MICRO BIOLOGY TODAY

QUARTERLY MAGAZINE OF THE SOCIETY FOR GENERAL MICROBIOLOGY 39:2 MAY 2012

RHS CHELSEA FLOWER SHOW ISSUE

ARBUSCULAR MYCORRHIZA

FIXATION WITH INTIMACY

FRIENDLY VIRUSES

SALT AND METAL

MYCOFUMIGATION

CAN MICROBES FEED THE WORLD?

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FEATURES

REGULARS

39:2 MAY 2012 CONTENTS

EDITORIAL

Welcome to the May issue of *Microbiology Today* (MT). We are particularly excited about this issue of MT as it will form part of the Society for General Microbiology's public display at the 2012 Chelsea Flower Show.


Paul Hoskisson. *I. Atherton*

MICROBIOLOGY makes the world go round. Every fundamental process on the planet is underpinned by the actions of micro-organisms. They impact on our everyday lives in direct and indirect ways, most visibly in terms of disease and degradation. However, we shouldn't always think of micro-organisms in negative terms. One of the most obvious positive ways they affect our lives is through the provision of food. Even here, if we dig deeper beyond the obvious use of micro-organisms, such as the fermentation of beer, the leavening of bread, and the production of cheeses and yoghurt, we can find ways in which micro-organisms affect the wider provision of our food.

On a planet where the population has recently expanded to 7 billion people, the issue of food security is paramount. The ability to feed those people is a major challenge to science and society. Food security encompasses a wide range of issues relating to microbes, plants and the planet, such as soil health and nutrient cycling, plant–microbe interactions, crop pathogens, gut microbiology and pathogens of livestock, food spoilage, food safety and human disease, and waste management. These issues are summarized in the recent Society for General Microbiology *Position Statement on Food Security and Safety* (www.sgm.ac.uk/news/positionstatements.cfm).

In this issue of MT we have aimed to bring our readers some fascinating insights and novel perspectives into the influence micro-organisms have on a range of plant–microbe systems. From Angela Hodge telling us about the role of fungus–plant root interactions and their benefit to plant growth through to the production of volatile antibiotics that may find utility in plant protection by Gary Strobel. The benefit that plant viruses may play in maintaining diversity in plant populations is discussed by Marilyn Roossinck, and Allan Downie and Philip Poole from the John Innes Centre discuss the elegant role that bacteria known as rhizobia play in the formation of nitrogen-fixing root nodules in legumes. Elisa Gamalero and Bernard Glick talk about the influence micro-organisms have in enabling plant growth in harsh environments, and finally, Sophien Kamoun from the Sainsbury Laboratory comments on the role genome sequencing can play in understanding plant pathogens.

Hopefully our new readers of MT will find this issue relevant and we hope that it stimulates interest and appreciation of the vital role microbiology plays in society and globally.

The theme of the next issue of the magazine (August) will be 'Infection' in tribute to the late Professor Harry Smith CBE FRS.

PAUL A. HOSKISSON, Editor
(email paul.hoskisson@strath.ac.uk)


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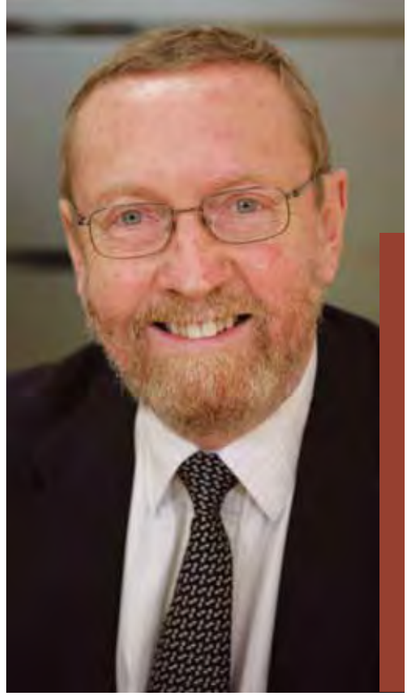


Sir John Beddington CMG FRS, Chief Scientific Adviser to the UK Government (GCSA), expresses his views on food security and his role as GCSA.

Q When you took your present role, you highlighted food security as a major issue. Why was that?

A The global food system is failing on two fronts: it is consuming the world's natural resources at an unsustainable rate and failing the world's poorest, with almost one billion still suffering from hunger. Therefore, the case for global action in the food system was and still is compelling. We need a redesign of the whole food system to bring sustainability to the fore.

Q What do you believe to be the key scientific challenges in food security?

A The key challenge for food security is containing the demand of resource-intensive types of food production, principally meat. Advances in nutrition offer prospects for improving the efficiency and sustainability of animal production.

The key scientific challenge for food security is how to implement sustainable intensification of agriculture in the global food system.

Brand X Pictures

It requires economic and social changes to recognize the multiple outputs required of land managers, farmers and other food producers, and a redirection of research to address a more complex set of goals than just increasing yield.

Q The role of microbiology is often poorly understood and under-represented in meeting the needs of a safe and sustainable food supply for a growing population – a key interest for SGM. How can microbiologists make their voice heard in the policy community?

A The Public Attitudes to Science 2011 survey showed that public attitude towards science is generally positive. For instance, nearly 90% thought '*scientists make a valuable contribution to society*' and 80% accepted that scientists '*want to make life better for the average person*'. I think we need to put the overall perception of microbiology within that context. I do recognize the importance of life sciences in relation to food security. For example, our *Future of Food and Farming Foresight Report* talks about the potential benefits of introducing nitrogen-fixing properties to non-legumes as one possible important area for research. Our *Detection and Identification of Infectious Diseases Foresight Report* (2006) also consulted closely with microbiologists in developing its evidence base and synthesizing its conclusions.

As with all science disciplines, keys to successful engagement with the policy-making community remain the underpinning principles of good science, such as robust evidence, stringent peer review and close ongoing dialogue with the public.

Q Food safety and security is an issue for all governments. In a globalized world, is a 'national' science and innovation policy possible, or even desirable?

A Today's global food system is complex and dynamic, perhaps more so than at any time. Good global governance of the food system is based on similarly good leadership at a national and regional level. Given that timescales to impact for research and innovations can be years, it is vital for governments to take a long-term view and fund research now to meet future challenges. We also need to transfer new knowledge and current best practice and technologies into practical solutions.

Q Should the Government's Chief Scientific Advisor (GCSA) be the voice of scientists in Government – or the voice of Government among the scientists?

A The GCSA represents scientists in Government as the Head of the Science and Engineering Profession and, through this role is responsible for supporting the professional development of scientists and engineers within the Civil Service. In 2008, I established Government Science & Engineering (GSE), a cross-Government community which, by March 2010, had attracted over 3,000 members from more than 30 different Government organizations. These scientists carry out a huge range of occupations, from radiation health and safety to brain electrophysiology, cloud physics, and agricultural processing. GSE aims to increase recognition of the profession's contribution to policy as well as build a strong and vibrant community with robust links between the different analytical streams and policy-makers.

It is also important to represent the wider science community's interests at the heart of Government which I do alongside the Science Minister David Willetts and Sir Adrian Smith in the Department for Business, Innovation & Skills. The Government does take the importance of science very seriously; you can see this by looking at the settlement science got at the last spending review for instance.

With regard to being the voice of Government amongst scientists, I and my office work to ensure the quality of science and engineering advice across the work of Government, but it is the Science Minister David Willetts who is the Government's spokesperson on issues of science policy.

Q The first official chief science advisor was Solly Zuckerman, back in the 1960s. How do you think the role has evolved since? Are we any nearer to 'evidence-based policy-making' now than we were then?

A As we face major global challenges of climate change, population growth, threats to food and water security, human and animal diseases, and terrorism, there has never been a time when there has been a greater need for science and engineering to contribute to good policy-making and sound Government.

I think the answer is yes, we have got better and better at using evidence in policy-making. Indeed, we now have one of the most mature systems for providing scientific advice anywhere in the world. We now have Chief Scientific Advisers in every department who work collectively with other analytical disciplines and with departmental boards and Ministers, to ensure that science and engineering are at the core of decisions within departments and across Government.

Interestingly, the Science Minister David Willetts has said that the Coalition Government has been a good thing for evidence-based policy because with different political parties represented at ministerial meetings you can't for instance rely on tribal loyalties to get things through.

Stockphoto

Undergraduate members in Dublin

Seven UG members received grants from SGM to attend and present work at the SGM Spring 2012 Conference in Dublin. Three – **AMBER RIAZ-BRADLEY**, **EDWARD FARRIES** and **ELEANOR McMAHON** – had received a Vacation Studentship from the Society in 2011 and were presenting the findings of their projects. Also being presented were results from an Honours project and work undertaken during students' placement year.

Samuel Beckett Bridge, Dublin. *I. Atherton*

I. Atherton

NETWORKING WORKSHOP AND SUPPER FOR EARLY-CAREER DELEGATES IN DUBLIN

Conferences are all about communicating with other scientists – either formally when you present your research as a poster or a talk, or informally when you chat with other delegates during refreshment breaks. A conference also offers networking opportunities which can lead to fresh ideas, a new collaboration or maybe even your next job (see Gradline on p. 120).

SGM ran a networking workshop and supper on the Sunday evening before the start of the conference for PhD students, postdoctoral researchers and other interested early-career delegates wanting tips and advice on how to make the most of the communication opportunities available at the SGM conference. The evening was led by **KAREN MCGREGOR**, from the SGM Office, and the 52 attendees threw themselves into practising the networking skills they had learned during the activities, which included networking bingo.

Amber Riaz-Bradley. *K. McGregor, SGM*

AMBER RIAZ-BRADLEY

3rd-year MSc Biochemistry and Genetics student at the University of Nottingham

'The conference was a fantastic experience. I enjoyed the range of talks and material on offer and it was great to see the latest research showcased. I found the experience of presenting a poster less nerve-wracking than I expected. It was really fun conversing with others about the work I had done and I was given many helpful suggestions regarding further experiments. After I graduate I would like to study for a PhD and have a career in research so I hope that this conference was the first of many.'

HELEN COPE

1st-year PhD, attending first SGM Conference

'The skills we were taught in the networking event made me feel more confident in approaching other researchers. Being at a conference and having the opportunity to talk face-to-face with others researching in your area really improves your relationship with them and it shortcuts communications greatly compared to trying to build up a relationship via email. I also met lots of other postgraduate students at the networking event. This event and the conference as a whole has made me feel part of a network of UK postgrad microbiologists.'

I. Atherton

ANGELIQUE DUDMAN

Final-year PhD, presenting a poster at her first SGM Conference

'The networking event was a great way to get to know lots of people … a particular help if you had come to the conference on your own. I saw many of the people from this event during the conference and we had good discussions about our research and our poster presentations.'

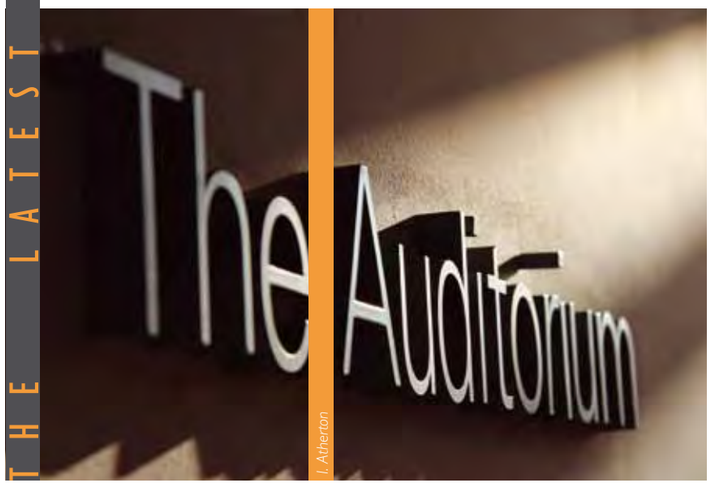
EDWARD FARRIES

Final-year BSc Molecular Biology student at Exeter University

'I was nervous about presenting my poster as I didn't know who would come up and what questions they might ask, but at the same time I really enjoyed being able to show my personal work in such a setting. Attending the conference and experiencing that side of the life of a research scientist has really inspired me to do a PhD where I hope to be able to continue to work with Clostridium difficile.'

Edward Farries. *K. McGregor, SGM*

Eleanor McMahon, University College London. *I. Atherton*



I. Atherton

Dublin on video

The SGM 'film crew' (**RICHARD SCRASE**, **IAN ATHERTON** and **LAURA UDAKIS**) were kept busy during the SGM Spring Conference in Dublin this year. As well as filming TWiV (see p. 78), they recorded all the Prize Lectures, and a series of interviews with journal Editors-in-Chief and students for future short films.

The first 'release', featuring **RICHARD ELLIOTT** (JGV Editor-in-Chief, University of St Andrews) delivering his Hot Topic Lecture on Schmallenberg virus (see p. 125) is now available at **www.youtube.com/user/SocGenMicrobiology**

More videos from the conference will become available on our video portal and on *YouTube* in due course – watch this space!

Supporting the professional development of SGM members

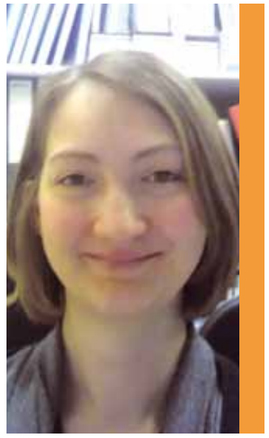
VACATION STUDENTSHIPS 2012

A record 115 applications were received to this grant scheme that aims to offer supervised research experience in microbiology to undergraduates in the summer vacation before their final year. Following review of the applications (with thanks to the panel of referees for their efforts), 52 awards were made for 2012.

Vacation Studentships provide support to a student at a rate of £185 per week for a period of up to 8 weeks, plus up to £400 for laboratory consumables. The student also receives free Undergraduate Membership of the Society for a year.

The purpose of these awards is primarily to benefit the student candidate, but there are many benefits for the supervisor as well. For postdoctoral researchers, supervising a summer project student can form an important part of their strategy towards becoming an independent researcher. Student projects can be an opportunity for candidates to try out a new idea or develop their own research interests. This year approximately 12% of applications came from early-career members (postdoc researchers and new lecturers). SGM is keen to encourage applications from this category of member.

Two postdoctoral researchers, **HELENA MAIER** and **DAVID ROOKS**, who received vacation studentships for 2012, told *Microbiology Today* about the impact of this award on their professional development.



PROFILE – Helena Maier

Education and employment history

BSc Hons Virology, University of Warwick, 2004
DPhil, University of Oxford, 2007
Postdoctoral Researcher, Institute for Animal Health, since 2008

'My motivation for applying for Vacation Studentship funding was borne out of my own experience as an SGM Vacation Studentship candidate when I was an undergraduate. It gave me valuable skills and confidence and confirmed for me that I would like to pursue a career in laboratory research. I am now keen to provide that same opportunity to undergraduate students.

This is my third time supervising a summer project student (and the second funded by an SGM Vacation Studentship). I find it very rewarding to see students develop during the 8-week period and I get to gain valuable teaching experience.

The project that will be worked on by the student this summer will provide preliminary data that I hope will allow me to write a new research proposal.'

PROFILE – David Rooks

Education and employment history

BSc Hons Applied Microbiology with industrial placement year, University of Liverpool, 2006
PhD, University of Liverpool, 2010
Postdoctoral Research Associate, University of Liverpool, since 2010

'There are limited opportunities for junior postdoctoral scientists who are aiming to establish a career as a lead researcher to bid for independent funding, so the SGM Vacation Studentship scheme is ideal at this stage of my career. It allows me to gain experience in writing grants and applying for competitive funding. Additionally, the summer project will provide experience of supervising a student full-time in the laboratory.

I also applied for an SGM Vacation Sstudentship last year. Although this was unsuccessful, the process demonstrated to me the importance of designing concise and structured projects that are achievable in the time available and also engage and challenge the student.'

TWiV@SGM

W B Yeats @WBYpoet
#education is not the filling of a pail, but the lighting of a fire – #sgmdub
Retweeted by @10queues

Someone from my lab laughed and shot a look of disbelief, tinged with pity when, just before the *Viral zoonosis* symposium was about to begin at this year's SGM annual meeting, I asked the simple question, '*what's a hashtag?*' To him this seemed tantamount to asking, '*is Dublin where Guinness comes from?*' or, '*what's the point in vaccinating my kid?*' Therefore if you, like me at the time I asked that question, need a translation of the above, then read on!

One of the key functions of the Virus Division is organizing two symposia at the Spring Meeting with the aim of ensuring the virological community is kept up to date with state-of-the-art science. Education and training are vital elements which underpin the thinking of the committee and our working model is to arrange one fundamental and one applied symposium to ensure we engage with as many virologists as possible. It is somewhat of a top–down approach where we bat ideas around, come up with a title and goal, and invite some of the best speakers in the world to the meeting. It works well; last year's fundamental symposium, *Seeing the cell through the 'eyes' of the virus*, was rated as a great success in the Survey Monkey questionnaire circulated by SGM.

As scientists we are experimental and this year our division decided to try something just a little bit different in the applied *Viral zoonoses* symposium. Partnering with our colleagues in the Education Division, we nominated Vincent Racaniello (Columbia University, New York) for the Peter Wildy Prize in Education, which he won. Vincent, or @*profvrr* as he's known on *Twitter*, has led the way in effectively communicating science in general and microbiology in particular, to the public using social media outlets, blogs and netcasts. Internationally, he has blazed a trail into eLearning and is someone who argues that it is vital to make the science we do relevant, exciting, accessible and meaningful to a wide audience. His enthusiasm for teaching inspired him to reach beyond the classroom and establish the virology blog (www.virology.ws) which explains concepts in virology to scientifically and non-scientifically trained people in a creative and innovative manner. The blog has spawned a conversational netcast entitled *This Week in Virology* (TWiV). Each week Racaniello and friends invite virologists to discuss current news, scientific papers and answer listeners' questions which are emailed or tweeted to #TWiV. The show is downloaded about 50,000 times each month and is becoming a staple for PhD students and professors alike. However, in his Wildy Lecture

Vicnet Racaniello receives the Peter Wildy Prize from Joanna Verran, SGM Education Officer at the SGM Spring Conference in Dublin. *I. Atherton*

(video soon to be available at www.youtube.com/user/SocGenMicrobiology) Vincent shared how this netcast has reached well beyond academic virologists. Having Vincent at the SGM and streaming the first live TWiV from Europe was, to use the US word, a no-brainer! This was a phenomenal success and if you didn't catch it live or were not at the Dublin meeting, check out TWiV 177 (www.twiv.tv). From my perspective this was education and training in the truest sense being neither exclusive nor simply the didactic filling of a pail. Rather it represents the fire of the spoken word, conversational virology, which spreads so readily in the virtual world or, for want of a better analogy, goes viral.

The beauty of a TWiV netcast is that it is far from only the preserve of those fortunate enough to be involved in science professionally. Rather, it engages a wider audience and helps to explain that what is achieved at the virological bench impacts society as a whole. This, in turn enhances engagement in, and appreciation of, our science by the individuals whose taxes fund the work we do. From the Society's perspective it also gave the communications teams in the American Society for Microbiology, who jointly supported the TWiV, and the SGM a great opportunity to work together and learn from each other, something we plan to build on in the future.

Recognizing the power of social medial and wanting to involve the wider community in a 'bottom-up' symposium the Virus Division decided to organize *10 Questions in Virology*. Armed with a new *Twitter* account (@10queues) and the sgmdub hashtag (#sgmdub) we asked our community to submit their burning virological questions to us. With this instantaneous connection to anyone following @SocGenMicro and #sgmdub, the fire was lit and questions (qs) came in. Bloggers @AJCann and @cggbamford took up the baton and have spread the idea to a much broader audience. It will be an interesting experiment and we encourage you all to get involved.

So '*what's next?*' asked @Dariel_Burdass. Is this just for the virologists? Of course not! Colleagues from the Eukaryotic and Prokaryotic Divisions might consider getting in touch with @10queues; after all #TWiP and #TWiM are alive and well too!

For posterity here's how it began and how I discovered the value of a #tag!

Paul Duprex @10queues
#sgmdub want to help shape a virus symposium? Tweet your top virology qs to me!

PAUL DUPREX is Chair of the Virology Division (email pduprex@bu.edu)

STAFF

Once again, we have said a sad goodbye to two long-serving and highly respected members of staff – **CHRIS SINCLAIR**, who retired in March, and **ROBIN DUNFORD** who has moved on to start up his own consultancy business.

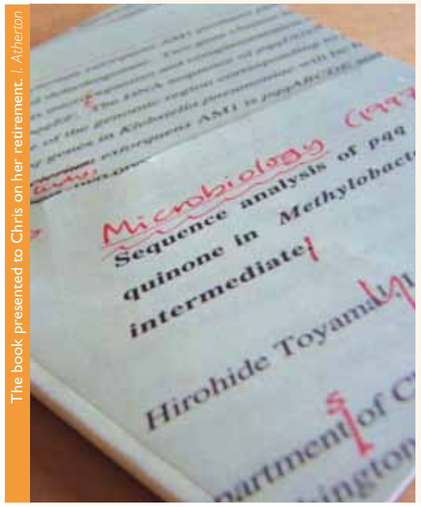
CHRIS SINCLAIR

Chris (known to all as CS) worked at SGM for 32 years, first as a copy-editor on *Journal of General Microbiology* (JGM) and later as manager of that journal – a post which she held for over 22 years, overseeing many significant changes in journal publishing, such as the change from red pen to on-screen editing and the move to online submission; not forgetting managing the re-launch of JGM as *Microbiology*. Chris has seen 7 Editors-in-Chief come and go over the years, and has worked with dozens of Editors, in-house staff and countless Associate Editors.

Chris' ability to train editorial staff was exemplary, and most of the journal team today, as well as many others who have moved on, are indebted directly or indirectly to Chris's teaching. She was always a very sincere and thoughtful member of the SGM team, and her honest views, often expressed with passion during the countless meetings she attended and chaired, were always greatly valued.

With Chris' retirement, Marlborough House loses some of its colour and some of its character. Everyone who has been privileged enough to work with Chris will always look back on those days with great fondness, and will have many great memories and stories to tell. The journals, indeed the whole Society, owe her a great debt of gratitude for all she achieved.

On 23 March, the staff organized a farewell buffet lunch at which she was presented with a number of gifts and cards. Contributions from many of the Editors and Editors-in-Chief that Chris has worked with were put toward the production of a book containing messages from past and present Editors and Staff and photographs illustrating Chris' time at SGM.



The book presented to Chris on her retirement. *I. Atherton*

ROBIN DUNFORD

Robin has left his position as Head of Journal Publishing at SGM to found Dunford Consulting Ltd, with the aim of providing technology and workflow consulting to scholarly publishers. Among his first clients are Inera, Inc., the company behind the eXtyles software that is used by SGM during production of its journals. Robin will be providing training and services to eXtyles users, particularly in the UK and Europe; this is likely to include SGM. Robin will also be undertaking various technical projects for SGM, and keeping his copy-editing hand in by doing some freelance work for the Society journals.

Robin joined SGM in 1998, initially as a Staff Editor on JGV, having previously undertaken postdoctoral research in the botany departments of Queen's University in Kingston, Ontario, and Oxford University. Following a move to become Deputy Managing Editor of IJSEM and JMM in 2001, Robin took over as Managing Editor of the two journals in 2003. In 2004, following a reorganization of the Editorial Offices of the Society's journals, Robin became Journals Manager (lately 'rebranded' as Head of Journals Publishing), with overall responsibility for the four SGM journals. The last


Robin Dunford. *I. Atherton*

8 years have seen a number of technological developments for the SGM journals, including a new manuscript submission system, adoption of the eXtyles software, the move to an XML workflow, the digitization of the entire back content of the SGM journals, the launch of publish ahead of print and the move of the online journals to the new HighWire 2.0 platform.

Staff gathered in the newly refurbished 'Staph Room' at Marlborough House on Robin's last day and presented him with a hamper of gifts from the Somerset Cider Company, and some staff also met for a farewell dinner during the recent SGM Spring Conference in Dublin.

Robin will be much missed by the staff, not least when we need to form a quiz team, but we wish Robin every success in his new venture.

In addition, we temporarily say cheerio to **VICTORIA HURR** as she starts her maternity leave, and we send Victoria and her husband Brandon all our very best wishes.

ABIGAIL LAYTON has been appointed as a Staff Editor on IJSEM to cover Victoria's maternity leave for 1-year. Abigail previously worked as a senior post-doctoral research scientist on bacterial virulence at the Institute for Animal Health, and is joining SGM following a short break with her young children.


Abigail Layton. *I. Atherton*

ROISIN McCORKELL has also joined us as a Staff Editor. She attended the University of Leeds where she studied Medical Microbiology, has worked in several laboratories within Europe and also has experience in copy-editing.


Roisin McCorkell. *I. Atherton*

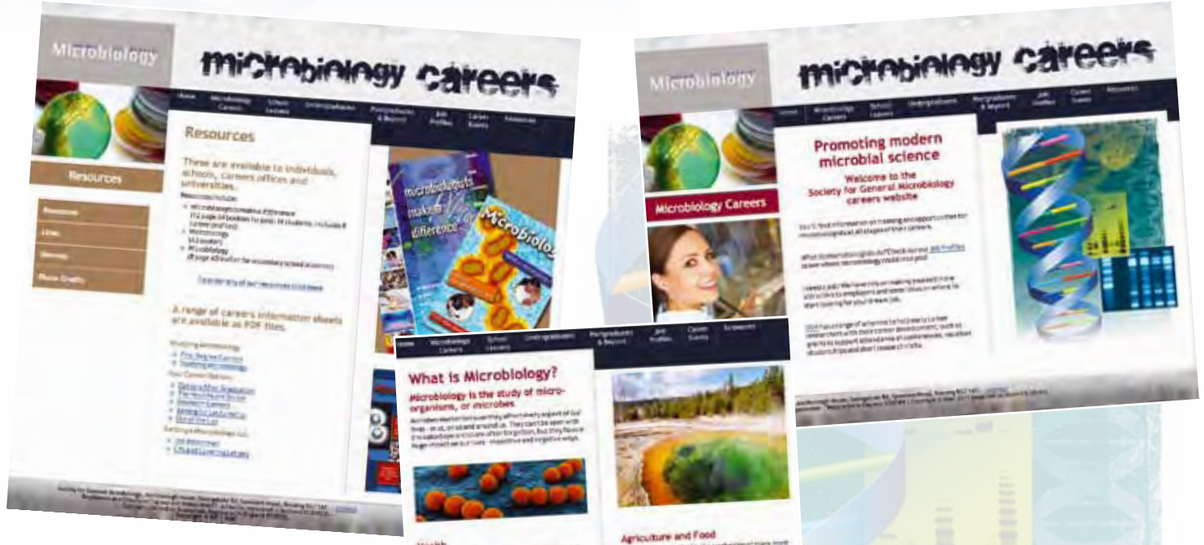
News of Members

The Society offers its congratulations to the following Members who have won 2012 ASM Achievement Awards. **MICAH KRICHEVSKY** (Chairman, Bionomics International) has been honoured with the prestigious 2012 Roche Diagnostics Alice C. Evans Award. This award, established by ASM's Committee on the Status of Women in Microbiology, recognizes contributions towards the full participation and advancement of women in microbiology. **PROF. GEOFFREY SMITH** (Wellcome Trust Principal Research Fellow and Head, Department of Pathology, University of Cambridge) has been awarded the 2012 GlaxoSmithKline International Member of the Year Award, recognizing exemplary leadership in the international microbiological community.

DR STEVE DIGGLE, a Royal Society Research Fellow at The University of Nottingham, has been awarded a £300,000 Young Investigator grant from the Human Frontier Science Program (HFSP) to fund collaborative research into cell assembly with the Universities of Edinburgh, Copenhagen and Austin.

PROF. GORDON DOUGAN, Principal Research Scientist, Head of Pathogens, Wellcome Trust Sanger Institute, has been elected Fellow of the Royal Society.

Other microbiologists elected FRS include Professor Gabriel Waksman and Professor Bonnie L. Bassler.



PRIZE LECTURES

A range of prestigious awards is made by the Society in recognition of distinguished contributions to microbiology. Nominations are now sought for the 2013 prize lectures. The award panel will consider the submissions in the autumn and take their recommendations to November Council for approval. The outcome will be announced in the February 2013 issue of *Microbiology Today*. Prize lecture rules and a nomination form are on the SGM website: www.sgm.ac.uk/about/prize_lectures.cfm

FLEMING PRIZE LECTURE – This is awarded annually for outstanding research in any branch of microbiology by a young microbiologist in the early stages of his/her career.

FRED GRIFFITH REVIEW LECTURE – This is awarded biennially in recognition of long and distinguished service to microbiology.

COLWORTH PRIZE LECTURE – This is awarded biennially for an outstanding contribution in an area of applied microbiology. It is sponsored by the Colworth Laboratory of Unilever Research.

PETER WILDY PRIZE FOR MICROBIOLOGY EDUCATION – This is awarded annually for an outstanding contribution to any area of microbiology education.

The winners of the above prizes will each receive £1,000 and will give a lecture at a Society conference in 2013. The lectures are usually published in a Society journal.

Completed nomination forms, together with the supporting documents, should be sent to Jane Westwell (j.westwell@sgm.ac.uk). The closing date for all nominations is **28 September 2012**.

Bill Hanage delivering the Fleming Lecture in Dublin, March 2012. *Ir. Atherton*

PRIZES

Undergraduate Microbiology Prizes

The prizes aim to encourage excellence in the study of microbiology by undergraduate students and to promote scholarship in, and awareness of, microbiology in universities. The prizes are awarded annually to the undergraduate student in each qualifying institution who performs best in microbiology in their second year of full-time study (or part-time equivalent) for a Bachelor's degree. Each winning student will be awarded £150, a certificate and a free year's undergraduate membership of the SGM.

One prize is available to each university in the UK and Republic of Ireland offering a degree course with a significant microbiology content. The university chooses the assessed microbiological work for which the prize is awarded. The submission should be supported by formal marks, not an informal assessment. Winning students should have attained at least a 2(I) overall in their degree examinations at the stage at which the award is made.

Universities are now invited to nominate a student for a 2012 SGM Undergraduate Microbiology Prize. Submissions can only be accepted on the form which has been sent to all institutions. The full rules and further copies of the form may be downloaded from the SGM website or obtained from the Grants Office at Marlborough House. The closing date for nominations is **24 August 2012**.

A 2011 recipient of the Prize, **BEN JEVANS**, now a third-year BSc Biomedicine student at University of East Anglia, is shown (*left*) receiving his certificate from Head of School, Professor Dylan Edwards (*right*).

GRANTS
MAKE THE MOST OF YOUR MEMBERSHIP

SGM has a wide range of grant schemes to support microbiology. See www.sgm.ac.uk for details. Enquiries should be made to: **SGM Grants Office** (**email** grants@sgm.ac.uk), **Marlborough House, Basingstoke Road, Spencers Wood, Reading RG7 1AG** (**tel.** 0118 988 1807; **fax** 0118 988 5656).

SGM CONFERENCE GRANTS

SGM conferences are the ideal place to develop research ideas, communicate results, catch up on other people's research findings and network with fellow microbiologists. We offer several grant schemes to support attendance at our conferences. The 2012 closing dates are:

- Autumn Conference (Warwick) – **31 August**
- Irish Division (Cork) – **9 November**

POSTGRADUATE STUDENT CONFERENCE GRANTS

All PG Student Associate Members, resident and registered for a PhD in an EU country, are eligible to apply for a grant to support their attendance at one SGM conference each year. Grants contribute towards travel, registration and accommodation expenses. The student need not be presenting their research, so it is an ideal introduction to scientific meetings at little or no cost to themselves or their supervisor's budget.

TECHNICIAN CONFERENCE GRANTS

All Associate Members who are technicians are eligible to apply for a grant to support their attendance at one SGM conference each year. Applicants need not be presenting work at the conference. Some microbiology technicians who are not members of SGM may also apply for a grant to attend a Society conference.

UNDERGRADUATE STUDENT CONFERENCE GRANTS

UG Student Members who have results to present from either their final year or vacation project can apply for funding to attend one SGM conference per year. The grant contributes towards travel and accommodation costs (registration is free), and applicants must have their abstract accepted for presentation. Students need not be the first author, but should be present at the poster session to talk about their work.

RETIRED MEMBER GRANTS

These cover accommodation and the Society Dinner at one SGM conference per year.

TRAVEL & MEETINGS

PRESIDENT'S FUND FOR RESEARCH VISIT GRANTS

Many researchers reach a point where they would benefit from a visit to another lab to learn a new technique or gain access to specialist equipment and knowledge. SGM recognizes this need and offers grants of up to £3,000 to support early-career microbiologists who are planning a short research visit to another laboratory (minimum visit 4 weeks, maximum visit 3 months). Closing date: **21 September 2012**.

SCIENTIFIC MEETINGS TRAVEL GRANTS

Support for early-career microbiologists wishing to present work at scientific and education meetings in the UK or overseas. Graduate research assistants, lecturers and teaching fellows (within 3 years of first appointment) in the UK and Ireland, and postdoctoral researchers (within 3 years of first appointment) and postgraduate students in the EU are eligible to apply. Retrospective applications are not considered.

SHORT REGIONAL MEETING GRANTS

Contribution of up to £2,000 towards the costs of running a regional or specific topic microbiology meeting.

EDUCATION & DEVELOPMENT

NATIONAL

PRACTICAL TEACHING AIDS

Small grants to members for developments likely to lead to an improvement in the teaching of any aspect of microbiology relevant to secondary or tertiary education in the UK.

PUBLIC ENGAGEMENT WITH MICROBIOLOGY AWARDS

Up to £1,000 to support projects that promote public engagement with microbiology.

GRADSCHOOL GRANTS

PG Student Associate Members who are not eligible for a free place on a Vitae (www.vitae.ac.uk) personal development course (National GRADSchool) can apply for a grant from SGM to cover full course fees. Retrospective applications are not considered.

SEMINAR SPEAKERS FUND

Small grants to cover the travel and other expenses of up to two speakers on microbiological topics in annual departmental seminar programmes.

STUDENT SOCIETY SPONSERED LECTURES

Small grants to cover the travel and other expenses of up to two speakers on microbiological topics at student society meetings.

INTERNATIONAL

INTERNATIONAL DEVELOPMENT FUND

Supports members to provide training courses, publications and other help to microbiologists in countries with economies defined by the World Bank as low-income or lower-middle-income. Closing date: **21 September 2012**.

THE WATANABE BOOK FUND

Members who are permanently resident in a country with an economy defined by the World Bank as low-income or lower-middle-income may apply for funding to acquire books for their libraries. The annual awards are available as a result of a generous donation from Professor T. Watanabe of Japan. Closing date: **21 September 2012**.

MEDICAL MICROBIOLOGY SUPPORT GRANTS

ELECTIVE GRANTS

Funding for medical/dental/veterinary students to work on lab-based microbiology projects in their elective periods. Closing date: **21 September 2012**.

TRAINEE SUPPORT GRANTS

Funding for SGM members carrying out small lab-based microbiology projects during either foundation or specialty postgraduate medical training. Up to £3,000 is available towards the consumables costs of a project. Closing date: **21 September 2012**.

Microbiology and … stamps?

Several UK postage stamps have relevance to microbiology, but the latest connection is subtle.

Two stamps, issued by the Post Office on 2 February 2012, are copies of portraits of Edward VII and George V painted by Sir Luke Fildes whose most famous painting, *The Doctor* (1891) is in the Tate Gallery. The painting shows a doctor sitting beside a sick child, with the parents in the background. Fildes was inspired by the dedication of the doctor that attended his dying eldest child. His second child, Paul (1882–1971), qualified as a doctor in 1909, had an important career in microbiology, and became FRS in 1934. He studied fundamental phenomena of microbial growth and influenced many: the second SGM President Marjory Stephenson, whose book *Bacterial Metabolism* (1930, 1939, 1949) was of outstanding importance; B.C.J.G. Knight, founder of the first Microbiology Department in the UK and Editor of the *Journal of General Microbiology* from its launch in 1947 until 1970; and D.D. Woods, discoverer of the mode of action of sulphonamides.

A charming obituary of Sir Paul Fildes was published by G.P. Gladstone in *Journal of General Microbiology* **70**, 1–11.

BOB PARK is a retired Senior Lecturer from the University of Reading

Get LinkedIn with SGM journals

Each of SGM's journals now has group on *LinkedIn*.

Editors, reviewers, authors and readers – join for journal news, updates and discussions.

Seaweed. *iStockphoto / Thinkstock*

Making biofuels from seaweed

Engineered micro-organisms have been used to produce bioethanol from seaweed with much higher yields than previously reported. The key to improving seaweed-to-ethanol conversion efficiency was finding a way to ferment all major seaweed sugars simultaneously. Previously, one of these sugars – alginate – had not been utilized since it could not be broken down by industrial microbes. Now, researchers from the Bio Architecture Lab in California have successfully engineered *Escherichia coli* – using DNA from the marine bacterium *Vibrio splendidus* – to degrade and ferment alginate along with other sugar constituents. Testing fermentation performance on a common brown seaweed, researchers reported that the engineered *E. coli* produced 80% maximum theoretical yield of ethanol. Although scale-up viability of the technology is not yet proven, seaweed is an attractive biofuel feedstock proposition, since the industry is already established and seaweed does not compete with staple food crops for land or fertilizer.

***Science* doi:10.1126/science.1214547**

Helen Cope, University of Edinburgh

Life at the extreme

Microbes have been found to live at temperatures as low as –33°C in experiments designed to simulate conditions found at the bottom of Arctic and Antarctic glaciers. Researchers at Pennsylvania State University and Montana State University have identified signs of respiration in ice in the bacteria *Chryseobacterium* and *Paenisporosarcina* – both of which need carbon to respire. Many bacterial species use sugars as a primary carbon source; however, *Chryseobacterium* and *Paenisporosarcina* get their carbon from acetate, a form of vinegar. Respiration was reported between –33 and –4°C, and the respiration rate of the bacteria increased as the temperature rose. Cell structure and viability was maintained throughout this temperature range. Glaciers and ice sheets represent large ecosystems that cover more than 10% of the Earth and contain around 78% of the planet's fresh water. If bacteria can grow at such extremely low temperatures on Earth, it suggests life could potentially exist in similarly cold areas on other planets.

Perito Moreno Glacier. *Hemera / Thinkstock*

***Environmental Microbiology Reports* doi:10.1111/j.1758-2229.2011.00298.x**

John Kendall, University of Sheffield

Late Spider Orchid (*Ophrys fuciflora*), an extremely rare and endangered species in the UK. *Paul Harcourt Davies / Science Photo Library*

Key to orchid success lies beneath ground

Locations with abundant soil fungi enhance the success of rare and endangered orchids, according to new research. The Smithsonian Environmental Research Center analysed three protected orchid species and found that factors limiting orchid success were those that limited the abundance of plant-associated mychorrhizal fungi, such as forest successional stage and soil organic matter. Older forests supported a wider and more abundant range of fungi, which increased orchid germination and growth. It has long been known that orchids are dependent on mycorrhizal fungi to survive: without this partnership a baby orchid can't access the nutrients it needs to germinate and grow. This research suggests that understanding the limiting factors to fungal growth may be the key to conserving rare orchids. This will mean conserving mature forests rather than planting new ones.

***Molecular Ecology* doi:10.1111/j.1365-294X.2012.05468.x**

Rachel Roberts, University of Reading

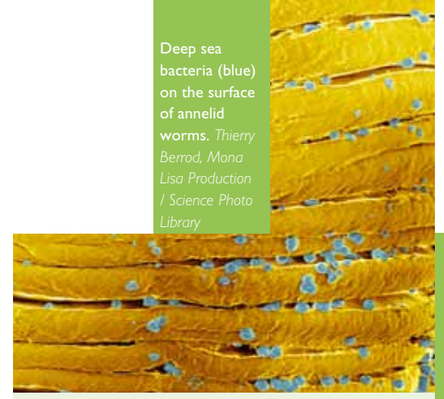
SGM MEMBERS HIGHLIGHT SOME RECENT MICROBIOLOGY STORIES

Staying alive: rapid adaptation to new environments

Scientists have revealed how some bacteria are able to quickly adapt and thrive in new environments. During early lag phase, *Salmonella enterica* serovar Typhimurium has been shown to switch on a specific set of genes allowing uptake of precise nutrients in a new environment. These nutrients include phosphate and iron, which are required for cellular metabolism and growth, as well as manganese and calcium. Uptake is spurred by 522 genes which are transcribed within 4 minutes of leaving stationary phase. The study, carried out by researchers at the Institute of Food Research, provides a rare insight into the activity of bacteria during lag phase – the poorly understood time period preceding exponential growth. It has been hypothesized that lag phase allows for the repair of damaged cells and the manufacture of cellular components required for growth. This study shows the physiological processes that occur during lag phase and illustrates how rapidly *Salmonella* can sense favourable conditions and switch on the genes necessary to acquire minerals and nutrients for growth. The research could ultimately lead to new ways of preventing transmission of *Salmonella* in the food chain.

***Journal of Bacteriology* doi:10.1128/JB.06112-11**

Alan Marsh, Teagasc Food Research Centre



Deep sea bacteria (blue) on the surface of annelid worms. *Thierry Berrod, Mona Lisa Production / Science Photo Library*

Metagenomics to find needles in the haystack

A way of extracting genomic information from unculturable microbes of low abundance in marine environments has been established by researchers at the University of Washington. Their method separates sequences from complex environmental samples containing many different organisms – a so-called 'metagenomic' sample. Genome reconstruction is done by putting together short individual sequences. The team discovered the genome of an organism belonging to the *Euryarchaeota* with a metabolism focused on protein and lipid degradation. It is abundant during the summer months and has eluded scientists since its discovery a decade ago. The genome sequence made up just 1.7% of the total sample. Importantly, the study also clarified the ancestral origin of proteorhodopsin – a light-driven bacterial proton pump allowing many marine bacteria to produce energy from light, without photosynthesis. This method provides important information that contributes to the general understanding of marine ecosystems, where accessing unculturable organisms is a particular problem. The approach could also help predict the behaviour of ecosystems due to human or climatic influences.

***Science* doi:10.1126/science.1212665**

Jana Hiltner, University of Strathclyde

Fruiting bodies of the fungus *Penicillium roqueforti*. *Power and Syred / Science Photo Library*

Penicillium roqueforti – a smart cleaner

Penicillium roqueforti has been used to create the first living self-cleaning material. Scientists at the Institute for Chemical and Bioengineering, Switzerland, have designed a smart material capable of metabolizing standardized food spills, which can also withstand harsh handling and stress conditions. The living material is composed of three functional layers: a base layer (polyvinyl chloride) for support, an agar-based living layer for growth and maintenance of the fungus, and a porous membrane layer to protect the material from environmental influences. Following a food spill, nutrients are consumed through the porous top layer by *P. roqueforti* in the living layer, resulting in a dense two-dimensional hyphae network. Furthermore, the fungus shows not only an ability to consume the nutrients in its active state, but can also exist in its dormant state and reactivate when a nutrient source comes into contact with the surface of the material. Only severe dryness and the amount of food provided seems to affect the material's metabolizing capability. Researchers believe such materials are capable of evolutionary adaptation and could pave the way for novel design opportunities in material sciences.

***PNAS* doi:10.1073/pnas.1115381109**

Sruthi Raghavan, British Medical Ultrasound Society

FUTURE IRISH DIVISION EVENTS

Spring 2013
Manchester Central, Manchester
25–28 March 2013

University College Cork
14–16 November 2012
Marine microbiology and biotechnology: biodiscovery, biodiversity and bioremediation
www.ucc.ie/en/mmbiotech2012
Organizer: Niall O'Leary
(n.oleary@ucc.ie)

University College Dublin
21–23 March 2013
Gene regulation and microbial pathogenicity
Organizer: Tadhg Ó'Croínín
(tadhg.ocroinin@ucd.ie)

OTHER EVENTS

SGM is supporting the following meetings:

30th Anniversary Tenovus Symposium: Molecular Mechanisms of Disease
University of Glasgow
7 June 2012
www.tenovussymposium.org.uk

Young Microbiologists Symposium on Microbe Signalling, Organization and Pathogenesis
University College Cork, Ireland
21–22 June 2012

How Bugs Kill Bugs: Progress and Challenges in Bacteriocin Research
University of Nottingham
16–18 July 2012
www.biochemistry.org/MeetingNo/SA140/view/Conference

European Microscopy Congress
Manchester Central Conference Centre
16–21 September 2012
www.rms.org.uk/events/EMC2012

The Molecular & Cellular Biology of Human Papillomaviruses (HPV UK)
Rydall Hall, Ambleside, Cumbria
9–11 November 2012

WWW.SGM.AC.UK/MEETINGS — DELIVERING MODERN MICROBIAL SCIENCE

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AUTUMN 2012

UNIVERSITY OF WARWICK
3–5 SEPTEMBER 2012

www.sgmwarwick2012.org.uk

If you have a device that can read QR codes, access the conference website here.

Symposia

Dynamic genome | Next generation sequencing – enabling new technology | Concept of the species | Designer microbes | Molecular motors | *Streptococcus* in health & disease | Developing winning ways and competitive success

Also featuring

Sir Howard Dalton Young Microbiologist of the Year Competition final | Outreach Prize lecture | Grant-writing workshop | CV clinic | Annual General Meeting

Call for Abstracts

Take the opportunity to share your latest research findings by submitting an abstract.

Deadline for submissions: **Monday 18 June 2012**.

CPD

Points available for members of the Royal College of Pathologists, Institute of Biomedical Science and Society of Biology.

Grants

Conference grants are available to eligible SGM Associate Members who are postgraduate students, technicians or retired and to Undergraduate Members who are presenting work at the conference.

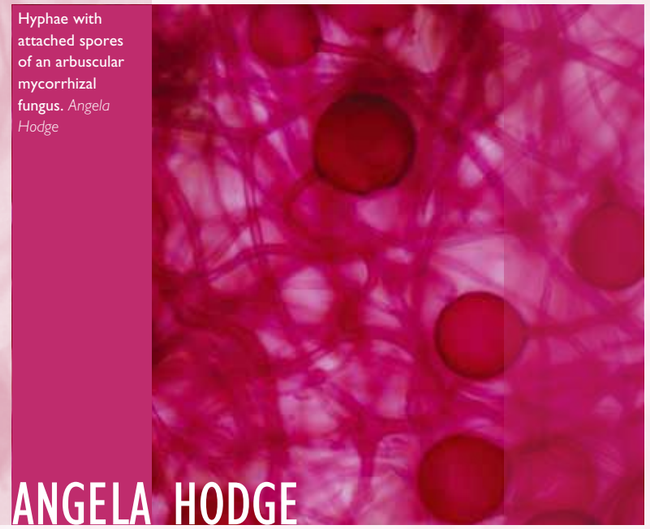
Registration

Register online at **www.sgmwarwick2012.org.uk** or complete (and return) the downloadable PDF. Earlybird registration rate deadline: **Friday 3 August 2012**. Registration fees include refreshments, lunch, drinks receptions, the abstracts book, exhibition entry and all conference literature. Specially discounted rates are available for SGM Associate/Postgraduate Student Associate Members.

Feed the world?

Hyphae (fine thread-like structures) with attached spores (circular structures) of an arbuscular mycorrhizal fungus. *Angela Hodge*

Arbuscular mycorrhiza and agriculture



Hyphae with attached spores of an arbuscular mycorrhizal fungus. *Angela Hodge*

ANGELA HODGE

As the world's population continues to increase, and as the production of fertilizer becomes evermore unsustainable, is it time to consider another agricultural revolution – the 'microbial revolution'?

IN 30–50 YEARS TIME, 9–10 billion people will live on the planet and one of the main issues will be how to feed them. Historically, key developments in agricultural practices have enabled population growth to be sustained, achieved mainly through increasing the amount of land given over to food production and through agricultural intensification. For example, in Europe, the 'agricultural revolution' of 1750–1880 was achieved largely by selective breeding for desired traits, crop rotation, enclosures and mechanization. In the 1940s, another global crisis in agricultural production loomed, giving rise to the 'green revolution' where new high-yield cultivars were developed that showed a good response to fertilizer application, more uniform productivity and matured earlier. The green revolution helped countries such as Mexico transform from being a net importer of wheat to a net exporter. However, the widespread use of fertilizer is unsustainable for a number of reasons; these include high energy costs associated with fertilizer production, availability of rock phosphate and environmental problems such as contamination of water courses and increased greenhouse gas emissions.

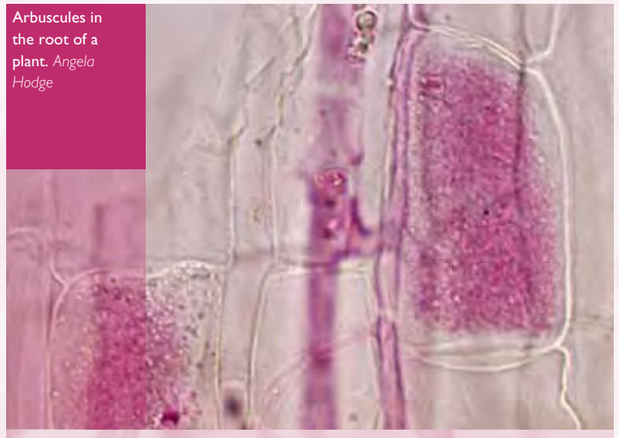
Furthermore, both soil and water resources have become depleted in many areas as a direct result of current agricultural practices. History also points to the consequences of failing to manage our soils correctly, the classic example being the 1930s 'dust bowl' events in the mid-west USA; one of the worst environmental disasters of the 20th century. Thus, we need to exploit natural resources and nutrient cycling processes more effectively. In short, another revolution is required and this time soil micro-organisms may be part of the answer. What then are the likely candidates for such a 'microbial revolution'? Addition of micro-organisms to soil can be risky. A point illustrated by the unintentional introduction of *Phytophthora cinnamomi* to Australia which had a devastating impact upon native forest tree species. Yet, there is an obvious candidate, one that has been around for many millions of years and which the majority of plants in the natural environment still form an association with today – the mycorrhizal fungi.

ANCIENT – BUT STILL RELEVANT

Mycorrhizal (from the Greek, meaning 'fungus root') associations occur between certain soil fungi and the roots of most plants. Although there are several different types depending on the fungus and plant species involved, the most common and ancient type is that of the arbuscular mycorrhizal (AM) association. This association goes back a remarkable 400 million years and probably enabled the early land plants to colonize the terrestrial environment. These early plants had no real root systems that we would

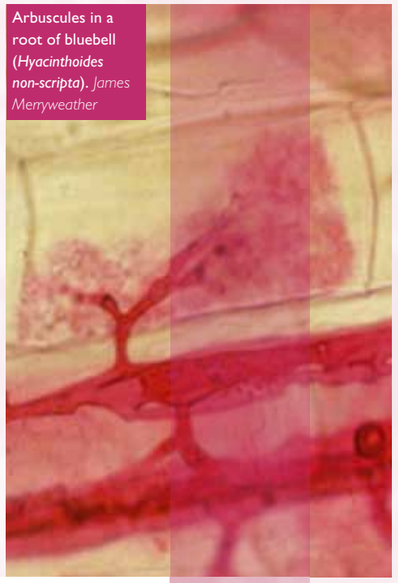
recognize today but rather they had underground stems. This presented a problem when they moved to land because acquiring phosphate became a key issue. Unlike the aquatic environment where all nutrient ions diffuse at a similar rate, phosphate forms insoluble complexes with other ions such as aluminium, iron and calcium in soils. Thus, acquiring sufficient phosphate was a challenge – and remains so today, which is presumably why the symbiosis has persisted. It has also changed little over this period with the diagnostic structure, the arbuscule (derived from the Latin, meaning 'little tree'), in a modern-day root system indistinguishable to that from a 400-million-year-old fossil 'root'. The arbuscule, a fungal structure, is the site where nutrients are exchanged between the fungus and host plant. In addition to being inside the root, the fungal partner has a network of hyphae (fine, thread-like structures) that extend out into the soil, so increasing the effective area for nutrient adsorption for the plant. In addition to enhanced acquisition of phosphate, the fungus confers a range of other benefits to its associated host plant, including increased nitrogen and micro-nutrient acquisition, improved drought resistance and enhanced resistance to pathogens. In return, the plant supplies the fungal partner with carbon from photosynthesis.

We may come to rely on these fungal partners more in the future as global supplies of high-quality rock phosphate, used in the manufacture of fertilizers, are a finite resource. Estimates on when these reserves will be exhausted, however, vary widely with the more pessimistic suggestions predicting that they may only last another 50–100 years. Some phosphate reserves are not mined currently because they contain too many contaminants; thus it may become commercially viable to extract these in the future but, inevitably this will come at a cost. While it is possible to generate nitrogen fertilizer using the Haber–Bosch process, albeit at a high energy cost, we cannot synthesize phosphate. Thus once these supplies of rock phosphate are exhausted we then face a crisis in how to maintain agricultural crop yields and to feed the growing population. In the UK, fertilizers have been applied on agricultural land for many years, yet only a small percentage (5–10%) of that applied is actually available to the growing crop, the rest is retained by the soil. Thus, phosphate levels have been built up through time; we now need to extract these so that the plant benefits and this is where AM fungi can play a role.

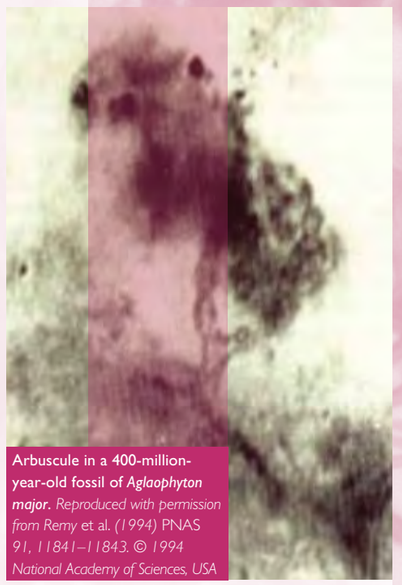


Arbuscules in the root of a plant. *Angela Hodge*

Hyphae (fine thread-like structures) with attached spores (circular structures) of an arbuscular mycorrhizal fungus in soil. The pink colour is due to a stain to enable the hyphae to be more easily visualized. *Angela Hodge*



Arbuscules in a root of bluebell (*Hyacinthoides non-scripta*). *James Merryweather*



Arbuscule in a 400-million-year-old fossil of *Aglaophyton major*. *Reproduced with permission from Remy* et al. *(1994)* PNAS *91, 11841–11843. © 1994 National Academy of Sciences, USA*

A ROLE FOR AM FUNGI

Why then have AM fungi not played a larger role in agricultural systems before now? They probably have done, but the move towards wide-scale fertilizer application made the nutrient acquisition role of AM fungi redundant: at high soil nutrient levels, root colonization by AM fungi is greatly reduced. Moreover, other current agricultural practices, such as pesticide application, large-scale monoculture production (including non-mycorrhizal species such as brassicas) and repeated tillage (which disrupts the below-ground fungal hyphal network), do not encourage a functioning symbiosis. Also, decades of plant breeding to encourage certain characteristics in crop plants under current agricultural conditions may have inadvertently resulted in a loss of some of the genetic information required to form a fully functional AM symbiosis. Thus, while AM fungi are present in agricultural soils, the species that survive there may not be the most effective ones, or even the most effective strains of the species. This is important because AM fungi are multi-functional and differ in their ability to confer nutritional benefits to different host plants. In the natural environment, this helps promote plant diversity.

AM fungi are asexual but their spores contain thousands of nuclei that are genetically diverse. A single hyphal 'thread' may therefore be equivalent to a population of individuals, or even greater. When new spores are formed, random distribution of these genetically diverse nuclei means that the new spores (and so subsequent offspring) may have different complements of nuclei compared to either the parent or other offspring (called segregation). In addition, different isolates of the same AM fungal species have been shown to exchange genetic information, also allowing the mixing of nuclei. By screening the resulting offspring for their impact upon the plant, it is possible to select the fungi that benefit the plant the most, as recently demonstrated in rice plants that showed fivefold greater growth enhancement using selected segregated offspring. This suggests that it may soon be possible to produce effective AM inocula for particular conditions (enhanced growth, nutrient acquisition, drought tolerance, etc.) tailored to the particular needs of the crop plant and the soil.

"We may come to rely on these fungal partners more in the future as global supplies of high-quality rock phosphate, used in the manufacture of fertilizers, are a finite resource."

ANGELA HODGE is Senior lecturer in the Department of Biology (Area 14), University of York, Wentworth Way, York YO10 5DD (email angela.hodge@york.ac.uk)

FURTHER READING

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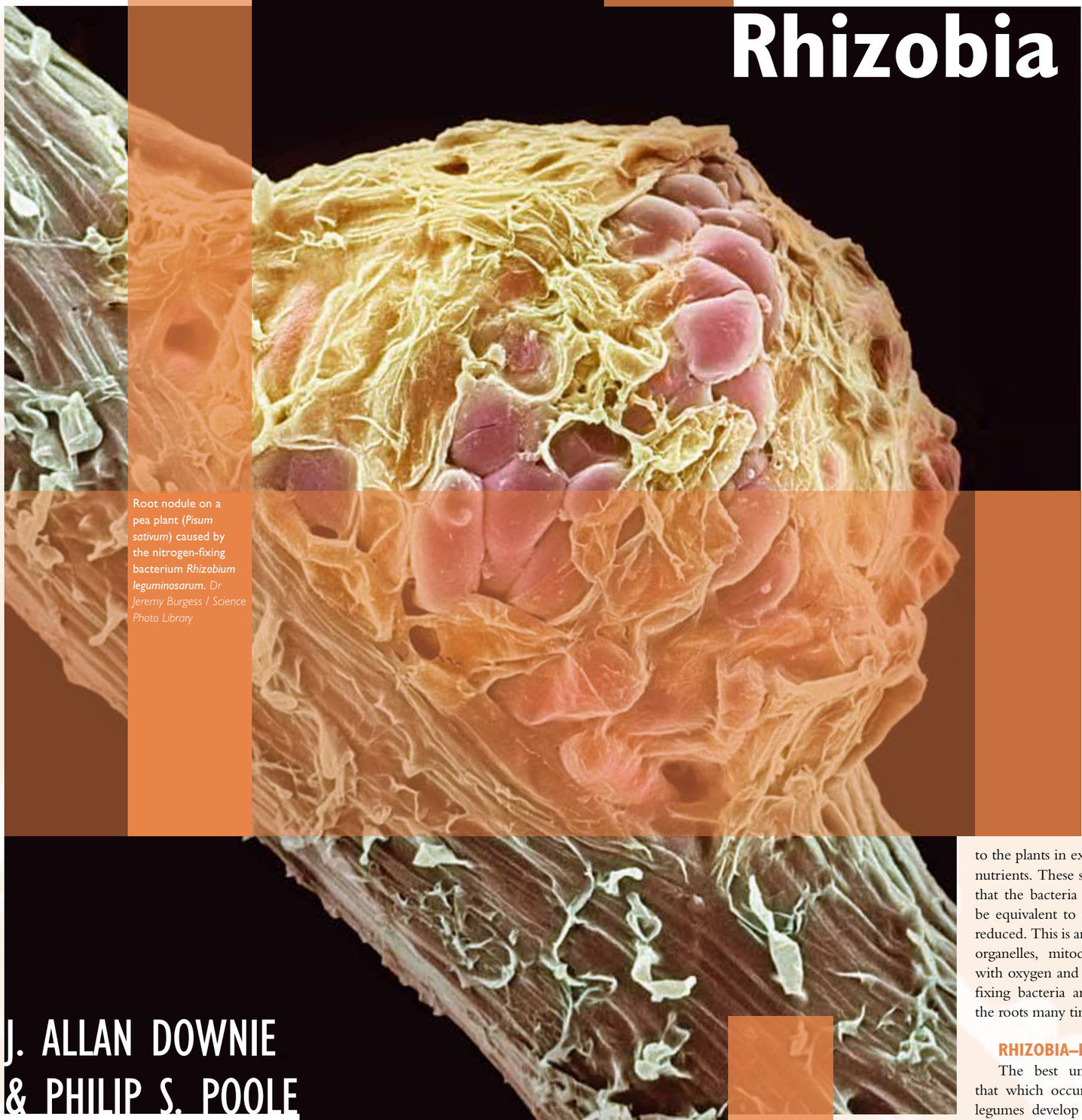
Rhizobia and legumes: fixation with intimacy



Root nodule on a pea plant (*Pisum sativum*) caused by the nitrogen-fixing bacterium *Rhizobium leguminosarum*. *Dr Jeremy Burgess / Science Photo Library*

Background. Roots of a pea plant with root nodules. *Dr Jeremy Burgess/ Science Photo Library*

J. ALLAN DOWNIE & PHILIP S. POOLE

Nitrogen is an essential building block of all life. But eukaryotes have never evolved a biochemical pathway to fix atmospheric nitrogen. However, some plants have developed intimate symbiotic relationships that enable direct transfer of fixed nitrogen from bacteria.

PROKARYOTES are the only life forms that have the nitrogenase enzyme that reduces N_2. Ammonia produced by nitrogenase is assimilated by the enzyme glutamine synthetase, which forms glutamine from glutamate and ammonia. The 'fixed' nitrogen in the glutamine is then used in the biosynthesis of the other nitrogen-containing building blocks of life.

Ultimately, eukaryotes depend on bacterially fixed nitrogen for growth, and it is surprising that no eukaryotes have evolved the ability to fix nitrogen. However, some plants have evolved symbiotic associations with bacteria, which supply ammonia to the plants in exchange for a supply of carbon and other nutrients. These symbiotic associations can be so intimate that the bacteria within the plants can be considered to be equivalent to organelle-like structures in which N_2 is reduced. This is analogous to the other prokaryote-derived organelles, mitochondria and chloroplasts, which deal with oxygen and carbon dioxide. However, the nitrogen-fixing bacteria are not inherited and so must re-infect the roots many times.

RHIZOBIA–LEGUME SYMBIOSIS

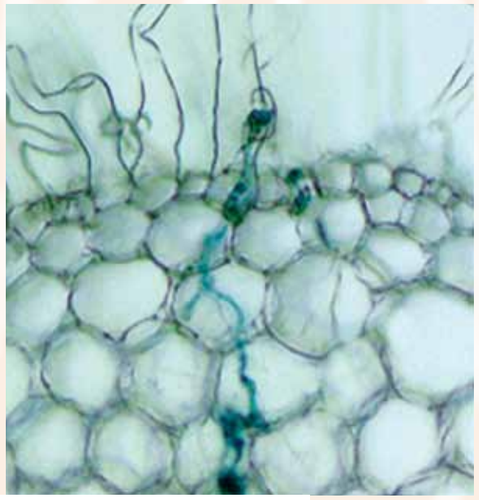
The best understood nitrogen-fixing symbiosis is that which occurs between rhizobia and legumes. The legumes develop root outgrowths called nodules, often

several hundred on a root system (and in some legumes nodules also form on the stems). Each nodule contains many nitrogen-fixing bacteria (10^8–10^{10}), all of which are usually clonal, derived from a single infecting bacterium. The benefits of growing legumes have long been recognized; for example, the Roman, Theophrastus (370–285 BC) wrote '*Beans are not a burdensome crop to the ground: they even seem to manure it*'. In the last 20 years or so, research in rhizobial and legume molecular genetics, biochemistry and cell biology has given significant insights into the signalling that occurs between the symbiotic partners to allow this symbiosis to be established.

Unlike pathogenic infections of plants and animals, rhizobial infection of legumes is actively promoted by the plants, most of which produce specialized tunnel-like infection structures called 'infection threads' in response to signals from the bacteria. The bacteria grow at the tips of the infection threads, which grow down through root cells, eventually depositing the bacteria into plant cells in the growing nodule meristem. The process of infection can take 10–14 days and during this period the rhizobia do not fix nitrogen. Therefore, the bacteria and the plant have developed layers of recognition that greatly reduce the chances of inappropriate bacteria gaining entry looking for a free meal.

"Legume nodulation probably evolved around 60 million years ago; the huge diversity of extant legumes attests to the evolutionary success of this strategy for assimilating nitrogen."

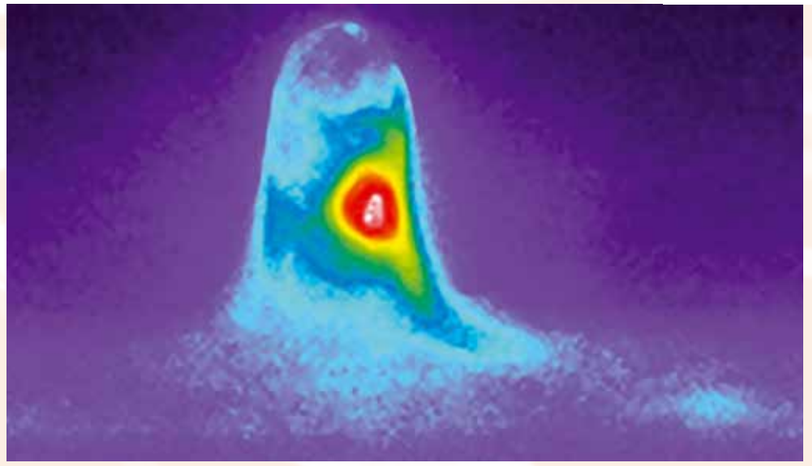
Top Infection thread in pea 12 days after inoculation with *Rhizobium leguminosarum* initiating a curled root tip. *Reproduced with permission from Walker & Downie (2000)* Mol Plant–Microbe Interact *13, 754–762.*



Bottom Infection thread (blue) in vetch 12 days after inoculation with *Rhizobium leguminosarum*, initiating a curled outgrowth at the base of a root hair and travelling through cortical cell layers. *Reproduced with permission from Walker & Downie (2000)* Mol Plant–Microbe Interact *13, 754–762.*

SIGNAL EXCHANGE BETWEEN SYMBIOTIC PARTNERS

Rhizobia recognize flavonoids secreted from legume roots; regulatory (NodD) proteins bind the flavonoids and induce expression at conserved promoters upstream of rhizobial nodulation (*nod*) genes. Different NodDs vary in their specificity for flavonoids, some for example preferring isoflavones to flavones. The conserved promoters bound by NodD proteins are highly conserved, are easy to recognize and there can be several *nod* gene operons in one strain. Several of the *nod* gene products synthesize and export highly specific plant signals called Nod factors. These are oligomers of four or five β1,4-linked *N*-acetylglucosamine residues (chitin oligomers) carrying an *N*-linked fatty acyl group replacing the acetyl on the terminal sugar. This core structure can vary greatly; in addition to different numbers of residues and different types of *N*-linked fatty acyl groups, there can be various chemical substituents such as sulfate, acetyl, carbamoyl or methyl groups, and additional sugars at various locations. The complement of *nod* genes determining these variations is mostly what determines which rhizobia can nodulate which legumes. Some rhizobia make a few Nod factors whereas others make a variety.



Root hair injected with dye showing a peak of calcium (a calcium spike) around the nucleus (red). *Jong Ho Sun*

As little as 10^{-12} M Nod factor is sufficient to induce signalling in roots; higher concentrations can induce nodule development in the absence of bacteria. Legumes have multiple receptors that recognize these signals; their activation results in the induction of signalling pathways required for both nodule development and infection thread growth. There appear to be different outputs from the receptors. For example, there are two calcium responses: one is induction of a Ca^{2+} influx across the root hair tip and this is correlated with an alteration in the membrane potential and induction of reactive oxygen production. A second calcium response is an oscillation of calcium in and around the nucleus. Activation of both pathways requires the appropriate Nod factor structures. The signalling pathway activated via calcium oscillations induces the expression of many legume genes. Evidently, this nodulation signalling pathway has been adapted from an ancient signalling pathway that is induced by mycorrhizal fungi, because some legume mutants blocked for nodulation signalling are also blocked for infection by symbiotic arbuscular mycorrhizal fungi which transfer nutrients from soil and decaying organic matter to plant roots (see the article by Angela Hodge on p. 90). The arbuscular mycorrhizal symbiosis is thought to have developed along with the evolution of land plants (about 450 million years ago), whereas legume nodulation probably evolved around 60 million years ago; the huge diversity of extant legumes attests to the evolutionary success of this strategy for assimilating nitrogen.

RECOGNITION VIA SECRETED PROTEINS AND CELL SURFACE COMPONENTS

Some *nod* gene products are secreted proteins. For example, some rhizobia secrete a protein (NodO) across both bacterial membranes via a Type I secretion system; the protein forms cation-selective pores in membranes, probably complementing the Nod-factor induced calcium influx and decrease in membrane polarization. In addition, some rhizobia can deliver effector proteins into the cytoplasm of plant cells via Type III and Type IV secretion systems that inject proteins across the plant cell membrane. These effectors can assist plant infection, most probably by suppressing plant defence systems; in addition, some of the injected proteins probably play a direct role in assisting infection.

Bacteria must have an appropriate surface to be able to infect legumes. Mutations blocking the production of surface exopolysaccharides (EPS), the lipopolysaccharide (LPS) or the tightly bound capsular polysaccharides can all block infection. In some rhizobia, some *nod* gene products are involved in biosynthesis of a modified LPS. At least in some symbioses, short oligomeric fragments of the EPS appear to act as signals, because if EPS biosynthesis and processing is altered such that long-chain EPS

Section through a mature nodule. The red colouration shows where the leghaemoglobin is. *Allan Downie*

are formed but short oligomers of the EPS are not, then infection can be blocked. Furthermore, appropriate EPS oligomers have been reported to restore infection by EPS mutants, implying a signalling role.

A RACE IN A TUBE FROM HELL

Rhizobia growing down infection threads actively divide only at the growing tip, usually resulting in a column of clonally derived bacteria. In mixed infections there is essentially a race between bacteria, ensuring that a strong selection pressure is applied to any rhizobia that gain entry to root hairs. In many ways infection threads are tubes from hell as the plant is producing large amounts of reactive oxygen species and almost certainly other potentially antibacterial compounds. Rhizobial adaptation to this environment includes production of catalases, peroxidases and efflux systems that exude plant toxins.

PLANTS TAKE CONTROL AND CONFER ORGANELLE STATUS ON INTRACELLULAR ENDOSYMBIONTS

Rhizobia eventually reach the nodule cells in which they will fix nitrogen, are released from the infection threads and are engulfed by endocytosis, whereupon they differentiate into nitrogen-fixing bacteroids. Plants such as pea, vetch, alfalfa and clover then take over control of the bacterial cell cycle causing multiple replication cycles of the bacterial chromosome without cell division; this is achieved by a cocktail of around 400 plant-made cysteine-rich antimicrobial peptides. The resulting bacteroids are terminally differentiated with a surrounding plant-derived membrane, are greatly increased in size, are often branched, have leaky cell membranes and cannot regrow if isolated from nodules. In some other legumes, such as soybean and *Phaseolus*, that do not produce antimicrobial peptides, the bacteroids have a chromosome number of 1–2, do not increase in size, their membranes do not become leaky and they can be regrown when isolated from nodules; usually several such bacteroids are contained within the plant-derived symbiosome membrane.

Mature bacteroids are no longer actively dividing so it is perhaps no surprise that there is a wholesale reduction in transcription of many biosynthetic genes. However, the intimate nature of control and exchange between the plant and bacteria is far more subtle than this. Rhizobia from pea and bean nodules reduce their synthesis of branched chain amino acids to the point that they become dependent on the plant for their supply. This phenomenon is called symbiotic auxotrophy because the auxotrophy only occurs in bacteroids. Once again, the plant takes control of bacterial development and persistence ensuring that bacteroids behave like plant organelles. A further dependency is that most rhizobia cannot synthesize the nitrogenase cofactor homocitrate and rely on the plant to provide it. Free-living nitrogen-fixing bacteria such as *Azotobacter vinelandii* have a homocitrate synthase gene (*nifV*), which is absent from most rhizobia.

BACTEROIDS ARE AWASH WITH AMMONIA

Many aspects of bacteroid development are determined by the very low O_2 tension in nodules that plants maintain with the O_2-binding protein leghaemoglobin. It is the low O_2 tension that induces many of the *nif* and *fix* genes in developing bacteroids rather than limiting nitrogen. In fact, the bacteroids cannot assimilate the ammonia they produce because they switch off their glutamine synthetase. Of course this makes perfect sense because bacteroids are effectively 'ammoniaplasts' that continue to reduce N_2 to ammonia and export it to the plant even though they are bathed in high concentrations of ammonia. It is this unusual characteristic that makes rhizobial–legume symbioses so highly efficient as a means of reducing nitrogen and supplying the ammonia directly to the plant.

J. ALLAN DOWNIE and **PHILIP S. POOLE** work on *Rhizobium*–legume interactions at the Department of Molecular Microbiology, John Innes Centre, Norwich Research Park, Norwich NR4 7UH (emails allan.downie@jic.ac.uk; philip.poole@jic.ac.uk)

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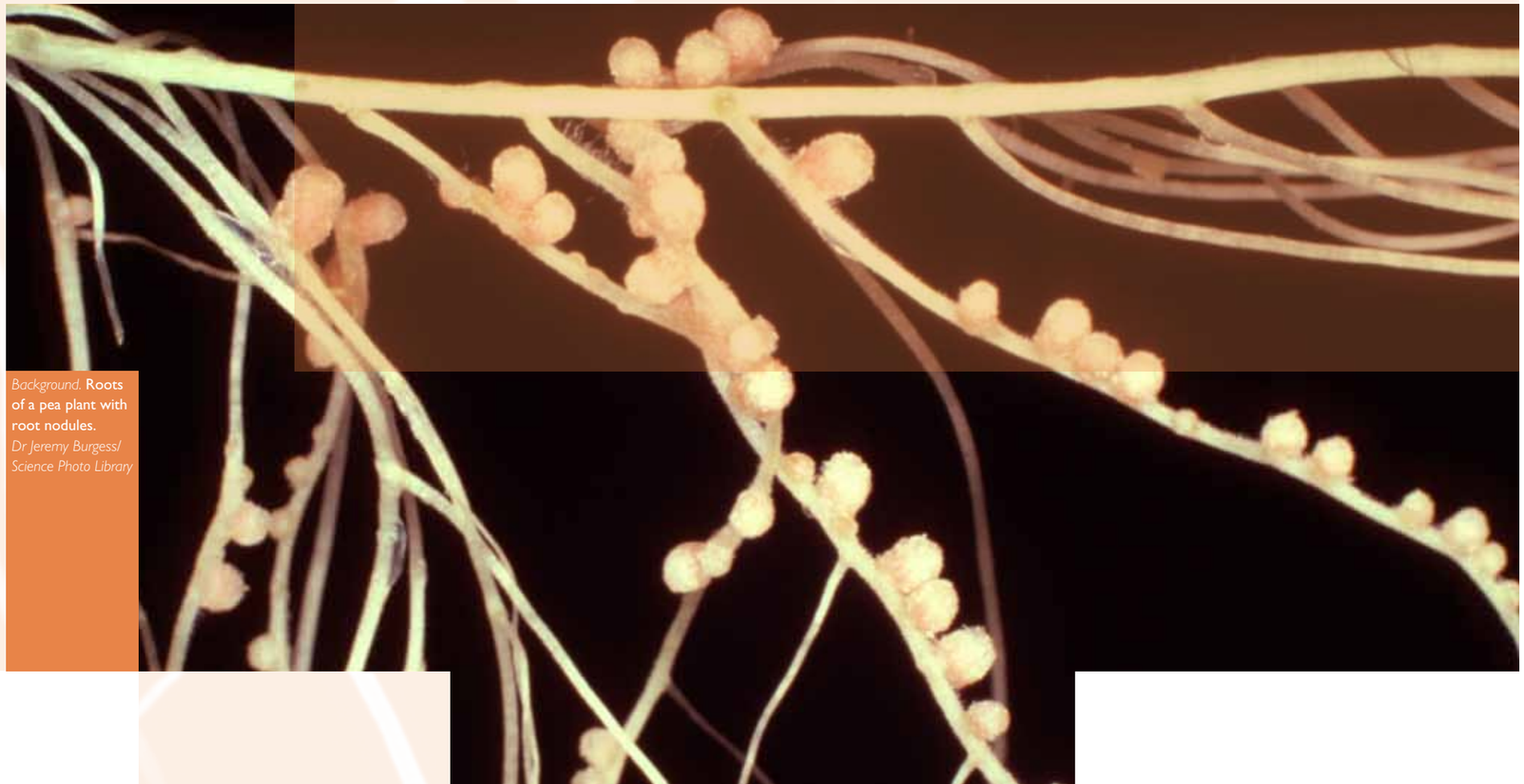
"In many ways infection threads are tubes from hell as the plant is producing large amounts of reactive oxygen species and almost certainly other potentially antibacterial compounds. Rhizobial adaptation to this environment includes production of catalases, peroxidases and efflux systems that exude plant toxins."

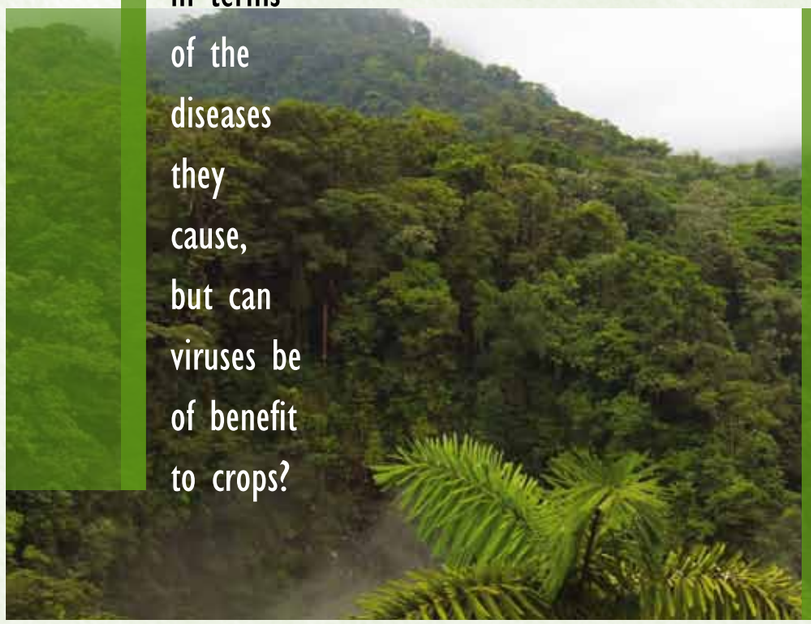


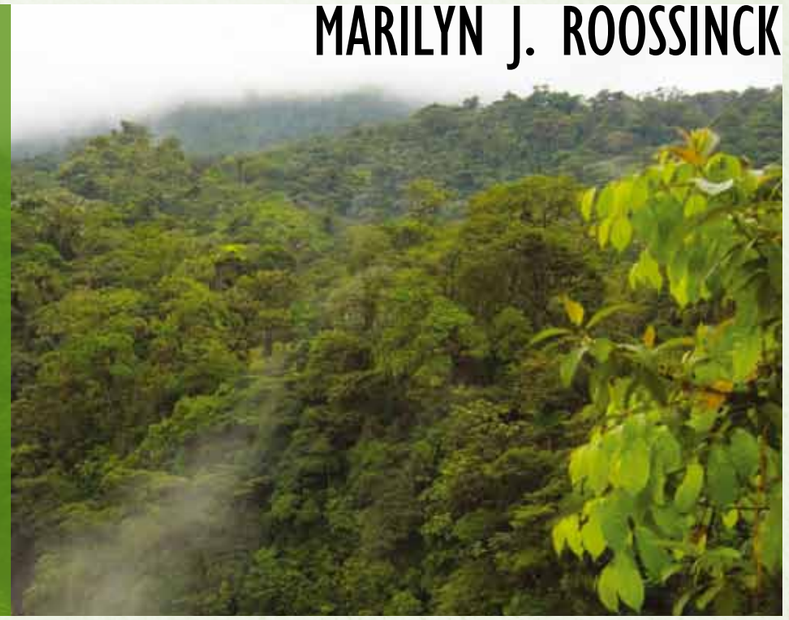
Background. **Roots of a pea plant with root nodules.** *Dr Jeremy Burgess/ Science Photo Library*

Viruses can be our friends

MARILYN J. ROOSSINCK

Plant viruses are invariably thought of in terms of the diseases they cause, but can viruses be of benefit to crops?





A Costa Rican forest landscape. *iStockphoto / Thinkstock*

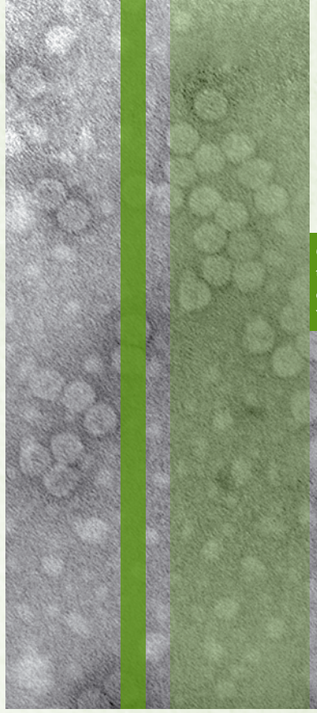
WHILE WORKING ON VIRUSES of wild plants in Costa Rica, I noticed something remarkable. All of the plants in the forest looked very healthy, while in neighbouring agricultural areas there was a lot of disease. I knew from our studies that the plants in the forest were full of microbes, including viruses. In fact, plants in the forest often had multiple virus infections, as many as 11 in a single plant in one case. I also knew that in agriculture there is a lot of effort to keep plants free of viruses. It made me wonder, could these viruses be good for the plants?

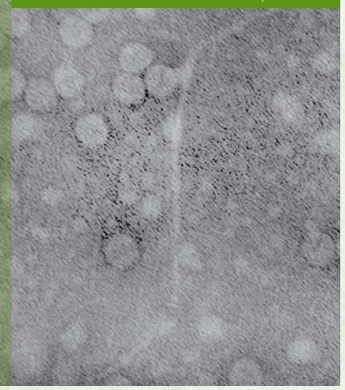
Keeping viruses out of plants is not easy. Once a plant has a virus there are no practical ways to 'cure' it. In agriculture, virus infection is either prevented by using virus-resistant plants or by spraying with pesticides to kill the vectors of plant viruses (mostly insects and occasionally fungi), or infected plants are destroyed to keep the virus from spreading. Virus resistance is rarely stable for long periods, because viruses tend to evolve rapidly, and new strains appear that overcome the resistance, so this is an ongoing battle. Pesticides present another set of problems, including pollution, destruction of beneficial insects and fungi, and development of resistant pests. In addition, most virus-resistant seeds are hybrids and must be purchased every year, and pesticides are expensive, so these options are not usually available for small-holder farmers.

One big difference between wild plants and agricultural plants is diversity. The wild plants live among a mixture of many different species, and even within a single species there is a lot of genetic diversity. Many farms plant very large areas of one cultivar of a crop, a monoculture that enhances the evolution and emergence of diseases. When a pathogenic virus gets into a monoculture, it can spread very rapidly. Monoculture also increases the incidence of vectors like aphids that move viruses from plant to plant. In the forest, aphids are not very common, probably because they are eaten by predators (beneficial insects). These factors clearly contribute to the virus diseases we see in agriculture – but is there something more going on?

Recently, a few examples of viruses that are beneficial to plants and animals have been found. Mycologists have shown that plants that grow in the very hot geothermal soils of Yellowstone National Park, Montana, USA, are able to grow there because they are colonized by a fungus. Neither the fungus nor the plant can grow at these temperatures by themselves. Later, a virus was discovered in this fungus, and when the fungus was cured of the virus in the lab, the virus no longer conferred the thermal tolerance. Re-introducing the virus restored the thermal tolerance. This remarkable symbiotic relationship between the virus, the fungus and the plant is almost certainly not unique. Viruses may have many other beneficial effects, but the bias of virus research has always leaned toward pathogens.

Botanist Adrian Guadumas collects plants for a plant virus biodiversity study in a montane forest in north-western Costa Rica. Most of the plants in the photo harbour one or more plant viruses, but none show any symptoms of virus disease. In agricultural areas nearby, disease symptoms are common. *Felipe Chavarría*





Curvularia thermal tolerance virus, the virus that allows plants and fungi to grow in the extreme geothermal soil temperatures of Yellowstone National Park. *Luis Márquez*

In another study, a plant virus was being used to suppress genes in plants in a process called RNA silencing, to look for things that might affect drought tolerance. The experiment used two types of 'control' plants: ones that had the virus alone, and ones that had no virus. The surprise was that the plants with the virus alone were very drought-tolerant compared to those with no virus. More experiments showed that many plant viruses could confer this drought tolerance, and it worked in all of the plants tested, including important crop plants like beets, peppers, cucumber, courgettes, rice, watermelon and tomato. A relative of tobacco, *Nicotiana benthamiana*, was also drought-tolerant when infected with any of four different viruses used in the study. This plant is sometimes referred to as a 'universal host' because it can be infected by almost all known acute plant viruses. The plant originates from the very hot and dry deserts of western Australia. Maybe it has survived in its harsh native climate because it is so susceptible to viruses.

In addition to drought tolerance, plant viruses can provide cold tolerance. In an experiment done in the lab that mimicked the beginning or the end of a natural growing season, red beet plants were subjected to temperatures just below freezing at night, and then returned to normal temperatures during the day. The plants infected with virus survived the cold treatment, while those without any virus infection all died.

A feature of viruses in wild plants is that many of them might be associated with their hosts for long periods of time, perhaps many generations, while crop viruses may have recently jumped to a new host species. A long association would lead to adaptation; it is rarely an advantage for the virus to cause disease to its host in the long run. However, this is not the only explanation, because we occasionally find the same viruses in wild plants as we find in nearby crop plants, but they are not causing disease in the wild plants. Analysing these viruses indicates that they are moving from the crops to the wild plants, rather than the other way around.

We usually think of viruses as our mortal enemies, the cause of human pain and suffering from HIV/AIDS and influenza to the common cold, the killers of our crops and farm animals. The first virus ever described was tobacco mosaic virus; it was discovered in the late 19th century because it was causing a disease in tobacco plants that was not due to a bacterium, but rather something much smaller that could pass through 0.4 µm filters. Perhaps that set the tone for the field of virology, because until recently almost everything we knew about viruses was related to those that cause disease. Now we know that there is a lot more to the story. Most viruses are probably benign, some are clearly beneficial, and some are probably essential for the very existence of their hosts. Studying viruses from this new perspective will allow us to find the ones that can be used to benefit, rather than harm, agriculture.

Cold tolerance is conferred to beet plants by the presence of a common plant virus, cucumber mosaic virus, in this experimental study (plants on the left are virus-infected, plants on the right are 'healthy'). Plants were subjected to below freezing temperatures at night, similar to what is found at the beginning or end of a growing season in temperate climates. *Ping Xu*

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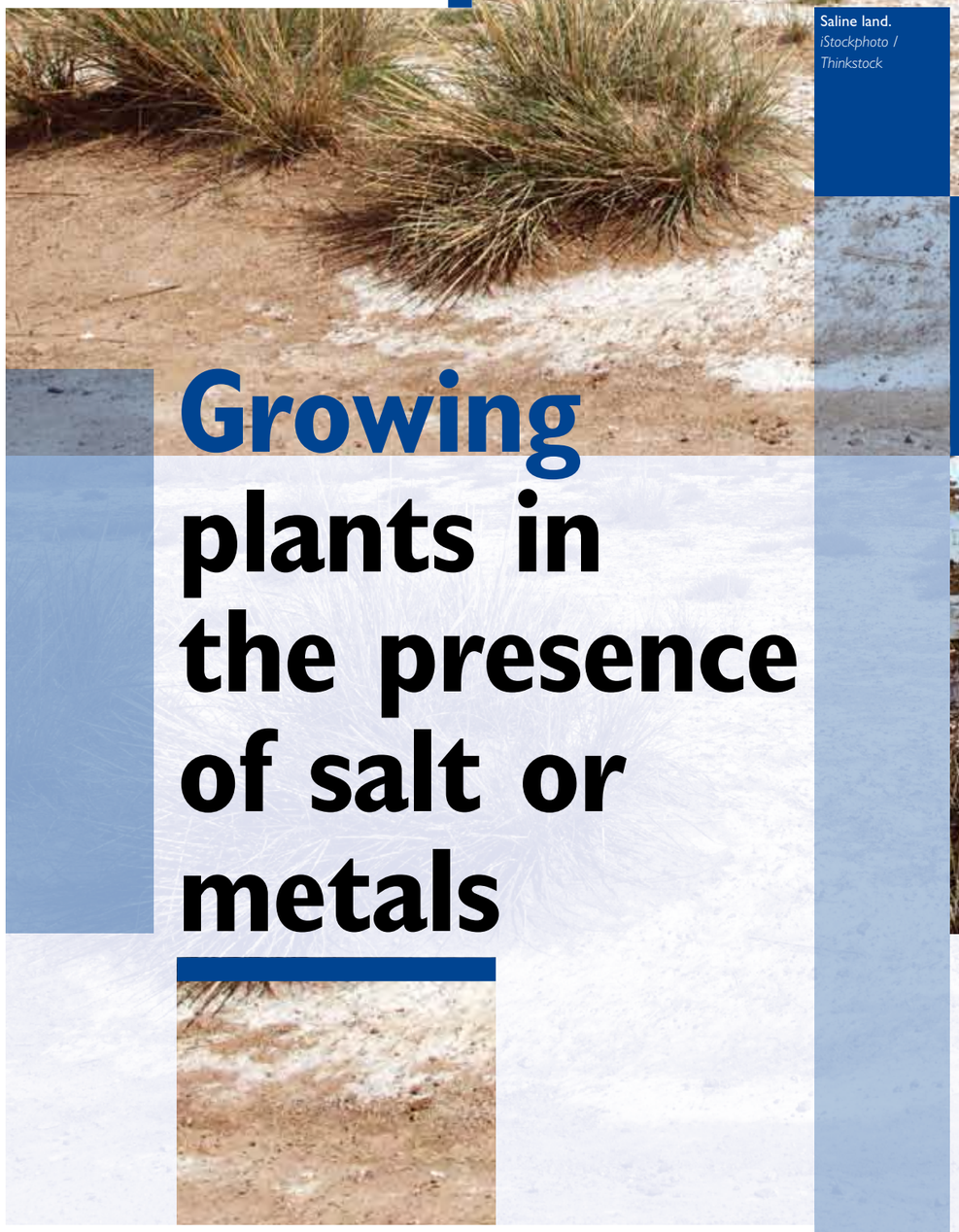
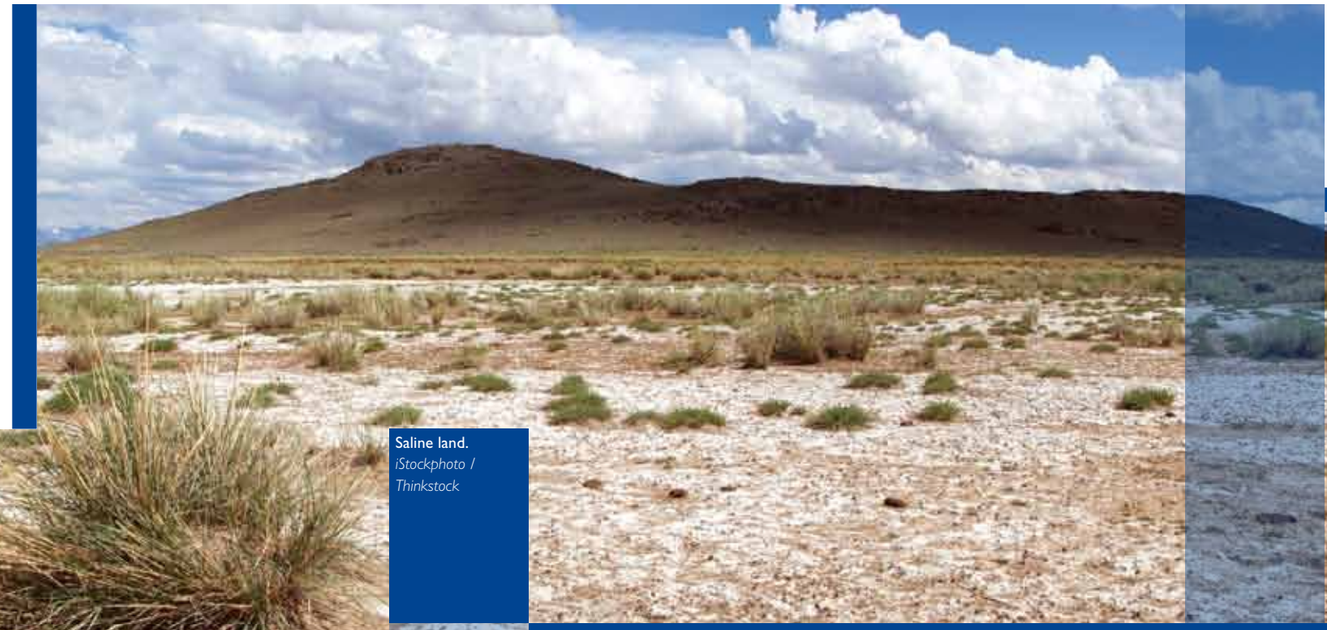
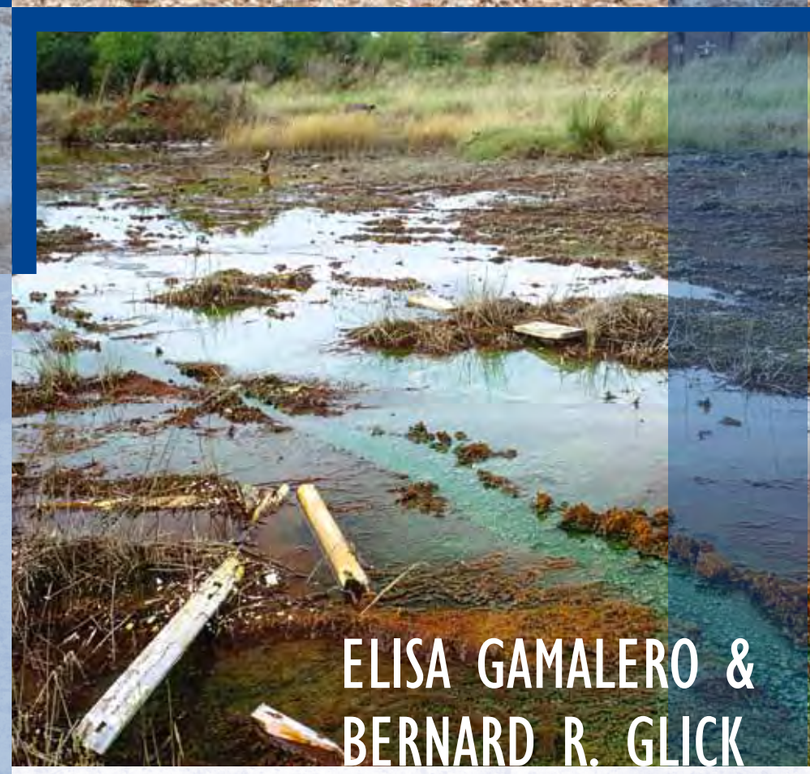
"Most viruses are probably benign, some are clearly beneficial, and some are probably essential for the very existence of their hosts."





Saline land.
iStockphoto / Thinkstock

Growing plants in the presence of salt or metals



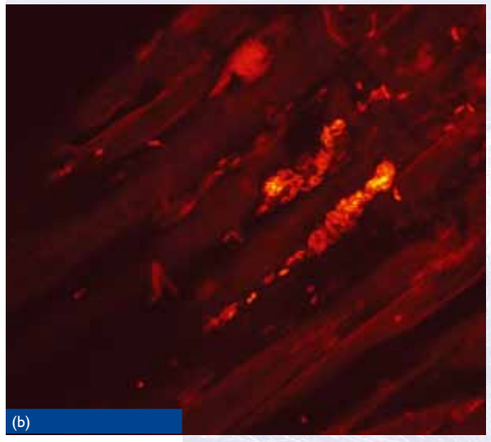
Land contaminated by heavy metals.
Robert Brook / Science Photo Library

ELISA GAMALERO & BERNARD R. GLICK

How can microbes be used to alleviate the stress caused by high salinity and heavy metal pollution that afflict a large proportion of agricultural land around the world?

LIFE IS HARD for plants! In fact, as is the case for all living things, during their lifetime, plants are exposed to a variety of different stresses. Among them, salinity is an enormous worldwide problem for agriculture, especially for crops that are grown under irrigation. In addition, heavy metal pollution of soils impacts negatively, first on plants and the environment, and subsequently on human health.

Soil salinization may occur due to natural causes, and is common in the hot and dry regions of the world, or it may be a consequence of inadequate irrigation management practices. Salt inhibits the growth of a large number of different plant species, and it has been estimated that the amount of salt-affected land worldwide is ~900 million hectares, which means about 20% of the world's land is negatively affected by salt. Excess salt adversely affects seed germination, seedling growth and vigour, flowering and fruit set. The deleterious effects of salt are the consequence of osmotic stress, Na^+ and Cl^- toxicity, ethylene production, plasmo-



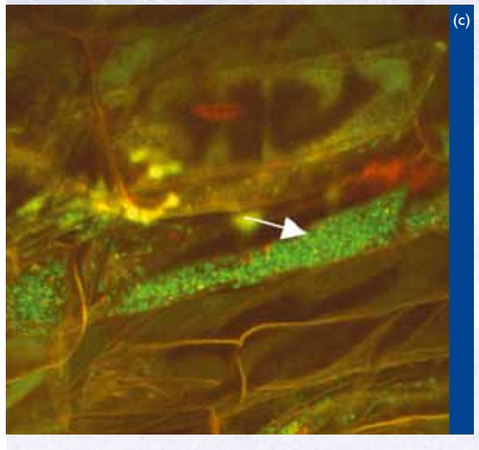


Fig. 1. **Root colonization by plant growth-promoting bacteria. (a) Bean roots colonized by rhizobia: note the nodules where nitrogen fixation occurs. (b) Endophytic bacteria located inside the cortex cells of a tobacco plant. (c) Cells of a fluorescent pseudomonad (white arrow) distributed along the root surface of tomato plants.** *(a) Nigel Cattlin / Science Photo Library; (b, c) E. Gamalero & B. Glick*

"The symptoms shown by plants exposed to high salinity or heavy metal pollution are partly the result of ethylene production by the plant itself."

lysis, nutrient imbalance, production of reactive oxygen species and interference with photosynthesis.

Heavy metals are naturally present in small amounts in many soils, but human activities such as mining, metal working, combustion of fossil fuels, disposal of residues from coal combustion, vehicular traffic and the use of pesticides and fertilizers in agriculture may lead to large increases in the concentration of metals in soil. Although some heavy metals play a role as micronutrients (Fe, Mo, Mn) or trace elements (Zn, Ni, Cu, V, Co, W, Cr) that are important for plant nutrition, other metals are toxic both for plants and micro-organisms (e.g. Hg, Ag, Cd, Pb, U). As a result of their sensitivity to heavy metals, plants exposed to these inorganic pollutants are characterized by reduced biomass, leaf chlorosis and necrosis, loss of plant water content, reduced rate and extent of seed germination, and plant death. Heavy metals that are taken up by plants from the soil may induce modifications to the plant's protein composition, accumulation of reactive oxygen species within plant cells, plant nutrient levels and water status, plant cell membrane H^+-ATPase activity and photosynthesis.

The symptoms shown by plants exposed to high salinity or heavy metal pollution are partly the result of ethylene production by the plant itself. Ethylene is a gaseous plant hormone that is involved in modulating various phases of plant life (e.g. fruit ripening, flower senescence, leaf and petal abscission) as well as a plant's responses to biotic and abiotic stresses. In fact, the term 'stress ethylene' was introduced to indicate the increase in ethylene synthesis that occurs in plants after they experience an environmental stress such as extremes of temperature, high light, flooding, drought, heavy metal and organic pollution, radiation, wounding, insect predation, salinity or the presence of various pathogens.

PLANT GROWTH-PROMOTING BACTERIA

Approximately 10–30% of the carbon that is captured by a growing plant as a result of photosynthesis leaks out of the plant roots, and is called root exudate. As a result of this, a large number of soil bacteria establish themselves in, on or around plant root tissues where they find abundant sources of small molecules that they use as food. These bacteria, collectively known as plant growth-promoting bacteria, can stimulate plant growth by a variety of mechanisms. Some plant growth-promoting bacteria can form a symbiotic relationship where the bacteria occupy specialized structures on host plant roots called nodules (Fig. 1a; see article by Downie & Poole on p. 94); others bind to the outer surface of plant roots (Fig. 1b); while a third group of these bacteria, called endophytes, enter into the plant roots and from there may occupy spaces throughout the interior of the plant (Fig. 1c).

The mechanisms used by plant growth-promoting bacteria fall into two categories: direct stimulation of plant growth and biocontrol (i.e. suppressive activity against soil-borne diseases). A number of plant growth-promoting bacteria that can stimulate the growth of different crop plants or protect them against the deleterious effects of plant pathogens have been commercialized as biofertilizers or biocontrol agents. One of the key mechanisms used by some of these bacteria to promote plant growth includes lowering the ethylene that might otherwise form as a consequence of the various biotic and abiotic stresses experienced by the plant. The bacteria do this by synthesizing the enzyme ACC deaminase that cleaves plant-produced ACC, the immediate precursor of ethylene, thereby lowering the amount of inhibitory stress ethylene that the plant synthesizes. For example, in Fig. 2 it can be seen that addition of a bacterium that contains ACC deaminase to either canola plants grown in the presence of high levels of salt or tobacco plants grown in the presence of a high concentration of copper significantly prevents the stress from inhibiting plant growth. Although various plants have differing levels of sensitivity to ethylene, most plants may be protected to a significant extent from the stress ethylene that is generated following any one of a number of abiotic (or biotic) environmental stresses.

Fig. 2. **(a) Growth of canola in the presence of (***from left to right***) no added salt, high salt, and high salt plus a plant growth-promoting bacterium containing ACC deaminase. (b) Growth of tobacco in the presence of (***from left to right***) no added metal, copper, and copper plus a plant growth-promoting bacterium containing ACC deaminase.** *E. Gamalero & B. Glick*

In recent years, there have been a large number of studies, both in the laboratory and in the field, demonstrating that the use of plant growth-promoting bacteria is quite beneficial to plants. This is particularly true for plant growth in the presence of a wide range of environmental stresses, including high salt and the presence of metals. A lot remains to be learned about how different plants, different conditions, and treatment with different bacteria may be combined to optimally facilitate plant growth. Nevertheless, given the fundamental understanding of some of the key mechanisms of plant growth promotion that currently exists, we are optimistic that we are on the verge of an era where the purposeful use of plant growth-promoting bacteria will begin to replace the use of energy-intensive and often polluting chemicals in agricultural practice.

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Muscodor albus – the anatomy of an important biological discovery

GARY STROBEL

The discovery in the 1990s of a novel genus of fungus, *Muscodor*, that lives harmlessly inside plant tissues and produces several bioactive compounds, has opened up a new range of possibilities for controlling plant diseases and bacterial food contamination by 'mycofumigation'.

A DRAMATIC INCREASE in the number of people in the world having health problems caused by certain cancers, drug-resistant bacteria, parasitic protozoans and fungi has caused alarm. An intensive search for newer and more effective agents to deal with these problems is now underway. Endophytes are a potential source of novel chemistry and biology to assist in helping solve not only human health, but plant and animal health problems also.

INTRODUCTION TO ENDOPHYTES

Endophytes reside in the tissues between living plant cells. The relationship that they establish with the plant varies from symbiotic to bordering on pathogenic. Of all of the world's plants, it seems that only a few grass species have had their complete complement of endophytes studied. As a result, the opportunity to find new and interesting endophytes among the myriad of plants is great.

Occasionally, extremely unusual and valuable organic substances are produced by these endophytes. These compounds may contribute to the host–microbe relationship.

Muscodor is a novel endophytic fungal genus that produces bioactive volatile organic compounds (VOCs). The first fungal isolate to be obtained, *Muscodor albus* isolate 620 was discovered as an endophyte in a cinnamon tree (*Cinnamomum zeylanicum*) in a Honduran rainforest. The VOC mixture made by this fungus is lethal to a wide variety of plant- and human-pathogenic fungi and bacteria. This mixture of gases, analysed by gas chromatography/mass spectrometry (GC/MS), consists primarily of various alcohols, acids, esters, ketones and lipids. Artificial mixtures of the VOCs mostly mimic the biological effects of the fungal VOCs when tested against a wide range of fungal and bacterial pathogens. Many other species of this fungus have been isolated, as endophytes, existing in a broad range of plant families in many areas of the world. Each organism makes its own set of VOCs and all have biological activity of some type and description. Many practical biological control applications for 'mycofumigation' by *M. albus* and other *Muscodor* species are currently being investigated, including uses in agriculture, medicine and industry. Other newly described endophytic species of *Muscodor* include *M. vitigenus*, *M. roseus*, *M. crispans*, *M. yucatanensis*, *M. cinnamomi* and *M. fengyangensis*. Now, an artificial mixture of the *M. crispans* VOCs is being made by bacterial fermentation technologies and is on the market for controlling plant diseases, bacterial food contamination and many other uses.

THE DISCOVERY OF *M. ALBUS* – A SCIENTIFIC ACCIDENT

In the late 1990s, I was on a plant-collecting trip in the jungles near to the Caribbean coast of Honduras. I had selected this area to visit because Central America is one of the world's 'hot spots of biodiversity'. One modestly sized tree, not native to the new world, was introduced to me as *Cinnamomum zeylanicum*. Small limb specimens were taken and placed in a plastic bag and brought back to Montana, and the sample was processed according to standard isolation procedures for endophytes. Endophytes are fungi or bacteria or other microbes that live inside plant tissues and cause no overt signs or symptoms of their presence in the plant. It is important to find and understand them since they may have many potential uses.

We had been plagued with microscopic phytophagous mites in the lab for many months. This is not uncommon for labs into which plant materials are being brought on a regular basis. Mites infest the bench tops and invade parafilm-sealed Petri dishes containing agar in which they take up residence. Thus, in order to eliminate this persistent mite problem we decided to place the Petri dishes, with plant tissues, in a large plastic box having a firmly fitting lid. This manoeuvre would make it difficult for the tiny animals to find their way from the bench surfaces to the inside of the box. After a few days,

Cinnamon tree (*Cinnamomum zeylanicum*). *Gary Strobel*

"It has recently been discovered that M. albus *has activity against certain plant-pathogenic nematodes and insects."*

most plant specimens had sported endophytic fungal growth. Eventually the plates were removed and the individual hyphae transferred to fresh plates of potato dextrose agar (PDA). After a day or two of incubation we noted that no transferred endophyte grew except one. Had the placement of the endophytes in the large plastic box killed the endophytes by limiting oxygen availability? Soon it became obvious that the one endophytic fungus (designated isolate 620) that remained alive was producing volatile antibiotics or VOCs. The hypothesis that an endophyte can make volatile antibiotic substances with a wide range of biological activity was born.

M. ALBUS AND ITS VOCs

Isolate 620 is a sterile (non-spore-producing) endophytic fungus possessing some interesting hyphal characteristics, including a white appearance, coiling, formation of hyphal 'ropes', and branching at right angles. In fact, the mycelia commonly make undulations on the agar surface. In order to taxonomically characterize this organism, partial regions of the internal transcribed spacer (ITS) region of the fungal DNA were isolated; these regions are highly variable between species and allow them to be discriminated. GC/MS analysis of the fungal VOCs showed the presence of at least 28 VOCs. These compounds represented at least five general classes of organic substance (lipids, esters, alcohol, ketones and acids). With this chemical information in hand, along with the DNA sequence data, we felt secure in proposing a Latin binomial for this novel fungus, *Muscodor albus* (stinky white fungus).

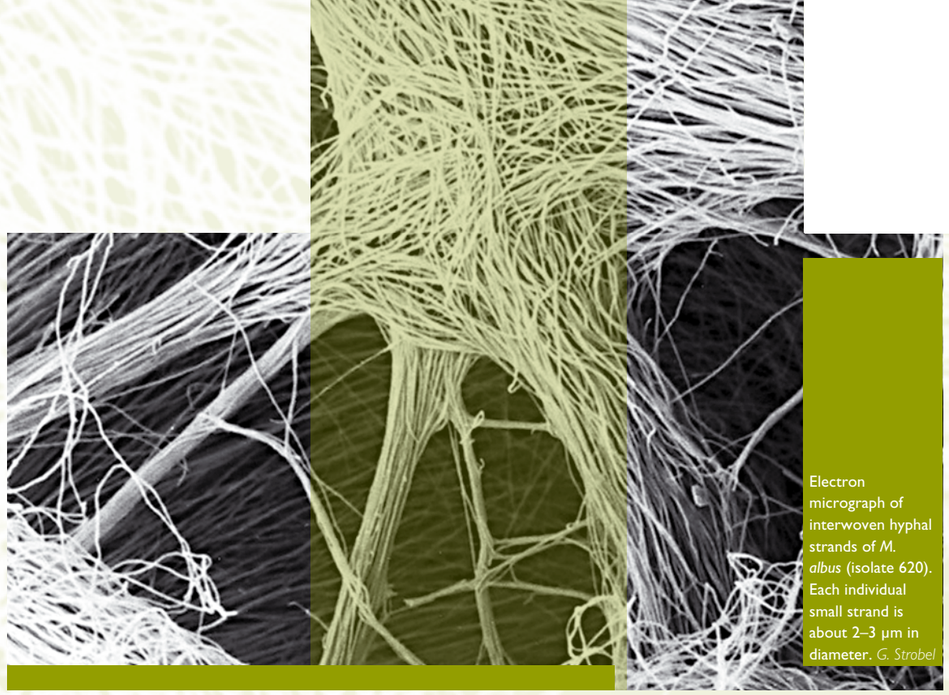
Once the VOCs had been identified, we could make artificial mixtures of the compounds for use in a biological assay system to demonstrate the activity of individual compounds. Over 80% of the volatiles could be identified, and this was adequate to reproduce the antibiotic effects of the VOCs that were being produced by the fungus. Interestingly, no individual compound or class of compounds was lethal to any of the test microbes alone, which consisted of representative plant-pathogenic fungi, and Gram-positive and -negative bacteria. Obviously, the antibiotic effect of the VOCs of *M. albus* is the result of the synergistic activity of the compounds in the gas phase. Very little is known about the mode of action of these compounds on the test microbes; thus this represents an interesting academic avenue to pursue in the future.

OTHER ISOLATES AND SPECIES OF *MUSCODOR*

Two further species of *Muscodor* have recently been found: *M. roseus* (endophytic on *Grevillea pteridifolia* in Australia) and *M. vitigenus* (endophytic on *Paullinia paullinoides* in Peru). These isolates are also closely related genetically to some new Australian isolates of *M. albus*, being 96–99% similar at the genetic level. *M. vitigenus* makes only naphthalene as a VOC and its repellence of a plant-associated insect has been demonstrated. Other investigators have recently described novel species from around the world – *M. yucatanensis* (Mexico), *M. cinnamomi* (Thailand) and *M. fengyangensis* (China). Finally, many temperate areas of the world have been explored and examined for the presence of *Muscodor* species, with some success, namely an isolate of *Muscodor* has been found in *Prosopis* sp. in the Little Karoo of South Africa and *M. albus* has been discovered in *Ginkgo biloba* on Rhode Island, USA.

The newest addition to the list is *M. crispans*. This endophytic fungus resides within the stem tissues of *Ananas ananassoides*, a wild pineapple in the Bolivian Amazon. The fungus, like all other muscodors, produces no fruiting structures or spores of any kind when incubated on multiple synthetic or natural media. On PDA, its hyphae develop into regular undulating patterns and associated with them are cauliflower-like structures. Analysis of the VOCs by GC/MS showed that *M. crispans* primarily produces a number of esters, alcohols, and small molecular mass acids, but no naphthalene or azulene derivatives like other members of this genus. These volatiles also possess antibiotic properties, making this organism potentially useful in a number of areas. Recently, using multiple fermentation technologies, each of the important VOCs of *M. crispans* has been made. These products can be produced in large quantities and are being sold to control certain pathogens in humans, plants and animals. The product is sold as Flavorzon by Jeneil Biotech (NR Gandhi) of Saukville, Wisconsin, USA, and is one of the first products from endophytes on the international market. Each of the *M. crispans* ingredients being used are on the *Federal Drug Administration–Generally Regarded As Safe* (FDA-GRAS) list and it is registered with the Environmental Protection Agency in the USA.

A culture of *M. albus* (isolate 620). The culture shown is 10 days old, growing on potato dextrose agar. Note the undulations on the mycelial surface. These are characteristic of many isolates of this fungus. *G. Strobel*



Electron micrograph of interwoven hyphal strands of *M. albus* (isolate 620). Each individual small strand is about 2–3 µm in diameter. *G. Strobel*

'MYCOFUMIGATION' WITH *MUSCODOR* SPECIES

The VOCs of *M. albus* kill many of the pathogens that can affect plants, people and even buildings. The term 'mycofumigation' has been applied to the use of this fungus for decontamination. The first demonstration of its effects against a pathogen was the mycofumigation of smut-infected barley seeds for a few days followed by planting and harvesting. The resulting plants, in contrast to the untreated control group, produced no infected heads. Mycofumigation may also be important for the treatment of fruit in storage and transit. Soil treatments have also been effectively used in both field and greenhouse situations. In these cases, soils are pretreated with an *M. albus* formulation in order to preclude the development of infected seedlings.

Marrone BioInnovations, a US biotech company, is developing *M. albus* for numerous agricultural applications. The concept of mycofumigation as a safe, environmentally friendly treatment, for a multitude of uses, has the potential to replace hazardous substances that are currently applied to humans, food, soil and buildings. The most notable is methyl-bromide that ceased to be used for soil sterilization in 2007 because of toxicity and negative effects on the world's ozone layer.

CONCLUDING REMARKS AND FUTURE PROSPECTS

The impressive biological activity of *M. albus* and its practical use in agriculture and industry suggest that the fungus should be better studied in terms of its ecology and role in nature. Overall, the most pressing question regarding *M. albus* is the mode of action of the multitude of volatile compounds it produces and how they act synergistically to cause the death of microbes.

Certainly, knowledge of its host preferences and those factors controlling host preference may eventually allow for the use and development of this organism with a wider host range, resulting in further applications. Moreover, we need to learn if *Muscodor* isolates can be directly inoculated into agricultural and forest species in order to provide protection against invading pests and pathogens. In this regard, it has recently been discovered that *M. albus* has activity against certain plant -pathogenic nematodes and insects.

There may be some factors that limit the use of *M. albus* for biological control. One of the most important is that *M. albus* does not kill *Fusarium* species, a significant plant pathogen, but can inhibit its growth, which seems to be a universal observation with all isolates of *Muscodor*.

GARY STROBEL's interests centre on microbe–higher plant relationships, particularly endophytic fungi and bacteria; he is based in the Department of Plant Sciences, Montana State University, Bozeman, Montana 59717, USA (email uplgs@montana.edu)

FURTHER READING

Strobel, G.A., Dirksie, E., Sears, J. & Markworth, C. (2001). Volatile antimicrobials from a novel endophytic fungus. *Microbiology* 147, 2943–2950.

The nitrogen cycle

Various processes are responsible for recycling the chemicals necessary for life on Earth. The nitrogen cycle is the most complex of these. Carbon, sulfur and phosphorus are the other main cycles. In this article we explore how nitrogen is cycled and the important role of microbes in this cycle.

NITROGEN IS REQUIRED by all living organisms for the synthesis of organic molecules such as amino acids, nucleic acids and proteins. The Earth's atmosphere contains almost 80% nitrogen gas. It cannot be used in this form by most living organisms until it has been fixed, that is reduced (combined with hydrogen), to ammonia. Green plants, the main producers of organic matter, use this supply of fixed nitrogen to make proteins that enter and pass through the food chain. Micro-organisms (the decomposers) break down the proteins in excretions and dead organisms, releasing ammonium ions. These two processes form part of the nitrogen cycle.

THE NITROGEN CYCLE

The nitrogen cycle is the movement of nitrogen between the earth and the atmosphere. It consists of a series of processes that convert nitrogen gas to organic substances and these back to nitrogen in nature. It is a continuous cycle maintained by the decomposers and other bacteria. The nitrogen cycle can be broken down into four types of reaction and micro-organisms play roles in all of these (see Table 1).

NITROGEN FIXATION

Nitrogen gas is composed of two atoms of nitrogen linked by a very strong triple bond. This makes it chemically unreactive and large amounts of energy are required to break the bond. Nitrogen gas can be fixed in three ways.

1. Atmospheric fixation. This occurs spontaneously by lightning; only a small amount (5–8%) is fixed this way. Lightning allows nitrogen and oxygen to combine to produce various oxides of nitrogen. These are carried by the rain into the soil where they can be used by plants.
2. Industrial fixation. The Haber–Bosch process is used to make nitrogen-containing fertilizers. This is a very energy-inefficient process.
3. Biological fixation. Nitrogen-fixing bacteria fix 60% of nitrogen gas in the atmosphere.

BIOLOGICAL FIXATION

The reduction of nitrogen gas to ammonia is energy-intensive. It requires 16 molecules of ATP and a complex set of enzymes to break the bonds so that the nitrogen can combine with hydrogen. Its reduction can be written as:

$$N_2 + 3H_2 \xrightarrow{energy} 2NH_3$$

Relatively few bacteria (the nitrogen-fixing bacteria) are able to carry out this reaction. Fixed nitrogen is made available to plants by the death and lysis of free-living nitrogen-fixing bacteria or from the symbiotic association of some nitrogen-fixing bacteria with plants.

Red nitrogen-fixing nodules on the roots of a black alder tree (*Alnus glutinosa*). The nodules contain symbiotic bacteria (*Frankia* sp.), which take nitrogen from the air and convert it into forms the tree can use for nutrition. In return, the bacteria feed on sugars produced by the tree. This symbiosis means that the alder can grow in less fertile soils than many other plants. *Biophoto Associates / Science Photo Library*

TABLE 1. REACTIONS OF THE NITROGEN CYCLE

Reaction	Micro-organism	Conditions	Process
Nitrogen fixation	Nitrogen-fixing bacteria, e.g. *Rhizobium*	Aerobic/anaerobic	The first step in the synthesis of virtually all nitrogenous compounds. Nitrogen gas is fixed into forms other organisms can use.
Ammonification (decay)	Ammonifying bacteria (decomposers)	Aerobic/anaerobic	The decomposers, certain soil bacteria and fungi, break down proteins in dead organisms and animal wastes, releasing ammonium ions which can be converted to other nitrogen compounds.
Nitrification	Nitrifying bacteria, e.g. *Nitrosomonas*, *Nitrobacter*	Aerobic	Nitrification is a two-step process. Ammonia or ammonium ions are oxidized first to nitrites and then to nitrates, which is the form most usable by plant.
Denitrification	Denitrifying bacteria	Anaerobic	Nitrates are reduced to nitrogen gas, returning nitrogen to the air and completing the cycle.

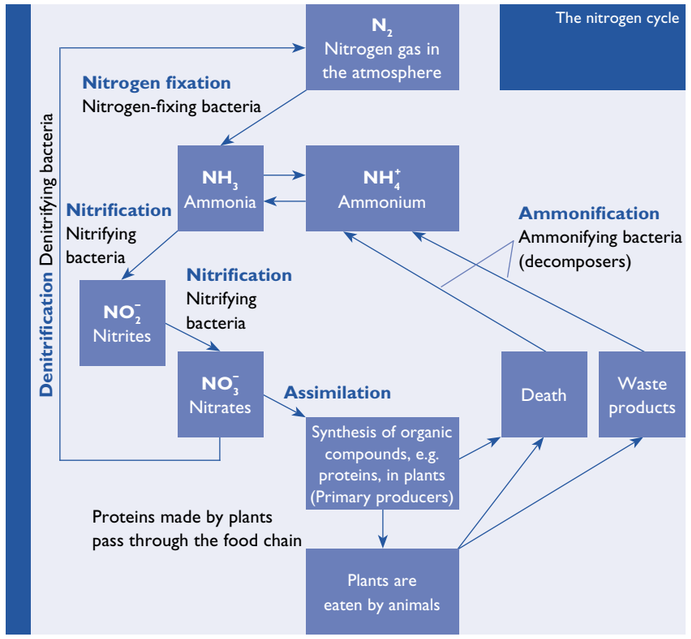
TYPES OF NITROGEN-FIXING BACTERIA

Some nitrogen-fixing bacteria are free-living in the soil, fixing nitrogen independently of other organisms, e.g. *Azotobacter* (aerobic) and *Clostridium* (anaerobic). Other nitrogen-fixing bacteria form symbiotic associations with plants.

Root-nodulated legumes, such as peas and beans, with e.g. *Rhizobium*. Free-living rhizobia invade the legume through an infection thread formed in the root hair of the plant. The infection thread is constructed by the root cells, not the bacteria, and is formed only in response to infection. The infection thread grows through the root hair cells and penetrates other root cells nearby, often with branching of the thread. The root cells then proliferate to form a root nodule. Within a week of infection, small nodules are visible to the naked eye. Each root nodule is packed with thousands of living *Rhizobium* bacteria (known as bacteroids).

Root-nodulated non-legumes, a diverse group of woody species such as alder, with e.g. *Frankia*. These filamentous bacteria infect the roots of plants forming actinorhizal root nodules.

Azolla (tiny free-floating water ferns) with e.g. *Anabaena azollae*. This is a cyanobacterium that infects new leaves of Azollas as they develop from the stem. Strings of *Anabaena* get caught in tiny leaf hairs that grow from a dimple on the developing leaf. The dimple grows larger into a pouch-like structure that eventually closes up, locking the *Anabaena* inside the leaf.



ADAPTING TO THEIR ENVIRONMENT

Nitrogen-fixing bacteria contain an enzyme complex called nitrogenase which catalyses the conversion of nitrogen gas to ammonia. It supplies hydrogen ions as well as energy from ATP. The nitrogenase complex is sensitive to oxygen, becoming inactivated when exposed to it. This is not a problem with the free-living anaerobic bacteria such as *Clostridium*. Free-living aerobic bacteria have a variety of different mechanisms for protecting the nitrogenase complex, including high rates of metabolism and physical barriers. *Azotobacter* overcome this problem by having the highest rate of respiration of any organism, thus maintaining a low level of oxygen in their cells.

Rhizobium contains leghaemoglobin. This functions similarly to haemoglobin,

i.e. it binds to oxygen. This provides sufficient oxygen for the metabolic functions of the bacteroids, but prevents the accumulation of free oxygen that would destroy the activity of nitrogenase.

Frankia and *Anabaena* are able to exclude oxygen by carrying out the fixation in specialized structures known, respectively, as a vesicle and a heterocyst. The thick walls of the vesicle and heterocyst form an oxygen diffusion barrier.

NITRIFICATION

This is the oxidation of ammonium compounds to nitrites and then to nitrates by the nitrifying bacteria. During these oxidation reactions energy is released. The nitrifying bacteria are chemoautotrophs and are able to use this source of energy to produce organic compounds from inorganic ones (photo-autotrophs use light energy to produce organic compounds from inorganic ones).

Nitrification is a two-step process.

1. Bacteria of the genus *Nitrosomonas* convert ammonium ions to nitrites (NO_2^-). (Nitrite is toxic to plants and animals in high concentrations.)

2. Bacteria of the genus *Nitrobacter* convert nitrites to nitrates (NO_3^-). The nitrates can then be taken in by plants.

Nitrification occurs in well-drained and aerated soils at neutral pH.

DENITRIFICATION

This is the conversion of nitrates into primarily nitrogen gas, but also nitrous oxide gas by the denitrifying bacteria, e.g. *Pseudomonas*.

Denitrifying bacteria transform nitrate in extremely wet soils and swampy grounds where there is very little oxygen, i.e. the conditions are anaerobic. The bacteria get the oxygen they need for respiration from the breakdown of nitrates. The gases that are formed escape into the atmosphere completing the nitrogen cycle. This can be a harmful process as fixed nitrogen is removed from the soil making it less fertile.

AMMONIFICATION (DECAY)

This is the conversion of organic forms of nitrogen (e.g. in dead organisms and their excretions) into inorganic nitrogen. A wide range of soil fungi and bacteria, called the decomposers, carry out the ammonification process. The decomposers consume the organic matter, and the nitrogen contained in the dead organism is converted to ammonium ions. The ammonium is then converted to nitrates by the nitrifying bacteria.

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Practical – isolating microbes from root nodules

LEARNING OBJECTIVES

To show the role of microbes in the nitrogen cycle, how microbes can be grown from root nodules and an example of symbiosis

MATERIALS

- Plant with root nodules, e.g. clover, peas
- Mannitol yeast extract agar plate [*Recipe. Suspend 10 g agar in 1 litre water. Heat to dissolve. Add 0.5 g K_2HPO_4, 0.2 g $MgSO_4.7H_2O$, 0.2 g NaCl, 0.2 g $CaCl_2.6H_2O$, 10 g mannitol and 0.4 g yeast extract. Dispense and sterilize by autoclaving.*]
- Sterile distilled water in beaker (covered)
- 70% (v/v) industrial denatured alcohol in a small beaker or glass Petri dish covered in foil (*caution*: flammable, keep covered and away from lit Bunsen burner)
- 5 sterile Petri dishes
- Bunsen burner
- Pasteur pipettes: 1 sterile, 1 non-sterile
- Sterile glass rod
- Scalpel
- Metal forceps (can be pre-sterilized by autoclaving)
- Wire loop
- Beaker of disinfectant
- Discard pot
- Marker pen
- Adhesive tape

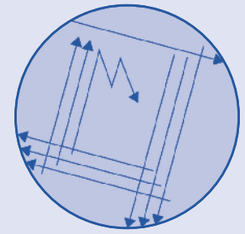
Root nodules on clover roots. *Dr Jeremy Burgess / Science Photo Library*

RECOMMENDATIONS

1. Advance planning is necessary to obtain suitable plant material. Clover (obtain seeds from school science suppliers or plants from a field or lawn) is recommended as the nodules are relatively soft.
2. Potato dextrose agar supplemented with 0.25 g yeast extract per litre may be used instead of mannitol yeast extract agar.
3. The plates should be incubated preferably at 20–25°C or at room temperature for 2–3 days.
4. If the nodules are cleaned well in the alcohol, a population of predominantly *Rhizobium* should result. Students should be informed that they are using sterile apparatus so that any bacteria that do grow on their plates are likely to have come from the root nodules.
5. 1% bleach solution can be used instead of alcohol to clean the nodules.
6. The colonies of *Rhizobium* are off-white with a sticky appearance. Colonies of other colours are *not Rhizobium*; they may be either intracellular contaminants from the nodule or soil microbes that have survived the washing and alcohol treatment.

PROCEDURE

1. Choose a length of root that has nodules and cut off a portion about 1 cm long using a scalpel. Hold the portion of root by forceps and wash free of soil using tap water.
2. Transfer several drops of 70% (v/v) industrial denatured alcohol by Pasteur pipette fitted with a teat to a sterile Petri dish. The pipette need not be sterile for this operation; put the pipette into a discard pot. Transfer the washed portion of the root to the alcohol in the Petri dish with forceps and leave immersed for 1–2 minutes to sterilize it. Use aseptic technique from this stage forward.
3. Transfer sufficient sterile water to cover the base of another Petri dish using a sterile Pasteur pipette fitted with a teat. If it is necessary to re-use the pipette, keep it sterile, e.g. by resting under the lid of a sterile Petri dish base.
4. Use sterile forceps or sterilize them by dipping in alcohol (keeping the points facing downward) and passing quickly through the Bunsen burner flame, allow to cool and use to transfer the portion of root to the sterile water in the Petri dish to rinse off the alcohol. Repeat this operation at least twice more with fresh sterile water. If using alcohol take care to keep the pot well away from the Bunsen burner flame.
5. Transfer a few drops of sterile water to a sterile Petri dish and add the portion of root using sterile metal forceps. Macerate the nodules using a sterile glass rod (or forceps) to produce a milky fluid.
6. Label the base of a mannitol yeast extract agar plate with your name, the date and MYEA. Sterilize a wire loop by flaming, cool it, take a loopful of the nodule macerate and streak it out on the plate as shown here:



Reflame the loop. Tape the lid on the plate, invert it and incubate for 3–4 days. Dispose of contaminated materials appropriately.

Next lesson…

7. Examine the MYEA plate without removing the lid, noting the appearance of any colonies growing on the agar.

Reproduced from the SGM publication Practical Microbiology for Secondary Schools. *This publication and its companion* Basic Practical Microbiology *(which contains details of how to carry out a risk assessment) are available free to School Members. Please contact Yvonne Taylor (y.taylor@sgm.ac.uk).*

Would you like to see glow-in-the-dark algae? Would you like to see green, tailed cells swimming in spirals through still water? How about growing these micro-organisms yourselves? Well you can! In just a few weeks and in your classroom.

CCAP biodiversity. © *CCAP*

The Culture Collection of Algae and Protozoa

THE CULTURE COLLECTION OF ALGAE AND PROTOZOA (CCAP) at the Scottish Marine Institute (www.smi.ac.uk) has designed a culture kit with all you need to culture samples of two types of algae, one freshwater and one marine.

Euglena gracilis is green like a land plant, but is found in freshwater ponds and uses its whip-like flagellum to propel itself through motionless water.

Pyrocystis lunula is a bioluminescent dinoflagellate that lives in the ocean and although in the daylight it is a dull brown colour, it can glow bright turquoise in the dark. This luminescent function is not fully understood but it is likely to help deter predators. Shaking the sample during its dark phase induces this luminous response.

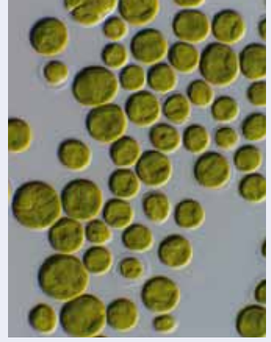
The CCAP culture kit has been designed to accompany the recently launched Society for General Microbiology publication *Algae: a practical resource for secondary schools* (see www.sgm.ac.uk). *Euglena gracilis* is used in Practicals 2, 4 and 5, and *Pyrocystis lunula* is used in Practical 3 in the SGM resource. The CCAP kit includes an instruction leaflet on culturing and everything necessary to make the growth media to provide the algae with the nutrients they need to thrive.

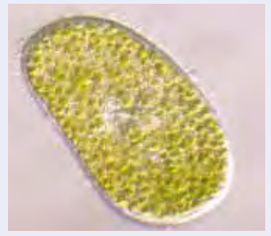
UK secondary schools can purchase the culture kit for £29 (including P&P) from www.ccap.ac.uk

THE COLLECTION AND BIODIVERSITY

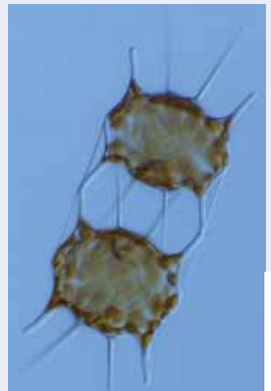
CCAP is housed in purpose-built laboratories within the Scottish Marine Institute near Oban in the west of Scotland with direct access to coastal waters. The Collection contains about 3,000 living strains of microalgae, cyanobacteria, seaweeds and protozoa from marine, freshwater, hypersaline and terrestrial environments, making it the most taxonomically diverse microbial culture collection in Europe. New strains are continually being added to the Collection, found for example, in local seawater samples, collected on polar research cruises, or donated by external scientists. Some cultures, however, have been in the collection for over 90 years having been isolated by the founder E.G. Pringsheim in the early part of the 20th century.

As part of its core work, CCAP is currently sequencing and identifying 'barcode' marker genes for all its strains to help sort out the complicated taxonomy of algae and protozoa species. Taxonomy is the science of identifying, naming and classifying organisms.





A few examples of CCAP stock cultures. © *CCAP*



THE COLLECTION AS A SERVICE

CCAP acts as a service culture collection, providing biological materials, bioinformatics data, advice and services to the scientific community worldwide. Strains can be ordered directly online from our website (www.ccap.ac.uk), and every week cultures are sent from Oban to academic research laboratories, biotechnology companies and aquaculture establishments all over the world. If an algal strain is part of a patent, it must be deposited in a recognized culture collection for 20 years. CCAP is an International Depository Authority (IDA) of Micro-organisms for the Purposes of Patent Procedures and Regulations. In the past few years, with the need to identify sustainable biofuels as an alternative to fossil fuels and increased interest in algal biotechnology, CCAP has seen an exponential rise in the number of patent strains deposited as researchers try to find the biodiesel 'super-strain'.

TRAINING

CCAP run two short CPD courses to help match the growing interest in algae and the need to train research staff and postgraduate students in the specialized techniques involved in culturing, maintenance and DNA extraction. For more information on these and other courses offered by SAMS, visit www.smi.ac.uk/education/short-courses

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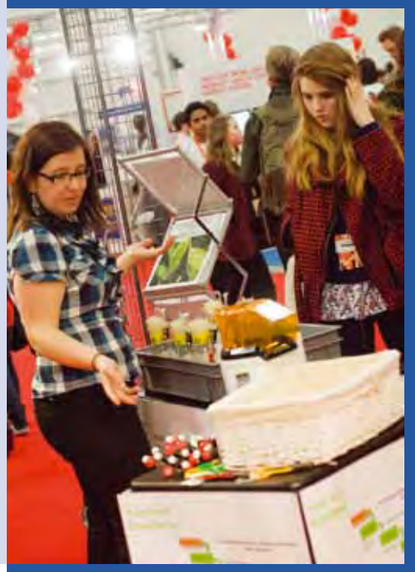
Biofuels School Engagement

The Biotechnology and Biological Sciences Research Council (BBSRC) has recently launched a series of practical biofuel activities for school engagement and outreach. The collection is part of an online toolkit to enable researchers to engage the public with the issues surrounding bioenergy and biofuels.

IN OCTOBER 2010, BBSRC held a workshop to hear from scientists, educationalists and public engagement professionals, and collate ideas for engaging and communicating with the public and young people about the research being conducted in the fields of bioenergy and biofuels. The workshop was attended by researchers involved in fields ranging from algae to perennial bioenergy crops alongside representatives from a number of science education organizations, including Science and Plants for Schools (SAPS), the Society for General Microbiology (SGM) and the National Centre for Biotechnology Education (NCBE). A huge number of ideas were suggested from smart phone apps to pub science props and, over the following months, a selection of key activities and resources were chosen for development into resources to enable dialogue and discussion, as well as to support the education of young people.



Trialling activities at various science fairs, and attracting attention from celebrities such as John Tickle (*top right*). *BBSRC*

The aim of the resources was to provide some hands-on practical activities that scientists could confidently use in school or at science fairs. It was important that researchers could carry out activities that were safe and structured to effectively enhance the learning of young people while providing the opportunity to discuss the cutting edge research that is being undertaken. There have been concerns that practical science in schools is in decline and these hands-on investigations will hopefully help scientists to address this.

Over 30 researchers, including many members of the BBSRC Sustainable Bioenergy Centre and four BBSRC-funded institutes, contributed to the development of the resources and trialled activities at science fairs and schools. Events were held at regional and national *Big Bang* fairs, Edinburgh International Science Festival, in schools and at a host of smaller science fairs, attracting attention from the public, peers and celebrities, including Lord Sainsbury and Jon Tickle. As a result, over 20 activities were developed that span a wide range of bioenergy research, along with supporting materials that cater for a range of interactions and audiences.

From the start, it was important that the resources catered for both researchers and teachers. To try and achieve this aim, the content included the background science to biofuels, learning outcomes, useful facts and figures, images, and health and safety advice. It was important to provide both early-career researchers and senior scientists, many of whom are world experts in their specialist chosen field, with an overview of the breadth of the bioenergy field and a set of key phrases and terms that they could use confidently and appropriately to convey the key ideas and issues to young people. For teachers who want information on the cutting edge research to pass on to their pupils, the background information provides an introduction to the field and links to the work that is being carried out to tackle climate change and energy security.

The resources were designed to make it easier for researchers to apply pedagogical approaches to facilitate learning in their engagement activities and for teachers to deliver activities in the classroom by incorporating learning outcomes, curriculum links, supporting PowerPoints, literacy activities and a pupil-friendly glossary. Likewise, though scientists are often very familiar with health and safety procedures in the laboratory, the regulations and safe working practice in schools or at public science events can be somewhat unfamiliar and it was desirable that they could carry out activities that would be appropriate for the environment.

Some of the activities are based on existing investigations used in school that will be familiar to teachers. They build on the development and experience in delivery of practical activities by science education organizations, including SAPS, SGM, NCBE and capture outreach initiatives by researchers, such as *Meet the Algae* created by Professor Alison Smith's group. By linking the practicals to current biofuel research and adding new dimensions, they provide a rich context to inspire and enrich the experience and understanding of young people.

The activities have been received extremely well and are now available online: www.bbsrc.ac.uk/society/schools/practical-biofuel-activities.aspx

TRISTAN BUNN is the Inspiring Young Scientists Co-ordinator for the Biotechnology and Biological Sciences Research Council (BBSRC) (email tristan.bunn@bbsrc.ac.uk)

Job seeking – strategies, stories and words from a recruiter

With final-year undergraduates preparing for their final assessments and final year PhD students immersing themselves in thesis writing, thoughts will soon turn to the question '*what next?*' In this article, Karen McGregor offers some advice to undergraduate and postgraduate students about how to find that first job. There is not the space here to cover every single aspect of this topic – we could take the whole magazine over! The article is largely aimed at looking for research jobs and Karen has included her own stories of seeking (and gaining) work in this area.

STRATEGY 1 – USING YOUR CONTACTS

When you are looking for a job, the old adage '*it's not what you know but who you know*' still rings true. It's a good idea to let as many people as possible know you are looking for a job – tell your university lecturers, people you have met at conferences and colleagues at your institution.

Remember your broader network of contacts as well – family, friends and neighbours. Even if they don't work in science, you never know whether they might have contacts that do.

In recent years, the opportunities to create a network of online contacts have boomed. Of particular relevance to job seekers are *LinkedIn* and *Academia*. Many specific topic groups exist on *LinkedIn* and the site includes the possibility for jobs to be advertised within these groups. Why not join a few groups to get access to the jobs information? Being an active member of the group (joining discussions and posting comments) can also help raise your profile within this field.

MY STORY

'I knew that at the end of my PhD I wanted to continue in research and get a job as a postdoctoral researcher. In my final year I specifically chose to go to conferences where I knew several people I potentially wanted to work for were attending. Rather than introduce myself (which was a bit scary) I got my supervisor to introduce me. He did introduce me as "this is Karen, she wants a job" – thanks Tom! – but at least it got straight to the point. Following the initial introduction I asked if they could spare some time to have a coffee with me to discuss their work and whether they had any projects coming up that might be suitable for me. As I knew in advance that they were attending the conference, I had already researched them and their laboratories so that I could discuss their work with them in an informed, and I hoped an intelligent-sounding, way. Although I didn't end up working for any of the people I met, one of them did tell me about a position his colleague would be advertising later in the year, and the rest, as they say, is history…'

STRATEGY 2 – TARGETED SPECULATIVE ENQUIRES

If there is a particular organization, or laboratory, you would like to work for you could consider contacting them on a speculative basis. This strategy can work well for grant-funded research posts as laboratory leaders will know what positions they might – depending on the success of funding applications – have available up to a year before they are in a position to advertise.

In your enquiry email, or covering letter for postal enquires, you need to say very clearly why you are contacting them and why you think you are suited to work in their organization/laboratory. Use positive language about yourself – choose words that are active and strong. You should give some information on what you are looking for (full-time, part-time, etc.) and when you would be available to start.

Supply a CV. Although you are not applying for a specific job, the CV should still be targeted to the organization/laboratory you are writing to.

MY STORY

'In the final year of my first postdoc, I started looking for another postdoc position. I wrote to three principal investigators I was interested in working for. I had never met any of them previously so I was a complete stranger to them. All three replied to me and I went to visit two of them. It was great to meet them informally and, unlike a job interview, it was very much a two-way process with me able to ask all the questions I had about their work, the set-up of the lab, where they saw the future of their research, what they expected of postdocs in their lab, and many other things. In fact, now I think about it, it was more like I was interviewing them! My second postdoc was with one of the people I met through this speculative enquiry. I still had to go through the process of applying for the position when it was advertised, but I think that having met them first and established that they ran the type of laboratory I wanted to work in, helped me target my CV to the position better and made me feel (slightly) more confident in the interview.'

Got a question about your own professional development or finding a job in microbiology?

I can be contacted at any time of the year at **careers@sgm.ac.uk**. I don't guarantee to know everything about every area of microbiology, but I may give you information and ideas that you hadn't already considered.

CAREER MICROBIOLOGISTS – UPDATES AND ADVICE FOR EARLY

STRATEGY 3 – APPYLING FOR ADVERTISED POSITIONS

Science jobs are widely advertised in newspapers, scientific magazines and journals, and on websites. Application is by CV with a covering letter or, increasingly, by online application form. The main purpose of the application is not to get you the job but to get you an interview (the purpose of the interview is to get you the job!). You should put time and effort into every application and, most importantly, tailor the application to the job. There are many websites providing information and tips for writing CVs and application forms.

If you are based in a university, your careers service is an excellent place to start for advice on your CV (particularly about whether you are providing appropriate evidence of your skills). They will also be able to help you with interview techniques. Even after you have finished your studies you will often still have access to this service.

If you are not at the stage of applying for jobs, it is useful to routinely search websites to see what opportunities there are in your field of interest. Don't just read the job titles; examine the details to see what the job involves and what the person specifications are. This will help you identify any gaps in your skills and experience that you can work on filling before you are at the stage of applying for positions.

MY STORY

'In addition to the two jobs I have already mentioned, I have applied for five advertised positions in my career, was invited for interview for all five and got job offers from two of them. From my stories above you will have seen that I like to go in 'eyes open' when looking for jobs. You can't always do this with an advertised position as you (often) don't know the company, or how they work. I therefore find it very useful to phone before submitting my application – advertised positions do come with contact information after all – to ask them more details about the job and about the general working environment.'

A WORD FROM A RECRUITER

Catherine Gutsell from CK Science (http://ckscience.co.uk/) says:

'We see many people who are sending out generic CVs and wondering why they aren't getting job offers. It is so important to tailor your CV for every single job, ensuring that the information you are giving is relevant for that position.

Perfect spelling and grammar is essential. Have your CV checked by as many people as possible. The most important place to get the information correct is your contact details. It sounds crazy that people can misspell their own name, or mistype their contact phone number, but it happens more often than you would think.'

If you would be interested in seeing a similar article about job-seeking or a more detailed article on one (or more) of these strategies in a future Gradline, or have any other suggestions for stories, please contact me at **careers@sgm.ac.uk**

STRATEGY 4 – RECRUITMENT AGENCIES

There are many recruitment agencies out there, including many that specialize in science jobs. The role of the recruitment agency is to fill specific positions for a variety of employers (their clients). They will put forward a number of potential employees (candidates) to the client.

What each recruitment agency offers to candidates will differ, but typically they will help you ensure that you are marketing yourself in the best possible way and work with you on improving your CV. There should be no fee for the candidate to register with the agency.

You can register your details with more than one agency – joining two or three different agencies will give you access to a greater number and range of jobs. Different agencies may specialize in different areas, so carry out some research before you register to make sure they specialize in the area you are interested in.

Although the recruitment agency is not the one hiring you, it is important to always be professional in your dealings with them, including when you first register (first impressions always count). This will help ensure that they get a good impression of your abilities and therefore will be better able to highlight these abilities to the client.

A WORD FROM A RECRUITER

Catherine Gutsell from CK Science (http://ckscience.co.uk/) says:

'The positions we get contracted to fill are mainly laboratory-based, from junior to very senior posts, on a permanent or short-term basis. We work with companies of various sizes in all areas of science, from medical, to food, to biotechnology, to oil and gas. To ensure we match our clients' recruitment needs, we work very closely with candidates to establish the type of position and company they want to work in and what their long-term goals are. We offer extensive CV advice and support. We will contact candidates when positions come up that we think they may be suitable for.

My best advice to your readers considering seeking employment through CK science would be:

***For graduates**, it is very helpful if you have some industry experience – having done a placement as part of your studies is ideal. If you are still early on in your studies, consider getting some work experience during your summer vacations.*

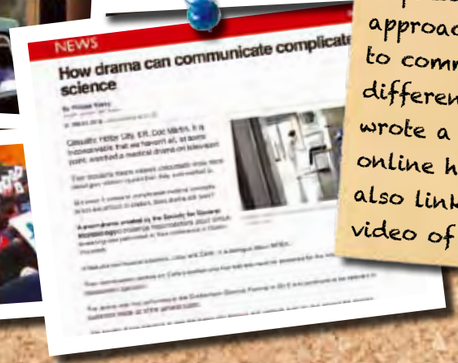
***For postgraduates (and postdoctoral researchers)**, think carefully about what you want long term and your expectations of a position in industry. The reality is that you may not get your ideal job on your first move into industry – but you should view it as a first rung of the ladder.'*

WANT TO FIND OUT MORE?

- **SGM microbiology careers website (www.sgm-microbiologycareers.org.uk)**
  Includes free resources on writing CVs and covering letters and job interviews
- **Next Steps: options after a bioscience degree (www.societyofbiology.org/documents/view/794)**
  A careers guide for biological sciences students and graduates
- **Science Recruitment Agencies**
  List available at University of Kent Careers and Employability Service (www.kent.ac.uk/careers/sitephar.htm)
- **Science job websites**
  www.prospects.ac.uk (for advice on careers, jobs and study)
  www.jobs.ac.uk
  www.jobsite.co.uk
  www.careerscene.com
- **Think 'Skill' not 'DPhil' (www.biosciencecareers.org/2012/01/think-skill-not-dphil.html)**
  Blog by Sarah Blackford with examples of how to effectively describe and demonstrate all the great transferable skills you have gained as a researcher to employers in a variety of fields
- **Vitae (www.vitae.ac.uk)**
  Essential information for researchers looking for jobs in (and out of) research, including:
  Marketing yourself – a skill for life (www.vitae.ac.uk/researchers/1339/Marketing-yourself.html)
  List of online careers support information (www.vitae.ac.uk/researchers/1679/Websites.html)
- **Guardian Careers live q&a sessions (http://careers.guardian.co.uk/live-q-and-a/discuss)**
  Covers a variety of targeted topics, e.g. Masters degrees – do employers value them?

Séamus Fanning, Tom Humphrey, Mark Stevens and Nigel Brown conveyed a clear message about how microbiology research can improve food safety at a press conference, reinforcing key points in SGM's Position Statement on Food Security & Safety. The event was live-streamed!

RTÉ Radio One's Science Correspondent was in the audience at our public event 'Stopping the Spread of Superbugs'. Clips from the play and interviews with the panel were featured on the Mooney Show – audience ~400,000 listeners!



The BBC was also impressed with SGM's novel approach of using drama to communicate science to different audiences and wrote a feature for their online health pages. They also linked to the online video of the play. :)

MICROBIOLOGY IN THE PRESS

TOP STORIES from the Conference

PRESS
SGM Spring Conference
Dublin 2012

Richard Elliott was quoted in The Sunday Telegraph talking about Schmallenberg virus, ahead of his Hot Topic lecture on the subject.

TAKING MICROBIOLOGY TO THE PUBLIC

SGM AT THE BIRMINGHAM BIG BANG

MARCH 15–17 saw more than 55,000 people congregate in Birmingham's NEC for *The Big Bang* – the UK's annual young scientists and engineers fair. As the largest single celebration of science, technology, engineering and mathematics for young people in the UK, *The Big Bang* brings together more than 150 organizations from the public, private and voluntary sectors with the united aim of inspiring the scientists and engineers of the future.

SGM was proud to be one of the sponsors of this fantastic event for the third year running and to sit on its stakeholders committee.

As well as sponsoring the event, the SGM were there to raise awareness of the wonderful world of algae with our new offering *The Good, The Bad and The Algae!* After the success of the recently launched *Algae: a practical resource for secondary schools*, we decided to make algae the sole focus of our stand at *The Big Bang*.

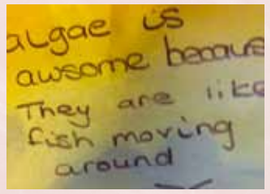
Arriving the day before the event opened, Yvonne, James and I had the usual teething problems associated with an event of this size (i.e. what had happened to our tables!) but we were soon able to get going. We set up an 'identifying algae activity' using LCD-screen digital microscopes and an identification key. Representing this hugely diverse group of micro-organisms we had the beautiful filamentous *Spirogyra*, the star-shaped *Pediastrum*, the huge colonies of *Volvox*, the motile *Chlamydomonas*, the even more motile *Euglena* and the fascinating diatoms. On the stand we also had a plasma screen showing a slideshow of 3D images of multicellular algae which we used to further show the diversity of this group. Finally, we had 'the algae drop'; this activity proved to be a great draw. The algae drop was a Perspex box which represented 10 µl of water from a summer pond. We invited attendees to model an alga of their choice – from some green plasticine – to scale, (2 cm wide) using the algae they had seen on the microscope screens for inspiration, and hang it in our drop with the intention of showing the density of these micro-organisms in a drop of water. On day one we had 224 algae, day two 247 and day three 368! In 1 ml of water from a summer pond you might expect to find 20,000 algae so in 10 µl you would expect around 200 individual algal cells, therefore each day *The Big Bang* audience had demonstrated eutrophication in our 'pond'!

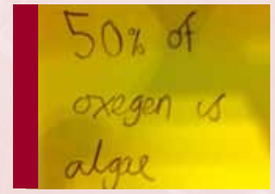
Among many other fantastic algae facts *The Big Bang* attendees all went home with the knowledge that the silica in toothpaste and dynamite and the carrageenan in ice-cream all originate from algae! This delighted more than a few!

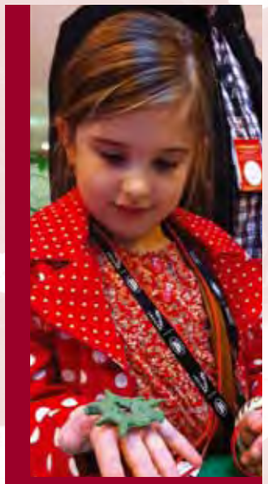
The Big Bang was a huge success for us again this year; we interacted with over 2,200 people across the 3 days and as usual we couldn't have done it without the help of the fantastic SGM staff and volunteers and to them we are amazingly grateful: James, Laura, Dariel, Yvonne, Richard, Sue, Karen, Dave, Jane, Lydia, Chris, Vydeki, Tom, Chandrika and Avika! We are also very grateful to Jane Lewis from the University of Westminster for sharing her algae drop activity with us, and to Chris Carter for supplying us with 3D images for the stand.

If you are interested in experimenting with algae please get in touch to order your copy of *Algae: a practical resource for secondary schools* (y.taylor@sgm.ac.uk). Further photographs from this event can be seen on our *Facebook* page. If you would like to volunteer for SGM at future events please let me know.

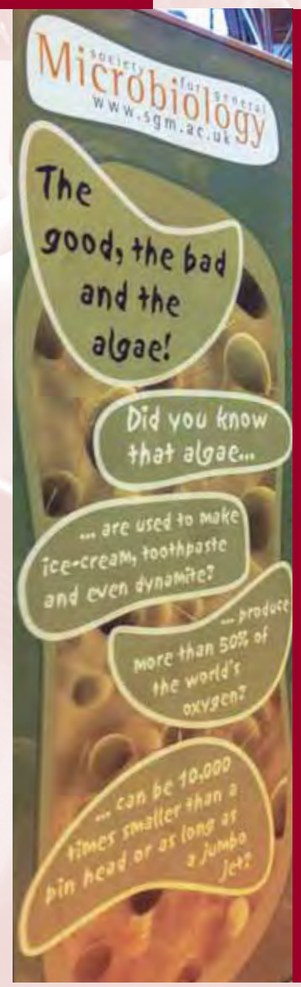
VICKI SYMINGTON is the SGM Education & Outreach Officer (email v.symington@sgm.ac.uk)







What do dynamite, ice-cream and toothpaste have in common? If you had been in Birmingham's NEC in March you'd know!



SGM staff, volunteers and visitors to the SGM stand at the 2012 *Big Bang*. *V. Symington*

Industry, academia and learned societies search for solutions to the pharma jobs crisis

Against a backdrop of disastrous employment news from the pharmaceutical industry – AstraZeneca's job cutting plans were announced the week before – 40 representatives from academia, the chemical industry and learned societies, including SGM, met on 8 February to ask how to kick-start job growth in drug discovery.

DR DAVID ALLEN, Senior Vice-president for R&D at GlaxoSmithKline (GSK) and a chemist by training, set a gloomy tone with the prediction that there would be no return to the 'boom years' of the 1980s, with research efforts often being scaled back.

While he felt British science graduates had the right skills to succeed in industry, stable employment as a pharmaceutical researcher in a large firm might be a thing of the past. The big companies were hiring fewer people and did not always participate in 'the milk round' – once the conventional means of recruiting high-calibre graduates.

Some companies were less inclined to offer industrial placements for undergraduate students, while the commercial benefits of interaction at PhD level would need to be proven case-by-case.

Beyond the recruitment strategies of individual pharmaceutical firms, many agreed that what mattered was a strong base for future innovation and job growth. This included the small- and medium-sized enterprise (SME) sector that might increasingly draw life science graduates with industrial ambitions, now that in-house research in 'big pharma' was being scaled down.

The Ethical Medicines Industry Group (EMIG) that represents part of the sector has indicated that SMEs currently constitute 90% of all pharmaceutical companies in the UK and collectively employ over 10,000 people. A particular type of SME, the contract research organization (CRO), has emerged from the latest spate of closures in big pharma. The Research Network popped up at Pfizer's former centre in Sandwich, and Aurelia Biosciences emerged last year from AstraZeneca's Chamwood site.

Even large firms like GSK now try to mimic SME management structures, according to a briefing issued in February by the Economist Intelligence Unit.

To succeed in this new environment, delegates at the meeting felt that recruits had to be flexible and open to collaboration, as well as able to exchange freely between jobs in academia and industry as their career progressed.

The familiar call for flexibility did not just apply to employees – but also to employers. The problem was that industry experience could block an academic career, where the focus was on peer-reviewed papers rather than marketable products.

Continuing professional development (CPD) accreditations were suggested as one way of making skills transferable between sectors. But there was concern that continued emphasis on scientific publications in the new Research Excellence Framework (REF) might thwart university academics' attempts to collaborate with the private sector.

Joanne Lyall, Chief Executive of the Society for Chemical Industry, talked-up the need for connections between the varied actors involved in drug development. SMEs might usefully make links both with academia and with the more-established companies, but they often didn't know who to call on.

While multinational pharmaceutical companies appeared to be scaling back in-house R&D in the UK, they were also expanding their research efforts overseas, for example in China, in what has been described as 'the third wave of globalization'. This process was led in the early 1990s by electronics and IT firms such as Nortel Networks and Microsoft, but has now spread to the pharmaceutical sector.

A report from Monitor Group, a leading American strategy firm, claims that 'China's life sciences industry is quietly gathering a critical mass of skilled talent and savvy and focussed venture investors, all tied to increased support from the Chinese government.'

Both AstraZeneca and GSK opened research institutions in China in 2007. AstraZeneca employs 3,500 staff in the country and operates a US$100 million research centre in Shanghai. On its website, the company says that it is "*committed to being 'In China, For China; In China, For Global' with long-term planning and investment.*"

Future research openings for bright UK graduates might lie overseas as well as in a diverse range of companies with R&D nodes in Britain.

WHO MATTERS IN UK PHARMA?

Established firms

GlaxoSmithKline (GSK)
Glaxo started life in 1904 as a New Zealand-based powdered milk supplier. Employs 3,700 research staff in the UK over seven R&D sites.

AstraZeneca
Anglo-Swedish group which incorporates the pharmaceuticals arm of the defunct British chemical giant, ICI, founded in 1926. In 2009, it employed 11,000 staff of all types over eight sites.

Novartis UK
Traces its history back to 1758 and a druggist in Basel, Switzerland. Employs 3,600 staff over eight sites in the UK. The Novartis Vaccines facility in Liverpool is the UK's only large-scale producer of influenza vaccines.

On the way up?

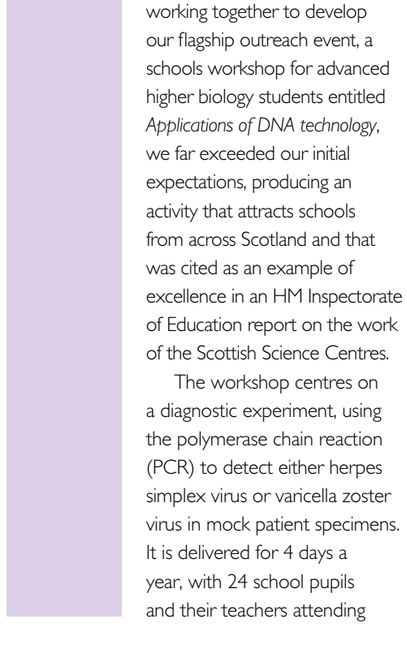
BioCity Nottingham
Opened in 2003 as a 'bioscience incubator' backed by Nottingham Trent University, The University of Nottingham and the East Midlands Development Agency, the incubator now hosts over 70 companies and 600 staff.

Global Medical Excellence Cluster (GMEC)
London-based business cluster founded in 2008 and comprising five leading UK universities, the National Health Service, GSK, GE Healthcare and Pfizer.

Stevenage BioScience Catalyst
A 'bioscience community' for biotech and life sciences start-ups, giving them access to high-end expertise from established pharmaceutical firms. Funded by GSK, the Wellcome Trust and the UK Government, it opened this year.

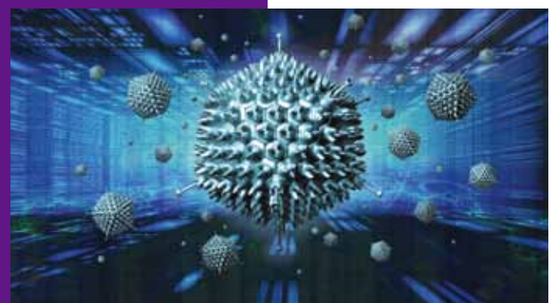
WILLIAM BURNS is the SGM Policy Officer (email w.burns@sgm.ac.uk)

INFECTIOUS ENGAGEMENT AT THE MRC CENTRE FOR VIRUS RESEARCH



Dr David Bhella, a programme leader at the Medical Research Council – University of Glasgow Centre for Virus Research (CVR) discusses working with Glasgow Science Centre to deliver public engagement activities.

A selection of images from the *Applications of DNA technology* workshop and the *Molecular machines* art exhibition. *D. Bhella*



'IT STINKS!' shrieked a young girl as she opened the universal containing a fake stool sample that I had just passed her. As icebreakers go a small bottle of pretend poo might be considered rather unconventional; however, when participating in a *Meet the expert* day at Glasgow Science Centre (GSC) recently, a mocked-up norovirus latex agglutination test proved ideal. Inviting a public audience to perform a 'real' experiment is hugely enjoyable, both children and adults alike revel in the opportunity to use scientific equipment; a favourite of mine is the humble vortex mixer, which never fails to elicit giggles and laughter. For younger children at an adjacent bench in the GSC science mall, students and postdocs were delivering our 'build a virus' activity, a gentle introduction to virus structure involving play dough, small plastic gaming pegs and shredded paper. This fun, friendly activity allows us to teach some very young children surprisingly challenging concepts, such as the function of a genome and the need to protect it, the intracellular parasitic nature of viruses and the role of structural proteins in engaging and entering the host cell.

APPLICATIONS OF DNA TECHNOLOGY WORKSHOP

Meet the expert days at science centres and museums are a perfect way for scientists to begin to engage with a public audience in a fun, supportive environment. The CVR enjoys a strong working relationship with the education team at GSC, providing access to a large public audience as well as contact with schools across Scotland. Moreover the team's expertise in developing exciting workshops for all age groups and their in-depth understanding of the Scottish curriculum, teacher's requirements and cutting edge educational theory, have proven invaluable in helping us to ensure that we deliver high-quality engagement activities. In particular, by working together to develop our flagship outreach event, a schools workshop for advanced higher biology students entitled *Applications of DNA technology*, we far exceeded our initial expectations, producing an activity that attracts schools from across Scotland and that was cited as an example of excellence in an HM Inspectorate of Education report on the work of the Scottish Science Centres.

The workshop centres on a diagnostic experiment, using the polymerase chain reaction (PCR) to detect either herpes simplex virus or varicella zoster virus in mock patient specimens. It is delivered for 4 days a year, with 24 school pupils and their teachers attending each day, providing them with the opportunity to meet and work with CVR scientists, technicians and students. Indeed involvement of all categories of staff is one of the strengths of this event, giving insight into the various roles in academic research laboratories and providing our PhD students with valuable experience of public engagement. A key element of the workshop is an ethics debate that takes place in groups of six with a CVR or GSC facilitator to play devil's advocate. The students are asked to consider who should have access to their genome sequence information if the Government undertake to sequence the genomes of the entire UK population? They are presented with a selection of groups, such as their parents, government scientists, pharmaceutical companies, etc., and are first asked to discuss their views in pairs before bringing decisions to the group for further discussion. The debate can yield some surprising outcomes and brings the complex ethical questions brought about by modern molecular biology into sharp focus.

Most schools do not have the resources to teach molecular biology and teachers often lack confidence in their ability to cover emerging technologies adequately. The creation of *Applications of DNA technology* was therefore entirely driven by audience need.

MOLECULAR MACHINES

Another recent project, an art–science exhibition *Molecular machines – images from virus research* targeted a public audience in the broadest sense. The motivation to create an art exhibition, however, came from my interest in virus structure and assembly rather than a defined target audience or need. My research employs cryoelectron microscopy and computerized three-dimensional image reconstruction to investigate virus structure and host interactions. The resulting 3D structures can be strikingly beautiful, owing to their high symmetry. Images of such structures as well as data produced by techniques such as confocal fluorescence microscopy are both captivating and intriguing. To help develop our image data into an exhibition, we worked with renowned Glasgow artist Murray Robertson who had previously produced the highly successful 109 visual elements exhibition in partnership with the Royal Society of Chemistry. GSC helped to secure funding for the project from the Scottish Government, provided a

venue for the launch and initial display of the exhibition, and arranged for the exhibition to tour the Scottish science centres (*Our Dynamic Earth* – Edinburgh, *Dundee Science Centre* – Dundee and *Satrosphere* – Aberdeen). The exhibition was a great success and achieved considerable coverage in both print and broadcast media.

WHAT HAVE WE ACHIEVED?

Working with GSC has allowed the CVR to develop an ambitious outreach programme that has had impact across the whole of Scotland and has raised the profile of the CVR, MRC and University of Glasgow. We have built a portfolio of proven engagement activities that have been delivered at both Edinburgh and Glasgow science festivals and I think we have gone a long way towards embedding public engagement within the CVR's ethos. Events such as these allow a depth of engagement that can be deeply rewarding, in particular postgraduate students are invariably excited by the experience of working with the public and school students. I hope that they will carry forward this enthusiasm for public engagement as they become the next generation of virologists in the UK. I chose to pursue a career in biology as a direct result of the impact a school field trip to ancient woodland had on me. I didn't become an ecologist, but that exposure to practical science had a profound influence on my thinking for many years. Likewise, all of the school pupils and children we interact with will certainly not become microbiologists; however, I am confident that we can provide a life-changing experience for the young participants that we engage with, that will sow the seeds for the next generation of scientists.

Molecular machines can be viewed online at **www.molecularmachines.org.uk**. Read more about the CVR at **www.cvr.ac.uk** and GSC at **www.gsc.org.uk**. Many thanks to Christine Peters for providing the mock latex agglutination protocol.

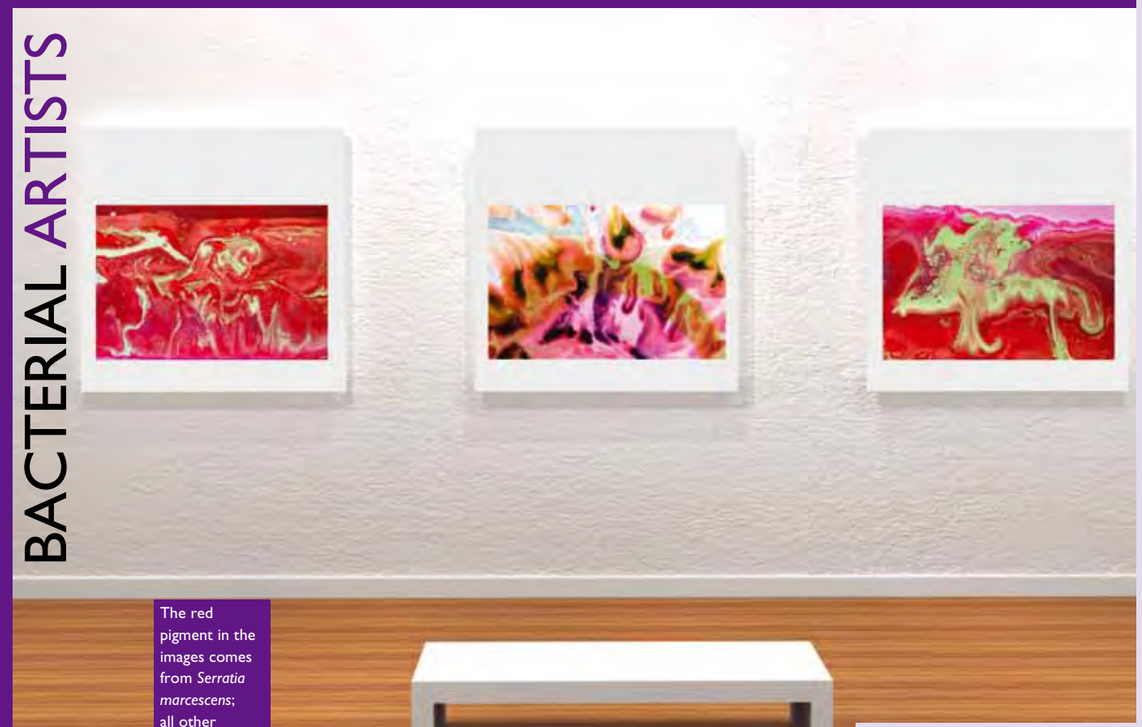
DAVID BHELLA is a Programme Leader at MRC – University of Glasgow Centre for Virus Research, Church Street, Glasgow G11 5JR (email david.bhella@glasgow.ac.uk)

BACTERIAL ARTISTS

I AM A MICROBIOLOGIST who has collaborated with many artists in order to engage the public. In a recent project, a watercolour artist, Sarah Roberts, visited my lab and asked if she could paint with traditional watercolours on bacteriological growth media to see how the bacteria interacted with them. The outcome was remarkable and very unexpected. Many people, including Alexander Fleming, have painted with bacteria before, but here the bacteria swarmed over the agar surface and actually moved the watercolours around their medium according their own designs and whims, so that in a sense, they are actually painting. The bacteria interact with the paint to change the painting completely and in doing so convert a lifeless image into something far more dynamic. What emerges is an expression of their activity and also a manifestation of our scientific understanding of the complexity of bacterial behaviour, how they swarm, communicate, move together in a coordinated manner and are able to circulate fluids within large bacterial communities.

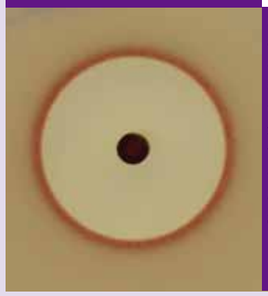
For further information, see **http://blogs.nature.com/news/2011/10/van_gogh_picasso_pollock_and_s.html**

SIMON F. PARK is Senior Lecturer in Molecular Microbiology, Faculty of Health and Medical Sciences, University of Surrey, Guildford (email s.park@surrey.ac.uk)



The red pigment in the images comes from *Serratia marcescens*; all other colours are watercolours. *Simon Park / Sarah Roberts*

DISCUSSING THE DILEMMAS OF ANTIBIOTIC DISCOVERY AND ANTIBIOTIC RESISTANCE WITH THE ROSS SCIENCE SOCIETY



Burkholderia ambifaria (central colony) is shown secreting antibiotics that produce a zone of clearing within an overlay of *Acinetobacter baumannii* (red-stained growth) that has been poured on top). *E. Mahenthiralingam*

SGM WERE CONTACTED in June 2011 by the Ross Science Society (**www.rossciencesociety.org.uk**) to enquire if a microbiologist could contribute to their 2012 programme of meetings. As a local SGM Member at Cardiff University, I agreed to present a talk on antibiotic discovery and antibiotic resistance as suitably broad and topical issues in microbiology. So on the evening of 11 January 2012, I headed up to the Castle Lodge Hotel in Ross and presented to a small audience of highly interested Ross Science Society members.

I opened the presentation with an overview of the golden age of antibiotic discovery (1950–1970) when the majority of antibiotic classes in clinical use today were discovered. I then ran through the increasing problems with antibiotic resistance. The audience were shocked to hear that meticillin-resistance in *Staphylococcus aureus* (i.e. MRSA) had appeared just 1 year after this antibiotic was first introduced. They also did not really understand that antibiotic resistance was not a new phenomenon, since ancient antibiotic resistance genes have been found in pristine natural environments. But they all understood that overuse or inappropriate use of antibiotics led to the emergence of antibiotic-resistant superbugs. They had all heard of MRSA, but were not really aware that other bacteria, e.g. *Entercococcus faecium*, extended-spectrum beta-lactamase-producing *Escherichia coli*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa* and *Enterobacter* species, also pose major clinical threats.

Earlier in 2011, I had given another public engagement talk to the Monmouth University of the Third Age (U3A) on cystic fibrosis (CF) microbiology. So to finish off the Ross Society presentation, I adapted the U3A talk and introduced the various problems associated with antibiotic-resistant *Burkholderia cepacia* complex bacteria which are particularly devastating CF pathogens. They found it amusing that a 'spoonful of sugar' could help reduce antibiotic resistance in *B. cenocepacia*. This was the way in which I explained how catabolite repression with glucose seems to reduce the minimal inhibitory concentration of the antibiotic meropenem against *B. cenocepacia*, an observation we had published last year (Sass *et al.*, 2011, *BMC Genomics* **12**, 373).

I finished the presentation by discussing how we have recently found that *Burkholderia* species, even though they are antibiotic-resistant pathogens, are also a novel source of potent antibiotics that can kill pathogens such as *A. baumannii*. I described work from a recent publication on the *Burkholderia* polyketide antibiotic, enacyloxin (Mahenthiralingam *et al.*, 2011, *Chem Biol* **18**, 665–677). The members of the Ross Science Society were very interested in hearing how this novel antibiotic discovery had been made; however, they were also amazed that the research had not yet been funded by any government agency. Most of their members were under the impression that combating antibiotic resistance was a major funding priority, but they did not realize just how competitive it is to get new research in this area funded.

I was very impressed by how switched-on and receptive the Ross Science Society members were to microbiology research. They asked the most questions I have ever had from any audience I have presented to and I was quizzed for over 20 minutes at the end of my talk. Overall, I really enjoyed this public engagement opportunity to present topical microbiological issues and my own research to a wider non-specialist audience. I can highly recommend it as a welcome break to the normal high-powered presentations made at scientific meetings.

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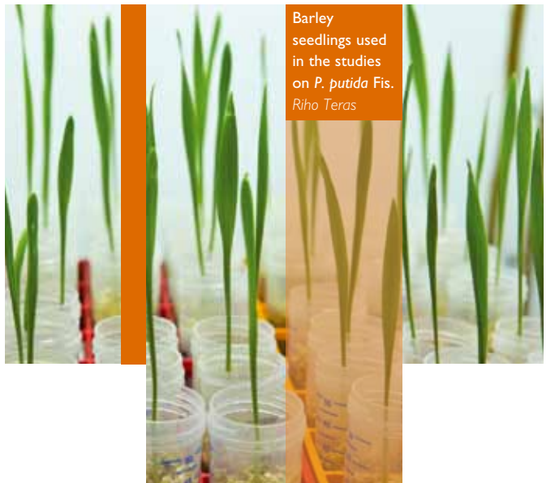
How do you discover what a protein essential for bacterial life does?

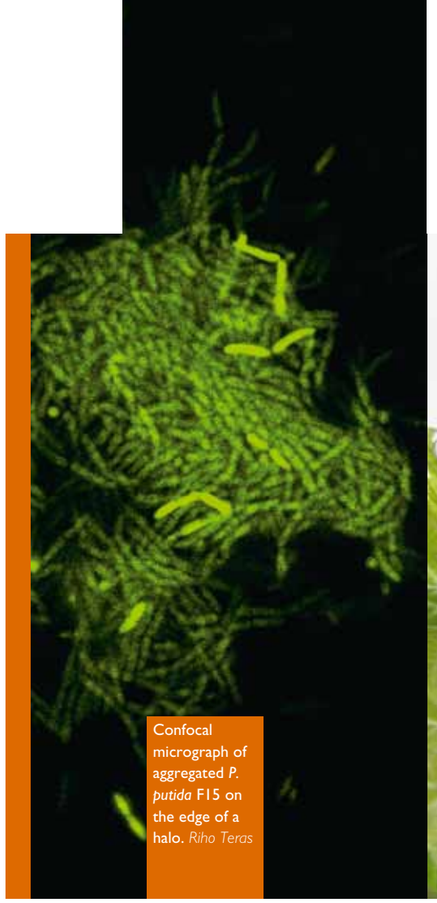
That was the challenge faced unexpectedly by researchers from the Institute of Molecular and Cell Biology at Tartu University and Estonian Biocentre, led by Riho Teras. They had begun to investigate Fis, one of the global regulatory proteins in *Pseudomonas putida*. This protein is well known to be important in bacteria, regulating movement so that bacteria can travel in liquids in response to environmental cues. The researchers tried to obtain *P. putida* cells that lacked the Fis protein by deleting its gene. This has been done in many other bacterial species to gain insight into the role of Fis. However, to their surprise, every strategy they used to delete the Fis gene killed the *P. putida* cells, indicating that the protein had an essential role, unlike in all other species. The researchers had to turn to an alternative strategy of forcing the cells to make higher than normal levels of Fis to finally obtain living bacteria to study.

The reason why they embarked on this quest was because *P. putida* normally lives in the soil, avidly colonizing the region around plant roots and resulting in improved plant growth and productivity. Indeed, *P. putida* has been recorded to be antagonistic towards bacterial pathogens of crop plants. The Fis protein turned out to be intimately involved in these processes and regulated both colonization of new surfaces and persistence as a biofilm. *P. putida* cells with extra Fis formed a much better biofilm layer over artificial surfaces but, surprisingly, stuck less well to plant roots. They also lost out in competition with normal *P. putida* cells. After a series of tests, the researchers predicted that the reason for this difference is because the bacteria producing extra Fis could not travel as well as normal and so could not move easily along the roots. Although the cells formed a thicker biofilm as they first arrived because of their enforced sessile lifestyle, an inability to swim meant that the bacteria could not move to new regions as the roots grew. They could still move by twitching, showing that bacteria are able to manage the energy-demanding process and the reduced motility is not caused by energy crises, but that regulation of genes involved in motility by Fis is needed. This role for Fis is significantly different in *P. putida* than in other, related, bacteria and there is obviously much more to be discovered.

Jakovleva, J., Teppo, A., Velts, A., Saumaa, S., Moor, H., Kivisaar, M. & Teras, R. (2012). Fis regulates competitiveness of *Pseudomonas putida* on barley roots by inducing biofilm formation. *Microbiology* 158, 708–720 (doi:10.1099/mic.0.053355-0)



Barley seedlings used in the studies on *P. putida* Fis. *Riho Teras*



Confocal micrograph of aggregated *P. putida* F15 on the edge of a halo. *Riho Teras*

Raspberry leaf exhibiting symptoms of RLBD. *Stuart MacFarlane*

Blotchy virus

Virus diseases of plants are a worldwide problem for agriculture, mostly controlled by treatments against virus transmission by arthropod, nematode or fungal vectors. Diseases result in losses from blemishes to the appearance of fruit and foliage, as well as losses in total yield. For a crop like raspberries, the size and appearance of the berries are crucial. The plants are susceptible to many diseases, including raspberry leaf blotch disorder (RLBD). This disease distorts the shape of leaves and causes them to develop yellow blotches, the berries ripen irregularly and the growing tip of the cane can die. RLBD is associated with infestations of mites, a specific species called raspberry leaf and bud mite (RLBM; *Phyllocoptes gracilis*). Investigations in the 1980s indicated that the disease was caused by mite infestation, rather than any other cause, and insecticides provided adequate protection.

Researchers led by Stuart MacFarlane at the James Hutton Institute in Scotland have re-investigated the cause of RLBD, using advances in knowledge and technology. This was prompted in part because RLBD has become an increasing problem for commercial growers in the UK, particularly affecting the popular cultivar 'Glen Ample' when grown in protective tunnels. The Scottish Government Rural and Environment Science and Analytical Services funded the project. The researchers identified an RNA sequence within raspberry leaves collected from a small farm in Fife where almost all of the plants showed very severe symptoms of the disease; the sequence was similar to RNA of mite-transmitted members of the genus *Emaravirus*. The researchers went on to obtain the full sequence of all five RNA segments of the virus, which they have tentatively named raspberry leaf blotch virus (RLBV), and studied its transmission. Like the majority of plant viruses, RLBV has a genome made of single-stranded RNA, although it is unusual because the negative RNA strand encodes the viral proteins and each gene is on a separate RNA segment within the virus particle. A further unusual feature is that an outer-membrane layer may surround each particle. The five genes encode the coat protein, an RNA polymerase to replicate the viral genome, an envelope glycoprotein, a second possible membrane protein (P4) and a fifth protein of unknown function that lies in the cytoplasm of infected cells. All previously studied emaraviruses lack this fifth protein, but the researchers have convincing evidence for it. The second membrane protein, P4, integrates into plasma membranes and plasmodesmata, and may be involved in viral RNA passing from cell to cell. Plasmodesmata are narrow channels in plant cell walls that provide connections between cells and many viruses have movement proteins that direct viral materials to adjacent, uninfected cells.

Following identification of the virus, the researchers undertook larger-scale tests of raspberry plants around Scotland, England and Serbia and found the virus in all plants exhibiting symptoms of RLBD. The virus is also present in mites from RLBD-affected plants. Once these mites are placed onto healthy raspberries, disease symptoms appear within a month, reinforcing evidence of an essential role for mites in the disease. The authors are still not sure whether both mites and virus contribute to the symptoms, or whether the mites only transmit the virus from plant to plant. This new knowledge about the cause of RLBD is a step towards solving the problems that it presents.

McGavin, W.J., Mitchell, C., Cock, P.J.A., Wright, K.M. & MacFarlane, S.A. (2012). Raspberry leaf blotch virus, a putative new member of the genus *Emaravirus*, encodes a novel genomic RNA. *J Gen Virol* 93, 430–437 (doi:10.1099/vir.0.037937-0).

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Nidadavolu, P., Amor, W., Tran, P.L., Dertien, J., Colmer-Hamood, J.A. & Hamood, A.N. (2012). Garlic ointment inhibits biofilm formation by bacterial pathogens from burn wounds. *J Med Microbiol* doi:10.1099/jmm.0.038638-0

Treating burns with garlic

A collaboration led by Abdul N. Hamood between researchers within several specialities at the Texas Tech University Health Sciences Center in Lubbock, USA, is testing a new strategy to deal with bacterial infection of wounds. The challenge is that the body's natural healing processes attempt to seal over the damage, but the outer surface remains very exposed to bacteria from the patient's body and the hospital environment. Antibiotics are the first line of treatment, but this is complicated by the very diverse bacterial species that set up residence in surface wounds. Some species are naturally resistant to certain antibiotics while others gain resistance during the prolonged healing process, making treatment of burns in particular very challenging.

The bacteria develop into a biofilm, where the cells are embedded in a mixture of bacterial polysaccharide and human tissue. Bacteria in biofilms are much less accessible to antibiotics and the natural immune system, which slows wound healing and also gives greater opportunities for the bacteria to invade the body through the healing tissues. The consequence once the bacteria access the bloodstream can be life-threatening septicaemia.

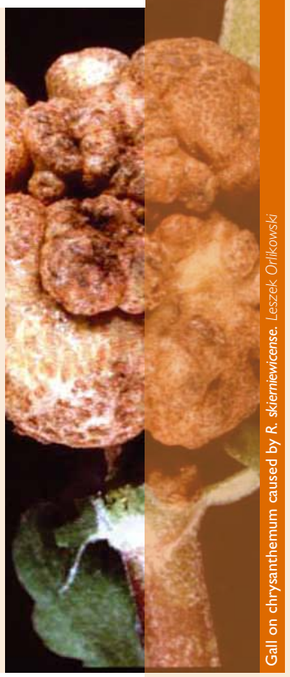
Researchers around the world are therefore investigating new ways to prevent biofilm formation. The team in Texas has turned to garlic, which has well-documented antimicrobial properties, as the active agent in an ointment that shows promise in a new therapy for these complicated situations. This followed their work testing an ointment containing a mixture of antibiotics that, in laboratory tests, inhibited biofilm formation by the two species most commonly found in infected burns, *Staphylococcus aureus* and *Pseudomonas aeruginosa*.

The researchers tested several formulations of commercial garlic powder mixed with a viscous petroleum jelly against a simulated wound infected with bacteria. An ointment is, of course, a particularly suitable delivery medium for open wounds on the body surface. The ointment strongly inhibited bacterial growth, but more interestingly, it prevented, or reduced, biofilm formation by many bacterial species. It could also reduce or eliminate pre-existing biofilms, although the efficacy differed between bacterial species. Of course, for practical use, the effect has to continue for an extended period and the researchers found that it worked for at least 9 days, and that their ointment was as effective when it had been stored in sterile conditions for 3 months as when newly prepared.

The broad-spectrum antibacterial biofilm activity of this ointment is particularly interesting. Researchers already knew that bacteria differ in sensitivity to garlic extracts and, taken together with an ointment formulation, this provides a new approach that deserves further development and testing to see whether it can become a valuable addition to the physician's arsenal.

Novel plant gall bacterium

The systematic names given to living creatures by scientists aim to reflect their natural relationships to one another. As a result, even very familiar names can change due to new discoveries. One of these at the turn of the century, in 2001, led to the merging of the genera *Agrobacterium* and *Rhizobium* together under the name *Rhizobium*. Pathogenic bacteria that affect over 800 species of plants, causing tumours or hairy roots, have been classified within *Agrobacterium* for many years, while the well-known feature of bacteria within *Rhizobium* is the ability to 'fix' atmospheric nitrogen by converting it to ammonium ions. However, bacteria from both genera have to exert partial control over the growth and development of plant cells to achieve these results in ways that turn out to be increasingly similar, and commonalities between the genera led to the reclassification. As a consequence, *Agrobacterium tumefaciens*, the bacterial species typically used in genetic engineering of plants, is now called *Rhizobium radiobacter*.



Gall on chrysanthemum caused by *R. skierniewicense*. Leszek Orlikowski

J. Puławska and P. Sobiczewshi at the Research Institute of Horticulture at Skierniewice in Poland, have worked with Anne Willems from Ghent University, Belgium, to add a novel species to this enlarged genus of *Rhizobium* that has characteristics that in the past would have placed it firmly within *Agrobacterium*. They isolated three bacterial strains, two from tumours on chrysanthemum plants and the third from a gall on a *Prunus cerasifera* tree. The bacteria were rod-shaped, Gram-negative, required oxygen and could grow on a wide range of sugars and amino acids. All three strains were pathogenic, causing crown gall on a range of plants, including sunflower, chrysanthemum and *Rosa* species.

The relationships of bacterial species can usually be decided from the DNA sequence of the16S rRNA gene. The researchers matched the sequence from their three novel strains with sequences from authentic *Rhizobium* and *Agrobacterium* species. The sequence of all three strains was most similar to *R. rubi* and *R. radiobacter*. The researchers also sequenced three other genes as a further check on the taxonomic position of the novel strains, as well as conducting a series of physiological, biochemical and compositional tests.

The end result was convincing evidence that the strains all belonged within the genus *Rhizobium* but were sufficiently dissimilar from all previously reported species to be the first three individuals of a novel species. Two characteristics that differentiated the strains from closely related species were an inability to grow on the sugar fucose together with the ability to metabolize β-hydroxybutyric acid. The researchers picked the name *Rhizobium skierniewicense* to refer to the place where the bacteria were first isolated.

Puławska, J., Willems, A. & Sobiczewski, P. (2012). *Rhizobium skierniewicense* sp. nov. isolated from tumours on chrysanthemum and cherry plum. *Int J Syst Evol Microbiol* 62, 895–899 (doi:10.1099/ijs.0.032532-0).

Water and Sanitation-Related Diseases and the Environment. Challenges, Interventions, and Preventive Measures

Editor J.M.H. Selendy
Publisher John Wiley & Sons Ltd (2011)
Details £93.50 | pp. 552 | ISBN 978-0-47052-785-6
Reviewer Chris Hodgson, Rothamsted Research

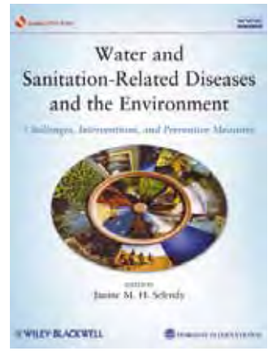
Having first baulked at the size of the book, over 500 pages, I actually found it a stimulating and very interesting read. It perhaps paints a gloomy picture of the problems faced by people around the world in relation to the lack of safe water, poor sanitation and the associated diseases, something that many of us will probably never experience. However, glimmers of hope appear regularly through each section of the book, highlighting the tremendous on-going work into improving the supply of safe water and adequate sanitation.

This is a truly interdisciplinary book and reflects really well the need to work across scientific boundaries, and I think shows what can be achieved through collaboration.

There is one thing I don't quite get, the 16 colour pages in the centre of the book – why couldn't these colour pictures not appear in the text instead of the black and white ones?

'*Day-care centres are often the industrialized country equivalent of these faecally promiscuous environments.*' This was a great quote and I think sums up the issue vividly, breaking the cycle of the faecal–oral route is key – in any nation!

I think this book is probably more suited to institutional purchase than the individual, but a great resource. The additional information contained within the two supporting DVDs was fascinating.



Antibiotic and Chemotherapy: Anti-infective Agents and Their Use in Therapy

Editors R.G. Finch, D. Greenwood, S. Ragnar Norrby & R.J. Whitley
Publisher Elsevier (2010)
Details £119.85 | pp. 916 | ISBN 978-0-70204-064-1
Reviewer Alan Johnson, HPA Centre for Infections, London

Many advances in medicine such as cancer therapy, transplantation or use of prosthetic devices predispose patients to increased risk of infection. Consequently, use of anti-infective agents now plays a part in the management of patients across a diverse spectrum of clinical conditions. Moreover, the choice of anti-infective therapy is being increasingly compromised by the emergence of resistance. This excellent book serves to give the reader expert information on issues relating to anti-infective chemotherapy. This includes the structures and mode of action of individual drugs, pharmacokinetics, metabolism, toxicity and clinical use. About half of the book focuses on treatment and is consolidated by coverage of the general principles and laboratory management of chemotherapy coupled with information on formulation of antibiotic policies and antibiotic stewardship. While the price may be beyond the budget of many individuals, I would strongly recommend that microbiologists with an interest in infection and chemotherapy urge their institutional libraries to purchase this book.

Topics in Ecological and Environmental Microbiology

Editors T.M. Schmidt & M. Schaechter
Publisher Elsevier (2011)
Details US$99.95 | pp. 730 | ISBN 978-0-12-383878-0
Reviewer Roger Pickup, Lancaster University

This is an extremely informative book. Rather than describing microbial ecology in terms of genus and species, it neatly describes concepts by principle, metabolism, biogeochemical cycling and habitat. It also considers microbial ecology in terms of its environmental and biotechnological impact. The environment is diverse and so are the chapters, with each written by experts in their respective fields. Many chapters provide distinct information about specialized organisms as epitomized by those found in 'acid environments'. Some chapters are complementary such as 'Freshwater habitats' and 'Low nutrient environments' without being repetitive. Chapters also cover the emerging fields of spacecraft ecology and biological warfare (although the text reliably informs you that acts of biowarfare were recorded throughout history and as early as 300 BC). The strength of this book lies in the information being drawn from nearly 80 contributors and in its layout which is clear and concise. Each chapter contains photographs that, despite being only black and white, are well presented and complemented by good figures that represent salient points in the text. I thoroughly recommend this book to both practitioners and students alike.

Eukaryotic Microbes

Editor M. Schaechter
Publisher Elsevier Science & Technology Books (2012)
Details US$99.95 | pp. 496 | ISBN 978-0-12383-876-6
Reviewer Geoffrey Gadd, University of Dundee

Protists, fungi and microalgae comprise a huge number of organisms playing highly important roles in biosphere processes and biotechnology. This book comprises 33 chapters by authorities in their fields on the main groups of eukaryotic microbes. Part I deals with fungi and includes chapters on yeasts, *Aspergillus*, mycorrhizas, lichens, plant pathogens, endophytes, systemic and cutaneous fungal infections, and entomogenous fungi. Part II comprises the protists and chapters include those on amoebae, ciliates, coccolithophores, diatoms, dinoflagellates, *Dictyostelium*, foraminiferans, oomycetes, stramenopiles, trypanosomes and algal blooms. Within the chapters, aspects of evolution and taxonomy, life cycle, cell structure and morphology, environmental significance, and pathogenesis are covered in detail. The book is well illustrated with diagrams, figures and tables, and the chapters are thorough, well presented and easy to read. The content has been carefully selected from the huge range of topics that are covered under eukaryotic microbiology, and provides an excellent overview. It will be a useful reference work for researchers and students in many areas of eukaryotic microbiology, and of course for all other microbiologists fascinated by these incredible, beautiful and important organisms.

Reviews on the web

Reviews of the following books are available on the website at **www.sgm.ac.uk/pubs/micro_today/reviews.cfm**

Microbial Biofilms: Current Research and Applications

Editors G. Lear & G. Lewis
Publisher Caister Academic Press (2012)
Details £159.00 | pp. 228 | ISBN 978-1-90445-596-7
Reviewer Joanna Verran, Manchester Metropolitan University

Antituberculosis Chemotherapy

Editors P.R. Donald & P.D. van Helden
Publisher S. Karger AG (2011)
Details €157.00 | pp. 252 | ISBN 978-3-80559-627-5
Reviewer Timothy McHugh, University College London

An Introduction to Metabolic and Cellular Engineering, 2nd edn

Author S. Cortassa, M.A. Aon, A.A. Iglesias, J.C. Aon & D. Lloyd
Publisher World Scientific Publishing (UK) Ltd (2011)
Details £79.00 | pp. 381 | ISBN 978-9-81436-571-0
Reviewer John Ward, University College London

Principles of Molecular Virology, 5th edn

Author A.J. Cann
Publisher Elsevier (2011)
Details US$69.95 | pp. 320 | ISBN 978-0-12384-939-7
Reviewer Gavin Wilkinson, University of Cardiff

Extremophiles: Microbiology and Biotechnology

Editor R.P. Anitori
Publisher Caister Academic Press (2012)
Details £159.00 | pp. 300 | ISBN 978-1-90445-598-1
Reviewer Arwyn Edwards, Aberystwyth University

Medically Important Fungi: A Guide to Identification, 5th edn

Author D.H. Larone
Publisher American Society for Microbiology (2011)
Details US$109.95 | pp. 508 | ISBN 978-1-55581-660-5
Reviewer Neil Gow, University of Aberdeen

Oral Microbial Communities: Genomic Inquiry and Interspecies Communication

Editor P.E. Kolenbrander
Publisher American Society for Microbiology (2011)
Details US$179.95 | pp. 440 | ISBN 978-1-55581-503-5
Reviewer Rob Allaker, Queen Mary University of London

Candida and Candidiasis 2nd edn

Editors R.A. Calderone & C.J. Clancy
Publisher American Society for Microbiology (2011)
Details US$159.95 pp. 544 ISBN 978-1-55581-539-4
Reviewer Donna MacCallum, University of Aberdeen

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Coffee berries. *iStockphoto / Thinkstock*

COMMENT

Genomics of emerging plant pathogens: too little, too late

We need to rapidly sequence and release the genomes of emerging plant pathogens. Food security and environmental preservation hang in the balance.

SOPHIEN KAMOUN

LAST YEAR during a visit to Colombia's Zona Cafetera, my host singled out one coffee farm amid the enchanting rolling hills. That farm's owner may have looked like the iconic Juan Valdez, but he is far from being cherished by his 'cafeteros' colleagues. He is infamous for having brought into Colombia a few coffee plants from Brazil. Unbeknown to him, a few leaves bore small orange spots, the telltale sign of the terrible coffee rust fungus, *Hemileia vastatrix*. Ever since that fateful introduction in 1983, Colombian cafeteros have struggled with managing this formidable foe. In recent years, after a brief lull, coffee rust came back with a vengeance casting a shadow on a critical Colombian agroindustry just as the country was emerging from years of social instability.

The history of agriculture is replete with sorry tales like the one of '*la roya del café*'. From the upheaval caused by the Irish potato famine pathogen to recent epidemics such as wheat yellow rust, sudden oak death and horse chestnut canker, the British Isles have seen their share of plant pathogen introductions. Elsewhere, emerging infectious plant diseases cause havoc to world agriculture and threaten to slow laudable efforts to launch a second green revolution to meet the food security needs of a booming world population.

When faced with opponents like these, we need to know our adversary. The genome sequence of a plant pathogen is a deep look into its soul. From important and often unexpected insights into the biology of the pathogen to the tools needed to develop surveillance and diagnostic DNA markers, the genome is an invaluable resource that accelerates research and output delivery. With the cost of gene sequencing decreasing even faster than Moore's law, the cost-benefit calculation is evident. For instance, countless time and money are spent in developing DNA markers, investigating population structures, debating the pathogen origin, etc. – activities that can be greatly hastened by the genome sequence. Many of the plant pathologists that sit on the front line of the epidemics are not properly trained to fully exploit the genome data and may not be inclined to lobby for sequencing funds. We simply cannot afford to wait. Genomes of emerging plant pathogens need to be immediately sequenced and released into the public domain as is routinely done with human pathogens.

A few months ago, I watched in awe as my bacteriologist colleagues accessed within days of the first reports the genome sequence of the *Escherichia coli* O104:H4 strain that killed about 50 people in Germany. The following 'crowdsourcing' of the genome analysis, during which scientists around the world pored over the freely available data to mine it and openly share their results on the internet, is a sure sign of things to come. A similar exercise is yet to happen in plant pathology.

Meanwhile, back in Colombia, scientists continue to scrape together enough funds to sequence and analyse the genome of the coffee rust fungus. I wholeheartedly support Bill Gates' recent call to arms for innovation in agricultural research, a philosophy we have fully embraced at The Sainsbury Laboratory over our 23-year history. But first things first – lets get the basics in place and develop lists of emerging and important plant pathogens. We have enough genome sequencing capacity, but progress so far has been piecemeal. We need to accelerate efforts to sequence and analyse the genomes of multiple races of the world's most important plant pathogens. Otherwise, you may have to start worrying about the cost of your lunch, and of your espresso!

SOPHIEN KAMOUN is Senior Scientist and Head of The Sainsbury Laboratory, Norwich Research Park, Norwich, NR4 7UH (email sophien.kamoun@tsl.ac.uk)

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Bacterial Spores

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