to announce that a team from the University of East Anglia (UEA) have been chosen to host the Society's match-funded PhD studentship as part of the Small World Initiative. Dr Laura Bowater, Professor Elena Nardi and Dr Gary Rowley will draw on their expertise in searching for new antibiotics in soil, public engagement in science and educational theory in this multi-disciplinary project. Applications for the match-funded studentship were extremely strong and Council would like to thank all those that took part as they recognised the enormous amount of work that had gone into preparing the proposals. The Education and Outreach team is very much looking forward to working with the UEA on this exciting project.

Grant deadlines

Date	Grant	Notes
1 June 2015	Travel Grants	For conferences and courses from 1 July onwards
10 August 2015	Society Conference Grants	For support to attend the 2015 Focused Meetings*
10 August 2015	Inclusion Grant	
10 August 2015	Undergraduate Student Conference Grant	

Rolling application

Local Microbiology Event Sponsorship

All members can apply for funds to support microbiology-related events, e.g. sponsored talks.

**Please note, you do not need to have received confirmation of abstract acceptance to apply for these grants as conditional offers will be made. In this case, evidence of acceptance is required to claim your grant.*

Contributions and feedback

The Society welcomes contributions and feedback from members. Please contact **mtoday@sgm.ac.uk** with ideas.

Dariel Burdass

Deputy Chief Executive and
Director of Strategy and Communications
d.burdass@sgm.ac.uk

Aral sea ships. Captain_Nimmo/ThinkStock

Best of the blog

I can't believe we're in May already; where does the time go? Thankfully – for those of us in the Northern Hemisphere, at least – summer is right around the corner. Sure, you could go out and enjoy the beautiful outdoors, or you could stay in and read some of the great microbiology content we've had on our blog over the past few months.

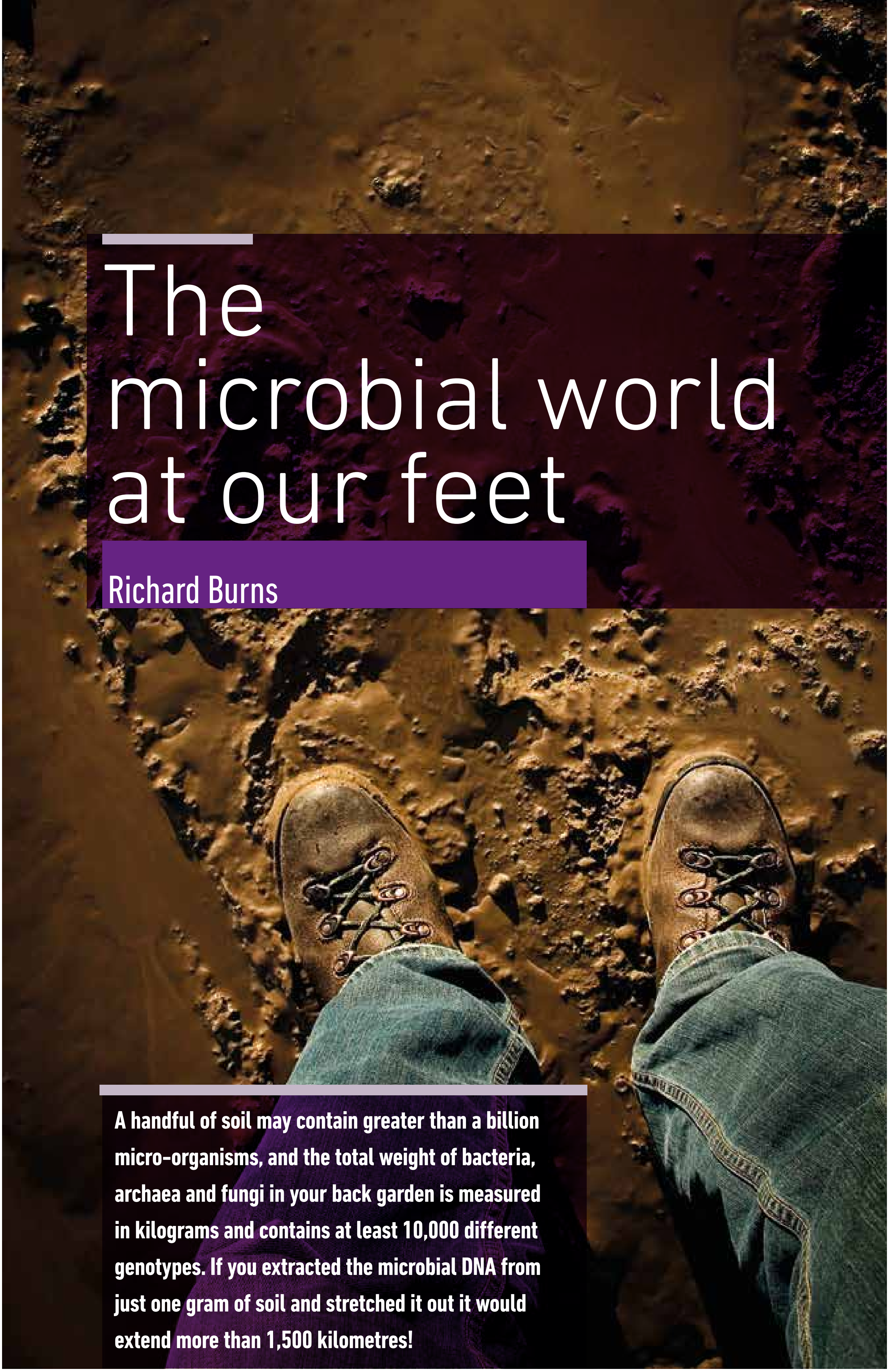
Earlier in the year, we learnt a lot about an emerging disease with a very long name: Crimean–Congo Haemorrhagic Fever. This viral pathogen is spread by ticks and has a high mortality rate. Thankfully, microbiologists are working on a vaccine, as Jon Fuhrmann learnt while interviewing Society member Dr Karen Buttigieg (**http://microb.io/1usrctR**).

I read a great thought-experiment paper in January – what would happen if every bacteria and archaea disappeared with the wave of a magic wand? This is a scenario that Dr Jack Gilbert and Dr Josh Neufeld tried to imagine. I recorded a podcast (**http://microb.io/1EpxtbC**) with them both, outlining the likely outcome for this microbe-free future (spoiler: it's not pretty).

A lack of archaea would certainly affect the digestive tracts of cattle. Jon spoke to Dr Christopher Buck to find out about a different aspect of bovine research, learning about the polyomaviruses that were isolated from ground beef bought in American supermarkets. Other polyomaviruses are known to raise the risk of some cancers – Dr Buck is working to see if this is the case with the newly discovered viruses (**http://microb.io/1AJmQz1**).

Finally in this round up, we learnt about two new species of bacteria that were isolated from bats emerging from hibernation in the Czech Republic. The researchers behind these discoveries hope that the bacteria might have a role to play in controlling the fungus that causes "white nose", a disease that has decimated bat populations in North America (**http://microb.io/1yft6il**)

Benjamin Thompson
Public Relations Manager
b.thompson@sgm.ac.uk

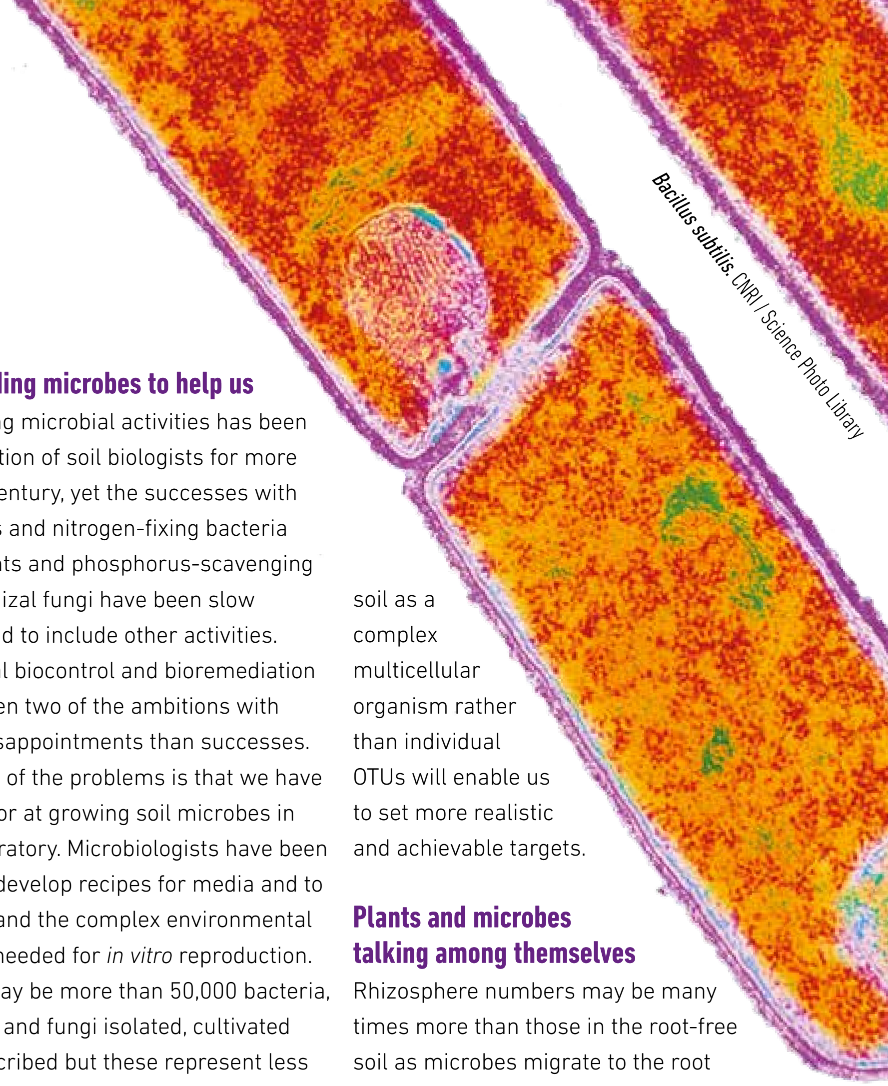


The microbial world at our feet

Richard Burns

A handful of soil may contain greater than a billion micro-organisms, and the total weight of bacteria, archaea and fungi in your back garden is measured in kilograms and contains at least 10,000 different genotypes. If you extracted the microbial DNA from just one gram of soil and stretched it out it would extend more than 1,500 kilometres!

Design Pics / Thinkstock



Bacillus subtilis. CNRI / Science Photo Library

Nowadays, we tend to talk not about microbial species but operational taxonomic units (OTUs). This is because horizontal transfer of DNA between bacteria housed within biofilms at organic matter and plant root surfaces, coupled with mutation and selection pressures, are commonplace. In other words, the soil microbiota is dynamic and evolving.

So many microbes and so much to do

Some soil microbes are competing or collaborating in their attempts to capture the limited resources and occupy the prime real estate. Others lay dormant or are just ticking over waiting for the environment to shift from dry to wet, aerobic to anaerobic, cool to warm, for the arrival of a plant root, the death of an adjacent microbe, or the appearance of an exotic substrate that the majority of the population doesn't recognise.

The soil is a massive and versatile repository of activities capable of responding to any number of chemical, physical and biological conditions. The microbes are the agents for many of the processes that keep our world alive: carbon and nitrogen cycling, generating essential plant nutrients, degrading potentially dangerous chemicals, controlling plant pathogens, building and retaining soil structure, forming symbioses with plants, sequestering carbon, and so on. So, can we be complacent and assume that microbes will continue to do their job regardless of how we treat them? This is an important question and must be framed in the context of climate change with its associated increases in temperature and carbon dioxide, more frequent extremes of weather conditions, and the consequential impacts on the above-ground flora and fauna.

Persuading microbes to help us

Exploiting microbial activities has been an ambition of soil biologists for more than a century, yet the successes with legumes and nitrogen-fixing bacteria and plants and phosphorus-scavenging mycorrhizal fungi have been slow to expand to include other activities. Microbial biocontrol and bioremediation have been two of the ambitions with more disappointments than successes.

One of the problems is that we have been poor at growing soil microbes in the laboratory. Microbiologists have been slow to develop recipes for media and to understand the complex environmental factors needed for *in vitro* reproduction. There may be more than 50,000 bacteria, archaea and fungi isolated, cultivated and described but these represent less than 5% of the total soil population.

Developments in microscopy, modelling and, above all else, molecular biology are providing us with information about these difficult to grow microbes. At the heart of these advances is the 'omics' revolution: genomics, proteomics, transcriptomics and metabolomics. 'Terragenomics' are here to stay.

The new techniques are telling us more about the potential of microbes and how, why, when and what they express in the ever-changing soil microenvironment. Of course, the astronomical volume of data generated demands substantial computational resources if they are to reveal their secrets. But even with sophisticated equipment and limitless computer access, sequencing the entire soil microbial genome is a daunting challenge. And that is even before we try to understand how each strain works independently and collectively. It may be that treating the soil as a complex multicellular organism rather than individual OTUs will enable us to set more realistic and achievable targets.

Plants and microbes talking among themselves

Rhizosphere numbers may be many times more than those in the root-free soil as microbes migrate to the root surface in response to the dozens of signals and substrates exuded by the plant. The most integrated of plant–microbe relationships (mycorrhizas) involve fungi and more than 90% of land plants and may represent the earliest examples (~450 million years ago) of the co-evolution of plants and microbes in soil. The other major integrated plant–microbe symbiosis, involving legumes and rhizobia, is closely linked to mycorrhizal activities. The fungi and the bacteria work together with the plant for their mutual benefit even though the tripartite relationship may be fragile and a trade-off under the prevailing circumstances.

In recent years we have identified more and more of the signals that microbes and plants use to communicate. Many involve acyl homoserine lactones (AHLs), flavonoids and peptides in what is called quorum sensing but any potential substrate may act as a chemo-attractant as long as it sets up a concentration gradient in the aqueous phase. Plants not only engage in this mutually beneficial chatter but also fight back against any negative or competitive challenges. There are AHL mimics that fool small numbers of potential phytopathogens into synthesising and secreting invasive enzymes long before there are enough of them to do any damage. Then there are compounds that block microbial receptors so that the signals they send to each other are not detected.

Microbes talking to other microbes trigger individual and collective responses in order to exploit potential substrates. This type of cooperation is essential in the breakdown and metabolism of complex macromolecules, such as lignocellulose: a process that involves dozens of OTUs and many different extracellular and intracellular enzymes.

Getting rid of the mess

Many soils suffer from chronic or acute pollution from industrial sources and are rendered unsuitable for human habitation, agriculture and recreation. In addition, contaminated soil acts as a source of organic and inorganic toxins for water, the atmosphere and wildlife in general. There are millions of hectares that are in need of remediation and, for a long time, exploiting the catabolic potential of the microbial world has had great appeal. An optimistic view might be that microbes are so smart that they will break down all pollutants and render them harmless. All we need to do is to persuade them to set about saving our soil.

Sometimes chronic pollution serves as a selection pressure and competent degraders are already present in the soil. But other factors may limit the expression of their degradative potential: pH, compaction and poor oxygen penetration as well as electron acceptor/donor concentrations and carbon-to-nitrogen ratios. Some of these constraints can be overcome by *in situ* biostimulation (e.g. rotovation, liming, adding organic matter). If this doesn't work, bioaugmentation with a cocktail of microbes may be the remedy.

Large numbers of bacteria and fungi have been generated in laboratories using the target pollutant(s) to select competent microbial populations. The majority of these isolates fail when applied to soil. The reasons for this are not hard to find. If you were to name all the properties of a successful bioremediation inoculant the list would go on for some time. Catabolic potency – yes, but this needs to be expressed at an appropriate level by the bacteria and fungi, which must stay focused on the xenobiotic and not switch their attention to other more easily available and higher energy yielding natural compounds. The inoculant also needs to be a good competitor in an established and aggressive microbial community, detect and migrate to its unevenly distributed target, have affinity for the differing concentrations of the pollutant, and be physiologically versatile by functioning at various temperatures, redox conditions and pH values. The best biodegrader might even need to form a close partnership with indigenous microbes or plants to achieve the ultimate goal of converting the pollutant into carbon dioxide and water.

Another constraint to successful bioremediation is that the pollutants may be bio-unavailable because they are bound to clays and humic matter, hidden within soil aggregates, or hydrophobic and much too large (e.g. many aromatic hydrocarbons) to enter the microbial cell without prior disintegration. In these cases, 'remediationists' have turned to

False-colour scanning electron micrograph of a root nodule on a pea plant.
Dr Jeremy Burgess / Science Photo Library

surfactants to increase the solubility of the troublesome compounds and considered using depolymerases to generate small molecular mass products that the cell can recognise. Knowledge of the catabolic stages involved in a pollutant breakdown may reveal a small number of rate-limiting steps. In this context, genetically manipulating indigenous microbes to express dehalogenases is a promising avenue for research.

As important as pollutant breakdown is, the rate at which decontamination takes place, tracking the inoculant and monitoring the products are essential. Reporter genes, introduced into the biodegraders or other soil microbes, can detect end-points and prescribed targets as well as informing risk assessment, and are necessary components of any credible bioremediation protocol. Too many snake oil remedies have already hit the market.

There are more than 250,000 polluted sites in the EU alone with a remediated value of twice the gross annual product. These are the numbers that influence politicians and funding agencies. Bioremediation must play a major role in our stewardship of soil in the 21st century.

Soil microbes are as important as plants and animals

Soil microbes play a major role in generating long-lived soil organic matter. Bacteria and fungi do this using enzymes, which generate polyaromatic compounds that are components of recalcitrant humic substances. The sink of carbon is under threat from climate change. This is because frequent wetting and drying cycles and elevated temperatures increase the accessibility of humic matter, raise enzyme activities, and stimulate microbial respiration resulting in more carbon dioxide evolution – and exacerbating the greenhouse gas effect. Among the numerous schemes for reducing atmospheric carbon dioxide is to persuade more soil microbes to carry out humification and generate recalcitrant carbon.

> **An optimistic view might be that microbes are so smart that they will break down all pollutants and render them harmless. All we need to do is to persuade them to set about saving our soil.**

Where to now?

In a changing climate with increasing demands on land use, microbes are as much at risk as animal and plant communities. Soil microbial ecology is an essential component of macroecology and the below- and above-ground worlds are part of the same global environment. Does anyone know the rate of extinction of microbial genotypes in the tropics, the tundra, the rainforest or the Antarctic? Is microbial diversity disappearing at the same fast rate shown by plants and animals? Should we be storing and preserving, not only isolated microbial strains, but also soil samples? These would serve as reference points and help us evaluate the impacts of subsequent changes in soil use and management as well as climate change.

The 2015 International Year of Soils should remind the world that what we are standing on is not only growing our food, fuel and fibre but also maintaining the quality of our air and water. It is a precious resource that is under threat from human activities as well as commercial interests and political ignorance. Talking to other soil biologists is easy (we agree on the importance of our subject!) but it is making the connection between our science and national and international socio-economic policies and priorities that might win the day.

Half a millennium ago Leonardo da Vinci got it about right when he said, "We know more about the movement of celestial bodies than about the soil underfoot": a thought echoed today by such luminaries as Julian Davies, Norman Pace and Craig Venter. Increasingly sophisticated molecular, microscopic, modelling and computational techniques are taking us closer towards untangling the complexity of the soil environment and revealing its many secrets. However, the ultimate practical goal is to manipulate our increasingly threatened soil resource to restore and maintain its crucial role in the biosphere and to enhance its capacity for food production.

Richard Burns

School of Land and Food Sciences, The University of Queensland, Brisbane, Queensland 4072, Australia

r.burns@uq.edu.au

and Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore, Queensland 4558, Australia

rburns1@usc.edu.au

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Micro-organisms, -biomes and -networks of Earth's living soils

Robin Sen

Soils tend to be taken for granted or just seen as a surface layer of sand, rock, dirt and mud from which plants grow. In reality, the evolution of soils and life on earth are inextricably linked. These very soils are now under grave threat from agricultural expansion, urbanisation, pollution and climate change.

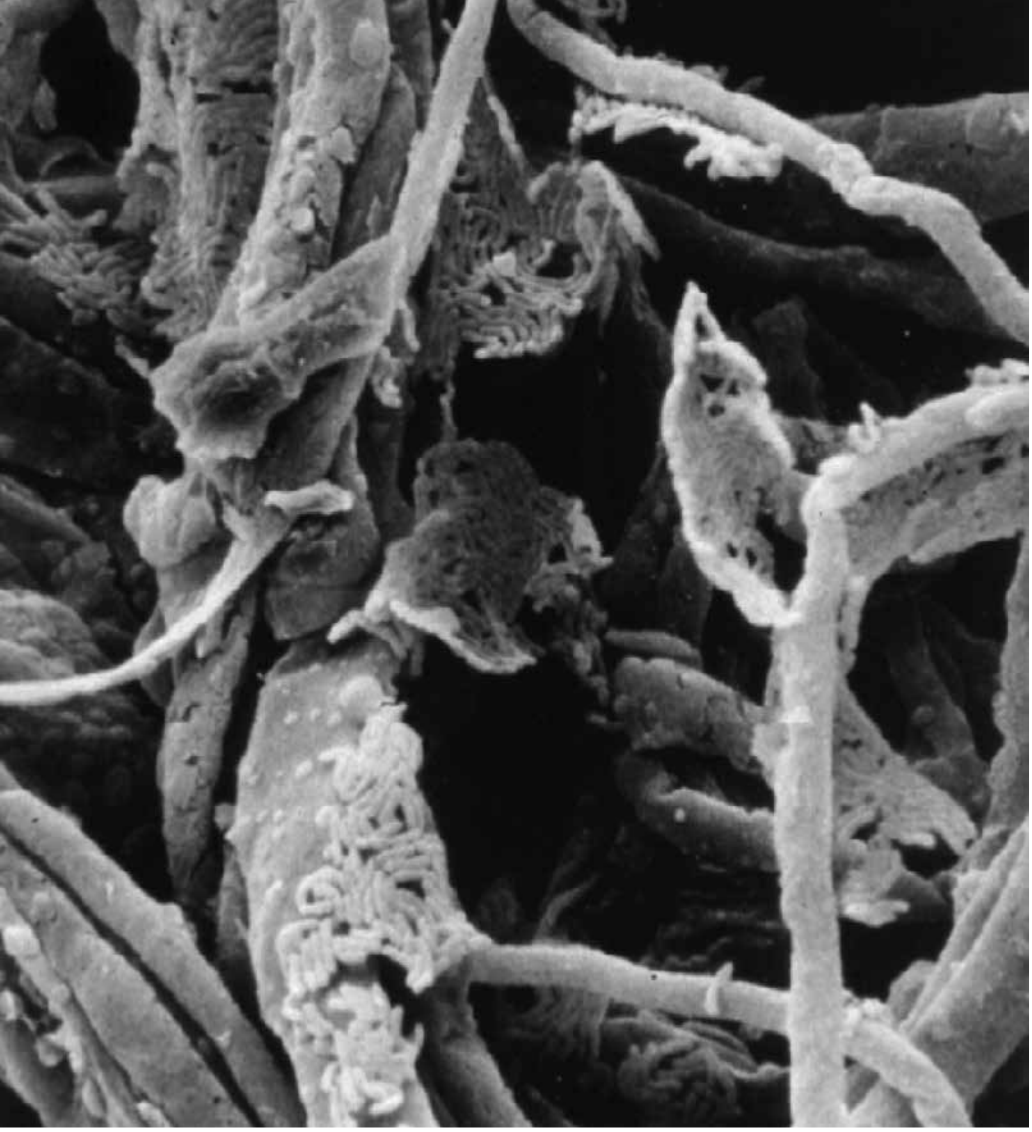
Leonardo da Vinci's statement that "we know more about the movement of celestial bodies than about the soil underfoot" remains as true today as when it was made over half a millennium ago. The 2015 International Year of Soils aims to raise general awareness and understanding, and drive urgent solutions for reversing an impending global soil and food security crisis.

Mars and Earth: a difference between twins

Over the last two years, NASA's Curiosity rover has been returning tantalising images of sedimentary rocks and river basins together with chemical signatures of the Martian atmosphere and surface regolith. What distinguishes the surface of Mars from Earth is not the presence of water and nutrient-bearing minerals or even methane and oxygen but the apparent absence of microbial life. At first glance, arid deserts and the Martian environment show striking similarities but the presence of micro-organisms representing all three domains of life, Bacteria, Archaea and Eukaryota, highlights a fundamental difference – Earth's living soil ecosystems. So how did soils evolve?

Microbial-driven carbon and nitrogen fixation

Evolution and radiation of aquatic and later land species was undoubtedly triggered by the appearance of cyanobacteria around 3 to 3.4 billion years ago. These photosynthetic bacteria



Scanning electron micrograph of soil colonising mycorrhizal fungi showing bacterial biofilm association with fungal hyphae. Nurmiaho-Lassila *et al.* (1997). NRC Press, Canada

fixed inorganic carbon dioxide (CO_2) to organic sugars releasing oxygen into the atmosphere and supported biological nitrogen fixation (BNF) of di-nitrogen (N_2) to reactive ammonia. Selection for evolution of BNF in existing domains, Bacteria and Archaea, was overwhelming as the most abundant form of nitrogen, a central building block of DNA and amino acids, was inert N_2.

Cyanobacteria inhabited nutrient-rich coastal habitats until at least around 2.6 billion years ago when unicellular and filamentous forms colonised land surfaces and associated with bacteria and archaea to form microbial biofilms and cryptogamic covers. Growth and turnover of microbial consortia generated trace but priming levels of soil organic matter (SOM), the crucial component that turned mineral regolith into a proto-soil.

Evidence of land colonisation by primitive filamentous fungi (domain Eukaryota), in the Cambrian period about 500 million years ago allowed further inter-domain interactions. Cyanobacteria established intimate and mutually beneficial endo-symbiotic relationships with filamentous glomeromycotan fungi as seen today in *Geosiphon pyriformi*s. More complex multi-organismal symbioses followed in associations that resemble lichen and biological soil crust found on exposed upper surfaces of rocky and desert terrain. In return for fixed carbon and nitrogen supplies provided by the cyanobacterial symbionts, the heterotrophic filamentous fungal mycobionts were able to access, translocate and conserve limited water resources and chemically weather the underlying rock to mobilise essential macro- and micro-nutrients, e.g. phosphorus, calcium and iron. Fixation of atmospheric CO_2 and N_2 into living and ultimately dead microbial biomass in lichens and cryptogamic covers allowed for a gradual increased build-up of microbial SOM.

Soil and terrestrial ecosystem evolution

Increasing oxygen levels drove an explosion in evolution of multi-cellular non-vascular and later vascular land plants over the Devonian period. Symbiotic associations, between glomeromycotan arbuscular mycorrhizal (AM) fungi and roots of early vascular plants, termed mycorrhiza, were favoured for the same mutual benefits gained by lichen symbionts. Co-evolutionary radiation of vascular and woody plant families and mycorrhizal AM, and later higher mushroom-forming ascomycete and basidiomycete, fungi from the early Cretaceous period, resulted in massive plant and microbial SOM input. Turnover of recalcitrant cellulose and lignin-derived SOM in soils supporting dense forests required combined activities of higher decomposer and mycorrhizal fungi.

Depending on geographical location, climatic conditions, underlying geology and hydrology, SOM can account for nearly 100% to below 1% of soil carbon as typified by peatland and arid desert soil systems. Functioning of SOM in soils far outweighs representation in improving water-holding and cation-exchange capacities, organic nutrients status and microbial diversity of soils. Properties that explain high plant diversity and productivity of semi-natural ecosystems, such as tropical forests, grasslands, peatlands and drylands.

With the population expected to reach 9 billion by 2050, future global soil and food security is in the balance. Agricultural expansion and intensification are contributing to major degradation of the world's soils already under threat from pollution and climate change.

Soil microbiomes, antibiotics and networks

Significant amounts of photosynthetically fixed carbon are allocated to root growth and exudation that constitute major pools of SOM in soils. Soil microbes, that are generally carbon and/or nitrogen limited, migrate to the nutrient-rich root zone termed the 'rhizosphere' or the 'mycorrhizosphere' of over 85% of mycorrhizal land plants. Modern molecular 'omics' tools have uncovered enormous previously unknown microbial diversity that constitutes the soil food-web. Soil bacterial, fungal and archaeal microbiomes, characterised at local-to-global scales, have confirmed or shed new light on evolutionary plant–microbe associations and trajectories. Soil microbiomics has also recently been featured on the BBC with the discovery by US researchers of Teixobactin, a new class of antibiotic that is effective against multi-resistant *Staphylococcus aureus* (MRSA) and *Mycobacterium tuberculosis*.

Plant–fungal relationships tend to be viewed negatively due to a plethora of crop and tree diseases but beneficial mycorrhizal fungi support plant productivity in nutrient-limited soils. Over the last two decades those researching the mycorrhizal symbiosis have come to realise that mycorrhizal fungi also form extensive below-ground mycelial networks that not only stabilise soil structure in association with bacterial and archaeal biofilms but also interconnect plant communities and facilitate plant recruitment and inter-plant communication. No surprise that these fungal networks were called the wood-wide web by the journal *Nature* following publication of the seminal paper by Simard & others (1997). With inter-plant signalling detected, these fungal networks are now being called the Earth's internet that underpins above-ground plant diversity and resilience to stress, e.g. drought, herbivory, diseases and climate change.

International Year of Soils and sustainable agricultural intensification

With the population expected to reach 9 billion by 2050, future global soil and food security is in the balance. Agricultural expansion and intensification are contributing to major degradation of the world's soils already under threat from pollution and climate change. Heavy reliance on soil tillage and chemical fertiliser/pesticide application in mono-crop systems contributes to loss of mycorrhizal symbioses and increased eutrophication and emissions of greenhouse gasses (methane and nitrous oxide). Problems of nutrient runoff, soil erosion and desertification are exacerbated through lack of both plant SOM input and mycorrhizal networks. The Food and Agriculture Organization focus on soils in 2015 can help raise general awareness of threats to soils and the urgent need for sustainable agricultural intensification. Planning and action should be informed by past successful evolution of plant–microbe–soil interactions to secure future global soil and food security. There is no time to lose.

Scots pine seedling growing in forest soil containing microcosms highlighting extensive white mycorrhizal fungal colonisation of brown roots and fungal 'network' growth into the soil mycorrhizosphere. Robin Sen

Robin Sen

School of Science and The Environment. Manchester Metropolitan University, Manchester M1 5GD, UK

r.sen@mmu.ac.uk

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Microbial modulation of soil ecosystem processes

Geertje van Keulen & Ingrid Hallin

Soils are teeming with micro-organisms. Estimates vary from thousands to millions of microbial 'species' per gram of soil, with particle numbers including phages totalling more than astronomical objects in the universe. The application of modern sequencing technologies to biomes means we are beginning to know a lot more about what is present in soils.

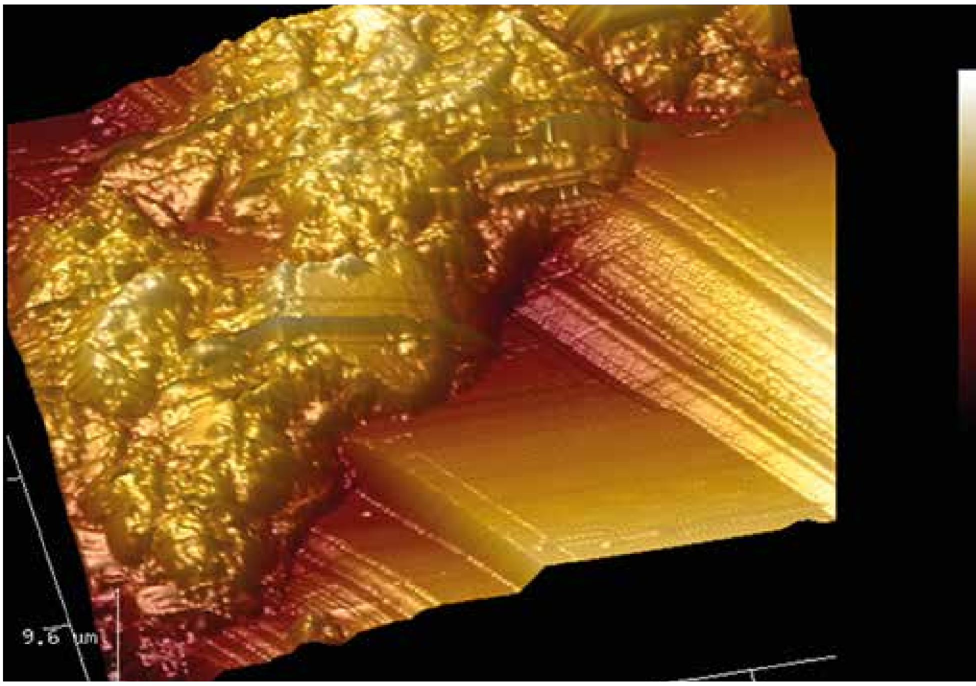
The Earth Microbiome Project (www.earthmicrobiome.org) is logging microbial community composition and diversity in a staggering 50,000 biomes, a scale impossible to study until recently, providing insight into the vast scale of global microbial diversity. However, we still know rather little about the essential functional properties of these microbial cells in facilitating nutrient cycling, plant growth and general ecosystem processes, or about how they adapt to change and disturbance, in an array of terrestrial environments.

Soil heterogeneity and microbial diversity

While a soil may appear to be rather homogeneous at larger scales, extreme heterogeneity is apparent at scales of microbial importance. Soil micro- and macro-aggregate formation is driven by organic matter such as plant roots, filamentous microbial hyphae and extracellular polymeric substances. This in turn creates micro-, meso- and macro-pores, each providing different microhabitats offering protection from biotic and abiotic stresses such as predation and desiccation. Microbial interaction is dependent on the patchy distribution of resources, cell-to-cell distances (which can be vast in soil) and soil pore connectivity, which in turn depends on soil moisture content. An increase in matric potential will lead to a decrease in water-filled pores and water-film thickness. Macro-pores will empty first, followed by meso- and ultimately micro-pores, leading to changes in microbial access to water and diffusion- and transport-driven substrate availability. Perhaps, counter intuitively, greater microbial community diversity can evolve under drier soil conditions and increased spatial heterogeneity.

Nutrient cycling

Microbial-driven ecosystem processes are largely determined by soil moisture. Prokaryotes tend to be more prominent in wet or disturbed systems, such as tilled agricultural land and marshlands, while the abundance of fungi increases in drier, less disturbed areas like forests, but both are necessary for nutrient cycling in soils. Ultimately, nutrient cycling is the breakdown of complex organic compounds from dead biomass to simple forms that can be used by the soil biosphere. Prokaryotes alone contain most of the total nitrogen and phosphorus and up to half of the carbon stored in the biosphere. Importantly, microbes decompose the bulk of soil organic matter, catalysing



Atomic force microscopy image of a soil mineral covered partially with amorphous organic matter.
Dr Salvatore Andrea Gazze (Swansea University)

Scanning electron micrograph image of a soil mini-aggregate with a filamentous hypha.
Dr Salvatore Andrea Gazze (Swansea University)

critical transformations in the carbon and nitrogen cycles.

Not all biomass gets degraded in the same way or at the same rate. Micro-organisms are specialised in their tasks within the 'decomposition assembly line', with different microbial communities operating best under different soil conditions. All soil micro-organisms require respiration, moisture and certain pH conditions to perform best, but to varying degrees and with varying limitations. The soil matrix heterogeneity allows buffering of (sub-) optimal conditions, thereby maintaining the necessary microhabitats. Soil characteristics such as organic matter quantity, soil texture (the relative proportions of sand, silt and clay) and structure allow aeration, pH, temperature and moisture gradients to develop across very small areas, which in turn are able to sustain different microbial communities working in close proximity to each other.

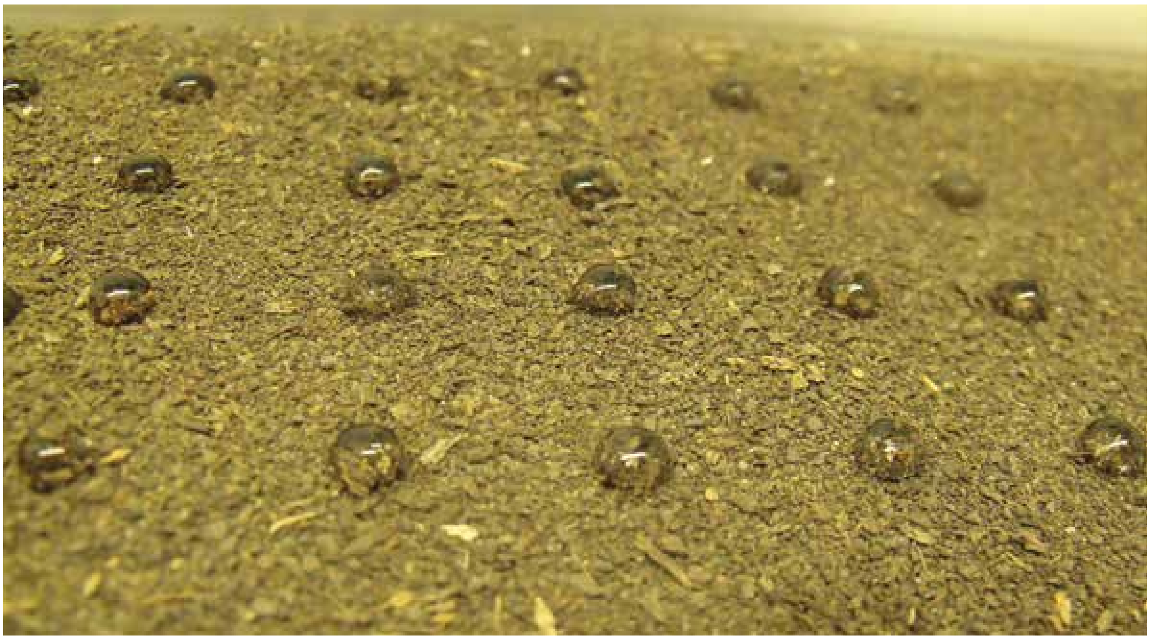
While the quantity of soil organic matter helps sustain microhabitats, the quality and composition of organic matter helps to determine the rate of microbial activity and its effect on soil nutrient dynamics. Microbes require both carbon and nitrogen for food, and while carbon is readily available in plant biomass, nitrogen (in its useable organic forms) tends to be limiting. Therefore, in general, the rate of biomass decomposition can be linked to the quantity of nitrogen available relative to the amount of carbon (the carbon to nitrogen, C:N, ratio). Woody biomass with a high C:N ratio can take a long time to degrade because microbes must find nitrogen from their surrounding environment, rather than directly from the biomass itself, to enable the degradation. Low C:N ratio biomass, such as manure, degrades quickly because there is enough available nitrogen within manure for microbial growth during decomposition; this is why manure makes such a good fertiliser.

Soil moisture also strongly affects the microbial dynamics of soil organic matter, forming an important variable in global soil carbon prediction models, which remains poorly understood mechanistically. An important transient response, the Birch effect, is observed as a temporal increase in soil microbial respiration upon rewetting of soil after drying, which in natural soils is strongest after the first rain events following a prolonged dry period. It is thought that these pulses in microbial respiration upon rewetting are due to a temporal increase in substrate availability from dead microbial biomass, the release and re-use of osmolytes, soil aggregate breakups and the uncoupling of extracellular enzyme activity from microbial respiration. Soil respiration is indirectly affected by soil water repellency, which develops naturally upon drying–wetting cycles, rendering soil carbon less available.

Microbial response and adaptation to disturbance

In ecosystem modelling, plant community composition and changes therein upon disturbance are generally considered key for predicting changes in ecosystem processes under global change. Until recently the functional composition of and disturbance-related changes to the microbial community were simplified to the modelling of 'black boxes'. These models are valid if microbial community composition is indeed resistant, resilient and/or functionally redundant over a range of environmental conditions, with microbial abundances never limiting microbial processes. If a particular microbial community is sensitive to change (not resistant), does not quickly recover to its initial composition (not resilient), and becomes functionally different to the original composition (not redundant), then changes in composition make a difference for modelling and predicting the rates of ecosystem processes. The degree of resistance, resilience and functional redundancy of a microbial community will also shape the level of influence to which composition

> **It is now possible to start understanding in more detail what the most relevant community-level characteristics are for better predicting of functional attributes to ecosystem processes, like how climate change will affect soil microbial dynamics and nutrient cycling in polar regions and other parts of the world.**



Water-repellent soil. I. Hallin

matters to an ecosystem process. A simple modelling framework was successfully introduced allowing incorporation of microbes into models by using physiological traits and process response curves to disturbance. The model now requires more data on how microbes respond to disturbance specifically with increasing knowledge of physiological traits.

Such functional metagenomic studies have only recently been initiated. Analysis of soil microbiome changes in a chronosequence of land-use from a native tropical forest, through deforestation to the establishment of agricultural and pasture soils showed that the disturbed soils were among the most microbially diverse with an increase in functional redundancy. The forest ecosystem equilibrium was upheld with a higher abundance of microbes, however, of lower alpha diversity. An extensive compositional and functional comparison of 16 diverse soils, including cold and hot deserts, forests, grasslands and tundra, showed that in plant-free cold deserts the lowest functional diversity was linked with the lowest phylogenetic and taxonomic diversity. Functional, taxonomic and phylogenetic beta diversity was correlated strongly across the biomes. It is now possible to start understanding in more detail what the most relevant community-level characteristics are for better predicting of functional attributes to ecosystem processes, like how climate change will affect soil microbial dynamics and nutrient cycling in polar regions and other parts of the world. Nonetheless, we still require extensive culture-dependent and *in vitro* studies to understand the current unknown function(s) of at least a third of genes in metagenomic sequences.

Microbes as indicators of soil health and ecosystem function

In conclusion, we have seen major advances in soil metagenomic and spatial studies recently. Whole microbial communities and community-level molecular characteristics can now be exploited as 'biomarker' indicators of ecosystem processes for monitoring and managing sustainable soil health under global change.

Geertje van Keulen

Institute of Life Science, Swansea University, Swansea SA2 8PP, UK
g.van.keulen@swansea.ac.uk

Ingrid Hallin

Centre for Research in Earth Sciences, School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth PL4 8AA, UK
ingrid.hallin@plymouth.ac.uk

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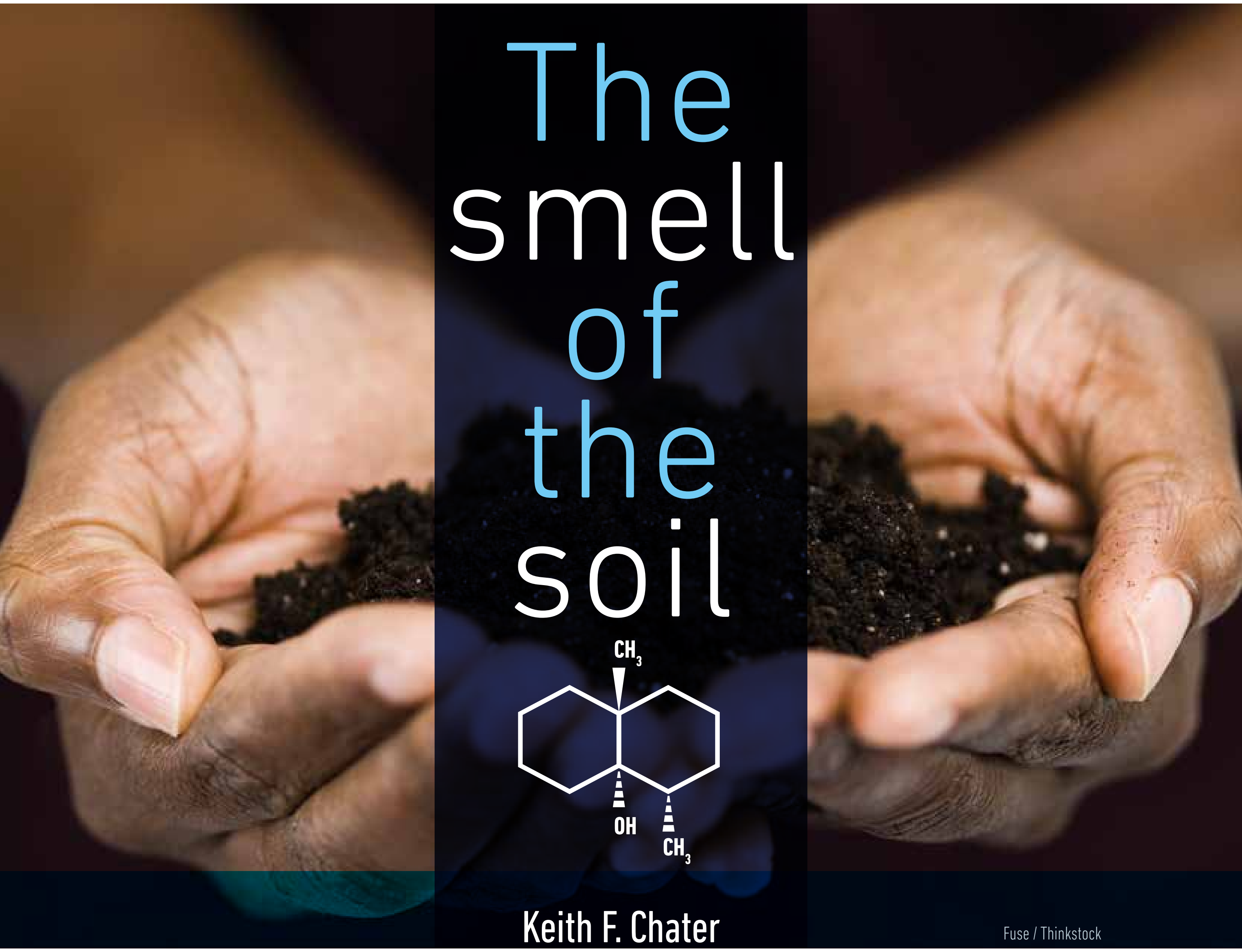


The smell of the soil

Keith F. Chater

Fuse / Thinkstock

'You speak like the very spirit of earth, imbued with a scent of freshly turned soil'
The Hall of Fantasy by Nathaniel Hawthorne

'And scent of earth, sweet with the evening rain...'
All Round the Year
by Edith and Saretta Nesbit

Just what is the scent that inspires such celebratory descriptions? The chemical responsible has been given the name 'geosmin'. In the last few decades we have learnt not only its molecular structure, but also its microbial and biochemical origins. It has turned out that geosmin must have perfumed the soil that first began to cover the land half a billion years ago, thanks to the activity of the earliest *Streptomyces* bacteria.

Animals as diverse as flies and humans are incredibly sensitive to geosmin, so its perception probably evolved very early in the emergence of primitive animals.

The evocative smell of freshly disturbed or wetted soil was first studied scientifically towards the end of the 19th century, when French biochemists Berthelot and André succeeded in extracting 'l'odeur propre de la terre'; but it was not until 1965 that the Americans Gerber and Lechevalier tracked down the main odour component to a single compound, which they called geosmin [from the Greek, *geo* (earth) and *osme* (odour)]. Gerber finally published the structure of geosmin in 1968. It is a member of the extensive family of terpenoid oils that are natural odours, flavours and signalling molecules (more than 70,000 naturally occurring terpenoids have been discovered). The sensitivity of diverse animals to geosmin is astonishing: it is reported that humans – not famous for their olfactory virtuosity – can smell it at levels as low as 100 parts per trillion.

The ability to make geosmin is an ancient bacterial trait

By the time that geosmin was chemically characterised it was well established that its major source in soil was bacteria of the genus *Streptomyces*. These abundant and complex bacteria grow like fungal moulds as a mycelium of branching thread-like hyphae, playing a very important part in the recycling of vegetable matter. Echoing fungal moulds, they reproduce by sending up aerial hyphal branches that bear spores. Geosmin is associated with *Streptomyces* spores, which are present in huge numbers in many soils. We can safely assume that the time-traveller visiting the planet as it was about 440,000,000 years ago would recognise the familiar smell of soil, as the earliest land plants collaborated with the first streptomycetes to generate protocompost.

Some other bacteria that are very unlike streptomycetes produce geosmin too. They include some myxobacteria, which roam the soil in swarms consuming other bacteria, before building elaborate multicellular fruiting bodies big enough to be visible to the naked eye. Geosmin is also produced by many cyanobacteria: photosynthetic bacteria well known as the agents of toxic blue-green scums, inaccurately called 'algal blooms', on recreational waters. Clearly, the production of geosmin and other earthy odours preceded the origin of streptomycetes, since the last common ancestor of these diverse geosmin-producing bacteria probably existed more than two billion years ago. Geosmin is also made by some soil-dwelling eukaryotic organisms, including some fungal moulds (notably *Penicillium* species), and beetroots, which owe their characteristic earthy taste to geosmin.

Bottle of *Dirt* perfume.
Demeter Fragrances

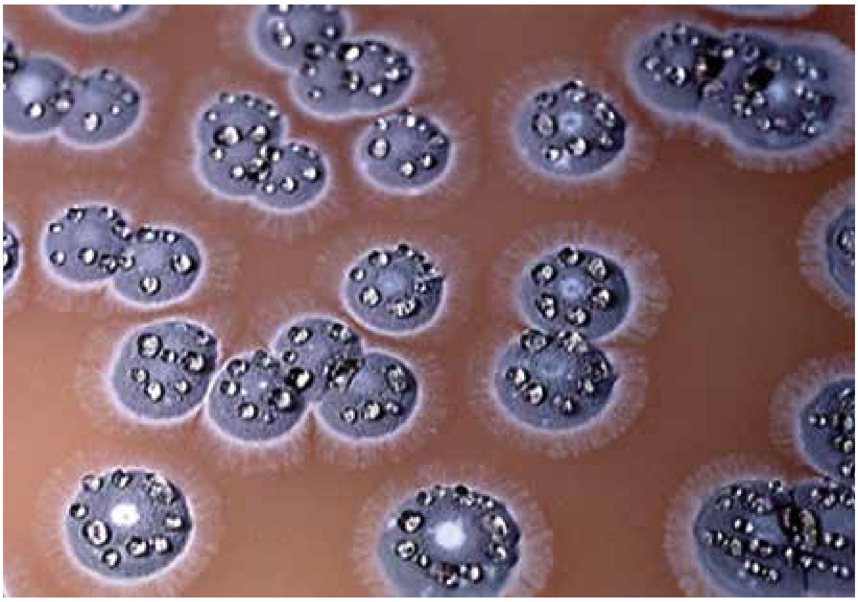
Geosmin and countless other terpenoids are made by variations on the same biosynthetic route

Although geosmin is not needed for basic cellular physiology, some other terpenoids are involved in such essential functions as electron transport, bacterial cell wall biosynthesis, sterol biosynthesis and photosynthesis. All terpenoids are made from the universal acyclic precursors geranyl diphosphate, farnesyl diphosphate, or geranylgeranyl diphosphate. These are themselves made by the condensation of the 5-carbon precursors dimethylallyl diphosphate (DMAPP) and isopentenyl diphosphate (IPP) in the ratios 1:1, 1:2 and 1:3, respectively. Usually only one appropriate synthase enzyme is needed to convert geranyl diphosphate into a particular monoterpenoid, farnesyl diphosphate into a certain sesquiterpenoid (meaning "one-and-a-half monoterpenoids"), or geranylgeranyl diphosphate into a specific diterpenoid. These enzymes catalyse what may be the most complex transformations mediated by any class of enzymes in all biology, typically changing the linkage and hybridisation states of more than half of the carbon atoms in their substrate.

The first sesquiterpene synthase to be studied was that involved in making pentalenolactone, an unusual antibiotic made by a few streptomycetes. Studies led by David Cane at Brown University, USA, established many of the key features of the enzyme's action. When UK and Japanese scientists determined the first genome sequences of streptomycetes, several genes related to the pentalenene synthase gene were found. In the hope of finding the determinant(s) of geosmin production, mutations were introduced into these genes in the model organism *Streptomyces coelicolor*, and indeed one of the mutants could no longer make geosmin. The relevant gene encodes a geosmin synthase with two distinct pentalenene synthase-like domains, one of which converts farnesyl diphosphate into the sesquiterpene germacradienol. The other domain then converts germacradienol into geosmin. The genes responsible for geosmin synthesis in myxobacteria and cyanobacteria are homologous with the *Streptomyces* genes, consistent with the idea that they have a common origin in an ancient progenitor of these diverse bacteria that lived nearly three billion years ago.

S. coelicolor additionally produces a monoterpene, methylisoborneol, that also contributes to earthy odours. Two adjacent genes determine methylisoborneol synthesis, in which geranyl diphosphate is first methylated, and then cyclised. A third odorous sesquiterpenoid, albaflavenone, which has antibiotic activity, results from the activity of another gene pair in *S. coelicolor*. One of the genes encodes a terpene cyclase that acts on farnesyl diphosphate to make the tricyclic epi-isozizaene, and the other encodes a cytochrome P450 that oxidises epi-isozizaene to generate albaflavenone. This gene pair, like the methylisoborneol genes, occurs in about half of streptomycetes (most often, streptomycetes have one or the other pathway). It is curious that genes for *Streptomyces* antibiotics are usually of much rarer occurrence than the albaflavenone genes, suggesting that albaflavenone may benefit the producing organisms in a different way from most antibiotics, but perhaps similar to that of methylisoborneol.

The dramatic increase in understanding of terpenoid synthases has been exploited in the case of epi-isozizaene synthase, the hydrophobic active site contour of which has been remoulded to change the profile of products, giving rise to hopes that the knowledge-based manipulation of such enzymes may be exploited in the production of biofuels.



Colonies of *Streptomyces ambofaciens*. The fuzzy surface of these geosmin-producing colonies is made up of millions of spores so hydrophobic that water droplets form on the colonies as perfect spheres. Streptomycetes are famous for their ability to make antibiotics, *S. ambofaciens* being used in the production of spiramycin.
Tobias Kieser

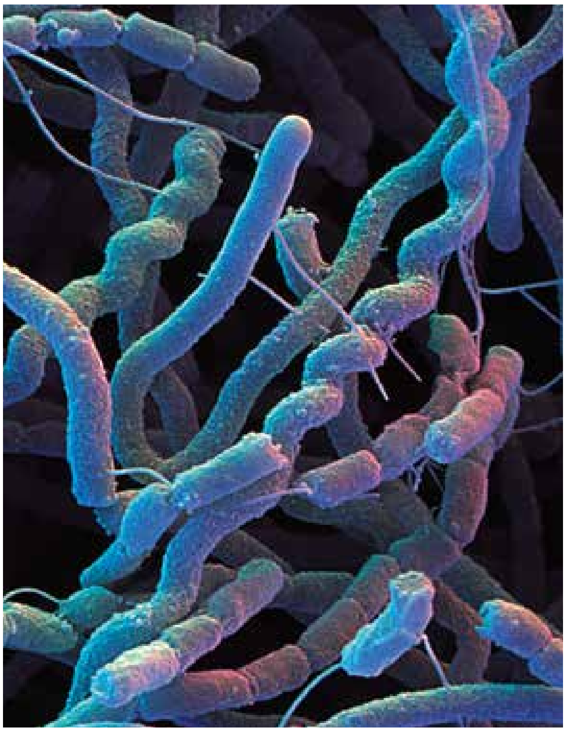
How ancient and pervasive is the ability of animals to sense geosmin?

Sensing of geosmin has recently been studied in detail in the fruit fly *Drosophila melanogaster*. The ability of fruit flies to detect geosmin is exquisite, and they hate the smell – so much so that it overrides the attraction of the flies to all known food sources. This extreme chemorepulsion is mediated by a dedicated neural connection to the brain from specific geosmin sensors, and allows flies to avoid food sources contaminated by micro-organisms toxic to them and their larvae. Since humans

The ability of fruit flies to detect geosmin is exquisite, and they hate the smell – so much so that it overrides the attraction of the flies to all known food sources.

are also so good at detecting geosmin, it seems very likely that this ability (and hence the possession of geosmin receptors) is very widespread among all animals, perhaps sometimes serving to attract and sometimes to repel. In his 2007 book *Streptomyces in Nature and Medicine*, past Society for General Microbiology President, Sir David Hopwood, entertainingly rehearsed speculations about the detection of geosmin by animals, ranging from primitive worms and arthropods that use the producing micro-organisms as a food source, to camels looking for water in the desert. The animals would then convey the geosmin-producing organisms to new locations, either after passage through the vector's gut, aided by the ability of the tough spores to withstand digestion, or carried externally. In Sir David's words, "this is such a nice idea; let's hope it turns out to be true". A 1978 American study showed that a *Streptomyces* that causes potato scab was present on, and in, soil arthropods associated with the infected potatoes. Whether notions of geosmin attracting animals are true or not, they have not depended on modern scientific advances: in 1903 the American writer Mary Austin wrote, in *The Land of Little Rain*, "the coyote is your true water-witch, one who snuffs and paws, snuffs and paws again at the smallest spot of moisture-scented earth until he has freed the blind water". As outlined previously, geosmin was evidently being produced two to three billion years ago, before the emergence of eukaryotes (ca. two billion years ago), let alone of multicellular animals (ca. 600,000 years ago). It is therefore quite plausible that geosmin sensing by animals may have had a single evolutionary origin in an ancient universal common ancestor.

Perfumiers have found geosmin an irresistible component of some of their concoctions, either as a purified commercially available product (as a 1% solution) or, as in the case of a more traditional potion, Mitti Attar, by distilling sun-baked earth with sandalwood (it is said to resemble the smell of the first monsoon rain on parched soil). For example, in the perfume *The Smell of Weather Turning* by the cosmetics company Lush, "geosmin is supported by oak wood, hay, beeswax, nettle, English peppermint, mint and Roman chamomile". On the other hand, geosmin also has a considerable nuisance value, sometimes being the cause of off-tastes in water, wine and freshwater fish – there is a considerable library of research papers devoted to these aspects. It may also contribute to the smells generated during the large-scale industrial culture of streptomycetes for the production of antibiotics. Annoyance to nearby communities might perhaps be mitigated by the use of molecular genetic techniques to disrupt the geosmin synthase gene.



False-colour scanning electron micrograph of *Streptomyces* sp. bacteria. David Scharf / Science Photo Library

Keith F. Chater
John Innes Centre, Norwich NR4 7UH, UK
keith.chater@jic.ac.uk

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The International Year of Soils, as declared by the 68th United Nations General Assembly, aims to raise awareness of soils and the numerous vital ecosystem services that they provide, including the provision of food, fuel and fibre, storage and filtration of water, climatic regulation and waste decomposition. All of these services are the result of the myriad of interactions of organisms in the soil, including bacteria, archaea, protozoa, fungi and soil fauna. The functioning of these organisms is so vital that there would likely be no above-ground life on Earth, and certainly no human life, without life in soil. It is with this in mind that the following article on soil-borne human diseases should be read.

The ecology of soil-borne human diseases

Simon Jeffery & Wim H. van der Putten

Soil is vital to human existence and the vast majority of organisms that reside in it function to our benefit. However, soil also harbours a minority of organisms – some of which call soil their home, while others pass through it transiently – that are capable of causing diseases in humans: these are soil-borne human pathogens and parasites. These organisms represent a relatively understudied group; indeed, the World Health Organization does not yet recognise soil-borne human diseases as a distinct group (with the exception of soil-transmitted helminths), as they do with food-borne diseases or zoonoses, for example. However, these diseases cause considerable mortality and morbidity worldwide. It may be possible to reduce incidents of such diseases through increased understanding of their ecology, their role and survival in soil, and the land management practices that can exacerbate or reduce infection rates.

Grouping soil-borne diseases

There is currently no internationally recognised, comprehensive list classifying which human diseases are soil-borne. Part of the difficulty in compiling such a list is that many pathogens can be transmitted through the soil if they come into contact with an infectious host in a suitably short time frame. For example, measles can theoretically cause infection from

Soil erosion. Soil scientist taking readings from an area of a wheat field that has suffered severe soil erosion. Photographed in Washington State, USA. Jack Dykinga / US Department of Agriculture / Science Photo Library

surfaces, including the soil surface, as opposed to direct transmission through the air. However, as there is a 30–70% reduction in viable virus particles in the first minute that they are outside of a host, infection by such a route is unlikely – over such a short time frame the infectious host is likely to still be present in the vicinity and infection from them is a more probable route. To include all such diseases under the umbrella term of 'soil-borne human diseases' seems likely to be unhelpful at best. Therefore, in a report to the European Commission in 2011 we proposed a definition of soil-borne human diseases to be '…human diseases resulting from any pathogen or parasite, transmission of which can occur from the soil, even in the absence of other infectious individuals'. In the same report we identified 39 diseases that occur globally and which fit these criteria (see Further reading).

From an ecological perspective it is apparent that the identified pathogenic organisms can be classified into two groups. Some of the organisms are true soil organisms in that they are capable of completing their lifecycles in the soil (or potentially with an aquatic or semi-aquatic phase) without the need to infect a human (or any other) host. Hence, we named them edaphic (from the Greek for 'true soil') pathogenic organisms (EPOs). This group includes most of the bacterial and all of the fungal pathogens. These are opportunistic pathogens that generally only infect susceptible individuals, such as those who are immuno-compromised, or those who have repeated or large exposures to such organisms.

False-colour scanning electron micrograph of the soil bacterium *Sporosarcina ureae*. Martin Oeggerli / Science Photo Library

The second group consists of obligate pathogens that are capable of surviving within the soil for extended periods of time before infecting humans who come into contact with contaminated soil. However, they cannot complete their entire life cycle in soil; they are not true soil organisms. These can be referred to as soil transmitted pathogens/parasites (STPs).

As is often the case with the natural world, strict categorisation has its limitations. Instead a continuum is likely to exist with some overlap of organisms between the two groupings (for example, strongyloidiasis and shigellosis). Nevertheless, such a distinction is helpful as it highlights areas for further research and aids epidemiological data interpretation; for example, it is probable that infection by EPOs came from the soil but with STPs this is much less certain. This consideration is important for investigating whether a particular land management practice enhances or mitigates soil-borne infection rates.

Human harm vs. soil degradation

This distinction between soil-borne human diseases based on life history has further utility as it is likely that EPOs provide ecosystem services such as breaking down organic matter, potentially remediating pollutants, or affecting soil sensitivity to erosion while within the soil. As such, reducing the abundance of these organisms in the soil may have negative effects such as enhanced soil degradation. The trade-offs between promoting human health and preventing soil degradation will need identifying and quantifying on a locational basis. Conversely, it is likely

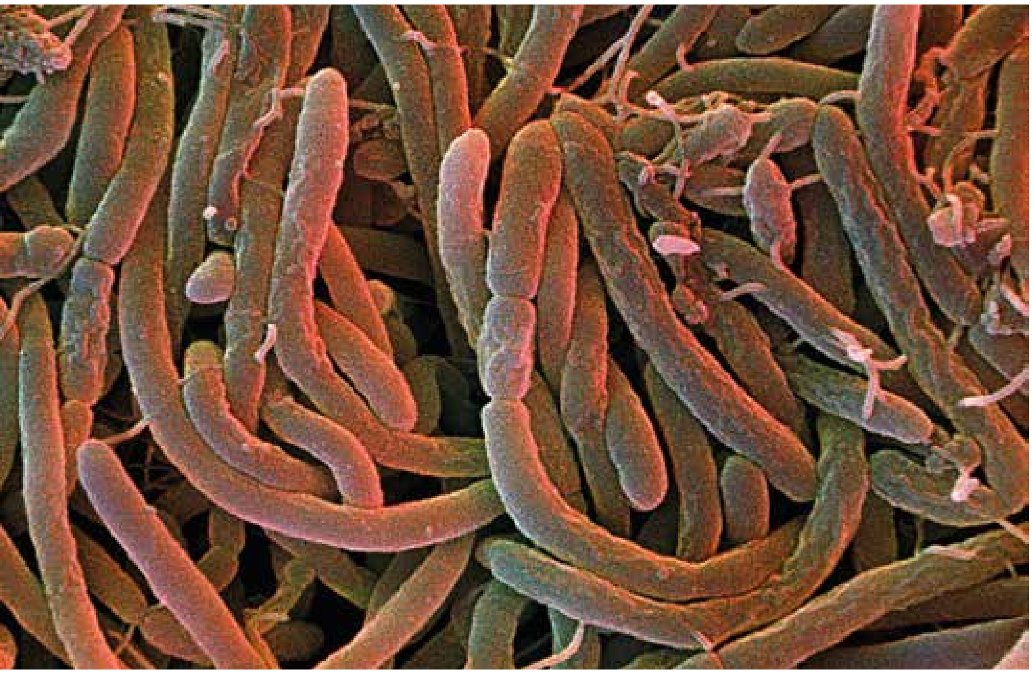
Soil degradation through processes such as erosion, loss of soil structure, desertification, excessive soil tillage, and soil mining activities are likely to impact on human health in several ways.

that STPs will interact less with the provision of ecosystem services as such organisms are likely to be in dormant forms or only have limited activities while in the soil. Therefore, there remains a need to identify how land or agricultural practices may reduce the abundance of STPs within the soil, or the length of time that such organisms remain viable. Such work may allow soil management practices that suppress STPs to be developed such that their implementation may have positive impacts on human health, preferably with minimal effects in terms of soil degradation.

The viability and maintenance of virulence of pathogens outside of their hosts depends on several environmental factors such as temperature, moisture, UV light and pH. It might be possible to control some of these factors through land management practices. For example, the surface layers of cultivated soil tend to dry faster those of non-cultivated soils, which may cause soil particles and soil-borne pathogens to be blown around. Currently, the importance of each factor on pathogen survival in soil is not yet well understood although temperature is generally thought to be the most important factor for modelling microbial decay rates for microbes that are unable to replicate in the environment (i.e. STPs). Furthermore, interactions between such factors are complex. For example, increased soil moisture may both cause and be influenced by increased survival and activity of micro-organisms within the soil. Reduced soil moisture has been shown to increase the transmission of some pathogens from soil by increasing the amount of dust available on which the pathogens may disperse. Vegetation, such as cover crops, is likely to lead to reduced infection rates due to reduced wind erosion, but canopy cover will also reduce the amount of UV reaching the soil surface thereby potentially increasing survival rates of pathogens at the soil surface.

Soil degradation through processes such as erosion, loss of soil structure, desertification, excessive soil tillage, and soil mining activities are likely to impact on human health in several ways. Such degradation results in reduced crop productivity but is also likely to increase infection from soils as infectious organisms become air-borne on eroded soils, or pathogens survive longer in soils which have reduced biodiversity. As such, there is a clear link between 'healthy' soils and healthy humans and it is important that this link is recognised so that we can maximise the benefits and minimise the risks as we utilise the fundamental, life-giving and non-renewable resource that is the soil.

Coloured scanning electron micrograph of *Bacillus* sp. soil bacteria. These Gram-positive bacteria are saprotrophs, organisms that feed and grow on dead and decaying organic material. They are part of a diverse ecology of soil micro-organisms that play a vital role in decomposing and recycling organic matter. David Scharf / Science Photo Library



Simon Jeffery

Department of Soil Quality, Wageningen University, PO Box 47, 6708 PB Wageningen, The Netherlands
simon.jeffery@wur.nl

Wim H. van der Putten

Department of Terrestrial Ecology of the Netherlands Institute of Ecology, and Laboratory of Nematology of Wageningen University. PO Box 50, 6700 AB Wageningen, The Netherlands
w.vanderputten@nioo.knaw.nl

Further reading

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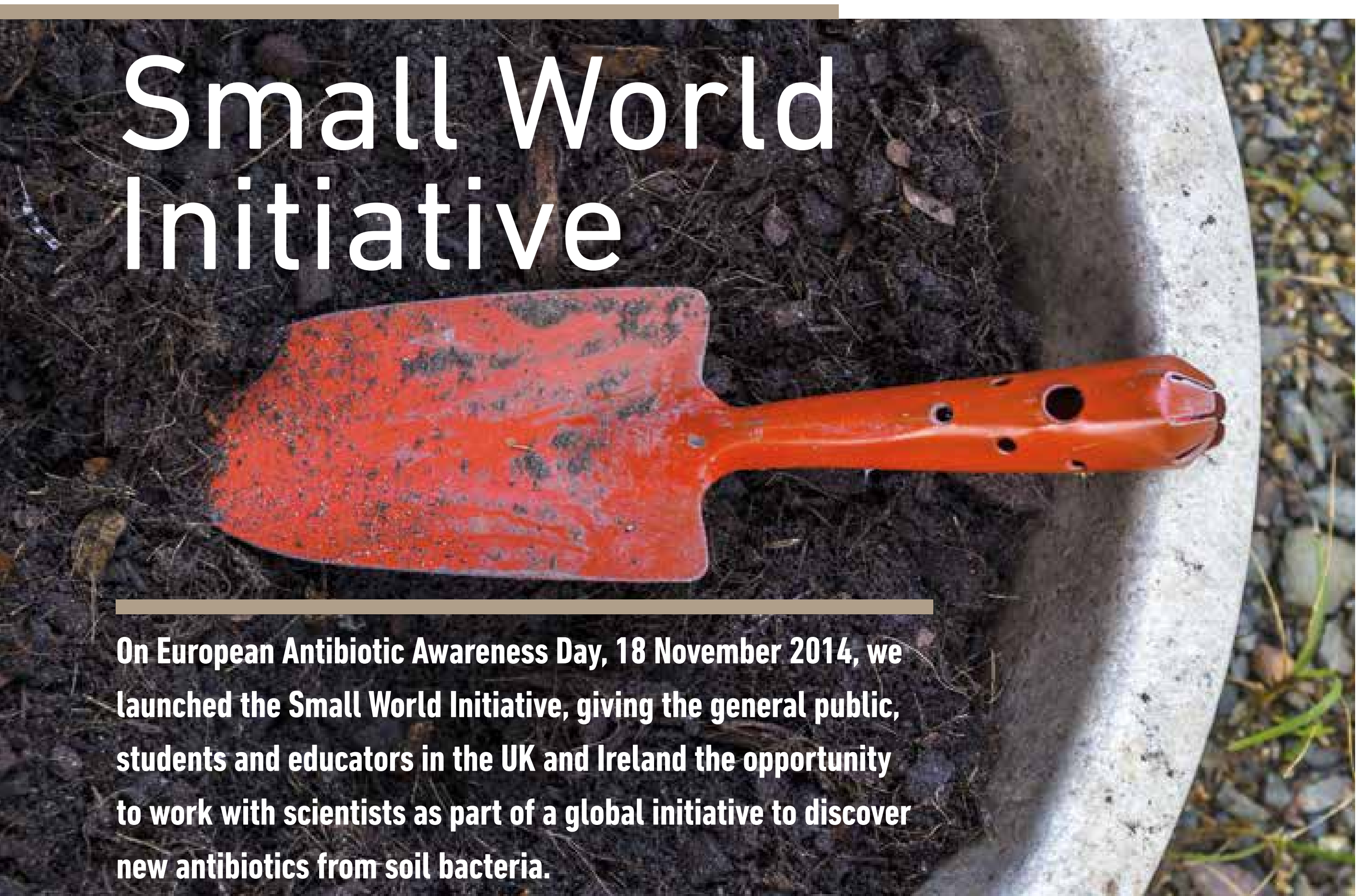
Schoolzone and Outreach Special



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Small World Initiative

On European Antibiotic Awareness Day, 18 November 2014, we launched the Small World Initiative, giving the general public, students and educators in the UK and Ireland the opportunity to work with scientists as part of a global initiative to discover new antibiotics from soil bacteria.

Why soil?

Most antibiotics in current use have come from soil bacteria, for example, Actinomycetes produce over 60% of clinically important antibiotics. The Initiative, first organised by Yale University, is an innovative research project, which uses crowd-sourcing to discover new antibiotics from soil bacteria. It is now running in higher education institutions across the USA. It is hoped that exposing their undergraduates to research experiences will inspire them to major in a science-based degree. The Society is also expanding the project beyond undergraduate students to include school pupils and the general public in the Initiative so as to engage as many as possible with the topic of soil microbiology and antibiotics, and its wider implications in society.

Why are we running the Small World Initiative?

Antibiotic resistance is an issue of international importance that will impact all of us. The World Health Organization estimates that antibiotic treatments add an average of 20 years to our lives. How we respond to the growing global threat of antimicrobial resistance is one of the most important science questions of our age (see section: Tackling the problem of antimicrobial resistance).

The Small World Initiative's search for new antibiotics will help engage the public with the problems surrounding drug resistance, drug discovery and the scientific research process. The Initiative will support teachers in providing practical lessons with links to the wider curriculum and give students the opportunity to take part in 'hands-on' research that will both encourage them to study science further and to increase the scientific literacy of all of the students involved.

What is the Society doing as part of the Initiative?

The Small World Initiative will have three main areas of work:

Biology students in their first year of post-16 studies (Year 12 or equivalent)

We have chosen five school partnerships to take part in the Initiative. Each student will collect a soil sample and carry out a series of experiments, looking for novel antimicrobial compounds. The aim is to inspire and motivate students by providing them with the opportunity to take part in a biology-related research project, focusing on the global issue of antimicrobial resistance. It will also be a platform from which to teach a number

The first school students try out the Small World Initiative

In the Spring term of this year, 20 budding researchers took on the challenge of being the Small World Initiative's first participants in the UK. The Sir Isaac Newton Sixth Form College in Norwich teamed up with Dr Laura Bowater from the University of East Anglia to run the programme, which had two students apply for every place available. Each successful student was provided with a sampling kit and a lab book, especially designed and branded for the project.

The students collected soil from a variety of local places, including gardens and local parks, and carried out a series of experiments and investigations in the search for novel antimicrobial compounds. Using different media and dilutions of their soil samples, they grew up cultures and all the students identified zones of inhibition on all of their culture plates. At the time of writing, they had begun to investigate whether these may contain potentially unknown antimicrobial compounds.

Dr Laura Bowater said of the project: "The Small World Initiative is a fantastic project. I am enjoying the whole process of offering students a research project that genuinely excites and engages them. Also, undertaking the project over several sessions allows the opportunity to follow students on their personal research journey which is an absolute privilege."

The students were equally as enthusiastic, and had the opportunity to present their work at the Society's Annual Conference in Birmingham. These 20 students are just the first group of many who will be participating in the Small World Initiative School Partnerships. As well as having a great experience doing their research, we hope that one of them will be lucky enough to identify a novel antimicrobial compound.

Some of the students presenting their work in Birmingham. Ian Atherton of key biological concepts and give students the chance to visit a university/workplace partner to do some of the practical work.

Undergraduate students

The aim is to encourage and progress students by allowing them to do real research and take ownership of their science. Each of the 10 universities chosen to take part will use its own expertise so the students can take part in research focused on the global issue of antimicrobial resistance with the scientists who are already working in this area. It will provide them with the vehicle for the investigation of biological and chemical soil ecology and be a platform from which to teach a number of key biological concepts as well as giving all of the students a realistic research experience.

Public through citizen science project

Throughout the summer of 2015, the Education and Outreach team will be at various locations around the UK, looking

Tackling the problem of antimicrobial resistance

The Society's first President, Alexander Fleming, warned about antimicrobial resistance (AMR) during his 1945 Nobel Prize Speech. However, it is only over the past couple of years that this threat to global health security has hit the mainstream news headlines.

AMR now features regularly in the media and, importantly, policy makers and the science, health and agricultural communities, both in the UK and abroad, have begun a concerted effort to tackle this threat. Even the Prime Minister has warned that we could be "cast back into the dark ages of medicine" if nothing is done, when he commissioned an independent review to identify international actions to tackle AMR in July 2014.


Jupiterimages / Photos.com / Thinkstock

It is also clear that there is growing concern amongst the public on this issue as over 12,000 people have pledged to be 'Antibiotic Guardians' and AMR was voted as the challenge for 2014 Longitude Prize.

The UK Government was spurred into action back in 2013 by the Chief Medical Officer, Dame Sally Davies, who warned in a first report that the "catastrophic threat" posed by AMR should be ranked alongside terrorism and climate change as a critical risk to the UK. Later that year the Government published a five-year strategy to tackle AMR through a 'one health' approach to promote surveillance, drug and diagnostic development, and antimicrobial stewardship across animal and human health.

December 2014 saw high-profile coverage of the first report from the independent review commissioned by the Prime Minster, which provided estimates of the global human and economic costs of inaction. Even just using data from three common forms of resistance, the report estimated that unchecked AMR could cause at least 10 million extra deaths a year, with a cumulative cost to the global economy of up to US$100 trillion by 2050. This makes the nearly for people to collect a soil sample and follow the research online, where we will be looking for the next new antibiotic! We want to engage the public, through practical activities, with the global issue of antimicrobial resistance and address some of the challenges associated with the discovery of novel antibiotics. The interactive stand will contain information and activities regarding antimicrobial resistance and drug discovery. To find out where we will be and when, please check the website for details: **www.sgm.ac.uk/smallworld**.

As part of the Small World Initiative, the Society is collaborating with the University of East Anglia in providing match-funds for a PhD student. With a multi-disciplinary team in microbiology, antibiotic resistance, public engagement and science communication, the student will work as part of the citizen science project, measuring the impact of public engagement in science and analysing the soil samples collected by the public. The Society is really excited to be working with Dr Laura Bowater, Professor Elena Nardi and Dr Gary Rowley, and is looking forward to the great work that this collaboration will produce to advance both microbiology and public engagement with science.

Theresa Hudson
Education and Outreach Officer
t.hudson@sgm.ac.uk

For more information on the Small World Initiative, visit **www.sgm.ac.uk/smallworld** or contact the team on **smallworld@sgm.ac.uk**.

US$1.2 billion President Obama has recently proposed to invest in tackling AMR in his 2015 Federal budget proposal look like a good investment.

The review's second report, published in February, recommended initial actions the international community should take, namely investing in the human and economic capital needed to tackle AMR now and in the future. Jim O'Neill, the renowned economist chairing the review, called on "international funders, philanthropic or governmental, to allocate money to a fund that can support blue-sky science and incubate ideas that are more mature" and to invest in the workforce of scientists and health workers needed to fight AMR.

Looking forward, new progress should hopefully be made with the UK five-year Action Plan, the World Health Organization is launching an AMR Global Action Plan in May, and the independent review will be recommending market incentives to revitalise the pharmaceutical industry's investment in the development of sorely needed new antimicrobials and diagnostics.

Paul Richards
Policy Officer

Marine actinomycetes. Charlotte Raymond / Science Photo Library

The Society for General Microbiology's new journal: Microbial Genomics

The Society for General Microbiology is pleased to announce the forthcoming launch of a new fully open access, open data and peer-reviewed journal, *Microbial Genomics: Bases to Biology*.

***Microbial Genomics* will provide a forum to present and integrate the next generation of knowledge and insight in genome-wide analyses ...**

Professor Stephen Bentley, Editor-in-Chief

Microbial Genomics (or **MGen**) will publish original and high-profile research on archaea, bacteria, microbial eukaryotes and viruses, through articles that use genomic approaches to further our understanding of microbiology.

Led by Professors Nicholas Thomson and Stephen Bentley from the Wellcome Trust Sanger Institute, UK, and recognised as "Most Cited Researchers" by Thomson Reuters (2014), *Microbial Genomics* marks the Society's second fully open access offering and first mandatory open data journal.

"The team *Microbial Genomics* has assembled represents some of the most creative and forward-thinking researchers in the field, with a strong commitment to open access, open data, communicating online, and moving science forward through collaboration ... *Microbial Genomics* is set to have a very big impact." Dr Jennifer Gardy, Senior Editor.

"*Microbial Genomics* provides a natural home for top-class research in this burgeoning field ... I hope this new journal will inspire insightful articles to help grow this powerful discipline." Dr Kathryn Holt, Senior Editor

"*Microbial Genomics* fills a gap in reporting developments in the field with a focus on microbial genomes in a far more coherent and integrated way than any other journal I am aware of." Dr Christos Ouzounis, Senior Editor

The new journal was announced at the Society's Annual Conference in Birmingham last month. Submissions are now open and the journal will launch fully in July 2015.

***Microbial Genomics* provides a new and exciting opportunity to capture cutting-edge science that is driven by technology and imagination.**

Professor Nicholas Thomson, Editor-in-Chief

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Wellcome Trust Sanger Institute, UK

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Wellcome Trust Sanger Institute, UK

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Did you have an inspiring science teacher at school?

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With recent concerns around increasing drug resistance, and the spread of new infections such as Ebola, we should rightly be considering the microbiological legacy we will be passing on to future generations. And that is one very important reason the Society is committed to ensuring today's schoolchildren are given every opportunity to broaden their understanding of microbiology.

For many children of school age, this understanding will come from an inspirational teacher. If you had one, you will know the impact they can have. The Society is especially keen to support these teachers and their schools. One of the ways we do this is by offering affordable School Membership to any primary, middle or secondary school or sixth form college in the UK or Ireland involved in teaching microbiology.

Over 500 schools are now members of the Society. We deliberately keep School Membership subscriptions low (it costs just £15 a year) to ensure as many children as possible can benefit from what we offer. And just what is it we do offer?

Broadly speaking, we support the delivery of high-quality classroom teaching through the provision of training, networking opportunities, grants and a series of resources.

In recent years, the Society has produced a number of resources for children including *The Secret World of Microbes*, *Algae: A Practical Resource for Secondary Schools*, *Viruses: A Practical Resource for Post-16 Biology Teachers*. Single copies are made freely available to School Members. School Members also receive the magazine *Microbiology Today*, incorporating the regular Schoolzone section. In addition there are hard copy and downloadable posters, comics, books and fact files covering a range of curriculum subject material.

We also have a grants programme specifically aimed at schools. School Members can apply for a grant of up to £1,000. Grants can be used for a number of initiatives; from organising a visit to a working microbiology establishment, to running a school-based science week, to buying materials and equipment (outside of normal department resources) to support a microbiology activity. One recent grant recipient, Ruth McClaren, from Barnstaple, ran an after school club for Key Stage 2 pupils to develop their scientific thinking and have some fun. "I wanted the pupils to understand that microbes are essential to all life on Earth, and that they are not all 'germs'". Ruth was clearly successful in this endeavour as the feedback was overwhelmingly positive. In answer to the question "what did you like about the club?" many pupils responded with "everything"!

Teachers like Ruth play a very important part in switching on the 'light bulb' for children, to enable them to play their part in future scientific discovery.

You can play your part too. There are many more schools out there whose children could benefit from School Membership of the Society. They either haven't heard of us or face financial constraints preventing them joining.

Here's what you can do:

- If you have teachers in your network, why not highlight School Membership of the Society? They may not be microbiologists themselves, but they will know the right contact in their school.
- Bring School Membership to the attention of the schools in your neighbourhood. A phone call or a note to the headteacher could be all it takes.
- If you have children or grandchildren at school, why not ask if their school has Society membership at the next parents' evening? Asking that simple question could help provide the scientific inspiration for hundreds more children.
- Consider 'sponsoring a school'. If you would like to sponsor a school we can help. You may want to offer to pay for a neighbouring school or one with which you already have a connection. Alternatively, we can match you up with a school from here. For £15 a year, you can help a teacher inspire a new generation.

Simon Fraser / Science Photo Library

If you would like to help us bring School Membership to the wider microbiological community please contact us. Call the Acting Head of Membership Services Paul Easton on **020 7685 2680** or email him at **p.easton@sgm.ac.uk**.

Conferences

Focused Meetings **2015**

International Meeting on Arboviruses and their Vectors (IMAV)

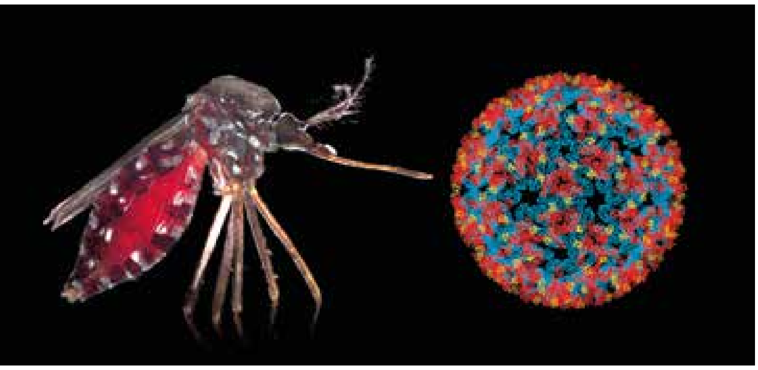
7–8 September
University of Glasgow, UK

IMAV 2015 is aimed at those working on arboviruses or those with an interest in this group of viruses and their biology, from academics to students to companies to policy makers. The topics will cover virus replication, host responses to infection, vector biology, virus evolution and more clinical aspects. We have invited speakers who are recognised international experts in their areas of research. This is indeed one of the few occasions for the field to come together and focus on these increasingly important viruses.

Topics will include:

- Arbovirus–vector interactions and immune responses
- Preventing arbovirus transmission: novel strategies
- Arbovirus–vertebrate host interactions
- Verterbrate immune responses to arbovirus infection
- Arbovirus replication and evolution

Abstract submission deadline is **Friday 10 July 2015**.

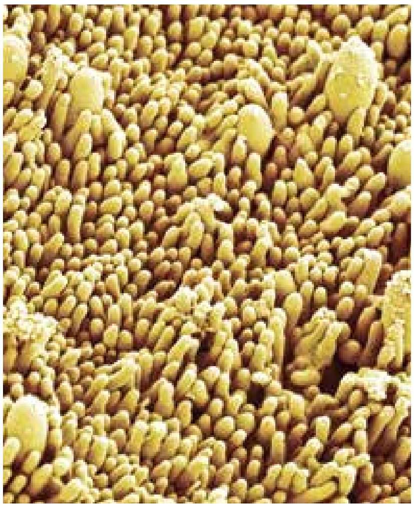


Asian tiger mosquito (*Aedes albopictus*) next to a Chikungunya virus particle.
Pascal Goetgheluck / Science Photo Library

International Meeting on the Invasive Fungus

7–9 September
Mercure Hotel, Manchester, UK

This Focused Meeting, jointly hosted by the Society for General Microbiology and the British Mycological Society, will consider the fungal hypha as a fundamental unit of fungal growth that underpins invasion.



False-coloured scanning electron micrograph of the surface of a fruiting body of the Ash Dieback fungus *Chalara fraxinea* (*Hymenoscyphus pseudoalbidus*).
Crown Copyright FERA / Science Photo Library

Recent work in fungal biology has highlighted the huge importance of invasive development in fungal lifestyles. Much of the current high-profile fungal research deals with the concept of invasion; from the mechanistic basis of fungal cell invasion, to the invasion of plant and animal tissues, through to invasion of non-living matter and finally to the invasion of new geographical or biological niches. The universally understood concept of invasion also provides a public-friendly entry into the complex issues of disease, geographical spread and ecology covered in this meeting. Topics will include the invasive fungus in relation to defence, penetration, the environment and invasion.

Please contact **conferences@sgm.ac.uk** to register your interest in attending this meeting.

Quadrangle in Galway.
Elzbieta Sekowska / iStock / ThinkStock

Irish Division Meeting 2015: Microbial Interfaces

17–19 June
University of Galway, Ireland

The National University of Ireland, Galway will celebrate 50 years of microbiology in June 2015, and to mark the occasion, it will be hosting the Society for Microbiology Irish Division Meeting.

This Annual Conference focuses on the diverse range of microbial interfaces in the microscopic world and will be a stimulating event for all those who attend.

Topics will include:

- The host–microbe interface
- Health from the environment
- Microbiology for engineering and the bioeconomy
- The pathogen–device interface
- Ecosystems microbiology

Find out more about the event online: **http://microb.io/MicroInt2015Ire**

Annual Conference 2016

21–24 March 2016
Arena and Convention Centre, Liverpool, UK

Following the success of the Annual Conference 2015, the Society is happy to announce that the next Annual Conference will take place from Monday 21 March to Thursday 24 March 2016 at the Arena and Convention Centre, Liverpool. The conference will feature four packed days of microbiological science aimed at scientists of all levels.

George-Standen / iStock / Thinkstock

Do you have an idea for a Focused Meeting, or need funding for your own microbiology meeting?

Focused Meetings are stand-alone events that take place outside of the Society's Annual Conference and concentrate on one specific area of microbiology.

Organisers retain control of the scientific content with the support of the Society's Scientific Conferences Committee. The proposal forms and full details on how to apply are available online.

Society-supported Conference Grants

Members can also apply for a Society-supported Conference Grant to fund reasonable speaker expenses associated with a microbiological conference they are organising. Support is in the form of a grant of up to £2,000 but does not include secretariat support. Application forms are available online.

Peshkova / iStock / Thinkstock

Submit your proposals/applications

If you are thinking of submitting proposals/applications for any of the above you are actively encouraged to discuss your proposal prior to submission with the relevant Division. View the Divisions page on the website for contact details: **www.sgm.ac.uk/divisions**. Alternatively, contact the Conferences team at **conferences@sgm.ac.uk**.

Conferences information – visit **www.sgm.ac.uk/conferences**

Membership Q&A Steve Diggle

Where are you currently based?

I am based at the Centre for Biomolecular Sciences, in the School of Life Sciences at the University of Nottingham.

What is your area of specialism?

I have worked for many years on a cell-to-cell signalling system in *Pseudomonas aeruginosa* known as quorum sensing. When I started my PhD, and during my postdoctoral work, I focused on understanding the mechanism of how quorum sensing works. Over the last 10 years I have focused on social evolution in bacteria and asked more adaptive questions about quorum sensing: why do these behaviours evolve and why and how are they maintained in natural populations? Understanding whether or not a behaviour is social can help us understand how bacterial populations interact within infected hosts, explaining some kinds of clinical observations as well as how virulence and antibiotic resistance evolves.

Tell us about your education to date

I went to a comprehensive school in Stockport, which I left at age 17 without doing any A-levels. I began working in a small company that isolated a compound from rabbit brains that was used to test the clotting time of blood, and my job was to remove 200 brains from rabbit heads that we got every day from the local abattoir. After 18 months, I moved to work at Withington Hospital before moving to the Paterson Institute for Cancer Research in Manchester. I knew I needed to get a degree to move on, so before attending Salford University full-time in 1993, I did a one-day a week access course in science for two years. I graduated from Salford University in 1997 at age 27 and earned my PhD from the University of Nottingham in 2001, and then did postdoctoral research until 2006. I was awarded a Royal Society University Research Fellowship in 2006 which finished in 2014, and I was appointed to Associate Professor in 2013.

Where did your interest in microbiology come from?

When I was 10 years old, my junior school teacher Mrs Liversage told us about the Great Plague of London in 1665. From that moment, I have always been fascinated by microbes and disease.

What are the professional challenges that present themselves and how do you try to overcome them?

Balancing research, teaching, admin and family life. I imagine most people would say the same, and I don't particularly know how I manage this, or if I am doing a good job managing it!

What is the best part about 'doing science'?

There are so many good things. Discovering things that only you in the world at that moment know about is pretty cool. Publishing papers is great although the reviewing process can be very tiresome at times. Certainly science should not be about having to reformat your paper for another journal due to a rejection! I think the best thing is that you get to meet and work with people from many different countries and backgrounds. Science brings all sorts of people together and I think this is a really positive thing. It's also great when you can have some influence on the careers of the next generation of microbiologists.

Who is your role model?

Role models can come from anywhere, and I have met many along the way that I would call role models. I won't embarass them all by naming them, but I will give one special mention. My junior school teacher Mrs Liversage was a big influence. Not only did she teach me about the plague, she taught me the first chords I learnt on the guitar. Now I look back, she was a very important influence on both my career and my favourite hobby.

What do you do to relax?

I play bass guitar and write and record music with my band Mr Meaner. I helped form this band when I was 19. The name was supposed to be an amusing play on the word misdemeanor. It was funny for about 10 minutes and then it became annoying, but we stuck with it. After calling it a day in 1995, we recently reformed the band to record what we should have done 20 years ago. We are just known as Meaner now. I also like to read. I'm a bit of a Tolkien nerd, and I like the *Game of Thrones* novels and TV series.

What one record and luxury item would you take to a desert island?

This is very difficult as I like so many records! An album I always go back to is *Abbey Road* by the Beatles. They had just finished recording *Let It Be*, which was an unhappy album where there appeared to be a lot of fighting between them all. I think they felt they couldn't leave it like that so they decided to record *Abbey Road*. You can tell this was an album recorded by a group of people who did actually really like each other so I think it's a very positive album and a very fitting end to the Beatles' career. Luxury item? Probably an iPad if there was electricity to charge it.

Tell us one thing that your work colleagues won't know about you!

I used to have very long hair, wear an Iron Maiden T-shirt, and play Dungeons and Dragons. Actually they would all probably guess that!

If you weren't a scientist, what would you be?

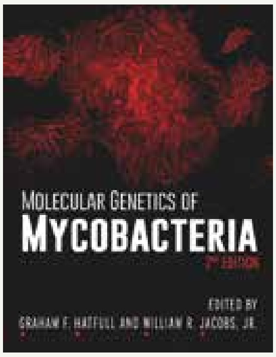
The easy answer to that is that I'd like to be a rock star, but obviously that is not going to happen! I don't know why but I always quite fancied being a postman, so that's what I'd be interested in doing.

If you would like to be featured in this section or know someone who may, contact Paul Easton, Acting Head of Membership Services, at **p.easton@sgm.ac.uk**

Reviews

Molecular Genetics of Mycobacteria, 2nd Edition

Edited by G. F. Hatfull & W. R. Jacobs Jr
ASM Press (2014)
US$160.00 ISBN 978-1555818838



This is a very welcome update to the first edition, which I was surprised to learn was 15 years old! There has been a wealth of developments within the field of mycobacterial molecular genetics during this period and this book does a great job in reflecting this. It is vastly expanded from the first edition and much of this is displayed in the chapters dealing with genomics and other 'omics. Particularly nice is the inclusion of a specific section on the 'genetics of drug resistance'. This is especially pertinent given the clinical interest in this area due to the rise of multi-drug-resistant tuberculosis (MDR-TB) and more recently the emergence of extensively-drug resistant tuberculosis (XDR-TB). There is also an excellent section on the innovations in making gene knock-outs in tuberculosis which have really allowed rapid progress in research since the first edition.

Overall, this is an excellent update to the title and I'm sure it will find a place on the bookshelves of tuberculosis and *Actinobacteria* researchers everywhere.

Paul Hoskisson
University of Strathclyde

Antibiotics: Current Innovations and Future Trends

Edited by S. Sánchez & A. L. Demain
Caister Academic Press (2014)
£180.00 ISBN 978-1908230546

This timely book gives an overview of the antimicrobial resistance (AMR) crisis and talks about past and future efforts to develop new anti-infectives. It is packed full of useful information, including the number of antibiotics used in the clinic or currently in the clinical trials pipeline and sources and targets of clinically used antibiotics, information which is difficult to find elsewhere. Inevitably, there is a lot of repetition and overlap between chapters and no attempts at cross-referencing, e.g. the origins and definition of the word 'antibiotic' is covered in detail by several chapters. There are also inconsistencies; the 'golden age' of antibiotic discovery is variously described as between 1940 and 60 or 1950 and 80. Overall though I found the book informative and easy to read, and the scope is huge with a lot of coverage given to the new sources of antibiotics, i.e. genome-mining strains from under-explored niches and unlocking cryptic pathways. The chapter on animal venoms was particularly fascinating and completely new to me. I recommend this book as an essential reference for anyone interested in the field of AMR and antibiotic discovery, a field currently undergoing a renaissance as governments realise the scale of the crisis and promise much needed funding. The message from this book is that the future is bright if governments and industry are prepared to invest in antibiotic discovery.

Matt Hutchings
University of East Anglia

Comment

Can microbes solve the time of death questions?

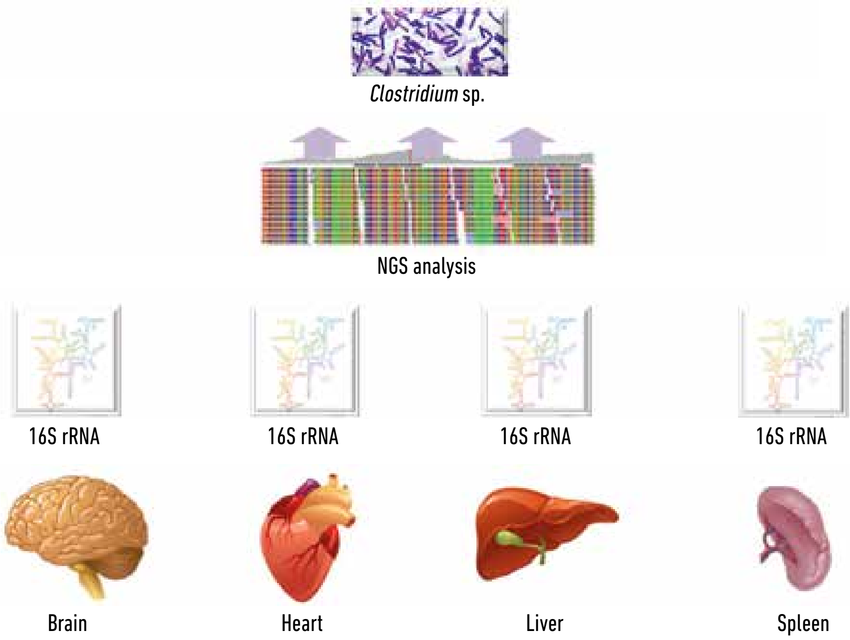
Gulnaz Javan

Is death the end of life? In some ways, it is; but in terms of the microbial activity on, in and around cadavers, there is an abundance of microbial life in human fatalities that may potentially aid death scene investigations.

One of the major goals of criminal death investigations is to determine the post-mortem interval (PMI) of the deceased person. A dead body is teeming with micro-organisms. These microscopic decomposers proliferate as they mediate decay, and they can be comprehensively studied using both cadavers' and the grave-soil environments. Scientists including a team at Alabama State University are undertaking the daunting task of producing the largest cohort of relevant micro-organisms found in organs such as the liver, skin, and in cadaver grave-soil during decomposition: the thanatomicrobiome, or 'microbes of death'.

Microbiome of death studies seek to catalogue all micro-organisms involved in human decomposition. Studies have included the identification and characterisation of micro-organisms extracted from over 400 specimens obtained from 100 cadavers acquired from homicides, suicides, over-doses and accidental death investigations. Soil samples are collected beneath body zones of cadavers at varied stages of decomposition at the Forensic Anthropology Research Facility (FARF) 'body farm', a 26-acre outdoor human decomposition research laboratory located in Texas State University's Freeman Ranch. This is spatially the largest facility of its kind on the globe. It receives body donations for scientific research studies according to the Universal Anatomical Gift Act. Since 2008, research has been conducted on more than 150 donated bodies, with another 200 living people pre-registered for donation upon their demise.

The cadaver soil studies catalogue the microbial diversity in soil collected under strategic locations from cadavers' remains on soil. Decomposition of human remains placed on soil is biologically mediated by three main decomposers – endogenous and soil microbes (e.g. bacteria and fungi), insects (such as flies and beetles) and scavengers (e.g. moles and vultures). As with the thanatomicrobiome study, the aims of our study is to determine if there is a correlation between microbial populations in the cadaver



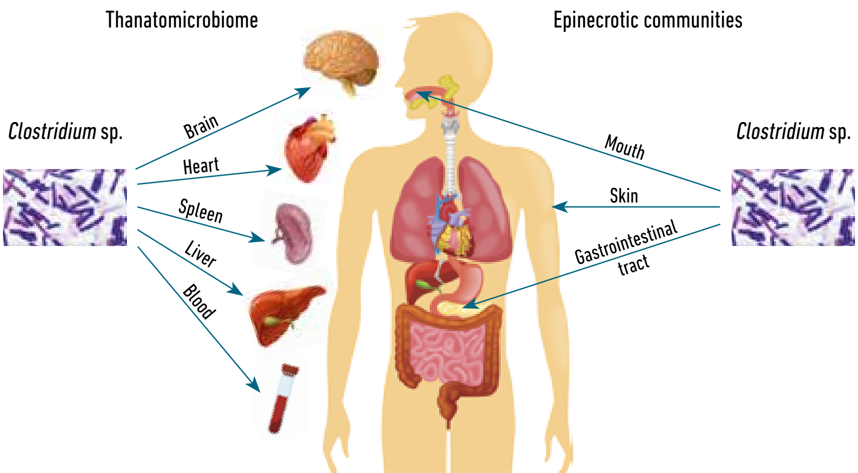
Microbial composition of internal organs (thanatomicrobiome). Gulnaz Javan decomposition soil and the time of death and/or the time of placement of the human body on the soil. Traditional forensic decomposition investigations of human remains have focused primarily on the macroscopic, observable post-mortem evidence such as decomposition stages, animal scavengers or insect developmental stages. But these techniques depend heavily on the subjective opinions of the investigator. Further, these types of investigations often do not correlate with fixed time points. But there is a growing awareness that the micro-organisms on human remains and in the soil beneath them could potentially provide molecular clues in criminal investigations.

In the microbial forensics studies molecular techniques are used, due to the fact that a vast majority of micro-organisms proliferating in the human body and in soil cannot be cultured. Studies have been undertaken to design and optimise cadaver tissue and soil sampling methods, DNA extraction techniques, DNA amplification via polymerase chain reaction (PCR) and next-generation metagenomic sequencing platforms to characterise the fluxes of the microbial communities during decomposition. The beauty of next-generation metagenomic sequencing is that it can assess the DNA sequences of an entire microbial community in a single run of less than 10 hours. Bacterial species identification and changes in richness are determined to provide information that aid in the development of forensic tools based on the variations in the microbial populations.

Human corpses are not as easily accessible for research as are animal models. Studies of this kind have been conducted using replicate mice and pig models, but not using decomposing human tissue. Studies performed by a research team at Sam Houston State University and Baylor College of Medicine catalogued the bacteria existing internally at the onset and end of the bloat stage of cadavers placed at Southeast Texas Applied Forensic Science Facility. Their results show that the bacterial communities were different between the corpses and between regions on the same corpse, and these bacteria changed over time during the course of decomposition.

Grave-soil studies of microbial diversity are more common, but are yet hampered by the sheer number of microbial cells and diversity of distinct taxa per gram of soil. Studies have estimated that the number of species of bacteria per gram of soil varies between 2,000 and 8.3 million cells, depending on the soil type. Jessica Metcalf of Colorado University-Boulder's BioFrontiers Institute and a team of scientists used the mouse model system to study the body cavities and associated grave soil of 40 decaying mice over a 48-day period, and a 'microbial clock' was demonstrated. Their PMI estimates correlate to actual PMIs within approximately three days.

The future direction of these studies will assuredly determine if there is a correlation between the microbial abundances of specific communities of bacteria and the time of death of the human body. These studies are daunting and non-trivial tasks. But through state-of-the-art, metagenomic efforts led by myself and my team and others around the world, the clues provided by microbes of death will be discovered.



Microbial composition of internal organs/blood (thanatomicrobiome) and epinecrotic communities.
Gulnaz Javan; iStock / Thinkstock (test tube and human figure)

Gulnaz Javan

Physical Science Department, Alabama State University, Montgomery, Alabama AL 36104, USA
gjavan@alasu.edu

Dr Gulnaz Javan and her team of microbial forensic scientists, Ismail Can and Sheree Finley at Alabama State University are endeavouring to use molecular innovation to pin-point the precise time of death in criminal cases, funded by a $200,000 National Science Foundation grant.

Further reading

Finley, S. J., Benbow, E. M. & Javan, G. T. (2014). Microbial communities associated with human decomposition and their potential use as postmortem clocks. *Int J Legal Med* doi:10.1007/s00414-014-1059-0.

Can, I. & others (2014). Distinctive thanatomicrobiome signatures found in the blood and internal organs of human. *J Microbiol Methods* 106, 1–7.

Metcalf, J. L & others (2013). A microbial clock provides an accurate estimate of the postmortem interval in a mouse model system. *eLife* 2, e01104.